Implementation of the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) for Regional Drought Assessment: A case study for Cyprus

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Abstract: In the first part of the study, an overview of the precipitation regime of the island of Cyprus is presented, describing the spatial and temporal distribution of this element over the island. The basic data which are used in this analysis are the monthly area average precipitation for the whole island, which is estimated from the records obtained from all rainfall stations using GIS techniques. Regional drought assessment is conventionally based on drought indices for the identification of drought intensity, duration and its areal extent. Therefore, in the second part of the study, a regional drought assessment is attempted, by calculating two well known indices, namely, the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) which are based on historical monthly precipitation and temperature data. Both indices respond in a similar fashion and can be used effectively to analyze drought conditions and for monitor drought events.

Key words: meteorological drought, drought indices, Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Cyprus rainfall regime, drought frequencies

1. INTRODUCTION

Regional drought assessment is conventionally based on drought indices for the identification of drought characteristics, such as its intensity or severity, duration and its areal extent. Drought indices are mainly special combinations of indicators which are based mainly on meteorological and hydrological data. A complete analysis of drought indices is provided by Hayes (2004) and Wilhite (2005), while Tsakiris et al. (2006) give a comprehensive overview of the above indices.

Drought indices are employed to characterize drought and its statistical properties. They provide spatial and temporal representations of historical droughts and therefore place current conditions in historical perspective. They are valuable for providing decision makers with a measurement of the abnormality of recent weather for a region (Wilhite et al., 2000). It is generally accepted that drought is a regional phenomenon. However, information is collected at selected meteorological stations, which can be considered as representing the areas attributed to them. The extent of regional drought is obtained by spatial integration of the meteorological elements using Thiessen polygons or any other GIS techniques.

In the current study, drought assessment is achieved using the Standardized Precipitation Index (SPI, McKee et al., 1993) and the Reconnaissance Drought Index (RDI, see Tsakiris and Vangelis, 2005; Tsakiris et al., 2007) for the whole area of Cyprus. SPI is calculated from the monthly precipitation data, while RDI, apart from precipitation, it also incorporates the potential evapotranspiration which is estimated from the monthly mean temperature data. SPI has been introduced by McKee et al. (1993) and is based only on precipitation data. It was designed to quantify the precipitation deficit for multiple time scales, which reflect the impact of drought on the availability of the different water resources. The basic advantages of using the SPI are the simplicity of its calculation, the possibility to describe drought on different time scales and its standardization which ensures independence from the geographical position of the measuring stations. RDI is similar to the Aridity Index which was proposed by FAO. Since precipitation plays a fundamental role in the estimation of both indices, an overview of the precipitation characteristics of the island...
will be presented in the next section. The third section of this study gives information on water demand and supply over the island. The calculation of the regional drought indices of SPI and RDI, considering Cyprus as one catchment area, is covered in the fourth section of the study, while in the final part of the study a frequency of the occurrence of the drought in Cyprus is presented, including drought monitoring procedures.

2. OVERVIEW OF THE PRECIPITATION REGIME OF THE ISLAND

Cyprus has a typical Mediterranean climate with a strongly marked seasonal rhythm regarding the principal meteorological parameters of temperature and precipitation. Hot dry summers from mid-May to mid-September and rainy winters from November to mid-March are separated by short autumn and spring seasons of rapid change in weather conditions. Rainfall in winter is caused by unstable weather systems often in connection to upper trough induced cyclogenesis and its frontal regimes. These depressions give periods of disturbed weather usually lasting from one to three days and produce most of the annual precipitation (Meteorological Service, 1986). The average precipitation from December to February is about 60% of the annual total (Fig.1).

The annual total ranges from 300 mm in inland plain areas, to 1100 mm at the top of Troodos mountain. Generally, the distribution of rainfall is strongly influenced by the complex topography of Cyprus (Figure 2). The Troodos massif has a considerably higher (locally more than three times higher) amount of yearly precipitation compared to the lowland regions like the Mesaoria Plain and the coastal zones. The west and south-west exposed areas accumulate about 450 mm/year due to the prevailing winds from this direction during the rainy season. In the leeward slopes, rainfall amounts decrease steadily northwards and eastwards to 300 mm in the central plain and the flat eastern parts of the island. The narrow ridge of the Kyrenia range, stretching 160 km from west to east along the extreme north of the island, produces a relatively small increase of precipitation to nearly 550 mm along its ridge at about 1000 m.

![Boxplots of monthly area average precipitation over Cyprus (1961-1990).](image)
The yearly area average precipitation for the island as a whole is about 500 mm but it was as low as 213 mm in 1972/73 and as high as 800 mm in 1968/69. The frequency distribution of the Area Average Annual precipitation of Cyprus for the period 1961-1990, which is the current normal period as suggested by the World Meteorological Organization, is shown in Figure 3, while the time series of the Annual Area Average precipitation starting from 1916 when rainfall measurements begun in Cyprus is shown in Figure 4. The frequency distribution indicates that the annual rainfall data are normally distributed. Figure 4 shows that the annual precipitation in Cyprus is decreasing. The mean annual rainfall in the period 1931-1960 was 524 mm, while in the period 1961-1990 it was about 500 mm and during the period 1971-2000 it was only 460 mm. Generally, a decreasing trend of about 125 mm to the mean annual rainfall of Cyprus was deducted for the 20th century. The non-parametric Mann-Kendal test shows that this trend is highly significant (Water Development Department and FAO, 2002). A similar decreasing trend is shown for the annual number of rain days above given thresholds for a selected location in Cyprus (Fig. 5). The trend of the lines is negative, but it is not significant for the rain days above 20 mm and 50 mm.

Snow occurs rarely in the lowlands and on the Kyrenia range but falls frequently every winter on Troodos mountains above 1000 m. The first snowfalls occur in the first week of December and the last by mid-April. Although, snow cover is not continuous during the winter months, it may lie to considerable depths accumulated up to 1 or 1.5 m for several weeks.

The above characteristics of precipitation affect the length of the growing season of the annual crops. Based on daily precipitation data, the length of the growing season is estimated using a simple water balance model. It is assumed that evaporation proceeds at a constant rate irrespective of the amount of water left in the soil and that the available water capacity of soil was set equal to 100 mm. The end of the growing season is defined as the date when the water balance first falls to zero. Therefore, the length of the growing season is defined as the period when soil moisture is positive (Stern et al., 2006). Using the above simple water balance model, the length of the growing season was estimated for a number of locations below the elevation of 800 m for a period of 15 years. Table 1 shows that the length of the growing season is highly variable, ranging from 65 days to 160 days.
Figure 3. Frequency distribution of the Area Annual Average precipitation in Cyprus (1961 – 1990).

Figure 4. Time series of the Annual Area Average precipitation in Cyprus (1916-2008).
Figure 5. Annual number of rain days above given thresholds (≥2, ≥10, ≥20 and ≥50 mm) at Saittas.

Table 1. Percentiles of the length of the growing season.

<table>
<thead>
<tr>
<th>Percentile</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
</tr>
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<tbody>
<tr>
<td>69.8</td>
<td>85.3</td>
<td>93.7</td>
<td>107.1</td>
<td>113.3</td>
<td>121.1</td>
<td>131.9</td>
<td>136.3</td>
<td>145.1</td>
<td></td>
</tr>
</tbody>
</table>

3. OVERVIEW OF THE WATER DEMAND AND SUPPLY OVER CYPRUS

As it was indicated in the previous section, Cyprus has a semi-arid climate, with an average annual precipitation of about 460 mm (1971-2000) with considerable interannual variations. The island gets through rainfall about 4255 Mm³ every year, 80% of which is lost to the atmosphere by evaporation, resulting in an average water crop of about 800 Mm³ per year. Some 65% or 520 Mm³ of the total annual water crop appears as surface runoff. Of the total surface runoff, 45% or 230 Mm³ is lost to the sea, 27% or 140 Mm³ infiltrates into riverbed aquifers, 8% or 40 Mm³ is used for irrigation and the rest is captured in surface reservoirs. The island’s total surface reservoir capacity is about 300 Mm³ (Water Development Department and FAO, 2002).

The total consumption of water in Cyprus is estimated at 280 Mm³ out of which 210 Mm³ are used for agriculture (75%) and the remaining 70 Mm³ of water are used for domestic and industrial needs (25%). Presently, the contribution of the various water sources to the overall demand for all sectors is as follows: 48% from groundwater, 38% from surface water, 13% from desalination and 1% from springs.

4. RESULTS AND DISCUSSION

4.1. Regional Drought Assessment

Droughts in Cyprus are becoming more frequent events with adverse impacts on the economy, social life and on the environment. During the period 1971-2008, Cyprus suffered from nine meteorological drought events, with the most significant ones in the periods 1971-1974, 1981-1984,
1989-1991, 1993-1994, 1995-2000 and 2004-2008. The first five meteorological droughts were followed by acute water shortage and affected the entire population of Cyprus, whereas the last one developed into hydrological and agriculture drought, although the preceding years were relatively wet and the surface reservoirs were filled with water. It has to be stressed that the amount of rainfall during the hydrological year 2007-2008 was only half the mean annual rainfall which is the second lowest during the whole period of measurements in Cyprus. As a result, in 2008 the dams are almost empty and the government has imposed a number of water saving measures in order to overcome the problem. Details about the drought conditions prevailed during the current hydrometeorological year are given by Michaelides and Pashiardis (2009). The second characteristic of the drought periods is the fact that the duration of the drought episodes is usually 1 to 3 years, with the exception of the last cases when drought was recorded for five consecutive years.

4.2. SPI and RDI regional drought indices

In this section, an attempt is made to calculate SPI and RDI indices for the whole island using the DrinC software that was developed by the Laboratory of Reclamation Works and Water Resources Management of the National Technical University of Athens, Greece (Tsakiris, 2004). The regional drought indices were estimated for the period 1971-2008 by integrating spatially precipitation and potential evapotranspiration using GIS techniques. During the period 1971-2008, 9 drought spells were recorded, while the return period of the drought spells practically ranges from 4 to 5 years.

Figures 6 and 7 show the regional SPI and RDI for the whole island. The diagrams show that there is a very good correlation between the two indices, with a mean correlation coefficient of 0.95. Apart from the correlation of the two indices, the graphs demonstrate a lot of similarities. Extreme drought conditions were recorded in the years 1972-1973, with the SPI reaching the value of -3. Severe drought spells (SPI or RDI less than -1) were also recorded in the periods of 1989-91, 2005-06 and the most recent one in 2007-08. It has also to be stressed that more frequent and severe drought events were recorded during the last 15 years (since 1990). Figure 8 shows the percentages of the wet and dry years based on the SPI classification for the period 1971-2008. The total percentage of the wet years is 27% and of the dry years is 16%.

![Figure 6. SPI annual drought indices for the whole island of Cyprus.](image-url)
4.3. Drought monitoring

For the needs of the monitoring of drought, the SPI was calculated for shorter periods. On the one hand, 3-month SPI is a suitable representation of short and medium term moisture conditions and offers a seasonal estimation of precipitation deficit or surplus that is particularly useful in agricultural activities. On the other hand, the 12-month time scale avoids intra-annual frequency variations and allows the identification of the main hydrological droughts and dry/wet periods (Vicente-Serrano, 2005). Figure 9 shows the SPI series for the reference periods October-December (SPI3) and October-March (SPI6) for the whole area of Cyprus. The graph shows that the time series of SPI3 can be used effectively to predict the reference period of SPI6 or later period calculations, since both graphs follow the same pattern.
5. CONCLUSIONS

From the analysis presented in this paper, it may be concluded that both SPI and RDI can be used for drought assessment and monitoring. Both indices can be used effectively to analyze drought conditions and possibly can be used by an expert system to predict and assess the effects of drought on various sectors of the economy. In rainfed systems where cereals are the dominant crops, cereal yields are appropriate drought indicators. Therefore, the relationship between the above drought indices and cereal yields will give valuable information of the impacts of drought on agriculture.

According to the Intergovernmental Panel on Climate Change (IPCC) estimations, it is anticipated that the climate change in the Eastern Mediterranean will have an impact on both the temperature and precipitation regimes: an increase in the former and a decrease in the latter. As a consequence of the temperature increase, the potential evapotranspiration is also expected to rise. The time series of the annual area average precipitation of Cyprus exhibits a decreasing trend of 1 mm per year, while temperature has increased by about 0.8 °C. (Price et al., 1999).

The statistical analysis of any drought indicator is not sufficient to ensure a complete climatic characterization of meteorological drought, but it must be supported by an adequate characterization of the spatial-temporal variability of the atmospheric circulation, from large-scale to meso-scale, taking also into account the connections existing between various spatial scales. Moving down from the hemispheric scale, it is possible to identify several important circulation patterns, such as the North Atlantic Oscillation (NAO), the situations with blocking phenomena, and the cyclonic and anticyclonic features of the pressure field at ground level. These structures have to be related with the precipitation and the drought indicators. Several studies indicate that during the positive phase of NAO, the jet stream is more intense with a shifting towards northern Europe. As a result, Atlantic storms are more likely to shift towards higher latitudes in Europe, bringing heavier precipitation in these areas. On the contrary, in the Mediterranean basin, under such conditions, precipitation is very low, leading to the establishment of drought conditions (Quadrelli et al., 2001). Therefore, a relationship between the regional drought indices and the North Atlantic Oscillation Index should be established.
REFERENCES


