Chapter 6
Drought Characterisation in the Mediterranean

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Abstract Drought identification and characterisation is a complicated task, because drought is a complex natural phenomenon difficult to detect. Several methodologies have been proposed for drought characterisation, based either on the consequences or on specially devised indices. This chapter focuses on the critical presentation of some of the most popular drought indices. Duration and spatial extent of drought are also dimensions that are analysed.

Introduction

Drought is a complex natural phenomenon, which, from a hydrological perspective, is characterised by a significant decrease of water availability during a significant period of time and over a large area.

Identification, quantification and monitoring of drought phenomena are difficult tasks, since these phenomena are very complex and cannot be detected directly at the time they occur.

Several methodologies have been proposed for drought assessment. The major categories of these methodologies are the following:

(a) Methodologies based on indications of consequences
(b) Methodologies based on indices, which are special combinations of meteorological, hydrological or other indicators.

The first category is more comprehensive for the analysis of historical droughts; however, it fails to identify and monitor drought episodes in real time. Therefore,

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although this category of methodologies is generally useful, it cannot practically assist the decision makers to face developing drought events.

The second category of methodologies for drought assessment involves several drought indices. It is customary to characterise drought as meteorological, hydrological, agricultural, socio-economic etc. Although this type of categorisation has been widely accepted by the scientific community, the authors support the idea that drought is a unique natural phenomenon, the impact of which affects various sectors and systems. Therefore, what is different is not the type of drought but the sectors that are affected and used for its quantification.

Drought indices provide representations of historical droughts and therefore place current conditions in historical perspective. They are valuable for planning purposes as well as for providing decision makers with a representative value of negative deviation from normal conditions of water availability.

A key issue, when drought indices are used, is the establishment of the thresholds representing the boundaries of the severity classes. Unfortunately, these thresholds cannot be the same for all the cases studied, since they are dependent on the location and the system, which is analysed. Therefore, if a drought index is used for decisions during a drought episode, the thresholds should somehow be associated with the affected area and the affected system. To overcome this drawback, the drought index should be accompanied by a vulnerability and risk analysis based on the assessment of historical drought events and the recorded consequences.

In any case, drought indices are useful tools for planning and management especially in the arid and semi-arid zones. They can also be used as the basis for monitoring and early warning systems, provided they will be used with care.

A comprehensive characterisation of a drought event affecting a certain system, from a water resources management point of view, is comprised of the following determinants:

1. Temporal dimension including the onset and termination of drought (timing and duration of drought)
2. Severity dimension, measured by drought indices
3. Spatial dimension estimated by the territorial area affected by the drought event.

This chapter addresses all these dimensions. However, the emphasis is given on the severity issue and the drought indices, which are used for its estimation.

No special reference is made on the various satellite-derived indices, since they come from a very different background. They are based on the monitoring of vegetation changes and interpretation of the impacts of climatic events on the biosphere. Comprehensive reviews on satellite-derived drought indices may be found in other specialised publications (e.g. Justice et al., 1989, Franklin and Hiernaux, 1991, Vogt et al., 2000, Kühbauch and Rademacher, 2000, Tsiros et al., 2004).

Basic Notions

Indices Attributes

For the selection of indices, which are most appropriate for estimating the severity of drought, a number of items could be examined. The most important of these items are:

- Simplicity (to be easily used and understood by the stakeholders)
- Rationality (scientifically sound, physically meaningful)
- Sensitivity (wide range of values)
- Timely response (short lag time)
- Transferability (appropriate for use in other areas)
- Data availability (including long time series and good quality data)
- Cost effectiveness (low cost for procuring the data needed)

As it can be easily understood, some of the above items are conflicting with each other. This means that if an index requires many determinants and is scientifically sound, it may not be acceptable for use, due to the lack of the required data or to the long lag time needed for recording the drought event. Needless to say, that some of the indices are better for the analysis of historical droughts, whereas others are preferred for monitoring purposes.

Before the critical presentation of some widely used or promising indices, it would be wise to discuss three important issues for the use of drought indices. These are the "normal conditions", the time step of the required data, the reference period and the territorial unit for drought analysis.

Normal Conditions

Since drought has been postulated as the deficient deviation from the normal conditions, it is necessary to clarify what is meant by *normal conditions*. Some researchers use a general level, which corresponds to the level for fulfilling certain consumption. Most of the researchers however use the mean figures of meteorological or hydrological parameters to establish the normal conditions. If, for instance, the precipitation is the key parameter to measure annual drought, the arithmetic mean of annual precipitation based on a significant number of years is the level taken as the basis for calculating the deviations.

From results of various studies, it can be inferred that the *median* instead of the arithmetic mean can represent the normal conditions in an area more reliably. This is mainly because extreme values of fatal outliers do not influence the median as they influence the arithmetic mean. The same happens when new data are added to the existing series of data, that is the median is not easily affected.

In conclusion, in several cases, the arithmetic mean could be replaced by the median for establishing the normal conditions mainly for large reference periods.

A simplifying assumption for determining the normal conditions is that of "stationarity". However, this assumption should be examined before establishing the level of normal conditions. Care should also be taken for establishing seasonal normal conditions due to seasonality effects.

Time Step and Reference Period

The data required for drought assessment are usually monthly data. No smaller time step has any significant effect when drought is assessed by drought indices. Only in some very specialised indices related to crucial water deficit aspects, could a smaller time step possibly be used.

Therefore, for the purpose of establishing drought-monitoring networks, monthly values of the key meteorological/hydrological parameters are required.

Further regarding the *reference period* for drought assessment, it seems wise to consider long periods of time, including a significant number of months. If a short reference period is selected, many complications will be encountered related to carry-over quantity of water from period to period. Furthermore, lag time in hydrological processes makes any kind of drought assessment unreliable if a short reference period is adopted.

Based on these thoughts, the task of assessing droughts using general indices can be more efficiently implemented, if the reference period is an entire season or an entire year.

Spatial Integration

It is generally accepted that drought is characterised by its spatial coverage. However, meteorological information is collected from selected stations, which can be considered as representing the area attributed to them (e.g. by Thiessen polygons). The spatial integration is based on these areas/polygons. Polygons under drought are aggregated to estimate the total area affected by drought.

However, this approach disregards the hydrological processes, which are based on the hydrological basin scale.

It could be proposed that drought analysis is applied to the basin or sub-basin as the spatial unit, after transferring the data from the existing stations on the average basin scale. There might be cases in which one station can represent an entire basin or a sub-basin sufficiently and in this case, calculations for drought indices can be performed directly.

In case of assessment of drought at a basin scale the "interpolate – calculate" method could be also used. By this method, all principal data (e.g. precipitation, temperature, etc) are transferred to the squares in which the basin is divided. The weighted average is used to calculate the representative meteorological data of the entire basin and then the drought indices are calculated. The opposite procedure, by which the drought indices are calculated at the locations of the meteorological stations and then transferred to the basin scale, should be avoided, mainly due to the "non-linearity" problems related to this transformation.

The approach above seems to give significant opportunities for relating meteorological drought to hydrological drought and also it will lead to a more efficient linkage between meteorological drought indices and the anticipated damage in the various sectors of the economy.

Apart from the approach suggested above, in a number of cases (e.g. very big river basins) it could also be possible to calculate severity indices on sub-areas corresponding directly to the existing meteorological stations. By this technique, isolines of the selected indices could be constructed, which show the spatial variability of the drought severity.

Selected Drought Indices

From the numerous drought indices developed, some have been selected for review, whereas only three are briefly presented below. These indices (of general meteorological type) are the Deciles, the Standardised Precipitation Index, and the new promising Reconnaissance Drought Index.

Deciles

A simple meteorological index is the rainfall deciles (Gibbs and Maher, 1967), in which the precipitation totals for the preceding three months are ranked against climatologic records. If the sum falls within the lowest decile of the historical distribution of 3-month totals, then the region is considered to be under drought conditions (Kinninmonth et al., 2000). The drought ends when a) the precipitation measured during the past month already places the 3-month total in or above the fourth decile, or b) the precipitation total for the past three months is in or above the eighth decile.

The first decile is the precipitation amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classes. Table 6.1 presents the classes of drought conditions according to deciles.

The advantage of the decile approach is its computational ease, but its simplicity can lead to conceptual difficulties. For example, it is reasonable for a drought to terminate when observed rainfall is close to or above normal conditions. But minor amounts of precipitation during periods in which little or no precipitation usually falls, can activate the first stopping rule, even though the amount of precipitation is trivial and does not terminate the water deficit. A supplemental third rule, that considers the total precipitation since the beginning of drought, may be used (Keyantash and Dracup, 2002). According to this rule, if the total precipitation exceeds the first decile for all drought months, then the meteorological drought may be considered terminated.

Table 6.1 Classification of drought conditions according to deciles

Decile classes	
deciles 1–2: lowest 20%	much below normal
deciles 3–4: next lowest 20%	below normal
deciles 5–6: middle 20%	near normal
deciles 7–8: next highest 20%	above normal
deciles 9–10: highest 20%	much above normal

Standardised Precipitation Index

The Standardised Precipitation Index (SPI) was developed for the purpose of defining and monitoring drought (McKee et al., 1993).

The SPI calculation for any location is based on a series of accumulated precipitation for a fixed time scale of interest (i.e. 1, 3, 6, 9, 12, ... months). Such a series is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than mean precipitation, and negative values indicate less than mean precipitation. Because the SPI is normalised, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the SPI.

The Gamma probability distribution is used for representing cumulative precipitation time series, which are needed for the SPI calculation. However, since the gamma probability function cannot incorporate zeros, a composite probability function *H(x)* is proposed (Eq. 6.1):

$$H(x) = q + (1 - q)\,G\,(x) \tag{6.1}$$

where q is the probability of a zero and *G(x)* the cumulative probability of the gamma distribution. The composite probability *H(x)* is then transformed to the standard normal probability through the random variable z with mean zero and variance one, which is the value of the SPI. Once standardised, the strength of the anomaly is classified as set out in Table 6.2. This table also contains the corresponding probabilities of occurrence of each severity arising naturally from the normal probability density function. Thus, at a given location for an individual month, at least moderate droughts (SPI ≤ –1) have an occurrence probability of 15.9%, whereas extreme droughts (SPI ≤ –2) have an event probability of 2.3%. Extreme values in the SPI will occur, by definition, with the same frequency at all locations.

Table 6.2 Drought classification by SPI value and corresponding event probabilities

SPI value	Category	Probability (%)
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
0 to 0.99	Mildly wet	34.1
0 to −0.99	Mild drought	34.1
−1.00 to −1.49	Moderate drought	9.2
−1.50 to −1.99	Severe drought	4.4
−2 or less	Extreme drought	2.3

The SPI can track drought on multiple time-scales. The U.S. National Drought Mitigation Center (NDMC) computes the SPI with five running time intervals, i.e. 1-, 3-, 6-, 9-, and 12-months. This can provide an overwhelming amount of information (sometimes confusing), unless researchers have a clear idea of the desired intervals. Moreover, being a standardised index, the SPI is particularly suited to compare drought conditions among different time periods.

The method of calculation includes the following steps:

1. Data preparation. Computation of a time series of cumulative precipitation for a fixed time scale. At least 30 years of data are highly recommended.
2. Determination of a probability frequency distribution that statistically fits the time series of precipitation data.
3. Calculation of the non-exceedence probabilities related to the cumulative values.
4. Derivation of the corresponding normal standard quantiles, which represent the SPI values.

Reconnaissance Drought Index (RDI)

The "Reconnaissance Drought Index – RDI" is based on the ratio between two aggregated quantities of precipitation and potential evapotranspiration (Tsakiris and Vangelis, 2005, Tsakiris et al., 2007a). The initial value of the index for a certain period, from the beginning of the hydrological year up to the k-month, is calculated by the following equation:

$$\alpha_k = \frac{\sum\limits_{j=1}^{j=k} P_j}{\sum\limits_{j=1}^{j=k} PET_j} \tag{6.2}$$

in which P_j and PET_j are the precipitation and potential evapotranspiration of the j-th month of the hydrological year respectively. The hydrological year for the Mediterranean region starts in October, hence for October k = 1.

Equation. 6.2 may be calculated for any period of the year. It can be also written starting from any month of the year different from October if necessary (Tsakiris et al., 2007b).

For real world applications if a_k is calculated as a general index of meteorological drought it is advisable to use periods of 3, 6, 9 and 12 months. In cases where a 12-month period is selected, the result could be directly compared with the Aridity Index produced for the area under study. If a_{12} for a certain year is lower than Aridity Index calculated according to UNEP (1992) then the area is suffering from drought during this year.

Two additional expressions of the Reconnaissance Drought Index are the Normalised RDI and the Standardised RDI:

The Normalised RDI (RDI_n), which represents the deviation from the normal conditions, is computed as follows:

$$RDI_n(k) = \frac{\alpha_k}{\overline{\alpha}_k} - 1 \tag{6.3}$$

in which $\overline{\alpha}_k$ is the arithmetic mean of a_ks for a number of years.

Finally, the Standardised RDI (RDI_{st}) is computed following a similar procedure to the one that is used for the calculation of SPI:

$$RDI_{st}(k) = \frac{y_k - \overline{y}_k}{\hat{\sigma}_k} \tag{6.4}$$

in which y_k is the $\ln a_k$, $\bar{y}_k$ is its arithmetic mean and $\hat{\sigma}_k$ is its standard deviation.

Regarding Eq. 6.4 the standardisation is achieved by assuming that a_k follows a lognormal distribution. This assumption was tested using data from a variety of stations in Greece. Although the choice of lognormal distribution is not constraining, it does assist in devising a unique procedure for assessing drought severity. The gamma distribution may also be used instead.

The Standardised RDI (RDI_{st}), behaves in a generally similar way to the SPI and therefore the interpretation of the results is similar since the same thresholds as SPI can be used.

Other Drought Indices

Apart from the general indices that were presented so far, it is also worth presenting concisely some specific indices that are quite widely used. These indices are used for agricultural, economic, industrial, tourist and recreational uses.

The *Palmer Drought Severity Index (PDSI)* was introduced by Palmer (1965) for the assessment of the meteorological drought. Although, PDSI is referred to as an index of meteorological drought, however, the procedure considers precipitation, evapotranspiration, and soil moisture conditions, which are determinants of hydrological drought, i.e. the period during which the actual water supply is less than the minimum water supply necessary for normal operations in a particular region.

The *Palmer Hydrological Drought Severity Index (PHDI)* has a similar behaviour to PDSI. The distinction between PHDI and PDSI is that the PHDI has a more stringent criterion for the elimination of the drought or wet spell, which results in the index rebounding gradually and more slowly than the PDSI towards the normal state. It should be mentioned that PDSI can be computed only when the drought event finished, i.e. only on past series, while PHDI can be computed in the current time interval (Alley, 1984).

The *Bhalme – Mooley Drought Index (BMDI)* (Bhalme and Mooley, 1980) provides a good measure of the current status of drought that is the effect of short periods of dry weather. It is an easy index to calculate, since it does not involve terms such as evapotranspiration or soil water capacity, which are parameters especially difficult to estimate and it is based only on monthly precipitation.

The *Rainfall Anomaly Index (RAI)* was developed by Van Rooy (1965) to incorporate a ranking procedure to assign magnitudes to positive and negative precipitation anomalies.

A traditional assessment of hydrological drought is the *Total Water Deficit*, which is synonymous with drought severity S. This severity is the product of the duration D, during which observed flows are consistently below some truncation level, and magnitude M, which is the average departure of streamflow from the truncation level during the drought period (Dracup et al., 1980).

This method basically coincides with the *Run Method*, which can also be applied to streamflow.

The *Surface Water Supply Index (SWSI)*, developed by Shafer and Dezman (1982), explicitly accounts for snowpack and its delayed runoff. The SWSI is a suitable measure of hydrological drought for mountainous regions, where snow contributes significantly to the annual streamflow.

Palmer (1968) developed the *Crop Moisture Index (CMI)* to monitor short-term changes in moisture conditions affecting crops. The CMI is the sum of an evapotranspiration deficit (with respect to normal conditions) and soil water recharge.

The *Palmer Moisture Anomaly Index (Z-Index)* is the moisture anomaly for the current month. The Z-Index can track agricultural drought, as it responds quickly to changes in soil moisture values. Karl (1986) found that the Z-Index is preferable for quantifying agricultural drought than the more commonly used CMI. However, like all the Palmer indices, it suffers from a complicated formulation and computation and it is only slightly less complex than the PDSI.

The *Soil Moisture Anomaly Index (SMAI)* was developed by Bergman et al. (1988) to characterise droughts on a global basis. The method inherently relies upon the moisture accounting method of Thornthwaite and operates within a two-layer soil model used to track the movement of water, ultimately resulting in a running assessment of percent soil saturation.

A complete overview of drought indices is provided by Hayes (2004).

Duration and Spatial Extent of Drought

The Run Method

The use of run analysis has been proposed as an objective method for identifying drought periods and for evaluating the statistical properties of drought. According to this method, a drought period coincides with a "negative run", defined as a consecutive number of intervals where a selected hydrological variable remains below a chosen truncation level or threshold (Yevjevich, 1967).

Such a threshold can be a fixed value in the case of a non-periodic (e.g. annual) stationary time series or a seasonally varying truncation level in the case of a stationary periodic series. The truncation level in each time interval is somewhat arbitrary and it must be selected based on the objective of the study. Usually it is assumed equal to the long-period mean (or median) of the variable of interest, while other possible choices include a fraction of the mean (Clausen and Pearson, 1995), a value corresponding to a given non-exceedence probability (Zelenhasic and Salvai, 1987, and Correia et al., 1987), or a level defined as one standard deviation below the mean (Ben-Zvi, 1987). In any case, the threshold should be chosen in such a way to be considered representative of the water demand level (Yevjevich et al., 1983, Rossi et al., 1992).

The advantage of using the run method for drought definition consists in the possibility of deriving the probabilistic features of drought characteristics (such as duration, cumulative deficit) analytically or by data generation, once the stochastic properties of the basic variable are known. This possibility is not limited to relatively simple cases where time dependence of consecutive values can be neglected but also when a Markov chain structure is assumed for the underlying variable (Cancelliere et al., 1998; Fernandez and Salas, 1999). Furthermore, procedures to assess the return period of droughts defined according to the run method have been derived recently (Shiau and Shen, 2001; Bonaccorso et al., 2003; Cancelliere and Salas, 2004), thus making the method an ideal candidate to perform drought risk analysis.

The Cumulative "or more" Curves

A better representation of the spatial extent of drought can be achieved using a type of curves known as cumulative 'or more' curves (ogives) (Tsakiris et al., 2007a). These curves can be produced by plotting the severity of drought (y-axis) versus the percentage of the affected area (x-axis). The severity of drought is presented by a drought index and the area refers to that affected by at least the corresponding severity level. This type of graph can be used not only for the characterisation of drought and the determination of its areal extent, but also for comparisons with the critical area percentage (related to severity) directly. Clearly, more than one threshold referring to the percentage of critical area can be used defining different levels of severity.

Concluding Remarks

Drought as a regional phenomenon can be identified and quantified if its severity, its timing, duration and its spatial extent are known. Drought severity indices are proposed to identify and characterise drought (severity, timing and duration) whereas duration and spatial extent estimation can be achieved by the "run" method or the "or more" cumulative curves.

In this chapter, an attempt to review the most popular drought severity indices was made. Although the list of indices is not comprehensive, the critical assessment of the most popular of them revealed their usefulness and applicability.

It was concluded that indices exhibit attributes, which make them appropriate either for the analysis of past drought events or for the monitoring and operational management of droughts during the time they occur.

It should become clear that drought indices accompanied by their thresholds of drought severity classes should always be referred to the local conditions.

In order to associate drought indices with consequences, a thorough analysis of vulnerability and risk of the areas or systems, which could be affected by drought, should always be conducted.

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