JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 12 2004

A NEW INSIGHT INTO DROUGHT VULNERABILITY IN TURKEY USING THE STANDARD PRECIPITATION INDEX

Ali Ümran Kömüsçü[1]
Ayhan Erkan[1]
Ertan Turgu[1]
F. Kemal Sönmez[2]

[1]Turkish State Meteorological Service
Ankara, Turkey
[2]University of Ankara, Faculty of Agriculture
Ankara, Turkey

Drought has become a recurrent phenomenon in Turkey in the last few decades. Significant drought conditions were observed during the late 1980s and the trend continued in the late 1990s. The magnitude of drought related losses and impacts in the agricultural sector and water resources indicate continuing vulnerability of the country to drought. In this study, the frequency and severity of meteorological droughts in Turkey have been investigated in relation to vulnerability concept using the Standard Precipitation Index (SPI). Frequency of drought events at different severity categories and critical threshold rainfall data are computed at different time scales to identify drought climatology. The study found that drought occurrences portray a very diverse but consistent picture with varying time scales. At the regional scale, southeastern and eastern Anatolia are characterized with moderate droughts at shorter time scales, while the occurrence of severe droughts at shorter time scales are typical at non-coastal parts of the country. A similar picture was observed with very severe drought variability. That led us to conclude that while the central parts of the country are more vulnerable to agricultural drought with faster depletion of the soil moisture, the coastal parts and eastern regions will suffer from hydrological drought, with consequent loss of water resources. In this study, critical threshold rainfall values were also computed to identify areas which must receive at least some amount of rainfall to avoid from drought conditions. The critical threshold values exhibited rising numbers during the growing season at the 3-month scale in the southeastern Anatolia, which is a significant result considering the presence of large irrigation projects in the area. In general, rainfall amounts required for non-drought conditions decrease from the coast toward the interior with increasing time scales.

INTRODUCTION

Drought is one of the most damaging climate-related hazards to impact societies. Although drought is a normal part of climate, it can develop as an extreme climatic event and can have severe impact on local people and water-dependent sectors. Therefore, it is of a great importance to develop measures of drought severity both at spatial and temporal scales. Most definitions of drought are based on expression of deficiency of precipitation that results in water shortage for some activity related to use of water (Wilhite and Glantz, 1985; Dracup et al., 1980). In general terms, drought usually is perceived to be a prolonged period without precipitation resulting in moisture deficiency which produces a hydrologic imbalance between precipitation and evapotranspiration in a particular area. Although precipitation is the primary controlling factor of the drought, other climatic factors such as high wind, high temperature or low relative humidity can contribute to amplify its intensity. The severity of the 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 but gradually move to streamflows and groundwaters.

Drought affected large areas of Europe during the 20th century and is not restricted to the Mediterranean region alone as it can 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 low and highly variable. The combination of rainfall deficiency with other climatic factors, in particular high temperatures, creates serious vulnerability to drought in the central and southeastern parts of the country where agriculture is the main economic sector (Komuscu, 1998). The impacts of drought in the low and variable rainfall regions of the country can be widespread, affecting such diverse sectors as agriculture, irrigation, and energy. In fact, drinking water supplies dropped drastically in major urban areas during the early 1990s due to severe droughts and led to initiation of several rain enhancement projects to meet 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 a need for better identification of the drought at varying time scales and severity.

In this study, the drought climatology of 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 the multi-natural aspects of the drought with respect to frequency of drought occurrence in intensity and its spatial extension to identify drought-prone areas and drought vulnerability. The study also aimed at treating the drought occurrence from a different perspective by analyzing threshold rainfall values by which a minimum amount of rainfall can be established for non-drought conditions. However, 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.

BACKGROUND

Drought is a recurrent phenomenon in Turkey over the last several decades. A warming trend that began in the early 1990s has continued in recent years despite some cooling (Figure 1). The annual mean temperatures have remained above average since 1995. A significant drought is observed during 1999 and 2000, which was associated with a lack of precipitation during the winter and spring,

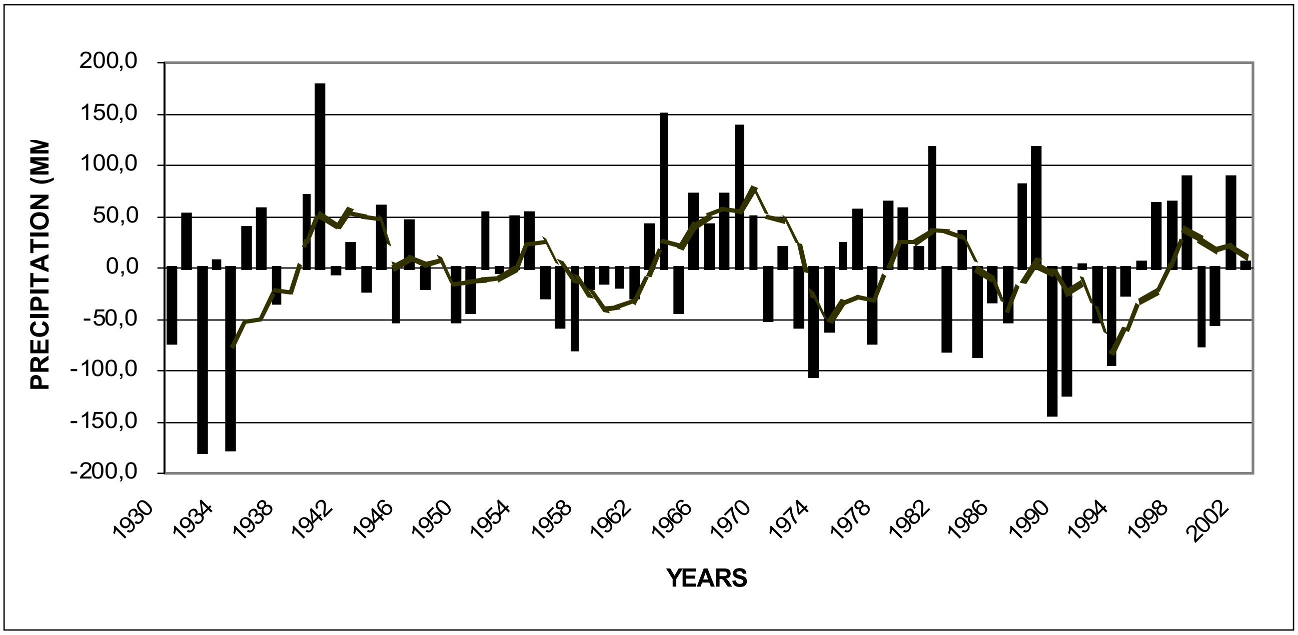

Figure 1. Long-term precipitation anomalies of Turkey.

normally the wettest seasons. Almost two thirds of the country, mainly the southeastern part and central Anatolia experienced severe drought in 1999, and the drought continued in 2000 with slight differences in areal coverage. The country has recovered from drought conditions in recent years with increasing rainfall.

With respect to rainfall characteristics, most central and southeastern parts of Turkey are considered to be semiarid, 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 the P/PET ratio as suggested by the UNCCD, arid and semiarid regions can be identified, especially in the central and southeastern parts of the country (Komuscu, 2002).

Namias (1985) argues that drought is associated with persistent or persistently recurring atmospheric circulation patterns. Changes in the North Atlantic Oscillation (NAO) are believed to be an important factor that controls rainfall variability in Turkey (Cullen and deMonecal, 1999). During the positive phases of the 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). It has been observed that during positive NAO years Turkey becomes significantly cooler and drier. Figure 2 shows a correlation between annual rainfall and NAO indices over the last three decades. It has been shown that the dry periods correspond well with the positive phases of the NAO, and similarly humid conditions prevail during the negative phases of the NAO. Considering the country receives most of its rainfall in winter and spring, winter droughts in Turkey can be attributed to positive NAO anomalies. This also means that the country will be more vulnerable to drought during the negative phases of the NAO.

USE OF STANDARDIZED PRECIPITATION INDEX (SPI) FOR DROUGHT ANALYSIS

Precipitation is the primary factor controlling the formation and persistence of drought along with other variables such as evapotranspiration. It has been found that indices based solely on precipitation data perform well when compared with more complex hydrological indices (Oladipio, 1985).

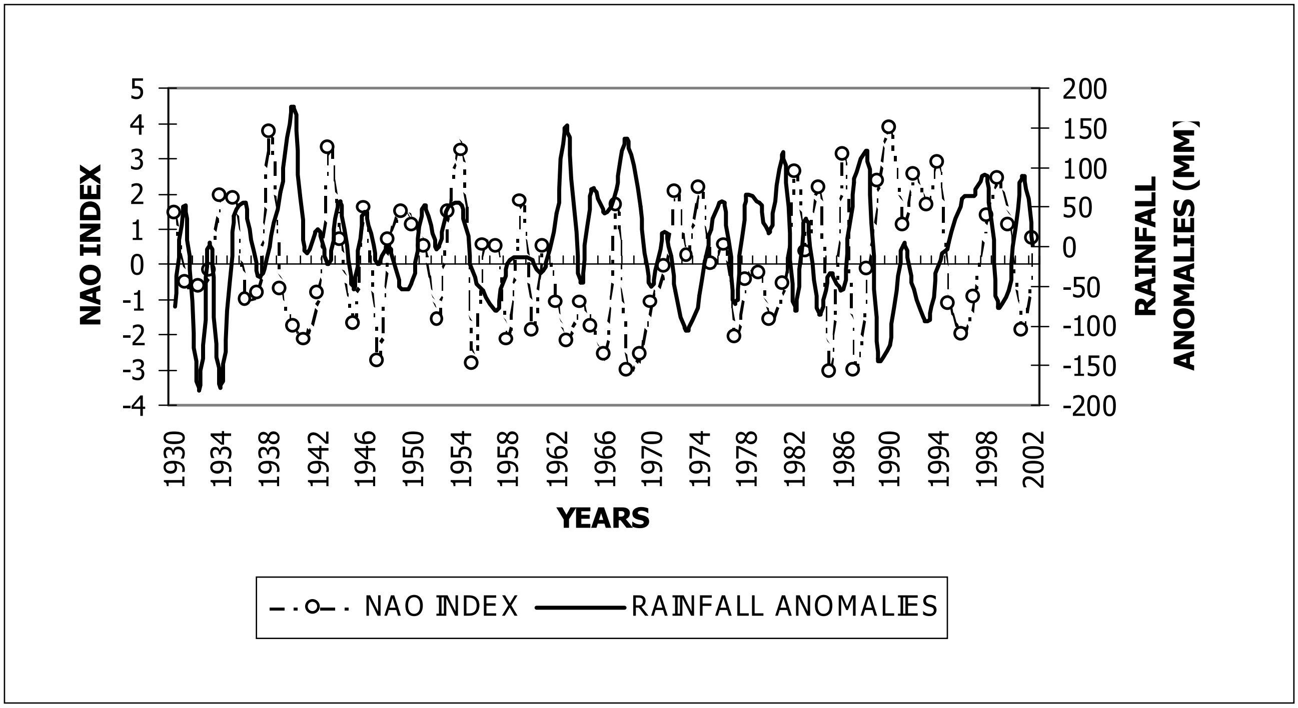

Figure 2. Relationship between long-term rainfall anomalies of Turkey and NAO Index.

Several indices have been developed and adopted to measure drought or wet spell intensity. Generally, they are based on the deviation of precipitation for a given period from historically established norms. Among these indicators, the ones that have been most used are: Percent of Normal, Deciles, SPI, Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI) and Surface Water Supply Index (SWSI).

The impact of rainfall deficiency on water resources varies on a temporal scale. While soil moisture responds to precipitation anomalies on a relatively short scale, 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 scales, which reflected the impact of precipitation deficiency on the availability of the different water suppliers. The different times scales (seasons) for which the index is computed address the various types of drought: shorter seasons for agricultural and meteorological drought and longer seasons for hydrological drought, etc. with those in the PDSI. Guttman (1997) 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).

Besides its advantages, practical applications of the SPI revealed several disadvantages; first being the assumption 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; namely that extreme droughts (or any other drought threshold) measured by the SPI will occur with the same frequency at all locations when considered over a long time period.

In this study, the computed values of the SPI have been tested against corresponding precipitation data for some selected stations. Figure 3 presents comparison of SPI and precipitation for Konya station at 3- and 12-month time scales for 1981-2001 period.

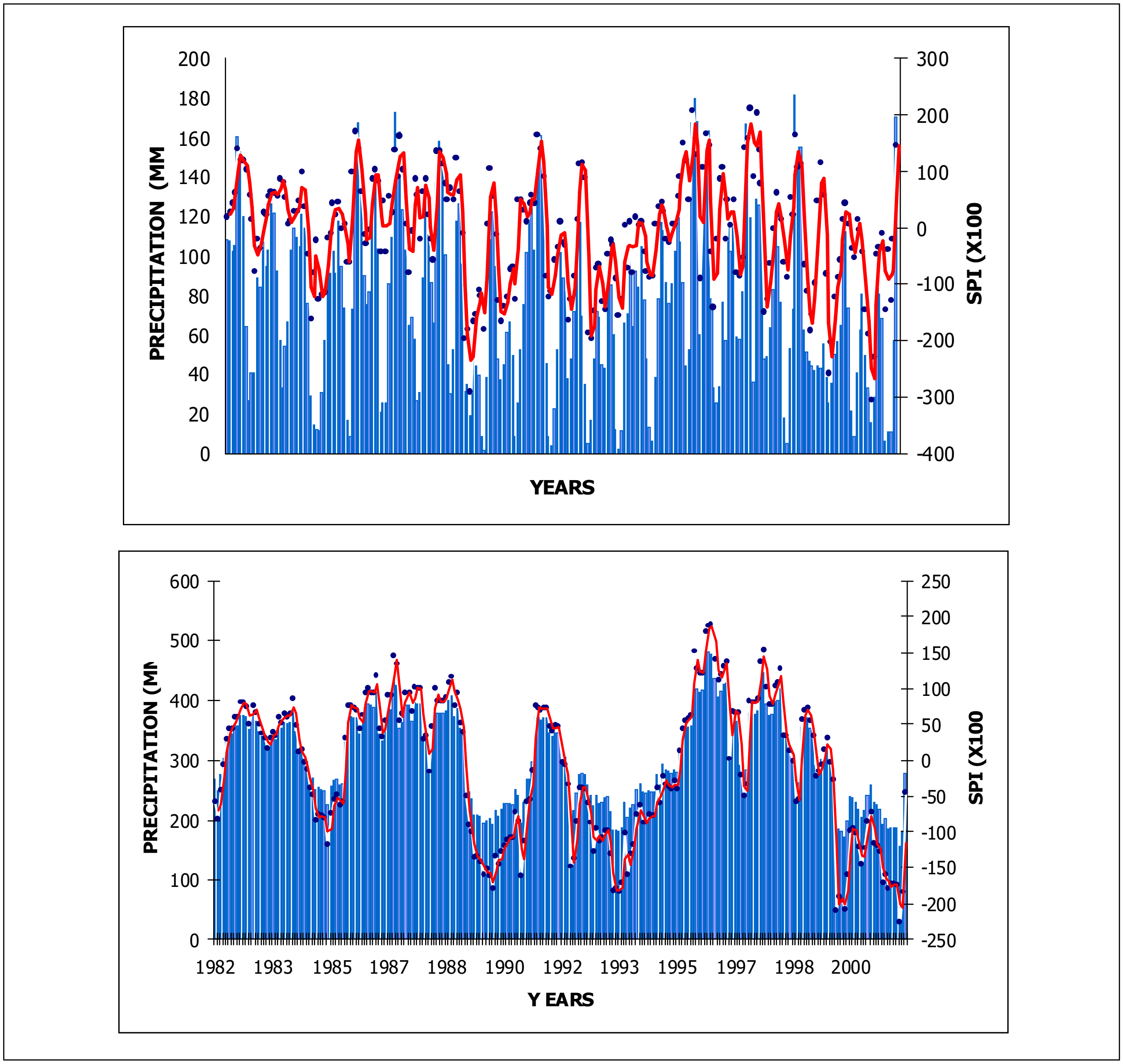

Figure 3. Comparison of computed SPI values and precipitation data for Konya station at 3 and 12 month time scales for the period of 1982-2001.

CALCULATION OF THE SPI

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

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

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 data-based probability of emerging from a specific drought. The calculations, however, take a more complicated form when the SPI is normalized to reflect the variable behavior of the precipitation for time scales shorter than 12 months. The long-term data is fitted with a gamma probability density function to a given frequency distribution of precipitation totals for a station. The gamma probability density function parameters are estimated for each station, for each time scale of interest (3 months, 12 months, 48 months, etc.), and for each month of the year. The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. The method of computation the SPI may be found in Guttman (1999). The normalized series of SPI values represent wetter and drier climates in the same way. McKee et al. (1994) defined the criteria for a "drought event" for any of the time scales, and classified the SPI to define various drought intensities (Table 1). Given the advantages of the index standardization, the SPI has been largely used operationally to monitor climatic conditions across different locations.

Table 1. 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

In this study, we have developed a computerized version of the SPI in the Delphi programming language and added some features to make it practically usable for drought assessment and producing critical threshold rainfall values at corresponding drought severities. The program has capabilities of calculating and displaying SPI values at 3,6,12, and 24-month time scales both in ASCI and graphical formats, displaying charts of equiprobability transformation from the fitted Gamma distribution to the Standard Normal Distribution, illustrating cumulative probability versus precipitation, and displaying drought categories at the selected time scales as percentage of drought occurrence.

The monthly precipitation time series are modelled using different statistical distributions. The probability distribution function is determined from the long-term record by fitting a gamma function to the data. The gamma distribution is defined as:

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

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. Detailed procedures of the calculation of the above parameters can be found in Gutmann (1999) and Hughes and Saunders (2002).

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 scale:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{a}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \tag{3}$$

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:

$$H(x) = q + (1-q)G(x) \tag{4}$$

The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI. This process is illustrated in Figure 4. The first panel shows the empirical cumulative probability distribution for a 3 month average December–January–February (DJF) of precipitation at Zonguldak station on the Black Sea cost. Over-plotted is the theoretical cumulative probability distribution of the fitted gamma distribution. The second panel displays a graph of standard normal cumulative probability. To convert a given precipitation level to its corresponding SPI value, first locate the precipitation amount on the abscissa of the left-hand panel, draw a perpendicular, and locate the point of intersection with the theoretical distribution. Then project this point horizontally (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 Figure 4, 307 mm rainfall corresponds to 0 (zero) SPI value, which means that at least 307 mm is needed at Zonguldak during J-F-M period to avoid drought formation. It is important to remember that the SPI values below 0 represent drought formation and as the number goes down the severity of drought increases.

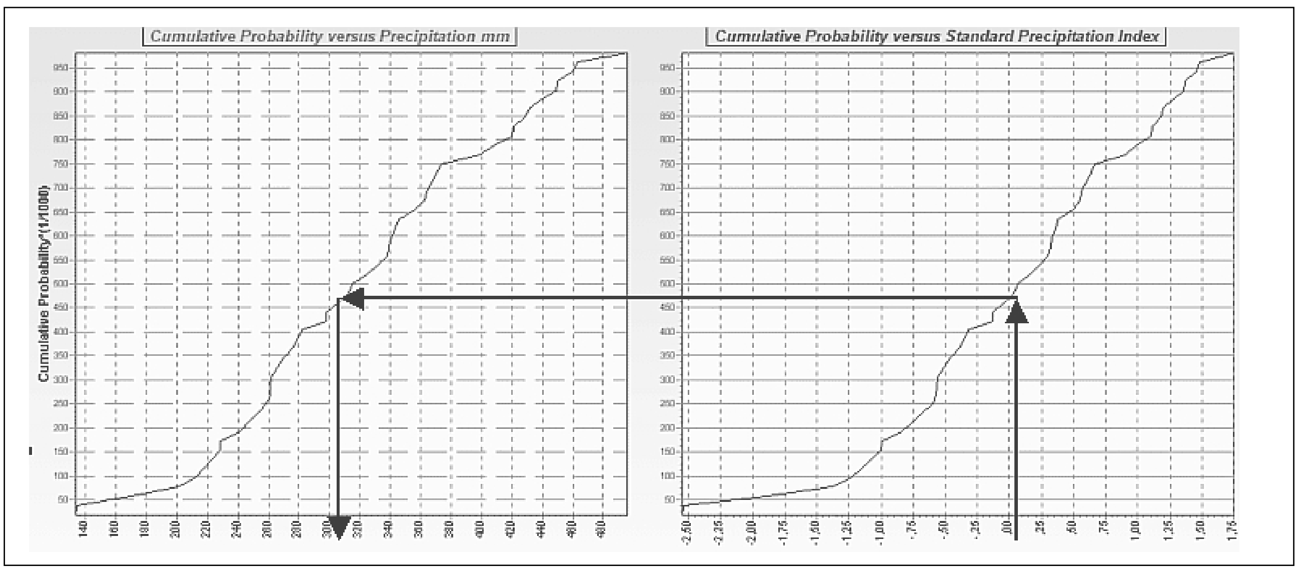

Figure 4. Equiprobability transformation from the fitted Gamma distribution to the Standard Normal Distribution, illustrating cumulative probability of SPI versus precipitation.

DROUGHT ANALYSIS

In this study we presented an analysis of drought variations in Turkey using drought frequency information at varying time scales (i.e., 3,6, and 12-month) and drought severity categories and threshold rainfall values below which a drought can be expected for different drought categories. The drought analysis has been made at a total of 101 stations distributed across the country and covers the 1951-2001 period (Figure 5).

Drought Occurrence

In this study, drought occurrences in Turkey have been identified based on the frequency of the events for each drought category at different time scales. Then the frequencies were mapped to analyze their spatial distribution. In other words, drought events have been categorized based on their frequency for varying drought categories at 3,6, and 12, and 24-month time scales and then were analyzed on a regional basis. The aim here was to identify areas vulnerable to drought at comparable

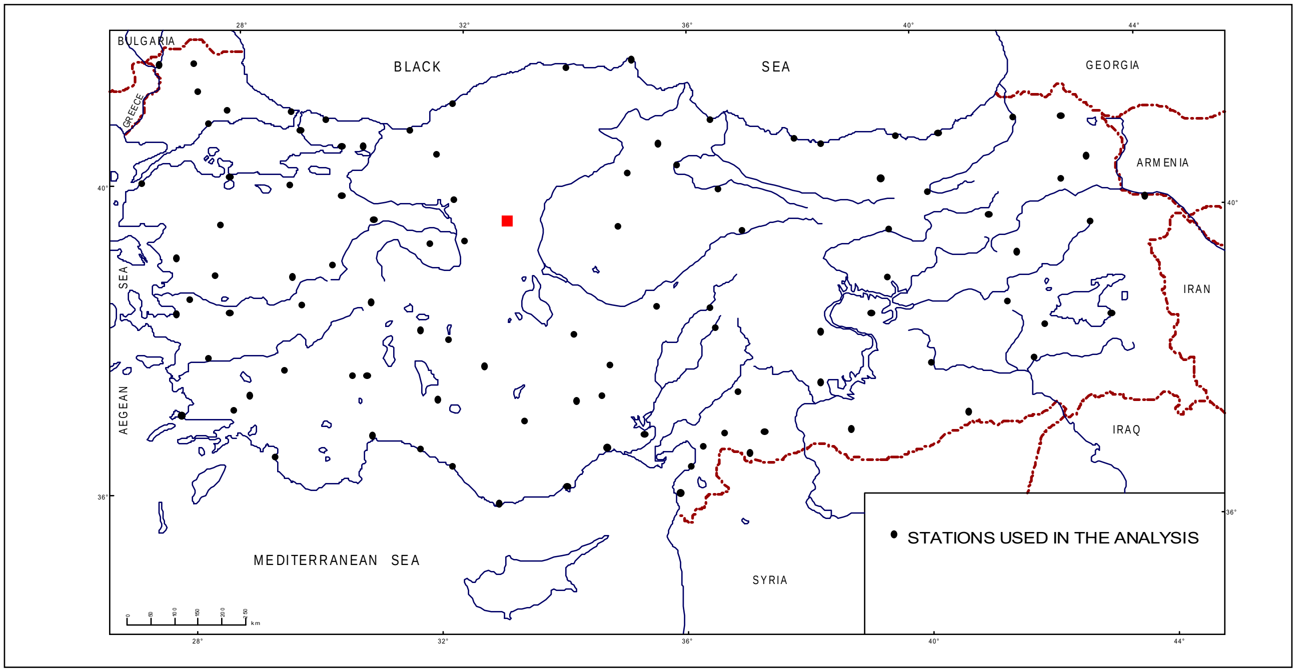

Figure 5. Geographical distributions of the stations used in the analysis.

time scales based on their occurrence frequencies. A sample table describing the above analysis is given below for Konya station located in a central part of the country where semiarid climate predominates (Table 2).

We initially examined occurrences of moderate droughts and found that they tend to occur in eastern and southeastern Anatolia at a 3-month time scale, while the coastal areas are characterized by the lowest frequencies at the same temporal scale (Figure 6). In other words, from the historical perspective, a majority of the droughts that occurred in eastern and southeastern Anatolia were moderate over short time scales. As the time scale increases to 6 months, 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 a 12-month time scale, moderate droughts occurred more often covering nearly two-thirds of the country. The moderate droughts exhibit more variable behavior when the time scale increases to a 2-year period, and no large areas are identified with moderate droughts at this scale. At a station level, most southeastern and eastern Anatolia stations are characterized with moderate droughts at shorter time scales while the stations in central Anatolia exhibit lessening frequencies at the same time scales.

The occurrence of severe droughts at shorter time scales is typical at non-coastal areas of the country. Especially parts of the eastern Anatolia bordering Armenia and Iran and the European part

Table 2. Drought Occurrence in Konya Station

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 and -1.49	Moderate drought	8.6	9.2	9.2
-1.50 and -1.99	Severe drought	4.1	3.6	6.2
≤ -2.0	Very severe drought	3.0	3.4	2.3

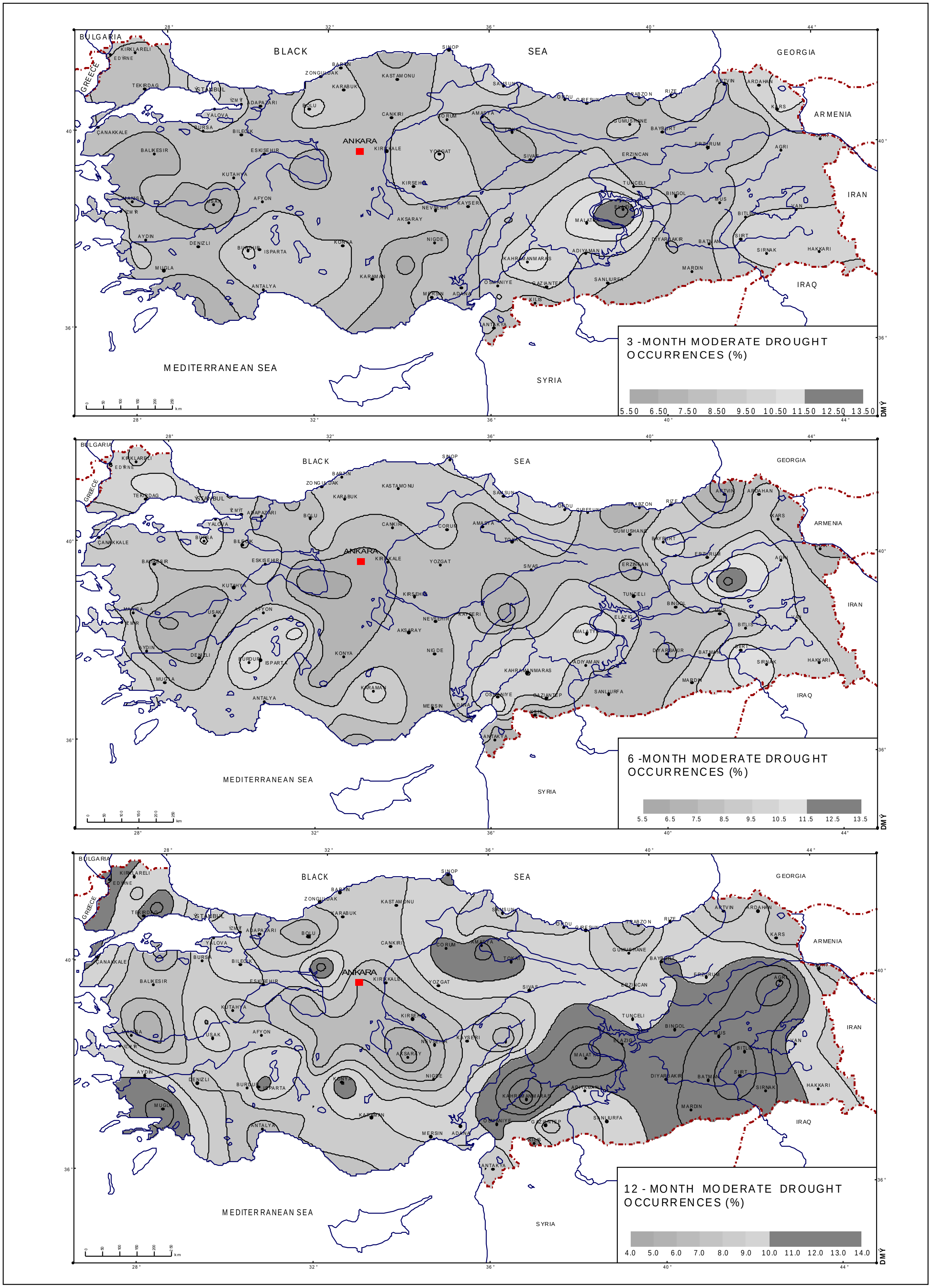

Figure 6. Moderate drought occurrences at 3,6, and 12-month time scales.

of the Marmara Region exhibit maximum frequencies (Figure 7). This severe drought characterization totally changes at longer time scales. Except for central Anatolia, a majority of the country has low occurrences of severe droughts at a 12-month time scale. It can be concluded that severe droughts in Turkey have more seasonal behavior than a long-lasting character. At a 2-year scale, no extended severe drought areas are identified, rather few localities display high severe drought occurrence. Another interesting result is that while the interior parts of the country are characterized with severe drought at shorter time scales, coastal areas experience severe drought at longer-time scales at higher frequencies. This means that while the central parts of the country are probably affected by agricultural drought with faster depletion of the soil moisture, the coastal areas 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 coastal and interior parts at shorter time scales, except eastern Anatolia where drought occurs at low frequencies (Figure 8). As the time scale increases, frequency of severe droughts increases as well, especially along the Mediterranean coast and some localities in the central parts. At a 2-year time scale, severe drought occurrences extend to other coastal areas and parts of central Anatolia where maximum drought frequencies are observed. Interestingly, eastern Anatolia experiences the lowest occurrences of prolonged droughts at longer time scales, as well as the parts of the Black Sea region. That means at longer time scales hydrologic drought is likely to occur at the coastal areas while the interior suffers from agricultural drought under severe drought conditions.

In this study we also briefly looked at how severe drought evolved over time in its spatial extent. In this respect, we looked at the number of stations which exhibited severe drought conditions over the given time scales between 1951 and 2001. The idea here was to see persistence in the areal extent of the drought based on the station data over time (Figure 9). Four severe drought periods have been identified in the last 50 years; namely 1953-1959, 1972-1977, 1989-1994, and finally 1999-2001. At the 24-month scale, those periods were better identified. As the time scale increases, the total number of stations which experience severe drought increases while the number is relatively low at shorter time scales. The results also indicate that recovery from drought conditions at longer durations is also slower as compared to those of the short duration.

Critical Rainfall Analysis

One of the advantages of the SPI model developed in this study is that it provides not only the SPI for a given rainfall total but also computes critical rainfall values (threshold rainfall) for corresponding drought categories. In other words, we can determine the minimum amount of rainfall that is required to avoid drought formation at different severity categories and varying time scales. In this respect, we calculated the critical rainfall values for an SPI value of zero, defined as the threshold at which drought begins to form. As stated previously, the SPI values below zero indicate a drought occurrence, and as the values descend below zero the severity of drought increases. After computing the critical rainfall values for each station, they are mapped to see their geographical distribution to identify areas that must receive a minimum amount of rainfall for a drought event not to form.

In order to relate the rainfall requirement with a practical application, the analyses first were made at 3- and 6-month time scales to correspond to the growing season when the soil moisture demand is maximized and can be related to the drought conditions. The critical threshold values that exhibited rising numbers during the growing season at a 3-month scale are generally located in southeastern Anatolia (Figure 10). That means a maximal demand for rainfall to avoid drought conditions in the region. This is a very significant result considering presence of large irrigation projects developed in

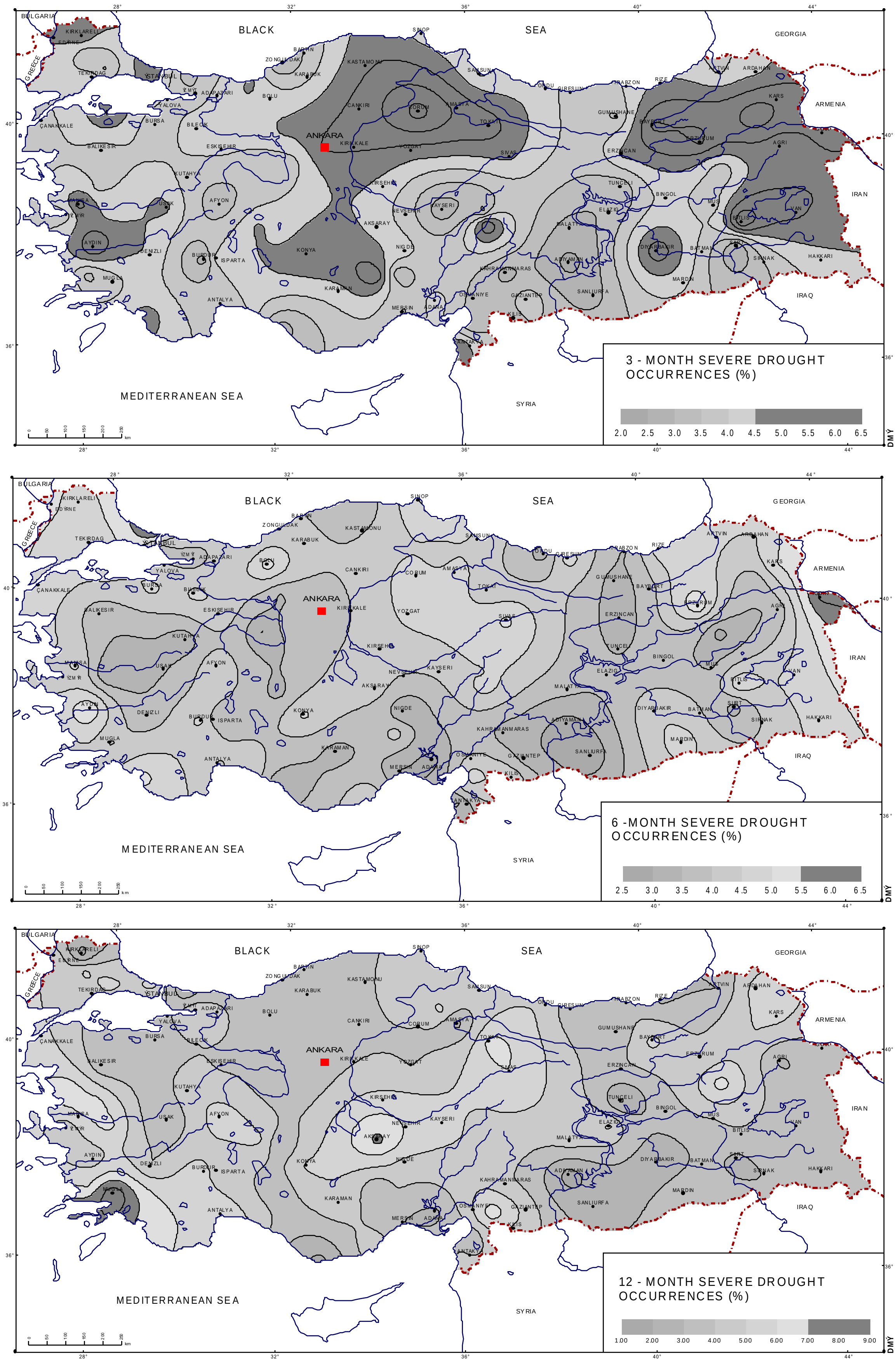

Figure 7. Severe drought occurrences at 3,6, and 12-month time scales.

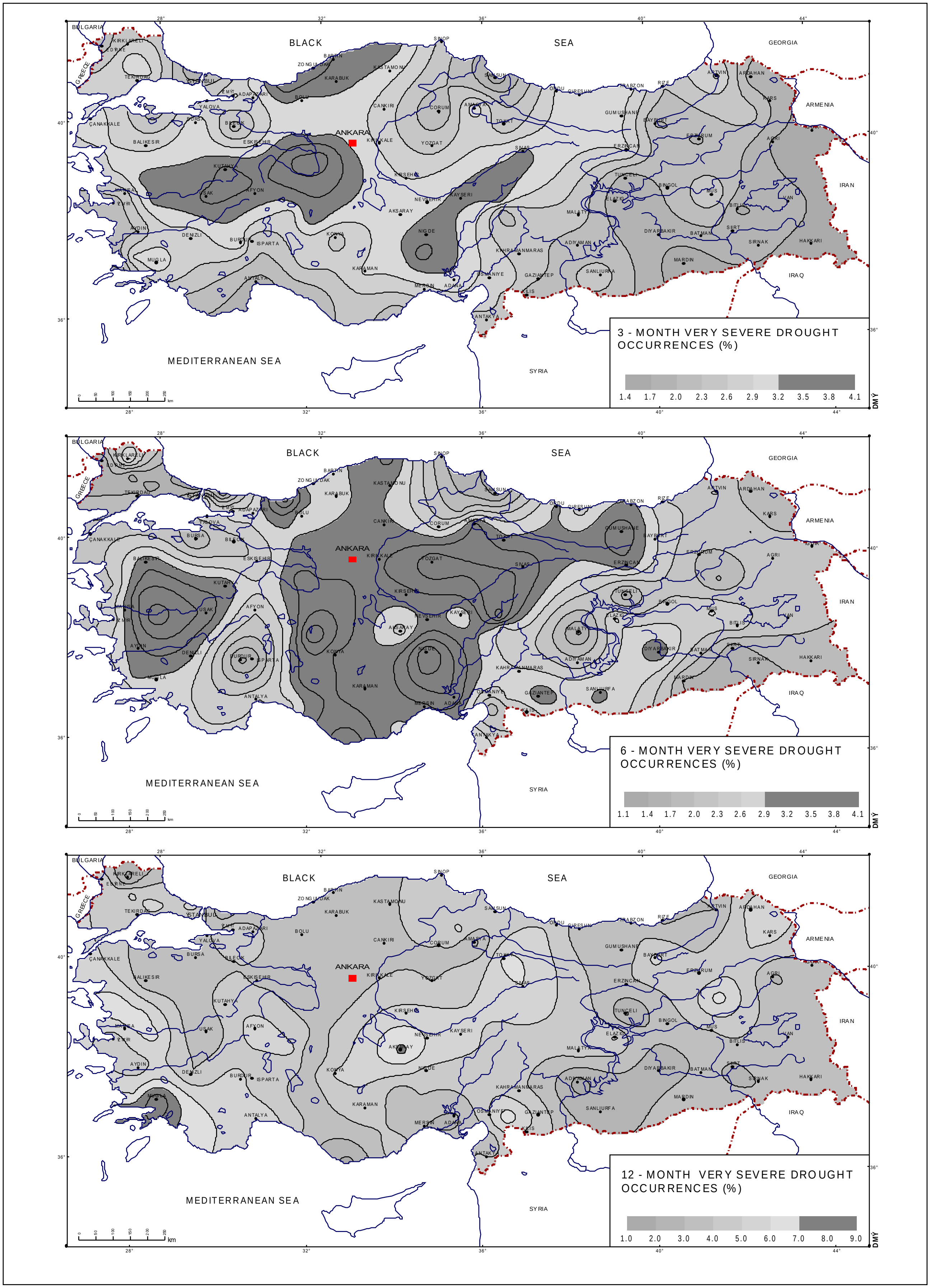

Figure 8. Very severe drought occurrences at 3,6, and 12-month time scales.

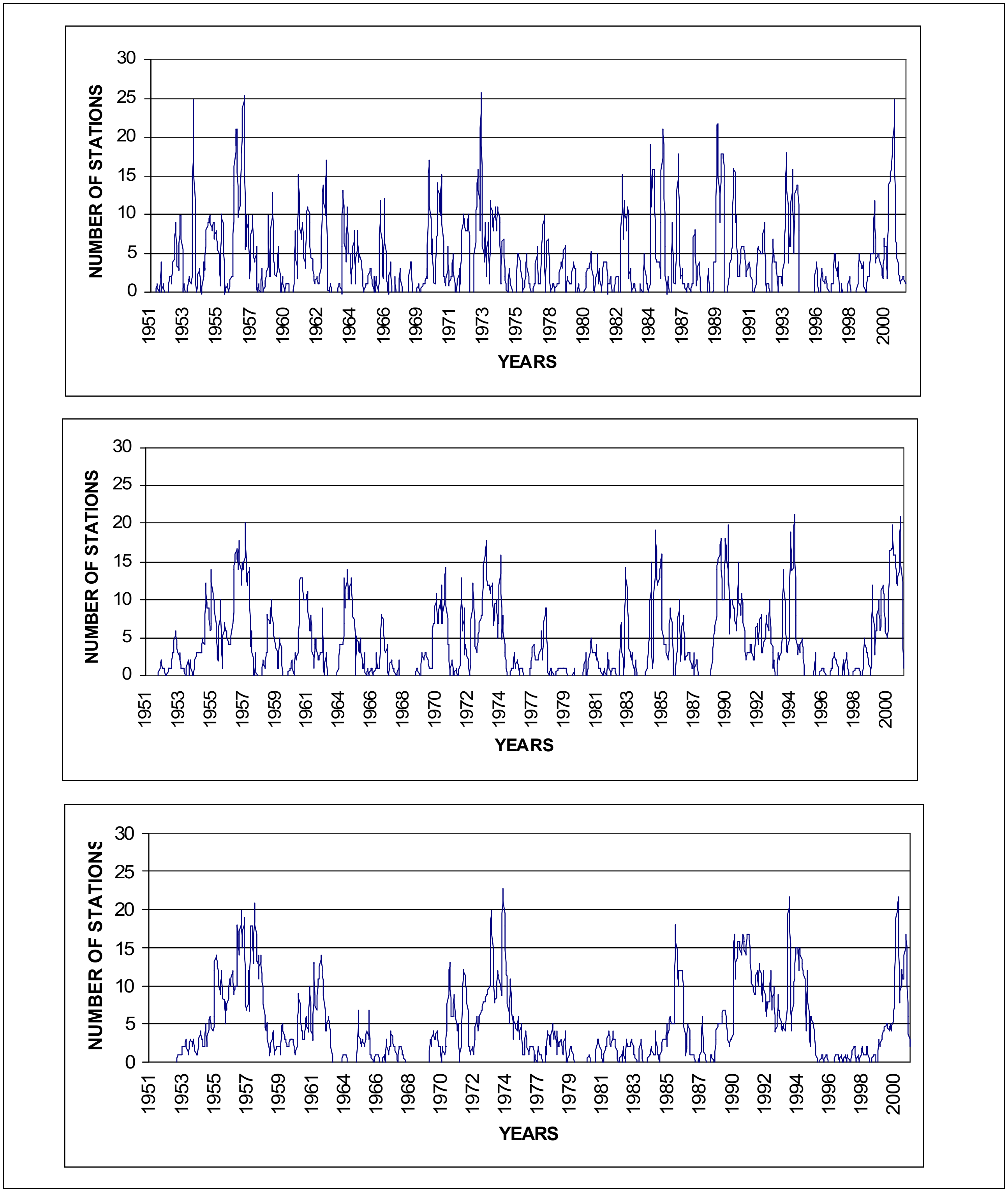

Figure 9. Number of stations experienced severe drought at 6,12, and 24-month time scales.

the area. Rainfall demand for no-drought occurrence increases from west to east, and in general the central parts will be least affected from a drought event during growing season.

At a 6-month scale covering the winter-spring period, threshold rainfall values for non-drought conditions reach their maxima in southeastern Anatolia and parts of the Mediterranean and northern Black Sea coasts (Figure 11). In general, rainfall amounts required for non-drought conditions decrease from the coastal areas toward the interior. This is not a surprising conclusion considering the fact that the coastal areas, mainly the Mediterranean coasts, receive most of their rainfall during the winter-spring period. The results also indicate that the areas that have higher rainfalls on average are affected by a drought event more severely as compared to another region, which receives lower rainfall.

Interestingly, critical threshold rainfall values at a 12-month scale exhibit a similar behavior to those observed at the 6-month scale, except the area of higher rainfall demand moves to the northern Black Sea region (Figure 12). The figure also shows that threshold values exhibit sharp differences in their geographical distribution. For example, nearly 2000 mm of rainfall is needed to avoid a drought in the Northern Black Sea region, while the rainfall amount required for a non-drought condition drops to as little as 300 mm in the central parts and in the eastern border with Iran.

At a 24-month scale, rainfall threshold values reach their maxima in the northern Black-Sea region (Figure 13). The coastal areas still exhibit higher values as compared to the central locations where rainfall demand for non-drought conditions is minimal. Similarly, neighboring regions with Iran and Armenia are characterized with the least rainfall demand required to avoid drought conditions. In general, rainfall demand decreases from the coastal areas toward the interior if a drought event is to be avoided. Considering the fact that the coastal areas usually receive higher rainfall than the interior regions, it is likely that they will be more vulnerable to long-term droughts at 2-year scale.

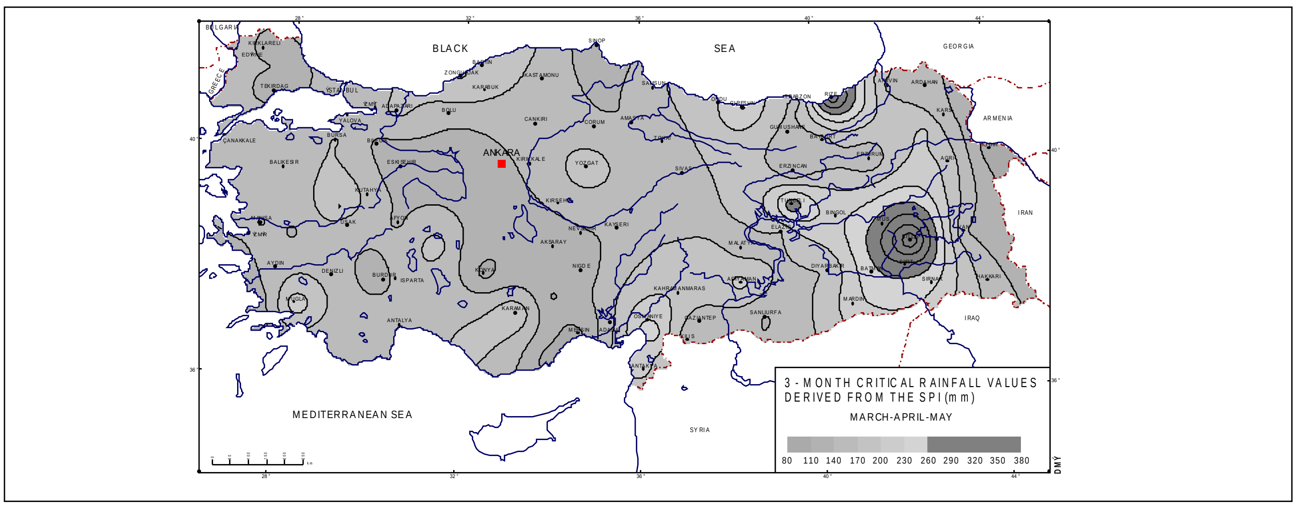

Figure 10. 3-Month critical rainfall values for March-April derived from the SPI.

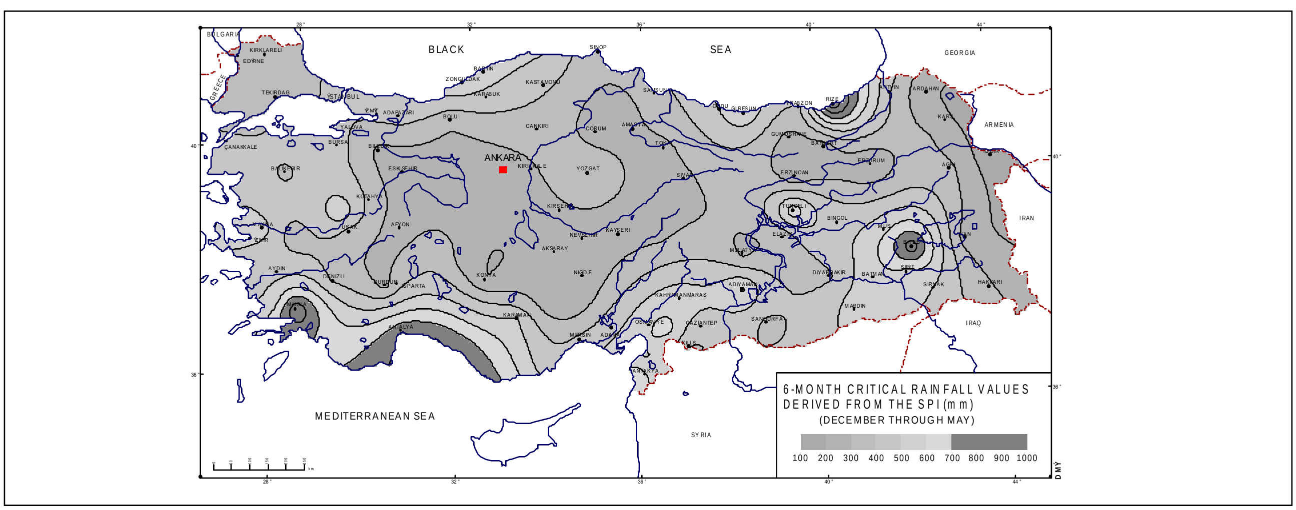

Figure 11. 6-Month critical rainfall values for March-April derived from the SPI.

RESULTS & DISCUSSIONS

This study assessed overall meteorological drought variability in Turkey by reconstructing historical occurrences of drought at varying time scales and drought categories. The assessment further included analysis of critical threshold rainfall requirements for the occurrence of non-drought conditions. It is our thought that an improved understanding of drought climatology (frequency, intensity, and spatial extent of drought patterns) helps to identify the hazard associated with the drought. Although using varying time scales and drought categories complicates the analysis a bit to arrive at precise conclusions about drought vulnerability in Turkey, we believe the study offers some new insight into drought phenomena in Turkey, especially with regard to variability at varying time scales.

It is obvious that drought will create a vulnerable environment for the agricultural and water resources sectors in Turkey considering spatial and temporal impacts. However, the impacts vary greatly when we insert the idea of time scale. While the southeastern and eastern parts of the country

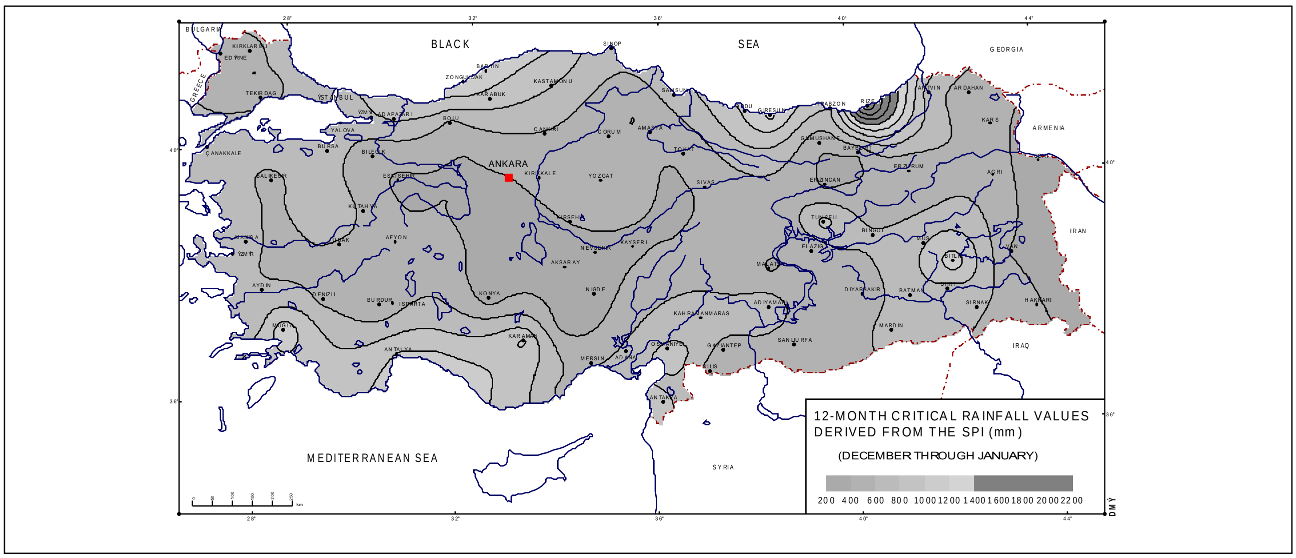

Figure 12. 12-month critical rainfall values for December through January derived from the SPI.

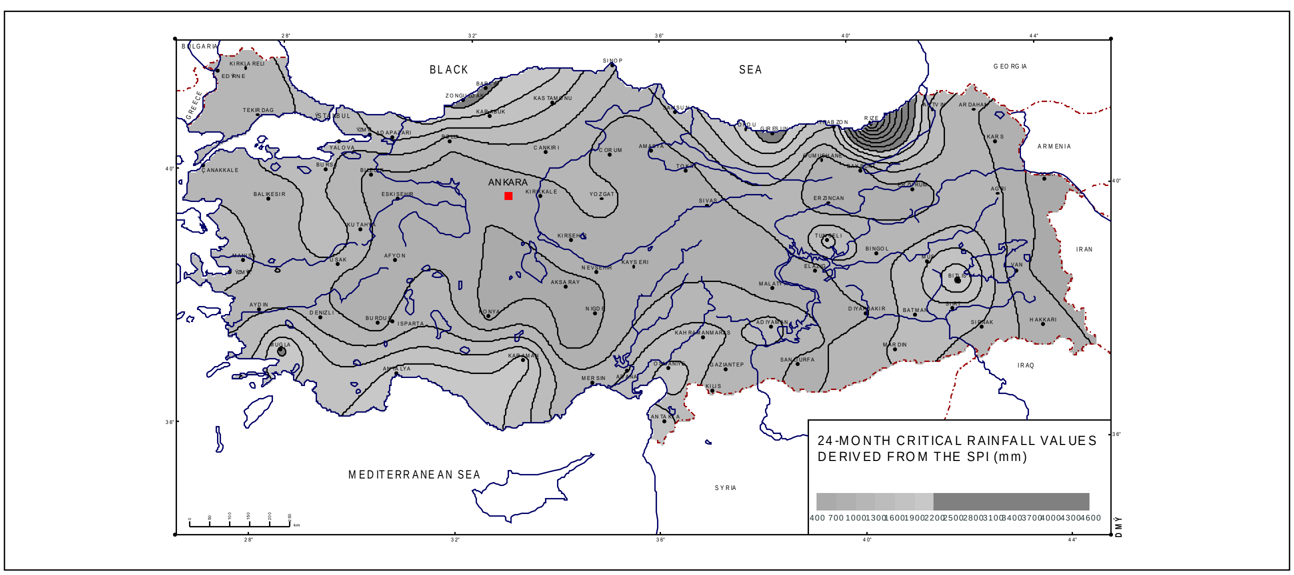

Figure 13. 24-month critical rainfall values derived from the SPI.

are more vulnerable to moderate droughts at short time scales, the impacts is relatively less at the coastal areas where drought is only effective at longer durations and at moderate drought levels. A similar picture has been observed with severe droughts. On the other hand, the coast and interior are more vulnerable to severe droughts as opposed to the eastern Turkey where drought frequencies lessen. That leads us to think that at longer time scales hydrologic drought is likely to occur at the coastal areas while the interior will suffer from agricultural drought under severe drought conditions. In this study we also conduct a critical rainfall (threshold) analysis to determine the minimum amount of rainfall required to avoid drought formation for different severity categories and varying time scales. It has been found that at a 3-month scale, the rainfall requirement for non-drought conditions decreases from west to east, and in general the central areas will be least affected from a drought event during the growing season. The maximum rainfall requirements at this scale are usually concentrated in southeastern Turkey. As the time scale increases, the area of maximum rainfall requirement shifts to the north. It can also be concluded that areas that have normally higher rainfalls are affected by a drought event more severely as compared to another region, which receives lower rainfall. It can be concluded that the increase in the drought hazard may result from an increased frequency and severity of meteorological drought, which may then lead to increased societal vulnerability to drought.

The conclusions reached in this study can be an essential step toward addressing the issue of drought vulnerability in the country, and can serve as a 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 drought into account from the hazard perspective and include the concept of drought vulnerability into natural resource planning. Since the impacts of drought vary significantly between locations because of differences in economic, social, and environmental characteristics at the micro and macro scales, further research is needed to determine how the vulnerability concept can be applied in practice to specific regions and different water-dependent sectors.

REFERENCES

Cullen, H.M. and P.B. deMonecal; (1999). North Atlantic Influence on Tigris-Euphrates Streamflow. Lamont Doherty Earth Observatory of Columbia University, New York.

Dracup, J.A., K.S.Lee and E.G. Paulson Jr; (1980). On the Definition of Droughts. *Water Resources Research*, (16) 297-302.

Downing, T.E. and K. Bakker; (2000). Drought discourse and vulnerability. Chapter 45, in D. A. Wilhite (ed.), *Drought: A Global Assessment, Natural Hazards and Disasters Series*, Routledge Publishers, U.K.

Guttman, N.B.; (1997). Comparing the Palmer Drought Index and the Standardized Precipitation Index. *J. Amer. Water Resour. Assoc*., 34, 113–121.

Guttman, N. B.; (1999). Accepting the Standardized Precipitation Index: A calculation algorithm. *Journal of the American Water Resources Association (JAWRA)* 35, no 2 (Apr): 311-22.

Guttman, N.B. and American Water Resources Association; (1998). Comparing the Palmer Drought Index and the standardized precipitation index. *Journal of the American Water Resources Association (JAWRA)* 34, no. 1 (Feb): 113-121.

Hurrell, J.W.; (1995). Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. *Science,* 269, 676-679.

Keenan, S.P. and R.S. Krannich; (1997). The social context of perceived drought vulnerability. *Rural Sociology*, 62(1), 69–88.

Komuscu, A.U., A. Erkan and Sukriye Oz; (1998). Possible impacts of climate change on soil moisture variability in the Southeast Anatolian Development Project (GAP) Region; An analysis from agricultural drought perspective. *Climatic Change*, (40) 519-545.

Komuscu, A.U.; (2002). An Analysis of Recent Drought Conditions in Turkey in relation to Circulation Patterns, *Drought Network News*, Vol.13, No.2-3, 5-6

Komuscu, A.U.; (2003), Weather Modification Activities in Turkey. *Proceedings of Eight WMO Scientific Conference on Weather Modification.*, Casablanca, Morocco. WMO Report No.39, pp.39-42, Geneve, Switzerland

Lloyd-Hughes B., M. Saunders; (20020. A drought Climatology for Europe, *Int. J. Climatol*. 22: 1571–1592

McKee, T.B., N.J. Doesken and J. Kleist; (1993). The Relationship of Drought Frequency and Duration to Time Scales. *Preprints, 8 th. Conference on Applied Climatology*, 17-22 January, Anaheim, CA, 179-184.

McKee, T.B., N.J. Doesken and J. Kleist; (1994). Drought Monitoring With Multiple Time Scales. American Meteorological Society, *Proceedings of 9 th. Conference on Applied Climatology*, 233-236.

Namias, J.; (1985). Hydrologic aspects of drought, in Beran, M.A., and Rodier, J.A., eds., Unesco-World Meteorological Organization, A Contribution to the International Hydrologic Programme, Paris, France, p. 27-64.

Wilhite, D. A. and M.H. Glantz; (1985). Understanding the drought phenomenon: The role of Definitions.*Water International* (10) 111-20.

Wilhite, D.A.; (1993). The enigma of drought, Chapter 1, in D. A. Wilhite (ed.), *Drought Assessment, Management, and Planning: Theory and Case Studies*, Kluwer Academic Publishers, Boston, MA, pp. 3–17.

Wilhite, D.A.; (2000b). Drought as a natural hazard: Concepts and definitions, Chapter 1, in D.A. Wilhite (ed.), *Drought: A Global Assessment, Natural Hazards and Disasters Series*, Routledge Publishers, U.K.

ADDRESS FOR CORRESPONDENCE
Dr. Ali Umran Komuscu
Turkish State Metereological Service
Research Department
Kalaba
06120 Ankara
Turkey

E-mail: aukomuscu@meteor.gov.tr