Assessing the Areal Extent of Drought

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Abstract: Drought is a three dimensional natural phenomenon characterised by its severity, duration and areal extent. The study deals with the areal extent of drought proposing two ways of its illustration and assessment: Discretised severity maps and “or more” cumulative curves of the affected area in relation to severity level. Using a reference period (e.g. year) instead of duration and a severity index such as the Standardized Precipitation Index (SPI) or the Reconnaissance Drought Index (RDI), discretised maps show the areas affected by the corresponding severity of drought whereas the “or more” cumulative curves produce directly the percentages of areas belonging to each class of drought severity. Finally an illustrative application of both ways of drought areal extent estimation is presented for Eastern Crete, an area facing frequent droughts.

Key words: areal extent, drought indices, “or more” curves, Reconnaissance Drought Index, Standardized Precipitation Index.

1. INTRODUCTION

Drought is a recurring natural phenomenon characterised by its severity, duration and areal extent. It is therefore a three-dimensional phenomenon, which is difficult to assess. Significant work has been done over the last decades for devising indices, which represent the severity of drought (Yevjevich, 1967, Yevjevich et al., 1983, Rossi et al., 1992). Although the severity of drought could be rationally assessed from the anticipated consequences, drought indices have been widely used due to their simplicity, which they offer to both scientists and water management professionals.

Some of the widely used drought indices are the PDSI (Palmer, 1965), the Deciles (Kinninmonth et al., 2000), the SPI (McKee et al., 1993) and many others. Comprehensive reviews on these indices may be found in specific papers and publications (Richard and Heim, 2002, Hayes, 2004, Tsakiris et al, 2005, etc.). Recently a new index was proposed by Tsakiris (2004), the RDI – Reconnaissance Drought Index – which uses potential evapotranspiration in conjunction with precipitation as the variables, which the drought assessment is based upon. In its
standardized form, in most of the cases, the RDI responds in a similar way as the SPI and the various thresholds representing the borders of severity classes are the same (Tsakiris and Vangelis, 2005, Tsakiris et al., 2006).

By fixing the time reference of analysis, the “duration” dimension may be omitted. If for instance the hydrological year is selected as the reference period (that is from October to next September for the Mediterranean countries), drought can be assessed for each year of the historical record based on the selected drought index and its spatial distribution.

2. OVERVIEW OF DROUGHT INDICES

For the purposes of this paper two drought indices were used: the SPI and the RDI.

The Standardized Precipitation Index (SPI) was developed for the purpose of defining and monitoring drought based on a single meteorological determinant, the precipitation (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 median precipitation, and negative values indicate less than median 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 RDI (Reconnaissance Drought Index) is based on the ratio between two aggregated quantities of precipitation and potential evapotranspiration. It appears in three forms: the initial value \( a_i \), the Normalised \( (RDI_n) \) and the Standardised \( (RDI_{st}) \). For real world applications if RDI is calculated as a general index of meteorological drought it is advisable to use periods of 3, 6, 9 and 12 months. In its initial formulation RDI for a 12 month period could be directly compared with the Aridity Index produced for the area under study. If \( a_{i1} \) for a certain year is lower than Aridity Index calculated according to UNEP (1992) then the area is suffering from drought during this year. The Standardised RDI \( (RDI_{st}) \), behaves similarly to the SPI and therefore the interpretation of the results is similar since the same thresholds as SPI can be used. The equations for calculating RDI are presented in the Appendix.

3. DROUGHT SEVERITY MAPS AND CUMULATIVE “OR MORE” CURVES

Drought severity maps have been used in many studies during the last decade (Kim et al., 2002, Tsakiris and Vangelis, 2004, Loukas and Vasilides, 2004). Based on a descretisation procedure, the area under study can be divided into a number of
squares, at which the meteorological variables are transferred. Various methods for this transfer may be used (e.g. the weight of each station is taken as a reciprocal of square distance between the centre of the square in question and the location of the meteorological station in operation). Altitude correction should be also introduced if it is necessary. Then, the selected drought index is calculated at each square for the reference period. Using different colours for each severity class a drought severity map is produced. Drought maps are very important tools for delineating the particular parts of the area under study, which are affected by drought.

Although drought maps are useful, they exhibit two major drawbacks:

a) They do not assess drought at the river basin level, at which water resources management is practised.

b) They do not illustrate the areal extent of drought in relation to the threshold value of “the critical area percentage”.

In order to correct the first drawback an additional drought map can be produced by a spatial integration, so that drought is expressed at the river basin scale. For this purpose it is advisable to transfer the values of the meteorological determinants to the river basin and particularly at the actual mean elevation of the basin. In case the basin is very large subbasins could be used as territorial units.

As regards the second drawback, this work proposes to use the cumulative “or more” curves (ogives), also known as “drought severity – areal extent” curves, which express directly the percentage of the area under drought, which then can be compared with the critical area percentage. It is customary to compare the areal extent of drought with a preset “critical area” percentage. 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 graphs 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 thresholds referring to the percentage of critical area can be used defining different levels of severity. Since each class of drought severity has a different threshold, it is obvious that various critical area percentages could be simultaneously adopted for characterising a drought episode in relation to its areal extent.

4. APPLICATION

For the application of the proposed methodology, the area of Eastern Crete - Greece (Prefectures of Heraklion and Lassithi) was selected.

Both annual SPI and RDI were calculated, for the period of 30 hydrological years. Maps for one wet and one dry year (1964-65 and 1969-70 respectively) appear in Fig.1. As expected SPI and RDI give comparable results. However discrepancies occur due to the fact that RDI is using an additional meteorological determinant
(PET) apart from precipitation.

Further in Fig.2 the most dry year (1989-90) during the examined period from 1962-63 to 1991-92 is presented. In Fig.3, the cumulative “or more” curves for both SPI and RDI are presented for the wet year 1964-65 and the dry year 1969-70. The boundaries of the drought severity classes [0,-1] normal to dry, [-1, -1.5] moderate dry, [-1.5, -2] severe dry and [<-2] extreme dry appear also in Fig 3. Focussing on the dry year 1969-70 it may be observed that various percentages of “critical area” may be adopted and may be directly compared with the areal extent of each drought level. If the RDI is considered it can be seen that about 10% of the total area is under extreme drought, whereas 25% of the area is under extreme or severe drought and 70% is under at least moderate drought. In other words, 10% of the area is under extreme drought, 15% under severe drought and 50% of the area is under moderate drought.

Finally in Fig.4 the cumulative “or more” curves for the most dry year (1989-90) during the period examined are presented. From Fig.4 it can be concluded that more than 80% of the area is under extreme drought.

Figure 1. Drought Severity Maps for Eastern Crete for one wet (1964-65) and one dry year (1969-70), based on the severity indices SPI and RDI
Figure 2. The most dry year (1989-90) during the examined period 1962-63 – 1991-92 for Eastern Crete based on the SPI and the RDI.

Figure 3. The cumulative “or more” curves for both SPI and RDI for the wet year 1964-65 and the dry year 1969-70.
5. CONCLUDING REMARKS

The proposed methodology showed that Drought Discretised Maps and Cumulative “or more” curves can be presented to illustrate the severity of drought and its areal extent.

In particular, the cumulative “or more” curves describe the areal extent of drought in direct percentage figures, which may be compared with the adopted critical area percentage for each class of drought severity. Based on this information, a comprehensive analysis of past droughts can be assessed and sound preparedness plans can be devised for facing future droughts.

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REFERENCES


