DROUGHTS AND RAINFALL IN MAINLAND PORTUGAL AT DIFFERENT TIME SCALES: INTENSITY, MAGNTUDE, DURATION AND FREQUENCY OF THE DROUGHTS AND TRENDS IN RAINFALL SERIES

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Abstract: Climate change, along with the apparently increase in recent years, has heightened the society vulnerability to the extreme hydrological phenomena, undermining the agricultural, economic and social sectors.

This paper presents a drought analysis in mainland Portugal based on two equivalent approaches along with a trend analysis in rainfall series. For that purpose, 39 rain gauges, uniformly distributed over the country, were selected with a long-term dataset spanning over 105 hydrologic years (October 1912 to September 2017).

To analyse the intensity, magnitude and duration of the drought occurrences, the Standardized Precipitation Index (SPI) and Drought Severity Index (DSI) were applied to different time scales and drought thresholds.

The yearly occurrence rates of the periods under drought conditions was assessed by a non-parametric method, namely a kernel occurrence rate estimation (KORE), with a pointwise 90% confidence band around the frequency estimates.

In order to identify significant trends in rainfall, the Mann-Kendall test was applied along with the Sen's slope estimator to assign a numerical value to the trend magnitudes.

The results thus achieved provided evidence of agreement between drought events and the intra-annual rainfall pattern. The findings suggested an increased frequency of the periods under drought conditions and a widespread increasing in the intensity and magnitude of drought events over the last 15 years, compared to the initial 90 years of the study. Furthermore, decreasing trends in the rainfall were generally stood out over different time scales, particularly in March.

Keywords: drought, standardized precipitation index (SPI), drought severity index (DSI), KORE, trend detection, moving average, Mann-Kendall test

1. Introduction

Climate change is predicted to compromise water availability, as global temperature increases. Population growth triggers increases in water demand and considerable water supply deficits are likely to become more regular.

The European Commission (2012) pointed out that between 1976 and 2006 the areas and people affected by droughts across Europe raised over 20% with a total cost amounted to 100 billion EUR.

According to Lloyd-Hughes & Saunders (2002), Europe's vulnerability to droughts and water scarcity are highlighted, likewise their environmental, economic and social impacts.

Besides, spatial and temporal climate behaviour in the Mediterranean region is highly irregular (Lionello, 2012) and extreme climatic events are expected to increase in frequency over southern Europe (Ummenhofer & Meehl, 2017).

Located between temperate and subtropical climate zones, the Iberian Peninsula comprises a very pronounced variability in the rainfall pattern (Rodó *et al.*, 1997, Rodriguez-Puebla *et al.*, 1998, Serrano *et al.*, 1999) and dry summers are consistently denoted.

According to IPMA (2018), over the last 75 years, Portugal has experienced 12 major drought episodes: 1980/1981, 1991/1992, 1994/1995, 1998/1999, 2004/2006, 2008/2009, 2011/2012, 2014/2015 and 2016/2017. Particular emphasis is given on longer term droughts, like the 2004/2006 one that lasted for 10 consecutive months and attained an extreme intensity across more than 10% of the country.

Regarding the 2016/2017 drought, the GPP (2018) report found that the water deficit conditions in mainland territory have worsened throughout the autumn and winter, which was unthinkable to occur. In fact, the 2016/2017 drought was the only event with the entire country under severe to extreme drought classes, by the end of October. In Portugal, the hydrological year starts on 1st October, representing the beginning of the wet semester.

Notwithstanding the prior studies on droughts in mainland Portugal, they only intended to characterise the intensity of the events, whereas the study hereby also aimed at analysing the yearly frequency of the drought events. Along with the study on droughts, a rainfall trend analysis was also performed.

To comply with the that purpose, 39 rain gauges, fairly distributed over the country, were selected based on long-term monthly rainfall records.

2. Methods

2.1 Drought analysis

Standardized Precipitation Index (SPI)

The SPI was primarily adopted to assess patterns of droughts in mainland Portugal, as a noteworthy indicator of drought episodes (Vicente-Serrano *et al.*, 2012).

Originally developed by McKee *et al.* (1993), the SPI stands for standard deviation of mean precipitation, in association with different time scales. The most common are: 1, 3, 6 and 12 consecutive months (SPI1, SPI3, SPI6 and SPI12), corresponding, as the time scale increases, to meteorological, agricultural, hydrological and socioeconomic droughts.

The index remaps the rainfall records into a standardized probability distribution function, so that a value of zero indicates the median rainfall amount, whereas a negative index denotes drought conditions and a positive one, wet conditions.

The SPI computation utilized the Pearson Type III distribution for a distributed random variable, x ($x > 0$), (Vicente-Serrano, 2006 and Santos & Portela, 2010):

$$f(x) = \frac{1}{\alpha\Gamma(\beta)}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-\gamma}{\alpha}\right)} \qquad (1)$$

where Γ is the Gamma function; α is the shape parameter; β is the scale parameter; γ is the origin parameter. Eslamian & Feizi (2007) stated these parameters should be estimated using the L-moments method, due to its robustness to long data samples and to spurious values.

The drought categories adopted the SPI thresholds assigned by Agnew (2000), presented in Table 1.

Table 1 – Drought categories according to the SPI values by Agnew (2000)

Drought category	SPI	Non-exceedance probability
Normal	<0.84 e >-0.84	0.60
Moderate	<-0.84	0.20
Severe	<-1.28	0.10
Extreme	<-1.65	0.05

Drought Severity Index (DSI)

The DSI was proposed by Bryant *et al.* (1992) and further developed by Philips & McGregor's (1998). It is based on cumulative rainfall deficits (i.e. anomaly), also at multiscale, namely: 3, 6 and 12 consecutive months (DSI3, DSI6 and DSI12).

To calculate the DSI, the following procedure was adopted:

- For DSIi, $i = \{3,6,12\}$, let the rainfall anomaly in month t be X_t. If $X_t < 0$ and the anomalies at $t-(i-1)$, $X_{t-(i-1)}$, are also below its i-months average, then a drought sequence is initiated.
- DSI is a positive value corresponding to the anomaly in month t, X_t.
- In the following month, $t+1$, the rainfall anomaly is X_{t+1}. Then DSI equals $X_t + X_{t+1}$ if and only if the i-months average total for the months $t+1$, t, $t-1$,… $t-(i-1)$ has not been exceeded.

Finally, the DSI series obtained is standardized by dividing the absolute deficit by the mean annual precipitation and multiplying by 100 (expressed in percentage). The drought categories adopted the DSI thresholds assigned by Guerreiro *et al.* (2017), presented in Table 2.

Table 2 – Drought categories according to DSI values by Guerreiro et al. (2017)

Drought category	DSI
Normal	>50%
Severe	>100%

Drought characteristics

Concerning droughts prevention, monitoring and coordination network, for each drought index, some characteristics were considered: intensity (severity of impact due to the precipitation deficit, escalated into the aforementioned categories); magnitude (index accumulated value during each drought episode); duration; frequency (of the periods under drought conditions).

In this study, the frequency of droughts was assessed to ascertain whether, despite the changes in the other features, the droughts became more frequent in the course of time.

The analysis of the frequency of droughts intended to conclude if regardless any changes in the other characteristics, the droughts became more frequent towards the present. For that purpose, regarding the SPI, the Kernel occurrence rate estimation (KORE), a non-parametric method developed by Diggle (1985), was implemented.

To accomplish that, a smoothing point process data was used as followed:

$$\hat{\lambda}(t) = h^{-1}\sum_{i=1}^{m} K\left(\frac{t-T_i}{h}\right) \qquad (2)$$

where $\hat{\lambda}(t)$ defines the number of drought occurrences above threshold per day at a given point in time, t; h is the bandwidth, m is the total number of points; K is the kernel function. A Gaussian kernel was applied (Mudelsee *et al.*, 2003):

$$K(y) = \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{y^2}{2}\right)} \qquad (3)$$

In order to clarify its meaning, $\hat{\lambda}(t)$ is multiplied by 325.25, resulting in the number of drought occurrences above threshold per year at a given point in time, t.

Silverman (1986) formulated h as:

$$h = 0.9 \min\left\{s, \frac{IQR}{1,34}\right\} m^{-\frac{1}{5}} \qquad (4)$$

where s is the standard deviation and IQR is the interquartile range. To account for the uncertainty of the KORE estimates, according to the methodology described in Silva *et al.* (2012), a pointwise 90% confidence band was constructed around the frequency estimates, by means of bootstrap simulations.

2.2 Trends analysis of precipitation

Filling the gaps of sparse data

The accuracy of the drought and trend analysis requires reliable, dense and long-term precipitation datasets. However, underlying record gaps were noticed.

To fill the missing values a procedure based on linear regression analysis was used, Portela (n.d.). Let i and j denote the month and the year with missing rainfall in a given rain gage. The procedure identifies the k nearest-neighbour rain gages with rainfall data in that same month and year. For both the rain gage with missing data and for each one of its k neighbour rain gages, the paired simultaneous series of monthly rainfall in month i are obtained (obviously for years different from j), provided they have more than a m common values. From those series, the one with highest correlation coefficient between rainfalls in month j is selected and adopted to establish the linear regression model that is then applied to estimate the missing value based on the known rainfall in the selected neighbour rain gage. In the applications carried out k was set equal to 200 and m to 15 years. According to the previous procedure, each rainfall gap may utilize a different linear regression model.

Moving average technique; non-homogeneities

Assumed as one of the most widely used (Kenney & Keeping, 1962 in Portela *et al.*, 2011), the moving average technique was applied. This method smooths out spurious data and evidences long-term trends.

For a rainfall series with length N, the moving averages are built upon $N - n + 1$ subsets of n consecutive years in which the original series could be divided ($N > n$). In this study, a constant length, $n = 15$ years, was adopted.

Accordingly, it is described as:

$$\bar{P}_t = \frac{\sum_{k=1}^{t+(n-1)} p_k}{n} \tag{5}$$

where $\bar{P}_t$ are the consecutive averages comprised from t to $t + (n - 1)$; p_k is the precipitation at month t. The results thus obtained were made dimensionless by dividing the long term average rainfall in the period under consideration (e.g., given month or semester), ${}^{\bar{P}_t}\!/_{\bar{P}}$.

Aiming at detecting non-homogeneities, a statistical comparison between contiguous paired subsets was accomplished: an anterior subset, with length N_a, comprehending the first a years and a posterior subset, comprehending the last $N_p = N - N_a$ years, from $N_a + 1$ to N. As a result, the total number of the paired subsets whose averages were compared is $N - 2n + 1$.

The comparison between averages of each two paired subsets implemented the Student's t parametric test:

$$t_s = \frac{\left|\bar{P}_a - \bar{P}_p\right|}{s\sqrt{{}^{1}\!/_{N_a} + {}^{1}\!/_{N_p}}} \tag{6}$$

where t_s is the t-statistic; $\bar{P}_a$ and $\bar{P}_p$ are the anterior and posterior averages, respectively; s is the estimator of the population standard deviation.

At the significance level, $\alpha = 5\%$, the hypothesis that the mentioned averages are not significantly different was rejected if:

$$|t_s| > t_{(1-{}^{\alpha}\!/_{2})} \tag{7}$$

Mann-Kendall test; Sen's slope

The Mann-Kendall non-parametric test developed by Mann (1945) and Kendall (1975) was also performed to assess the significance of trends in annual and monthly rainfall series.

The statistic S is defined as hereinafter provided:

$$sgn(Y_j - Y_i) = \begin{cases} 1 & if\ Y_j > Y_i \\ 0 & if\ Y_j = Y_i \\ -1 & if\ Y_j < Y_i \end{cases} \tag{8}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Y_j - Y_i) \tag{9}$$

where Y_j and Y_i are successive data values ($j > i$); N is the length of data series. The null hypothesis, H_0, states that no monotonic trend is denoted, as data values are independent and evenly distributed. If so, the statistic S is assigned to a normal distribution as followed:

$$E(S) = 0 \tag{10}$$

$$Var(s) = \frac{N(N-1)(2N+5)}{18} - \frac{\sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)}{18} \tag{11}$$

where $E(S)$ and $Var(S)$ are the mean and variance of the distribution, respectively; t_j counts tied groups and p gives its total.

In this study, the $p - value$ approach was computed. So that, at the significance level, $\alpha = 5\%$, H_0 is rejected if:

$$p - value < \alpha \tag{12}$$

In order to quantify the magnitudes of the existing significant trends, the Sen's slope analysis (Sen, 1968) was applied as:

$$D_{ij} = \frac{Y_j - Y_i}{X_j - X_i} \tag{13}$$

where D_{ij} are the slope estimates of all data value pairs.

3. Data

Concerning the afore-stated analysis on the precipitation variability, high quality data was required. To ensure that, datasets from SNIRH (*Sistema Nacional de Informação de Recursos Hídricos*), falling within the competence of APA (Portuguese Environment Agency), were acquired.

The rain gauges collection carried out in those with lengthy rainfall series records. In the gap filling procedure, the correlation coefficients between simultaneous sets were iteratively obtained: 0.7 from October to June and 0.5 from July to September.

Hence, the selection of the hydrological years followed the criteria (after filling the gaps):

- Only the years with less than 4 missing values (33,3%), should be considered;
- In order to incorporate as much as possible up to date information, to the rain gages with data in 2015/2016 and 2016/2017 should be selected.

Complying with the criteria, 653 rain gauges were pointed over a data length of 105 hydrological years (October 1912 to September 2017). From these 653, the rain gauges with the least lack of records were selected and thereby resulting in 39 rain gauges evenly distributed throughout mainland Portugal. Those rain gauges are identified in Table 3.

4. Results and Discussion

Data series for 105-year period from 1912 to 2017 were considered in the preceding methods. In the SPI analysis, two subperiods were compared: an initial period, 90 years (October 1912 to September 2002) and a more recent one, with the last 15 years (October 2002 to September 2017).

The results thus achieved for the complete set of 39 rain gages are exemplified in Figures 1 to 3 for moderate to extreme droughts and for the SPI time scales of 6 and 12 months.

The results from the KORE method and from the DSI analysis are exemplified in Figures 4 and 5 for the rain gauges Leonte (03I/03UG), Carviçais (06P/02UG) and Pernes (17F/01UG).

Table 3 summarizes the results obtained for each given period of time (year, season or month) using the moving average technique and trend detection based on the identification of persistent non-homogeneities. The spurious non-homogeneities over the last 20 years (October 1996 to September 2017) were not considered and the period disregarded, as they cannot be projected to the future. Furthermore, Table 4 shows the Mann-Kendall test results coupled with Sen's slope to ascertain the significant long-term trends.

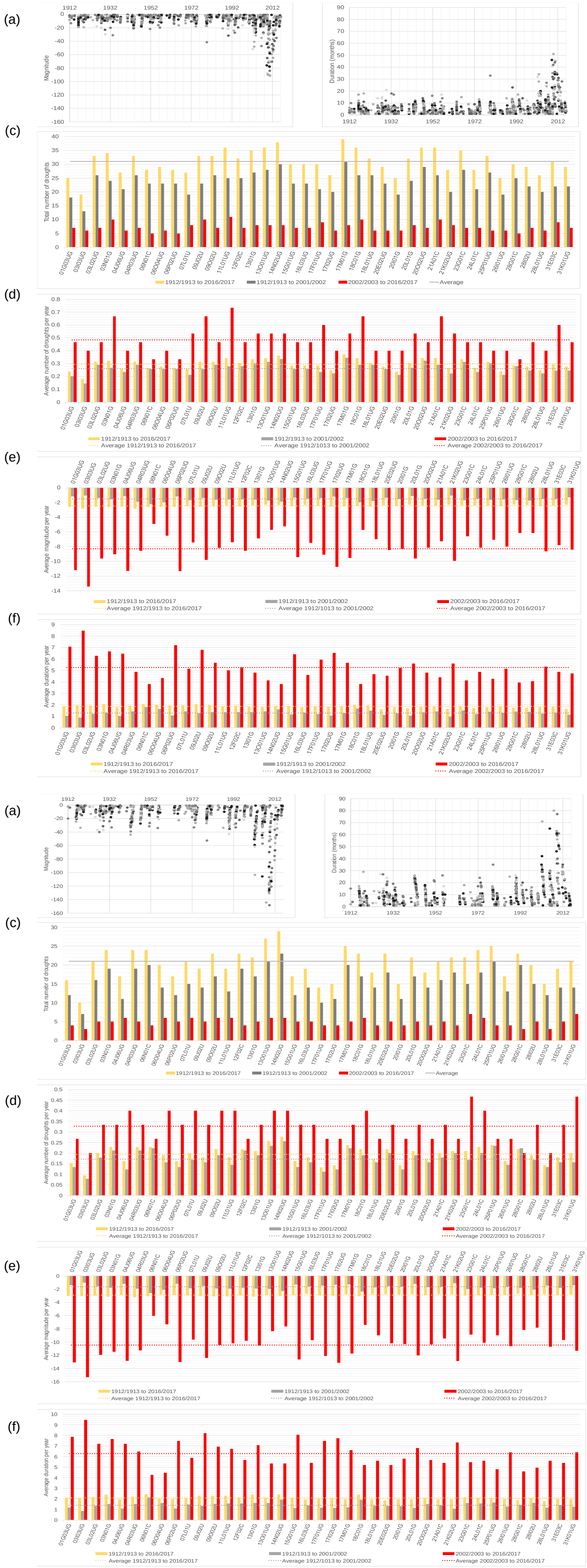

Figure 1 – Characteristics of moderate droughts (SPI =-0.84) for SPI6 and SPI12: (a) magnitude; (b) duration (months); (c) number of droughts per year; (d) average number of droughts per year; (e) average magnitude per year; (f) average duration per year (months). Periods: 1912/1913 to 2016/2017 (yellow); 1912/1913 to 2001/2002 (gray); 2002/2003 to 2016/2017 (red)

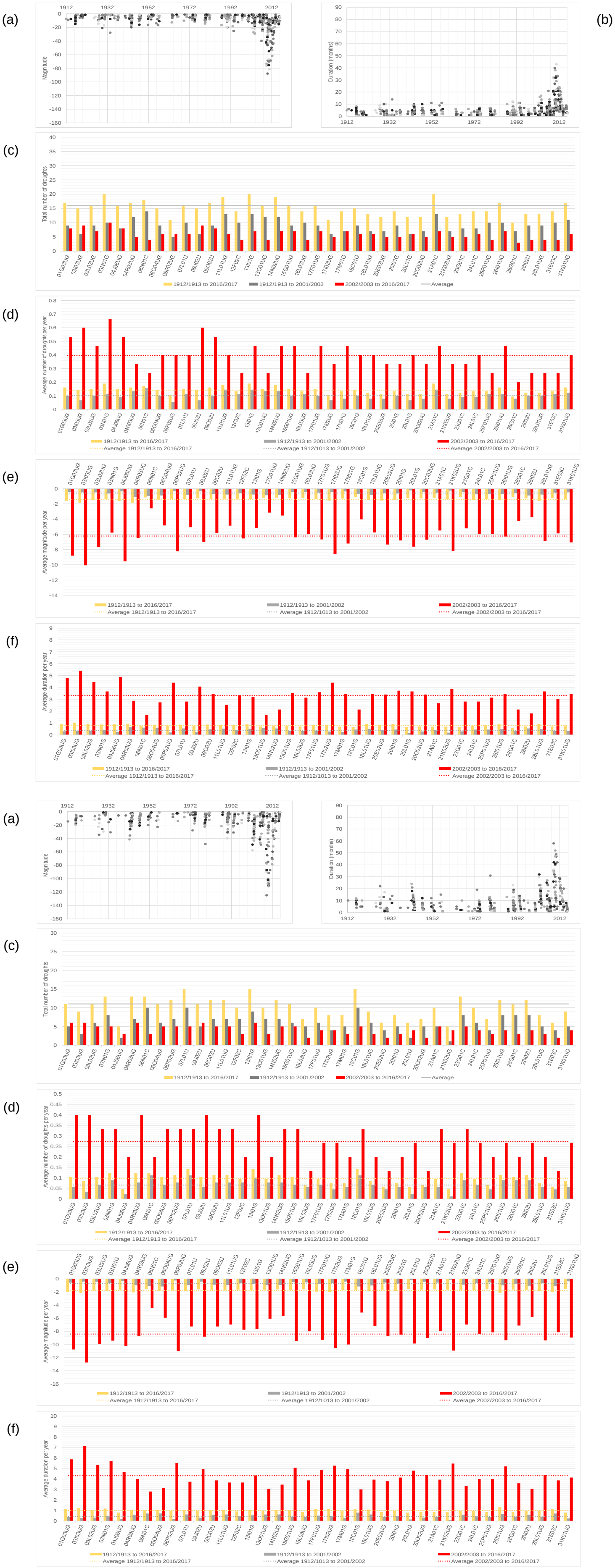

Figure 2 – Characteristics of severe droughts (SPI =-1.28) for SPI6 and SPI12: (a) magnitude; (b) duration (months); (c) number of droughts per year; (d) average number of droughts per year; (e) average magnitude per year; (f) average duration per year (months). Periods: 1912/1913 to 2016/2017 (yellow); 1912/1913 to 2001/2002 (gray); 2002/2003 to 2016/2017 (red)

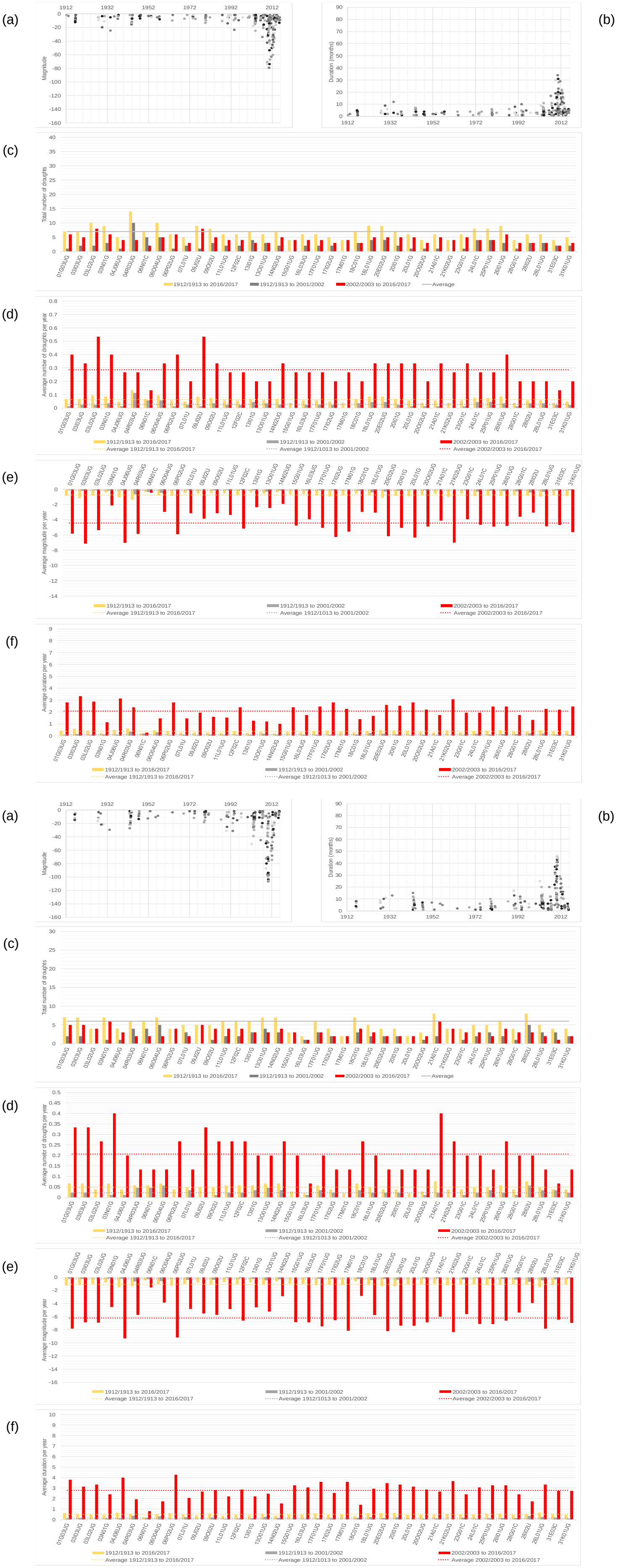

Figure 3 – Characteristics of extreme droughts (SPI =-1.65) for SPI6 and SPI12: (a) magnitude; (b) duration (months); (c) number of droughts per year; (d) average number of droughts per year; (e) average magnitude per year; (f) average duration per year (months). Periods: 1912/1913 to 2016/2017 (yellow); 1912/1913 to 2001/2002 (gray); 2002/2003 to 2016/2017 (red)

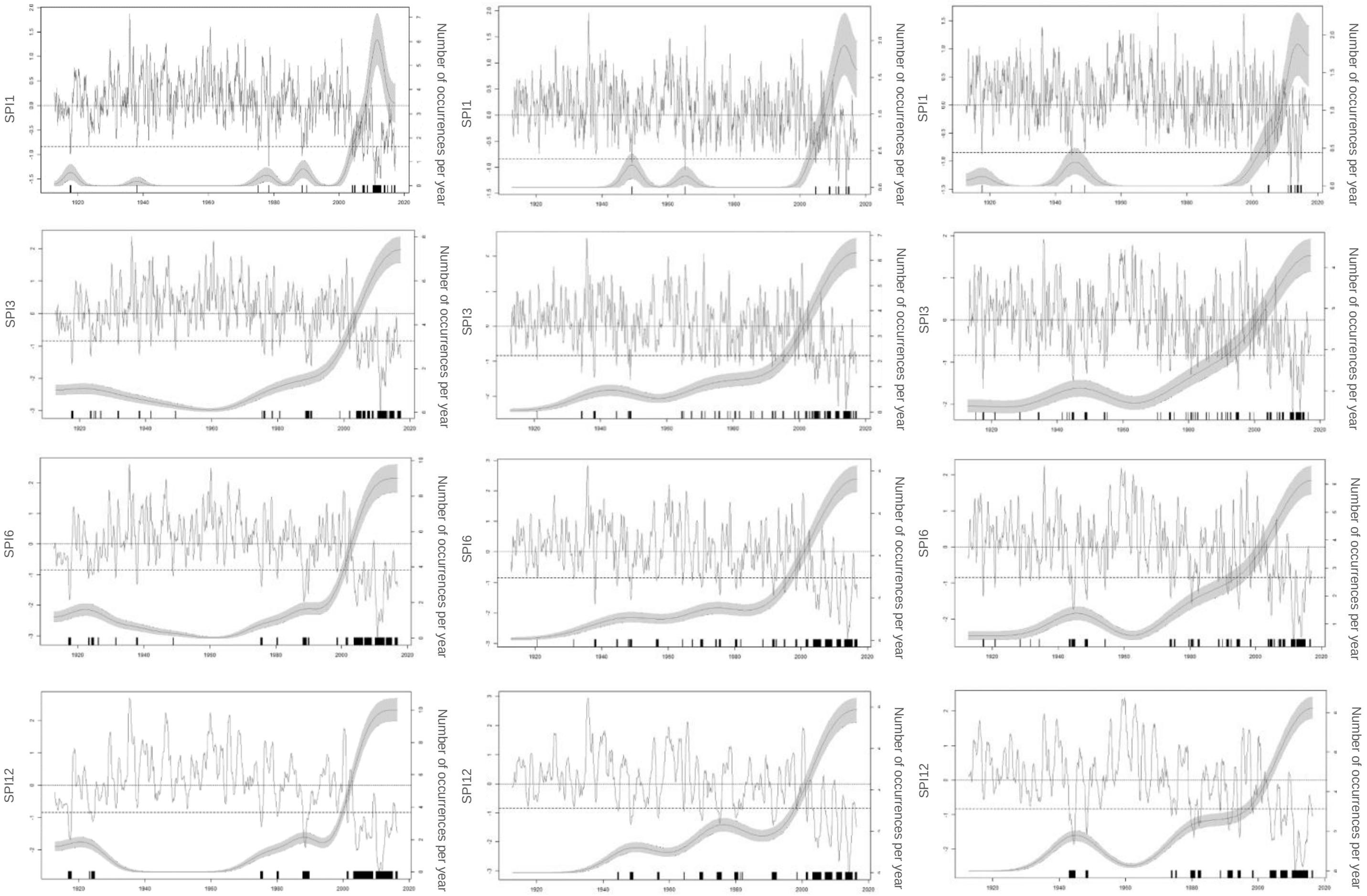

Figure 4 – Yearly frequency of the periods under drought conditions, with 90% confidence bands, for moderate droughts (SPI=0.84): SPI1, SPI3, SPI6, SPI12.. Rain gauges: Leonte (03I/03UG); Carviçais (06P/02UG); Pernes (17F/01UG). The vertical ticks indicate the points in time when droughts occurred

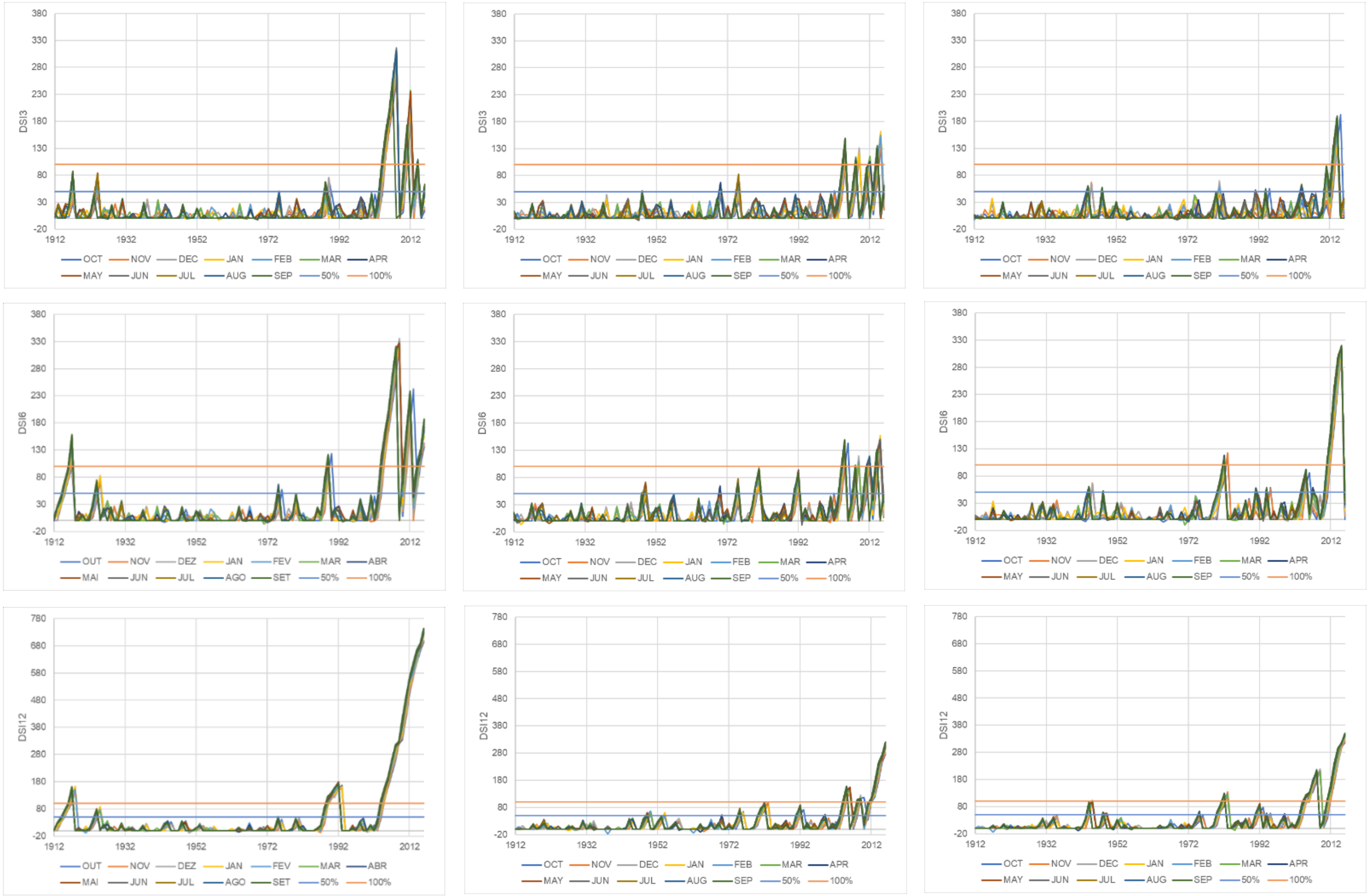

Figure 5 – DSI3, DSI6, DSI12. Rain gauges: Leonte (03I/03UG); Carviçais (06P/02UG); Pernes (17F/01UG). Drought thresholds: severe, DSI=50% (blue); extreme, DSI=100% (orange)

Table 3 – Trends in monthly and seasonal rainfall (referring to the hydrological year). Moving average technique and non-homogeneities, at the 5% significance level: increasing trend (▲); decreasing significant trend (▼); non-homogeneities detected (—); disregarded period (■); average precipitation; period including non-homogeneities and its dimensionless average precipitation.

Rain gauge		Recording period																																															
		YEAR						WINTER						SUMMER						1st QUARTER						2nd QUARTER						3rd QUARTER						4th QUARTER						MARCH					
Name	Code	Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall			Trend	Average (mm)	Period	Dimensionless average rainfall		
MERUFE	01G/03UG	▼	1827.63	1963 2001	1.0594 1.0600	- -	0.9417 0.6402	▼	1342.39	1965 2001	1.0766 1.0577	- -	0.9189 0.6541	▼	485.25	1967 2001	1.0649 1.0663	- -	0.9258 0.6019	▼	659.04	1995 2001	1.0242 1.0581	- -	0.9033 0.6512	■	683.35			- -		▼	338.94	1977 2001	1.0556 1.0566	- -	0.9059 0.6604	▼	146.31	1971 2001	1.0922 1.0889	- -	0.8771 0.4665	▼	179.81	1993 2001	1.0349 1.0440	- -	0.8754 0.7360
LEONTE	03I/03UG	▼	2873.93	1959 2001	1.0889 1.0813	- -	0.9251 0.5121	▼	2065.99	1959 2001	1.0907 1.0798	- -	0.9237 0.5209	▼	807.94	1959 2001	1.0844 1.0851	- -	0.9289 0.4896	▼	1004.69	1982 2001	1.0653 1.0738	- -	0.8636 0.5570	▼	1061.31	1959 2001	1.1386 1.0855	- -	0.8833 0.4868	▼	535.19	1965 2001	1.0893 1.0852	- -	0.9054 0.4889	▼	272.75	1990 2001	1.0643 1.0848	- -	0.8046 0.4909	■	310.77			- -	
SOUTELO (CHAVES)	03L/02UG	▼	816.81	1954 2001	1.0232 1.0584	- -	0.9839 0.6495	▼	570.10	1954 2001	1.0151 1.0581	- -	0.9895 0.6517	▼	246.70	1938 2001	1.0438 1.0593	- -	0.9848 0.6444	▼	288.84	1958 2001	1.0067 1.0499	- -	0.9946 0.7007	▼	281.26	1957 2001	1.0408 1.0664	- -	0.9682 0.6013	▼	177.38	1935 2001	1.0497 1.0557	- -	0.9853 0.6657	▼	69.32	1980 2001	1.0350 1.0684	- -	0.9329 0.5899	▼	77.33	1930 2001	1.0373 1.0694	- -	0.9918 0.5836
TRAVANCAS	03N/01G	▼	953.80	1959 2001	1.0480 1.0445	- -	0.9596 0.7332	▼	663.09	1961 2001	1.0596 1.0361	- -	0.9458 0.7835	▼	290.72	1970 2001	1.0644 1.0636	- -	0.9174 0.6184	—	338.38	_ _	_ _	- -	_ _	■	324.70			- -		▼	201.42	1968 2001	1.0729 1.0664	- -	0.9134 0.6015	■	89.30			- -		▼	101.65	1993 2001	1.0207 1.0428	- -	0.9261 0.7432
CABECEIRAS DE BASTO	04J/06UG	▼	1411.02	1976 2001	1.0634 1.0672	- -	0.8969 0.5969	▼	1032.66	1977 2001	1.0663 1.0649	- -	0.8878 0.6106	▼	378.36	1993 2001	1.0513 1.0734	- -	0.8172 0.5594	▼	502.71	1995 2001	1.0420 1.0738	- -	0.8320 0.5573	▼	529.95	1968 2001	1.1110 1.0565	- -	0.8682 0.6611	▼	270.53	1992 2001	1.0581 1.0736	- -	0.8040 0.5586	■	107.83			- -		▼	159.15	1996 2001	1.0510 1.0530	- -	0.7835 0.6822
CAMPO DE VÍBORAS	04R/03UG	▼	653.35	1996 2001	1.0069 1.0406	- -	0.9706 0.7565	■	431.91			- -		■	221.44			- -		—	222.42	_ _	_ _	- -	_ _	■	209.49			- -		■	155.06			- -		■	66.38			- -		■	65.81			- -	
FOLGARES	06N/01C	▼	601.04	1995 2001	1.0296 1.0283	- -	0.8817 0.8299	—	406.51	_ _	_ _	- -	_ _	▼	194.53	1996 2001	1.0359 1.0419	- -	0.8474 0.7488	—	213.03	_ _	_ _	- -	_ _	■	193.48			- -		▼	142.36	1991 2001	1.0398 1.0423	- -	0.8727 0.7464	—	52.17	_ _	_ _	- -	_ _	▼	56.02	1992 2001	1.0723 1.0564	- -	0.7561 0.6617
MONCORVO	06O/04UG	▼	523.72	1965 2001	1.0651 1.0379	- -	0.9311 0.7728	■	349.35			- -		■	174.37			- -		—	187.59	_ _	_ _	- -	_ _	■	161.76			- -		■	122.99			- -		■	51.39			- -		■	49.12			- -	
CARVIÇAIS	06P/02UG	▼	702.20	1936 2001	1.1193 1.0637	- -	0.9627 0.6175	▼	480.84	1936 2001	1.1466 1.0624	- -	0.9542 0.6255	▼	221.37	1951 2001	1.0832 1.0666	- -	0.9488 0.6002	▼	248.00	1995 2001	1.0487 1.0530	- -	0.8051 0.6819	▼	232.84	1939 2001	1.2129 1.0724	- -	0.9226 0.5655	▼	151.63	1970 2001	1.0803 1.0638	- -	0.8971 0.6173	▼	69.74	1996 2001	1.0683 1.0728	- -	0.7099 0.5629	■	69.96			- -	
ADORIGO	07L/01U	▼	627.79	1992 2001	1.0284 1.0447	- -	0.9040 0.7320	▼	442.15	1995 2001	1.0366 1.0425	- -	0.8536 0.7447	▼	185.63	1996 2001	1.0375 1.0497	- -	0.8407 0.7018	■	225.52			- -		■	216.63			- -		▼	132.26	1992 2001	1.0531 1.0593	- -	0.8208 0.6444	—	53.37	_ _	_ _	- -	_ _	■	62.43			- -	
PINDELO DOS MILAGRES	09J/02U	▼	1319.02	1959 2001	1.0661 1.0636	- -	0.9444 0.6186	▼	967.66	1960 2001	1.0794 1.0660	- -	0.9305 0.6041	▼	351.37	1980 2001	1.0494 1.0569	- -	0.9054 0.6586	▼	468.12	1994 2001	1.0415 1.0581	- -	0.8435 0.6513	▼	499.54	1962 2001	1.1119 1.0734	- -	0.8943 0.5599	▼	251.19	1968 2001	1.0706 1.0673	- -	0.9162 0.5962	—	100.18	_ _	_ _	- -	_ _	■	148.01			- -	
FREIXEDAS	09O/02U	▼	691.24	1960 2001	1.0583 1.0499	- -	0.9490 0.7007	▼	478.69	1962 2001	1.0716 1.0487	- -	0.9324 0.7076	▼	212.55	1968 2001	1.0637 1.0525	- -	0.9243 0.6850	▼	248.42	1977 2001	1.0676 1.0476	- -	0.8855 0.7146	■	230.27			- -		▼	157.58	1970 2001	1.0807 1.0506	- -	0.8965 0.6963	—	54.97	_ _	_ _	- -	_ _	▲	70.10	1994 2001	1.0713 1.0493	- -	0.7311 0.7041
GOUVEIA	11L/01UG	▼	1083.83	1965 2001	1.0600 1.0428	- -	0.9365 0.7433	▼	764.72	1960 2001	1.0691 1.0459	- -	0.9395 0.7243	■	319.11			- -		■	368.32			- -		▼	396.41	1928 2001	1.2108 1.0626	- -	0.9593 0.6244	■	234.78			- -		—	84.33	_ _	_ _	- -	_ _	■	123.28			- -	
SANTO VARÃO	12F/02C	▼	882.14	1960 2001	1.0626 1.0479	- -	0.9452 0.7127	▼	639.84	1961 2001	1.0667 1.0494	- -	0.9394 0.7036	■	242.30			- -		▼	330.77	1995 2001	1.0345 1.0431	- -	0.8622 0.7413	▼	309.07	1962 2001	1.0985 1.0561	- -	0.9070 0.6632	▼	181.18	1996 2001	1.0381 1.0468	- -	0.8381 0.7191	—	61.12	_ _	_ _	- -	_ _	▼	87.42	1929 2001	1.3137 1.0860	- -	0.9351 0.4837
GÓIS	13I/01G	▼	1116.27	1945 2001	1.0819 1.0438	- -	0.9608 0.7369	▼	813.14	1950 2001	1.0953 1.0452	- -	0.9437 0.7291	▼	303.13	1996 2001	1.0302 1.0404	- -	0.8716 0.7579	■	398.23			- -		▼	414.91	1946 2001	1.1526 1.0593	- -	0.9237 0.6442	▼	222.52	1991 2001	1.0392 1.0429	- -	0.8746 0.7428	—	80.61	_ _	_ _	- -	_ _	▼	123.54	1932 2001	1.2456 1.0866	- -	0.9386 0.4806
PENHA GARCIA	13O/01UG	▼	771.92	1968 2001	1.0534 1.0433	- -	0.9366 0.7403	▼	565.08	1962 2001	1.0568 1.0461	- -	0.9464 0.7233	■	206.84			- -		—	296.56	_ _	_ _	- -	_ _	▼	268.51	1962 2001	1.1160 1.0674	- -	0.8904 0.5959	■	148.85			- -		—	57.99	_ _	_ _	- -	_ _	■	83.82			- -	
LADOEIRO	14N/02UG	▼	594.33	1959 2001	1.0628 1.0374	- -	0.9472 0.7757	▼	427.30	1995 2001	1.0309 1.0342	- -	0.8762 0.7950	▼	167.03	1983 2001	1.0534 1.0456	- -	0.8836 0.7264	—	217.30	_ _	_ _	- -	_ _	▼	210.00	1958 2001	1.1270 1.0603	- -	0.8971 0.6380	▼	123.18	1983 2001	1.0599 1.0485	- -	0.8692 0.7088	—	43.85	_ _	_ _	- -	_ _	■	68.79			- -	
ALVAIÁZERE	15G/01UG	▼	1170.04	1935 2001	1.1110 1.0605	- -	0.9671 0.6370	▼	876.36	1935 2001	1.1407 1.0644	- -	0.9583 0.6137	■	293.68			- -		▼	435.67	1995 2001	1.0377 1.0501	- -	0.8492 0.6992	▼	440.69	1954 2001	1.1294 1.0785	- -	0.9103 0.5290	▼	219.56	1993 2001	1.0445 1.0528	- -	0.8415 0.6833	—	74.11	_ _	_ _	- -	_ _	▼	130.74	1935 2001	1.3171 1.0897	- -	0.9060 0.4620
NISA	16L/03UG	▼	681.58	1995 2001	1.0377 1.0475	- -	0.8493 0.7147	▼	513.27	1995 2001	1.0418 1.0502	- -	0.8326 0.6988	▼	168.31	1996 2001	1.0337 1.0395	- -	0.8569 0.7632	■	264.48			- -		▼	248.78	1962 2001	1.1332 1.0611	- -	0.8742 0.6334	▼	124.63	1996 2001	1.0403 1.0397	- -	0.8289 0.7620	—	43.68	_ _	_ _	- -	_ _	■	74.84			- -	
PERNES	17F/01UG	▼	789.52	1936 2001	1.1038 1.0631	- -	0.9676 0.6213	▼	597.91	1957 2001	1.0754 1.0659	- -	0.9412 0.6048	▼	191.61	1960 2001	1.0899 1.0546	- -	0.9214 0.6726	▼	299.56	1996 2001	1.0380 1.0484	- -	0.8384 0.7095	▼	298.36	1954 2001	1.1426 1.0834	- -	0.9011 0.4997	▼	142.40	1982 2001	1.0624 1.0561	- -	0.8697 0.6636	—	49.21	_ _	_ _	- -	_ _	▼	91.85	1930 2001	1.3314 1.0980	- -	0.9268 0.4120
BEMPOSTA	17I/02UG	▼	670.26	1962 2001	1.0741 1.0639	- -	0.9300 0.6166	▼	502.02	1963 2001	1.0894 1.0609	- -	0.9123 0.6349	▼	168.24	1984 2001	1.0572 1.0730	- -	0.8695 0.5621	■	258.29			- -		▼	243.72	1961 2001	1.1206 1.0828	- -	0.8903 0.5033	▼	122.41	1987 2001	1.0629 1.0761	- -	0.8350 0.5436	■	45.84			- -		▼	74.61	1936 2001	1.3522 1.1018	- -	0.8899 0.3890
CASTELO DE VIDE	17M/01G	▼	832.53	1959 2001	1.0841 1.0578	- -	0.9291 0.6530	▼	615.82	1954 2001	1.1056 1.0613	- -	0.9268 0.6320	■	216.71			- -		■	311.82			- -		▼	303.99	1946 2001	1.1989 1.0707	- -	0.9006 0.5758	■	158.53			- -		■	58.19			- -		▼	94.49	1930 2001	1.3258 1.0872	- -	0.9280 0.4768
PRAGANÇA	18C/01G	■	860.74			- -		■	656.25			- -		▼	204.49	1958 2001	0.9201 1.0129	- -	1.0648 0.9226	—	335.05	_ _	_ _	- -	_ _	▼	321.20	1962 2001	1.0998 1.0515	- -	0.9058 0.6911	—	157.43	_ _	_ _	- -	_ _	■	47.06			- -		▲	99.21	1996 2001	1.0487 1.0356	- -	0.7932 0.7863
ALTER DO CHÃO	18L/01UG	▼	593.94	1993 2001	1.0418 1.0488	- -	0.8508 0.7069	▼	436.82	1995 2001	1.0479 1.0538	- -	0.8083 0.6771	■	157.12			- -		■	216.83			- -		▼	219.99	1966 2001	1.0991 1.0633	- -	0.8910 0.6204	■	117.08			- -		—	40.04	_ _	_ _	- -	_ _	▼	67.44	1945 2001	1.2397 1.0848	- -	0.8852 0.4913
SANTO ESTEVÃO	20E/02UG	■	562.91			- -		■	419.68			- -		▼	143.24	1962 2001	0.9365 1.0346	- -	1.0600 0.7925	▼	218.63	1976 2001	0.9206 1.0237	- -	1.1290 0.8575	■	201.05			- -		—	108.78	_ _	_ _	- -	_ _	—	34.46	_ _	_ _	- -	_ _	■	65.63			- -	
PAVIA	20I/01G	▼	535.41	1984 2001	1.0521 1.0575	- -	0.8812 0.6549	▼	394.49	1984 2001	1.0555 1.0555	- -	0.8735 0.6669	■	140.92			- -		▼	197.95	1960 2001	0.8918 1.0324	- -	1.0947 0.8057	▼	196.53	1964 2001	1.1043 1.0788	- -	0.8937 0.5271	▼	108.29	1991 2001	1.0539 1.0647	- -	0.8275 0.6116	■	32.64			- -		▼	62.98	1951 2001	1.1787 1.0902	- -	0.8900 0.4589
ESTREMOZ	20L/01G	▼	621.89	1940 2001	1.1393 1.0663	- -	0.9468 0.6024	▼	461.99	1939 2001	1.1609 1.0702	- -	0.9415 0.5789	▼	159.91	1991 2001	1.0529 1.0549	- -	0.8308 0.6703	■	236.83			- -		▼	225.15	1939 2001	1.2107 1.0852	- -	0.9234 0.4890	▼	121.31	1992 2001	1.0682 1.0493	- -	0.7698 0.7042	■	38.59			- -		▼	73.03	1926 2001	1.4561 1.0992	- -	0.9240 0.4046
CAIA (MONTE CALDEIRAS)	20O/02UG	▼	494.77	1958 2001	1.0742 1.0584	- -	0.9399 0.6498	▼	358.07	1959 2001	1.0984 1.0618	- -	0.9172 0.6292	■	136.71			- -		■	182.12			- -		▼	175.94	1957 2001	1.1370 1.0766	- -	0.8932 0.5403	—	102.88	_ _		- -		■	33.83			- -		▼	61.08	1941 2001	1.2667 1.0854	- -	0.8933 0.4877
COLARES (SARRAZOLA)	21A/01C	▼	705.55	1983 2001	1.0317 1.0391	- -	0.9308 0.7651	▼	535.29	1983 2001	1.0354 1.0366	- -	0.9228 0.7805	■	170.26			- -		—	288.31	_ _	_ _	- -	_ _	▼	246.99	1962 2001	1.0823 1.0606	- -	0.9223 0.6364	■	125.04			- -		—	45.22	_ _	_ _	- -	_ _	▼	80.05	1941 2001	1.2565 1.0790	- -	0.8974 0.5260
ÉVORA-MONTE	21K/02UG	▼	571.57	1962 2001	1.0703 1.0702	- -	0.9336 0.5788	▼	422.62	1960 2001	1.0739 1.0723	- -	0.9353 0.5665	▼	148.95	1992 2001	1.0488 1.0643	- -	0.8354 0.6140	▼	221.56	1989 2001	1.0640 1.0710	- -	0.8150 0.5737	▼	201.06	1962 2001	1.1047 1.0736	- -	0.9011 0.5584	▼	109.57	1992 2001	1.0550 1.0587	- -	0.8145 0.6477	■	39.37			- -		▼	72.00	1932 2001	1.3161 1.0785	- -	0.9210 0.5289
BARRAGEM DE PEGO DO ALTAR	23G/01C	■	548.21			- -		■	411.16			- -		■	137.05			- -		▼	209.11	1977 2001	0.7567 0.8935	- -	1.0470 1.1006	▼	202.05	1967 2001	1.0839 1.0686	- -	0.9041 0.5884	—	104.11	_ _	_ _	- -	_ _	—	32.94	_ _	_ _	- -	_ _	■	64.04			- -	
AMIEIRA	24L/01C	▼	535.13	1995 2001	1.0330 1.0490	- -	0.8680 0.7059	▼	393.25	1995 2001	1.0419 1.0522	- -	0.8324 0.6869	■	141.88			- -		—	196.34	_ _	_ _	- -	_ _	▼	196.92	1962 2001	1.0984 1.0780	- -	0.9070 0.5321	■	111.81			- -		—	30.06	_ _	_ _	- -	_ _	▼	60.15	1946 2001	1.1749 1.0773	- -	0.9126 0.5360
BARRANCOS	25P/01UG	▼	532.86	1976 2001	1.0497 1.0437	- -	0.9192 0.7379	▼	383.22	1962 2001	1.0777 1.0469	- -	0.9266 0.7188	■	149.64			- -		▼	195.81	1996 2001	1.0458 1.0427	- -	0.8052 0.7441	▼	187.40	1961 2001	1.1077 1.0513	- -	0.9021 0.6924	—	114.56	_ _	_ _	- -	_ _	—	35.09	_ _	_ _	- -	_ _	▼	62.93	1930 2001	1.3182 1.0745	- -	0.9297 0.5529
SANTA VITÓRIA	26I/01UG	▼	503.08	1975 2001	1.0463 1.0507	- -	0.9277 0.6960	▼	382.55	1965 2001	1.0624 1.0556	- -	0.9339 0.6664	■	120.54			- -		■	196.67			- -		▼	185.87	1963 2001	1.0956 1.0625	- -	0.9062 0.6250	■	95.88			- -		—	24.66	_ _	_ _	- -	_ _	▼	60.13	1945 2001	1.1773 1.0757	- -	0.9151 0.5457
BARRAGEM DE MIRA	28G/01C	▼	570.30	1995 2001	1.0338 1.0369	- -	0.8650 0.7785	▼	438.20	1995 2001	1.0427 1.0379	- -	0.8290 0.7728	—	132.11	_ _	_ _	- -	_ _	▼	236.31	1976 2001	0.9276 1.0150	- -	1.1176 0.9101	▼	201.89	1961 2001	1.0946 1.0647	- -	0.9140 0.6120	—	104.80	_ _	_ _	- -	_ _	—	27.30	_ _	_ _	- -	_ _	▲	69.88	1994 2001	1.0611 1.0463	- -	0.7696 0.7221
ROSÁRIO (ALMODÔVAR)	28I/02U	▼	550.88	1996 2001	1.0313 1.0384	- -	0.8670 0.7694	▼	426.40	1995 2001	1.0360 1.0397	- -	0.8559 0.7618	■	124.48			- -		—	231.68	_ _	_ _	- -	_ _	▼	194.71	1962 2001	1.1083 1.0584	- -	0.8977 0.6496	—	95.60	_ _	_ _	- -	_ _	—	28.89	_ _	_ _	- -	_ _	■	63.00			- -	
MÉRTOLA	28L/01UG	▼	392.71	1977 2001	1.0532 1.0507	- -	0.9100 0.6955	▼	303.31	1977 2001	1.0589 1.0497	- -	0.9004 0.7017	▼	89.39	1995 2001	1.0514 1.0542	- -	0.7944 0.6745	—	167.88	_ _	_ _	- -	_ _	▼	135.44	1958 2001	1.0810 1.0615	- -	0.9344 0.6308	▼	69.38	1987 2001	1.0515 1.0478	- -	0.8650 0.7134	■	20.01			- -		▼	46.40	1945 2001	1.1406 1.0776	- -	0.9327 0.5347
VALVERDE	31E/03C	▼	524.13	1995 2001	1.0402 1.0477	- -	0.8392 0.7137	▼	428.55	1989 2001	1.0517 1.0517	- -	0.8507 0.6897	—	95.58	_ _	_ _	- -	_ _	■	222.81			- -		▼	205.74	1965 2001	1.0890 1.0627	- -	0.9057 0.6240	—	73.72	_ _	_ _	- -	_ _	—	21.85	_ _	_ _	- -	_ _	■	61.66			- -	
SANTA CATARINA (TAVIRA)	31K/01UG	▼	636.13	1995 2001	1.0457 1.0578	- -	0.8173 0.6534	▼	521.07	1989 2001	1.0445 1.0622	- -	0.8714 0.6271	—	132.11	_ _	_ _	- -	_ _	■	273.33			- -		▼	247.74	1958 2001	1.0829 1.0771	- -	0.9328 0.5373	■	89.31			- -		—	25.75	_ _	_ _	- -	_ _	▼	76.33	1946 2001	1.2220 1.0827	- -	0.8890 0.5039

Table 4 – Trends in monthly and seasonal rainfall (referring to the hydrological year). Mann-Kendall test and Sen’s slope estimator, at the 5% significance level: increasing significant trend (blue); decreasing significant trend (yellow); non-significant trend (blank)

Rain gauge		**Recording period**																		
Name	Code	YEAR	WINTER	SUMMER	1stQ	2ndQ	3rdQ	4thQ	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MERUFE	01G/03UG	-5.43977	-4.61042	-1.26096		-2.76429								-0.76142		-0.50145				-0.45689
LEONTE	03I/03UG	-10.65700	-8.21396	-3.00440		-5.51674	-2.08902					-1.72197		-1.82562		-0.95263	-0.54740	-0.27894		-0.67209
SOUTELO (CHAVES)	03L/02UG	-2.90428	-2.13074	-0.71578		-1.28711	-0.64404							-0.50729			-0.21320			
TRAVANCAS	03N/01G	-2.07796	-1.67669			-1.43590	-0.61880							-0.55457						
CABECEIRAS DE BASTO	04J/06UG	-4.93987	-3.94808	-1.42828		-2.35847	-1.19871							-1.30749		-0.49020	-0.27411			
CAMPO DE VÍBORAS	04R/03UG					-0.92154								-0.58865						
FOLGARES	06N/01C					-0.70868								-0.28560						
MONCORVO	06O/04UG	-1.41553	-1.29988			-0.87835								-0.38000						
CARVIÇAIS	06P/02UG	-3.11066	-2.46854	-0.82633	-0.96310	-1.47500	-0.58260	-0.25343		-0.40222				-0.53250			-0.19014			
ADORIGO	07L/01U					-0.78038								-0.53405						
PINDELO DOS MILAGRES	09J/02U	-5.66077	-4.27196	-0.94001		-2.90658	-0.90770			-0.73041	-0.79388			-1.43483		-0.44304	-0.22875			
FREIXEDAS	09O/02U	-2.32243	-1.80485	-0.59107	-0.94870	-0.95076					-0.46344	-0.46796		-0.35749			-0.19958			
GOUVEIA	11L/01UG	-2.83295	-2.76688			-2.33159								-1.05689						
SANTO VARÃO	12F/02C	-2.86152	-2.35164			-1.53250	-0.56696							-0.87594						
GÓIS	13I/01G	-3.81570	-3.15598			-2.43194								-1.25518						
PENHA GARCIA	13O/01UG	-1.74142	-1.65799			-1.33944								-0.86897					0.00001	
LADOEIRO	14N/02UG	-1.53732	-1.13032			-1.11209								-0.67560			-0.11931			
ALVAIÁZERE	15G/01UG	-4.66011	-4.34771		-1.60476	-2.89693				-0.70168	-0.68048	-0.79708		-1.28660						
NISA	16L/03UG	-1.53139	-1.49080			-1.22751								-0.55801			-0.07748			
PERNES	17F/01UG	-3.46633	-2.96186	-0.60423		-2.22640	-0.45038			-0.56220		-0.59132	-0.37101	-0.99161			-0.10000			
BEMPOSTA	17I/02UG	-1.67012	-1.41672			-1.40370				-0.56220		-0.59132	-0.37101	-0.99161			-0.10000			
CASTELO DE VIDE	17M/01G	-2.76412	-2.49581			-1.86402					-0.49867			-0.94909						
PRAGANÇA	18C/01G					-1.23717		0.19883						-0.65718					0.03333	
ALTER DO CHÃO	18L/01UG					-1.19033								-0.65718					0.03333	
SANTO ESTEVÃO	20E/02UG									-0.32017				-0.47402						
PAVIA	20I/01G					-0.96847								-0.47263				0.00001	0.00920	
ESTREMOZ	20L/01G	-2.80349	-2.35314			-1.61403					-0.43324	-0.32317	-0.36250	-0.73280					0.00001	
CAIA (MONTE CALDEIRAS)	20O/02UG	-1.56782	-1.37090			-1.04674					-0.26746		-0.29486	-0.50474						
COLARES (SARRAZOLA)	21A/01C					-1.03120								-0.68371						
ÉVORA-MONTE	21K/02UG	-1.95401	-1.79540		-0.77432	-1.05022					-0.42402			-0.65169						
BARRAGEM DE PEGO DO ALTAR	23G/01C				0.79781	-0.76338								-0.40933					0.01171	
AMIEIRA	24L/01C					-1.03707						-0.38052		-0.39275				0.00001		
BARRANCOS	25P/01UG		-1.26209			-0.88703				-0.27961				-0.56886						
SANTA VITÓRIA	26I/01UG		-1.00205			-0.78569				-0.29110				-0.44182			-0.05688	-0.00433	0.00001	
BARRAGEM DE MIRA	28G/01C					-0.92136							-0.33642	-0.38376						
ROSÁRIO (ALMODÔVAR)	28I/02U					-0.89271							-0.35569	-0.37602						
MÉRTOLA	28L/01UG					-0.63946								-0.34281			-0.03125			
VALVERDE	31E/03C					-0.71658								-0.34347				-0.00090	0.00001	
SANTA CATARINA (TAVIRA)	31K/01UG					-0.71658							-0.42524	-0.56780					0.00001	

The results presented in Figures 1 to 3 indicate:

- A greater number of severe droughts (-1.65<SPI≤-1.28), SPI6 and SPI12, occurred in the last 90 years, were denoted by 80% of the analysed rain gauges. This pattern was unmatched in smaller time scales, which accounted major droughts over the last 15 years.
- A greater number of extreme droughts (SPI≤-1.65), for all time scales, occurred in the last 15 years, were denoted by the majority of the analysed rain gauges.
- A notorious increase of the magnitude and duration of the droughts towards the present. The comparison among drought characteristics for the periods studied showed an astounding worsening in the drought conditions in the more recent period, with remarkable increase in the numbers of droughts per year, their magnitude and duration.

The results presented in Figure 4 indicate:

- A significant inter-annual variability with a non-stationary behaviour. For example, considering SPI6 at Pernes (17F/01UG), the peak of $\hat{\lambda}(t)$ in the 1970s is significantly lower than the upper limit of the confidence band in the 2010s.
- An increasing trend in the yearly occurrence rates of the periods under drought conditions, common to most rain gauges, as it progressed to the present. This trend has considerably heightened since the 1980s and 1990s to the most recent years. The maximum value in 2010s was stood out for Leonte (03I/03UG) and Carviçais (06P/02UG), followed by the decline in the following years.
- The drought patterns the 39 rain stations proved enhanced the frequency, such SPI3, SPI6 to the peak value for SPI12.

The results presented in Figure 5 indicate:

- The smaller the time scale, the drier the period, on average: 55% occurrences for DSI3, 52% for DSI6 and 50% for DSI12. Droughts become longer in duration for DSI12, verified to most rain gauges. For example, Leonte (03I/03UG).
- A greater number of severe (DSI=50%) and extreme droughts (DSI=100%), from DSI3 to DSI12. For example, in Pernes (17F/01UG).
- Although the average number of droughts was smaller for DSI6 and DSI12, their intensity was higher than the one for DSI3.

The results presented in Table 3 indicate:

- Most of the rain gages exhibited rainfall significant decreasing trends: 92% of rain gauges in the hydrological year, 58% in winter, 79% in the 2nd quarter and 56% in March (In fact, the downward trend in the 2nd quarter should be the result from the rainfall decline in March). On the other hand, Freixedas (09O/02U), Pragança (18C/01G) and Barragem de Mira (28G/01C) recorded an increase of rainfalls.
- The 4th quarter was the period for which most of the rain gauges (59%) did not report any non-homogeneities, i.e, the successive average values of the paired series, anterior and posterior, did not significantly change in the last years 20 years. However, the remaining 10% trends pointed to the decrease in precipitation.

The results presented in Table 4 indicate:

- At 5% significance level, Mann-Kendall test and Sen's slope detected the following statically significant trends in rainfall: 21% for monthly series, 34% for quarterly series, 41% for winter and summer series, 56% for annual series and 100% for March. At least a significant long-term declining trend was identified in every rain gauge.
- Regarding the monthly rainfall, 8 denoted an upward trend in rainfall between 0.00001 mm/year and 0.03333 mm/year, in July and August – e.g., Pragança (18C/01G), Alter do Chão (18L/01UG) and Barragem de Mira (28G/01C), however, in mainland Portugal the rainfall in those months is so small that is almost neglectable; 92 showed a decrease in precipitation, mostly in March, with the highest rate of decrease in Leonte (03I/03UG), 1.82562 mm/year.

  No significant monthly trends were found in October and April.
- In what concerns the quarterly rainfall, 2 rain gauges denoted an upward trend in precipitation, in the 1st and 4th quarters, namely 0.19883 mm/year in Pragança (18C/01G) and 0.79781 mm/year for Barragem de Pego do Altar (23G/01C); 51 showed a decrease in rainfall, in the 2nd quarter, with the highest value of 5.51674 mm/year, in Leonte (03I/03UG).
- The significant semi-annual decreasing trends were found essentially in the wet semester. The maximum values were 8.1396 mm/year and 3.00440 mm/year.
- The decreasing trend in the annual rainfall series, accompanied by magnitude of 10,65700 mm/year for Leonte (03I/03UG) and 5.66077 mm/year for Pindelo dos Milagres (09J/02U).

5. Conclusions

This paper presented a drought analysis, in terms of intensity, magnitude, duration and frequency of the periods under drought conditions, in mainland Portugal, based on the rainfall series at 39 rain gages uniformly distributed over the country and covering a time span of 105 hydrological years. Significant trend detection methods were also applied to the same data set.

The following main conclusions could be drawn from these studies:

- A greater number of agricultural to hydrological droughts (SPI6, SPI12) was reported, in absolute terms, over the period of 90 years (1912/1913 to 2001/2002) and the events were remarked as moderate droughts.

  Despite the fewer dry spells in the last 15 years (2002/2003 to 2016/2017), meteorological droughts (SPI1, SPI3) have prevailed in severe to extreme classes.
- Spatial extent of droughts episodes was not modelled in this paper, despite its relevance. Nevertheless, agricultural and hydrological droughts were shown to increase among central and southern regions of Portugal, in particular for severe and extreme thresholds. On the other hand, meteorological events are mostly evidenced in the northeast region.

  In a global context, the prior results and the presented distribution of rainfall were found to be spatially coherent.
- Over the last 15 years, correlation between drought magnitude and duration was established, the more evident the longer the temporal scale of SPI and the lower the drought threshold adopted.
- All the rain gauges experienced a non-stationary behaviour regarding the frequency of the periods under drought conditions, more often since the 1980s and 1990s to the most recent period.
- For DSI application, severe to extreme droughts pattern occurring were increased, as the time scale rises. As a result, attending to hydrological droughts, meaningful deficiencies in runoff and low recharge rates have been observed.
- Significant long-term trends in rainfall were exhibited at all rain gauges. Decreasing trends were mainly exhibited for the periods: hydrological year, winter, 2nd quarter and March.
- A decrease or lengthy lack of rainfall in winter, as a meaningful semester for the water balance, are not expected over the climatic zones in which mainland Portugal is included.

  Seasonal trend analysis corroborated the results found to drought occurrences.

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