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Index-based Drought Assessment in Semi-Arid Areas of Greece based on Conventional Data

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Abstract: Drought effects are very common and extremely serious nowadays, causing significant problems in rural and urban areas all over the world. Although drought is difficult to be understood, the use of various indices is feasible to describe the drought conditions in an area. In this paper, three drought indices are used to describe drought, namely meteorological drought, in several regions in Greece. These indices are the commonly used deciles and Palmer Z-index as well as a new one, the Reconnaissance Drought Index (RDI). Conventional measurements derived from meteorological stations of the areas under study are used for drought assessment for 45 hydrological years (1956 to 2001). The results of the indices are compared on a monthly basis for each area separately, except Deciles, which is examined on annual basis. The three indices are considered satisfactory to describe the drought conditions in the area and show similar performance. Deciles are used as an indication of drought spells, whereas RDI and Z-index provide additional information about the onset, the end and the severity of the phenomenon.

Key words: Deciles method, Drought assessment, Drought monitoring, Palmer Z-Index, RDI.

1. INTRODUCTION

Drought is one of the major natural hazards with significant impact to environment, society, agriculture and economy. Drought can be regarded as an extreme climatic phenomenon associated with water resources deficit. Drought impacts are especially costly and, on annual basis, affect more people than any other type of natural disaster universally (Keyantash and Dracup, 2002). It is difficult to determine the effect of drought as it constitutes a complicated phenomenon, which evolves gradually in any single region. Droughts are, by nature, regional phenomena and have been referred to as "non events", since their basic cause is the lack of precipitation events in a region over a time period. Drought impacts are very critical and so there is a need to detect the onset and assess their areal extent and severity (Prout *et al*., 1986). These drought characteristics should be known through monitoring and are very significant inputs in any drought preparedness and mitigation plan.

A drought could be meteorological or climatological, hydrological, agricultural, and usually has socioeconomic impacts (Keyantash and Dracup, 2002). The meteorological or climatological drought of an area is characterized by a prolonged and abnormal moisture deficiency (Palmer 1965). Hydrological drought is generally defined either by stream flow deficit measured from a certain reference discharge, or by groundwater level being lower than average annual recharge. Agricultural drought occurs when root-zone soil moisture reserves are insufficient to sustain crops and pasture between rainfalls. Socioeconomic impacts of drought are defined by the losses of an expected return. It can be measured by both social and economic indicators, with profit being just only one of them (McVicar and Jupp, 1998).

The monitoring and assessment of drought conditions in a region is normally performed using drought indices (Kanellou *et al*., 2008). Drought indices could assist decision makers by providing information on drought severity and other characteristics and could be used to trigger drought contingency plans, if these are available (Morid *et al*., 2006; Heim, 2002; Du Pissani *et al*., 1998). Internationally, there is a wide range of drought indices, classified according to the type of drought that is to be described (Oladipo, 1985; Guttman, 1998). In this work, three indices are selected according to their acceptability, input requirements and range with regards to different degrees of complexity. These indices are: Deciles, Palmer Z- index calculated by Drought Severity Index (PDSI) and the Reconnaissance Drought Index (RDI). These drought indices are applied to four areas in Greece (Larisa, Heraklion, Elliniko and Naxos) and intercomparison is carried out.

2. STUDY AREA AND DATA SET

The areas under study are located within two climatic zones. Athens (Elliniko station), Thessaly (Larisa station) and Cyclades (Naxos station) are included in the first zone known as the semiarid zone. This zone is characterized by low winter temperatures and short drought periods. Crete (Heraklion station) belongs to the second zone, namely Mediterranean desert type zone, with small annual precipitation and droughts of long duration (Mariolopoulos, 1938; Dalezios, 1994). The areas under study are presented in Figure 1. In both climatic zones drought could turn out being a major problem either affecting agriculture productivity or water reservoirs.

For the detection of the meteorological drought Deciles, Palmer Z- index and the Reconnaissance Drought Index (RDI) are calculated. The data requirements for RDI and Z- index are monthly precipitation and mean monthly temperature, while only cumulative monthly precipitation is needed for deciles. Additionally, for the Palmer Index the monthly air temperature, climatic values, as well as the available water capacity data of each area are needed. The precipitation and air temperature data cover a time period of 45 hydrological years (October to September) for each month from 1956 to 2001.

Figure 1. Location of the meteorological station of the areas under study.

3. DROUGHT INDICES

Drought features basically consist of type, severity, duration, frequency and spatial extent. A drought index can result from several indicators, which can be synthesized into a single indicator. Usually the data required are meteorological observations, which are normally readily available (Steinemann *et al*., 2005). In the paragraphs below, the three indices which are selected in this study are briefly described.

3.1 Deciles

Mean precipitation is, usually, a poor reference for typical conditions. The median may also be used to assess the central tendency of the record instead of the mean precipitation. Gibbs and Maher (1967) suggest a decile-based system for monitoring meteorological drought (Keyantash and Dracup, 2002) and they classify the precipitation data into 10 quantiles, or deciles.

According to Deciles method, monthly precipitation totals from a long-term record, are first ranked from highest to lowest to construct a cumulative distribution. Deciles Indices (DI) are grouped into five classes, two deciles per class, which are shown in Table 1. DI is relatively simple to calculate, requires only precipitation data and fewer assumptions than more comprehensive indices (e.g. Palmer indices).

Deciles can be easily calculated because they require precipitation only. However, this approach may lead to false conclusions in terms of drought assessment since drought depends on several parameters and not only on precipitation amount. Moreover, low rainfall values are an indicator for the onset of a drought event.

Table 1. Weather conditions classification by deciles categories.

Deciles	*Classes*	*Weather Conditions*
1-2	*<20%*	*Much below normal*
3-4	*20%-40%*	*Below normal*
5-6	*40%-60%*	*Near normal*
7-8	*60%-80%*	*Above normal*
9-10	*80%-100%*	*Much above normal*

3.2 Reconnaissance Drought Index (RDI)

RDI depends on the ratio between precipitation and potential evapotranspiration (Tsakiris and Vangelis 2005; Tsakiris *et al*., 2007). For the RDI calculation, an initial value for a certain period, namely a_k indicated by a certain month (k) during a year, is calculated by the following equation:

$$a_k = \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_J} \quad (1)$$

in which P_j and PET_j are the precipitation and potential evapotranspiration of the j-th month of the hydrological year respectively. In this study monthly air temperature of each meteorological station is used to estimate the monthly potential evapotranspiration by the Thorthwaite method. The k coefficient is equal to 1 for the first month of the hydrological year. For the Mediterranean region k=1 for October as the hydrological year starts at this month. The a_k coefficient can be calculated for any period of the year, which means that it can be calculated starting from any month of the year different than October if it is necessary. In practice, periods of 3, 6, 9 and 12 months are used. If a

12-month period is selected, the result could be directly compared with the Aridity Index produced for the area under study. An area can be supposed to suffer from drought if a_{12} for a certain year is lower than the Aridity Index.

The Normalised RDI (RDI_n), is computed using the equation.(2) where $\bar{a}_k$ is the average value of a_k for each time period.

$$RDI_n(k) = \frac{a_k}{\bar{a}_k} - 1 \qquad (2)$$

Finally, the Standardised RDI (RDI_{st}) is computed following a similar procedure (eq. 3) to the one that is used for the calculation of SPI:

$$RDI_{st}(k) = \frac{y_k - \bar{y}_k}{\hat{\sigma}_k} \qquad (3)$$

in which y_k is the ln a_k, $\bar{y}_k$ is its arithmetic mean and $\hat{\sigma}_k$ is its standard deviation. The drought categories based on RDI_{st} are shown in the Table 2.

Table 2. Drought categories based on RDI_{st}

Drought Categories	RDI Values
Extremely Wet	>2.00
Very Wet	1.50 to 1.99
Moderately Wet	1.00 to 1.49
Near Normal	-0.99 to 0.99
Moderately Dry	-1.00 to -1.49
Severely Dry	-1.50 to -1.99
Extremely Dry	<-2.00

3.3 Palmer Drought Severity Index (PDSI)

The PDSI was developed by Palmer (1965) and it is mainly used for the meteorological drought detection. Its procedure includes the computation of a climatic water balance which is determinant of hydrological drought (Dalezios *et al*., 2000). The data needed for the PDSI calculation consist of precipitation, potential evapotranspiration and the Available Water Capacity (AWC) of the soil system. AWC is effectively a "model parameter", which has to be set at the start of calculations. The potential evapotranspiration in this approach is calculated based on Thornthwaite method (Thornthwaite, 1948), as it is suggested in Palmer's first application.

Palmer used a two-layered model for soil moisture computations and made certain assumptions concerning field capacity and transfer of moisture to and from the layers. These assumptions include the following: the top soil layer ("plough layer") has a field capacity of 1 inch (2.54 cm), moisture is not transferred to the bottom layer ("root zone") until the top layer is saturated, runoff does not occur until both soil layers are saturated, and all of the precipitation occurring in a month is utilized during that month to meet evapotranspiration and soil moisture demand or be lost as runoff (Heim, 2002). Also, Palmer applied what he called Climatologically Appropriate for Existing Conditions (CAFEC) quantities to normalize his computations so he could compare the dimensionless index across space and time.

The PDSI resulting from this procedure provides a general methodology for evaluating the meteorological anomaly and permits temporal and spatial comparisons of drought severity as it indicates standardized moisture conditions. PDSI is normally calculated on a monthly basis and it is one of the few general indices which do address some of the elusive drought properties such as intensity, onset time and end time (Dalezios *et al*., 1991).

The standardised form of PDSI is called Z-index. The Palmer Z-index reflects the departure of the weather of a particular month from the average moisture climate for that month, regardless of what has occurred in prior or subsequent months, also known as moisture anomaly index (Dalezios *et al*., 1991). PDSI and Z- index vary roughly between -4.0 and +4.0. More wet conditions are indicated by positive values of Palmer indices, more dry conditions, by their negative values (Loukas *et al*., 2002). PDSI and Z-index categories are shown in the Table 3. A drought sequence is interpreted as a sequence of two or more consecutive months with a PDSI or Z-index value <= -0.50. A series of six or more months is a major drought event. The end of a drought sequence is taken as the last month where the PDSI or Z-index is > -0.5.

Table 3. Classification of weather conditions using PDSI or Z-index (Palmer, 1965).

Palmer Classifications	
PDSI and Z-index Values	**Weather Conditions**
4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
< -4.00	Extreme drought

4. RESULTS AND DISCUSSION

The three indices under examination, namely Deciles, RDI, and Z- index, are applied to the four study areas. The results are presented in Figures 2 to 13 for each index and for each station separately, for the whole time series, i.e. 45 hydrological years (1956 - 2001) as well as in Tables 4 and 5. The Z-index and RDI are estimated on a monthly basis, whereas Deciles is calculated on an annual basis for each hydrological year. The results show that all the indices identify the drought events which appear in the four study area. Specifically, the three indices identify drought in the same years and drought severity in the same or analogous class. Moreover, it is shown that in hydrological years with severe or extreme values according to Deciles, the corresponding values of Z-index and RDI are negative for most of the months within that year. Furthermore, these two indices (RDI and Z- index) indicate the onset and the end of the drought events providing additional information.

The results for the Larisa station are shown in Figures 2 to 4, for Elliniko station in Figures 5 to 7, for Naxos station in Figures 8 to 10 and for Heraklion station in Figures 11 to 13, respectively. At Larisa station the three indices show, in general, mild drought during 1967-1968, 1987-1988, 1992-1993 and from 1999 to 2001 hydrological years. However, moderate to severe drought conditions occurred in 1957-1958, 1967-1968, 1969-1970, 1973-1974 and 1976-1977. Finally, the hydrological year of 1984-1985 seems especially severe and extreme drought appears in the 1965-1966 hydrological years of Larisa station.

For the Elliniko station, the three indices indicate that mild drought appears in the hydrological years of 1961-1962, 1974-1975, 1976-1977 and 1996-1997. Moreover, moderate to severe drought appears quite often in the area. Characteristic hydrological years, which are included in this drought category, are 1956-1957, 1958-1959, 1959-1960, 1965-1966 and 1992-1993, respectively. Additionally, at Elliniko station the results show extreme drought in 1989-1990 and 1999-2000.

At Naxos station the three indices present mild drought in the 1959-1960, 1966-1967, 1982-1983 and the 1985-1986 hydrological years. From 1957 to 1959, in the 1965-66 and in the 2000-2001 hydrological years, the drought conditions in this area could be characterized as severe and during 1989-1990 and 1999-2000 as extreme. It should be mentioned that from 1956 to 1960 and from 1963 to 1968, there was a persistence of the phenomenon for 3 or 4 consequently years.

Mild drought at Heraklion station appears during the 1971-72, 1985-86 and from the 1990 to 1991 hydrological years. Moreover, moderate drought conditions occur in the hydrological years of 1966-1967, 1987-1988, 1988-89 and 1999-2000. In this region, extreme drought events appear quite often and especially in the 1958-1959, 1969-1970, 1973-1974, 1989-1990 and 1993-1994 hydrological years, whereas in 1992-1993 the drought conditions in the area were very extreme.

The results for the four stations indicate that RDI and Z-index describe the drought conditions in each area in a similar way. For Larisa station the two indices result the same drought periods in 36 out of 36 drought events (100 %). At Elliniko station the two indices mach in 33 out of 34 (98%) cases. At Naxos station the results are absolutely matched in 37 out of 37 cases (100%) and finally, at Heraklion station the result fit in 42 out of 44 drought events (95%).

In Table 4 the results according to RDI and Z-index for Larisa station are presented. The duration of drought in months is almost the same for both indices. In the 5th and 10th columns of Table 4 the sum of drought severities is shown for the corresponding periods and for both indices, respectively. Columns 6 and 11 of Table 4 show the mean monthly drought severity for each drought event. The two indices indicate similar performance with respect to drought severity and show the same classes in most of the cases. Analogous results of RDI and Z-index arise for the other three study areas.

In Table 5, the results for Deciles method for the four study areas are presented. The results indicate that most of the drought episodes are common in the four areas. In many cases, the drought periods are common to three or two out of the four stations. Moreover, Deciles method shows that drought severity is the same for the common drought periods for all the areas in most of the cases. There is an exception in the hydrological years of 1984-85 at Larisa station, 1956-57 and 1961-62 at Ellliniko station, as well as 1960-61 and 1997-98 for Heraklion station.

The comparison between RDI, Z-index and Deciles methods for Larisa station (Tables 4 and 5) results into common drought periods, except for the 1978-79 hydrological year.

5. CONCLUSIONS

In this paper three drought indices, namely RDI, Palmer Z-index and Deciles method, are calculated based on meteorological data from Larisa, Elliniko, Naxos and Heraklion stations. The data used consist of mean monthly potential evapotranspiration extracted by the use of mean monthly air temperature and monthly precipitation. The time series cover the period of 1956 to 2001 hydrological years. The main difference between the indices is that Palmer Z-index and RDI are estimated on a monthly basis for each hydrological year of the data set, whereas Deciles method is calculated on an annual basis for the same hydrological years. The results show that all the indices identify the drought events which appear in the four study area. Specifically, the three indices identify drought in the same years and drought severity in the same or analogous class. RDI and Z-index results indicate that the drought duration in months is matched in most of the drought events in each station (Larisa station 100 %, Elliniko station 98%, Naxos station 100% and Heraklion station 95% of the cases). The results of the Deciles method show that most of the drought episodes are common in the four areas. In many cases, the drought periods are common to three or two out of the four stations. Finally, the results indicate that the three indices describe drought in a similar way at each study area separately, as well as they indentify the common drought periods between the four stations.

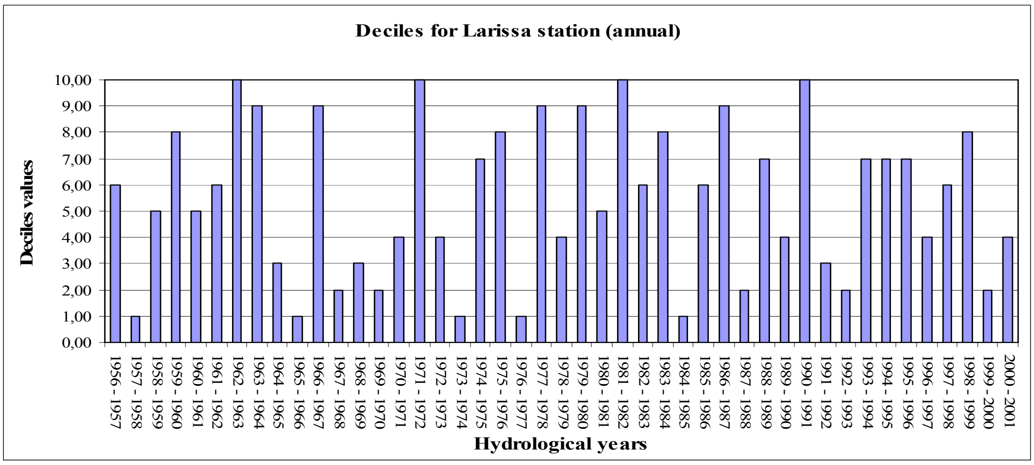

Figure 2. Deciles for Larisa station.

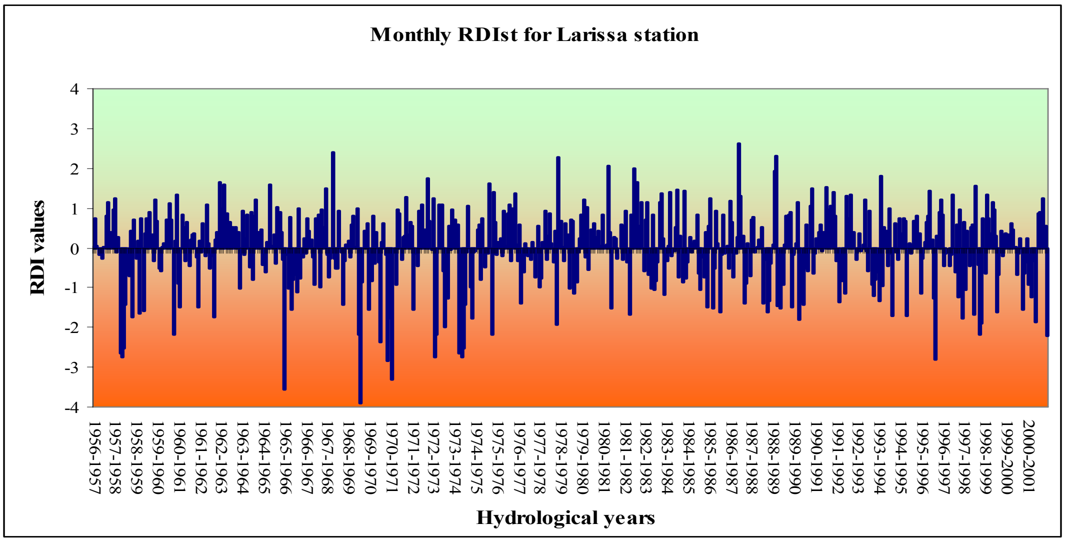

Figure 3. Monthly RDI for Larisa station.

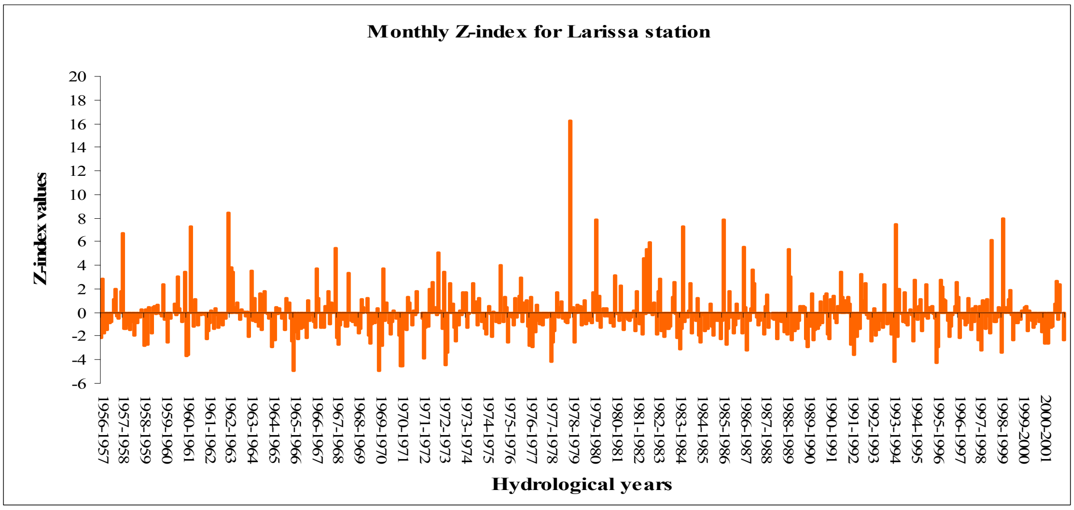

Figure 4. Monthly Z-index for Larisa station

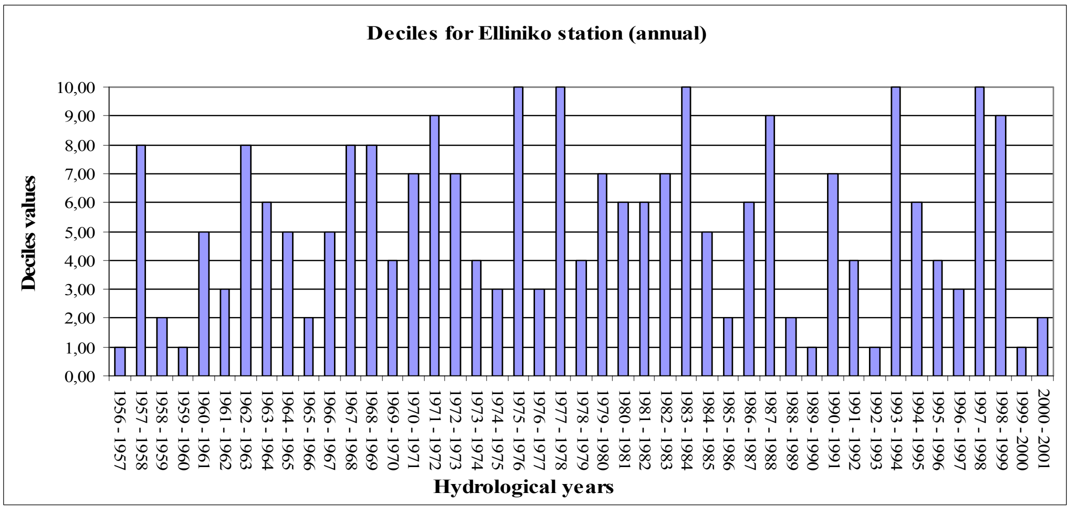

Figure 5. Deciles for Elliniko station.

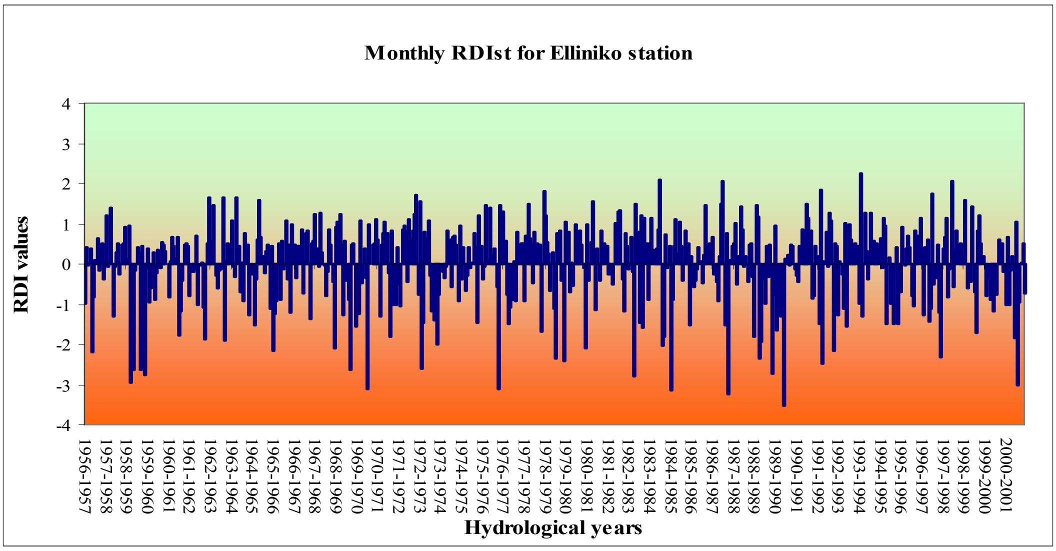

Figure 6. Monthly RDI for Elliniko station.

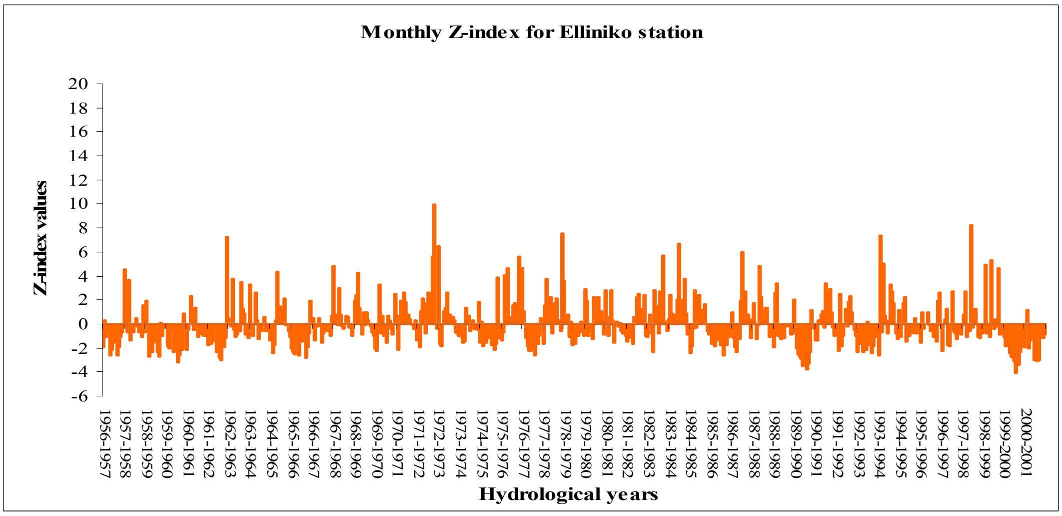

Figure 7.Monthly Z-index for Elliniko station.

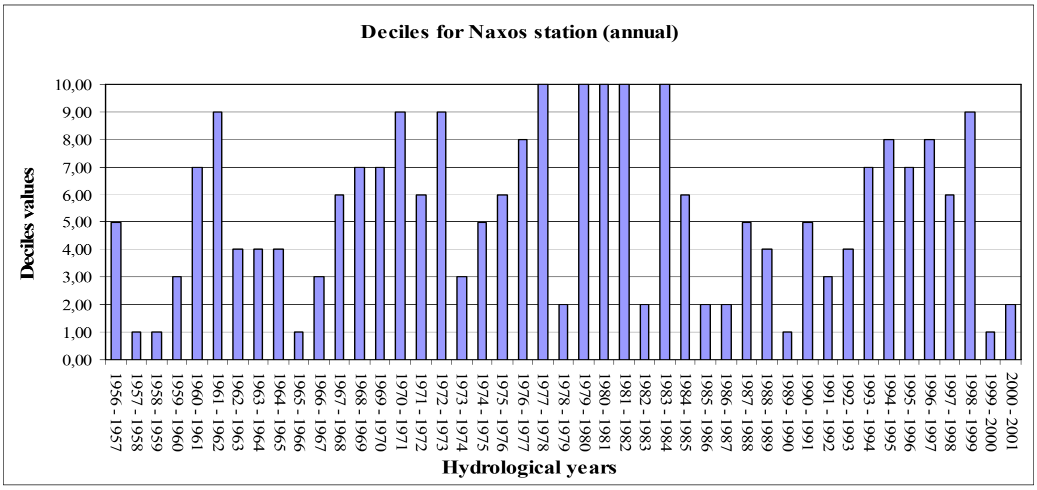

Figure 8. Deciles for Naxos station.

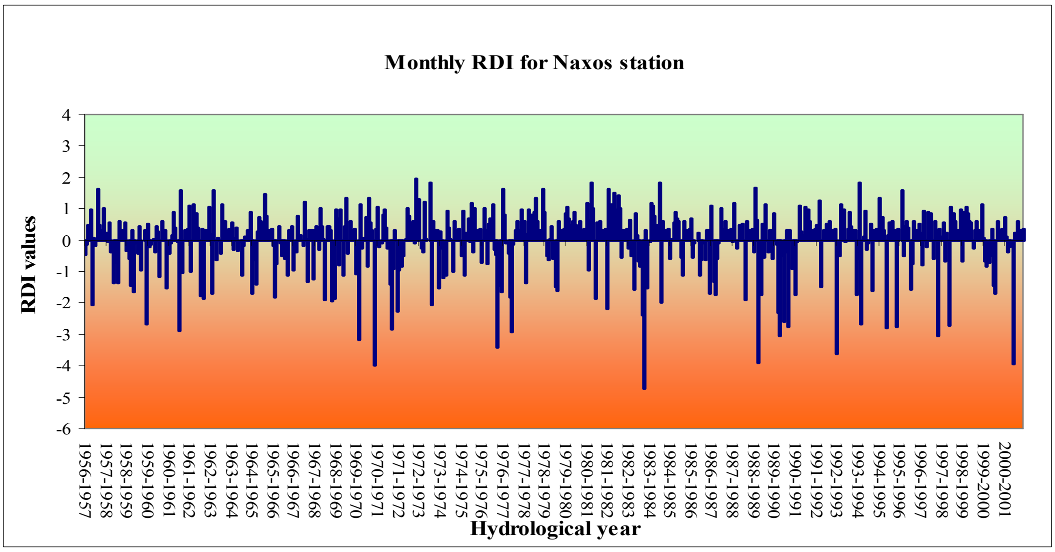

Figure 9. Monthly RDI for Naxos station.

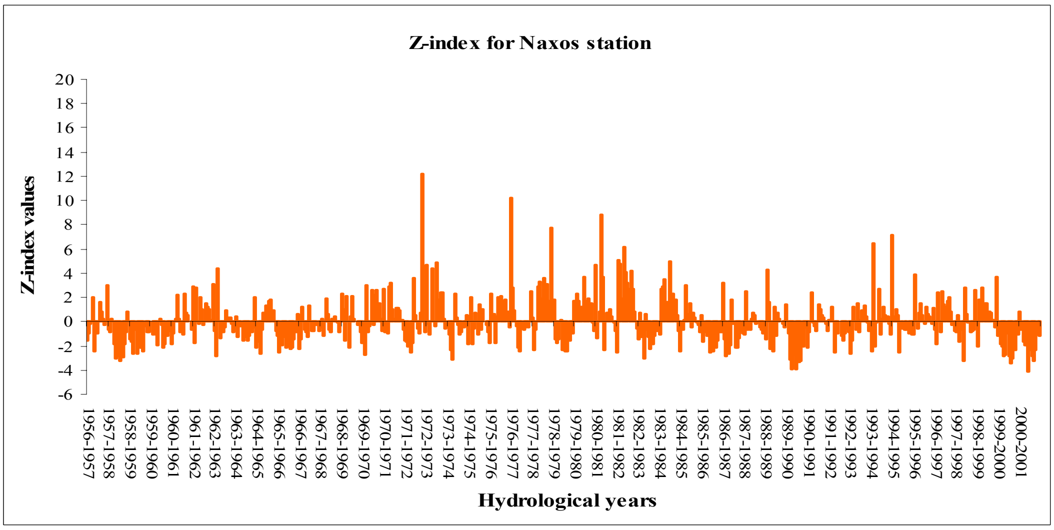

Figure 10. Monthly Z-index for Naxos station.

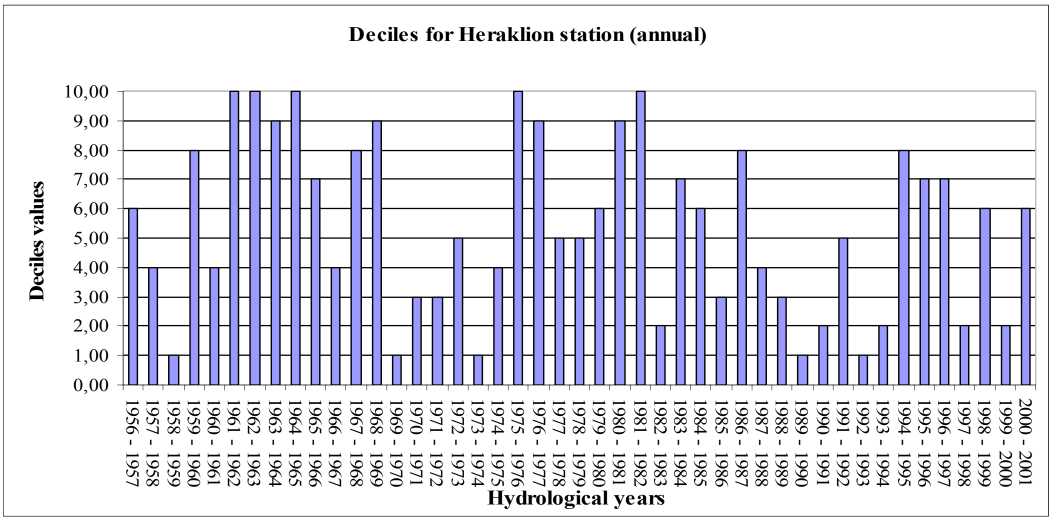

Figure 11. Deciles for Heraklion station.

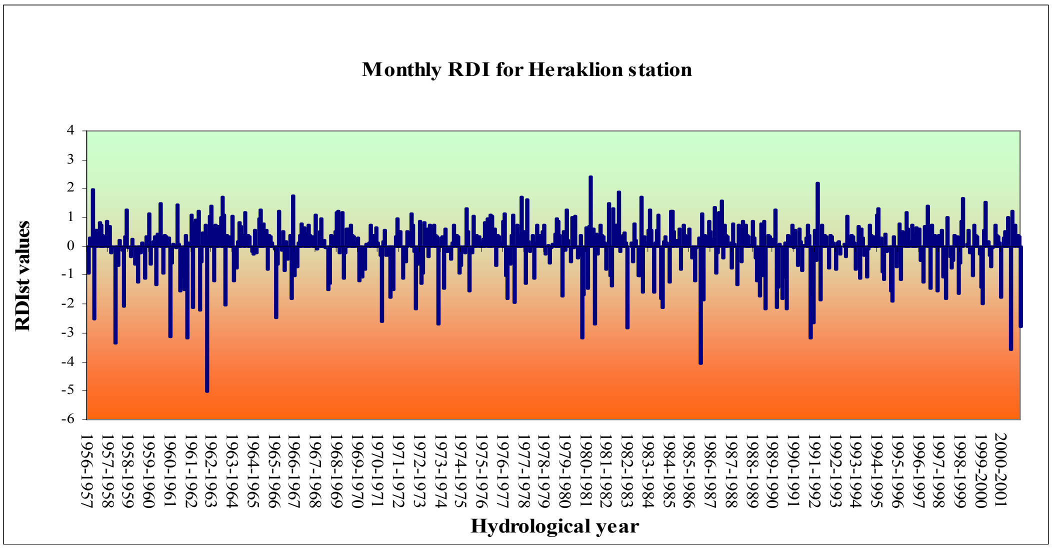

Figure 12. Monthly RDI for Heraklion station.

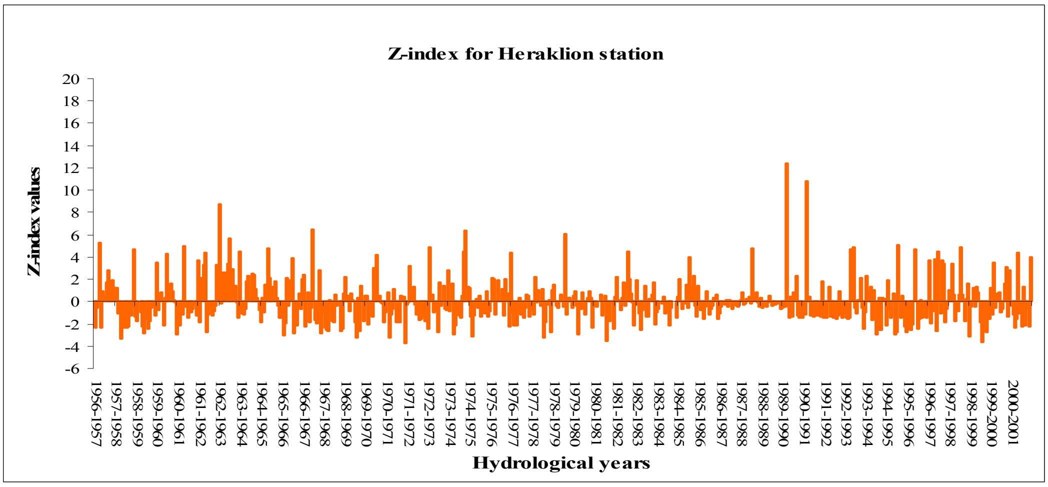

Figure 13. Monthly Z-index for Heraklion station.

Table 4. Duration and Severity of Drought for Larisa station based on RDI_{st} and Z-index.

	RDI_{st}					Z Index				
	Starting Period	**Ending Period**	**Dur ***	**ΣRDI**	**Average Sever ****	**Starting Period**	**Ending Period**	**Dur ***	**ΣZ-index**	**Average Sever *****
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	Jan 1957	Apr 1957	4	-0,53	-0,13	Dec 1956	Apr 1957	5	-4,94	-0,99
2	Nov 1957	Feb 1959	16	-16,08	-1,01	Nov 1957	Feb 1959	16	-16,70	-1,04
3	Oct 1959	Jan 1960	4	-1,08	-0,27	Oct 1959	Jan 1960	4	-4,16	-1,04
4	Oct 1960	Nov 1960	2	-2,37	-1,19	Oct 1960	Nov 1960	2	-7,29	-3,65
5	Apr 1961	Jun 1962	15	-4,96	-0,33	Apr 1961	Aug 1962	17	-11,46	-0,67
6	Oct 1964	Nov 1964	2	-1,06	-0,53	Jul 1964	Nov 1964	5	-6,22	-1,24
7	Sep 1965	Oct 1966	14	-10,29	-0,74	Sep 1965	Oct 1966	14	-20,45	-1,46
8	Jan 1967	Mar 1967	3	-1,17	-0,39	Jan 1967	Mar 1967	3	-3,28	-1,09
9	Oct 1967	Nov 1968	14	-4,55	-0,33	Oct 1967	Nov 1968	14	-15,55	-1,11
10	Apr 1969	Nov 1969	8	-9,32	-1,17	Apr 1969	Nov 1969	8	-14,32	-1,79
11	Mar 1970	Jan 1971	11	-12,59	-1,14	Mar 1970	Jan 1971	11	-18,32	-1,67
12	Nov 1971	Jan 1972	3	-2,15	-0,72	Nov 1971	Jan 1972	3	-6,32	-2,11
13	Nov 1972	Dec 1972	2	-4,90	-2,45	Nov 1972	Dec 1972	2	-7,83	-3,92
14	Apr 1973	Aug 1973	5	-3,90	-0,78	Apr 1973	Aug 1973	5	-5,01	-1,00
15	Jan 1974	May 1975	17	-13,92	-0,82	Mar 1974	May 1975	15	-10,17	-0,68
16	Sep 1976	Aug 1978	24	-8,18	-0,34	Sep 1976	Aug 1978	24	-24,31	-1,01
17	Jun 1979	Sep 1979	4	-2,11	-0,53	Jun 1979	Sep 1979	4	-2,89	-0,72
18	Feb 1981	Jan 1982	12	-4,15	-0,35	Feb 1981	Jan 1982	12	-8,36	-0,70
19	Dec 1982	May 1983	6	-3,96	-0,66	Dec 1982	May 1983	6	-7,87	-1,31
20	Sep 1983	Nov 1983	3	-1,52	-0,51	Sep 1983	Nov 1983	3	-6,63	-2,21
21	May 1984	Sep 1985	17	-6,99	-0,41	May 1984	Sep 1985	17	-18,36	-1,08
22	Dec 1985	Sep 1986	10	-4,46	-0,45	Dec 1985	Sep 1986	10	-9,85	-0,99
23	Dec 1986	Jan 1987	2	-0,90	-0,45	Dec 1986	Jan 1987	2	-3,88	-1,94
24	Jun 1987	Sep 1987	4	-3,02	-0,76	Jun 1987	Sep 1987	4	-3,84	-0,96
25	May 1988	Oct 1988	6	-5,02	-0,84	May 1988	Oct 1988	6	-7,74	-1,29
26	Jan 1989	Apr 1989	4	-4,07	-1,02	Jan 1989	Apr 1989	4	-5,48	-1,37
27	Sep 1989	Oct 1990	4	-8,15	-2,04	Sep 1989	Oct 1990	4	-18,19	-4,55
28	Oct 1991	Mar 1992	6	-4,31	-0,72	Oct 1991	Mar 1992	6	-11,94	-1,99
29	Sep 1992	Oct 1993	14	-6,00	-0,43	Sep 1992	Oct 1993	14	-17,71	-1,27
30	May 1994	Sep 1994	5	-2,26	-0,45	May 1994	Sep 1994	5	-4,61	-0,92
31	Oct 1995	Nov 1995	2	-1,41	-0,71	Oct 1995	Nov 1995	2	-7,16	-3,58
32	Apr 1996	Jun 1996	3	-3,86	-1,29	Apr 1996	Jun 1996	3	-3,93	-1,31
33	Nov 1996	Apr 1998	18	-8,01	-0,45	Nov 1996	Apr 1998	18	-16,14	-0,90
34	Jun 1998	Oct 1998	5	-5,14	-1,03	Jun 1998	Oct 1998	5	-5,51	-1,10
35	May 1999	Jun 1999	2	-2,29	-1,15	May 1999	Jul 1999	3	-4,09	-1,36
36	Mar 2000	Mar 2001	13	-7,93	-0,61	Mar 2000	Mar 2001	13	-15,55	-1,20

***Duration in months, **Drought categories are in Table 2, *** Drought categories are in Table 3.**

Table 5. Duration and Severity of Drought for the four stations based on Deciles method.

	Larisa			Elliniko			Naxos			Heraklion		
A/A	**Drought Periods**	**Dur***	**Average Sever ****	**Drought Periods**	**Dur***	**Average Sever****	**Drought Periods**	**Dur***	**Average Sever****	**Drought Periods**	**Dur***	**Average Sever****
1				1956-57	1	1						
2	1957-58	1	1	1958-60	2	1	1957-60	3	1	1957-59	2	1
3										1960-61	1	4
4				1961-62	1	3						
5	1964-66	2	1	1965-66	1	2	1962-67	5	2	1966-67	1	4
6	1967-71	4	2	1969-70	1	4				1969-72	3	2
7	1972-74	2	2	1973-75	2	3	1973-74	1	3	1973-75	2	2
8	1976-77	1	1	1976-77	1	3						
9	1978-79	1	4	1978-79	1	4	1978-79	1	2			
10							1982-83	1	2	1982-83	1	2
11	1984-85	1	1									
12				1985-86	1	1	1985-87	2	2	1985-86	1	3
13	1987-88 1989-90	1 1	2 4	1988-90	2	2	1988-90	2	2	1987-91	4	2
14	1991-93	2	2	1991-93	2	2	1991-93	2	3	1992-94	2	2
15	1996-97	1	4	1995-97	2	3						
16										1997-98	1	2
17	1999-01	2	2	1999-01	2	1	1999-01	2	1	1999-00	1	2

*** Duration in hydrological years (October to September), **Drought categories are in Table 1.**

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