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ARTIGO ORIGINAL

Analysis of climate indices and impacts on the rainfall regime in the Sub-medium stretch of the São Francisco River Basin, Brazil

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ABSTRACT: This article covers the trends in climate changes in the semiarid region of the Northeastern region of Brazil, with a spacial cutout to the sub-medium stretch of the São Francisco River Basin. As a methodology, the RClimdex software was used to calculate the climate extremes indices of precipitation for the period between 1964 and 2016. The results indicated changes in the rainfall patterns, denoting an increase in the number of consecutive dry days, a reduction of the total annual rainfall, and also exhibiting negative trends in the daily rainfall intensity, in the number of days with moderate, strong, and intense rain, in the number of very humid and extremely humid days, contributing to the recurrent droughts in the semiarid region of Northeastern Brazil.

Keywords: climate changes; precipitation; river basin; semiarid.

Análise de índices climáticos e impactos no regime de chuvas no trecho Submédio da Bacia do Rio São Francisco, Brasil

RESUMO: *Este artigo aborda as tendências de mudanças climáticas no semiárido do Nordeste do Brasil, com recorte espacial do trecho Submédio da bacia hidrográfica do rio São Francisco. Como metodologia, utilizou-se o software RClimdex para calcular os índices climáticos extremos de precipitação pluviométrica para o período de 1964 a 2016. Os resultados indicaram mudanças no padrão da precipitação, evidenciando aumento dos dias consecutivos secos e diminuição do total anual de chuvas, apresentando tendências negativas também para a intensidade diária das chuvas e para o número de dias com chuvas moderadas, fortes e intensas, de dias muito úmidos e de dias extremamente úmidos, tendências essas que contribuem para as recorrentes secas que atingem a porção semiárida do Nordeste brasileiro.*

Palavras-chave: *bacia hidrográfica; mudanças climáticas; precipitação; semiárido.*

1 Introduction

Changes in climate variability have threatened to transform the planet into a more uncomfortable place, with changes in temperature and precipitation throughout the different regions of the world. The atmosphere is expected to become warmer with more extreme and intense weather events, leading to more severe droughts and more destructive floods. Climate variability and/or climate change have further accentuated the problem of water scarcity, mainly in the arid and semiarid regions of the planet, which have a great tendency for aridization, followed by the change in rainfall patterns (MARENGO; BERNASCONI, 2015; RIBEIRO *et al*., 2016; XIA *et al*., 2017).

According to the Report from the Brazilian Panel on Climate Change (PBMC, 2013), the Northeastern semiarid region of Brazil is likely to have its precipitation reduced by 20% in 2040. This report also points out that all of Brazil can be at least 3 ºC warmer until the end of the current century, with rainfall increasing by 30% in the South and Southeast regions and reducing by 40% in the North and Northeast regions.

The number of studies that analyze local scales is still reduced but corroborates the scenario of even greater water scarcity in the future of the Brazilian semiarid region. In their study, Ferreira *et al*. (2017) obtained results that indicate a decrease in rainfall in the microregions of Araripina, Salgueiro, and Petrolina, in the semiarid region of Pernambuco. Assis *et al*. (2018), when analyzing the influence of the tropical Pacific and Atlantic oceans on the climate indices of precipitation in the Sub-medium São Francisco River Basin, observed that their results indicated that nearly all the indices of climate extremes evaluated showed a negative trend, with emphasis on the decrease of the total annual rainfall.

Other results from the Report from the Brazilian Panel on Climate Change (PBMC, 2013) indicate that climate change and the consequent alteration in the hydrologic cycle are evident not only in the rainfall patterns. Climate change may tend to affect groundwater recharge rates, that is, renewable groundwater resources and groundwater levels. Similarly, the rise in global temperature significantly affects the increase of evaporation, which can undermine the storage efficacy of superficial reservoirs.

According to Marengo *et al*. (2011), drought is the main manifestation of climate variability in Northeastern Brazil, since it has become an inevitable natural disaster, mainly in the semiarid Northeastern region. Moreover, this same author argues: “Such drought periods are related to the climate conditions in the region, with a great variability of precipitation in terms of space and time, as well as the concentration of more than 80% of the total annual rain being restricted to a period of only four months”.

Bezerra and Bezerra (2016) carried out a study that showed that 463 reservoirs in the Septentrional Northeast had their volume reduced in the period between 2012 and 2016 due to the low rainfall levels recorded in those years, characterizing the drought suffered by the region. Ferreira and Kemenes (2019) noted that evaporation had the largest number of significant correlations, followed by temperature anomalies on the surface of the Atlantic Ocean, in the influence on the volumes of 26 reservoirs spread across the Northeast. They also pointed out that the low correlation rates found, indicate that anthropic factors and other climatic events possibly govern the volume of water accumulated in the reservoirs of the interior of the Northeast, needing to be better examined.

To analyze the climate variability and climate changes in Northeastern Brazil it is important to identify the processes that affect both spatial and temporal rainfall patterns. A relevant factor to point out in this context is the irregularity in the distribution of rainfall indices, associated with the high interannual rainfall variability over the tropical region, with dry and wet years. Several factors can therefore contribute to explaining the high variability of precipitation over Northeastern Brazil, such as Sea Surface Temperature (SST) fluctuations in the Tropical Pacific and Atlantic Oceans. In general, the SST anomalies over the Tropical Pacific and Atlantic are related to the changes in the general atmospheric circulation pattern and the consequent variation of precipitation in the Northeast of Brazil.

Such climate changes potentially influenced by human activities are expected to have major impacts on agriculture, fragile ecosystems, and food and water security for the population of semi-arid areas. Thus, analysis of climate indices and their effects on precipitation can help to assess the susceptibility of water systems to possible threats from climate change and to identify effective adaptation strategies to reduce or mitigate the risk of serious adverse consequences. In this context, this article aims to analyze trends in indices of climate change based on rainfall, calculating climate extremes indices to monitor and detect climate changes.

In section 2, the methodology is presented, with the location of the study area, the description and spatialization of the rainfall data used and the description of the calculation method. In section 3, the results obtained during the investigation are presented, using as an instrument the analysis of the indexes of climatic extremes. Section 4 contains the article's conclusions.

2 Materials and methods

In this section, the materials and methods used in the research will be presented, with the delimitation of the study area, and the methodological procedures used to achieve the objective and obtain the results.

2.1 Study area

This article is aimed at studying the Sub-medium stretch of the São Francisco River Basin, located in the semiarid region of Northeastern Brazil. It covers all of the mesoregions of the Sertão of the State of Pernambuco and a great part of the mesoregion of the Agreste. The part located in the State of Pernambuco is limited in the east by the lower section of the São Francisco River Basin. For the part located in the State of Bahia, the Sub-medium São Francisco comprises a great part of the mesoregion of the São Francisco Valley and a small portion of the Central-North region. In total, the Sub-medium São Francisco covers 83 municipalities, with 59 being located in Pernambuco and 24 in Bahia.

From the climatic point of view, the Sub-medium area of São Francisco is characterized by the great irregularity of rainfalls and has the months from January to Abril as its main rainy period. The rainfall in the Sertão region originates from the Cold Fronts, the Upper Tropospheric Cyclonic Vortices (UTCVs), and the Intertropical Convergence Zone (ITCZ). The beginning of the pre-rainy season takes place in December (extreme west) and is associated with the unstable Cold Fronts and with the UTCVs, which occur mainly in January and February. From February or March, revista principia

depending on the year, the ITCZ starts acting over all of the Sertão, which is already in its rainy season (PERNAMBUCO, 2006).

On average, the annual rainfall varies between 300 mm and 1200 mm, with higher levels observed in the High-Sertão of Pernambuco, with precipitation above 600 mm. The lowest annual rainfall is found in the Sertão of São Francisco, in Pernambuco and Bahia, with a total average between 300 mm and 600 mm. In the study area, the dry season can be extended by 7 to 10 months. Semiaridity is more intense in the lower parts, close to the São Francisco River, which has the greatest number of consecutive dry days, with precipitations lower than expected.

2.2 Pluviometric data

The historical series of daily and annual rainfall data was gathered from 83 pluviometric stations located in the Sub-medium São Francisco River Basin in the period from 1964 to 2016. These data were obtained from the Pernambuco Water and Climate Agency (Agência Pernambucana de Águas e Clima – APAC), consulting their online database[1], and from the National Water Agency (Agência Nacional de Águas – ANA), in its hydrological information system – Hidroweb[2].

[1] APAC's online database. Available at: http://old.apac.pe.gov.br/meteorologia/monitoramento-pluvio.php. Accessed on: 18 Dec. 2022. In Portuguese

[2] Hidroweb. Available at: http://hidroweb.ana.gov.br/. Accessed on: 26 Sep. 2022. In Portuguese.

Following a detailed evaluation of the quality and homogeneity of the data, 36 pluviometric stations from different municipalities were selected, with 26 located in the State of Pernambuco and 10 in the State of Bahia, which showed good quality data and represented the study area in a good spatial distribution (Figure 1).

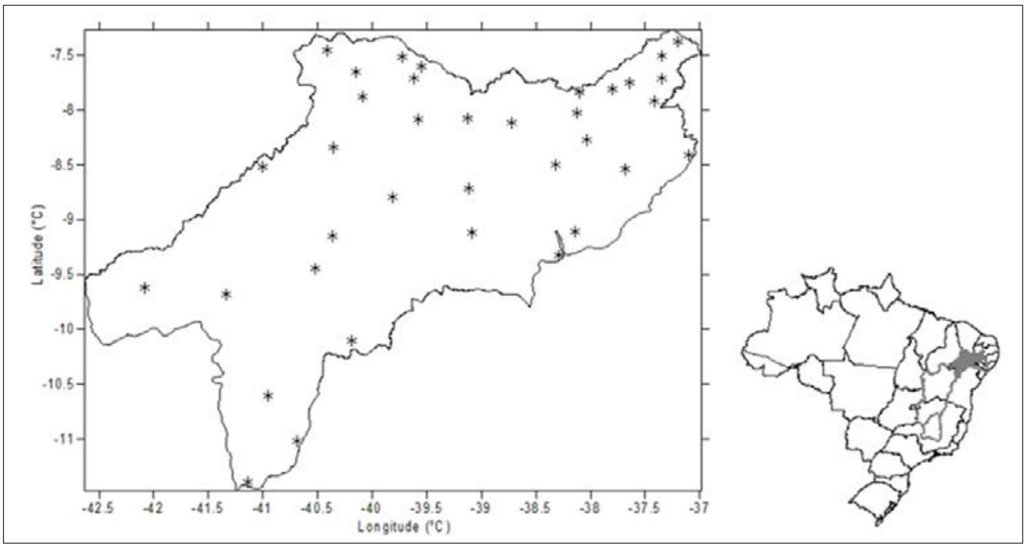

Figure 1 ▶ Spatial distribution of the pluviometric stations from the Sub-medium São Francisco region. *Source: elaborated by the authors*

2.3 Climate extremes indices of rainfall

Based on the guidelines suggested by the World Meteorological Organisation (WMO), the RClimdex 3.2.1 software was used to detect the climate extremes indices. This programme is used to calculate climate extremes indices for monitoring and detecting climate change, and it was developed by Byron Gleason, a researcher at the National Climate Data Centre (NCDC) of the NOAA (National Oceanic and Atmospheric Administration); it is distributed for free and available at ETCCDI's (Expert Team on Climate Change Detection and Indices) website[3].

[3] ETCCDI – EXPERT TEAM ON CLIMATE CHANGE DETECTION AND INDICES. Available at: http://etccdi.pacificclimate.org/software.shtml. Accessed on: 22 Sep. 2022.

RClimdex 3.2.1 calculates all 27 basic indices (11 related to precipitation and 16 to temperature) recommended by the Expert Team on Climate Change Detection Monitoring and Indices (ETCCDMI) and provides, for each calculated index, statistical information, such as linear trends calculated by the least square method, trend level of significance (p-value), determination coefficient (R2) and standard error of the estimate, besides the annual series graphs. In this specific case, the software was used to calculate the entire climate indices related to rainfall, exhibited in Table 1.

Table 1 ▼ Climate indices of daily rainfall, with descriptions and units. *Source: RClimdex 1.9 – User manual (ZHANG; FENG; CHAN, 2018)*

Index	Name of the indicator	Description	Unit	Equation
PRCPTOT	Annual total wet-day precipitation	Total annual precipitation of wet days (RR* ≥ 1 mm)	mm	$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$
CDD	Consecutive dry days	Annual total wet-day precipitation RR* < 1 mm	days	$RR_{ij} < 1mm$
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm	days	$RR_{ij} \geq 1mm$
R10mm	Number of days with precipitation above 10 mm	Annual count of days with precipitation ≥ 10 mm	days	$RR_{ij} \geq 10mm$
R20mm	Number of days with precipitation above 20 mm	Annual count of days with precipitation ≥ 20 mm	days	$RR_{ij} \geq 20mm$
R50mm	Number of days with precipitation above 50 mm	Annual count of days with precipitation ≥ 50 mm	days	$RR_{ij} \geq nnmm$
SDII	Simple Day Intensity Index	Annual total precipitation divided by the number of wet days (defined as PRCP >= 1.0 mm) in the year	mm/day	$SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}$
Rx1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm	$Rx1day_j = \max(RR_{ij})$
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm	$Rx5day_j = \max(RR_{kj})$
R95p	Very wet days	Annual total precipitation with RR > 95 percentile	mm	$R95p_j = \sum_{W=1}^{W} RR_{Wj}$
R99p	Extremely wet days	Annual total precipitation with RR > 99 percentile	mm	$R99p_j = \sum_{W=1}^{W} RR_{Wj}$

*RR indicates the daily precipitation amount

The climate indices described above generate annual series graphs, describing the trends and calculated by linear regression using the least square method, with statistical significance, statistically indicating the linear trends of graphs.

3 Results

The numbers for the trends in indices of climate extremes are shown in Table 2, for the 36 pluviometric stations, distributed along the Sub-medium São Francisco sub-basin, for the period from 1964 to 2016.

Table 2 ▼
Trends in indices of climate extremes for rainfall of the 36 locations distributed along the Sub-medium São Francisco River Basin.
Source: survey data

Location	PRCPTOT	CDD	CWD	R10mm	R20mm	R50mm	SDII	Rx1day	Rx5day	R95p	R99p
Abaré	*-8.145*	**1.563**	-0.015	**-0.197**	**-0.132**	-0.038	-0.01	-0.716	-0.943	-2.481	-1.058
Afogados da Ingazeira	0.906	*0.345*	*-0.03*	0.072	0.029	0.012	**0.085**	0.225	0.458	1.392	0.504
Afranio	-1.576	-0.715	-0.006	-0.058	-0.024	0.009	-0.012	0.197	0.101	0.243	0.088
Araripina	*-3.476*	-0.123	0.04	**-0.149**	**-0.097**	-0.011	**-0.11**	**-0.324**	*-0.663*	-1.011	-0.534
Arcoverde	0.711	-0.194	-0.019	-0.012	-0.029	0.010	*-0.026*	0.008	0.172	0.396	0.399
Betania	**-4.945**	0.546	-0.015	**-0.145**	*-0.06*	-0.016	-0.029	*-0.439*	**-1.081**	*-1.346*	-0.701
Campo Formoso	**-5.121**	-0.359	0.005	**-0.173**	**-0.076**	**-0.036**	-0.057	**-0.506**	-0.41	**-2.458**	*-0.804*
Carnaíba	*-7.617*	-0.987	0.009	**-0.328**	*-0.175*	0.006	**-0.15**	0.167	*-0.895*	0.085	0.782
Chorrochó	-1.887	*0.697*	*-0.023*	**-0.092**	*-0.048*	*-0.026*	**-0.169**	-0.063	-0.306	-0.863	0.421
Exu	**-13.669**	1.11	**-0.046**	**-0.533**	**-0.511**	**-0.061**	**-0.249**	0.27	-0.282	-1.267	*-0.925*
Floresta	-2.073	0.002	*-0.027*	*-0.103*	-0.039	*-0.016*	**-0.183**	-0.08	-0.446	*-1.231*	0.51
Granito	-2.849	0.742	-0.005	*-0.182*	0.043	0.007	*0.119*	-0.277	0.02	0.174	-0.696
Ibimirim	1.081	-0.585	**-0.053**	-0.054	-0.026	-0.001	**-0.177**	**0.353**	**1.162**	0.63	*-1.268*
Iguaraci	**-5.021**	*0.572*	-0.004	*-0.12*	*-0.076*	-0.006	0.035	-0.261	-0.272	-1.231	-1.204
Ipubi	**-7.434**	-0.159	**-0.071**	**-0.307**	**-0.127**	**-0.079**	**-0.147**	*-0.342*	*-0.86*	**-3.545**	-0.391
Itapetim	-3.661	0.191	-0.001	**-0.175**	*-0.077*	0.004	-0.039	-0.246	-0.301	0.008	-0.573
Jacobina	-0.267	-0.678	-0.031	*-0.136*	*-0.065*	-0.005	-0.043	-0.267	-0.276	-0.329	0.173
Jaguarari	**-6.243**	**1.787**	**-0.078**	*-0.113*	**-0.135**	**-0.085**	**-0.7**	**-1.317**	**-1.324**	**-7.428**	**-3.839**
Juazeiro	**-4.591**	-0.016	-0.016	**-0.146**	*-0.059*	-0.005	-0.015	-0.186	0.011	-0.29	-0.023
Mirandiba	*-4.885*	-0.074	**-0.056**	**-0.177**	*-0.09*	**-0.046**	**-0.181**	*-0.388*	-0.473	-1.523	-0.231
Moreilândia	**-4.382**	**0.767**	*-0.035*	*-0.131*	0.000	-0.003	*0.061*	*-0.385*	-0.51	-0.483	*-1.069*
Morro do Chapéu	*-6.948*	0.24	*-0.066*	**-0.286**	**-0.128**	-0.015	*-0.075*	-0.288	-0.49	-1.105	-0.069
Ouricuri	**-7.257**	*1.032*	0.006	**-0.323**	**-0.309**	-0.026	**-0.322**	0.257	0.279	0.593	*-1.376*
Parnamirim	**-4.941**	*0.844*	-0.028	**-0.194**	**-0.113**	**-0.039**	**-0.165**	-0.271	*-0.747*	**-2.752**	-0.371
Paulo Afonso	*-3.51*	0.227	-0.009	**-0.147**	*-0.05*	-0.004	*-0.043*	-0.233	-0.426	-1.009	-0.248
Petrolina	**-5.412**	0.156	-0.025	**-0.133**	**-0.112**	*-0.019*	*-0.062*	-0.41	-0.481	**-2.153**	*-1.646*

Continua

Conclusão

Remanso	**-5.131**	**1.034**	**-0.058**	**-0.13**	*-0.07*	*-0.029*	*0.069*	**-0.506**	-0.303	*-1.797*	-0.725
Salgueiro	**-3.956**	0.442	0.003	**-0.186**	*-0.052*	-0.01	-0.041	-0.255	*-0.793*	-0.549	-0.151
Santa Cruz da Venerada	*-2.76*	0.307	**0.086**	**-0.195**	**-0.167**	**0.026**	*-0.097*	**0.679**	**1.092**	**2.057**	*0.946*
Santa Maria da Boa Vista	**-6.217**	-0.269	0.01	**-0.228**	**-0.118**	**-0.038**	**-0.137**	-0.13	-0.423	**-1.982**	-0.28
São José do Egito	-2.37	-0.299	-0.002	-0.109	*-0.067*	-0.001	0.019	0.112	-0.328	-0.055	-0.175
Sento Sé	-0.628	*0.895*	-0.008	-0.063	-0.009	0	0.001	-0.095	0.053	-0.286	-0.168
Serra Talhada	*-4.398*	0.525	-0.009	*-0.126*	-0.031	-0.018	0.022	0.021	-0.298	-1.291	-0.201
Tacaratu	**-5.067**	*0.508*	**-0.054**	**-0.183**	**-0.141**	*-0.022*	**-0.111**	-0.285	-0.343	*-1.845*	0.409
Triunfo	-5.321	*0.703*	*-0.055*	-0.164	-0.096	0.003	0.037	*-0.302*	-0.472	-0.295	-0.479
Tuparetama	*-4.348*	-0.42	**0.057**	**-0.337**	**-0.151**	0.008	**-0.211**	0.377	-0.114	0.959	**-1.158**

The values highlighted in bold exhibited high statistical significance ($p < 0.05$), while the values in italics indicated a good statistical significance ($p < 0.1$), and the values were not highlighted without statistical significance. The indices with a p-value greater than 0.1 ($p > 0.1$) are seen as not statistically significant, thus not being safe to say that this is an ongoing trend; nonetheless, their indices were calculated, and their trend estimates were provided. The spatial distribution of all calculated climate indices for rainfall is presented in Figure 2.

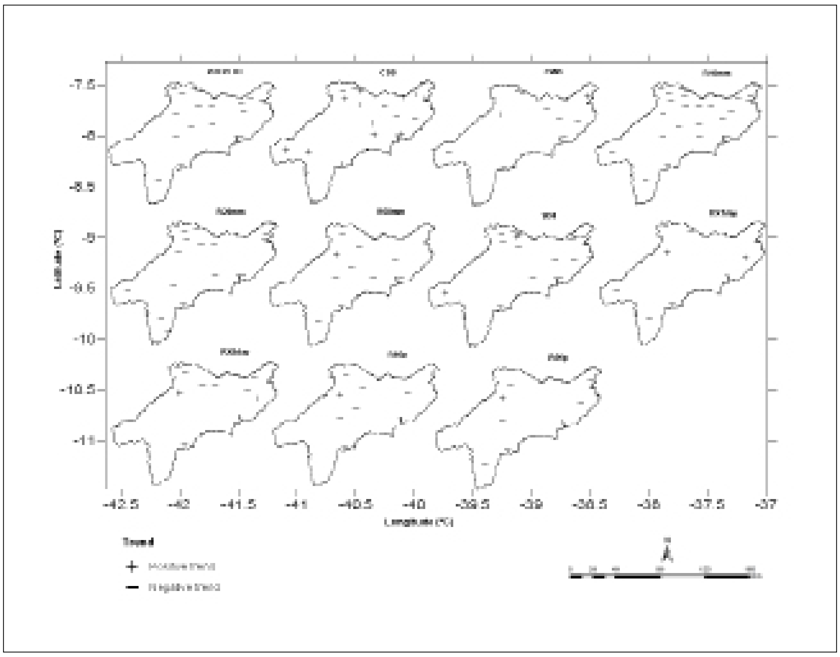

Figure 2 ▶ Spatial distribution of the climate indices in the Sub-medium São Francisco region. *Source: elaborated by the authors*

By first analyzing the PRCPOT index, there are indications of changes in the precipitation pattern in all pluviometric stations, unanimously implying the negative trend in annual rainfall pattern with statistical significance. It is therefore evident that, for the period studied, the annual rainfall reduction rate was from 2.76 mm.year^{-1} to 13.67 mm.year^{-1}.

In general, the analysis shows a decreasing trend in rainfall in the entire sub-basin of the Sub-medium São Francisco River, being more intense in the Northern part of the region, mainly located in the State of Pernambuco. This negative trend was less evident in the area of the Sub-medium São Francisco located in the State of Bahia. This result corroborates with the one found by Silva, Souza and Azevedo (2012), who evaluated Climate change detection indices for the State of Bahia in the period from 1970 to 2006; and diagnosed that the number of days with daily maximum temperature increased, while the daily rainfall and total annual precipitation reduced. This variation in precipitation in the region can be due to large-scale circulation, whereas the rainfall intensity may be influenced by climate variability.

Similar results were found in recent studies, using the same methodology. Assis, Sobral and Souza (2012), while analyzing the two river basins in the Sertão region of the State of Pernambuco in the years between 1964 and 2004, detected the same negative trend in precipitation. Similarly, Moncunill (2006) identified decreasing trends in annual precipitation in the State of Ceará, using 23 pluviometric stations between 1974 and 2003. It is noteworthy that there are not many studies in the Northeastern region of Brazil using this methodology, with most investigations of the sort being spread throughout the Southern, South-eastern, and Central-west regions of Brazil and in other South American countries.

The reduction in rainfall in the study area during the last 50 years corroborates with the past reports of water shortage, a persisting problem in the semiarid region of the Brazilian Northeast, which is currently facing its worst drought in decades.

The analysis of the CDD index demonstrated a positive trend, indicative of an increase in the number of consecutive dry days (Figure 2) in the Sub-medium São Francisco, with a statistical significance. All statically significant pluviometric stations converged to a result of a positive trend; with the trend values varying from 0.345 days.year^{-1} to 1.787 days.year^{-1}. The variation in the increasing trend in consecutive dry days is not considered high, albeit significant, since the study area, as well as the entire semiarid region of the Brazilian northeast, with an already low amount of rainfall, is facing a gradual reduction in precipitation and consequent variability in the region's climate pattern.

This result indicates that not only it is raining less in the region, but there is also evidence of increasingly sparse rainfall at times for a shorter period. A similar result was found in a study by Assis, Sobral and Souza (2012) on the Sertão region of Pernambuco, showing, through the analysis of the *veranicos* (five or more consecutive days without rain), an increasing number of dry days during the rainy season, indicating rainfall concentrated in few days. Soares and Nóbrega (2010), while analyzing 35 pluviometric stations in the Sertão of Pernambuco, found similar results to these, underlining the greater number of dry days during the rainy season. Nóbrega, Farias and Santos (2015), in an analysis of the entire State of Pernambuco for the period between 1978 and 2010 and using the same methodology for evaluating the climate extreme indices, concluded that rain has been more concentrated within a few days during the year in the Sertão and Agreste regions of the State of Pernambuco; with the Sertão exhibiting higher indices and facing extremely dry episodes.

The climate extreme index CWD indicated both positive and negative trends (Figure 2), having prevailed the decreasing trends in the maximum number of consecutive wet days, varying between 0.030 days.year^{-1} and 0.078 days.year^{-1}, as shown in Table 2. This index is inversely proportional to the CDD index since the pluviometric stations that had the number of wet days reduced were the same as the ones that exhibited an increase in the number of consecutive dry days.

By analyzing the extreme climate indices R10mm, R20mm, and R50mm, it is observed a predominance of negative trends (Figure 2), prevailing a decrease in the number of days per year with rainfall greater than 10 mm, 20 mm, and 50 mm, respectively. These indices are directly associated with the previous indices (PRCPTOT, CDD, and CWD), as the results presented so far show a reduction in rainfall, an increase in the number of consecutive days without rain, and a fall in the number of consecutive wet days; therefore, indicating that it is indeed raining less, with more sporadic rainfall. According to what has been found, there is evidence of a drop in rainfall intensity above 10 mm, 20 mm (moderate rain), and 50 mm (heavy rain) within the study area. The R10mm index oscillated negatively between 0.533 days.year^{-1} and 0.092 days.year^{-1}; while the index R20mm ranged negatively from 0.511 days.year^{-1} to 0.048 days.year^{-1}, and R50mm from 0.085 days.year^{-1} to 0.016 days.year^{-1}, according to Table 2.

The analysis of the extreme climate index SDII indicates both positive and negative trends, though the negative trends prevailed (Figure 2). This index that represents the daily rainfall intensity is related to the PRCPTOT and CDD indices since it represents the relation between both. The pluviometric stations that indicated a drop in daily intensity also exhibited a decrease in the total annual precipitation, thus, indicating a reduction in total rainfall in these regions. On the other hand, there was a higher increase in the frequency of annual dry days, therefore prevailing higher daily rainfall intensity.

The analysis of the RX1day and RX5day indices (Figure 2) indicated more negative than positive trends. These indices correspond to the maximum precipitation recorded in 1 and 5 consecutive days, respectively. RX1day and RX5day are coherent with the PRCPTOT and R50mm indices, as the decreasing trend in both total precipitations and the number of days with intense rain is also related to the decrease in such indices, both concentrated in 1 and 5 consecutive days. These indices are directly proportional to the CWD index since the drop in the number of consecutive days with rain is directly associated with the decrease in the rainfall amounts (in mm).

Santos, Assis and Souza (2014) presented opposite results in the analysis of the climate indices RX1day and RX5day, in a study of the Una River, in the Southern Zona da Mata region, in the State of Pernambuco, in an analysis for the period between 1963 and 2012. This disagreement in terms of results is justified since the river basins in question exhibit different physiographic characteristics, with one being located in the region between both the Zona da Mata and coastal zones of Pernambuco and the other located in the Semiarid region, which climatically has less rainfall and higher evapotranspiration, being more susceptible to extreme droughts periods.

Finally, the analysis of the climate indices R95p and R99p (Figure 2) indicates both positive and negative trends, while having prevailed a negative trend for both indices. These indices are related to extreme rainfall, characteristic of concentrated rainfall amounts. Ten negative trend values were observed in the 11 pluviometric stations with statistical significance for R95p and only 1 positive trend value; as for R99p, of the 9 statistically significant stations, 8 showed a negative trend and 1 positive trend, according to Figure 2.

The domination of negative trends in these indices further supports the trends already found of reduction in total precipitation, in the number of consecutive days with rain, in the maximum rainfall amounts in 1 and 5 consecutive days, in the number of days with heavy, moderate and intense rain, as well as an increase in the number of consecutive dry days.

Similar studies that used the same methodology showed both analogous and opposite results to the ones found in this study for the climate indices R95p and R99p. Santos *et al*. (2009), when analyzing the precipitation indices in the State of Ceará in the period from 1935 and 2006, found dominance in positive trends in such indices; however, the study was made in the State of Ceará, and comprises all of the States' micro-regions, including the Coastal and Zona da Mata regions, with different amounts of precipitation when compared to the semiarid region. As for the analysis made by Santos *et al*. (2006), there is an indication of negative trends in these indices in Brasília, Goiana, and Catalão in the period between 1962 and 2005, evidence of a decrease in the number of extreme events of total annual precipitation.

4 Conclusions

The climate analysis points out a significant ongoing alteration of climate in the last decades. In case these changes indeed materialize, the damages to society are alarming. For the semiarid region of Northeastern Brazil, the forecast is for a reduction in rainfall, together with a higher probability of more long-lasting and severe drought periods, due to the higher number of days without rain.

For a region with such social and environmental vulnerability, the negative impacts related to climate change aggravate these issues even further, as the drought will increase the conflict for the use of natural resources, mainly water resources. Therefore, drought is considered as being not only a climate problem but also a condition that leads to social and economic difficulties for the population.

More and more researchers warn about this change in climate patterns. This present study shows results that converge with other analyses when indicating a situation of higher environmental imbalance, as a consequence of climate factors.

Based on the results presented and analyzing the spatial and temporal settings of the trends in extreme climate indices for rainfall, both indices were considered to indicate similar trends. The decreasing trend in total rainfall is considered coherent with the other indices in demonstrating that the study area converged to a situation of water scarcity, presenting over time more indications that corroborate such a hypothesis.

Besides the reduction in rainfall, the dominance of negative trends in daily rainfall intensity was also analyzed, as well as the decreasing trend in maximum rainfall amounts in 1 and 5 consecutive days, consecutive wet days, the number of days with moderate, heavy, and intense rainfall, very humid and extremely humid days. The positive trends prevailed only in the index for consecutive dry days, which also converges to the shortage of rain in the region, contributing to the recurring droughts that affect the Brazilian Northeast.

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Conflict of interest

The authors declare no conflict of interest.

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