



Detection of climate trends in macroregions of the Ceará State using FUNCEME data

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ABSTRACT. The goal of this study was to apply the Mann-Kendall test to the rainfall data of eight macroregions of the Ceará State aiming to determine climate trends in their time series. To this end were used rainfall data obtained by the FUNCEME for the period 1974-2011. The Mann-Kendall test was applied to verify trends in rainfall series, and the Students's t-test to check significant differences in the trend values. Downward trends in annual rainfall were found for the metropolitan region of Fortaleza, Sertão dos Inhamuns and Sertão Central, areas that also presented smaller green areas and/or fewer vegetated areas. Upward trends in rainfall were observed on the West Coast, Sobral/Ibiapaba, Baturité, East Coast/ Jaguaribe and Cariri/South Central.

Keywords: Mann-Kendall test, T-Student's test, climate variations, Brazilian semi-arid.

Detecção de tendências climáticas em macroregiões do Estado do Ceará a partir de dados da FUNCEME

RESUMO. O objetivo desse trabalho é aplicar o teste de Mann-Kendall a dados de precipitação de oito macrorregiões cearenses no intuito de determinar tendências climáticas em suas séries temporais. Foram utilizados dados de precipitação obtidos através da FUNCEME para o período de 1974 a 2011. Foi aplicado o Teste de Mann-Kendall para verificar as tendências nas séries pluviométricas e o teste de T-Student para mostrar se os valores de tendências encontrados são significativos estatisticamente ou não, diante da amostra. Tendências de diminuição nas chuvas anuais foram encontradas para Região Metropolitana de Fortaleza, Sertão dos Inhamuns e Sertão Central, áreas que apresentaram também menores áreas verdes e/ou menor quantidade de áreas vegetadas. Tendências de aumento nas precipitações foram observadas no Litoral Oeste, Sobral/Ibiapaba, Baturité, Litoral Leste/Jaguaribe e Cariri/Centro Sul.

Palavras-chave: teste de Mann-Kendall, teste de T-Student, variações climáticas, semiárido brasileiro.

Introduction

A major concern of researchers has increased recently focusing the analysis of climate variability taking place on the planet, especially regarding a possible increase in intense rainfall events (Bertoni & Tucci, 1993).

Studies of this nature have proven to be very important and useful in the northeast region, since the benefits brought by results can be applied in the daily living of the population.

There are different techniques being used to diagnose trends and/or variations in time series of environmental data. Among them, mentions the Mann-Kendall test (Hamed & Rao, 1998; Haylock et al., 2006), which is indicated by the World Meteorological Organization to verify trends in meteorological data, as in this case, the rainfall. It is noteworthy to remember that trend within a time series is a continuous and systematic change in any

parameter of a given sample, excluding periodical or almost periodic changes (Yevjevich, 1972).

Back (2001) used the Mann-Kendall test among other statistical analysis, to identify annual trends in temperature and rainfall of the weather station of Urussanga, Santa Catarina State. No significant trend could be identified in the mean temperature of July. Also a significant increasing trend was found in the total annual rainfall and in the total rainfall in the fourth quarter. In the first three quarter, no significant trend was observed.

Liebmann et al. (2004) identified seasonal linear trends in the rainfall of the Central South America for the period 1976-1999, with the highest positive trend occurring to the south of 20°S and over southern Brazil from January to March. For the period 1948-1975, the trend was also positive but less intense. The possible cause for this trend may be an increased percentage of rainy days, and an increase in the average of rainy days.

The rainfall trend was also related to the positive trend of the sea surface temperature, in the Atlantic Ocean.

Marengo & Camargo (2008), by means of the Mann-Kendall test, have found warming trends in most stations of the southeast Brazil, from 0.5 to 0.8°C/decade in minimum temperatures and 0.4°C/decade in maximum temperatures.

Santos, Silva, Sousa, and Silva (2010) evaluated current climate conditions in northeast Brazil, and elaborated climate scenarios for 2050 and 2100 and applied the Mann-Kendall test to the data. The results indicated increasing trends in time series of air temperature, significant by the Mann-Kendall test for scenarios of 2050 and 2100. It was found increasing trends in potential evapotranspiration rates throughout northeastern Brazil, especially in central, western and northern region in both scenarios analyzed.

Silva, Silva, Cavalcanti, and Santos (2010) used the Mann-Kendall test in time series of radiation balance in the northeast of Brazil and concluded that they exhibited sharp reductions between 1948 and 1987, but in the period from 1988 to 2006, an opposite behavior, suggesting the global dimming phenomenon on the northeastern Brazil.

Minuzzi (2010) has identified changes in the behavior of maximum temperature (minimum temperature) between the years of 1995 to 1997 (from 1988 to 1991), since the mid-1950, declining trend (increase). As for precipitation there was slight sign of increase in trend.

In this context, this study applied the Mann-Kendall test to rainfall data from eight (8) macroregions of the Ceará State, aiming to determine climate trends in their series and indicate whether or not the rainfall has increased in these regions over time, simultaneously suggesting which pattern the future rainfall will follow.

Material and methods

Study area

The Ceará State (Figure 1) is one of 27 units of Brazil. It is the twelfth richest state in the country, located in the northeast region. It is limited by the Atlantic Ocean to the north and northeast, by the Rio Grande do Norte State to the east, Pernambuco State to the south, and Piauí to the west. Its total area is 146,348.30 km² or 9.37% northeast area, and 1.7% of Brazil. The population estimated to 2008 was 8,450,527 inhabitants, conferring to the territory the eighth place among the most populous federal units (Ceará, 2009 apud Lopes & Silva, 2014).

The capital and largest city is Fortaleza, seat of the Metropolitan Region of Fortaleza (RMF). Other major cities outside of RMF are: Juazeiro do Norte

and Crato in the metropolitan region of Cariri, Sobral in the northwest region, Itapipoca in the northern region, Iguatu in the south-central region, and Quixadá in the Sertão. Altogether there are 184 municipalities.

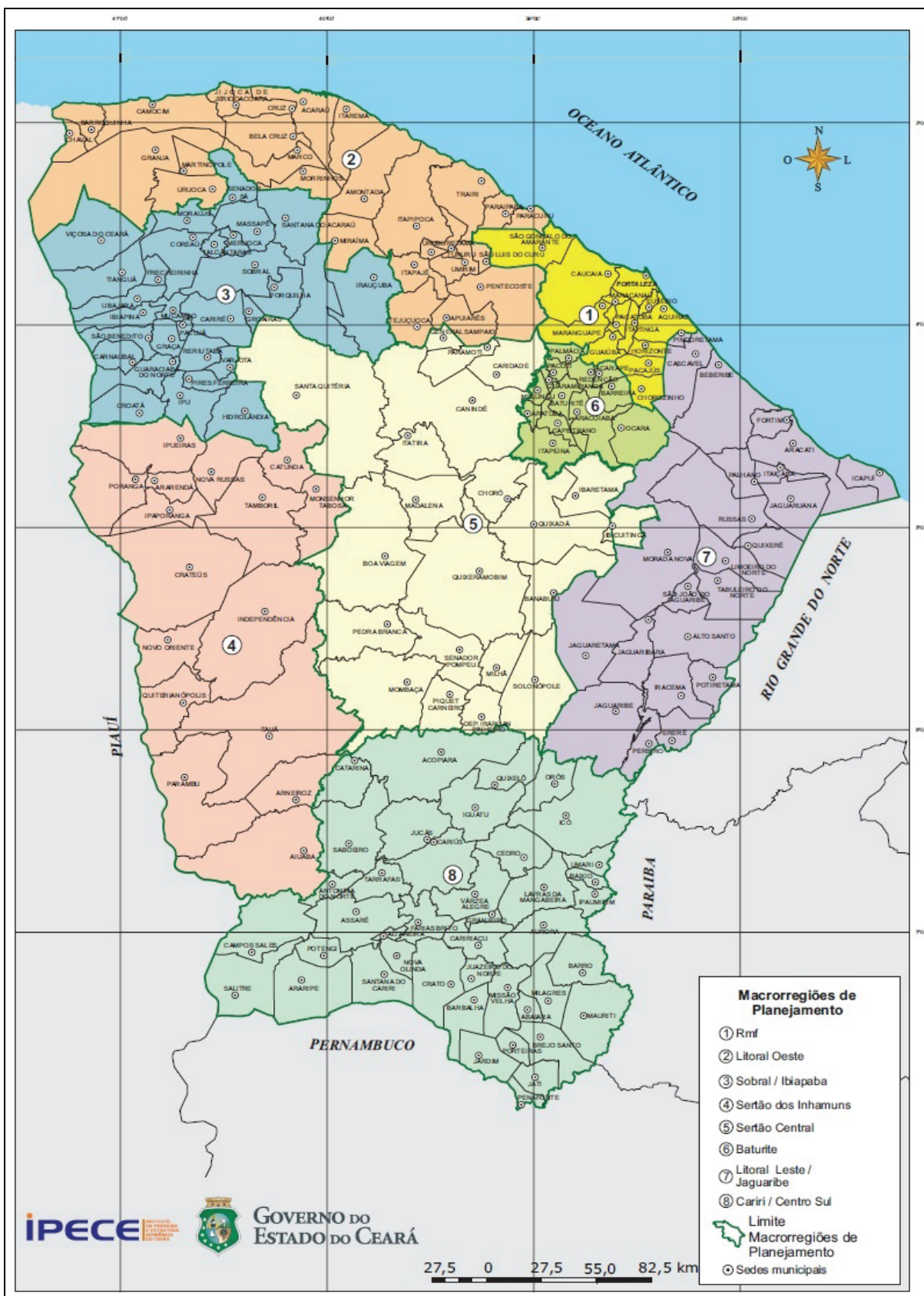
The State is nationally known for the beauty of its coasts, popular religiosity, and for the birthplace image of comedy talents. The raft, still common along the coast, is considered one of the main symbols of the people and culture of the State. The Ceará State concentrates 85% of all caatinga of Brazil, and is the second State with better quality of life in the north-northeast, according to FIRJAN.

The Ceará State is surrounded by relatively high relief formations; to the west is delimited by the Serra da Ibiapaba; to the east, partially by the Chapada do Apodi; to the south by the Chapada do Araripe; and to the north by the Atlantic Ocean. Hence the name of Depressão Sertaneja to the central area (Ceará, 2009 apud Lopes & Silva, 2014).

This State is within the caatinga domain, with rainy period restricted to about four months and high biodiversity adapted. The characteristics seasonality of this biome is reflected in a fauna and flora adapted to semi-arid conditions. Therefore, there is a great number of endemic species, especially in swamps and saws, isolated by caatinga and refuges of flora and fauna of tropical rain forests. The most arid regions are situated at Depression Sertaneja, to the west and southeast. Close to the coast, the influence of trade winds provides a sub-humid climate, where emerges a more dense vegetation, with strong presence of carnauba forests, which characterize stretches of mata dos cocais. The climate also becomes sub-humid, with more dense caatinga and heavier rainfall in the vicinity of highlands and saws.

The territory is divided into seven watersheds, and the major one is of the Jaguaribe River. Its basin covers more than 50% of the state. The river has 610 km length. The two largest reservoirs of water of the Ceará State are dams in the Jaguaribe River: Açude Orós and Açude Castanhão with 2.1 and 6.7 billion cubic meters of storage capacities, respectively. The most important tributaries of the Jaguaribe River are Salgado and Banabuiú.

For this study, eight macroregions were selected within the Ceará State (Figure 1): Metropolitan Region of Fortaleza (RMF), West coast region, Sobral-Ibiapaba region, Baturité region, Sertão dos Inhamuns region, Sertão Central region, East coast-Jaguaribe region, and Cariri-south center region, according to the division of macroregions of the Ceará State from the Planning and Coordination Secretariat (Seplan apud Lopes & Silva, 2014).



Source: Seplan (2011) apud Lopes and Silva (2014).

Figure 1. Ceará State and its eight macroregions.

Data

Rainfall data were obtained by the Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME) for the period 1974-2011 (38 years).

The Mann-Kendall test requires independent time series so a serial correlation test should be previously applied (Sneyers, 1975).

This is non-parametric test (Mann, 1945; Kendall, 1975), suggested by the World Meteorological Organization to evaluate trends in time series of environmental data.

In general, studies on climate trends neglect the serial correlation in time series; positive (negative) serial correlations increase (reduce) the probability of rejecting the null hypothesis (Von Storch, 1995). In these cases, series must be filtered with an autoregressive model, for example by using a modified Mann-Kendall test for autocorrelated series, as proposed by Hamed and Rao (1998).

The existence of serial correlation in the series should be evaluated by the sequences non-parametric test. Series not rejected in these tests were subjected to the Mann-Kendall test, a non-parametric test used to evaluate a possible trend. In the case of series rejected by the test, the modified Mann-Kendall test should be used to take into account the autocorrelation, but anyway significant trends should be removed a priori (Hamed & Rao, 1998).

The statistics of the test is as follows (Silva et al., 2010):

$$S = \sum_{i=2}^n \sum_{j=1}^{i-1} \text{sign}(X_i - X_j) \quad (1)$$

in which: x_j are data estimated of the sequence of values, n is the length of the time series, and the signal $(x_i - x_j)$ is equal to -1 for $(x_i - x_j) < 0$, 0 for $(x_i - x_j) = 0$, and 1 for $(x_i - x_j) > 0$.

Kendall (1975) showed that S is normally distributed with mean $E(S)$ and variance $\text{Var}(S)$ for a situation in which there may be equal values of x , calculated by the equations:

$$E[S] = 0 \quad (2)$$

$$\text{Var}[S] = \frac{n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5)}{18} \quad (3)$$

in which: (t_p) is the number of data with equal values within a given group $(p\text{th})$ and q is the

number of groups containing equal values in the data series in a given group p . The second term represents an adjustment for censored data.

The parameterized statistical test (Z_{MK}) is given by the following equation:

$$Z_{MK} = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(s)}} & \text{for } S > 0; \\ 0 & \text{for } S = 0; \\ \frac{s+1}{\sqrt{\text{Var}(s)}} & \text{for } S < 0 \end{cases} \quad (4)$$

A statistically significant trend is evaluated with the use of the Z -value. This statistics is used to test the null hypothesis, that is, no trend. A positive value of ZMK indicates an increased trend, when negative indicates a downward trend. In order to test the up- or downward trend in the significance level of p , the null hypothesis is rejected if the absolute value of Z is higher than $Z_{1-p/2}$, using the standard cumulative normal distribution table.

The significance levels of $p = 0.01$ and 0.05 were applied in this study. A non-parametric estimate for the value of the trend slope is obtained according to Silva et al. (2010):

$$\beta = \text{Median} \left[\frac{x_j - x_i}{j - i} \right] \text{ para } i < j \quad (5)$$

in which: x_j and x_i are the data measured in the time i and j , respectively.

Student's t-test of significance

This test was used to check significant differences in the values of trends. One of the most used distributions for small samples is the Student's t -test, which is widely used in meteorology studies (Kousky & Kayano, 1994; Kayano & Kousky, 1996), and can be calculated as follows:

$$t_c = t / \sqrt{(n-2) + t^2} \quad (6)$$

in which: t_c = percentile value and c is the degree of freedom. It was used $p = 0.95$, or 95%; t = percentile value tabulated according to v $(n-1)$; n is the number of data.

Results and discussion

The Mann-Kendall test indicated a downward trend for three macroregions of the Ceará State (metropolitan region of Fortaleza, Sertão dos

Inhamuns and Central Sertão) and upward trends for five macroregions (West coast, Sobral/Ibiapaba, Baturité, East coast/Jaguaribe, and Cariri/South center) (Table 1).

It is important to notice that areas with downward trend of rainfall have smaller green areas and/or fewer vegetated areas. In the RMF, with increasing urbanization the vegetation has been reduced, which influence by decreasing the evapotranspiration, infiltration and consequently decreasing local rainfall caused by local effects.

Table 1. Trends found for eight macroregions of the Ceará State.

Macroregions	Annual Trends (mm)	Trends in 38 years	Trends Status
Região Metropolitana de Fortaleza	-0.31649	-12.0266	decrease
Litoral Oeste	0.051945	1.973922	increase
Sobral/Ibiapaba	0.186973	7.104974	increase
Sertão dos Inhamuns	-0.07414	-2.81732	decrease
Sertão Central	-0.04375	-1.6625	decrease
Baturité	0.162301	12.8443	increase
Litoral Leste/Jaguaribe	0.294117	11.176	increase
Cariri/Centro Sul	0.162301	6.1674	increase

In the Sertão dos Inhamuns and Sertão Central the downward trends in annual rainfall were related to the predominant presence of Caatinga (vegetation that remains dry and without leaves in part of the year, reducing the evapotranspiration), to the low local water reserve and high index of local degradation, which leads to the risk of desertification, as occurred in Irauçuba, also in Ceará State (Vasques Landim, Silva, & Almeida, 2011).

Upward trends in annual rainfall were lower in the west coast, situated between Atlantic Ocean to the north of this area, to the east is found the mountain region of Baturité (higher value of upward trend) and to the south, another region of altitude, the Serra da Ibiapaba.

The highest upward trend in annual rainfall was observed in the Baturité region, area with high altitude and with native vegetation, despite the advancement of agriculture. In 38 years, an increase of 12.84 mm was observed in the Baturité region.

The greatest trend for decrease occurred in the RMF, with less than 12.02 mm in the last 38 years.

The Mann-Kendall test indicated a trend in the time series, showing a trend in the current pattern and suggesting the future behavior of the series (Figures 2a-h). A visualization of the future behavior of each series can be performed from the trends and their lines, as presented in Figures 2a-h.

These figures corroborated the results found by the Mann-Kendall test. Thus the trend values found generated a trend distribution map for the Ceará State (Figure 3), which shows negative signals only for the Sertão dos Inhamuns, Sertão Central and RMF.

Lopes and Silva (2014) have applied the Mann-Kendall test for series of rainfall data for the entire state of Ceará, but data from the ANA. There was a decrease trend in rainfall of four regions: RMF, West coast, Sertão Central, and East coast/Jaguaribe, whereas our results, with data from FUNCEME, decrease trends have been registered only for three regions: RMF, Sertão dos Inhamuns and Sertão Central. Besides this divergence, comparing the studies, while data from the ANA tend to reduce by 3.96 mm per year, data from the FUNCEME showed that the decrease would be 0.3164 mm. The east coast-Jaguaribe, with data from ANA, presented a downward trend of 0.75 mm per year, whereas with our data from FUNCEME, had an upward trend of 0.294 mm per year.

Regions that present distinct trends, as observed in the present study, were also found by other authors. Minetti (1998) and Minetti, Vargas, Poblete, Acuna, and Casagrande (2003) registered for the period of 1931-1999, a constant reduction in annual rainfall for a large area to the west of the Andes, an increase to the east in central Argentina, and a steady increase until the 1980's in northern Argentina.

Finally in Valdivia, Chile, it was observed a decrease in total annual rainfall during the period 1901-1990 (Rusticucci & Penalba, 2000).

The results of down- or upward trends in rainfall series found herein were also reported by other authors.

Haylock et al. (2006) observed an upward trend in total annual rainfall over northeast Brazil. Santos and Brito (2007) found upward trends of total annual rainfall in the states of Paraíba and Rio Grande do Norte. Santos, Brito, Ramana Rao, and Menezes (2009) identified local changes in rainfall and an increase in humidity conditions for the Ceará State. At last, Santos and Manzi (2011) verified that only the northern region of the Ceará had trends with high statistical significance for the indices of extreme events used in the study.

Thus, our results are coherent with those reported by Minetti (1998) and Minetti et al. (2003), Rusticucci and Penalba (2000), Haylock et al. (2006) Santos and Brito (2007) and Santos and Manzi (2011).

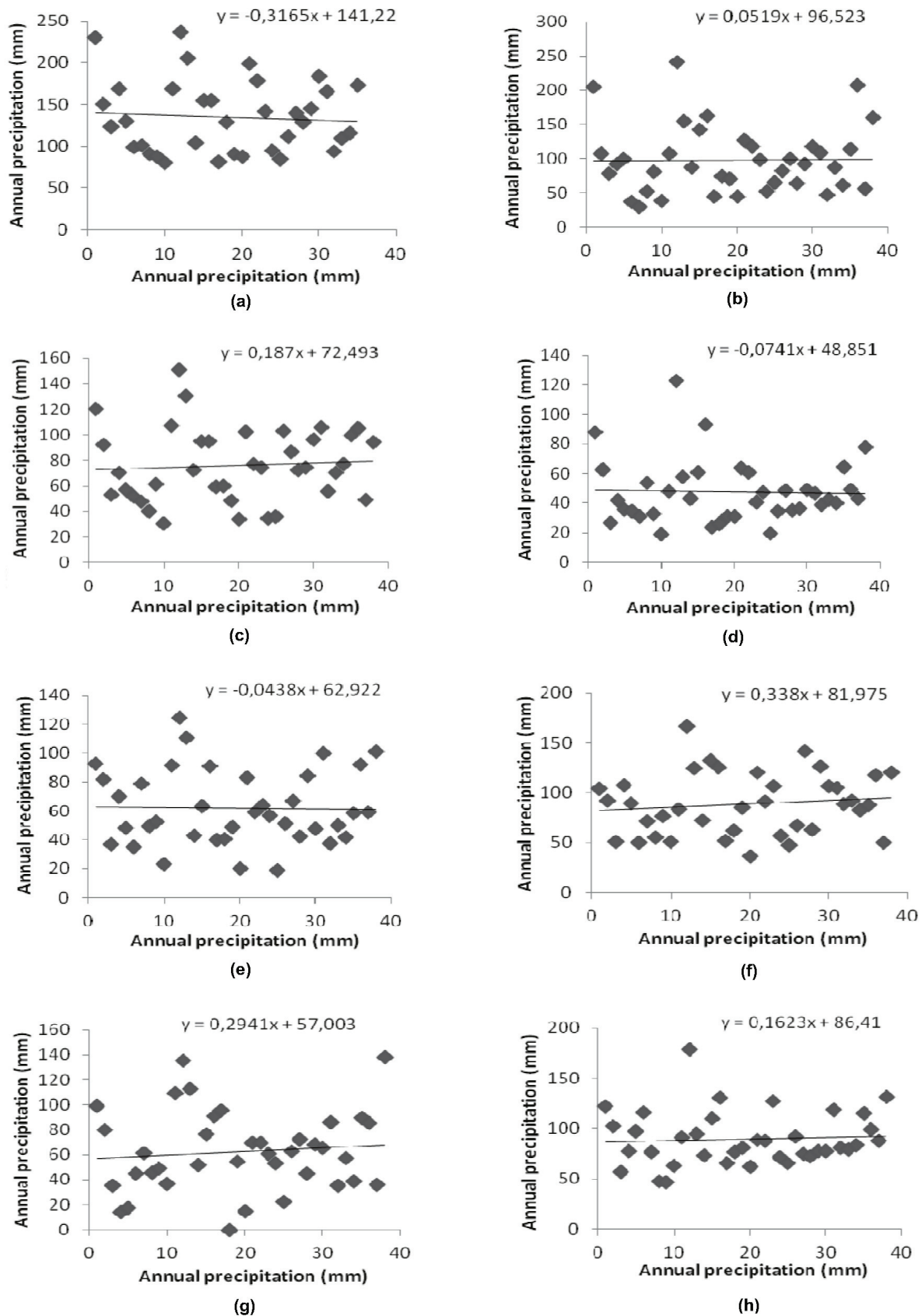


Figure 2. Trends for: a) RMF.; b) Litoral Oeste; c) Sobral – Ibiapaba.; d) Sertão dos Inhamuns; e) Sertão central; f) Baturité; g) Iste-Jaguaribe; h) Cariri-Centro Sul.

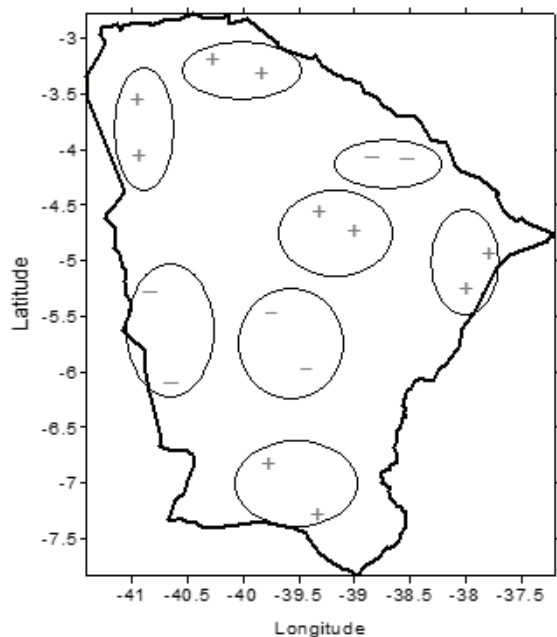


Figure 3. Trends registered for the Ceará State with Mann-Kendall test.

Conclusion

Concluding, for the Ceará State, downward trends of annual rainfall were found for the Metropolitan Region of Fortaleza, Sertão dos Inhamuns and Sertão Central, areas with smaller green areas and/or fewer vegetated areas. Upward trends in rainfall were observed in west coast, Sobral/Ibiapaba, Baturité, East coast/Jaguaribe and Cariri-South center.

Lastly, it was generated a map of climate trends observed in rainfall time series for the Ceará State, indicating areas with downward and increased trend of rainfall.

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