Application of the standardized precipitation index (SPI) to the Marmara region, Turkey

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Abstract Since droughts are natural phenomena, their occurrences cannot be predicted with certainty and thus they must be treated as random variables. Once drought duration and magnitude are found objectively, it is then possible to plan for the transport of water in known quantities to the drought stricken areas either from other water resource alternatives or from water stored during wet periods. Drought period affects economic, social and political events and the summation of deficits over that period is referred to as the drought magnitude. Drought intensity is the ratio of drought magnitude to its duration. Drought properties at different truncation levels provide significant hydrological and hydrometeorological design quantities. In this paper, standard precipitation index (SPI) is used for determining drought properties of a given hydrological series. This index is applied to the Edirne, Istanbul, and Kirkürek rainfall records in Turkey and then the drought period, magnitude, and SPI values are presented in the form of tables.

Key words deficit; drought intensity; drought magnitude; drought period; duration; hydrological series, standardized precipitation index, SPI; Turkey

INTRODUCTION

Droughts are extreme hydrological events which may adversely affect social, economic, cultural, political and other functions of a region during dry periods. Drought prediction may prevent these adverse consequences to a significant extent. In order to reach such a target, it is necessary to develop a method of prediction by either deterministic or stochastic techniques based on the available past experiences as well as environmental conditions. Drought occurrences are rather complex since they depend on various interactions of many hydrological phenomena such as rainfall, runoff, evaporation, infiltration, and surface and groundwater storages.

Drought analysis has concentrated on point analysis which yields the temporal variations at a specific site only. The first classical approach has been the evaluation of the instantaneously smallest value in an observed hydrological sequence recorded at a single site (Gumbel, 1963). This method gives information on the instantaneous maximum value of drought magnitude only, without any elaboration of either its duration or areal extent. Yevjevich (1967) presented the first objective definition of a hydrological point drought. Applications have been reported by Saldarriaga & Yevjevich (1970), Millan & Yevjevich (1971), Guerrero-Salazar & Yevjevich (1975), and Şen (1976, 1977, 1980).

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major
indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer (1965) Drought Severity Index has been widely used in Turkey.

In order to understand that a deficit of precipitation has different impacts on the groundwater, reservoir storage, soil moisture, snow cover, and streamflow, McKee et al. (1993) developed the standardized precipitation index (SPI). The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short time scale, while groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee et al. (1993) originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month time scales.

McKee et al. (1993) used a classification system which is normalized so that wetter and drier climates can be represented in the same way. In addition, wet periods can also be monitored using the SPI (McKee et al., 1995). McKee et al. (1993) also defined the criteria for a “drought event” for any time scale. A deficit occurs any time that the SPI is continuously negative. The accumulated magnitude of deficits is referred to as drought magnitude, and it is the positive sum of the SPI for all the months within a drought event.

**STANDARDIZED PRECIPITATION INDEX (SPI)**

This is simply standardization of a given time series, $X$, as $X_1, X_2, ..., X_n$. The standardized precipitation series, $x_i$, is:

$$x_i = \frac{X_i - \bar{X}}{S_x}$$

where $\bar{X}$ is the arithmetic mean and $S_x$ is the standard deviation of the series. The SPI is defined theoretically as the sub-areas under a normal (Gaussian) probability distribution function. It has many advantages over other drought indices which require more than two variables such as the Palmer approach. It needs consideration only of two parameters, the arithmetic mean and the standard deviation.

In papers by McKee only empirical calculations of drought descriptions such as mild (MID), moderate (MOD), severe (SED) and extreme (EXD) drought cases are calculated and accordingly the classifications are done quickly at a single site and correspond to SPI categories as shown in Table 1.

<table>
<thead>
<tr>
<th>SPI values</th>
<th>Drought category</th>
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<tbody>
<tr>
<td>0 to -0.99</td>
<td>mild drought</td>
</tr>
<tr>
<td>-1.00 to -1.49</td>
<td>moderate drought</td>
</tr>
<tr>
<td>-1.50 to -1.99</td>
<td>severe drought</td>
</tr>
<tr>
<td>-2.00</td>
<td>extreme drought</td>
</tr>
</tbody>
</table>

Table 1 Standard precipitation index categories.
Empirical drought descriptions are investigated by moving averages of 3, 6, 12, 24, and 48 months (McKee et al., 1993, 1995). Drought magnitude, $M_m$, is defined as:

$$ M_m = \sum_{i=1}^{m} |t - x_i| $$

where $m$ is the number of deficits during a drought period and $t$ is the truncation level for each drought description as 0, -1.0, -1.5 and -2.0. Drought intensity is defined as the ratio of drought magnitude over drought duration as:

$$ I_m = \frac{d_m}{M_m} $$

At each truncation level, extreme (greatest and smallest) values of the above-mentioned drought properties are $d_{max}$, $d_{min}$, $M_{max}$, $M_{min}$, $I_{max}$ and $I_{min}$.

**APPLICATION**

The SPI methodology is presented for the cities of Edirne, İstanbul, and Kırklareli in the northwestern area of Turkey. About 60 years of precipitation data are available, from 1931 to 1991 (Fig. 1).

Tables 2–5 show statistical parameters concerning drought duration, magnitude, and intensity (SPI) at 0.0, -1.0, -1.5 and -2.0 standard truncation levels, respectively.
In Fig. 2, the changes of drought magnitude versus duration are shown. Clearly, an increase in the drought duration results in an increase in drought magnitude. Similar
The SPI is commonly used for the identification of various drought characteristics such as the duration, magnitude, and intensity at different standard truncation levels. Basic formulations are given for these drought features and their applications are presented for Edirne, Istanbul, and Kirklareli precipitation records in northwestern Turkey. The graphs can be obtained for other truncation levels (e.g. −1.5 as illustrated in Fig. 3). The only expected difference will be in the slope of the relationships which are equivalent almost to straight lines that pass through the origin.

CONCLUSION

The SPI is commonly used for the identification of various drought characteristics such as the duration, magnitude, and intensity at different standard truncation levels. Basic formulations are given for these drought features and their applications are presented for Edirne, Istanbul, and Kirklareli precipitation records in northwestern Turkey. The
relationships between the drought duration and magnitude are provided in the form of scatter diagrams with the best straight-line fits. These are obtained for different truncation levels as 0, -1, -1.5, and -2. Maximum mild drought duration appears as 27.5 months; maximum moderate duration is 6 months; maximum severe duration is 4 months, and maximum extreme duration is 2 months.

REFERENCES


