Drought characterization using drought indices in two areas of the Mediterranean basin: Meknès, Morocco, and Córdoba, Spain

A. Aghrab*, R. Bouabid and A. Chafai Elalaoui****
*Fellah Conseil/Pack Info, N 6 imm. Moussaoui, Bd. Prince Héritier,
80 150 Ait Melloul, Agadir, Morocco
**Ecole Nationale d'Agriculture de Meknès, BP S 40, Meknès, Morocco

SUMMARY – In this paper, drought events were characterized using drought indices in two zones: Meknès, Morocco, and Córdoba, Spain. The Standard deviation method was used to determine drought thresholds on an annual basis, while the deciles method was used to identify the seasonal drought thresholds at the season level (monthly and 10-days periods). The standard deviation method was enabled to determine drought severity classes for the percent-to-normal index, the rainfall deficit index, the climatic deficit index and the standardized precipitation index. A yearly classification was also determined based on drought occurrence in relation to crop growth stage of the main rain-fed crops in Morocco and Spain namely cereal and olive.

Key words: Drought, early warning, drought indices, drought severity, drought position.

***RESUME –** "Caractérisation de la sécheresse en utilisant les indices de sécheresse dans deux zones du bassin méditerranéen : Meknès, Maroc, et Cordoue, Espagne". Dans cet article, les épisodes de sécheresse ont été caractérisés en utilisant les indices de sécheresse au niveau de deux zones : Meknès, Maroc et Cordoue, Espagne. A l'échelle annuelle, les seuils indiquant la sécheresse ont été déterminés par la méthode du nombre d'écarts-types, alors qu'à l'échelle saisonnière, mensuelle et décadaire, les seuils ont été déterminés par la méthode des déciles. La méthode du nombre d'écarts-types a permis de déterminer les classes de sévérité de la sécheresse par rapport à la normale, l'indice de déficit pluviométrique, l'indice de déficit climatique et l'indice de précipitations standardisé. Une classification des années selon la position de la sécheresse par rapport au cycle de développement a été également élaborée pour les principales cultures de l'agriculture pluviale au Maroc et en Espagne, à savoir les céréales et l'olivier.*

***Mots-clés :** Sécheresse, système d'alerte précoce, indices de sécheresse, sévérité de la sécheresse, position de la sécheresse.*

Introduction

Drought is an inherent characteristic of climates and occurs in all regions of the world. It is the consequence of a natural reduction in the amount of precipitation received over a period of time in relation to the normal. There are many types of drought: meteorological, agricultural, hydrological and socioeconomic drought. The economic, social and environmental impacts of drought depend not only on the duration, intensity and spatial extent, but also on the vulnerability of the society to the event. The biophysical and societal factors that define agricultural drought vulnerability are mainly climate, soil, land use and access to irrigation (Wilhelmi and Wilhite, 2002). The mitigation of the impacts of drought requires the use of all components of the drought management: risk management and crisis management. A drought management plan contains three components: monitoring and early warning system, risk assessment, and mitigation and response (Wilhite and Svoboda, 2000).

The drought monitoring or the early warning system is a system of data collection that gives timely and reliable information, that aids decision makers at all levels in making critical management decision and reduce the impacts of drought. The onset and the end of drought are difficult to determine and drought is related to timing, rainfall intensity, duration and spatial extent. A drought index or a drought indicator value is typically a single number, far more useful than raw data, for decision making (Hayes, 1998). Therefore, the drought indices are used to determine the thresholds, the severity, the duration, the position, the probability of occurrence, and the spatial extent of drought episodes. Different types of drought require different drought indicators. Some indicators are more suited to monitor agricultural drought, others to assess hydrological or meteorological drought. The assessment of socioeconomic drought requires socioeconomic and nutrition-based indicators (De Pauw, 2000). However, an integrated systems for drought management, like "the drought monitor" developed in USA, allows to reunite several drought indices of different types of drought in a unique map showing the areas suffering more from drought severity.

This paper presents the methodology and results of the study that we conducted in Morocco and in Spain to characterize drought on a long time series by using several drought indices. To address drought timing, the growth cycle, cereals and olives were used as the tow main rain-fed crops in Morocco y Spain.

Data and methods

Location of the study area

Meknès in Morocco and Córdoba in Spain are both situated continental Mediterranean regions. Meknès is located on the Saiss Plateau at an altitude of about 500 m and is characterized by a semi-arid climate. Córdoba is located in the Andalusia region on the Campiña plain (123 m altitude) south of the Sierra Morena Mountains and lies in a sub-humid to semi-arid climate. Both Meknès and Córdoba are considered good agricultural regions and have been subject to recurrent droughts in the last decades.

Data used

Climatic data of temperature, precipitation and potential evapo-transpiracion (ET_0) for 23 years (from 1983-1984 to 2005-2006) were collected for both study sites. For the Meknès station, we estimate the ET_0 from maximal and minimal temperature using the Blany-Criddle method, while for Córdoba, ET_0 was measured.

Determination of the drought thresholds

To choose the adequate method to determine the drought thresholds, a normality test of Shapiro-Wilk was conducted. If the distribution is normal, then the standard deviation number method is used. Otherwise, the deciles method was considered more appropriate.

The standard deviation number method

This method classify the years in seven classes following Table 1.

Table 1. Climatic classification following the standard deviation number method (Aghrab, 2005)

Classes	Limits[†]
Extremely dry	$P_i<p_m-2\sigma$
Severely dry	$P_m-2\sigma<P_i<P_m-\sigma$
Moderately dry	$P_m-\sigma<P_i<L_i$
Normal	$L_i<P_i<L_s$
Moderately wet	$L_s<P_i<P_m+\sigma$
Very wet	$P_m+\sigma<P_i<P_m+2\sigma$
Extremely wet	$P_i>P_m+2\sigma$

[†]P_i: actual precipitation (mm); P_m: mean precipitation (mm); σ: standard deviation; L_i: lower limit of the confidence interval for an error risk of 5%; L_s: higher limit of the confidence interval for an error risk of 5%.

The deciles method

The deciles method group the month, the season and the decade in five classes (Table 2).

Table 2. Climatic classification following the deciles method (Hayes, 1998)

Classes	Limits†
Severely dry	$P_i<d_2$
Moderately dry	$d_2<P_i<d_4$
Normal	$d_4<P_i<d_6$
Moderately wet	$d_6<P_i<d_8$
Very wet	$P_i>d_8$

†P_i: actual precipitation (mm); d_i: deciles.

Determination of the thresholds index

We have determined the drought classification for many drought indices using the standard deviation number method. These indices are explained in Table 3.

Table 3. The mathematic expression for various drought indices

Index	Expression	Legend
The percent to normal index (PNI)	$PNI = (P_i / P_m) * 100$	P_i: Actual precipitation (mm) P_m: Mean normal precipitation (mm)
The rainfall deficit index (RDI)	$RDI = [(Pi – Pm) / Pm] * 100$	P_i: Actual precipitation (mm) P_m: Mean precipitation (mm)
The climatic deficit index (CDI)	$CDI = [(Pi – ET0) / ET0] * 100$	P_i: Actual precipitation (mm) ET_0: Potential evapo-transpiracion (mm)
The standardized precipitation index (SPI)	$SPI = (Pi-Pm) / \sigma$	P_i: Actual precipitation (mm) P_m: Mean precipitation (mm) σ: Standard deviation

The drought position

Drought position consists on establishing a yearly classification following the drought timing in relation to crop growth stage for the two crops considered, cereal and olive. The probability of every class was determined thereafter.

For the cereal, tree seasons were considered (Yacoubi *et al.*, 1998):

(i) Season 1 – onset cycle (October, November and December).

(ii) Season 2 – vegetative growth (January and February).

(iii) Season 3 – reproduction cycle (Mars, April and May).

For the olive, four seasons were considered (Aghrab, 2007):

(i) Season 1 – hibernal rest (January and February).

(ii) Season 2 – vegetative growth, flowering and fecundation (Mars, April, May and June).

(iii) Season 3 – pit toughening (July and August).

(iv) Season 4 – fruit growth and maturation (September, October, November and December).

Results and discussion

Determination of the drought thresholds

Table 4 shows the class limits according to the standard deviation method. The values show that a year is considered as dry when the rainfall is less than 395 mm and 515 mm, respectively for Meknès and Córdoba regions. The data also shows that the threshold for Meknès is about 120 mm lesser than that of Córdoba, and this indicates that the vulnerability to drought will be more sensed in Meknès than in Córdoba for the same class.

Table 4. Limits of the different climatic class in the tow zones

Class	Meknès	Córdoba
Extremely wet	>684 mm	>958 mm
Very wet	565<P<684 mm	776<P<958 mm
Moderately wet	497<P<565 mm	673<P<776 mm
Normal	395<P<497 mm	515<P<673 mm
Moderately dry	328<P<395 mm	412<P<515 mm
Severely dry	209<P<328 mm	230<P<412 mm
Extremely dry	P<209 mm	P<230 mm

In general, the probability of occurrence of extreme events, either dry or wet, is inferior to the moderated and normal classes. The only exception is observed in Meknès where the probability of occurrence of the "Severely dry" class (26%) is greater than that of the "Moderately dry" class (13%). This shows that the zone of Meknès has known more severely dry years that the zone of Córdoba during the studied period.

In the case of the PNI and the RDI, climatic classes, established flowing the standard deviation method, are different from one zone to another, and do not show a significant difference. However, the difference is more marked between classifications of both zones according to the CDI. This difference can be attributed to the possible over-estimation of the ET0 in Meknès by the Blany-Criddle method. Therefore, the drought threshold following the percent-to-normal index (PNI) is 88% in Meknès and 87% in Córdoba. On the other hand, the drought threshold following rainfall deficit index is -12% in Meknès and -13% in Córdoba. Again, the drought threshold following according a the climatic deficit index is -75% and -58% in Córdoba. However, in the case of the SPI, the established classification is identical for both zones (Table 5).

Table 5. Climatic classification according to the SPI

Class	SPI
Extremely wet	>2
Very wet	2 – 1
Moderately wet	1 – 0.43
Normal	0.43 – -0.43
Moderately dry	-0.43 – -1
Severely dry	-1 – -2
Extremely dry	<-2

The deciles method has permitted to classify decades and months in 5 classes: very wet, moderately wet, normal, moderately dry and severely dry. Every class has the similar probability, such as 20%. For example, the drought threshold of February is 38 mm in Meknès and 38.2 mm in Córdoba. On the other hand, the drought threshold of the second decade of mars is 5 mm in Meknès and 7.1 mm in Córdoba.

The drought position

Both in Meknès as well as in Córdoba, we can notice differences in dry years in term of the position of the drought period with respect to growth cycle of cereal and olives. Moreover, year classes with one dry season and those with all seasons dry are less frequent in comparison with years with two dry seasons in the case of cereals and two or three dry seasons in the case of olives. Indeed, in the case of cereals, classes that are characterized by a single dry season present only about 22% in the region of Meknès and 37% in the region of Córdoba. Only one year has been dry for all seasons, 1994-1995 in Meknès and 2004-2005 in Córdoba. In the case of olives, the studied period has not recorded any year with a single dry season in both regions. The only year that has been dry for all seasons is 88-89 in Córdoba.

The data also shows also that most dry years are characterized by an early dry season. In the case of cereals, 67% and 50% of the years studied have a drought period in beginning of the growth cycle, respectively in Meknès and Córdoba. For olives, dry years with a dry season at beginning of the growth cycle presents respectively 67% and 88% in Meknès and Córdoba. Therefore, an early season drought can be considered as an alert indicator for the recurrence of drought in the rest of the year.

Conclusion

The Standard deviation method and the deciles method are considered good methods to determine the thresholds of different climatic classes. The deciles method presents the advantage of not requiring normality of the data distribution, which allows its use at different time scales. The standard deviation method has permitted to establish a climatic classification for the percent-to-normal index, the rainfall deficit index, the climatic deficit index and the standardized precipitation index. In the case of the percent-to-normal index and the rainfall deficit, the established classification does not show significant differences; however, the difference is quite evident in the case of the climatic deficit index, probably due to a possible over-estimation of the ET_0 by the Blany-Criddle method in the case of Meknès. Nevertheless, the classification based on the standardized precipitation index (SPI) is identical for both zones, indicating that this index in a better tool for comparison between different regions. The results showed that the last two decades have known many dry years. The probability of occurrence decreases with increasing severity, with the exception in the region of Meknès for moderate and severe dry year classes. The early season drought is an indicator for the recurrence of drought in late season, as most dry years have shown this tendency. All drought indices have shown good applicability to assess drought threshold, severity, duration, probability of occurrence and position in relation to crop growth stage. The SPI classification is a good tool for comparing drought severity among different regions.

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