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Artigo

Assessment of Precipitation Trends in the Sertão Paraibano Mesoregion

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Abstract

The state of *Paraíba*, located in the northeastern region of Brazil, comprises 223 municipalities and covers an area of 56,469 km^2. *Paraíba* is divided into four major mesoregions: Zona da Mata, Agreste, Borborema and Sertão Paraibano. For this study, the Sertão Paraibano mesoregion, a semiarid area, was chosen to understand vulnerability to climate change, taking into account the region's economic importance for water and energy supply. The Mann-Kendall non-parametric test was applied to evaluate trends in the historical series of monthly, trimestrial, biannual and annual precipitation data. The series utilized corresponded to the period 1912-2012 and were built from data generated by five meteorological stations distributed throughout the mesoregion. These stations are maintained by the Executive Agency for Water Management (AESA) and National Department of Works Against Drought (DNOCS). The results indicated increasing precipitation trends for the Sertão Paraibano mesoregion, especially in the annual evaluation, for the first semester of the year (January to June), for the trimester December-January-February and the month of January, with slopes between 2.67 mm/year and 5.45 mm/year. The results evidenced the need to deepen studies on the influence of climate change in the area, to promote prompt adaptation measures.

Keywords: precipitation, climate change, trend analysis, Mann-Kendall test, semiarid, Brazil.

Avaliação de Tendências de Precipitação na Mesorregião do Sertão Paraibano

Resumo

O estado da Paraíba, localizado na região Nordeste do Brasil, possui 223 municípios, distribuídos numa área de 56.469 km^2. A Paraíba é dividida em quatro mesorregiões: Zona da Mata, Agreste, Borborema e Sertão Paraibano. Para este estudo, a mesorregião semiárida, Sertão Paraibano, foi escolhida, a fim de compreender a vulnerabilidade às alterações climáticas, considerando sua importância econômica para fornecimento de água e energia. O teste não-paramétrico Mann-Kendall foi utilizado com a finalidade de avaliar tendências nas séries históricas de dados de precipitação mensal, trimestral, semestral e anual. As séries utilizadas correspondem ao período de 1912-2012, construídas a partir de dados provenientes de cinco estações meteorológicas, distribuídas pela mesorregião, mantidas pela Agência Executiva de Gestão das Águas (AESA) e Departamento Nacional de Obras Contra a Seca (DNOCS). Os resultados indicam tendência de aumento na precipitação, principalmente nos intervalos de tempo anual, no primeiro semestre de janeiro a junho (J-J), no trimestre dezembro, janeiro e fevereiro (DJF) e no mês de Janeiro, com incrementos anuais entre 2,67 mm/ano e 5,45 mm/ano. Os resultados evidenciam a necessidade de aprofundar estudos sobre influência das mudanças climáticas na mesorregião do Sertão Paraibano, com o intuito de mitigar os seus efeitos ou promover medidas de adaptação.

Palavras-chave: precipitação, mudança climática, análise de tendências, teste de Mann-Kendall, semiárido, Brasil.

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1. Introduction

Climate change can be defined as a set of statistical variations in the mean state of climate or its variability, attributed directly or indirectly to human activity or to natural causes as well. These variations persist for long periods of time and can be detected and assessed through historical series of meteorological data (IPCC, 2007). Furthermore, it is understood that climate trends are characterized by a soft or monotonous change (increase or decrease) in the mean values of these series. The occurrence of climate changes for a specific region can be confirmed by time series trends (Blain, 2010).

Among the topics of climate change, some works can be mentioned that approach trend analysis for meteorological variables in different locations, such as Groisman and Easterling (1993), Easterling *et al.* (1997), Karl and Knight (1998), Kheshgi and White (2001), Easterling (2002), Matsuyama *et al.* (2002), Modarres and Silva (2007), Fu *et al.* (2013). For Brazil, the study of Salviano *et al.* (2016) analyzed trends in precipitation and temperature data for the entire country. Awange *et al.* (2016) studied droughts in Brazil over a period of more than 100 years. Moraes *et al.* (1998), Marengo and Camargo (2008) and Pinheiro *et al.* (2013) evaluated trends for the South region of Brazil, while Marengo (2003) and Santos and Lucio (2015) studied climatic trends in the North region. Ramos (1975), Silva (2004), Moscati and Gan (2007), Oliveira and Lima (2014) and Costa *et al.* (2015) studied the dynamics, distribution and trend for precipitation in the Northeast region and Folhes and Fisch (2006), Minuzzi *et al.* (2007) and Blain (2009, 2010, 2012) focused on the Southeast region, specially the São Paulo state.

Lucena *et al.* (2009), based on long-term climate projections for the A2 and B2 IPCC emission scenarios, indicated that climate change will affect natural resources related to renewable energy, and predicted increases in vulnerability for all energy sectors in Brazil, especially in the Northeast region, where the worst climatic scenarios are foreseen, with substantial increases in temperature and drought. Changes in precipitation and temperature patterns can cause or accentuate water quantity and quality problems in the region as well (Benito, 2013).

The state of *Paraíba* is part of the Northeastern region of Brazil and presents semiarid climate in most of its territory, with consequent water scarcity and social issues (Pedroza, 2009). The *Coremas-Mãe D'água* dam complex is located in the semiarid region, belonging to the Piranhas river basin. The *Coremas-Mãe D'água* dam complex stands out for storing a total of 1,358 billion m^3 of water, thus composing the greatest water storage potential of the Sertão Paraibano mesoregion (AESA, 2009a). Since 1957, the area has a small hydroelectric power plant, which is supplied from the *Estevam Marinho* and *Mãe D'água* reservoirs, supplied by the *Piancó* and *Aguiar* rivers. The hydroelectric power plant has two generating units, 1,760 kW each, totalling 3,520 kW (CHESF, 2016). Due to the importance of this region to the water and energy supplies of the State of *Paraíba*, and the potential impact of changes in the availability of water resources, the present study aims to verify the existence (and understand the behavior) of possible precipitation trends in the area of the *Coremas-Mãe D'água* dam complex in the Sertão Paraibano mesoregion.

2. Material and Methods

2.1. Characterization of the study area, identification of meteorological stations and organization of data

The state of *Paraíba* is located in the northeastern region of Brazil. The state presents three types of climate: humid coastal, tropical and semiarid (IBGE, 2002), with a very variable annual regime of precipitations, ranging from 300 mm to 2,000 mm (Cavalcanti, 2009). The state is geographically divided in four mesoregions: Zona da Mata, Agreste, Borborema and Sertão Paraibano (AESA, 2009b); the latter is the main semiarid area and corresponds to the study area chosen for this study (Fig. 1).

The Sertão Paraibano mesoregion presents a semiarid tropical climate characterized by dry landscapes and high temperatures, accompanied by low annual thermal variability and high rainfall irregularities. In addition, the region is marked by long periods of drought (Cavalcanti *et al.*, 2009; Mendonça and Danni-Oliveira, 2007).

Time series with rainfall information were obtained from 1912 to 2012, to verify rainfall variability and trend analysis. Data were provided by the monitoring networks of the Executive Agency for Water Management (AESA) and National Department of Works Against Drought (DNOCS).

The pluviometric monitoring network of the state of *Paraíba* is standardized according to criteria from the World Meteorological Organization and presents 265 stations equipped with Ville de Paris rain gauges (Becker *et al.*, 2011). For this study, five meteorological stations were considered, out of the more than 40 that exist in the mesoregion of Sertão Paraibano, selected due to their proximity to the *Coremas-Mãe D'água* dams complex and data quality (more years available with less interruptions or data problems in the series). Pluviometric information was organized in discrete time series, following criteria of identification and evaluation of atypical values (outliers), in such a way that all analyzed years contain all months (January to December), without interruptions (Table 1). Therefore, for the construction of the series, the only years used were those containing complete precipitation data from January to December, without exception. Incomplete years were excluded from the series and represented between 2% and 17% of the stations series (Table 1).

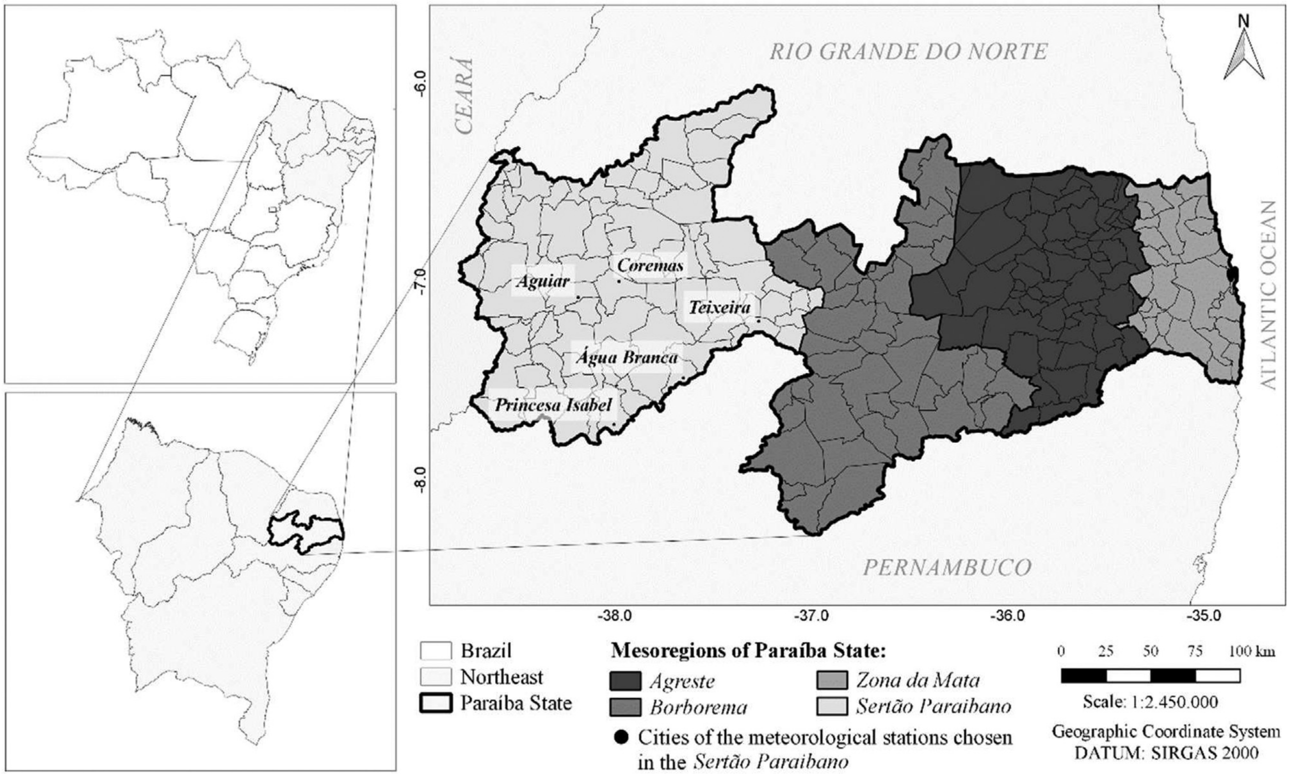

Figure 1 - Geographic locations of the mesoregions of the State of *Paraíba* and identification of the municipalities with the five meteorological stations studied (Adapted from AESA, 2009b).

Table 1 - Meteorological stations used in the study.

Station number	Operator	Station	Range of series (year)	Lat. S (°)	Lon. W (°)	Number of absent years	Period (years)
737022	AESA	Água Branca	1936-2012	-7.51	-37.62	4	72
	AESA			-7.51	-37.64		
738025	DNOCS	Aguiar	1935-2012	-7.08	-38.18	6	71
	AESA			-7.09	-38.17		
737019	DNOCS	Coremas	1934-2012	-7.02	-37.97	13	65
	AESA			-7.03	-37. 94		
738013	DNOCS	Princesa Isabel	1912-2012	-7.73	-38.02	2	98
	AESA			- 7.73	-37.99		
737002	DNOCS	Teixeira	1926-2011	-7.22	-37.27	7	78
	AESA			-7.22	-37.25		

2.2. Statistical methods for the trend analysis

The linear regression method and the non-parametric Mann-Kendall statistical test were applied according to the methodology proposed by Sneyers (1992) to describe the behavior of time series and verify the existence of trends.

The Mann-Kendall test is usually employed to understand trends in time series of climate data. One of the main advantages of non-parametric tests is that application is independent of data distribution. A limitation of these tests lies in the need for interdependence between the elements of the series, that is, sequence of data must occur independently and randomly, characterizing a simple random series whose distribution of probability is homogeneous (Goossens and Berger, 1986; Back, 2001; Fechine and Galvíncio, 2010).

The Future Climate and Hydrological Scenarios for Environmental Management and Assessment program (FuCHSIA) was applied to assess rainfall trends for the monthly, trimestrial (December-January-February: DJF, March-April-May: MAM, June-July-August: JJA, September-October-November: SON), biannual (January to June:

J-J and July to December: J-D), and annual precipitation data. FuCHSIA was developed to analyze time-series trends in scenarios of current climate and conditions of climate change (García-Garizábal and Espinoza, 2016; García-Garizábal *et al.*, 2017). The program was developed by the private sector and more details and information may be obtained in García-Garizábal *et al.* (2017). The FuCHSIA program applies the Mann-Kendall test to identify trends in time series and uses the Sen's linear regression method as a quantifier to define the slope of the line and provide the magnitude of the trend (Mann, 1945; Sen, 1968; Kendall, 1975).

3. Results and Discussion

The mean annual precipitation in the area varied between 715.59 mm (*Teixeira* station) and 879.11 mm (*Coremas* station). The monthly distribution of precipitation presents similar behavior across the five stations (Fig. 2), with maximum values for February, March and April, and minimum values for August, September and October, evidencing when wet and dry periods occur, which are a common characteristic of this area of the Brazilian semiarid.

The intra-annual variability of precipitation in the mesoregion is accentuated. The maximum values of the monthly mean rainfall occur in March for the five stations studied. The minimum values occur in August for the *Teixeira* station, in September for three of the five stations (*Aguiar*, *Coremas* and *Princesa Isabel* stations) and in October for the station in *Água Branca*. Significant increases in precipitation were detected for the annual, biannual, trimestrial and monthly trends, but with different magnitudes and error probabilities across stations (Table 2). All stations presented positive values with significant trends between 2.67 mm/year and 5.45 mm/year for the total annual precipitation, except for *Princesa Isabel*.

In the biannual intervals, for J-J all trends were significantly positive, between 3.10 mm/year and 3.97 mm/year, indicating precipitation increases in the area. The only exception was, again, the *Princesa Isabel* station. In the period J-D, only two stations presented significant trends, which ranged from 0.71 mm/year for *Teixeira* station and 1.23 mm/year for *Água Branca* station. In addition, the slopes in the J-J period were always higher than J-D slopes (Table 2).

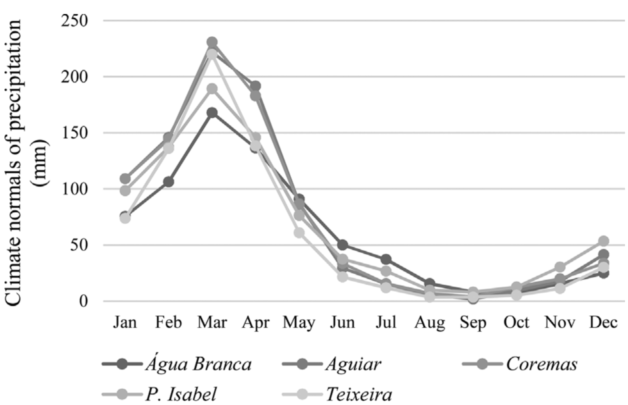

Figure 2 - Monthly climate normals of precipitation for the five stations studied (data from 1912 to 2012).

Regarding trimestrial analysis, significant trends were detected, with increased precipitation during DJF for four of the five meteorological stations, with values between 1.65 mm/year and 2.44 mm/year. In MAM, the *Princesa Isabel* station registered the only significant trend (increase of 1.10 mm/year). In JJA, the results indicated a significant increase trend of 0.59 mm/year and 1.00 mm/year for *Teixeira* and *Água Branca* stations, respectively. In SON, the only station that presented a significant trend was *Teixeira*, with an increase of 0.06 mm/year. In addition, 25% of slope values were negative, with no statistical significance.

For the monthly assessments, although the month with highest precipitation in the mesoregion is March, the month of January was the most affected of all, presenting values of significant trends between 0.58 mm/year and 0.88 mm/year in four of the five meteorological stations. In the same way, the *Água Branca* station presented the highest number of months affected by significant trends, between 0.09 mm/year in December and 0.88 mm/year in January. There was a predominance of positive trend values, and 33.3% presented statistical significance.

The results highlight that the annual cumulative values of precipitation presented stronger significant trends compared to some isolated periods of the year (*i.e.* biannual, trimestrial or monthly). This is due to the characteristics of trend tests, where greater variability in data decreases the determination of significant trends.

Four of the five meteorological stations showed significant increases in precipitation for the annual period, first semester (J-J), first quarter (DJF) and January. The meteorological stations *Água Branca* and *Teixeira* presented significant increasing trends for precipitation in higher number of periods. The stations *Coremas* and *Aguiar* presented similar behavior, with significant trends in the same periods, and the station in *Princesa Isabel* was the most different, showing significant increasing trends in only 10.5% of its series (in trimester MAM and the month July).

The differentiated behavior at *Princesa Isabel* station probably occurred due to the climatic factors influencing the flow of heat and humidity locally, such as the relief, which plays an important role as regulator of humidity and temperature by altitude (*Princesa Isabel* is at 683 m of altitude), besides its position, orientation of its slopes and declivity. In addition, rainfall irregularities and high temperatures are characteristic features of the Sertão region (Mendonça; Danni-Oliveira, 2007). Therefore, in order to better understand the singular behavior presented at *Prin-*

Table 2 - Precipitation trends (1912-2012) for the meteorological stations Água Branca, Aguiar, Coremas, Princesa Isabel and Teixeira.

	Precipitation trends (mm/year)				
Period	Água Branca	Aguiar	Coremas	Princesa Isabel	Teixeira
Annual	5.45 ***	2.67 +	3.43 *	0.61 ns	4.70 **
J-J	3.97 **	3.37 +	3.10 +	0.92 ns	3.61 **
J-D	1.23 ***	-0.19 ns	0.18 ns	-0.12 ns	0.71 ***
DJF	2.44 ***	1.65 *	1.77 *	-0.24 ns	1.93 **
MAM	1.11 ns	0.86 ns	-0.23 ns	1.10 +	1.44 ns
JJA	1.00 ***	-0.12 ns	0.10 ns	0.28 ns	0.59 ***
SON	0.05 ns	-0.07 ns	0.00 ns	-0.20 ns	0.06 *
January	0.88 **	0.80 +	0.86 *	0.32 ns	0.58 **
February	0.82 *	0.66 ns	0.38 ns	-0.18 ns	0.46 ns
March	0.17 ns	-0.45 ns	-0.76 ns	0.24 ns	0.07 ns
April	-0.01 ns	0.54 ns	0.13 ns	0.49 ns	0.75 ns
May	0.83 *	0.46 ns	0.20 ns	0.28 ns	0.31 ns
June	0.33 +	-0.08 ns	0.00 ns	0.01 ns	0.14 ***
July	0.30 *	-0.01 ns	0.03 ns	0.14 *	0.13 ***
August	0.15 ***	0.00 ns	0.00 ns	0.00 ns	0.00 ns
September	0.00 ns	0.00 ns	0.00 ns	0.00 ns	0.00 ns
October	0.00 ns	0.00 ns	0.00 ns	0.00 ns	0.00 ns
November	0.00 ns	0.00 ns	0.00 ns	-0.03 ns	0.00 ns
December	0.09 **	0.00 ns	0.06 ns	-0.01 ns	0.02 ns

ns: not significant; +p <0.10; *p <0.05; *p <0.01; *p <0.001.

cesa Isabel, a more in-depth local study of climatic factors and elements is necessary.

In the stations *Água Branca*, *Aguiar*, *Coremas* and *Princesa Isabel*, at least one of the intervals (annual, biannual, trimestrial or monthly) presented negative trends, which would indicate a decrease in rainfall. However, none presented statistical significance. Other statistical methods could be applied in conjunction with trend analysis to corroborate the understanding of the dynamics of climate change in the area, like cluster analysis (Abrahão, 2014; Lyra *et al.*, 2014; Teodoro *et al.*, 2016).

The detected trends indicate that, in 10 years, precipitation will be higher when compared to the means observed in 3% (in *Aguiar*) and 7% (in *Teixeira* and *Água Branca*), with the highest annual mean in *Coremas*, above 910 mm, indicating an increase of 4% in 10 years (Table 3). The expected increases in 30 years for *Água Branca* and *Teixeira* are sharper than those of *Aguiar* and *Coremas*. While these will increase by 9% and 12%, respectively, *Água Branca* may reach an annual mean of almost 900 mm, and *Teixeira* above 850 mm. In 50 years, *Água Branca*, *Aguiar* and *Coremas* may present annual precipitation means above 1000 mm. *Teixeira* could increase its annual mean by 33%, reaching more than 950 mm.

From what has been observed by the trends, these future increases will not be uniform throughout the year. At *Água Branca* station, the highest number of monthly series with significant trends (7 in 12 series) were detected. In 10 years, it may rain from 25.8 mm (in December) to 114.5 mm (in February). Keeping this perspective in 50 years, the observed trends indicate a possible increase in

Table 3 - Projected annual mean precipitation for 10, 20, 30, 40 and 50 years at stations with significant annual trends detected (Água Branca, Aguiar, Coremas and Teixeira).

Station	Precipitation means (mm)	Precipitation trends (mm/year)	Projected annual mean precipitation (mm)				
			10 years	20 years	30 years	40 years	50 years
Água Branca	735.31	5.45	789.81	844.31	898.81	953.31	1007.81
Aguiar	876.02	2.67	902.72	929.42	956.12	982.82	1009.52
Coremas	879.11	3.43	913.41	947.71	982.01	1016.31	1050.61
Teixeira	715.59	4.70	762.59	809.59	856.59	903.59	950.59

relation to the mean monthly precipitation between 18% and 58%, in December and January respectively.

The future projections reinforce the notion that it is raining more yearly and monthly in the mesoregion of Sertão Paraibano. However, to better understand this climatic dynamics, more detailed studies on the spatial and temporal distribution of precipitation are necessary, as well as the application of robust climate models, along with the observed trends.

The Nucleus of Strategic Affairs of the Brazilian Presidency (NAE, 2005a, b) indicates that Brazilian Northeast is one of the most vulnerable regions to climate change due to climate (mostly semiarid), social and economic factors. Therefore, the *Coremas-Mãe D'água* dam complex is a key infrastructure for supplying water to population and generating electricity. Thus, studies that include analysis of climate variability in the *Paraíba* region are necessary to preventively address the issues arising from climate change and its environmental, economic and social impacts. Although the Intergovernmental Panel on Climate Change (IPCC) projections indicated an increase in temperatures throughout the Brazilian territory, precipitation analyses did not present conclusive results (IPCC, 2007), evidencing the need to continue developing pluviometric studies that address the dynamics and evolution of this climate component.

In the present study, trends of increase in the total annual rainfall were observed. These results complement those reported by Peixoto and Abrahão (2015) for the municipalities of *Patos* and *São Gonçalo*, which also belong to the mesoregion of Sertão Paraibano. Also, decreases were detected in cloudiness and number of rainy days (Figs. 3 and 4), leading one to believe that rainfall intensity is increasing in the area. The study of Peixoto and Abrahão therefore detected that recent rainfall events were more intense, as a significant decreasing trend was detected for rainy days combined with an increase in total annual rainfall. Other studies based on climate models also suggest a higher probability of increased frequency of consecutive dry days in the Northeast region of Brazil, correlating with desertification processes, especially in the semiarid portion (Conti, 2005; IPCC, 2007; Nobre, 2011; Costa and Soares, 2012).

A study on extreme precipitation events for the semiarid region of the Brazilian Northeast by Costa *et al.* (2015) indicated an increase in drought intensity, which corroborates the results found by Peixoto and Abrahão (2015). However, Costa *et al.* (2015) detected decreasing trends for intense precipitation events and reduction of the annual precipitation in the dry and rainy periods. This highlights the lack of uniformity in rainfall distribution for this region as the meteorological stations considered were dif-

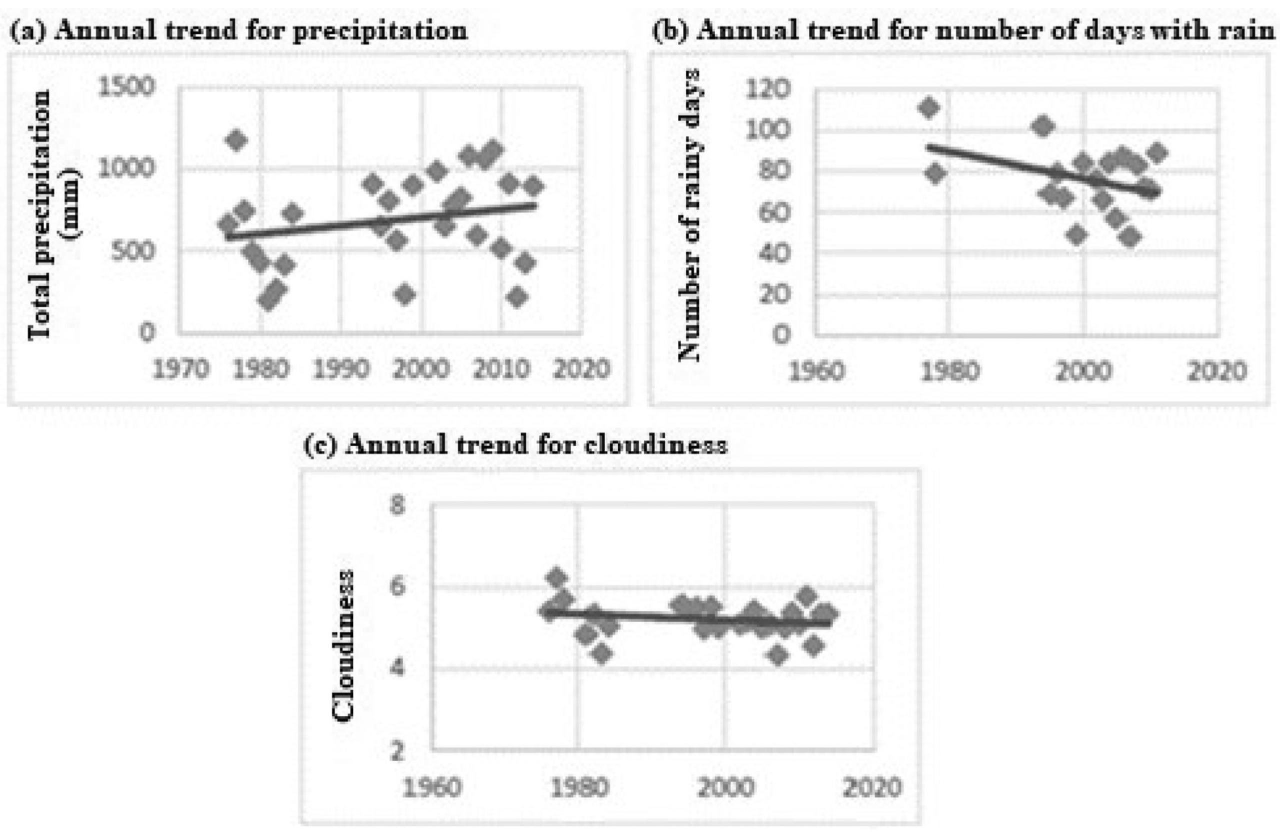

Figure 3 - Annual trends for precipitation (a), number of rainy days (b) and cloudiness (c) for the *Patos* station in the mesoregion of Sertão Paraibano (Adapted from Peixoto; Abrahão, 2015).

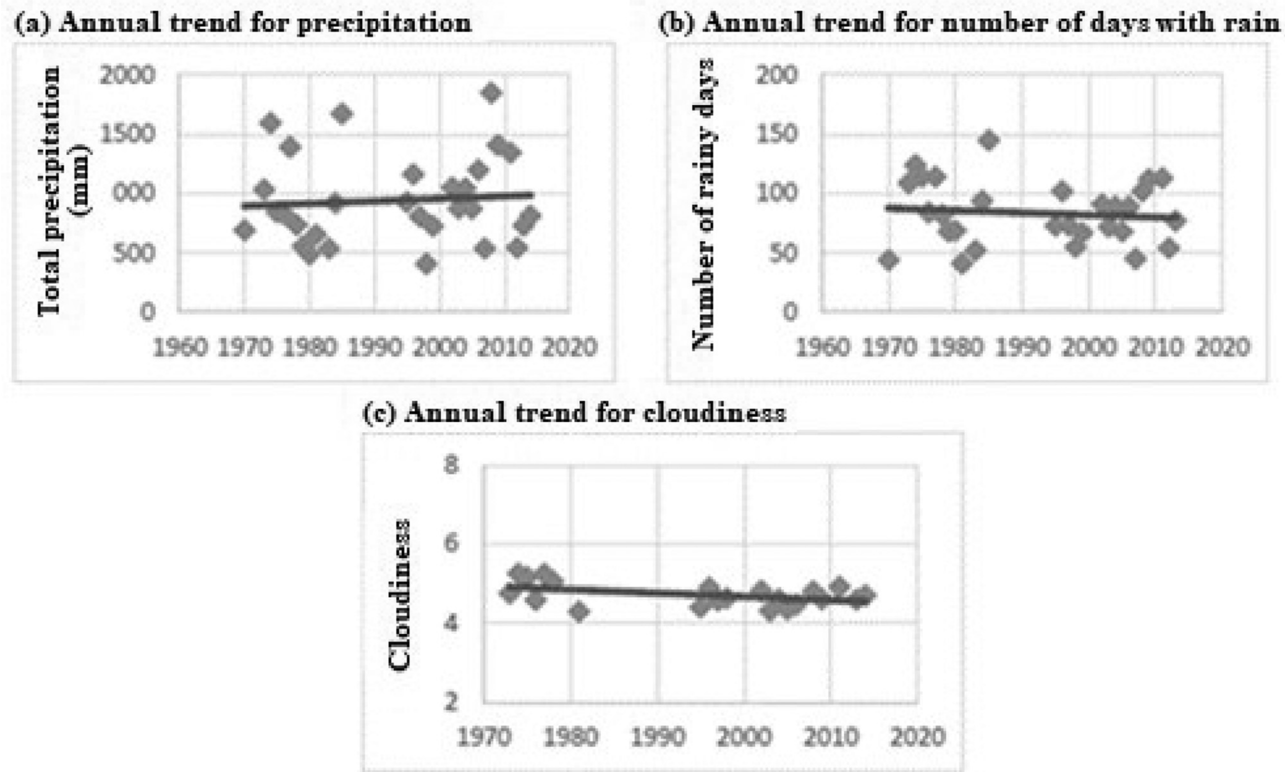

Figure 4 - Annual trends for precipitation (a), number of rainy days (b) and cloudiness (c) for the *São Gonçalo* station, in the Sertão Paraibano mesoregion (Adapted from Peixoto; Abrahão, 2015).

ferent. The study by Silva *et al.* (2004) observed high variability for the spatial distribution of precipitation and number of rainy days in Northeast Brazil. Variability is usually higher during the dry period. In addition, the authors affirm that the Northeastern semiarid region presents the highest coefficient of variation for rainfall and number of rainy days when compared to other areas of Brazil.

According to the Brazilian National Water Agency (ANA), during this century most cities with more than 5,000 inhabitants in the semiarid Northeast will face difficulties to supply water for human consumption due to population growth and increased water demands (ANA, 2005). Furthermore, it is important to emphasize that the Brazilian electricity grid is based on renewable sources, with hydroelectric being responsible for more than 60% of national electricity generation in 2015 (EPE, 2014; Delgado and Carvalho, 2016). However, for the state of *Paraíba*, electricity generation in hydroelectric power plants represented only 0.7% of installed capacity although electricity generated by hydroelectric plants in Northeast Brazil represents 49% of its total electricity generation capacity (EPE, 2014; Nogueira *et al.*, 2014).

Thus, the sustainability of an electricity matrix based on hydropower implies in the need to continue developing studies to better understand the occurrence and distribution of precipitation under climate change influence, to elaborate appropriate plans for the management of water and energy resources.

4. Conclusions

Trend analysis detected significant positive trends for precipitation in four of the five meteorological stations for the annual time interval in the Sertão Paraibano mesoregion. The trend values obtained in the different stations and analyzed time intervals were heterogeneous, although four of the five stations showed similar behavior in the evolution of precipitation. Trend values for the annual assessment were between 2.67 mm/year and 5.45 mm/year; biannual (J-J) were between 3.10 mm/year and 3.97 mm/year, trimestrial (DJF) between 1.65 mm/year and 2.44 mm/year and monthly (January) between 0.58 mm/year and 0.88 mm/year.

No significant negative trends were observed, which means that, according to the results obtained, it is possible to perceive significant trends only for the increase of precipitation in the mesoregion of Sertão Paraibano.

The work presented herein represents an important contribution for the comprehension of dynamics of climate evolution in the Brazilian semiarid, providing information that can be applied to the development of environmental measures and management of water resources in this vulnerable region.

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