TEMPORAL VARIABILITY OF PRECIPITATION INDICES AT A RAINGAUGE STATION IN PORTUGAL

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RESUMO

O objectivo deste estudo é avaliar variações nos índices de precipitação (precipitação total, intensidade, frequência, duração de dias secos e dias húmidos), que possam ser afectados por alterações climáticas numa estação udométrica, Chouto, no período de 1912-2007. Nessa estação não se observam variações significativas na precipitação anual no último século, o aumento de precipitação que se observa em Outubro é compensado pela diminuição da precipitação em Março. Em Outubro verifica-se um aumento de dias húmidos consecutivos e em Março uma diminuição dos mesmos e um aumento de dias secos consecutivos.

PALAVRAS-CHAVE

Alterações climáticas, índices de precipitação, períodos secos, períodos húmidos.

ABSTRACT

The objective of this study is to provide insight on variations of precipitation indices (total precipitation, intensity, frequency, duration of wet and dry spells), that may be affected by climate change at a local raingauge station, Chouto, in the period of 1912-2007. While no significant changes in precipitation totals were observed annually within the last century, the precipitation increase observed in the month of October is compensated by a precipitation decrease in March. Also in October, there has been an increase in the length of wet spells, whereas a decrease of these is observed in March, which also shows an increase in length of dry spells.

KEYWORDS

Climate change, precipitation indices, wet spells, dry spells.

1. **INTRODUCTION**

There is evidence that water resources may be affected by climate change, based on observational records and climate projections, and that it will also affect human societies and ecosystems (Bates *et al*., 2008).

Changes in mean and extreme values of precipitation will impact river flows, lake and wetland levels, and evaporation. More intense precipitation events will affect agriculture by damaging crops, increasing soil erosion, and contaminating surface and groundwater, which may increase the risk of diseases and may include loss of property. On the other hand, an increase in drought events may lead to lower yields and possible failure in agriculture and livestock development and consequent food and water shortage, increase of wildfires, and also loss of property. Integration of information on climate variability into water resources management would help to adapt to longer-term climate change impacts (Bates *et al.*, 2008).

The CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (CLIVAR Homepage) published a series of indices for characterization of climate variability and change, of which eleven are related to precipitation. These indices were explored by other authors and further developed.

Nicholls *et al.* (2000) examined three indices of extreme rainfall: extreme intensity - average intensity of rain falling above the long-term 95th percentile; extreme frequency - number of precipitation events above the long-term 95th percentile; and extreme percent - proportion of total rainfall falling above the long-term 95th percentile. They suggest that the extreme intensity incorporates changes in all events above the upper percentiles, and if the number of wetdays changes equally over all intensities, the extreme intensity will not change.

In a study developed by Nicholls *et al.* (2000), the results did not provide strong evidence of climate becoming more extreme or variable, although they point out that significant changes could possibly occur at a regional level.

According to the Climate Change and Water Report (Bates *et al.*, 2008), several studies indicate that southern Europe is more sensitive to climate change than the northern part. Although precipitation increased, in general, over the 20th century between 30ºN and 85º N, southern Europe is expected to become warmer and drier with impacts on precipitation patterns, intensity and extremes which may lead to changes in soil moisture and runoff (EEA, 2008).

Although precipitation decreases have been observed, an increase in heavy precipitation events has also been verified in Europe (Klein Tank and Können, 2003), with stronger increases in the cool season (Bates *et al.*, 2008). Wet extremes will be more severe where precipitation increases, and dry extremes will be more severe where mean precipitation decreases (Bates *et al.*, 2008).

Norrant and Douguédroit (2006) evaluated several precipitation indices for 63 stations in the Mediterranean to identify significant linear trends at monthly, seasonal and annual time scales and have identified a few significant monthly trends, diminishing primarily during the winter months, and especially in March in the Atlantic region.

A significant decrease in winter rainfall was observed on the Iberian Peninsula during the second half of the 20th century (Bustins *et al.*, 2008), whereas an increase in precipitation intensity and variability, frequency of heavy precipitation events, is expected to increase the risk of flood and drought.

Lima *et al.* (2005) revealed that the annual precipitation series for nine stations in Portugal show no trend. However, at the monthly level, there is a decreasing tendency in the rainfall of March and November, which is compensated by an increase in December and January, although not significant.

An increase in the frequency of heavy precipitation events was observed by Nastos and Zerefos (2009) in Greece, whereas, drought events have increased in most European regions during the last decades in frequency, duration, or intensity. Nastos and Zerefos (2009) have analyzed the dry and wet spells based on the largest number of consecutive dry or wet days, respectively, and concluded that the variability of wet spells shows significant negative trends.

Moberg and Jones (2005) analyzed precipitation data from approximately 80 stations in central and Western Europe and determined a significant increase in precipitation in the winter as far as average precipitation intensity and moderately strong events are concerned. The length of dry spells also showed an increasing tendency, although not significant. Costa *et al.* (2008) have detected an increase in the annual frequency of dry events, and a decrease in the frequency of heavy precipitation events, in southern Portugal, although both not statistically significant.

The objective of this study is to provide insight on variations of precipitation indices (total precipitation, intensity, frequency, duration of wet and dry spells), that may be affected by climate change at a local raingauge station.

2. **DATA AND METHODS**

2.1. **DATA**

In this work, Chouto raingauge was selected for analysis of the abovementioned indices (Figure 1). Chouto station is located at 39º 16’ 26.4” N and 8º 21’ 3.6” W, at an altitude of 126 m in the Tagus (Tejo) river basin. The Portuguese Water Institute INAG (www.inag.pt) is responsible for collection and publishing of rainfall data and has a database of daily rainfall data starting in 1911 to date, from which data was obtained.

Fig. 1. Location of Chouto raingauge.

A homogeneity test was performed on the annual data using the Shapiro-Wilk parametric hypothesis test of composite normality with a significance level of 5%.

The number of days with missing data was evaluated for the Chouto daily precipitation time series and a total of six missing days (one in March and two in November of 2003 and three in January of 2004) were detected, emphasizing the good quality of the data set.

2.2. **THE SET OF EXTREMES INDICES**

Extreme frequency indexes used in this study were related to total number of days, and associated precipitation above or below a certain threshold, their relative value (intensity), and duration of dry and wet spells. These indices were further analyzed for trends in extreme rainfall: intensity, frequency and respective relative values (Table 1).

Rx1day	Monthly maximum 1-day precipitation:	$Rx1day_j = \max(RR_{ij})$
Rx5day	Monthly maximum consecutive 5-day precipitation	$Rx5day_j = \max(RR_{kj})$
SDII	Simple daily intensity index	$SDDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}$
N_{pj}	Annual count of days with precipitation $\geq P_p$ or Annual count of days with precipitation $\leq P_p$	$N_{pj} = days(RR_{ij} \geq p)$

P_{pj}	Annual/monthly total precipitation when precipitation ≥ P_p	$P_{pj} = \sum_{w=1}^{W} RR_{wj}$
$PINT_p$	Annual average intensity for precipitation ≥ P_p	$PINT_p = \frac{P_p}{N_p}$
CDD	Annual/monthly maximum length of dry spell, maximum number of consecutive days with rainfall < 1mm	$CDD = \max\left(days(RR_{ij}) \leq 1\right)$
CWD	Annual/monthly maximum length of wet spell, maximum number of consecutive days with RR ≥ 1mm	$CWD = \max\left(days(RR_{ij}) > 1\right)$
PTOT	Annual total precipitation in wet days	$PTOT_j = \sum_{w=1}^{W} RR_{wj}$

j – period in analysis
RR_{ij} - daily precipitation amount on day *i* in period *j*
RR_{kj} - precipitation amount for the 5-day interval ending day $_k$, in period *j*
RR_{wj} - daily precipitation amount on wet days, *w (RR ≥ 1mm)* in period *j*.
W - number of wet days
p - user defined threshold (5, 10, 25, 75, 90, and 95th percentiles)
P_p - precipitation ≤ 5, 10, 25 percentiles or precipitation ≥ 75, 90, 95 percentiles

Table 1. Extreme indices used in the study.

Percentiles of daily precipitation rather than a fixed value are often used to evaluate extreme precipitation events, due to the spatial variation of rainfall intensity (Bates *et al.*, 2008). Percentiles were evaluated using all data set.

Extreme frequency indexes were calculated at different cut-offs - 5th, 10th, 25th, 75th, 90th and 95th percentiles rather than a fixed threshold (Nicholls, 2000, Bates *et al.*, 2008), both annually and monthly. Seasonality was accounted for by examining the indexes on a monthly basis (Silva *et al.*, 2009).

2.3. **TREND ESTIMATION METHODS**

A linear trend was evaluated using regression analysis on indexes for both the monthly and annual time series. The correlation coefficient, slope and its significance (p-value) were estimated for all indexes.

Comparisons of mean values of the indexes for the first and second halves of the series were also estimated using the t-test. A statistically significant difference was accepted for p-values<0.05.

3. **RESULTS AND DISCUSSION**

3.1. **PTOT – TOTAL PRECIPITATION**

Annual total precipitation (hydrologic years) do not show a significant linear trend (Figure 2) during the period in analysis (p-value=0.94), with an average value of 724 mm. Results of the t-test for the first half of the period and the second half show no significant difference (p-value=0.89), nor does the F-test for analysis of variance (p-value=0.36). The month of March shows a significant decrease (Figure 3) in total precipitation (p-value=0.003), whereas the month of October shows a significant increase (Figure 4) (p-value=0.03). All other months show no significant trend during the period in analysis.

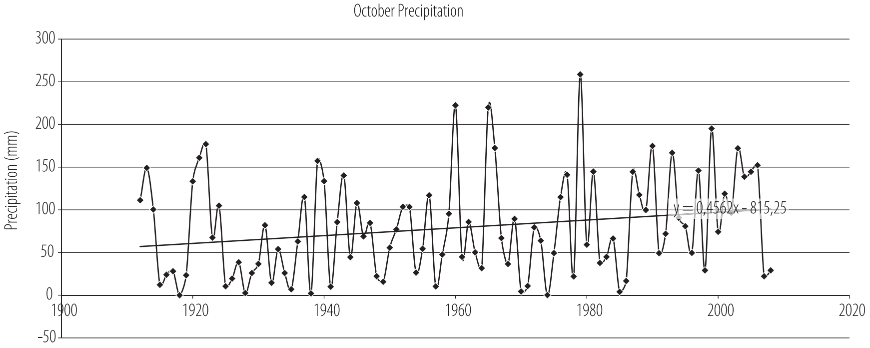

Fig. 2. Annual precipitation time series.

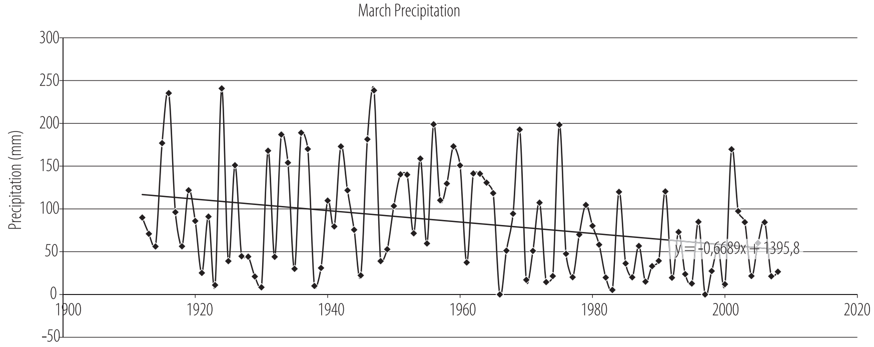

Fig. 3. March precipitation time series.

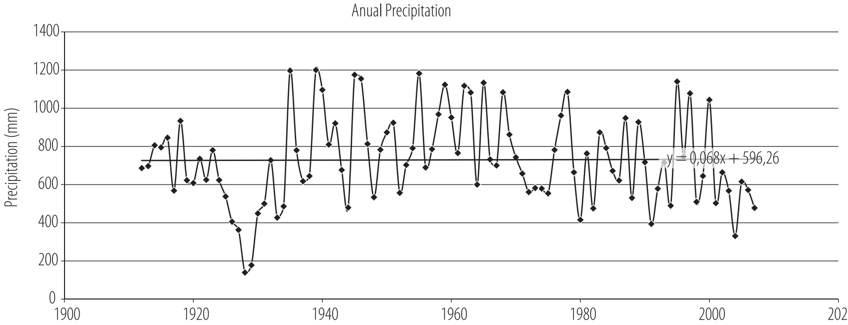

Fig. 4. October precipitation time series.

3.2. Rx1day – MAXIMUM DAILY PRECIPITATION

The maximum annual daily precipitation has a significant positive trend (p-value=0.003) with a slope of 0.19 mm.year^{-1}, as well as a significant difference between the first and second halves of the series (39.0 mm and 50.7 mm , respectively – p-value=0.001), representing a 30% increase. However, the only month in which there is a significant increase in maximum daily precipitation is October (p-value=0.002) with a slope of 0.212 mm.year^{-1}, and a difference between the first and second halves of the series (18.7 mm and 30.2 mm, respectively – p-value=0.002), representing a 61% increase in maximum daily precipitation.

3.3. Rx5day – MAXIMUM 5-DAY PRECIPITATION

It is the month of March that shows a significant (p-value=0.04) decrease in maximum consecutive 5-day precipitation with a slope of -0.2124 mm.year^{-1}, while October shows a significant increase (p-value=0.006) with a slope of 0.3183 mm.year^{-1}. The first and second half of the series show significant differences, in average, for both March (46.9 and 32.1 mm, respectively - p-value=0.007) and October (42.3 and 51.7 mm, respectively - p-value=0.011), representing a 32% decrease in maximum consecutive 5 days precipitation in the month of March and a 22% increase in the month of October.

3.4. SDII – SIMPLE DAILY INTENSITY INDEX

The simple intensity index does not show a significant linear trend during the period in analysis at a 5% significance level, although a difference is observed between the first and second halves of the series in the month of March (9.1 mm/day and 8.1 mm/day, respectively – p-value=0.012), representing a 11% decrease in the intensity of precipitation.

3.5. N_p and P_p – NUMBER OF DAYS AND PRECIPITATION

Precipitation and number of days with precipitation below the 25th percentile, increase significantly. A significant increase is also observed for total precipitation below the 5th and 10th precipitation percentile (Table 2).

p - percentile	Precipitation Percentile (mm)	N_p		P_p	
		p-value	Average (days)	p-value	Average (mm)
5	1.2	0.9439	288	6.49E-07	5.7/12.2[a]
10	1.6	0.59495	292	1.90E-06	9.6/19.4[a]
25	3.0	0.04931	302/307[a]	7.71E-08	28.7/51.2[a]
75	11.8	0.52404	20.2	0.43001	432
90	20.2	0.64016	8.1	0.36029	243
95	26.4	0.58145	4.05	0.25342	149

Table 2. N_p and P_p statistics.

[a] – average 1912-1959/1960-2007

Heavy rain (75th percentile and above) has not significantly changed in the last century. Only four days have precipitation above 26.4 mm, eight days above 20.2 mm and twenty days above 11.8 mm.

3.6. **PINTp** – PRECIPITATION INTENSITY

The comparative analysis between the first and second halves of the precipitation intensity series show a significant difference in average values on the 5th, 10th, and 25th precipitation percentiles with average values presented in Table 3.

Percentile	Precipitation Percentile (mm)	Precipitation intensity (mm/day)		% increase	p-value
		1912-1959	1960-2007		
5	1.2	0.02	0.04	119	3E-06
10	1.6	0.03	0.06	106	1.5E-07
25	3.0	0.09	0.17	76	9E-11
75	11.8	21.1			0.67
90	20.2	29.5			0.71
95	26.4	36.6			0.37

Table 3. Precipitation intensity statistics.

Total precipitation for smaller events has increased, as well as their intensities (no increase in their frequency), which means that more precipitation occurs at the smaller events. Increases in precipitation intensities in the range of 76% to 119% as observed in Table 3 may play a role in soil moisture storage, although they do not pose a threat to flooding, due to their low intensity, ranging from 0.02 mm/day to 0.17 mm/day.

3.7. **CDD - CONTINUOUS DRY DAYS**

Annual continuous dry days do not show a significant linear trend during the period in analysis, with an average value of 60 days. Results of the t-test when comparing the first half of the period and the second half, show no difference (p-value=0.5), nor does the F-test for analysis of variance (p-value=0.5).

Upon analysis of monthly CDD, the only month that shows a significant increase is March (p-value= 0.014), with a slope of 0.06 days/year. The first and second half of the series show significant differences in both average (11.2 and 14.0 days, respectively - p-value=0.024) and variances (p-value=0.036), representing a 20% increase in number of continuous dry days in the month of March.

On the other hand, October shows a significant decrease at 10% significance level (p-value=0.077) with a slope of -0.0425 days/year. Although the variance shows no significant difference on both halves of the series, the average is significantly different (14.8 and 12.1 days, respectively - p-value=0.047, representing a 18% decrease in number of continuous dry days in the month of October).

3.8. **CWD - CONTINUOUS WET DAYS**

Annual CWD significantly decreased over the 1911-2007 period (p-value=0.007) with a slope of -0.033 days/year. Upon comparison of the first and second halves of the series (average of 10.6 and 9.3 days, respectively) there is a significant difference at the 10% significance level (p-value=0.06), representing a 12% decrease in number of continuous wet days.

CWD shows a significant decrease (p-value=0.011) in the month of March (5.8 and 4.0, respectively), representing a 31% decrease in the number of continuous wet days in the month of March.

There is no evidence of trends in annual precipitation in the region of Chouto, in accordance with the Global Historical Climatology Network from 1901 to 2005 (Bates *et al.*, 2008) and Lima *et al.* (2005) for the Iberian Peninsula even though Klein Tank and Können (2003) and Bates *et al.* (2008) expect southern Europe to become drier. Nevertheless, precipitation has decreased in the month of March as also identified by Norrant and Douguédroit (2006) for the Mediterranean, and increased in the month of October.

As referred by Nastos and Zerefos (2009), a decrease in wet spells was observed annually. On one hand, in the month of March, length of dry spells have increased and length of wet spells have decreased, along with the decrease in total precipitation, decrease in maximum daily precipitation and decrease in 5-day precipitation, and on the other hand, an increase is evident in October as far as maximum daily precipitation, 5-day precipitation, and decrease in length of dry spells is concerned. However, unlike Nastos and Zarefos (2009), an increase in the frequency of heavy precipitation events was not observed.

4. **CONCLUSIONS**

While no significant changes in precipitation totals are observed annually within the last century, the precipitation increase in October is compensated by a precipitation decrease in March, and also the wet semester (October-March) begins wetter for longer periods (wet spells) and ends drier also for longer periods (dry spells), immediately before the beginning of the dry semester (April-September).

October is wetter, has higher intensity rainfall events, and longer wet spells. March is drier, longer dry spells and shorter wet spells along with less intense rainfall events.

Total precipitation for smaller events has increased, as well as their intensities, implying that more precipitation occurs at the smaller events with an opportunity to increase availability in soil moisture storage.

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