EPiC Series in Engineering
Volume 3, 2018, Pages 1868–1875
HIC 2018. 13th International Conference on Hydroinformatics

Variability of rainfall in the semi-arid region of Brazil

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Abstract

The Brazilian semi-arid region presents a highly variable rainfall regime in space and time. Although the mechanisms of rainfall have been well described and numerically modelled, reliable forecasts for more than six months in advance cannot be produced yet, as well as projections of climate change in the long term. This paper contributes to the understanding of the variability examining a more than 100-year time series of a rainfall gauge in this region, using three techniques: wavelet analysis, Mann-Kendall and Sen tests. The techniques allow the description of the patterns of variability of rainfall and suggest that there is not still a clear evidence of climate change.

1 Introduction

The Brazilian semi-arid area is a tropical drought-prone region subject to a high inter-annual variability of its seasonal rainfall. Most of the region presents rainfall concentrated in only 2–4 months of the year. Annual average ranges from about 400 to 800 mm, with high coefficient of variation. The mechanisms of rainfall generation in the region have been well described, but climate change detection and projection are still challenging climatologists for decades (Markham, 1974; Oliveira et al., 2017; Marengo et al., 2017). Drought in Northeast Brazil—past, present, and future, Theoretical and Applied Climatology, 129, 1189–1200). The work reported in this paper uses a combination of techniques to characterize a long rainfall time series in the region towards detection of change in the pattern of variability.

[*] Defined the research theme, performed the wavelet analysis and analyzed the results
[†] Defined the research theme, provided the data and analyzed the results
[‡] Performed the trend analysis and analyzed the results
[§] Analyzed the results

2 Material and Methods

The present analysis uses three techniques for characterization of the variability of the time series of rainfall in one location in the semi-arid region of Brazil: (a) Mann-Kendall test (MK), which has been widely used to detect trends in time series (Silva et al., 2015; Brito Neto et al., 2016), (b) Sen slope estimator, which calculates the rate of change if a significant trend is found (Silva et al., 2015), and (c) wavelet analysis, which can detect different frequencies of occurrence of events within a time series (Torrence & Compo, 1998; Santos et al., 2001; Santos & Morais, 2013).

The monthly rainfall time series from 1911 to 2016 (shown later in Figure 5a) is from São João do Cariri rain gauge, located at 7.38° S and 36.53° W. This rain gauge is representative of one sub-region in the wider semi-arid region of Brazil. Due to the lack of long and consistent time series in the region with few missing values, the complete analysis was performed solely for São João do Cariri gauge. However, other nine gauges in the vicinity were select to provide evidence of the representativeness of the longer time-series gauge (Figure 1). They present 18 years of consistent data (January 1998 – December 2015). Table 1 shows the latitude, longitude and annual rainfall depth for each rain gauge.

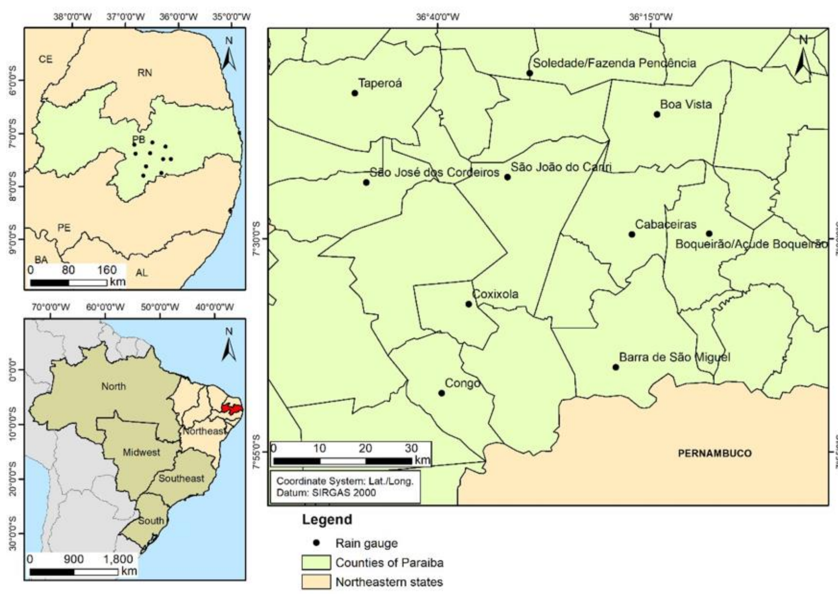

Figure 1: Brazil, Paraíba state maps and the location of the 10 rain gauges within the study area

ID	Rain gauge	Latitude	Longitude	Annual average (mm) (1998–2015)
1	São João do Cariri	–7.38	–36.53	528.1
2	Taperoá	–7.22	–36.83	621.0
3	Soledade/Fazenda Pendência	–7.18	–36.49	435.1
4	Boa Vista	–7.26	–36.24	401.3
5	São José dos Cordeiros	–7.39	–36.81	561.6
6	Boqueirão/Açude Boqueirão	–7.49	–36.14	437.7
7	Cabaceiras	–7.49	–36.29	424.4
8	Congo	–7.80	–36.66	431.9
9	Coxixola	–7.63	–36.61	495.8
10	Barra de São Miguel	–7.75	–36.32	363.4

Table 1: Rain gauges in the study area

3 Results and discussion

3.1 Rainfall characteristics

Monthly behavior of rainfall for 10 rain gauges in the period 1998–2015 (Figure 2) is similar among them, with high variability and marked seasonal rainy and dry months. Inter-annual variability of annual rainfall totals is high but also similar among the gauges (Figure 3). In some years, due to local spatial variability of the convective storms, there are differences in rainfall among the gauge locations: 2000, 2006, 2008–2011, 2015. Driest years (e.g., 1998, 2012 and 2015) contrast with the rainiest ones (2004, 2008, 2009 and 2011), with annual rainfall ranging from around 200 mm in 1998 to 1400 mm in 2011, for São João do Cariri gauge, being the annual average relatively low (528 mm). This analysis demonstrates that this gauge – with a longer and consistent time series – can be used in the further analyses as representative for the sub-region.

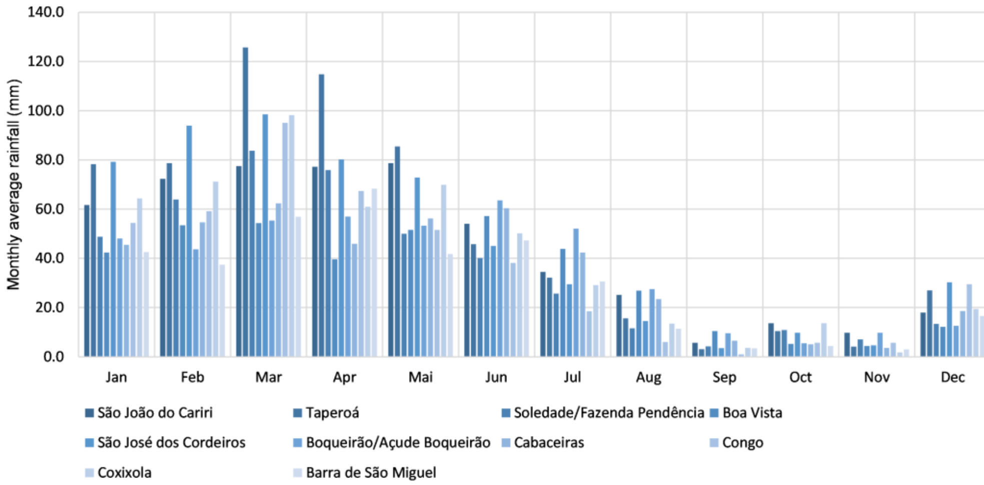

Figure 2: Monthly average rainfall for 10 gauges in the study area

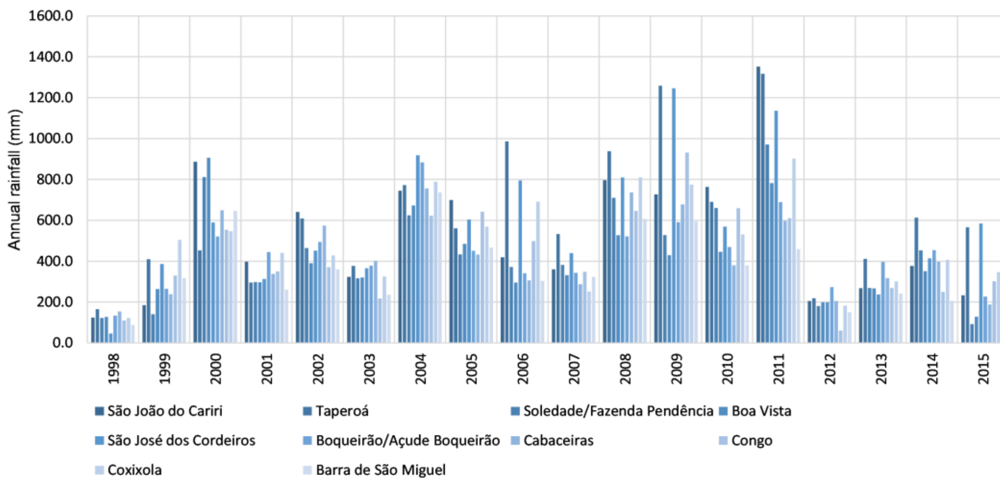

Figure 3: Annual rainfall for 10 gauges in the study area (1998–2015)

3.2 Mann-Kendall and Sen tests

For the application of the MK test, the annual cumulative precipitation values of São João do Cariri gauge were used over more than 100 years of data. It was decided to use the data in an annual scale taking into account the good suitability of the test in relation to this type of data. In addition, due to the size of the data time series and its representativeness over the study region, it is possible to estimate the trend of this series taking into account the lower levels of significance (i.e., higher levels of confidence). The results show that there is an increasing trend at a level of significance of 11%. This means that with 89% of confidence, the annual rainfall series of São João do Cariri gauge tends to increase. By applying the Sen non-parametric test, it is estimated that the true slope of this trend line indicated by the MK test is 1.0686, which indicates that the annual precipitation tends to increase each year following this positive rate of change. This is the true slope of the existing trend (change per year), as shown in Figure 4.

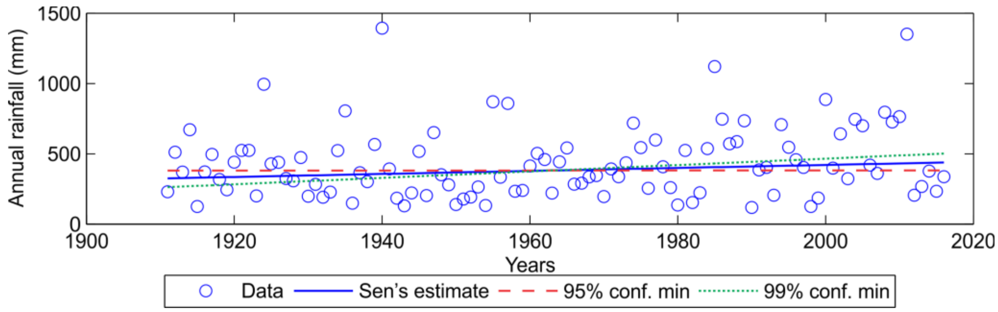

Figure 4: Annual rainfall time series (1911–2016) and trend analysis at a level of significance = 0.11 and Sen's slope = 1.0686

3.3 Wavelet transforms

The monthly rainfall in São João do Cariri is presented in Figure 5a, which is a record of the period between 1911 and 2016. Then, Figure 5b shows the power (absolute value squared) of the wavelet transform for such hyetograph. The spectrum in Figure 5b gives information on the relative power at a certain scale and a certain time and it shows the actual oscillations of the individual wavelets, rather than just their magnitude. It is possible to note that there is more concentration of power between the 8–16-month band. This frequency corresponds to the annual signal (12 month), which is confirmed by the global wavelet spectrum in Figure 5c. The region below the yellow line in this figure is the cone of influence, where zero padding has reduced the variance (Torrence & Compo, 1998; Santos et al., 2001; Santos & Morais, 2013). Because the present data is a finite-length time series, errors occur at the beginning and end of the wavelet power spectrum. One solution was to pad the end of the time series with zeroes before applying the wavelet transform and then remove them afterwards (Torrence & Compo, 1998). The black contour in this figure is the 5% significance level, using a white-noise background spectrum.

The null hypothesis is defined for the wavelet power spectrum as assuming that the time series has a mean power spectrum; if a peak in the wavelet power spectrum is significantly above this background spectrum, then it can be assumed to be a true feature with a certain per cent confidence. For definitions, "significant at the 5% level" is equivalent to "the 95% confidence level," and implies a test against a certain background level, while the "95% confidence interval" refers to the range of confidence about a given value. The 95% confidence implies that 5% of the wavelet power should be above this level (Torrence & Compo, 1998). As in the interannual analysis over the past 18 years, some reductions of power between the 8–16-month band were observed in 1998, 2012 and 2015, which can be understand as a decrease in the annual precipitation depth.

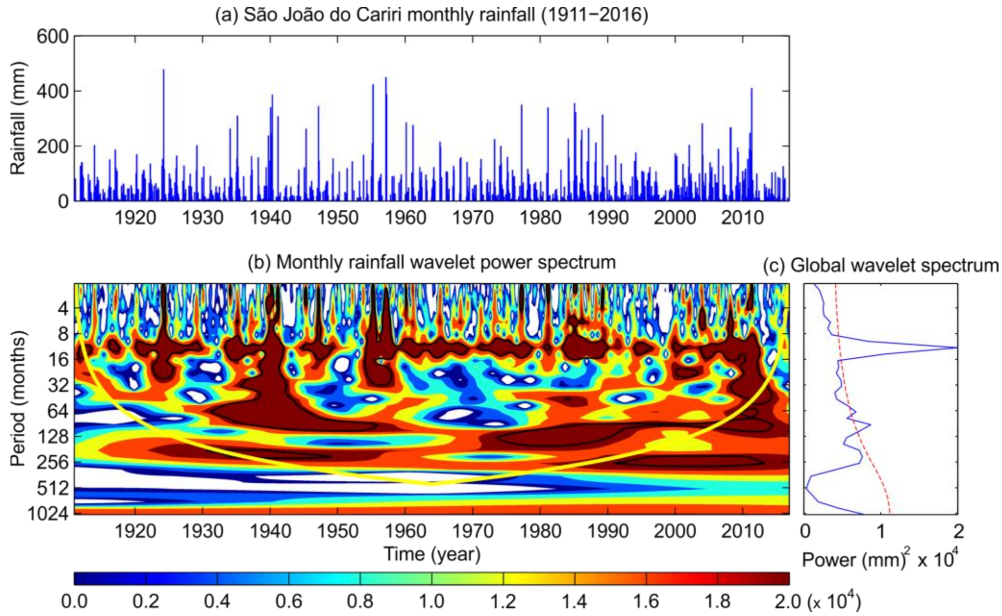

Figure 5: (a) Total annual rainfall series of São João do Cariri rain gauge. (b) The wavelet power spectrum using Morlet mother-wavelet. The contour levels are chosen according to the values in the color bar. Cross-hatched region is the cone of influence, where zero padding has reduced the variance. Black contour is the 5% significance level, using a white-noise (□ = 0.0) background spectrum. (c) The global wavelet power spectrum (black line). The dashed line is the 5% significance level for the global wavelet spectrum

The main frequencies of this time series are confirmed by an integration of power over time (Figure 5c), which shows three significant peaks (periodicity at 12, 64.1 and 96 months) above the 95% confidence level for the global wavelet spectrum, assuming white-noise, represented by the dashed lines. This global wavelet spectrum provides an unbiased and consistent estimation of the true power spectrum of the time series, and thus it is a simple and robust way to characterize the time series variability.

Figure 6 shows the scale-average wavelet power, which are the time series of the average variance in a certain band, i.e. (a) 2–4-month band, (b) 4–8-month band, (c) 8–16-month band, (d) 16–32-month band, (e) 32–64-month band, (f) 64–128-month band, (g) 128–256-month band, (h) 256–512-month band, (i) 512–1024-month band. These figures are made respectively by the average of Figure 5b over all scales between the respective months, which give a measure of the average year variance versus time. The variance plot shows distinct periods when the rainfall variance was low or high. From Figure 6, the following points can be highlighted: (i) the main periodicities apparent in the series are the 12-, 64- and 96-month; (ii) the drought and rainy years can be identified based on Figure 6c; (iii) additionally, low-frequency episodes of these extremes are shown in the 128–256-month and 256–512-month bands (Figure 6g and Figure 6h); and (iv) the rainy period of 2004–2011 appears to be unique in the whole series, significant in the 256–512-month band.

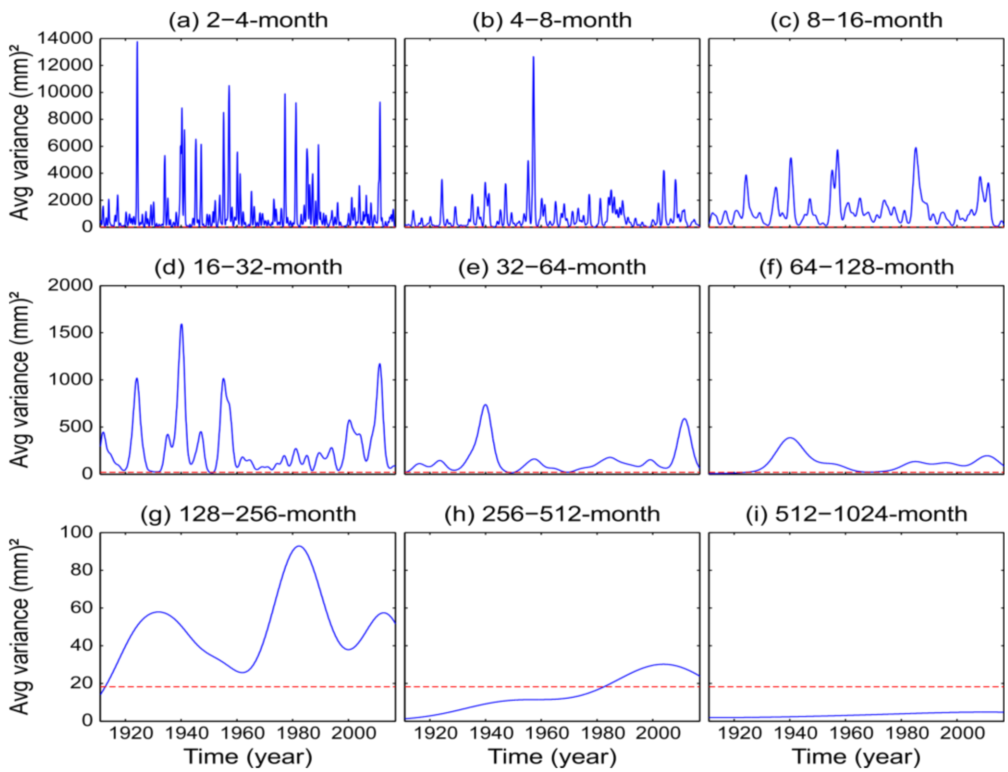

Figure 6: Scale-average wavelet power over the (a) 2–4-month band, (b) 4–8-month band, (c) 8–16-month band, (d) 16–32-month band, (e) 32–64-month band, (f) 64–128-month band, (g) 128–256-month band, (h) 256–512-month band, (i) 512–1024-month band, for the monthly rainfall in São João do Cariri. The dashed lines are the 95% confidence level assuming white-noise

4 Conclusions

The integrated analysis of the rainfall time series using wavelet transform, and the nonparametric tests of Mann-Kendall and Sen highlight the well-known characteristics of rainfall inter-annual variability in the semi-arid region of Brazil. Additionally, the wavelet analysis identifies the main bands of low-frequency variability, which are very relevant for designing drought preparedness measures. It also shows that the very rainy period 2001–2011 is a climatic extreme not present in the time series. Finally, the analysis suggests that these techniques could not reveal any significant evidence of climate change. The very high monthly and annual variability remains a challenge for further investigation.

References

Markham, C.G. (1974). Apparent periodicities in rainfall at Fortaleza, Ceará, Brazil. *Journal of Applied Meteorology*, 13, 176–179.

Oliveira, P.T., Silva, C.M.S., & Lima, K.C. (2017). Climatology and trend analysis of extreme precipitation in subregions of Northeast Brazil, *Theoretical and Applied Climatology*, 130, 77–90.

Marengo, J.A., Torres, R.R., & Alves, L.M. (2017). Drought in Northeast Brazil—past, present, and future, *Theoretical and Applied Climatology*, 129, 1189–1200.

Brito Neto, R.T., Santos, C.A.G., Mulligan, K., & Barbato, L. (2016). Spatial and temporal water-level variations in the Texas portion of the Ogallala Aquifer. *Nat. Hazards*, 80, 351–365.

Silva, R.M., Santos, C.A.G., Moreira, M., Corte-Real, J., Silva, V.C.L., & Medeiros, I.C. (2015). Rainfall and river flow trends using Mann-Kendall and Sen's slope estimator statistical tests in the Cobres River basin. *Nat. Hazards,* 77(2), 1205–1221.

Torrence, C., & Compo, G.P. (1998). A practical guide to wavelet analysis. *Bull. Amer. Meteor. Soc.*, 79(1), 61–78.

Santos, C.A.G., Galvão, C.O., Suzuki, K., & Trigo, R.M. (2001). Matsuyama city rainfall data analysis using wavelet transform. *Proc. Hydraul. Engng*, Tokyo, 45, 211–216.

Santos, C.A.G. & Morais, B.S. (2013). Identification of precipitation zones within São Francisco River basin (Brazil) by global wavelet power spectra. *Hydrol. Sci. J.*, 58(4), 789–796.