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Observed and projected changes in drought conditions of Turkey

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Abstract. Drought has become a recurring phenomenon in Turkey in the past few decades. Analyzing the historical occurrence and future projections of drought characteristics such as frequency, intensity and duration provide a better understanding of the range of climate futures for one particular country. Hence, this study aimed at analyzing the likely changes of drought characteristics in the future. The Standardized Precipitation Index (SPI) has been used to assess the drought characteristics. Rainfall datasets for the period 1960-1990 were acquired from 52 stations throughout Turkey. The future rainfall series for the years 2070-2100 were simulated using a regional climate model (RegCM3). The validated RegCM3 was used for simulating future climatic data, and the simulated rainfall series were used for calculation of drought indices. To asses the likely changes in future drought characteristics, each simulated future rainfall series was compared with the average rainfall amount derived from the reference period in SPI calculations. The maps were drawn to determine the spatial changes of droughts. The results showed that drought conditions are diverse in the country, and also increasing trends for intensity, frequency and duration were detected. The Eastern part of Marmara, the Black Sea and north-east part of the East Anatolia Region are characterized by wetter conditions. Particularly severe drought conditions are expected in the Western Mediterranean and Aegean Regions, although other regions will also confront with more frequent, intense and long lasting droughts.

Keywords. Drought monitoring – SPI – Climate change.

Changements observés et expectés dans les conditions de sécheresse en Turquie

Résumé. *Durant les dernières décennies, la sécheresse en Turquie est devenue un phénomène récurrent. Les événements historiques et les projections futures des caractéristiques principaux de la sécheresse comme la durée, l'intensité et la fréquence nous donnent une compréhension plus vaste sur les tendances climatiques d'un pays. Cette étude vise à une analyse de l'évolution probable des caractéristiques de la sécheresse à travers l'index de précipitation standard (Standardized Precipitation Index, SPI). Les données pluviométriques pour la période comprise entre 1960 et 1990 ont été obtenues auprès de 52 stations de toute la Turquie. Les précipitations futures pour les années 2070-2100 ont été simulés a partir d'un modèle climatique régional (RegCM3) et ont été utilisées pour le calcul des indices de sécheresse. Pour évaluer les changements probables des caractéristiques futures de la sécheresse, les précipitations simulées ont été comparée avec celles dérivées de la période de référence (1960-1990) dans les calcules du SPI. Les cartes ont été établies afin de déterminer les variations spatiales de la sécheresse. Les conditions de sécheresse sont variables tout au long du pays avec une tendance croissante pour l'intensité, la fréquence et la durée. La partie orientale de Marmara, la mer Noire et le nord-est de l'Anatolie de l'Est sont les plus humides. Des conditions de sécheresse particulièrement graves sont prévues pour la partie Méditerranéenne occidentale et la Région Égéenne du pays. Cette situation se répète dans autres régions de pays avec des périodes de sécheresse plus fréquentes, intenses et de longue durée.*

Mots-clés. *Monitorage de la sécheresse – SPI – Changement climatique.*

I – Introduction

Climate variability in the 20th century was characterized by apparent precipitation variability at both temporal and spatial scales. In addition to the well-known characteristic seasonal and year-to-year variability, some marked and long-term changes in precipitation occurred in Turkey, particularly after the early 1970s. Drought, originating from a deficiency of precipitation over an extended time period (which is usually a season or more) has become a recurring phenomenon in Turkey in the past few decades. Agriculture consumes about 75% of the available water in Turkey. When available water is insufficient to satisfy agricultural requirements, impacts can be acute. In extreme cases, lack of water can cause severe economic, social, and environmental crises, and recovery from these crises will require much time and money. Spatially coherent with the significant drought events since early 1970s, water stress and shortages for all water user sectors have also reached their critical points and up to 100% of yield losses have been reported in Turkey (Türkes, 1999; Türkes and Erlat, 2003, 2005; Anonymous, 2008).

Analyzing the historical occurrence of drought provides an understanding of the range of climate possibilities for a country, resulting in more informed management decision-making. There are several indices that measure to what extent precipitation for a given period has deviated from historically established norms. The Standardized Precipitation Index (SPI) is the number of standard deviations that the observed value would deviate from the long-term average (or median) for a normally distributed random variable (McKee *et al.*, 1993). The SPI has several advantages over previous indices, including its simplicity and temporal flexibility, which allow its application for water resources on all timescales, and will be used widely for detecting and monitoring droughts (e.g. Hayes *et al.*, 1999; Sırdas and Şen, 2001). Several studies have observed the spatial and temporal variations of Turkish standardized (normalized) precipitation series, and of the meteorological droughts and drought vulnerability of Turkey (e.g. Sırdas and Şen, 2001; Türkes and Tatlı, 2009).

Future projections about spatial and temporal changes in drought characteristics such as frequency, intensity and duration can be challenging for developing appropriate mitigation and adaptation strategies. There are a few studies dealing with drought occurrence probability in Turkey (i.e., Türkes, 1996, 1999). However these assessments were made using probability tests with historical drought statistics. Thus the climate-change projections, particularly those performed using high-resolution climate models, have not yet been used for future drought investigations. Hence, the objectives of this study are: (i) to analyze the spatial and temporal dimensions of historical droughts in Turkey; (ii) to predict the potential intensity, frequency and duration of droughts in Turkey for the future (2070-2100); and (iii) to determine likely changes in drought conditions in the future compared to the reference (1960-1990) conditions.

II – Study area, data and methodology

Turkey's climate is characterized mainly by the Mediterranean macro-climate. There is therefore a highly seasonal precipitation regime in the western and southern regions, continental semi-arid climate in the Central and Eastern Anatolia regions, and humid-temperate, uniformly rainy climate in the northern Marmara and Black Sea regions (Erinc, 1969; Türkes, 1999; Trigo *et al.*, 2006).

Historical rainfall data sets for the reference period, 1960-1990, were acquired from 52 stations representative of all kinds of regions with different rainfall regimes in the country. The data set includes monthly precipitation totals (mm) recorded at the stations of the Turkish State Meteorological Service (TSMS), most of which are principal climatological stations. Homogeneity analyses were applied to the historical rainfall series.

The future rainfall series for the 2070-2100 period was simulated using a regional climate model – RegCM3 (Giorgi and Bates, 1989), for IPCC's SRESS-A2 scenario conditions. To produce the

lateral meteorological boundary conditions for the RegCM3, the FvGCM fields, the regional model was run using global model outputs, which have grid interval 1° × 1.25°. The model resolution was 20 km.

The Standardized Precipitation Index (SPI) has been used to assess the drought characteristics, and is calculated by taking the difference of the precipitation from the mean for a particular time scale, then dividing it by the standard deviation.

$$SPI = (x_i - \bar{x}) / \sigma$$

where X_i is the precipitation, $\overline{X}$ is the arithmetic mean and σ is the standard deviation of the series.

The normalized series of SPI values represent wetter and drier climates in the same way. McKee *et al.* (1993) defined the criteria for a drought event for all of the time scales and classified the SPI to define various drought intensities (Table 1). In a drought evaluation using SPI, the period in which the index has a negative value is defined as a dry period. The month in which the index value drops to negative is evaluated as the start of drought and the month in which the index increases to positive values is defined as the end of drought (McKee *et al.*, 1995).

Table 1. SPI categories

SPI values		Index
2.0+	Extremely wet	1
1.5 to 1.99	Very wet	2
1.0 to 1.49	Moderately wet	3
-.99 to .99	Near normal	4
-1.49 to -1.0	Moderately dry	5
-1.99 to -1.5	Severely dry	6
-2 and less	Extremely dry	7

To verify RegCM3 simulations, the model was performed for the reference period and simulated rainfall data were used for computing SPI for the 1960-1990 period. Then, to proof the capturing capacity of the RegCM3, these results for the reference period were compared with SPI values calculated using observed climatic data. The validated climate model was used for performing climatic data for the future 30-year period (2070-2100). Using the projected climate data, the SPI series were computed for the future conditions, which indicates the drought events within future 30-year period. Furthermore, to determine the likely changes between reference and future periods, the projected future rainfall series was compared with the average rainfall amount derived from the reference period in SPI calculations.

III – Results and discussion

Drought index results were analysed at regional scale in particular referred to the rainfall regime regions in the country. In most stations in the Marmara Region, extremely severe drought (compared with average values) was experienced only in 1961. However, during the 1960-1990 period, particularly severe drought conditions occurred twice while one year was extremely wet in the region. The highest areal coverage of drought was observed in 1972 and 1990 in the region, while some cities West Turkey suffered moderate drought conditions for six years within the reference period (1960-1990). Adana, in the southern part of Turkey, experienced protracted moderate droughts between 1970 and 1973. The Black Sea Region suffered one year of extremely severe drought while severe drought conditions were observed for two years, particularly in coastal areas of the region. Contrary to the west of Turkey, East Anatolia faced

moderately wet conditions for up to seven years, whereas severe drought occurred for two years in one city only in those three decades, Southeastern Anatolia receives less rainfall compared to the other regions in Turkey, consequently the SPI values indicated that severe droughts occurred up to five times in four cities in the region. Drought-affected areas were largest in 1970, 1973, 1989 and 1990, while one station of the region experienced three years of consecutive drought events.

Figure 1 shows an example of a 12-month scale SPI time series for both reference and future 30-year-periods at one of the stations. Similar time series have been derived for the other 51 stations. The intensity, frequency and duration can be detected from those graphs, and the statistical analyses for each drought characteristics were done in detail. As shown in the graphic, the intensity and the frequency of droughts will likely be increased in Adana stations. Consecutive drought years can also be expected after 2080.

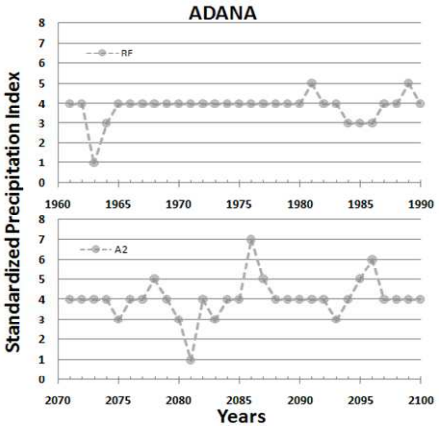

Fig. 1. Observed (reference period) and simulated (future period) SPI values.

The SPI values calculated using simulated future rainfall series and the arithmetic means of the reference period indicated increases up to three times the frequency and intensity of drought events in some cities of the Mediterranean Region. Additionally the wet conditions observed in the reference period are unlikely to occur in the Mediterranean and Aegean regions in future. Especially in the coastal areas of west and south-west Turkey, drastic increases in severe drought conditions can be expected. Evaluation of all stations in the Aegean and the Mediterranean regions showed a shift to more dry conditions in the future compared to the past observations (Fig. 2).

Most of the stations in the Marmara Region will experience more dry conditions while only two of them expected to get wetter in the future. The Black Sea Region is the only region which is generally will have wetter conditions than drier compared to the past during the years between 2070-2100.

IV – Conclusion

The study results showed that drought conditions are diverse in the country, while trends indicating increasing intensity, frequency and duration were detected. At the regional scale, the Eastern part of Marmara, the Black Sea Region and northern and eastern parts of the East Anatolia Region are characterized by wetter conditions. Particularly severe drought conditions are expected in the Western Mediterranean and Aegean Regions, although other regions of the

country will also confront with more frequent, intense and long-lasting droughts. Most of the agricultural production areas like central Anatolia (an important wheat production area for Turkey), Mediterranean (mainly corn and citrus products), Southeast Anatolia (cotton and cereals) and the Aegean (fruits trees, cotton, corn) are predicted to suffer more frequent and intense droughts in the future, thus shifting to drier conditions. As a consequence of meteorological drought, shortages in the water resources and losses in crop yields can also be expected.

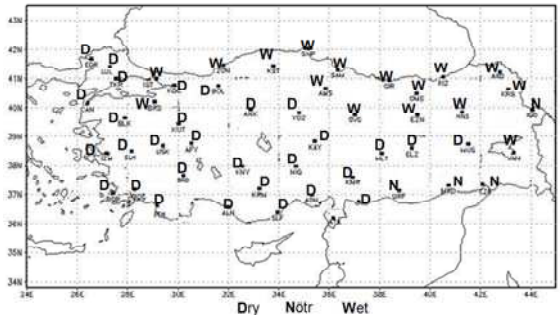

Fig. 2. Predicted changes of drought conditions in Turkey (D = drier, N = no change, W = wetter).

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