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Drought Characterisation and Monitoring in Regions of Greece

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Abstract: Drought is a natural recurrent phenomenon affecting most sectors of society and the environment. Therefore it is of great importance to devise tools for the identification of drought episodes and the assessment of their severity. In this paper the Reconnaissance Drought Index (RDI) is presented with some additional comments in the way of calculation of the standardised form of the index and it used for drought characterisation, analysing historical meteorological data (1955 – 2002) for four drought prone regions of Greece (Thessaly, Athens, Cyclades and Eastern Crete). Further, climatic scenarios are used for extending this period for some future decades based both on the customisation of General Circulation Models and statistical extrapolation of data time series. Finally, an attempt is made for establishing a drought monitoring system in these drought prone areas utilising the data of the hydrological year 2006 – 2007 and October 2007 – May 2008.

Keywords: Reconnaissance Drought Index, drought in Greece, drought monitoring, drought assessment, drought statistics

1. INTRODUCTION

Drought is a recurrent phenomenon which may affect several sectors of life and the environment and can be directly linked to water shortage problems. Drought can be considered as a three dimensional event characterised by its severity, duration and affected area. One of the most common methods to assess drought is the calculation of drought indices (Rossi *et al.*, 1992; Hubbard, 1993; Bonaccorso *et al.*, 2003; Paulo and Pereira, 2006; Tsakiris *et al.*, 2007a; Tsakiris and Tigkas, 2007).

The Reconnaissance Drought Index (RDI) was used in this study for the identification of drought conditions in four regions of Greece. Meteorological data from Thessaly, Athens, Cyclades and Eastern Crete were analysed in order to assess drought severity and duration in these areas.

Initially, the historical data series from 1955 to 2002 were analysed. Two climatic scenarios were formulated in order to investigate the possible meteorological conditions for the next decades. Finally, based on the historical data, a drought monitoring process was developed and implemented for the hydrological year 2006-07 and for the first 8 months (October - May) of 2007-08.

2. THE RECONNAISSANCE DROUGHT INDEX (RDI)

The Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis, 2005; Tsakiris *et al.*, 2007b) can be characterised as a general meteorological index for drought assessment. The RDI can be expressed with three forms: the initial value α_k, the normalised RDI (RDI_n) and the standardised RDI (RDI_{st}). In this paper we will focus on α_k and RDI_{st}.

The initial value (α_k) is presented in an aggregated form using a monthly time step and may be calculated on monthly, seasonal (3-month, 4-month, etc.) or annual basis. The α_k for the year i and a time basis k (months) is calculated as:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \; i = 1 \text{ to } N \tag{1}$$

where P_{ij} and PET_{ij} are the precipitation and the potential evapotranspiration of month j of year i, starting usually from October which is customary for Mediterranean countries and N is the total number of years of the available data.

The initial formulation of RDI_{st} (Tsakiris and Vangelis, 2005) used the assumption that α_k values follow the lognormal distribution and RDI_{st} is calculated as:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y} \tag{2}$$

in which y_i is the $ln(\alpha_k^{(i)})$, $\bar{y}$ is its arithmetic mean and $\hat{\sigma}_y$ is its standard deviation.

From the continuing research on the subject and by analysing various data from several locations and different time scales (3, 6, 9 and 12 months) it was concluded that α_k values follow satisfactorily both the lognormal and the gamma distributions in almost all locations and time scales, but in most of the cases the gamma distribution was more successful. Therefore, the calculation of RDI_{st} could be performed in many cases better by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k, following the procedure described below. This approach also solves the problem of calculating RDI_{st} for small time steps, such as monthly, which may include zero-precipitation values ($\alpha_k = 0$), for which Eq. (2) cannot be applied. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\gamma}\Gamma(\gamma)} x^{\gamma-1} e^{-x/\beta}, \quad \text{for } x > 0 \tag{3}$$

where γ and β are the shape and scale parameters respectively, x is the precipitation amount and $\Gamma(\gamma)$ is the gamma function. Parameters γ and β of the gamma pdf are estimated for each station and for each time scale of interest (1, 3, 6, 9, 12 months, etc.). Maximum likelihood estimations of γ and β are:

$$\gamma = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \; \beta = \frac{\bar{x}}{\gamma}, \quad \text{where} \quad A = ln(\bar{x}) - \frac{\sum ln(x)}{n} \tag{4}$$

and n is the number of observations.

The resulting parameters are then used to find the cumulative probability of α_k for a given year for the location in question. Since the gamma function is undefined for $x = 0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x) \tag{5}$$

where q is the probability of zero precipitation and $G(x)$ is the cumulative probability of the incomplete gamma function. If m is the number of zeros in α_k time series, then q can be estimated by m/n. The cumulative probability $H(x)$ is then transformed to the standard normal random variable z with mean zero and variance of one (Abramowitz and Stegun, 1965), which is the value of the RDI_{st}.

The Standardised RDI behaves in a similar manner as the SPI (McKee et al., 1993) and so is the interpretation of results. Therefore, the RDI_{st} values can be compared to the same thresholds as the SPI (Table 1).

Table 1. Drought classification thresholds.

RDI_{st} or SPI value	Category
2.00 or more	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0 to 0.99	Normal conditions - wet
0 to -0.99*	Normal conditions - dry
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2 or less	Extreme drought

* *values from -0.50 to -0.99 may be considered as a different category characterized as 'Mild drought'*

In order to facilitate the calculation process of RDI, the software DrinC – *Drought Indices Calculator* (Fig. 1) was developed at the Laboratory of Reclamation Works & Water Resources Management of the National Technical University of Athens (Tsakiris *et al.*, 2007c). An online version of the software can be found at www.ewra.net/drinc.

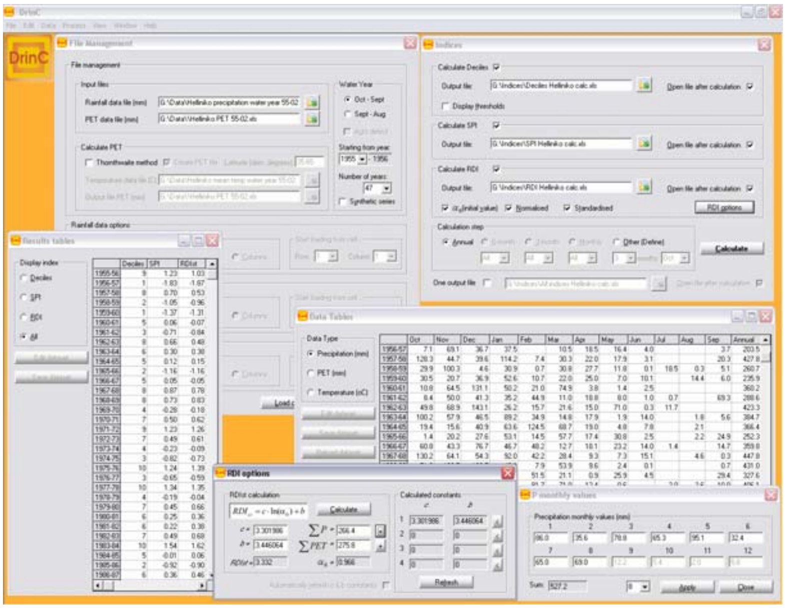

Figure 1. The main interface of DrinC software.

3. DROUGHT IDENTIFICATION

3.1 Study Areas

For the drought identification study, four areas in Greece were selected (Fig. 2):

- Thessaly, located in central Greece, with major agricultural activity
- Athens, highly populated urban area

- Cyclades, a group of islands in Aegean Sea and
- Eastern Crete, an area which has been characterised as one of the most drought prone areas of Greece

For the identification of drought, representative meteorological stations of the Greek Meteorological Service were selected, with good data quality, for each one of the areas under study. Monthly precipitation and temperature (average, minimum and maximum) data were analysed for a period of 47 hydrological years (1955–2002). The potential evapotranspiration (PET) was calculated using both Thornthwaite and Hargreaves methods; the PET results from Hargreaves method were finally used, considered as more reliable. Based on these data, the RDI (α values and RDI_{st}) was calculated for each one of the areas.

Figure 2. Selected case study areas.

3.2 Overview of drought conditions and drought events

As already mentioned, the drought identification of the areas under study was based on RDI. In Figure 3 the annual values of α (α_{12}) are presented. With the green line is indicated the average of α_{12} which is equal to the Aridity Index of each area.

The RDI_{st} values are shown in Figure 4, in which is more easy to identify the drought events and its severity for each area. For example, during the year 1989-90 drought events occurred in all the regions under study, classified within the severe or extreme drought levels. Other significant drought events were:

- in Thessaly during the hydrological years 1958-59, 1969-70, 1970-74, 1992-94, 1997-98 and 1999-00
- in Athens during the hydrological years 1956-57, 1959-60, 1965-66, 1992-93 and 1999-2001
- in Cyclades during the hydrological years 1957-59, 1965-66 and 1999-2001
- in Eastern Crete during the hydrological years 1958-59, 1969-70, 1973-74, 1992-94, 1997-98 and 1999-00

The frequency of droughts for the period 1955 – 2002 for each area is shown in Figure 5, while the cumulative percentage of severe and extreme drought years for the same period is presented in

Figure 6. It appears that Thessaly faced more severe and extreme droughts during this period (21%), followed by Cyclades (17%), Athens (15%) and E. Crete (15%).

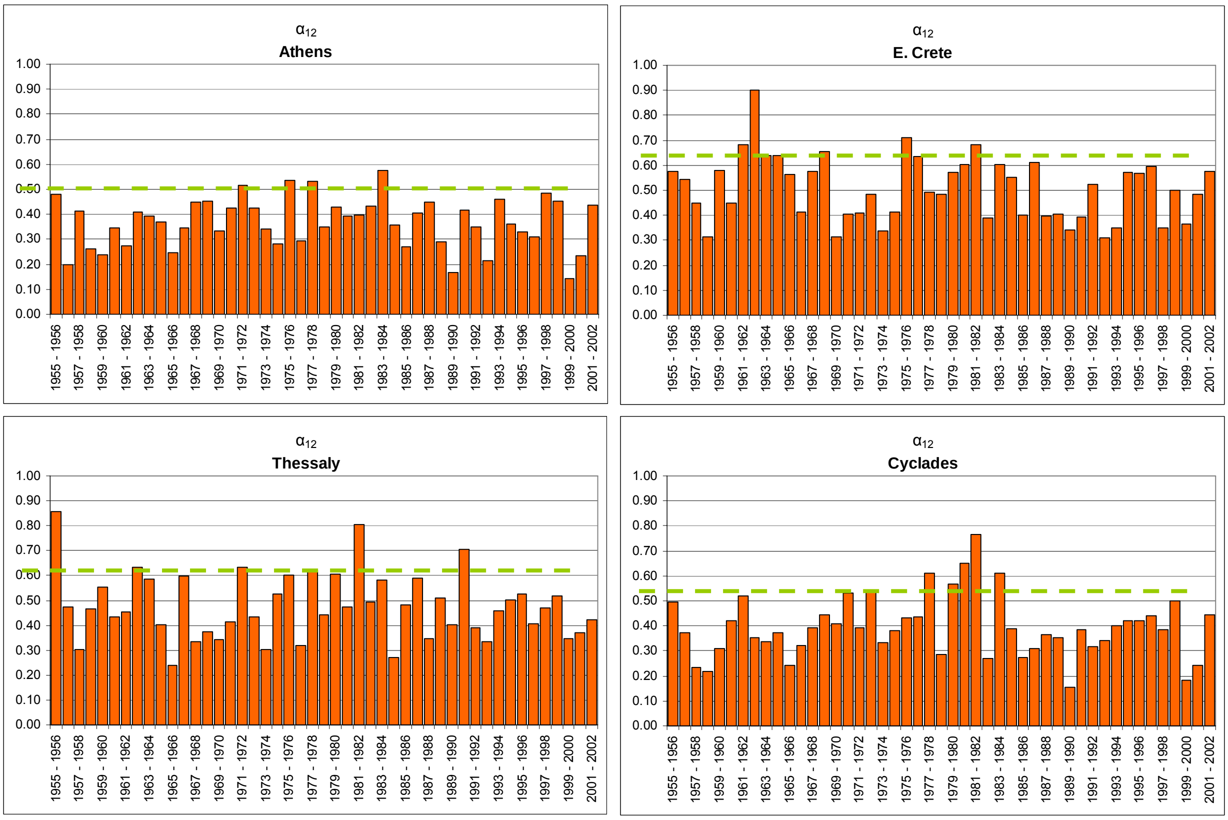

Figure 3. Drought conditions 1955-2002 (a_{12} values – green line indicates the average).

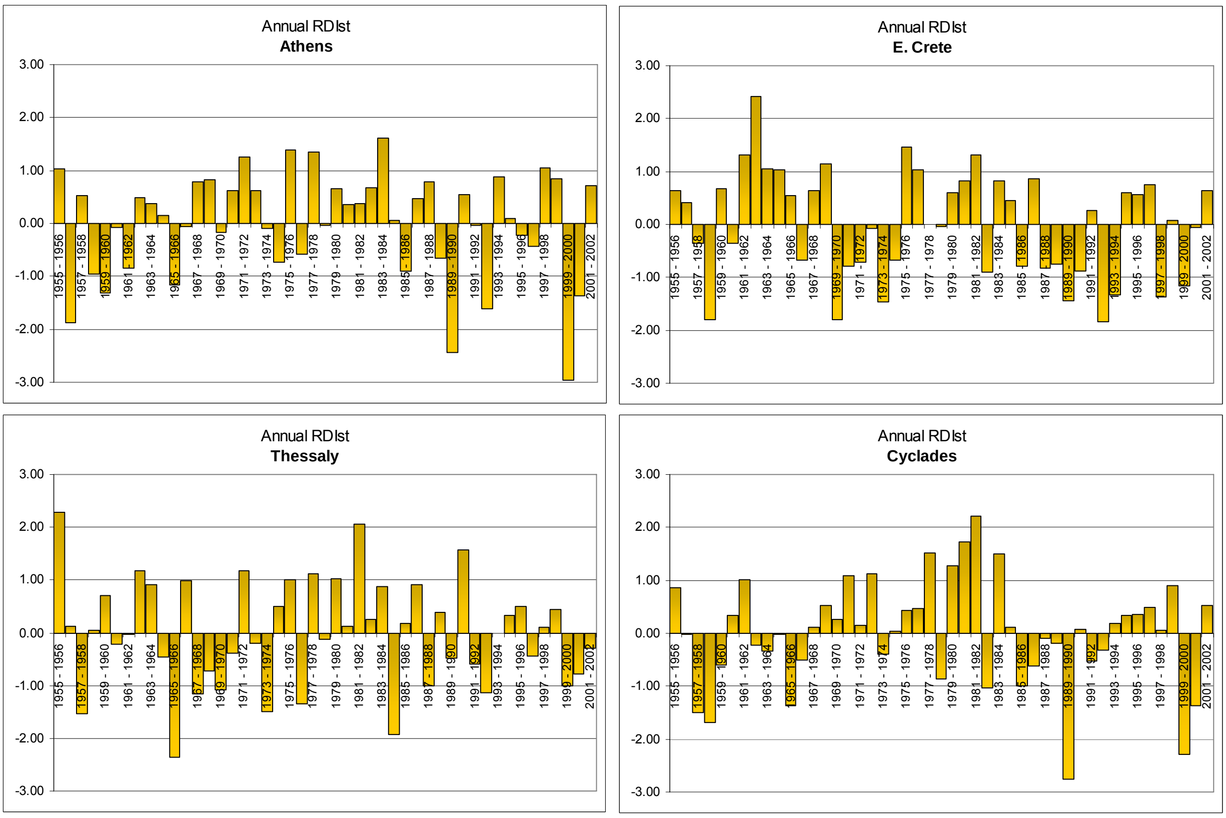

Figure 4. Drought conditions 1955-2002 (RDI_{st} values)

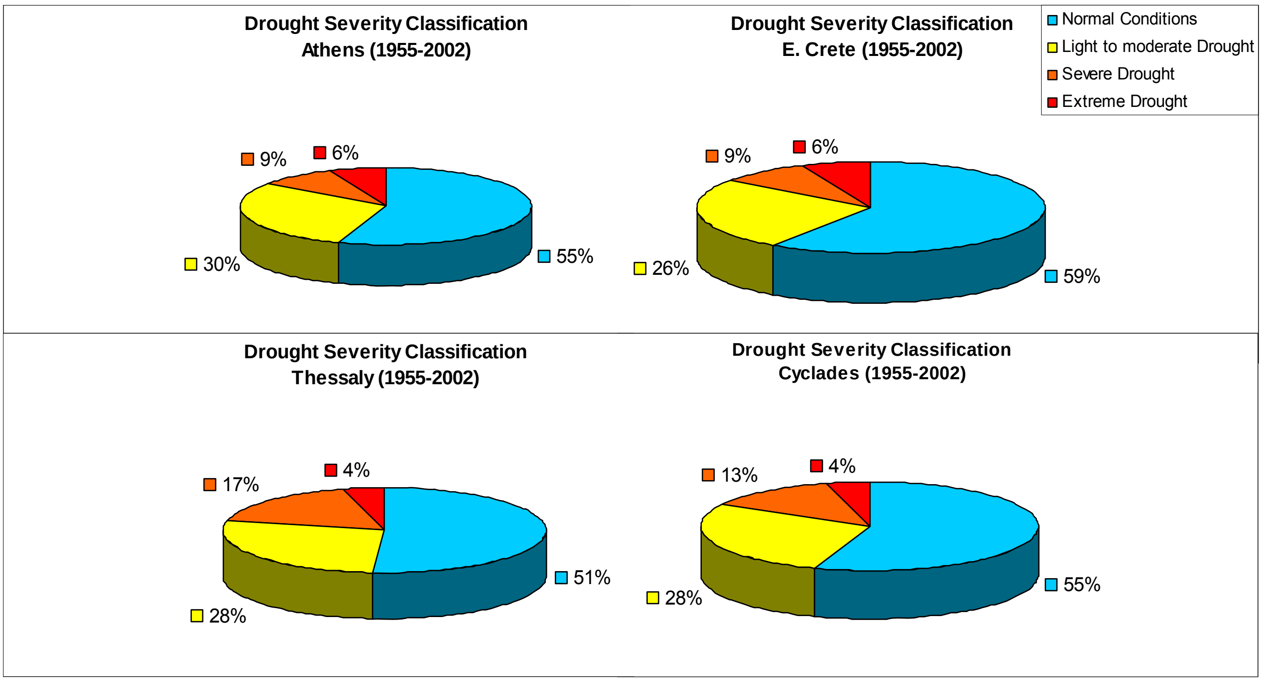

Figure 5. Frequency of droughts (1955-2002)

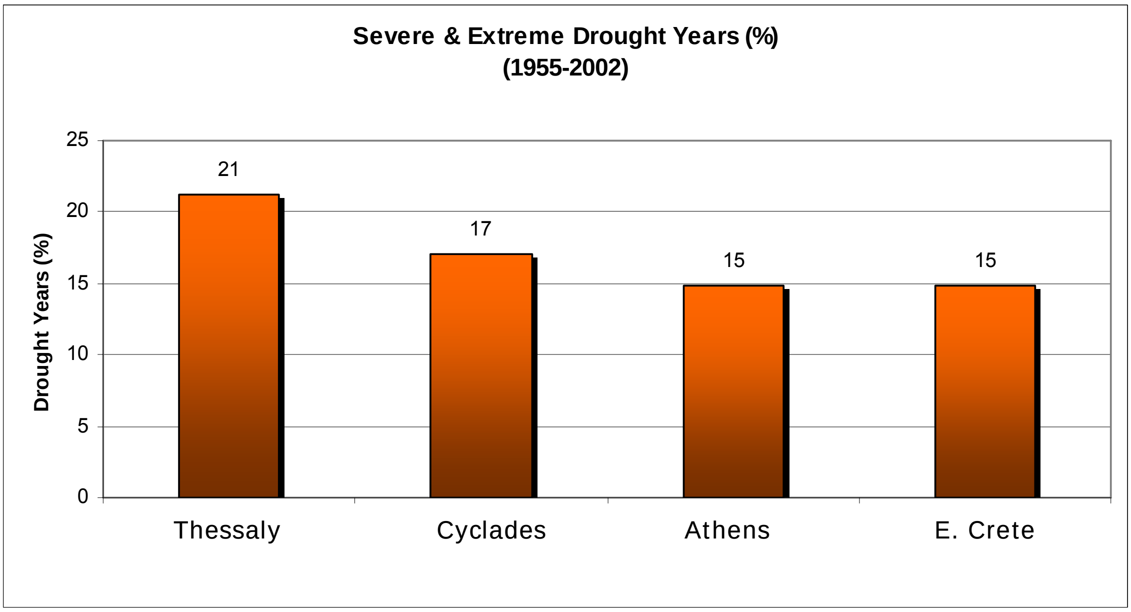

Figure 6. Percentage of severe and extreme drought years (1955-2002)

Another important aspect, together with the drought severity, is the duration of drought events, since even mild droughts may cause major problems if they last for several years. In Figures 7 and 8 appear the number of drought events and the number of severe and extreme drought events along with their duration (in years), respectively, for each area. In Cyclades there were drought events that lasted up to five years and severe or extreme drought events with duration up to two years. In Athens and in E. Crete there were many drought events with 2-year duration and one case for each area with 2-year of severe or extreme drought event, while in Thessaly there were drought events with duration up to four years, however no event of severe or extreme drought lasted over one year.

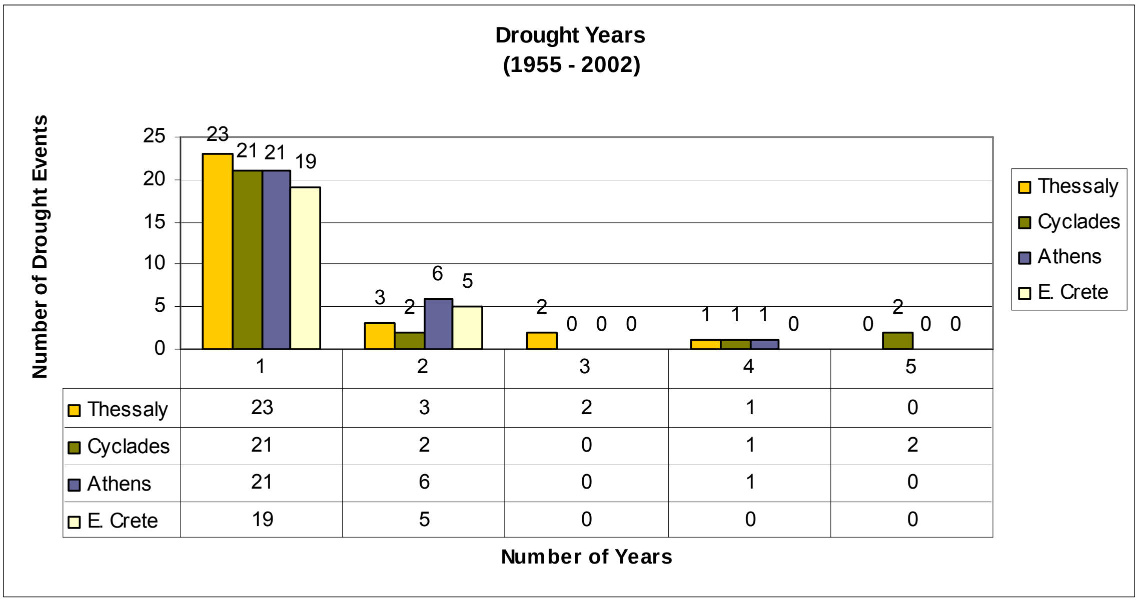

Figure 7. Duration of consecutive drought years (1955-2002)

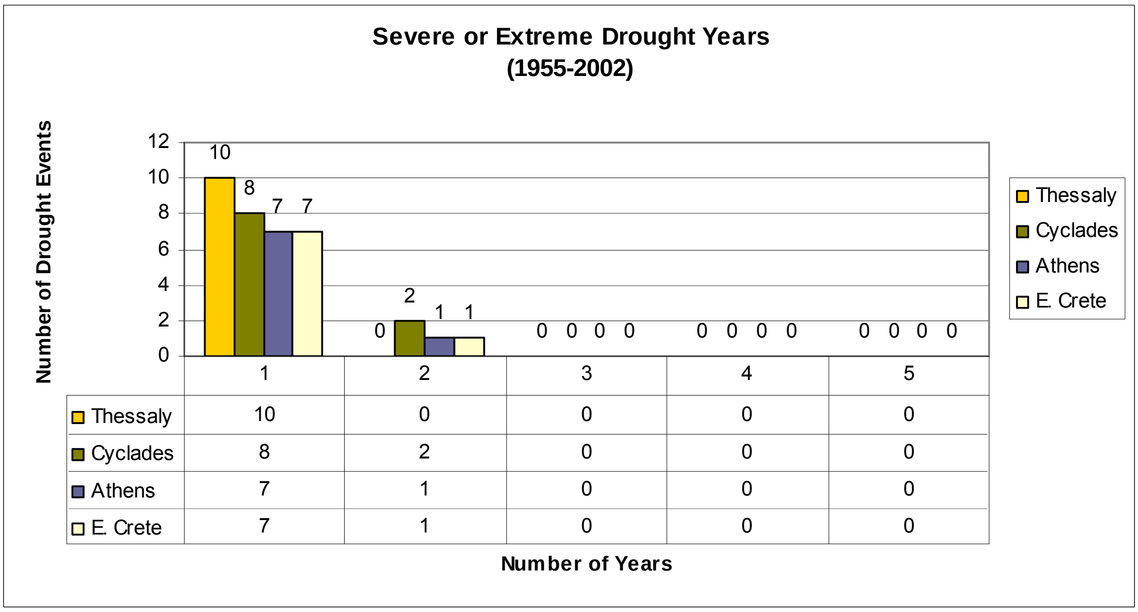

Figure 8. Duration of consecutive severe and extreme drought years (1955-2002)

3.3 Trends and future scenarios

The α_{12} and RDI_{st} time series were analysed for identifying trends. Both performed tests (linear regression, Mann-Kendall test) show that there is no significant statistical trend of variance (95% or higher confidence) in any of the 4 areas under study for the period 1955-2002 (Tables 2 and 3).

The results of the trend analysis were used in order to formulate a drought scenario (optimistic scenario) referring to the period 2050-2080, assuming that these trends will remain the same for the following years (Fig. 9). Based on this scenario the percentage of severe and extreme drought years will remain approximately the same for Thessaly, will be decreased in Cyclades and will be increased in Athens, while the greatest increase up to 13% will be in Eastern Crete.

Table 2. Trend analysis for α_{12} time series (1955-2002).

		Athens	E. Crete	Thessaly	Cyclades
α_{12} trend	slope coefficient (period 1955-2002)	0.016	-0.141	-0.188	0.094
	change / year	0.000	-0.003	-0.004	0.002

Table 3. Trend analysis for RDI_{st} time series (1955-2002).

		Athens	E. Crete	Thessaly	Cyclades
RDI_{st} trend	slope coefficient (period 1955-2002)	-0.047	-0.282	-0.188	0.235
	change / year	-0.001	-0.006	-0.004	0.005

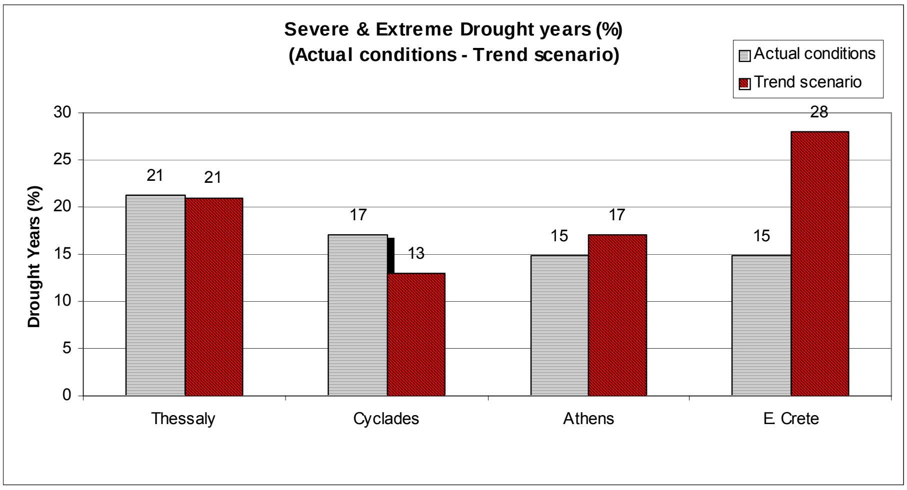

Figure 9. Severe and Extreme drought years based on trend analysis.

The second drought scenario (pessimistic scenario) was formulated by adopting the results of the HadCM3/A1F model regarding the climate change (precipitation and temperature) in each area (IPCC, 2001; Dalezios, 2007). The results of the application of this scenario (Fig. 10) show a significant change of the percentage of severe and extreme drought years which varies from 51% for the case of Eastern Crete, up to 85% for the case of Athens.

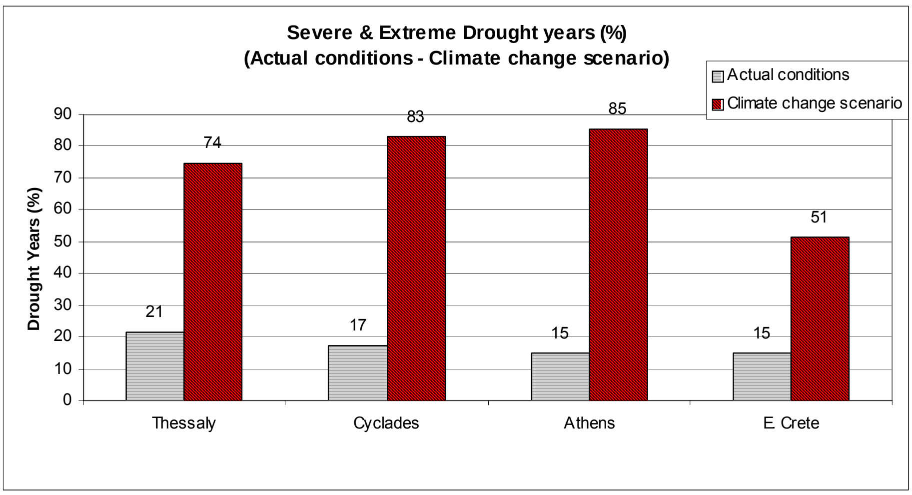

Figure 10. Severe and Extreme drought years based on climate change scenario.

It should be noted that the calculated percentages are based on the current climate situation and drought categorisation for each area. It is clear that if climate changes occur, the parameters for the standardisation procedure of RDI (i.e. mean and standard deviation of α_k) will change. Therefore, α_k values that in present conditions would be categorised as drought events, probably in a future horizon will fall in a different category (e.g. normal conditions). However, the percentages of drought years are presented here in this way in order to illustrate better the possible climate change effects and the magnitude of the consequences in the ecosystems and the local societies. Obviously, the above scenarios are indicative and they do not intent to result in absolute figures, but to demonstrate a range of probable future conditions.

3.4 Drought monitoring

The monitoring of drought is important in order to be able to foresee a possible drought event and to be better prepared to mitigate the anticipated damages of such an event (Wilhite *et al.*, 2005; Bordi and Sutera, 2007). In the four areas under study, a drought monitoring system was established using monthly updated data of the Greek Meteorological Service.

The monitoring system is based on the calculated series of the seasonal values of RDI (3-month, 4-month, …, 12-month) for the reference period 1955 – 2002 for each area, which were used for the standardisation procedure. The precipitation and the PET for the monitoring period were used for the calculation of α_3, α_4, ..., α_{12} and then were transformed to the standardised form, that is the seasonal values of RDI_{st}. These values are indicated hereafter with the initials of the months of the respective period (e.g. 'Oct-Dec' for the 3-month RDI).

In Figures 11 and 12 appear the results of the drought monitoring for each area during the hydrological years 2006-07 and the first 8 months of 2007-08, respectively. In Fig. 8 it is shown that during the year 2006-07, in general terms, the conditions were more wet during the first months (October - February), while in the following months the conditions were drier. More specifically, the RDI values recorded in Athens, Thessaly and Cyclades were within the 'normal conditions' category for the first months and eventually decreased to the 'mild drought' category. In Crete, the conditions varied between 'moderately wet' and 'severely wet' categories from October to February, however the next months were more dry so the annual RDI of 2006-07 is in 'normal – wet conditions' category.

The next hydrological year (2007-08) started also with a wet period, while from January the conditions in all areas, except Cyclades were drier. In Thessaly, the conditions were initially 'moderately wet' and eventually RDI values decreased to 'normal – dry conditions'. Athens was the only area in which RDI values were negative throughout this monitoring period and during February there were 'moderate drought' conditions, indicating a possible drought problem during the year, however the RDI values increased in the next months, so the conditions on May were in 'mild drought' category. Eastern Crete initially had normal conditions, but from March they passed to 'mild drought'. Cyclades is the only area that had positive RDI values during the whole monitoring period up to 'moderately wet' category.

4. CONCLUDING REMARKS

The main concept as well as some additional comments on the calculation procedure of the Reconnaissance Drought Index (RDI) were presented. Based on this index, the drought characteristics of four regions of Greece (Thessaly, Athens, Cyclades and Eastern Crete) were investigated by analysing meteorological data from 1955 to 2002. The results of this analysis show that more intense drought events have occurred in Thessaly during the past 50 years, while in Cyclades many drought episodes occurred with duration more than one year.

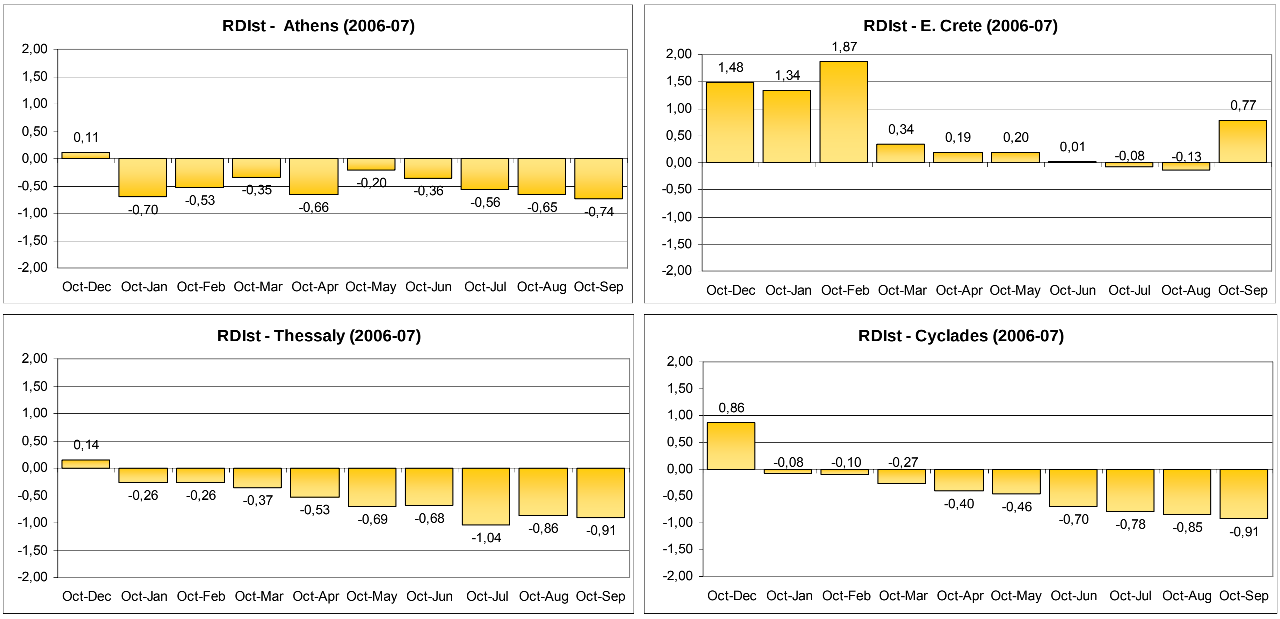

Figure 11. Seasonal RDI_{st} values for the hydrological year 2006-07 for the four areas under study.

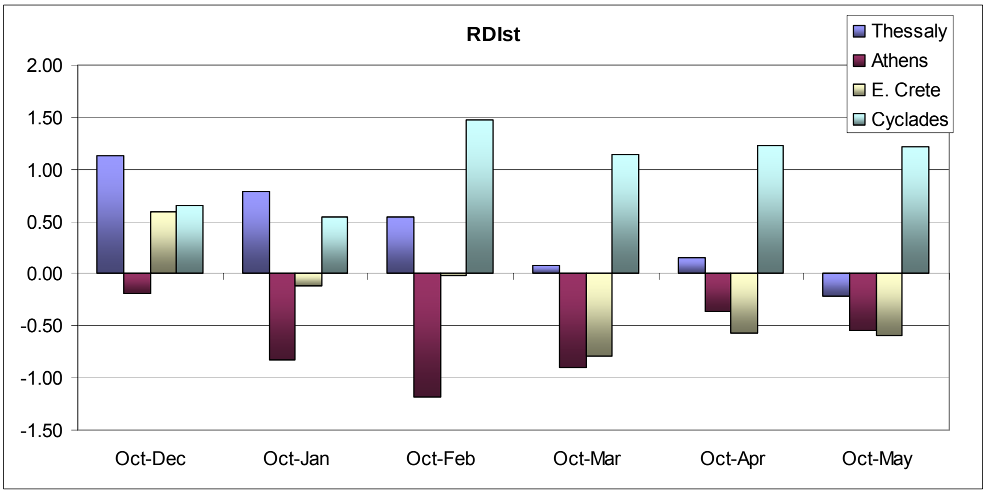

Figure 12. Seasonal RDI_{st} values for the hydrological year 2007-08 (October to May) for the four areas under study

Two drought scenarios were formulated for representing the possible conditions of 2050 - 2080, one based on the trend analysis of RDI data and one based on climate change predictions of customised climate models. The first, which can be characterised as optimistic scenario, does not show very significant changes, except from the case of E. Crete were the percentage of drought years appears to be increased from 15 to 28%. The second scenario show that the percentage of drought years will be dramatically increased and they will range from 51%, up to 85%.

The calculated data series of RDI for each area was used as the basis for the development of a drought monitoring process which was implemented during the hydrological year 2006-07 and the first 8 months of 2007-08.

It seems that in the near future we will face some major problems with drought, which will have major effects at the ecosystems and human environments and will lead to intense water scarcity problems. This shows that there is an urgent need to develop strategic water management and preparedness plans in all drought prone areas in order to combat the increased water shortage risk.

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