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Spatio-Temporal Assessment of Historical Droughts using SPI with GIS in GAP Region, Turkey

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Abstract: A study was carried out to investigate drought behaviors of the Southeastern parts of Turkey using SPI method for the period from 1962-2002. The multiple-time scaled SPI results were only evaluated for the rainy season of the area, from October to May. Point-wise indices were interpolated over the whole area using inverse distance technique in order to obtain areal extending of the drought quantity. The results indicated that a dramatic and widespread drought event was recorded in the year of 1973 at most of the stations and drought categories. However, regardless of drought severity, an extraordinary dryness was experienced from October 1999 to May 2000; the whole study area was under drought conditions for all months. In February of 1989, extreme drought was dominant over the region in the 2 month drought category. The highest SPI value of -5.46 was observed in May of 1984 at the Siverek station. A prolonged drought was experienced in the 12 month category that was successive for 49 months; from March, 1970 to March, 1976 in Siirt. The overall outcome of this study exhibits that hazardous droughts were experienced from time to time across the study area during the examination period. Those dry terms come out with unfavorable results on agricultural practices and water resources in the area. The lowest cereal yield and operational water levels of major dams were recorded during those unusual dry years. Better management of natural resources will be a good solution to overcoming these kinds of natural problems in the similar regions.

Key words: SPI, drought, GIS, areal extending

INTRODUCTION

Drought is one of the most serious natural hazards because of the complexity of the issue, which arises from climatic variability and its impact appears after the event is already over. We know that investing companies, governmental agencies and farming communities are suffering from rainfall anomalies around the world including Turkey, where they lose billions of dollars every year due to drought. Therefore, the occurrence of drought must be understood and appropriate drought indices should be investigated for different goals such as agricultural practices, engineering facilities, water management and fire control. In the past, many drought indices have been developed to address existing issues and are used by decision makers and planners for different purposes. The most well-known drought indices are Palmer Drought Severity Index (PDSI) (Palmer, 1965), Rainfall deciles (Gibbs and Maher, 1967) and Standardized Precipitation Index (SPI) (McKee *et al*., 1993). Although there is no common description of drought, scientist should analyze the available data and consider there to be four types of drought; the meteorological, hydrological, agricultural and social-economical drought, which will help to solve these issues. Regardless of methods, we need to know some vital features of droughts, such as duration, severity and spatiotemporal extension for the given period. We also know that throughout the ages some tribes moved from one place to another to sustain their generations from the danger of drought events. On the other hand, one should keep in mind that droughts lead to the end of several enormous civilizations throughout the ancient world history.

A number of studies have been done to investigate the ability of various drought indices to detect and monitor drought events on local and/or regional scales over the years, around the world and in Turkey (Lloyd-Hughes and Saunders, 2002; Bonaccorsa *et al*., 2003; McKee *et al*., 1993; Sönmez *et al*., 2005; Paula *et al*., 2005, Tuzun *et al*., 2001; Topçuoglu and Baykan, 2001). Among the drought indices the Palmer Drought Severity Index (PDSI) was development by Palmer (1965) and it uses observed precipitation, temperature and available soil water content of the soil of the region. In addition to those four main parameters, there are complicated numerical computation steps which are used to get 25 parameters in order to reach the final PDSI estimate. Despite its complexity, PDSI became the most prominent index for determining meteorological drought around the world. However, some researchers are suffering from the lack of availability of the required parameters in order to compute the PDSI.

After nearly three decades, a new drought index was introduced by McKee *et al.* (1993) called the Standardized Precipitation Index (SPI) which was mostly used by drought scientists. SPI then found a wide application area in different scientific disciplines due to its simplicity and user friendliness and its great success in describing drought severity. SPI is based on observed precipitation values gathered from meteorological stations and dimensionless SPI is computed based on the cumulative probability of the event. Besides some disadvantages of the SPI approach, there are advantages, the method computes drought quantity at the different time steps; shorter steps (1, 2, 3 and 6) stand for agricultural and meteorological droughts and longer steps (9, 12 and more) stand for hydrological drought. Therefore, the SPI method was chosen for detection and monitoring drought severity, considering agricultural and hydrological aspects in the Southeastern part of Anatolia of Turkey where a multi-purpose and integrated regional development project (called GAP in Turkish) was started in the second half of 20th century to provide a sustainable development in the region.

The GAP project of Turkey covers an area of nearly 75,000 km^2 (nearly 10% of Turkey) including nine administrative provinces. The expectations from Turkish government of the GAP project are much more than originally thought. According to officials, the project will provide enhancements in social status, improvements in agricultural productivity, reductions in unemployment, raises in education levels and increases in healthcare services in the project area. Reaching of those goals is not easy; it requires proper management of finite natural resources. We had been waiting for decades to have mentioned goals for the region. Although irrigation projects were planned and some of them are currently under operation, drought will still remain a major problem over the area because irrigation projects do not cover 1.4 million hectares out of the 3.1 million hectares of agricultural land (Anonymous, 2005).

With this study, it was aimed to investigate the multiple time scales drought indices for the rainy season of the GAP area using SPI at each station over several years. Areal extending maps of drought quantity were produced using an adequate interpolation technique for the different time scales for each month. Point-wise and areal distribution of drought quantify was evaluated accordingly.

MATERIALS AND METHODS

Materials: This study was conducted at Harran University, located in Southeastern Anatolia Project area,

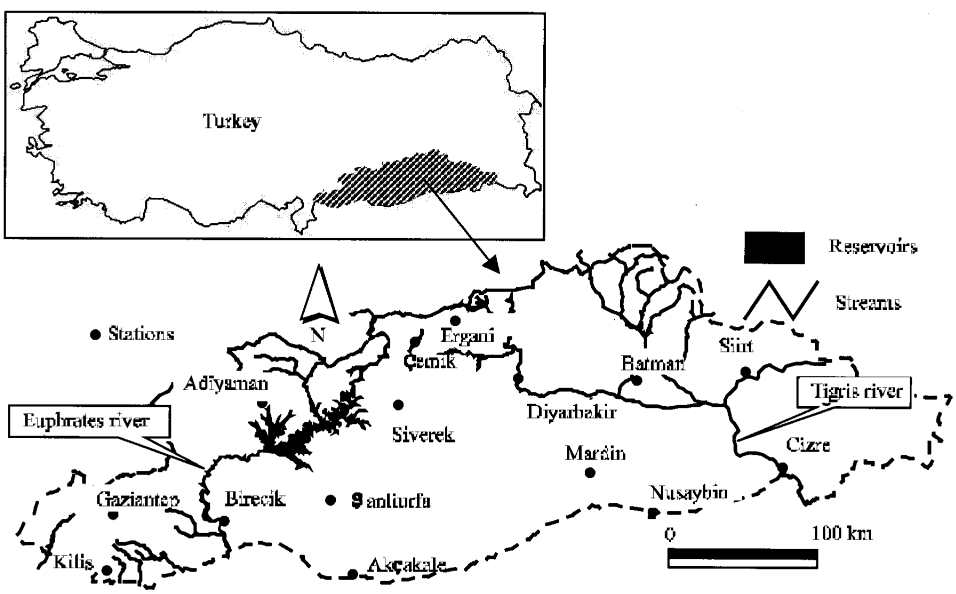

Fig. 1: Locations of the studied stations

Table 1: Calculated SPI quantities and its corresponding drought categories

SPI quantities	Drought category
0 - -0.99	Mild drought
-1.00 - -1.49	Moderate drought
-1.50 - -1.99	Severe drought
-2 or less	Extreme drought

southeastern part of Turkey, in 2005. Southeastern Anatolian Project (called GAP in Turkish) covers approximately an area of 75,000 km^2 comprised of 41% agricultural lands, 17% forest, 31% pasture and ranges and 11% other. The area is surrounded by Syria to the south and Iraq to the south and southeastern side.

Climatic observations were started in 1929 at the major Meteorological station and any others the came up in the study area after then. In this study, in order to provide a comparison period, monthly total precipitation values were used from 1962 to 2002 from the fifteen randomly distributed stations over the area (Fig. 1). Missing values were completed using the observations from the month before and the month after, not exceeding 5%.

Methods: The magnificence of the drought severity was estimated by researchers using different approaches such as PDSI, SPI, palmer, etc. indices to achieve their specific goals. In this study, standardized precipitation index was adopted to determine monthly drought indices at the stations. SPI method was developed by McKee *et al.* (1993) to quantify precipitation deficits based on different time scales. The basic idea behind this method is the standardization of different time scaled monthly total precipitation (x_i) using their long term mean ($\bar{x}_i$) and standard variation (σ) for each ending month as given below. Further details of the method were given intensively in the literature (McKee *et al.*, 1993; Bonaccorsa *et al.*, 2003; Sönmez *et al.*, 2005).

$$SPI = \frac{x_i - \bar{x}_i}{\sigma}$$

Drought categories using SPI indicator were proposed by McKee *et al.* (1993) as illustrated in Table 1. Although those categories were interpreted differently by some scientist, this study devoted the original classification.

In addition to this, point-wise calculated drought quantities were mapped using the inverse distance technique in order to determine and interpret areal extending of dryness in the area (Isaaks and Sritvastava, 1989).

RESULTS

In this study, SPI indices were determined using monthly total precipitation series at the fifteen meteorological stations in the GAP area. Multi time scales (1, 2, 3, 6, 9 and 12 month) were used in order to achieve different goals in the study. Since, a no rainfall event is usually experienced during the summer season over the years at the study area; results of the dry season (June, July, August and September) are not given. Calculated SPI indices were mapped in order to determine spatial distribution of drought magnitude over the area using an interpolation technique for the given time scales.

The SPI on 1 month time scale: The 1 month SPI results showed that the highest drought was experienced in Gaziantep with an SPI value of -4.87 in the month of December. Regarding to spatial distribution of drought magnitude, January was the most critical month; experiencing extreme drought that covered 86.4% of the total area (SPI>-2) in 1989 (Fig. 2). April followed January with extreme drought covering 74.4% of the study area for the same year. On the other hand, May was the next driest month with 52.7% of the drought event (SPI<0) throughout the study area at 15 stations for 40 years, while November exhibits only 43.4% of the drought event for the same time period. Successive drought events may contribute to ideas about drought behavior of the area. May is the most critical month considering that there are successive droughts having 28.2% during the months. May droughts are vitally essential for agricultural practices and may effect agricultural production.

The SPI on 2 month time scale: Drought magnitude is decreased the with 2 month scale as compared to the 1 month scale. The highest magnitude observed was -4.02 in the month of February in Sanliurfa during 1989. Consequently, lower drought magnitude during the 2 month scale, meant that almost the whole area (~100%) was suffering from extreme drought conditions during the same year and month (Fig. 3). Successive drought events were considerably decreased so that only 26.7% drought was observed in January which has the highest value among the months during the examination period as compared to the 1 month scale. These results may indicate that successive 2 months of drought in the study area were as common as in the 1 month scale.

The SPI on 3 month time scale: Regarding the 3-month events, the lowest extreme drought event was experienced in October with the value of -2.16 in Diyarbakir. At the

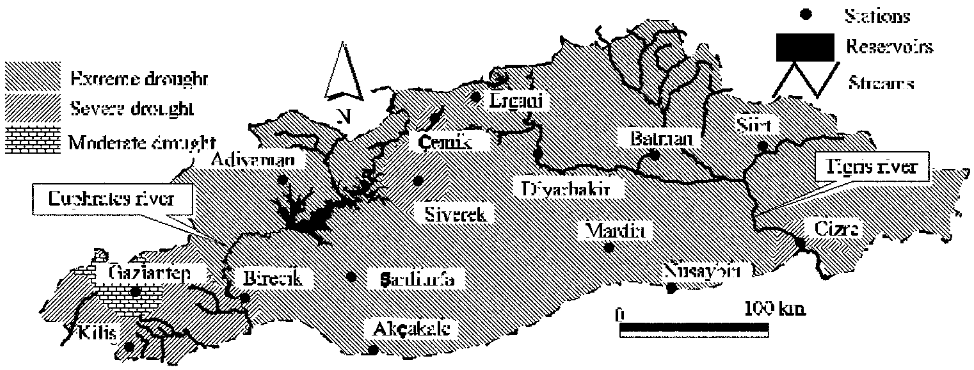

Fig. 2: Spatial distribution of 1 month scaled droughts in January of 1989

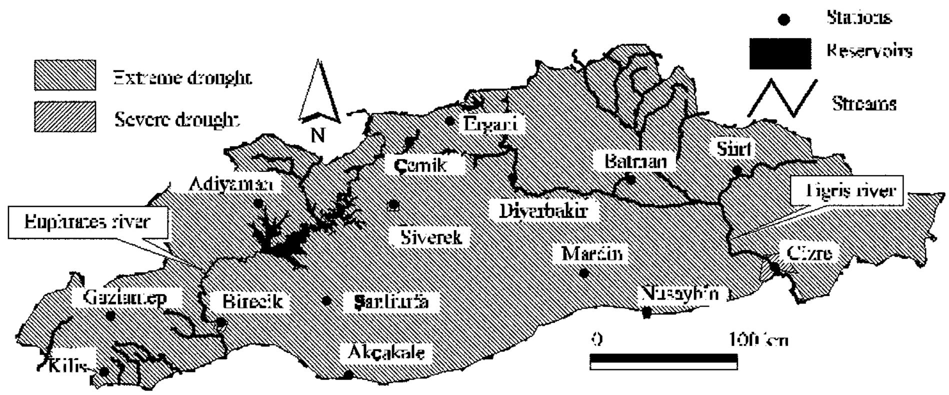

Fig. 3: Spatial distribution of 2 month scaled droughts in February of 1989

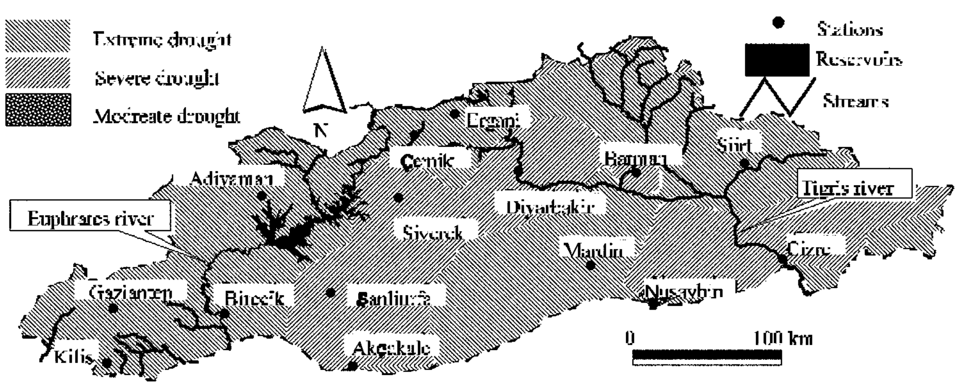

Fig. 4: Spatial distribution of 3 month scaled droughts in March of 1989

same time a 3-month drought had mild conditions for the whole area as compared to the other time scales. Spatial distributions showed that extreme drought events were negligible, while severe drought (-1.5<SPI<-1.99) covered 98.5% of the total area in October. March was found to be the most critical month with 63.8% of extreme drought and 36.8% of severe drought of the total area in 1989 with the highest values during the investigation period (Fig. 4). Three and six months (especially for March, April and May) drought events may provide useful information for agriculturalist and agricultural risk analyzers. The number of observed drought events was 318 (~51.7%), 290 (47.2%) and 313 (50.9%) for March, April and May, respectively. The 3-month SPI value through the end of March showed critical drought conditions; 26 drought events were experienced out of 41 years.

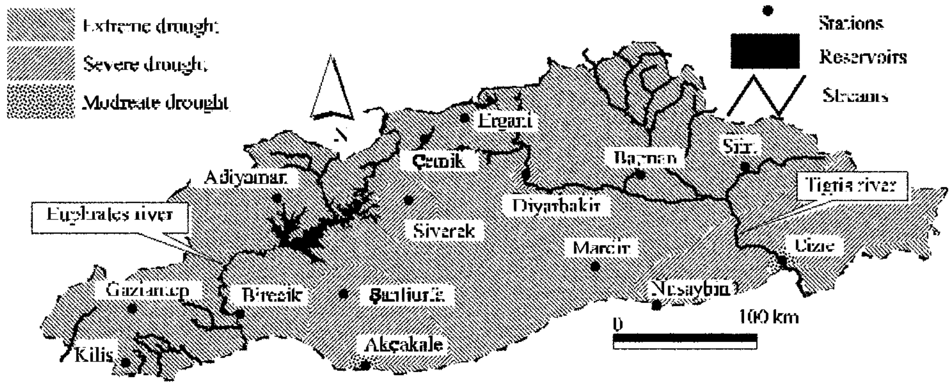

Fig. 5: Spatial distribution of 6 month scaled droughts in May of 1973

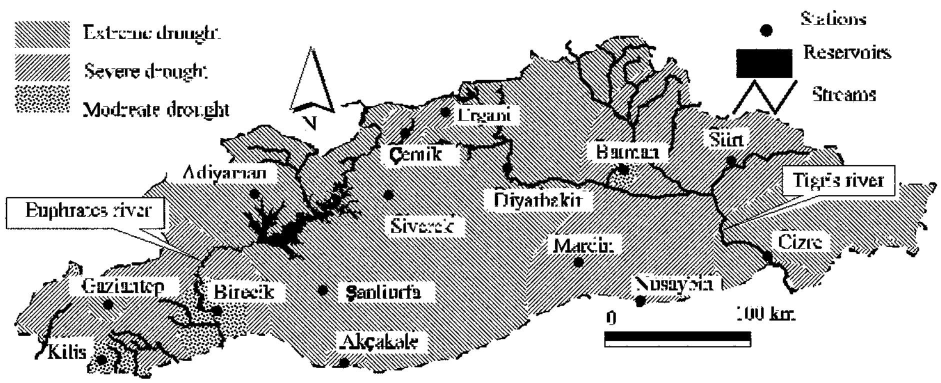

Fig. 6: Spatial distribution of 9 month scaled droughts in January of 1971

The SPI on 6 month time scale: Analyses showed that May was the most critical month considering both number of dry years and the extending area of extreme drought events. On the other hands, drought persistence was observed that ten years were successively dry during November at the Nusaybin station from 1969 to 1978. Numbers of dry months were found to be 313 (50.9%) with the highest value in December among the others during the examination period. By the end of May 1973, critical drought appeared and extreme drought covered an area of 78.5% of the total area and remaining areas stayed under severe drought conditions with a negligible moderate drought (Fig. 5). Those findings are closely related to agricultural production in the region. For example, since cereal production mainly relies on rain-fed agriculture, wheat yield was the lowest level ever recorded in the region at 405 kg ha^{-1}.

The highest drought was experienced with an SPI value of -3.6 in Diyarbakir in January, 1971. In the 1999-2000 rainy seasons, another dramatic prolonged event happened; all study areas experienced drought conditions for all investigated months. This drought period started in October 1999 with moderate drought covering an area of nearly 64.4% (lies mainly mid and eastern parts); mild drought covered 34.7% (western parts). In November 1999, drought reached its peak level; extreme, severe and moderate drought covered 8.8, 60.9 and 26.4% across the GAP region, respectively. The drought ended in May with mild conditions covering 88.5% of total area for the investigation period. During this period, the drought event started with an SPI value of -1.61 as the highest in October, reach to peak value (-2.43) in November at the Gaziantep station and ended in May with a value of -1.57. This event was similar to 1973 drought and the year 2000 drought which effected agricultural productivity in the GAP region. Wheat yields were 1305 kg ha^{-1} which was the lowest value for last decade in the year 2000, across the study area.

The SPI on 9 month time scale: Analyses exhibited that the 9 month droughts provide the smoothest conditions over the area in which every drought category was observed even if it is small. Severe and extreme droughts covered an area of 66.1% (December, 1970) and 61.4% in January, 1971, (Fig. 6), respectively. Those are the highest areal values considering spatial distributions of the experienced droughts. December was found to be the most vulnerable month to drought where 53.0% of years were drought during the whole period. Similar to the 6 month droughts, the year 2000 was found to be the driest year regardless of drought severity for the period from October, 1999 to May, 2000. The SPI values were negative for all the analyzed months. This prolonged drought resulted in some critical environmental and agricultural problems related to water resources and management in the study area. Water level of the Atatürk dam, placed in the GAP area, reached a minimum level during the years. Drought of this term was more dramatic than insight of water resources for agricultural productivity, farming communities suffered from the lowest cereal yield of the last decade. Drought persistence was observed in the month of January where 17 successive dry year-pairs were counted at Adiyaman among the climatic stations.

The SPI on 12 month time scale: In this category, the drought reached its maximum severity with value of -5.46 in May of 1984 at the Siverek climatic station. On the other hand, November showed a critical situation where the number of dry years was 53.8% which was the highest value among the drought categories and months. This finding indicates that the 12 month total precipitation ending in November exhibits non-normal distribution and droughts may effect sowing and seed emerging dates for some cereals in the area. A dramatic drought event had occurred in Siirt with 49 consecutive dry months, from March, 1970 to March, 1976 during the rainy season. Analogous to the previous two drought categories, again, we found a widespread drought event in the area where the rainy season of 1999-2000 year was dry for all stations and months. Unfavorable effects of desperate drought events were discussed earlier, but here the negative results on stream flows are emphasized. Unusual low flow may break down natural equilibrium in the river system considering the living habitat. From the engineering side, low operation levels in dams may result in reductions of electrical energy produced. To overcome that kind of risk, proper water management is essentially important for public and governmental benefits. Emergency action plans could be helpful in case of such drought severity level.

CONCLUSIONS

The present study has been made on the spatiotemporal behaviors of multiple time drought indices of SPI in the semi-arid region of Turkey. An assessment of findings has shown that the area was vulnerable to drought events. In some years, whole areas were exposed to extreme droughts, especially in 1973 with the 6 months drought which ended in May and caused the lowest cereal yield ever recorded. Prolonged drought events showed up for as long as 49 months consecutively in 1970s. Drought of the year 1999-2000 was extraordinary considering the management of water resources and agricultural productivity where dramatic decreases were recorded in both cases as compared to the last decade. Those inferences will be helpful for better water management and agricultural practices in the similar areas around the world.

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