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An Analysis of Spatial and Temporal Dimension of Drought Vulnerability in Turkey Using the Standardized Precipitation Index

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Abstract. Drought has become a recurrent phenomenon in Turkey in the last few decades. Significant drought conditions were observed during years of late 1980s and the trend continued in the late 1990s. The country's agricultural sector and water resources have been under severe constraints from the recurrent droughts. In this study, spatial and temporal dimensions of meteorological droughts in Turkey have been investigated from vulnerability concept. The Standardized Precipitation Index (SPI) method was used to detail geographical variations in the drought vulnerability based on frequency and severity of drought events at multiple time steps. Critical (threshold) rainfall values were derived for each station at multiple-time steps in varying drought categories to determine least amount of rainfall required to avoid from drought initiation. The study found that drought vulnerability portrays a very diverse but consistent picture with varying time steps. At regional scale, south-eastern and eastern Anatolia are characterized with moderate droughts at shorter time steps, while the occurrence of severe droughts at shorter time steps is observed at non-coastal parts of the country. A similar picture was observed with very severe droughts. The critical (threshold) values exhibited rising numbers during the growing season at 3-month step in the South-eastern Anatolia, which might have significant consequences considering presence of large irrigation projects under-development in the region. In general, rainfall amounts required for non-drought conditions decrease from the coastal parts toward the interiors with increasing time steps.

Key words: drought, drought vulnerability, Turkey, SPI, critical (threshold) rainfall

1. Introduction

Drought is one of the most damaging climate-related hazards. Drought is among the most multifaceted and least understood of all natural hazards, affecting more people than any other hazard. Although drought first appears as below-average rainfall within a normal part of climate, it can develop as an extreme climatic event and turn into a hazardous phenomenon which can

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have severe impact on communities and water-dependent sectors. Drought differs from most other natural hazards in many ways, especially in the sense that its onset and termination is difficult to predict (McKee *et al.*, 1993). The response and mitigation to drought entail a careful planning of water resources, design of a contingency plan to reduce the impacts, and set up early warning systems to predict onset of drought occurrence. It develops in slow temporal pattern and its impacts may prolong for a long period of time even during wet periods (Wilhite and Glantz, 1985). In the literature, many definitions of drought exist but the central theme in the definitions of a drought is the concept of a water deficit. Drought is defined based on some deficiency of precipitation that results in water shortage for some activity related to use of water (Dracup *et al.*, 1980; Wilhite and Glantz, 1985). Different types of droughts are identified in practical sense as drought differs between regions and its impacts vary significantly because of differences in economic, social, and environmental characteristics Meteorological drought is defined usually on the basis of the degree of dryness (departure from "normal" or average amount) and the duration of the dry period while agricultural drought links the various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential ET, soil–water deficits (Wilhite, 2000). Over the years, operational definitions of drought formulated in form of indices have emerged to answer such questions as; when, how long, and how severe a drought is. Drought planners usually rely on some mathematical indices to decide when to start implementing water conservation or mitigation measures against drought.

Although precipitation is the primary controlling factor of drought, other climatic factors such as high wind, high temperature or low relative humidity can contribute to amplify its intensity. The severity of drought depends upon the degree of moisture deficiency, the duration, and to a lesser extent, the size of the affected area. Impacts of drought are usually first apparent in agriculture through decrease in soil moisture and high evapotranspiration. Soil water can be rapidly depleted during extended dry periods. Surface water and subsurface water resources are usually the last to be affected from an extended period of dryness.

High economic cost and social vulnerability of drought problem has led to increasing attention to the drought vulnerability issue in recent years (Wilhite, 1993, 2000; Keenan and Krannich, 1997; Downing and Bakker, 2000). Losses from drought events across the world significantly increased as parallel to the increased number or severity of droughts (Wilhite, 2000). The losses from the 1988 drought in the U.S.A. alone have been estimated at more than $39 billion dollars. Europe has been heavily affected from drought during the 20th century and it has been observed that the drought was not restricted to the Mediterranean region alone since it could occur in high and low rainfall areas and in any season (Lloyd-Hughes and Saunders, 2002).

Drought is still a major concern in parts of Turkey where the rainfall is highly variable and low. The combination of rainfall deficiency with other climatic factors and in particular high temperature creates serious risk of drought in the central and south-eastern parts of the country where agriculture is the main economic sector (Komuscu *et al.*, 1998). Impact of drought in the low and variable rainfall regions of the country can be widespread, affecting such diverse sectors as agriculture, irrigation, and energy. Water supplies dropped drastically in major urban areas across the country during early 1990s due to severe droughts and led initiation of several rain enhancement projects to tackle the demand for water (Komuscu, 2003). Severe and prolonged droughts experienced in the last decade directed the attention to the country's vulnerability to this natural hazard and, therefore highlighted need for addressing temporal and spatial nature of drought occurrences in the country.

In this study, drought vulnerability in Turkey has been investigated using the Standard Precipitation Index (SPI), a relatively new meteorological index developed by McKee *et al.* (1993). The study aimed to address multi-nature aspects of drought with its several features; frequency of drought occurrence and its spatial distribution to identify drought-prone areas and drought vulnerability at multiple-time steps, such as 3, 6, 12, and 24-month so that the effects of rainfall deficiency can be assessed on different water resources component. In this study, the spatial variance of drought occurrences in Turkey have been approached from a different perspective by deriving information on critical (threshold) rainfall, which can be defined as level of minimum amount of moisture input required for non-drought conditions. In this sense we expect that this study will bring a new perspective to drought studies by addressing drought vulnerability with respect to setting some critical rainfall conditions. It should be noted that because of the complexity of the issue of vulnerability, assessments sometimes can be complicated and are not well understood. Downing and Bakker (2000) argue that vulnerability is a relative measure, and therefore critical levels should be defined. Information on regional drought vulnerability could aid decision makers in identifying appropriate mitigation actions for future drought events and minimize its impacts. With a map of drought vulnerability, decision makers can conceptually visualize the hazard risk and convey the vulnerability information to other sectors to ensure that they will act timely and effectively to tackle with drought related losses (Wilhelmi and Wilhite, 2002). One of the common problems in dealing with drought is not-planning, although drought is recognised to be a recurring and inevitable feature of climate, rarely is a plan developed to mitigate drought before its occurrence. Instead, in most cases drought is dealt with an approach commonly referred to as crisis management. It is our view that we should shift to risk management from crisis management in dealing with drought as a hazardous phenomenon and develop contingency plans accordingly.

2. Background

Drought is recurrent phenomenon in Turkey for the last several decades. The drought occurrences in general were closely related to lack of precipitation combined with high temperatures. A warming trend began in early 1990s have dominated nearly more than a decade and the annual mean temperatures have remained above average since 1995. A significant drought is observed during years of 1999 and 2000, which were associated with a lack of precipitation during the winter and spring, which normally are the wettest seasons. Almost two thirds of the country, mainly the South-eastern and the Central Anatolia experienced severe drought in 1999, and the drought continued in the year 2000 with slight differences in areal coverage. Onward from 2000, moisture conditions improved when rainfall remained above their seasonal averages. Nevertheless, average rainfall has been indicating declining trends since 2001 despite it remains above the long-term average (Figure 1).

Annual average rainfall in Turkey is around 630 mm and 67% of the annual average rainfall occurs during the winter and spring months with influence of eastward propagating mid-latitude cyclones and Mediterranean depressions. With respect to rainfall characteristics, most central and the South-eastern parts of Turkey are considered to be semi-arid, and to some extent parts of the Central Anatolia around Tuz Lake portray arid conditions with 300 mm/year rainfall. Based on the classification using P/PET ratio as

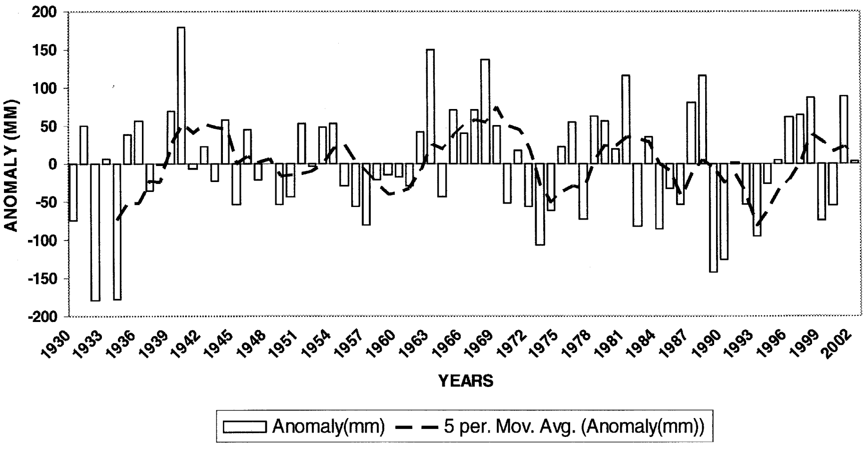

Figure 1. Long-term precipitation anomalies of Turkey (1930–2002).

suggested by the United Nations Convention on Combating Desertification (UNCCD), arid and semi-arid regions can be identified especially in the Central and the South-eastern parts of the country (Komuscu, 2002).

Meteorological conditions that lead to drought have been subject of much scientific research. Experimental studies suggest that drought is not solely the result of a single cause and even drought conditions themselves may play a role in the perpetuation of the drought through a feedback between the land surface and the overlying atmosphere. From meteorological perspectives, droughts are manifestations of persistent large-scale disruptions in the global circulation pattern of the atmosphere (Namias, 1985). Prolonged droughts occur when large-scale anomalies in atmospheric circulation patterns persist for months or seasons. The studies show that on a global context, Pacific sea surface temperature variations associated with the El Niño–Southern Oscillation (ENSO) phenomenon influence year-to-year global climate variations especially in tropics and mid-latitudes (American Meteorological Society, 2003). Similarly, changes in the North Atlantic Oscillation (NAO) are believed to be an important factor that control rainfall variability in Mediterranean region (Cullen and deMonecal, 1999). During the positive phases of NAO, the North Atlantic westerlies that provide much of the atmospheric moisture to North Africa and Europe shift northward, resulting in drier conditions over Southern Europe and the Mediterranean Sea (Hurrell, 1995). During the positive NAO years, Turkey becomes significantly cooler and drier. The Figure 2 shows a how temporal pattern of annual rainfall and NAO indices over the last three decades correlate. It has been shown that the dry periods correspond well with the positive phases of the NAO, and

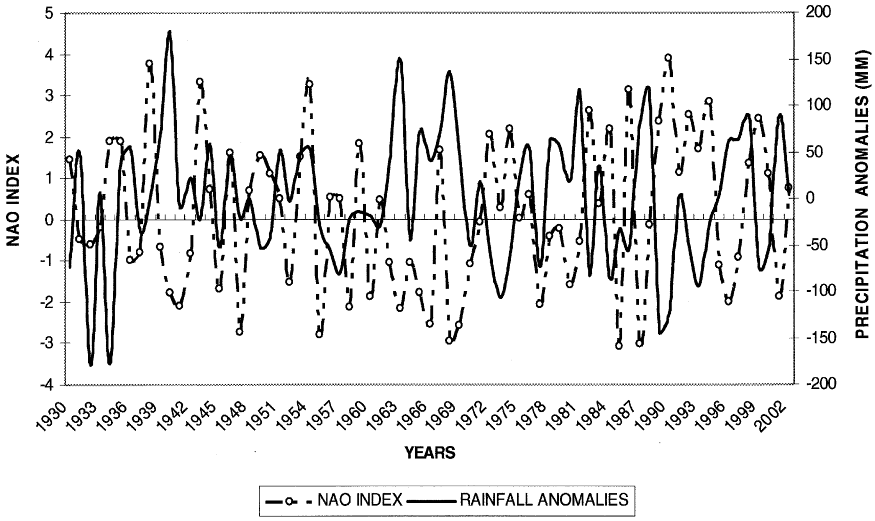

Figure 2. Long-term precipitation anomalies of Turkey and NAO index.

similarly humid conditions prevail during the negative phases of the NAO. In order to see correlation between the long-term precipitation anomalies and NAO indices, we run two separate correlation analysis and found inverse relationship between the two (Table I). From statistical sense, therefore, one can argue that winter droughts in Turkey can be associated with the positive NAO anomalies to some extent and the country will be more vulnerable to drought during the positive phases of the NAO as the country receives most of its rainfall in winter and spring.

3. Use of the SPI for Drought Analysis

Precipitation is the primary factor controlling formation and persistence of drought along with other variables such as evapotranspiration. Usually quantitative indices are used to identify presence of drought and along the

Table I. Results of the correlation tests for the long-term monthly NAO series and precipitation anomalies of Turkey.

		NAO	Precip. anomaly
NAO	Pearson correlation	1.000	−0.394(*)
	Sig. (2-tailed)		0.001
	Sum of squares and cross-products	248.97	−3827.57
	Covariance	3.4	−53.16
	N	73	73
Precip. anomaly	Pearson correlation	−0.394(*)	1
	Sig. (2-tailed)	0.001	
	Sum of squares and cross-products	−3827.57	378914.57
	Covariance	−53.16	5262.70
	N	73	73
NAO	Spearman's rho correlation coefficient	1.000	−0.397(*)
	Sig. (2-tailed)		0.000
	N	73	73
Precip. anomaly	Correlation coefficient	−0.397(*)	1.000
	Sig. (2-tailed)	0.000	
	N	73	73

*Correlation is significant at the 0.01 level (2-tailed).

years several indices have been developed and adopted to measure drought or wet spells intensity. Among these indicators, Percent of Normal, Deciles, SPI, Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), and Surface Water Supply Index (SWSI) are the ones that are used most commonly. It has been found that indices based solely on precipitation data perform well when compared with more complex hydrological indices (Oladipio, 1985). Nevertheless, most drought indices lack addressing multi-temporal nature of effect of rainfall deficiency and usually are computed for a certain time interval (monthly or seasonally). On the other hand, it is known that impact of rainfall deficiency on water resources varies on temporal scale. While soil moisture responds to precipitation anomalies on a relatively short time steps, most other water storages, such as groundwater, streamflow, and reservoir storage, reflect longer-term precipitation anomalies. McKee *et al.* (1993) developed the Standardized Precipitation Index (SPI) to quantify the precipitation deficit for multiple time steps, which reflected the impact of precipitation deficiency on the availability of the different water suppliers. Therefore, the different time steps (1, 3, 6 and 12 months) for which the index is computed address the various types of drought: the shorter seasons for agricultural and meteorological drought the longer seasons for hydrological drought. Guttman (1998) concluded the SPI is better able to show how drought in one region compares to drought in another region. Analysis of extreme drought events showed that the SPI provided a better spatial standardization than the PDSI (Lloyd-Hughes and Saunders, 2002). Another virtue of the SPI is that drought initiation and termination are implicit part of the index. Given the advantages of the index standardization, the SPI has been largely used operationally to monitor climatic conditions across different locations.

Besides its advantages, practical applications of the SPI revealed some disadvantages (Guttman, 1999). It is assumed that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization (Hayes *et al.*, 1999). Another limitation of the SPI emerges from the standardization process of the index itself. Drought measured by the SPI can occur with same frequency at all locations when considered over a long time period. A third problem is that misleadingly large positive or negative SPI values may result when the index is applied at short time steps to regions of low seasonal precipitation.

4. Calculation of the SPI

The SPI computation is based on the long-term precipitation data for the desired time step. It is simply calculated by taking the difference of the precipitation from the mean for a particular time step, and then dividing it by the standard deviation.

$$\mathrm{SPI} = \frac{x_i - \bar{x}_i}{\sigma} \tag{1}$$

The SPI is a dimensionless index where negative values indicate drought; positive values wet conditions. Drought intensity, magnitude, and duration can be determined, as well as the historical databased probability of emerging from a specific drought. The calculations, however, takes a more complicated form when the SPI is normalized to reflect the variable behaviour of precipitation for time steps shorter than 12 months. 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 any of the time steps and classified the SPI to define various drought intensities (Table II). Each drought event, therefore, is characterised with a duration defined by its beginning and end and intensity for period when the event continues.

In this study, we have developed a software package in Delphi for computations of the SPI and added some features to improve its practical use for drought analysis. The package included capabilities of calculating and displaying SPI values at 3, 6, 12, and 24-month time steps both in ASCI and graphical formats, displaying charts of equiprobability transformation from fitted gamma distribution to the Standard Normal Distribution, illustrating cumulative probability versus precipitation, and displaying drought categories at selected time steps as percentage of drought occurrence.

The monthly precipitation time series are modelled using different statistical distributions. Thom (1958) found the gamma distribution to fit climatological precipitation time series well. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{x/\beta} \quad \text{for } x > 0 \tag{2}$$

where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ defines the gamma function.

Fitting the distribution to data requires α and β to be estimated. They are estimated for each station, for each time step of interest (3 months,

Table II. Drought categories defined for SPI values.

SPI values	Drought category
0 to −0.99	Mild drought
−1.00 to −1.49	Moderate drought
−1.50 to −1.99	Severe drought
≤−2.0	Extreme drought

12 months, 48 months, etc.), and for each month of the year. Edwards and McKee (1997) suggest that those two parameters can be estimated using the approximation of Thom (1958) for maximum likelihood:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3}$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{4}$$

where:

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{5}$$

$$n = \text{number of precipitation observations} \tag{6}$$

Integrating the probability density function with respect to x and inserting the estimates of α and β yields an expression for the cumulative probability G(x) of an observed amount of precipitation occurring for a given month and time step:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)_0}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \tag{7}$$

Since the gamma distribution is undefined for $x = 0$ and $q = P(x = 0) > 0$ where $P(x = 0)$ is the probability of zero precipitation, the cumulative probability becomes as follow:

$$H(x) = q + (1 - q)G(x) \tag{8}$$

The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI. Since the above approach is not practical for computing the SPI for large numbers of data points, we used the approximate conversion suggested by Abramowitz and Stegun (1965). Detailed procedures of the calculation of the SPI can be found in Gutmann (1999) and Lloyd–Hughes and Saunders (2002).

The process of transforming cumulative probability distribution into the standard normal distribution to obtain corresponding SPI values is illustrated in Figure 3 for Zonguldak station (located in Black-Sea coast) as an example. The first panel in the figure shows the empirical cumulative probability distribution for a 3 month average December–January–February (DJF) of precipitation. The theoretical cumulative probability distribution of the fitted gamma distribution is plotted in Figure 3. The second panel displays a graph of standard normal cumulative probability. To convert a given precipitation level to its corresponding SPI value, first precipitation amount on the abscissa of the left-hand panel is located, then a perpendicular line is drawn and point of intersection with the theoretical distribution is located.

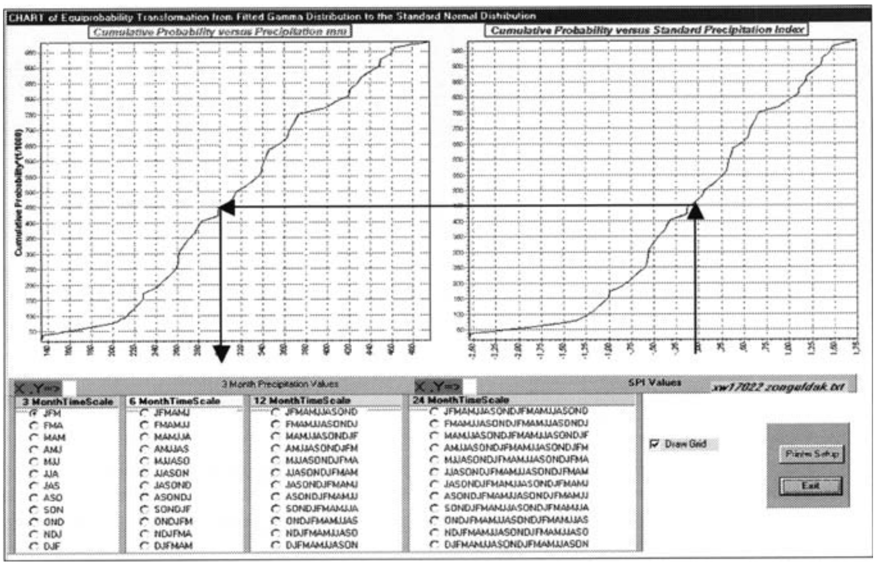

Figure 3. Equiprobability transformation from fitted gamma distribution to the standard normal distribution, illustrating cumulative probability of SPI *versus* precipitation.

Then, that point is horizontally traced (maintaining equal cumulative probability) until it intersects with the graph of standard normal cumulative probability. The intersection between a line drawn vertically downward from this point and the abscissa determines the SPI value. In the Figure 4, 307 mm rainfall corresponds to 0 (zero) SPI value, which means that a minimum of

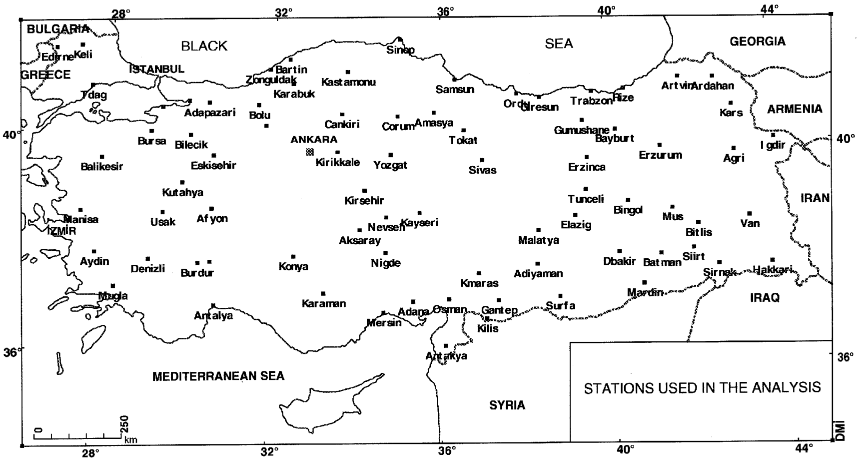

Figure 4. Geographical distributions of the stations used in the analysis.

307 mm rainfall input is needed in Zonguldak during the J–F–M period to avoid from initiation of drought.

5. Drought Occurrences and Analysis

In this study, drought occurrences in Turkey have been investigated based on frequency of the events for each drought category at multiple-time steps. The index has been applied to long-term precipitation data at 101 stations for 1951–2001 period (Figure 4). The occurrences in varying drought categories at 3, 6, 12-month and 2-year time steps were analysed on regional basis covering six main geographic divisions, including central, eastern, Mediterranean, Marmara, Black-Sea, and south-eastern Anatolia. The aim here was to identify areas vulnerable to drought at comparable time steps based on their occurrence frequencies. A sample table describing the above analysis is given below for Konya station located in the Central Turkey where semi-arid climate predominates (Table III). In the table, percentage of drought occurrence is expressed at multiple-time steps for varying drought severity categories. The numbers are obtained by taking ratio of drought occurrences in each time step to the total drought occurrences in the same time step and drought category.

The resulting SPI values at corresponding drought categories were mapped using Surfer program. Surfer is a grid based contour program and uses original data points (observations) in an XYZ data file to generate calculated data points on a regularly spaced grid (Surfer, 1997). Interpolation schemes estimate the value of the surface at locations where no observed data exists, based on the known data values (observations). Surfer then uses the grid to generate the contour map or surface plot. Kriging interpolation technique was used to obtain SPI values where no station data existed. This method produces visually appealing contour and surface plots from irregularly spaced data (Surfer, 1997). Kriging attempts to express trends in data, so that, “high points might be connected along a ridge, rather than isolated by bull’s-eye type contours”.

Table III. Drought occurrence in Konya at corresponding drought categories and time steps.

SPI	Drought category	Time (%) 3-month	Time (%) 6-month	Time (%) 12-month
0 and −0.99	Mild drought	31.7	30.5	28.1
−1.00 to −1.49	Moderate drought	8.6	9.2	9.2
−1.50 to −1.99	Severe drought	4.1	3.6	6.2
≤−2.0	Very severe drought	3.0	3.4	2.3

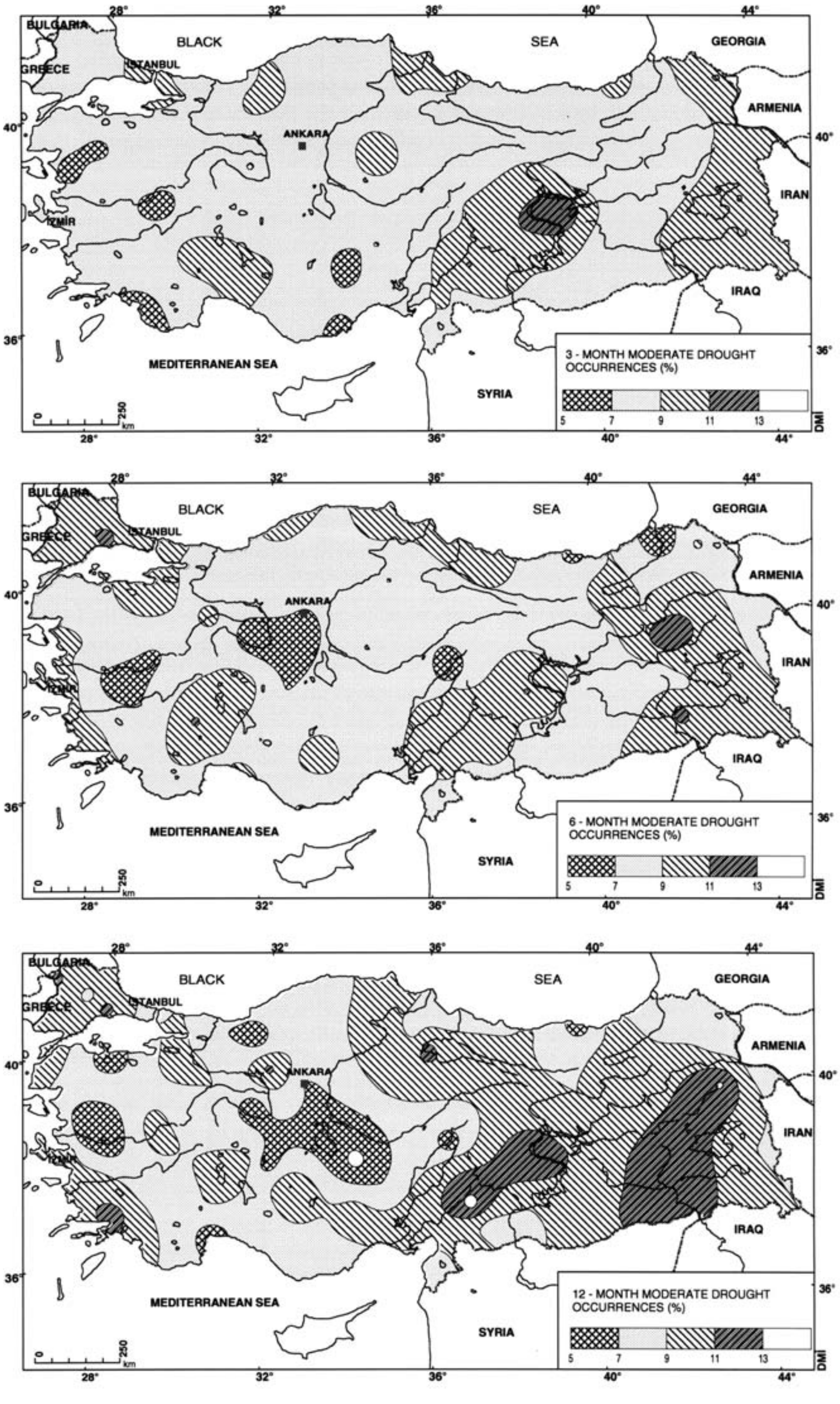

Figure 5. Moderate drought occurrences at 3, 6, and 12-month time steps.

The spatial analysis of moderate drought occurrences indicates that they tend to occur in eastern and south-eastern Anatolia at 3-month time step, while the coastal parts are characterized with the lowest frequencies at the same time step (Figure 5). In other words, majority of the historical droughts that occurred in the eastern and south-eastern Anatolia were moderate severity in short-time steps. As the time step increases to 6-month, no major changes are observed at maximum frequencies, rather there is a shift in the low drought occurrences toward interior parts of the country. At 12-month time step, moderate droughts occurred more frequently and covered nearly two-thirds of the country. The moderate droughts exhibit more variable behaviour when the time step increases to 2-year period and no large areas are identified with moderate droughts at this time step.

Occurrence of the severe droughts at shorter time steps is typical at non-coastal parts of the country. Especially parts of the eastern Anatolia bordering Armenia and Iran and European part of the Marmara region exhibit maximum frequencies (Figure 6). This severe drought characterization totally changes at longer time steps. Except the central Anatolia, majority of the country has low occurrences of severe droughts at 12-month time step. It can be concluded that the severe droughts in Turkey have more seasonal behaviour than having a long-lasting character. At 2-year step, no extended severe drought areas are identified, rather few localities display high severe drought occurrence. Another interesting result reached in the study is that while the interior parts of the country are characterized with severe drought at shorter-time steps, coastal parts experience severe drought at longer-time steps at higher frequencies. That led us to think that while the central parts of the country are more likely to be affected from agricultural drought with faster depletion of soil moisture, the coastal parts and eastern regions will suffer from hydrological drought, with consequent loss of water resources.

Very severe drought occurrences, on the other hand, are more typical both in the coastal and interior parts at shorter time steps, except the Eastern Anatolia where the drought occurs at low frequencies (Figure 7). As the time step increases, frequency of the severe droughts increases as well especially along the Mediterranean cost and some localities in the central parts. At 2-year time step, severe drought occurrences extend to the other coastal areas and parts of the central Anatolia where maximum drought frequencies are observed. Interestingly, the eastern Anatolia experience lowest occurrences of prolonged droughts at longer time steps as well as the parts of the Black-Sea region. That means at longer time steps the hydrologic drought is likely to occur at the coastal parts while the interior parts will suffer from agricultural drought under severe drought conditions.

In this study, we also analysed how severe drought-stricken areas evolved over time spatially (Figure 8). In this respect, number of stations which exhibited severe drought conditions over the given time steps was determined

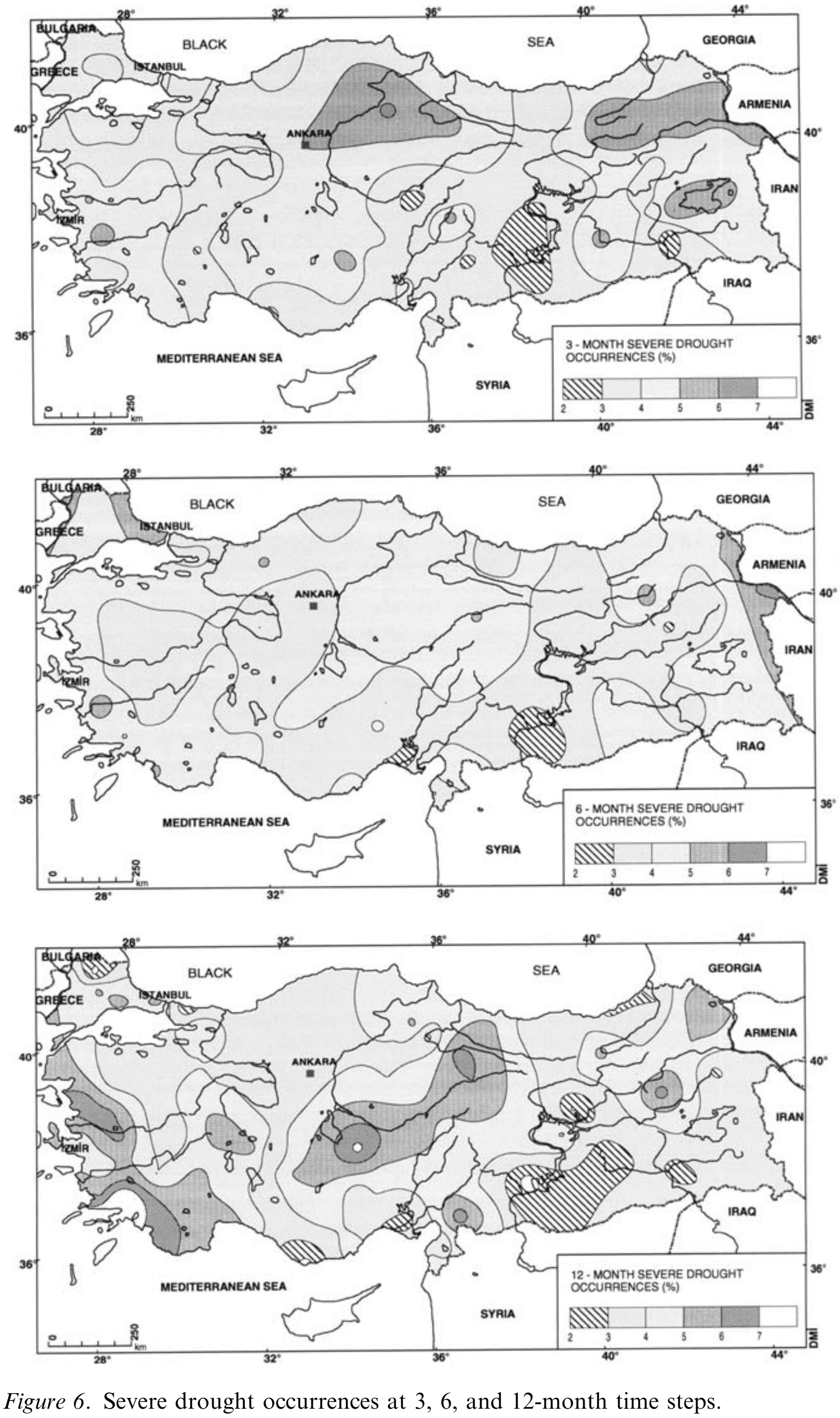

Figure 6. Severe drought occurrences at 3, 6, and 12-month time steps.

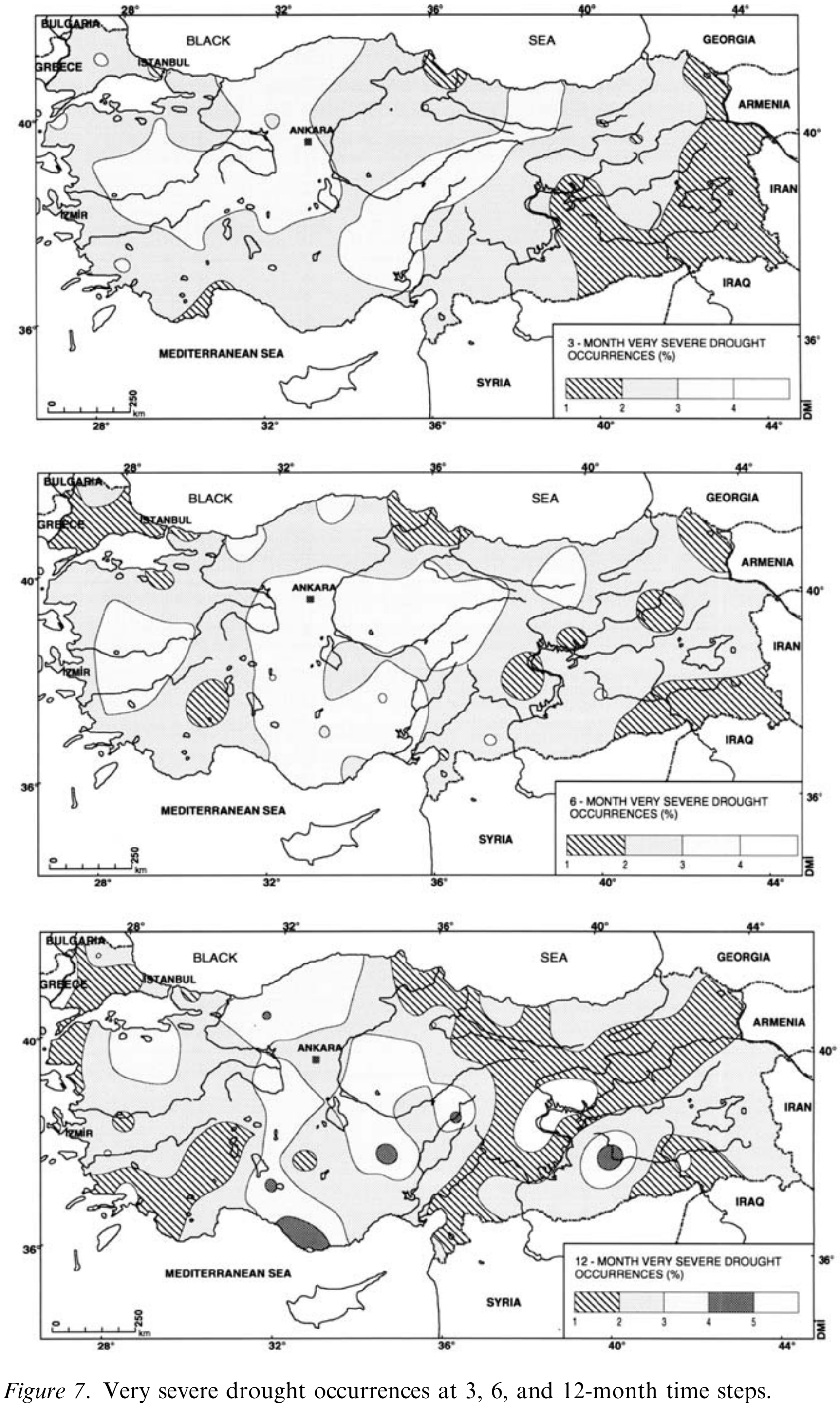

Figure 7. Very severe drought occurrences at 3, 6, and 12-month time steps.

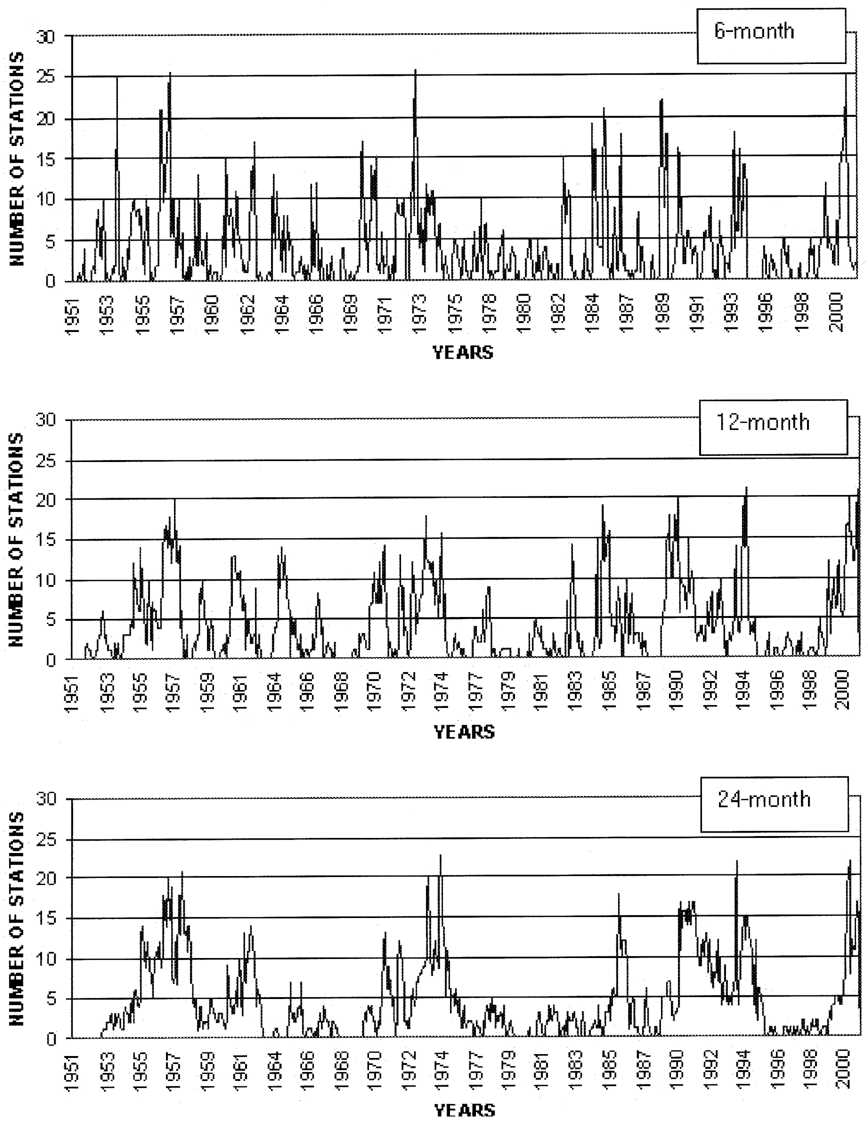

Figure 8. Number of stations experienced severe drought at 6, 12, and 24-month time steps.

for the corresponding SPI values (between −1.50 and −1.99) for the 1951 and 2001 period. In other words, number of stations that exhibited severe drought category for the pre-defined SPI values was identified and plotted for the 1951–2001 period to observe their trends. As a result, four severe drought periods have been identified in the last 50 years between 1953–1959, 1972–1977, 1989–1994, and finally 1999–2001. At the 24-month time step, those periods are identified even more clearly. As the time step increased, the total number of stations that experienced severe drought increased as well. The results also indicate that recovery from drought conditions at longer durations is also slower as compared to those of the short duration.

6. Critical (Threshold) Rainfall Analysis

One of the advantages of the SPI module developed in this study is that it provides not only SPI for a given rainfall total but also computes critical (threshold) rainfall values at corresponding drought categories. In other words, we can determine minimum amount of rainfall that is required to avoid from a drought formation at different severity categories and varying time steps. In this respect, we calculated the critical rainfall values at "0" (zero) SPI that is defined as threshold at which drought begins to form. As stated previously, the SPI values below zero indicate a drought occurrence, and as the values drop below zero the severity of drought increases. After computing the critical rainfall values for each station, they are mapped to visualise their geographical distribution to identify areas where at least some amount of rainfall is needed for a drought event not to initiate.

In order to relate the water demand with practical applications, the analyses first were made at 3- and 6-month time steps to correspond to growing season when soil moisture demand is maximized to relate it to the drought conditions. At the 3-month time step, critical values exhibited rising

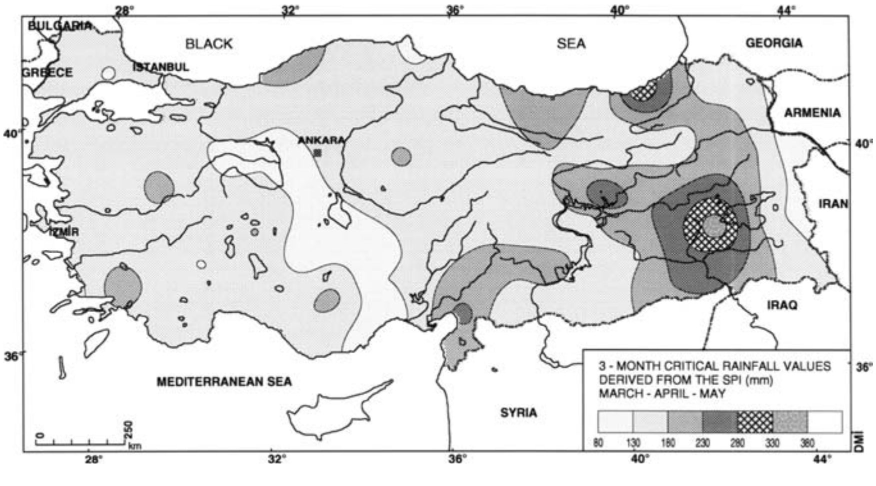

Figure 9. Three months critical rainfall values for March–April derived from the SPI.

numbers during the growing season in the south-eastern Anatolia where large areas of irrigated cropland exist (Figure 9). It is important to note that the maximal demand for rainfall to non-drought conditions in the region may have significant implications for immense water resources projects that are under development (known as south-eastern Anatolian Development Project – GAP). Rainfall demand for no-drought occurrences increases from west to east, and in general the central parts with non-irrigated croplands will be least affected from a drought event during growing season.

At 6-month time step covering winter-spring period, critical rainfall values for non-drought conditions reach their maximums in the south-eastern Anatolia and parts of the Mediterranean and northern Black-Sea coasts (Figure 10). In general, rainfall amounts required for non-drought conditions decrease from the coastal parts toward the interiors. This is not a surprising conclusion since the coastal parts, mainly the Mediterranean costs, receive most of their rainfall during the winter–spring period.

The critical rainfall values at 12-month time step exhibited a similar spatial pattern to those observed in the 6-month step, except those areas which require higher rainfall moved to the north-eastern Black Sea region (Figure 11). It is shown that the critical values exhibit sharp differences in their geographical distribution. For example, nearly 2000 mm of rainfall is needed to avoid from a drought in the Northern Black Sea region, while the rainfall amount required for a non-drought condition decreases to as little as 300 mm in the central parts and in the eastern border with Iran.

At 24-month time step, critical rainfall values reach their maximums in the north-eastern Black Sea region (Figure 12). The coastal areas still exhibit higher values as compared to the central locations where rainfall demand for

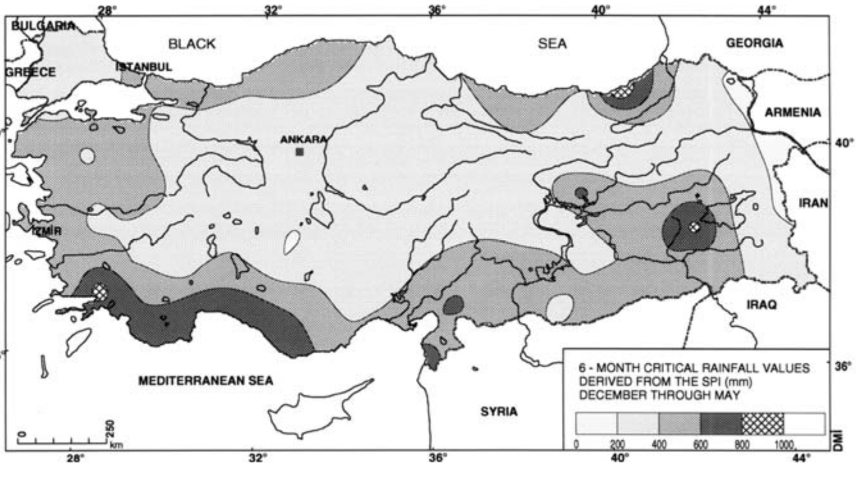

Figure 10. Six months critical rainfall values for March–April derived from the SPI.

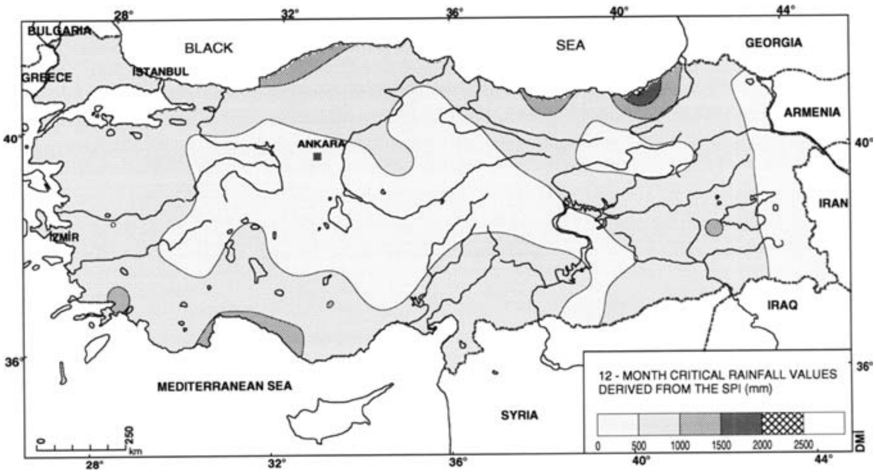

Figure 11. Twelve months critical rainfall values for December–January derived from the SPI.

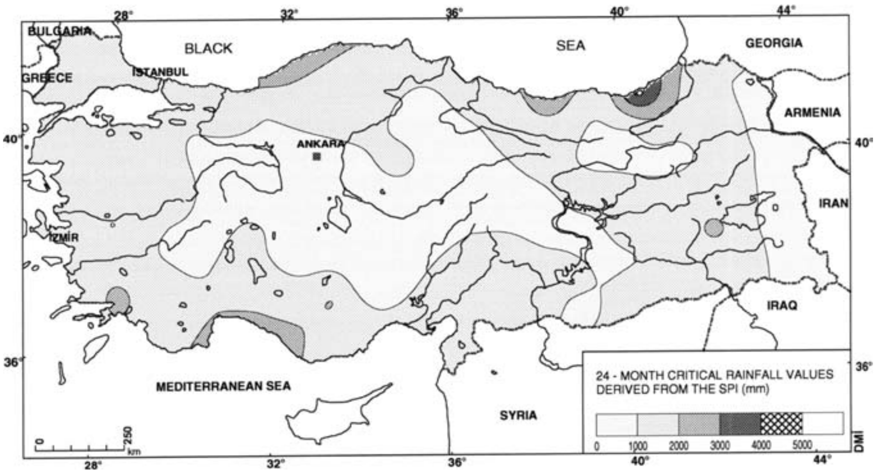

Figure 12. Twenty-four months critical rainfall values derived from the SPI.

non-drought conditions is minimal. Similarly, neighbouring regions with Iran and Armenia are characterized with the least rainfall demand to avoid drought conditions. In general, rainfall demand decreases from the coastal parts toward the interiors if a drought event to be avoided. Considering the fact that the coastal parts usually receive higher rainfall than the interior regions, it is likely that they will be more vulnerable to long-term droughts at 2-year time step.

7. Results and Discussions

In this study we assessed overall meteorological drought vulnerability in Turkey by reconstructing historical occurrences of drought at varying time steps and drought categories by employing SPI approach. The assessment further included analysis of critical (threshold) rainfall to determine minimum moisture input required for non-drought conditions. It is our thought that an improved understanding of drought occurrence (frequency, intensity, and spatial extent) could help to identify risks associated with the drought, and in this regard this study offers some new insight into drought phenomenon in Turkey especially with regard to degree of vulnerability at multiple-time steps to reflect influence of rainfall deficiency on different water resources.

It is obvious that drought phenomenon will create more vulnerable environment for the agricultural sector and water resources in Turkey. The impacts would vary greatly with varying time steps. While the south-eastern and eastern parts of the country are more vulnerable to moderate droughts at short time steps, the impact would be expected less at the coastal parts where the drought is only effective at longer durations and occur at moderate drought levels. On the other hand, the coastal and interior parts are more vulnerable to severe droughts as opposed to the eastern Turkey where the drought frequencies tend to lessen. That led us to conclude that at longer time steps hydrologic drought is likely to occur at the coastal parts while the interior parts will suffer from agricultural drought under severe drought conditions. With respect to the critical rainfall (threshold) analysis; it has been found that at 3-month step rainfall demand for non-drought conditions decreases in W–E direction toward the eastern Anatolia, and in general the central parts will be least affected from a drought event during growing season. The maximum rainfall demands are usually concentrated in the south-eastern parts of Turkey. As the time step increases, area of maximum rainfall demand shifts to the north. It can be concluded that the regions that have normally higher rainfalls are affected from a drought event more severely as compared to another region, which receives lower rainfall.

The increase in drought hazard may result from an increased frequency and severity of meteorological drought, which then may lead to increased societal vulnerability to drought. The conclusions reached in this study can be an essential step toward addressing the issue to drought vulnerability in the country and can guide for drought management strategies for mitigation purposes. Identifying regional vulnerabilities can lead to adjustment in practices in water-dependent sectors and can help decision makers to take the drought into account from hazard perspective and include the concept of drought vulnerability into natural resource planning.

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