Drought Tendencies in Mainland Portugal

V. Cabrinha and F.E. Santo
Meteorological Institute, Lisbon, Portugal

Abstract

Drought in Portugal is a phenomenon that affects some regions every year, with serious consequences to the economy. Any contribution to the understanding and prediction of drought conditions will be a step toward minimization of drought impacts. The purpose of this study is to characterize drought by using long time series of the Palmer Drought Severity Index (PDSI) in some stations of Portugal and short time series for the whole country. The time series are examined by means of graphic analyses and through a statistical test based on Szinell et al. (1998), with the main objective of featuring changes in drought occurrences: frequency, persistence, and severity in Portugal over the 20th century. With this test it can be shown whether drought events will tend to concentrate at the beginning or the end of the time series. For the stations in the southern part of Portugal, the results indicate that moderate, severe, and extreme droughts tend to concentrate near the end of the time series, therefore occurring with an increased frequency in the latest years.

Introduction

Drought is a natural phenomenon that usually is associated with a deficiency of rainfall from normal or expected amounts over an extended period of time. It occurs in many regions of the world every year, with serious damage to national economic structures, especially water resource, agriculture, and cattle breeding sectors. In extreme situations, it can also cause loss of human lives. This phenomenon is becoming more and more important at local, regional, and global scales, leading to increasing awareness at both scientific and political levels.

Long drought spells have already occurred in Portugal, with consequent damages to agriculture and water resources, especially in the southern part of Portugal. Gonçalves (1983) carried out a climatological analysis to determine the existence of drought spells and their duration and intensity, for a period of 29 years or more at 27 stations in Portugal, and detected the existence of 8 country-wide drought spells. Almeida (1981) describes a procedure to detect the occurrence of drought at some stations in the Portuguese mainland by means of the monthly rainfall amounts for the period 1857-1977.

Drought can be quantified by different indices, the Palmer Drought Severity Index (PDSI) developed by Palmer (1965) being one of the most commonly used. It was originally conceived as a meteorological index, expressing regional moisture supply, standardized in relation to local

climatological norms (Briffa et al. 1994). It can detect the existence of drought spells (or wet spells) in time series, allowing the quantification of a full range of moisture conditions, from extremely wet to extremely dry. In spite of some limitations of the PDSI (Alley 1984), this method is implemented over all of the United States (Palmer 1965; Karl 1983), and more recently in Europe (Briffa et al. 1994).

In this study, the Palmer Drought Severity Index is computed in order to feature some changes in drought tendencies, subsequently analyzing the persistence and severity of drought in mainland Portugal.

Climate Profile in Mainland Portugal

The climate over mainland Portugal is temperate, and variation in climate factors is small, although it is still sufficient to explain significant variations in the elements that are most characteristic of the climate (i.e., air temperature and precipitation amount).

Air Temperature

The lowest values of the mean annual air temperature (based on observations between 1961 and 1990) are in the northern part of the country, with a minimum around 7º C over the highlands of central Portugal, and the highest values are in the southern part, with a maximum of 18º C in the southern coastal region. This distribution shows a significant difference between northern and southern Portugal.

A statistical analysis of long-term climatological series of air temperature over mainland Portugal for the period 1931-99 can be seen in Figure 1. It shows the variability of the regional average of the mean annual temperature. For the last 30 years, there has been a trend toward an increase in the mean annual temperature, 1997 being the hottest year recorded since 1931, with 1.58º C above the 1961–90 normal.

The mean temperature anomalies with respect to 1961–90 for the last 20 years (Figure 2) show that the 6 hottest years ever recorded occurred in the last 11 years.

The mean annual maximum and minimum temperature (Figures 3a and 3b) show an increasing trend over the last 20-30 years. In fact, 1999 is the last of 13 consecutive years in which the minimum temperature reveals positive anomalies with respect to the 1961–90 mean. The year 1997 presents the highest maximum temperature since 1931, with 1.67º C above the 1961–90 normal.

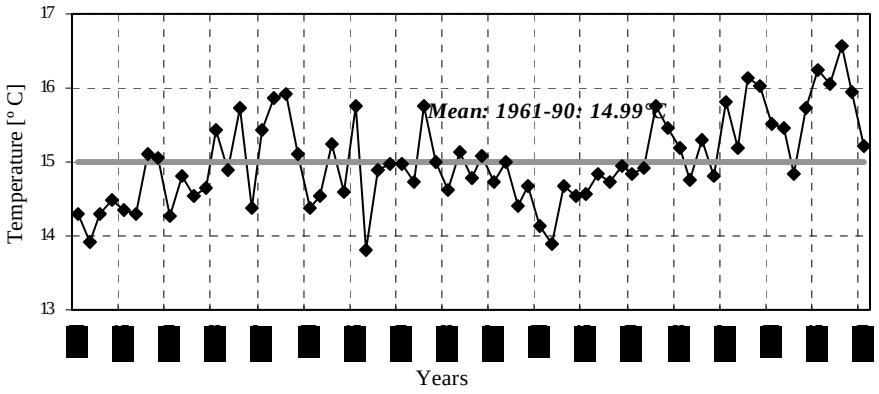


Figure 1. Variability of the regional average of the mean annual temperature in mainland Portugal for the period 1931-99.

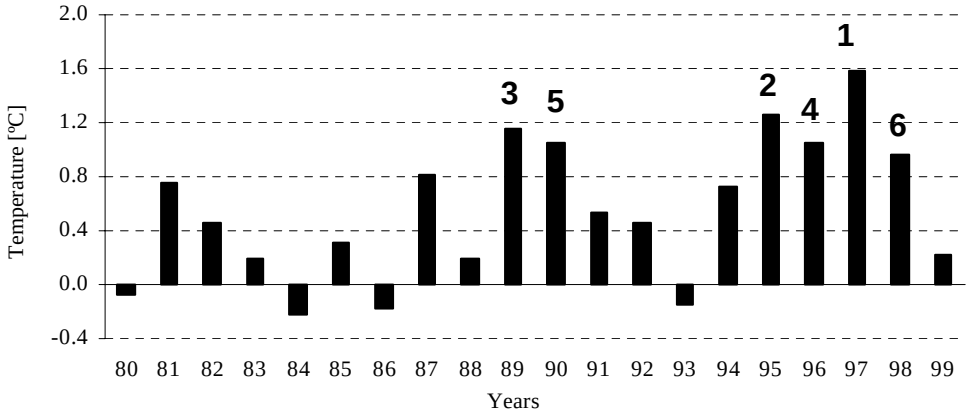
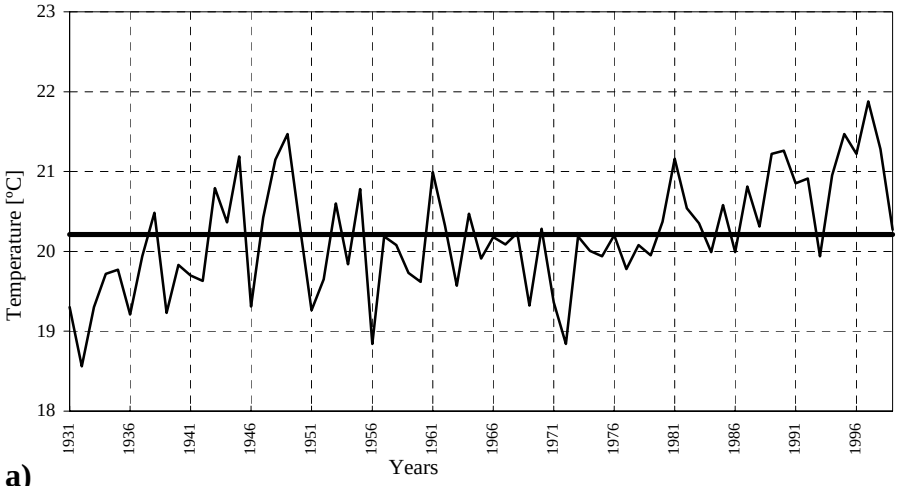


Figure 2. Mean annual temperature anomalies with respect to 1961-90 for the last 20 years.

Precipitation

The mean annual precipitation on mainland Portugal is around 900 mm, with the highest values (around 3,000 mm) in the highlands of the northwestern region, and the lowest values (around 500 mm) in the inner regions of the south. Also in this distribution, a significant difference can be seen between northern and southern Portugal.

The variability of the regional amount of annual precipitation (Figure 4) shows that in only 5 of the last 20 years, the precipitation values were above the mean for 1961-90. It can be observed that, in the last 20 years, precipitation values were abnormally below the mean between 1990 and 1994.



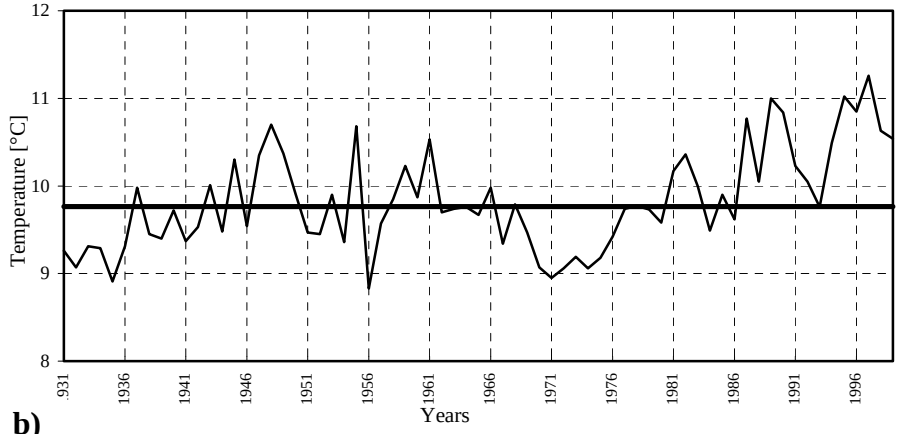


Figure 3. Variability of the regional average of the mean annual maximum (a) and minimum (b) temperatures in mainland Portugal for the period 1931-99.

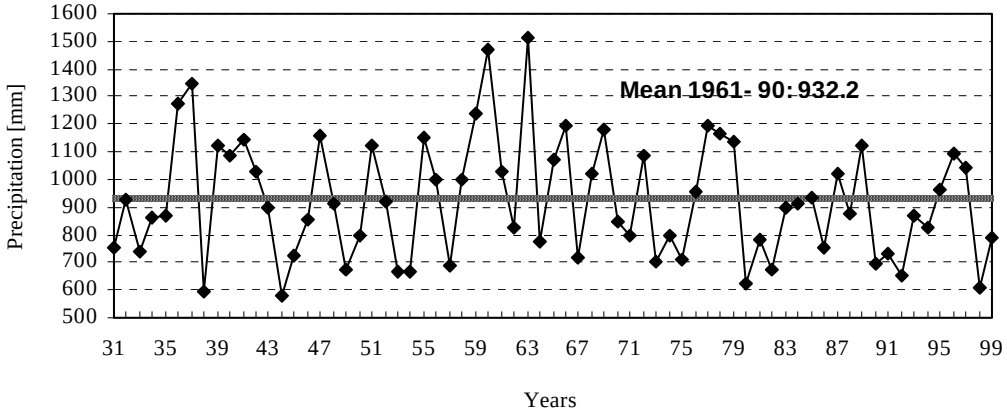


Figure 4. Variability of the regional average of annual precipitation in mainland Portugal for the period 1931–99. The mean for 1961–90 is 932.2 mm.

An analysis of Figure 5 for the period of 1931–99 shows a significant decrease in the precipitation amount in spring during the last 30 years. This decrease is essentially because of lower precipitation in March (Figure 6).

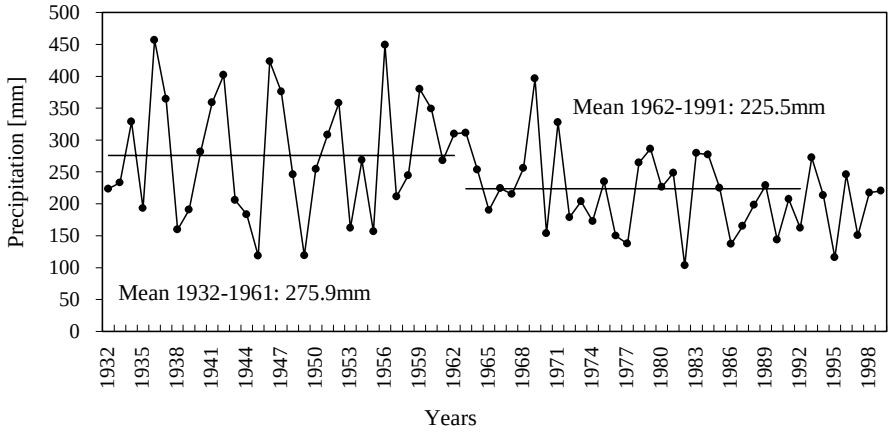


Figure 5. Variability of the regional average of annual precipitation in spring, 1932-99.

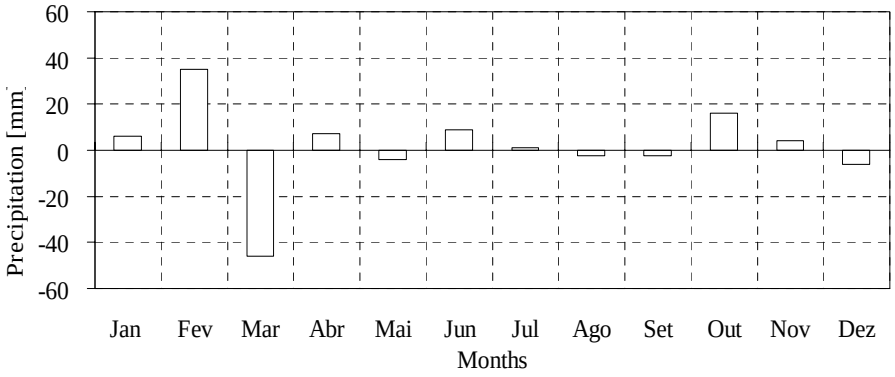


Figure 6. Variation of average monthly values for the 1961-90 period in comparison with the 1931-60 period.

Synoptic Situation

Mainland Portugal is located in the transitional region between the subpolar depression zone, which affects mainly the northern regions of the country, and the subtropical anticyclone, which affects mainly the southern regions (Figure 7). Under these conditions, it can be stated that in general there is a trend for droughts to occur more frequently in the southern part of mainland Portugal than in the north.

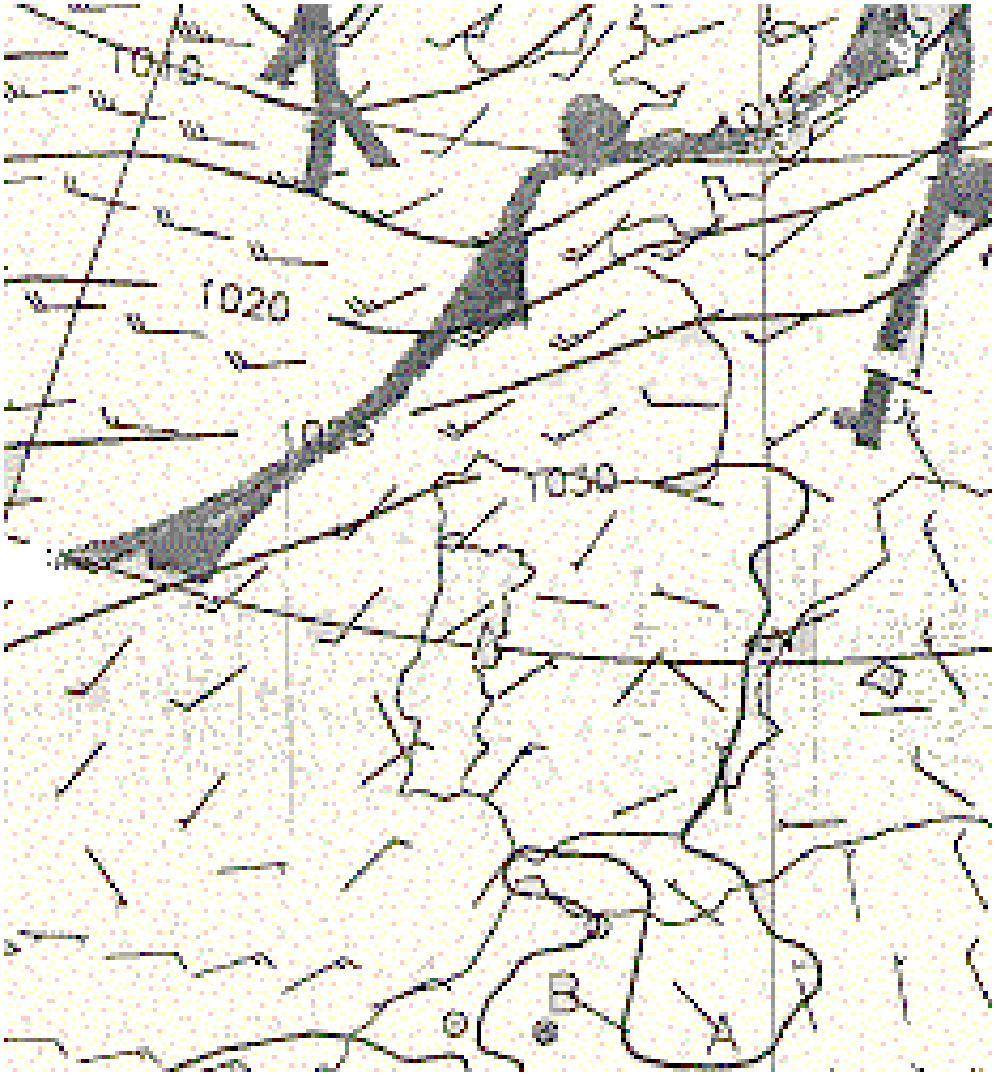


Figure 7. Synoptic conditions that frequently occur in mainland Portugal: a cold front affecting the northern regions and a ridge affecting the southern regions.

Data and Methods

The PDSI is a meteorological index that represents a range of climate conditions from "abnormally dry" to "abnormally wet" (I.C.I.D. Guide 1998). In the calculation procedure, a hydrological accounting is used, which compares the soil moisture content with the climatological mean, based on the supply-and-demand concept of the water balance equation. For the calculation of the monthly PDSI values, monthly temperature means and precipitation sums are needed. Another parameter that is needed is the available soil water capacity, which varies from region to region, depending on the characteristics of the soil.

The calculation procedure of the Palmer Drought Severity Index is well described in papers by Palmer (1965), Alley (1984), and Briffa et al. (1994). Palmer (1965) defined threshold values of PDSI for drought spells, given as follows: PDSI values between -2.0 and -3.0 refer to a moderate drought; between -3.0 and -4.0, a severe drought; and below -4.0, an extreme drought. In the case of wet spells, the range values are 2.0-3.0, 3.0-4.0, and above 4.0 for moderate, severe, and extreme wet conditions, respectively. To calculate the PDSI, historical time series of monthly temperature means and precipitation sums were used for the stations listed in Table 1. The temperature and precipitation data for the long time series from those stations were examined and showed no inhomogeneities.

Table 1. Stations of Portugal with the long time series. *The series contain values up to April 2000.

	Latitude (N)	Longitude (W)	Height (m)	Period
Oporto	41º 08'	8º 36'	93	1922–2000*
Lisbon	38º 43'	9º 09'	77	1883–2000*
Evora	38º 34'	7º 54'	309	1888–2000*
Beja	38º 01'	7º 52'	246	1901–2000*

The PDSI was also calculated for the whole country, by using monthly temperature means and rainfall amount sums measured at stations all over the country for the period 1931-99.

A statistical test was applied to the PDSI time series, with the purpose of finding changes in drought tendencies, especially in the temporal distribution through the time series. This test is based on the test used in Szinell et al. (1998), which was applied to PDSI series of Hungarian stations. It was developed to study normal and extreme climatic features through the thresholds established by Palmer (1965) for moderate, severe, and extreme droughts. The test is suitable for detecting an increase in the frequency of threshold events: if there is a trend in the occurrence, drought events will concentrate at one end of the time series (Szinell et al. 1998).

Analysis of the Results

Analysis of PDSI Values

Long Time Series

Monthly PDSI values have been calculated from 1871 (for the longest time series) to April 2000. The number of occurrences for moderate, severe, and extreme drought was obtained (Figure 8), as well as the corresponding percentage relative to the total number of months. Figure 8a shows the values for the complete time series and Figure 8b shows the values only for 1922-2000 (Oporto), allowing comparison of the 4 stations in that period. Oporto has the smallest percentage of droughts in all the categories, showing a difference in climate conditions relative to the other 3 stations.

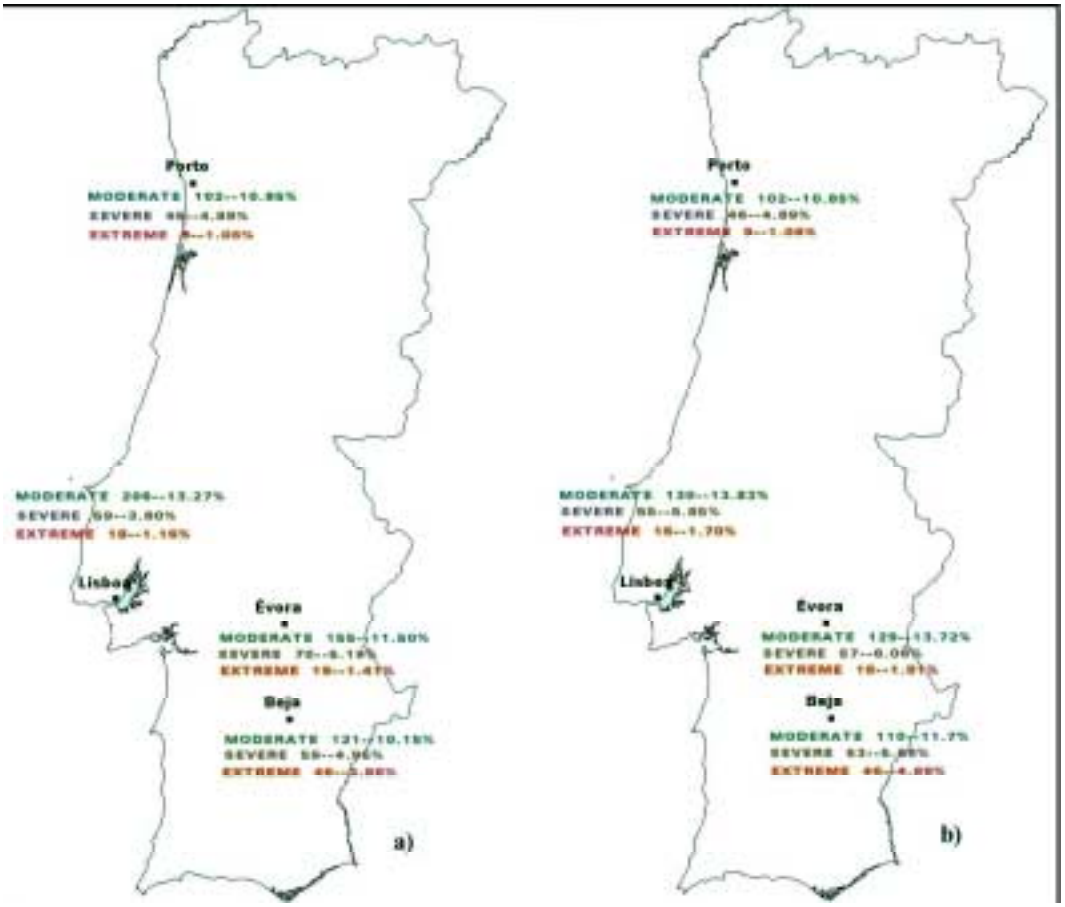


Figure 8. Number of occurrences and percentage of moderate, severe and extreme droughts in Beja, Evora, Lisbon, and Oporto (a) for the complete time series and (b) for the period of the smallest time series (Oporto 1922-2000).

Figure 9 shows the normalized cumulative PDSI for the longest time series, in which we can observe the evolution of the PDSI over the years, allowing us to detect periods of continuous drought as well as wet spells. For example, starting with Beja it can be seen that, until 1930, no long drought periods occur, only short ones, revealing a tendency for normal conditions. After 1930, cumulative PDSI values decrease considerably, indicating a long drought spell. This period continues until about 1960, only interrupted by a wet spell between 1940 and 1943 and some annual wet spells. A long period of drought can be seen in the 1930s, followed by the wet spell mentioned before. After that and until 1960, the cumulative PDSI continuously decreases, with some annual wet spells. Between 1960 and 1980, no long drought spells are observed, with a small exception in the mid 1970s. After 1980, the cumulative PDSI values continuously decrease, indicating a tendency for an increase in drought spells, but with a short duration. A drought spell of almost 3 years just after 1980 is the exception.

For the station of Lisbon in the first years, until about 1900, no long periods of drought occur and the cumulative PDSI values increase slightly, which shows a small prevalence of wet spells.

After 1901, a resemblance between the data for Beja and Lisbon can be observed. The long drought spells occur near the same years. Around 1930 the cumulative PDSI values decrease sharply, being interrupted by a long wet spell after 1940. It can also be noticed that, in Lisbon, after the strong increase in cumulative wet spells between 1960 and 1980, the trend toward a continuous decrease in cumulative PDSI values, associated with drought spells, is also present.

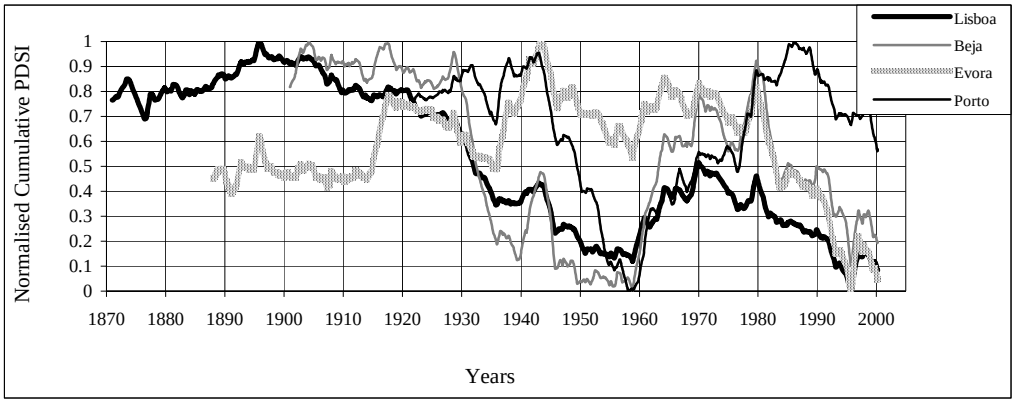


Figure 9. Normalized cumulative PDSI values for Beja, Lisbon, Evora, and Oporto.

The cumulative PDSI in Evora is different from that of Lisbon and Beja, but the main features are easily identified: a period between 1918 and 1935 where the cumulative PDSI decrease (high frequency of drought spells), followed by a wet spell, longer than in Beja and Lisbon. After 1980, a strong decrease in cumulative PDSI can be observed, with a small wet spell near the end, in the same position as in the time series for Beja and Lisbon.

The cumulative PDSI in Oporto is completely different from the other stations. A period of drought in the 1930s is followed by a wet spell and a stable period until 1944; then a long period of drought, interrupted only by small wet spells, can be observed until 1960. An inversion of the cumulative PDSI values (wet spells) lasts until the end of the 1980s, where a small increase in drought spells is registered until the end of the series.

In general, it can be seen that although some differences exist, the shape of the curves reveals the same pattern.

The Entire Country

The data series for the entire country (Figure 10) is shorter (1931-99), but some of the main features shown by the cumulative PDSI values in Lisbon, Evora, and Beja can be seen (Figure 9): the increase in cumulative PDSI values just before 1940 (wet spells) and a change in the trend in 1943 (drought spells); the increase in cumulative PDSI values around 1978 (wet spells) and a change in the trend in 1980 (drought spells); a similar annual cumulative PDSI value variation from 1980 to the end of the time series.

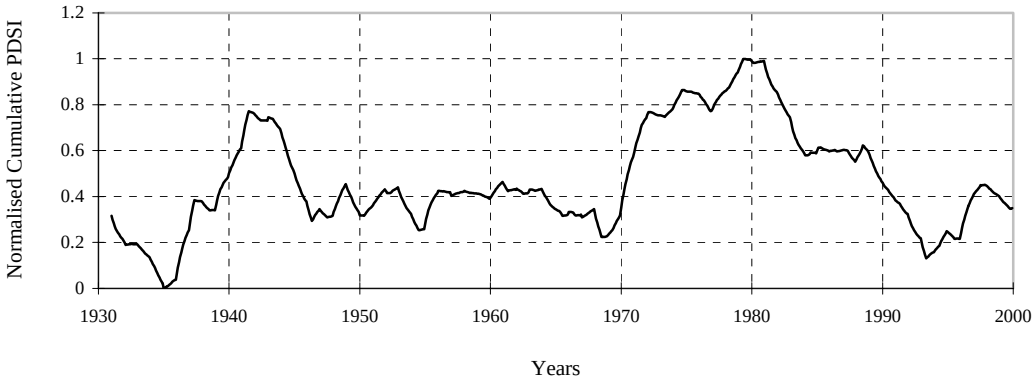


Figure 10. Cumulative PDSI values for Portugal for the period 1931-99.

Statistical Test

The statistical test is based on the Wilcoxon test (Szinell et al. 1998). It was applied to monthly PDSI series from the four stations of Portugal with the longest series and to the whole country on a monthly basis. The results are presented in Table 2, where the N column contains the number of months in which drought of that category occurred and the Test column represents the results of the statistical test.

Table 2. Results of the statistical test applied to the longest time series for four stations in Portugal and to a time series for the whole country.

	Moderate		Severe		Extreme	
	N	Test	N	Test	N	Test
Oporto	175	0.803	57	0.889	9	1.118
Lisbon	283	2.842	77	6.316	18	2.497
Evora	244	6.968	89	5.287	19	4.024
Beja	229	3.037	105	3.929	46	4.586

The statistical test implemented by Szinell et al. (1998) indicates whether the occurrence of drought in the given category tends to concentrate at the beginning or the end of the time series. Positive numbers correspond to a greater frequency in later years; a greater value (positive) means a larger number of drought spell occurrences near the end of the time series. Tests made for different periods of the PDSI series in which the drought trends were different confirmed these results.

In evaluating the tendencies of moderate, severe, and extreme droughts in the four stations, it can be observed that in Beja, Evora, and Lisbon, the results indicate that, generally, in some of the categories the droughts occurred more frequently just near the end of the time series. In Oporto, a station in northern Portugal, where drought does not occur as frequently as in the south (Figure 8), no well-defined tendency can be observed in moderate and severe droughts.

In Beja it can be seen that, although only extreme drought occurred more frequently in the second part of the series, there is also a trend for moderate and severe droughts to occur near the end of the series rather than at the beginning.

These statistics for extreme droughts are significant at the 1% level (Mann-Kendall test), except in Oporto, where the limited number of extreme droughts provides little information.

Figure 11 shows the percentage of monthly cumulative PDSI values below the three categories of drought for Beja, Lisbon, Evora, and Oporto. This figure shows the evolution of the PDSI for the different drought categories over the years. On this percentage scale, we can detect periods where the different categories of drought were more intense and periods were no droughts have occurred. In Beja (Figure 11a), 50% of the extreme droughts occur after 1980 (i.e., in the last 20 years of the 100-year series). For moderate and severe droughts, only about 10% of the occurrences were recorded in the first 20 years, while more than 20% occurred in the last 20 years. The long period of droughts in the intermediate region of the series (1930s and 1940s) does not allow us to conclude whether this is abnormal behavior for moderate and severe droughts. However, in the case of extreme droughts, it can be concluded that there is a trend for droughts to be more severe.

In Lisbon (Figure 11b), moderate drought events do not appear to show any special trend over the whole time series, except for a small increase in the 1930s and 1940s. The distribution of the drought events in both halves of the series is approximately equal, causing the test to provide a small value. In the 1930s and 1940s, a sudden increase in severe and extreme droughts was also detected. After a period of more than 30 years, between 1945 and 1978, with almost no severe and extreme drought events, a sudden increase in these events was detected in the last 20 years of the 130-year series, causing the test to provide high values. At the end of the time series, the increase in the drought trend is thus mainly due to severe and extreme droughts.

In Evora (Figure 11c) for all the drought categories, the 50% threshold is achieved in the second part of the time series, with special evidence of an increase in severe and extreme drought.

In Oporto (Figure 11d) for all the drought categories, two distinct periods can be observed: the first half of the time series contains a large percentage of droughts, and the last 10 years show a strong increase in severe and extreme droughts, balancing the test values and causing the test to provide small positive values. However, for extreme drought, the result provides little information, because there is a limited number (9) of droughts in that category.

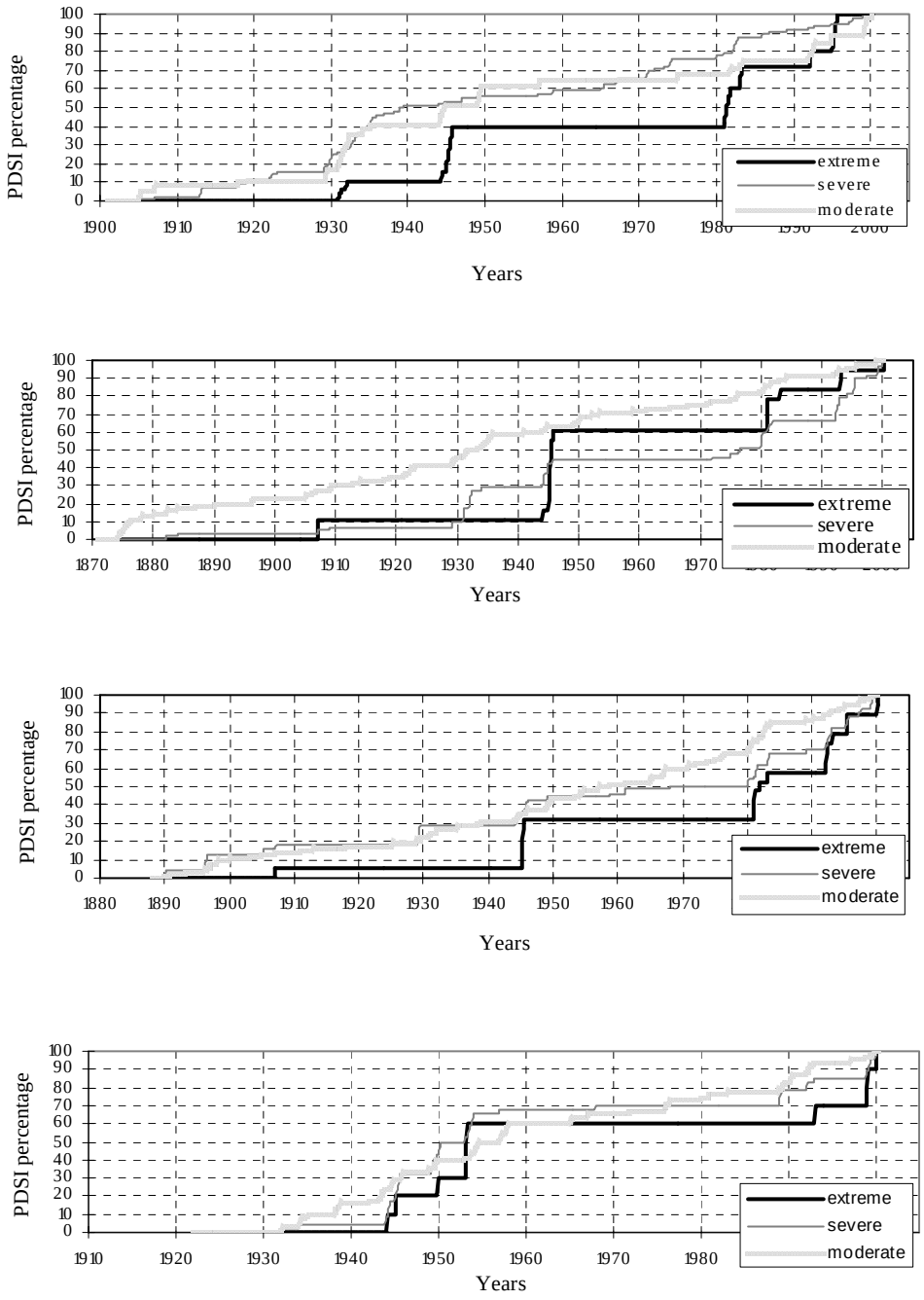


Figure 11. Cumulative percentage of PDSI values for moderate, severe, and extreme droughts: (a) Beja; (b) Lisbon; (c) Evora; (d) Oporto.

Conclusions

This chapter presents an analysis of the PDSI values for the longest time series of some stations in mainland Portugal as well as for the entire country. A statistical test was applied to the PDSI values to characterize the different categories of drought severity (moderate, severe, and extreme). This allows us to identify a trend in the frequency of those different categories along the time series. Of all the drought spells that occurred in Portugal, the percentage of those recorded in Oporto (northern Portugal) was lower than the percentages in Lisbon, Beja, and Evora (southern Portugal).

In the longest time series (without Oporto), two different periods of high occurrence of drought spells are detected: the 1930s and 1940s, and the last 20-year period. The statistical test shows an increase in severe and extreme drought spells at the end of the time series (the last 20 years), indicating that there is a trend for droughts to become more severe in Beja, Lisbon, and Evora. In Oporto, the droughts become more severe only in the last 10 years. For the analysis of mainland Portugal, the time series is shorter (1931-99), and the two different periods of high occurrence of drought spells mentioned above were also detected.

A larger number of stations covering the entire country by administrative regions must be analyzed using the PDSI series as well as other indexes, in order to confirm the different climate conditions in the various Portuguese regions, namely the difference between northern and southern Portugal, and also to confirm that in the last two decades there is a trend toward the occurrence of severe drought spells.

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