Tr. J. of Engineering and Environmental Science
23 (1999) , 363 – 380.


# Vulnerability of Turkey to Desertification With Respect to Precipitation and Aridity Conditions

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Received 19.01.1998

**Abstract**

Climatic factors that may lead to desertification in Turkey were investigated by analysis of the spatial and temporal variations of the precipitation and aridity index series, for the period 1930-1993. Semi-arid and dry sub-humid environmental conditions are dominant over the continental interiors and South-eastern Anatolia. Persistent dry conditions have been evident for the past two decades over a considerable part of Turkey. There has been a general tendency from humid conditions of around the 1960's towards dry sub-humid climatic conditions in the aridity index values of many stations and of Turkey, in general. At some stations in the Aegean Region, there has been a significant change from humid conditions to dry sub-humid or semi-arid climatic conditions. With regard to climatic factors, South-eastern Anatolia and the continental interiors of Turkey appear to be aridlands that are prone to desertification. When other natural and anthropogenic factors, such as high topography, forest fires and unsustainable use of agricultural lands are also taken into account, the Mediterranean and Aegean regions could be more vulnerable to desertification processes in the future.

**Key Words:** Precipitation, Aridity Index, Seasonality, Variability, Trend, Persistent and Periodicity Analysis.

## Yağış ve Kuraklık Koşulları Açısından Türkiye'nin Çölleşmeden Etkilenme Eğilimi

**Özet**

Türkiye'de çölleşmeyi yönlendirebilecek olan iklimsel etmenler, yağış ve kuraklık indisi dizilerinin alansal ve zamansal değişimleri 1930-1993 dönemi için analiz edilerek araştırılmıştır. Yarı-kurak ve kurak yarı-nemli çevresel koşullar, karasal iç bölgeler ve Güneydoğu Anadolu Bölgesi üzerinde egemendir. Israrlı kurak koşullar, yaklaşık son 20 yıl süresince Türkiye'nin önemli bölümünde belirgin olmuştur. Birçok istasyonun ve Türkiye'nin kuraklık indisi değerlerinde, 1960'lardaki nemli koşullardan kurak yarı-nemli iklim koşullarına doğru genel bir eğilim bulunmaktadır. Ege Bölgesi'nin bazı istasyonlarında, nemli koşullardan kurak yarı-nemli ya da yarı-kurak iklim koşullarına yönelik önemli bir değişim sözkonusudur. İklim etmenleri gözetildiğinde, Güneydoğu Anadolu Bölgesi ve Türkiye'nin karasal iç bölgeleri çölleşmeye eğilimli kurak alanlar olarak kendisini gösterir. Topoğrafyanın yüksek oluşu, tarım arazilerinin sürdürülebilir olmayan kullanımı ve orman yangınları gibi öteki doğal ve insan kaynaklı etmenler dikkate alındığı zaman da, Akdeniz ve Ege bölgeleri gelecekte çölleşme süreçlerine daha fazla açık olabilecek alanlar olarak düşünülebilir.

**Anahtar Sözcükler:** Yağış, Kuraklık İndisi, Mevsimsellik, Değişebilirlik, Eğilim, Israr ve Dönemsellik Analizi

## Introduction

The United Nations (UN) first put the issue of desertification on the international agenda at the UN Conference on Desertification (UNCD) in 1977, as a global socio-economic and environmental problem. The first international effort to combat desertification had begun at the end of the great Sahelian drought and famine of 1968-1974, in which over 200,000 people and millions of animals died (Lean, 1995). Developing countries, especially in Africa, insisted that particular attention should be given to desertification, during the preparations for the UN Conference on Environment and Development (UNCED) held in Rio in June, 1992. Then the world's leaders agreed in Agenda 21 to call on the UN General Assembly to set up an Intergovernmental Negotiating Committee to prepare a legally binding instrument by June, 1994. Finally, the UN Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, was adopted in Paris on 17 June 1994.

It would be useful at the beginning of this study to differentiate between the terms of aridity, drought and desertification, through the use of the terms accepted for the Convention to Combat Desertification (referred to hereinafter as the Convention). Aridity is the state of low average precipitation or available water in a region and, if the possibility of climatic change is not taken into consideration, is a permanent climatic feature (Gbeckor-Kove, 1989). Aridity generally arises from persistent widespread atmospheric subsidence or anticyclonic weather, and from more localized subsidence in the lee of mountains. Drought is "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems" (UNCCD, 1995). However, it is a temporary feature caused by climatic variations and occurs not only in arid and semi-arid regions but also in other climatic regions, such as in humid climates of mid-latitude regions. The term of desertification was defined at the Convention as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1995).

Major climatic factors that are likely to lead desertification include variations in climatic variables such as precipitation, aridity and wind, or changes in aridity, increase in the albedo of the land surface, drought events, sudden and high-intensity rainfall, shifting spatial and temporal distributions of precipitation, high temperature and high wind speed (Gbeckor-Kove, 1989). Most of these natural changes may be considered in the context of climatic variability, including long-period fluctuations of dry and wet conditions, persistence from year to year variations and secular trends. Thus, the aims of this study are as follows: (i) to give basic information on spatial distribution of mean precipitation totals, precipitation variability and seasonality of precipitation, and to examine the aridlands of Turkey by using an aridity index; (ii) to analyse the long-term variations, including trend and persistence in precipitation and the aridity index series, and periodicity in the aridity index series; and (iii) to assess the desertification vulnerability of Turkey, taking into account the climatic factors, particularly precipitation amount and variability, aridity, and long-term changes in precipitation totals and aridity index values throughout Turkey.

## Data and Method

For the time-series analysis of precipitation and the aridity index series, this study was carried out mainly with the use of annual and seasonal precipitation totals and mean annual temperatures, which were calculated from monthly values recorded at stations of 91 and 55 of the Turkish State Meteorological Service (TSMS), respectively, during the period 1930-1993. The lengths of records vary from 54 to 64 years for precipitation data and from 42 to 64 years for temperature data. The year was divided according to the basic seasons, namely, winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). This precipitation data set has been broadly explained already by Türkeş (1995b; 1996b). Missing values in monthly station records were replaced with estimates from nearby stations only if the gaps in a station's record did not consist of more than 5% of the total number of monthly values in that station's record. This was performed by using the normal ratio method, as described in Singh (1992). In this procedure, three nearby reference stations were chosen by taking into account the highest correlation coefficients (Pearson's r), between the base station to be filled and the possible reference stations.

Statistical evaluations of homogeneity for the annual and seasonal precipitation total series, and annual aridity index and temperature series were accomplished by the non-parametric Kruskal-Wallis test for the homogeneity of means of the sub-periods (Sneyers, 1990). For this study, homogeneity means that there is no jump in the climatic series of observations. Jumps consist of non-climatological abrupt falls and/or abrupt rises in the series. For the homogeneity test of precipitation amount series, annual and seasonal precipitation totals were expressed as percentages of their long-term average. The Kruskal-Wallis test was carried out for individual stations. For a more accurate assessment, statistical results from the homogeneity test were also checked by means of plotted graphs combined with the information available from the station history files, which were prepared especially for precipitation and temperature studies, and include necessary information for about 80 stations, such as changes of meteorological instruments and of the height and location of the stations, in order to detect inhomogeneity in the series. Monthly precipitation totals and mean monthly temperatures of the stations were also subjected to the homogeneity test, and checked the station files.

This type of information is useful in deciding whether a jump arose from a relocation of the station, or because of a low-frequency fluctuation (or a strong persistence) in the series. For instance, using additional information from the station history files, we found that significant inhomogeneities in the annual and seasonal air temperature series of Antalya, Anamur and Fethiye stations had occurred owing to relocation of the stations. In particular, relocation of Anamur station in 1962 from the inner part of the city land to its present site on coast has had an artificial cooling effect on the temperature variations throughout the year, particularly in the annual (Figure 1.a and b), summer (Figure 1.c and d) and autumn series (see sub-sections method and trend for sequential version of the Mann-Kendall test). This cooling effect, which appears to be stronger during summer and autumn months, is likely associated with land and especially sea breezes, which are dominant local wind circulation during the warmer part of the year on the Mediterranean coast.

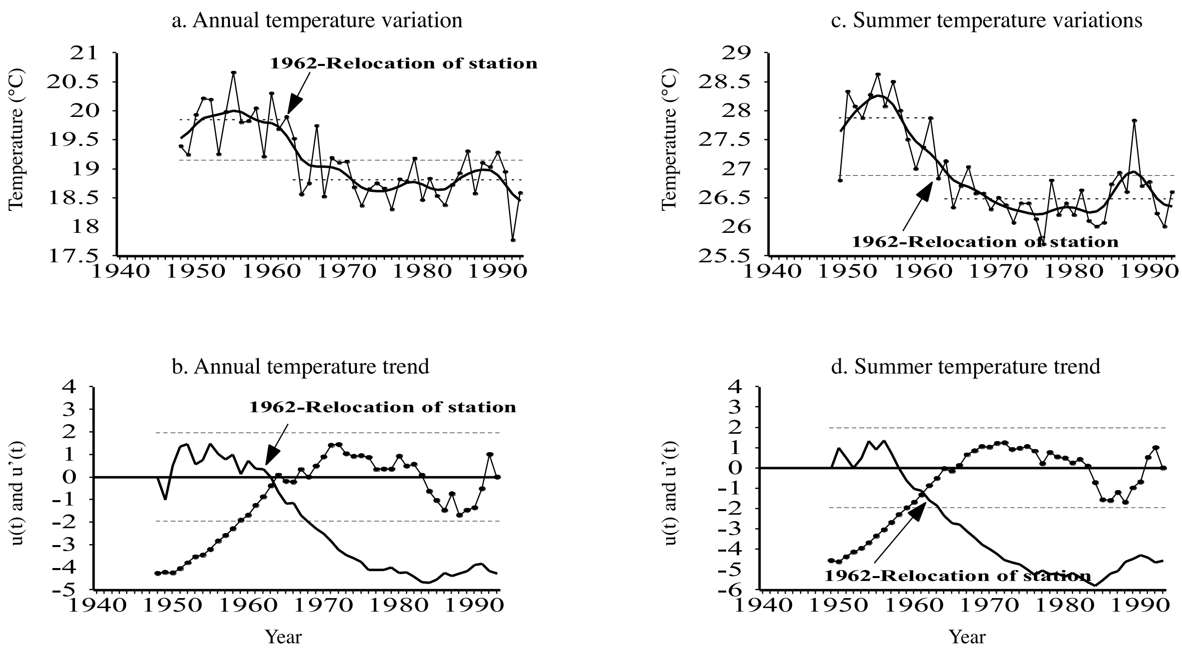


**Figure 1.** Variations and trends in mean annual and summer temperature series of Anamur. (a and c) Variations with smoothed line by the Gaussian filter (———), long-term average (− − − − −), and (·····) means of sub-periods before and after 1962; (b and d) trends from sequential values of the statistics u(t) (———) and u'(t) (− • −), with the critical significance value of ± 1.96 at the 0.05 level (− − − − −).

On the other hand, it was seen that monthly series were not good indicators some inhomogeneity types, such as in series that were exposed to a location change without considerable change in station height. This also occurs when a station relocation occurs from a relatively inland site to a new site on or near the coast. The effects of the local climatic conditions of a station could vary over the course of the year, when a relocation of the station occurs. For instance, again the relocation of the Anamur station has created a significant inhomogeneity in the mean monthly temperature series during the period from June to September. Strong inhomogeneities in the months of July to October are significant at the 0.01 level. The effects of this inhomogeneity, which are probably related to the cooling effect of the breezes occurring in these warm months, appears as a jump in the temperature series. As we have already seen above, this jump caused an abrupt cooling in temperature values after relocation in 1962. This, however, did not reflect in the cool months of the year, which are outside the period of land and sea breezes, as distinctly as in the warm months. Thus, in order for the best decision to be made as to whether a climatic series is appropriate for the time-series analysis or not, information from both objective and subjective analyses for the seasonal series should be examined.

According to the results of the objective and subjective analyses, the annual and seasonal precipitation series of 91 stations, and the mean annual temperature and aridity index series of 55 stations were found to be homogeneous, with respect to abrupt changes in the series. An additional 8 and 35 stations having relatively shorter series of observations were included in the 91 and 55 stations, respectively, for examination of the mean precipitation and aridity conditions of Turkey. The locations of all stations used in this study are shown in Figure 2, in which solid circles denote the 55 stations for which variations in aridity index values were investigated.

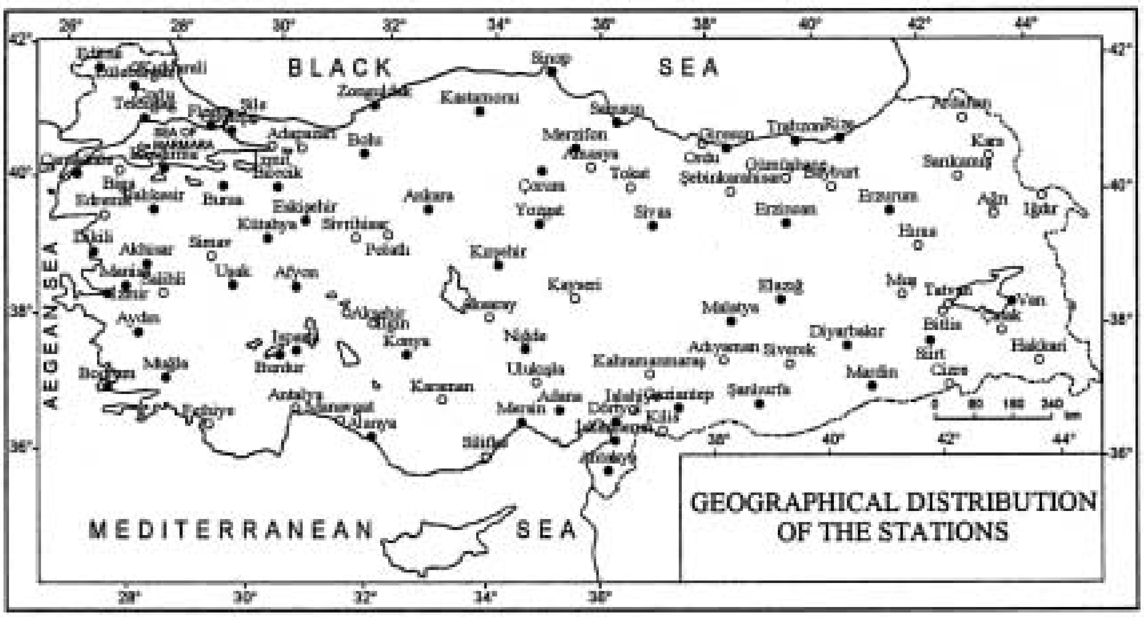


**Figure 2.** Geographical distribution of stations used in the study.

For the purposes of the Convention, arid, semiarid and dry sub-humid areas were defined as "areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65." In the present study, the same Aridity Index ($AI$) was adopted as the base method for determining dry land types and thereby delineating boundaries, and showing changes in aridity conditions in Turkey. Following the UNEP (1993), $AI$ could be written as

$$AI = P/PE$$

where $P$ is the annual precipitation total (mm) and $PE$ is potential evapotranspiration (mm). $PE$ values were calculated with the WATBUG program, which was developed by Willmott (1977) for calculation of the climatic water budgets. With this program, water budgets can be computed on a monthly (or daily) basis, and "look-up" tables are not needed as all relationships are explicitly specified. The required input is minimal: for example, air temperature, precipitation and a few initial parameters. Some outputs that the WATBUG produces are as follows: unadjusted potential evapotranspiration ($UPE$) in mm; adjusted $PE$ ($APE$) in mm; soil moisture storage ($ST$) in mm; actual evapotranspiration ($AE$) in mm; soil moisture deficit ($DEP$) and soil moisture surplus ($SURP$) in mm.

The WATBUG calculates monthly (or daily) $PE$, according to the well-known Thornthwaite (1948) methodology. To calculate the $UPE$, an array of monthly heat indices ($H$ and $HEAT$ are only calculated during balancing), an empirical coefficient ($A$), and an array of $UPE$ values are obtained. Annual totals are calculated from each January 1 to the end of that year (December 31).

With the Thornthwaite approach, a station's heat index is first obtained from

$$HEAT = (12/XN) \cdot \sum_{I=1}^{N} [T(I)/5]^{1.514}$$

where $T(I)$ is the mean monthly temperature and $XN(XN = N)$ is the number of months over which balancing is to occur. An empirically derived exponent is next defined as

$$A = \left(\frac{6.75}{10^7}\right) \cdot HEAT^3 - \left(\frac{7.71}{10^5}\right) \cdot HEAT^2 + \left(\frac{1.79}{10^2}\right) \cdot HEAT + 0.49$$

The UPE is then calculated, as a function of T(I), HEAT, and A, from

$$UPE(I) = 16 \cdot [10 \cdot T(I)/HEAT]^4$$

When $T(I) \geq 26.5°C,\ PE(I)$ is estimated from

$$PE(I) = -415.85 + 32.24 \cdot T(I) - 0.43 \cdot T(I)^2$$

' From which above relationship was developed, and which explains virtually all the variance in Thornthwaite's (1948) correction table. When daily computations are made, $PE(I)$ is divided by 30. Following this, $PE(I)$ is adjusted for variable day and month lengths. That is, adjusted $PE$ ($APE(I)$) is calculated as

$$APE(I) = PE(I) \cdot [DAYS(KM + 1)/30] \cdot (DL/12)$$

where $KM$ is the initial or previous month designation, $DAYS$ $(KM + 1)$ is the number of days in month $KM$, and $DL$ is the daylength (hours).

$AI$ values below 1.0 show an annual moisture deficit in average climatic conditions. The following general criteria are used to characterize the drylands:

| | |
|---|---|
| Arid areas | $(0.05 \leq P/PE < 0.20)$; |
| Semi-arid areas | $(0.20 \leq P/PE < 0.50)$; |
| Dry sub-humid areas | $(0.50 \leq P/PE < 0.65)$; |

For most of the stations, $AI$ series of cold and more rainy months are not suitable for representing long-term variations, because small and/or no evapotranspiration during the period mainly from November to March causes discordant $AI$ values in the series. This is reflected particularly in the winter. Thus, seasonal $AI$ series were not used in the study. The $AI$ values of 55 stations are averaged to provide a regional mean aridity value for a year $y(AI_{ry})$, and then to form an annual aridity series for all of Turkey, as

$$AI_{ry} = (1/N_s) \sum_{s=1}^{N_s} AI_{sy}$$

where $AI_{sy}$ is aridity index for a given station $s$ and a year $y$ and $N_s$ is the number of stations operating in year $y$. Turkey's mean precipitation series were also calculated by simple arithmetic averaging, as formulated for the annual aridity index series of Turkey.

A nine-point Gaussian filter is used as a low-pass filter to visually investigate characteristics of the long-period fluctuations in the series (WMO, 1966; Türkeş, 1995a). This gives a general idea of long-term fluctuations along with wetter and drier periods in the series. The main non-random characteristics of the series, such as trend, persistence and periodicity, were examined according to statistical methods. The author's previous experiences suggest that the use of the nine-point Gaussian filter superimposed on the long-term average (or median) over the time-series plot of a series indicates change points, existence of the systematic trends and starting points of the trends. These visual results are in good agreement with the results from plots of the sequential version of the Mann-Kendall test in most cases. This can easily be seen in the trend analysis section.

The Mann-Kendall rank correlation test (Sneyers, 1990) was chosen to detect any possible trend in the means of the series of annual and seasonal precipitation totals and the series of annual $AI$ values, and to test whether or not they are statistically significant. The Mann-Kendall statistic $u(t)$ is a value that indicates direction (or sign) and statistical magnitude of a secular trend in a series. When $u(t)$ value is significant at the 0.05 level of significance, it can be decided whether it is an increasing or a decreasing trend depending on whether $u(t) > 0$ or $u(t) < 0$. A 1% level of significance was also taken into consideration. In addition, partial and short-period trends, and a change point or beginning point of a trend in the series are also investigated by use of the time-series plot of the $u(ti)$ and $u'(ti)$ values. In order to have such a time-series plot, sequential values of the statistics $u(t)$ and $u'(t)$ are computed from the progressive analysis of the Mann-Kendall test. In Sneyers' methodology, the values of $u(ti)$ are automatically computed for all values of i, because computing the main statistic u(t) requires these values of $u(t_i)$. Following Sneyers (1990), this procedure can be formulated as follows: first the original observations are replaced by their corresponding ranks $y_i$, which are arranged in ascending order. Then, for each term $y_i$, the number $n_k$ of terms $y_j$ preceding it $(i > j)$ is calculated with $(y_i > y_j)$, and the test statistic $t_i$ is written as

$$t_i = \sum_{k=1}^{i} n_k$$

Distribution function of the test statistic $t_i$ has a mean and a variance derived by

$$E(t_i) = i(i-1)/4 \text{ and } \mathrm{var}(t_i) = [i(i-1)(2i+5)]/72$$

Values of the statistic u(ti) are then computed as

$$u(t_i) = [t_i - E(t_i)]/\sqrt{\mathrm{var}(t_i)}$$

Finally, the values of $u'(t_i)$ are similarly computed backward, starting from the end of the series. With a trend, the inter-section of these curves enables the beginning of a trend in the series to be located approximately. Without any trend, the time-series plot of the values $u(t_i)$ and $u'(t_i)$ indicates curves that overlap several times (Sneyers, 1990; Türkeş, 1996b; Kadıoğlu, 1997).

Another form of non-randomness in the climatic series is persistence, which is defined as "a tendency for successive values of the series to 'remember' their antecedent values, and to be influenced by them" (WMO, 1966). Lag-one serial correlation coefficient (L-1SC) was used to examine the nature and magnitude of the possible persistence in the long series. In accordance with WMO (1966), the non-circular L-1SC coefficient, $r_1$, is written as

$$r_1 = \frac{(N-1)\sum_{i=1}^{N-1} x_i x_{i+1} - \left(\sum_{i=1}^{N-1} x_i\right)\left(\sum_{i=2}^{N} x_i\right)}{\left[(N-1)\sum_{i=1}^{N-1} x_i^2 - \left(\sum_{i=1}^{N-1} x_i\right)^2\right]^{1/2}\left[(N-1)\sum_{i=2}^{N} x_i^2 - \left(\sum_{i=2}^{N} x_i\right)^2\right]^{1/2}}$$

and, by the one-sided test of normal distribution, the null hypothesis of randomness against the serial correlation is rejected for large values of $(r_1)_t$ with

$$(r_1)_t = \frac{-1 \pm t_g\sqrt{N-1}}{N-1}$$

where $t_g$ is 1.645 for the 0.05 level of significance, and 2.330 for the 0.01 level. The serial correlations for the second and third lags were also checked to determine whether the persistence in the series is a simple Markov type persistence. If the L-1SC coefficient significantly differs from zero, and if lag-two and lag-three serial correlations approximate the square and cube of the L-1SC, respectively, the series is assumed to contain a Markov type persistence (WMO, 1966).

The spectral (power spectrum) analysis, as described in WMO (1966), was applied to the normalized aridity index values to detect dominant and hidden cycles within the observed fluctuations. A detailed description of this approach can be found in various text books: Blackman and Tukey (1958); WMO (1966); Jenkins and Watts (1968). Maximum lag was chosen as about one-third of the record length (e.g., 21 years for a 64 year long aridity series). Final spectral estimates were calculated by smoothing raw spectral estimates with the three-term weighted average of the Hanning method. Then a procedure of the tests of statistical significance, which was proposed by WMO (1966), was used for objective assessment of the spectral estimates from the power spectrum analysis.

The gridding method of Kriging was used in order to produce contours of the spatial distribution maps. Detailed explanations of the method can be found in Delfiner and Delhomme (1975), Journel and Huijbregts (1978), Cressie (1991), and Hevesi *et al.,* (1992a, b). This method was applied to the stations' data by means of a mapping package.

## Results

### Mean Precipitation and Aridity Conditions

The climate of Turkey, which is mainly characterized by the Mediterranean macroclimate, results from the seasonal alternation of the mid-latitude frontal depressions, with polar air masses, and subtropical high pressures, with the subsiding maritime tropical and continental tropical air masses. Continental tropical airstreams from the north African and Arabian deserts dominate particularly throughout the summer, by causing long-lasting warm and dry conditions over Turkey, except in the Black Sea Region and North-eastern Anatolia. Mean annual precipitation totals range from below 500 mm over the continental interiors and eastern margin of the Eastern Anatolia to above 1000 mm along the Western Mediterranean, and the Western and Eastern Black Sea coasts (Figure 3). Annual precipitation below 400 mm extends over a large area of the Central Anatolia, especially over the Konya sub-region.

Precipitation is more seasonal over the western and southern regions of Turkey, with a winter maximum above 40 percent, whereas it is generally uniform over the Black Sea Region (maps for geographical distribution of the percentage contribution of mean seasonal precipitation amounts to mean annual total are not given here). Spring precipitation contributes more than 30 percent of the annual total over most of the continental interiors. In summer, maximum precipitation is concentrated over the North-eastern Anatolia, while the minimum occurs over the South-eastern Anatolia, with less than 5 percent of the annual total. Contribution of the autumn precipitation is above 30 percent along the Black Sea Coast. A seasonality index highlights this contrast of precipitation amounts between the seasons over different regions of Turkey. The seasonality index ($SI$) at a station is computed by summation of the absolute deviations of mean monthly precipitation from the overall mean and dividing it to the long-term average annual precipitation (Türkeş, 1998). Areas with $SI$ values greater than 0.55 generally have a Mediterranean type (winter-rainy) rainfall regime, which coincide with the regions of Aegean, Mediterranean and South-eastern Anatolia (Figure 4). However, if the contribution of the spring precipitation is taken into consideration, it can be seen that seasonality of most stations over the South-eastern Anatolia Region, differs, somewhat from those over the Aegean Region, and particularly over the Mediterranean Region. Contribution of the mean spring precipitation amount to the mean annual precipitation total ranges between about 30 percent and about 35 percent in the majority of the stations of the South-eastern Anatolia Region. This percentage pattern of the spring precipitation is similar to the pattern that found over the continental interiors rather than that of the Mediterranean and Aegean regions. On the other hand, SI values smaller than about 0.35 generally correspond to a uniform and quite uniform rainfall regime over the Black Sea Region and the Northern Marmara, respectively.

Spatial distribution of variability in annual and seasonal precipitation amounts was examined by a measure termed the coefficient of variation ($CV$). The $CV$ is calculated by expressing the standard deviation as a percentage of the long-term average. The $CVs$ of winter precipitation are well above 35 percent over most of the Eastern Anatolia, Marmara, Aegean and Mediterranean regions. Variability of summer rainfall is above 80 percent over the Aegean, Mediterranean and the South-astern Anatolia regions, and below 35 percent on the Eastern Black Sea Coast. Variability of annual precipitation decreases from the southern part of the country, which is generally characterized by the Mediterranean rainfall regime, to the Black Sea Coast, where a uniform rainfall regime is dominant (Figure 5). The CVs are greater than 25 percent over a great part of the Aegean and Mediterranean regions, and almost all over the South-eastern Anatolia. This map indicates that the higher the inter-annual variability, the higher the probability of drought occurrence.

The geographical distribution of the aridity index is shown in Figure 6. Areas having values of $0.65 \leq AI < 0.80$, where an annual moisture deficit exists, were shown to be concentrated in the surroundings of the semi-arid and dry sub-humid areas, although humid lands of Turkey were excluded as they were outside the scope of this study. Dry sub-humid climatic conditions extend over most of continental Central Anatolia and South-eastern Anatolia, some parts of the Eastern Mediterranean, and the eastern and western parts of the Eastern Anatolia. Semi-arid climatic conditions are dominant only over the Konya Plain and the Iğdır district of Eastern Anatolia. Dry land boundaries, however, may change, depending on the number of stations used and study period, and particularly because of high year to year variability in precipitation amounts and aridity conditions.

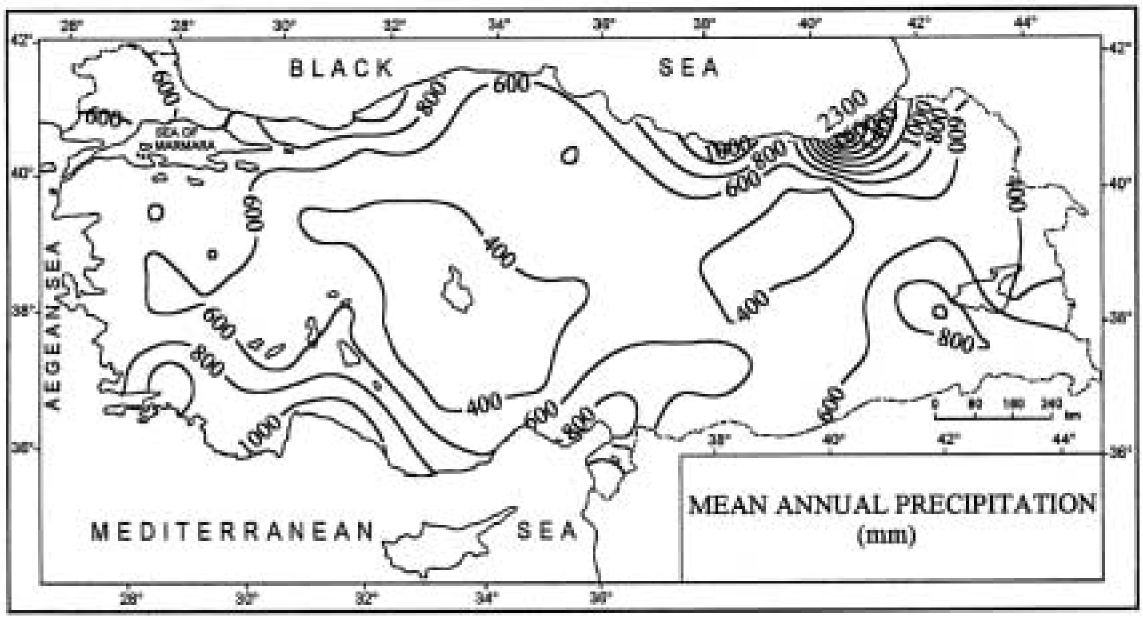


**Figure 3.** Geographical distribution of stations used in the study.

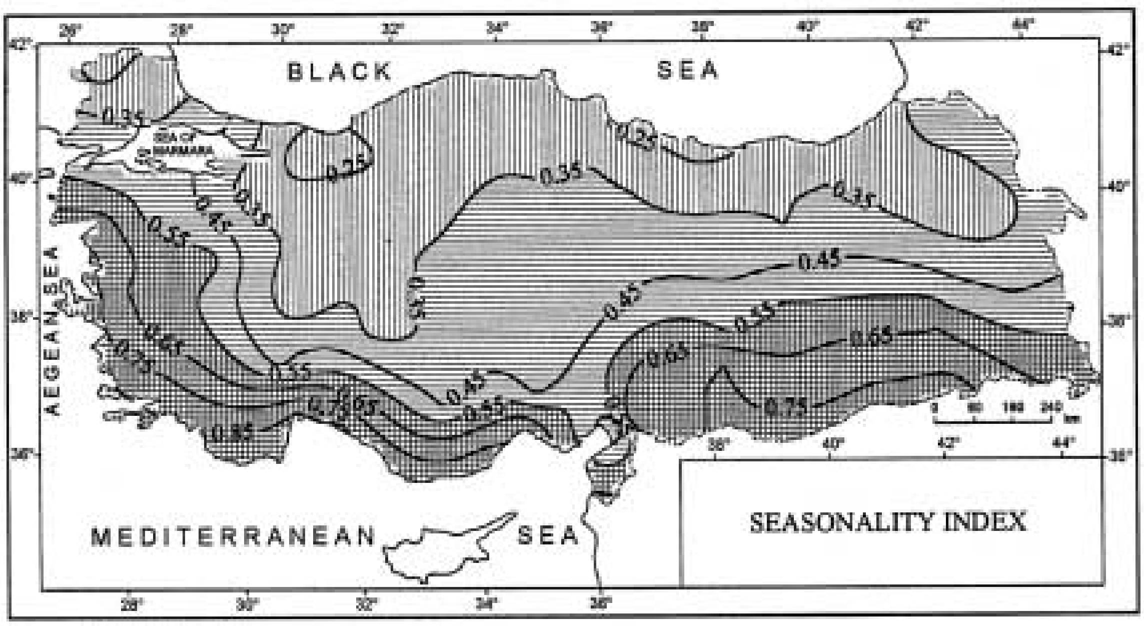


**Figure 4.** Geographical distribution of seasonality index values for 99 stations in Turkey.

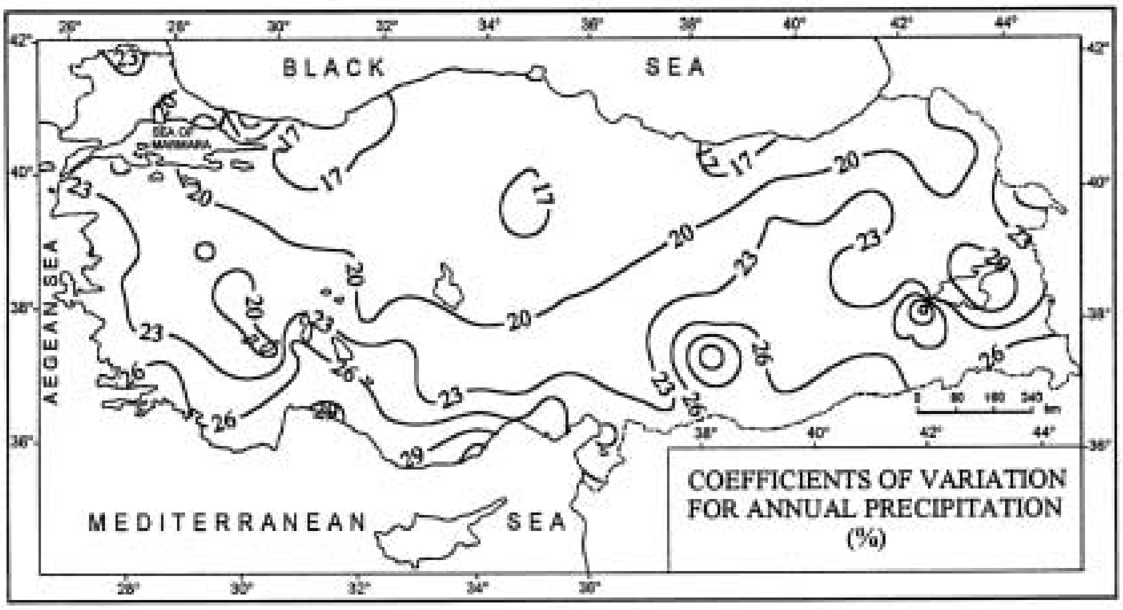


**Figure 5.** Geographical distribution of coefficients of variation for annual precipitation totals of 99 stations in Turkey.

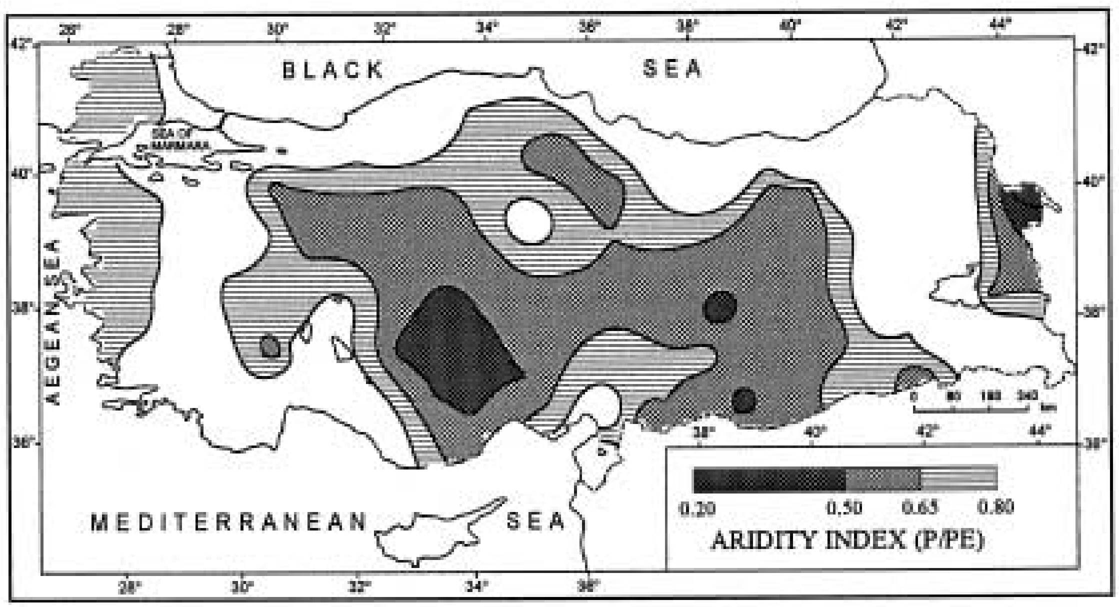


**Figure 6.** Geographical distribution of aridity index values for 90 stations in Turkey.

### Variations in Precipitation and Aridity Index Series

**Trend and fluctuation:** The main purpose of this study is to reveal variations and trends in the station-based series. Area-averaged annual and winter precipitation and annual *AI* series for all of Turkey were set to show a global view of the dominant variations over Turkey without regional aspects, which has the form of a decreasing trend in many annual and winter precipitation and annual aridity series. The winter time-series plot of Turkey from 91 stations shows a downward trend with a low-frequency fluctuation, during the period 1930-1993 (Figure 7.a). After a general run of the wet (relatively wetter than long-term average) conditions from 1940 to 1970, persistent dry (relatively drier than long-term average) conditions became generally dominant over the period 1971-1993, except for the two wet years of 1978 and 1981, with country-wide peaks of severe dry conditions in 1973 and 1989, respectively. The annual precipitation series of Turkey has generally had three wet periods, during the years 1935-1944, 1962-1969 and 1975-1981; along with four dry periods, during the years 1930-1934, 1955-1961, 1970-1974 and 1982-1993, except for a two-year wet break in 1987-1988 (Figure 7.b).

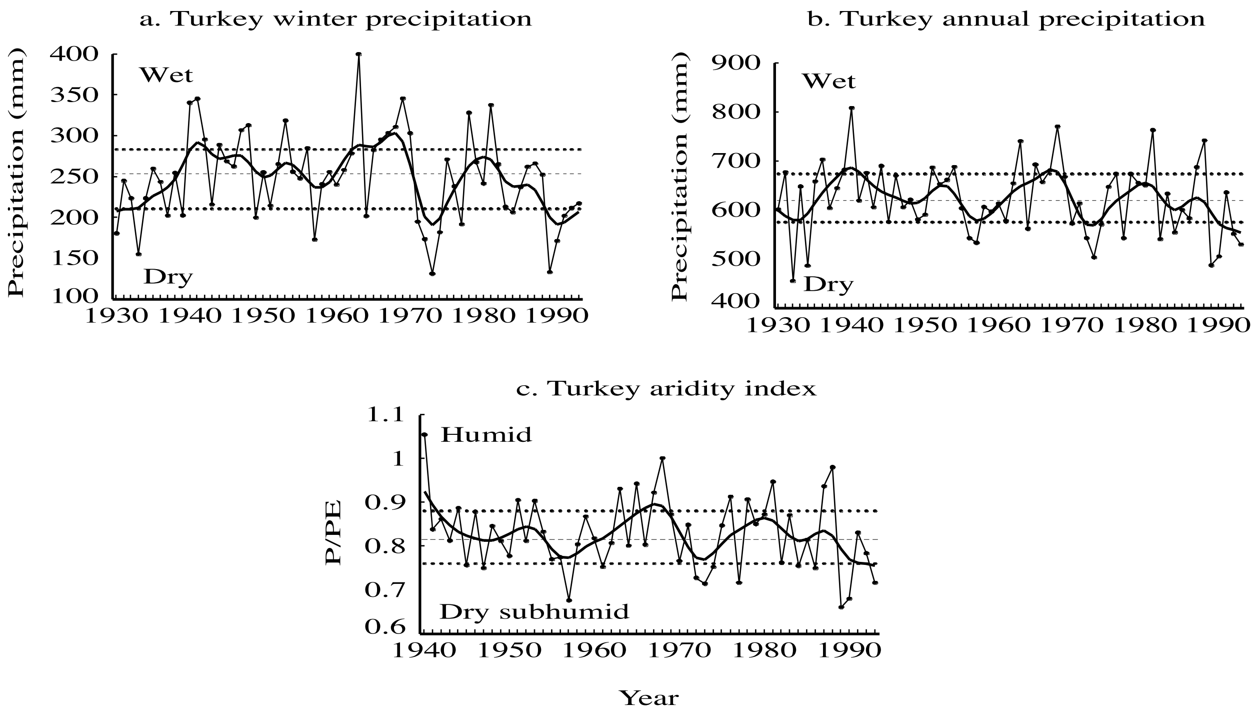


**Figure 7.** Variations in winter and annual precipitation, and annual aridity index series over Turkey, with smoothed line by the Gaussian filter (———), median (– – – – –), and upper and lower quartile lines (· · · · ·).

The length of the annual *AI* series for all of Turkey from 55 stations is ten years shorter than the study period of 1930-1993 for precipitation series of Turkey. This is because the numbers of the stations contributing to the first ten years of Turkey's annual *AI* series are not long enough to form a representative series. The annual *AI* series of Turkey from 55 stations also indicates a slightly decreasing trend, during the period 1940-1993. There is a general tendency from humid conditions around the 1960s towards dry sub-humid climatic conditions (Figure 7.c). According to results of the Mann-Kendall test, statistics for annual and winter precipitation series and annual *AI* series of Turkey have negative signs (not given here). None of the computed secular trends in these series, however, is significant at the 0.05 level.

The decrease in normalized precipitation anomaly series was evident in the annual and winter precipitation series of many stations (Türkeş, 1996a, b). In the present study, similar results were found for the annual and seasonal precipitation totals of 91 stations. Station-based results are presented in Table 1 for the seven well-known geographical regions of Turkey to show the spatial distribution of the statistical results.

The annual precipitation totals of 15 stations, most of which are in the Aegean and Mediterranean regions, show a significant decreasing trend in the mean (Table 1). Significant increasing trends are found in the series of two stations, which are located in the southern part of the Black Sea Region. Winter precipitation series generally show a long-period fluctuation about a decreasing mean. Fourteen stations, most of which are in the Aegean and Mediterranean regions, have a significant downward trend in winter (results for seasonal series not given in Table 1). Spring rainfall series show a general upward trend, but only two stations experience a significant upward trend, along with a significant downward trend in two stations. Summer rainfall series indicate a significant upward trend in seven stations, almost all of which are located in the Central and South-eastern Anatolia regions. Increased rainfall amounts, with flush flooding, during the last 15-20 years in spring and particularly in summer may have made existing soil erosion more disastrous in these semi-arid and arid semi-humid regions with sparse vegetation cover. Autumn rainfall series are random against the trend.

**Table 1.** Number of the stations indicating a significant trend and/or positive serial correlation in annual precipitation (for 91 stations) and aridity index (for 55 stations) series at the 0.05 or 0.01 level, according to the Mann-Kendall trend and serial correlation tests.

| | Mann-Kendall test | | | | Serial correlation test | |
|---|---|---|---|---|---|---|
| | Precipitation | | Aridity index | | Precipitation | Aridity index |
| Geographical region | + | - | + | - | + | + |
| Black Sea | 2 | 1 | 3 | | 2 | 1 |
| Marmara | | 1 | | 2 | 2 | 1 |
| Aegean | | 5 | | 3 | 3 | 3 |
| Mediterranean | | 4 | | 1 | 3 | |
| South-eastern Anatolia | | | | | 1 | |
| Central anatolia | | 2 | 2 | | 4 | 1 |
| Eastern anatolia | | 2 | | 1 | 2 | 1 |
| Total | 17 | | 12 | | 17 | 7 |

**(+):** Increasing trend from the Mann-Kendall test and positive serial correlation from the L-1SC test; (-): decreasing trend from the Mann-Kendall test.

As an expected result of the decreasing trends in annual precipitation of most stations, annual *AI* series have generally tended to decrease in many stations. Significant downward trends are found in some stations of the Marmara and Aegean regions (Table 1). In the stations of the Aegean Region with a significant decreasing trend, there is a marked change from the humid or near humid conditions of the 1960s to the dry sub-humid or semi-arid climatic conditions of the mid and late 1980s and early 1990s (Figure 8.1-5). In contrast, the annual *AI* values of few stations tend to increase significantly towards humid or semi-humid climatic conditions (Figure 8.6-8). These stations are located over northern part of the Central Anatolia Region and southern portion of the Black Sea Region.

In addition to the secular trends from the Mann-Kendall u(t) statistic, the beginning of secular or partial trends in *AI* series, the duration of significance and the change points were investigated by means of time-series plots of sequential values of the statistics u(t) and u'(t) from the Mann-Kendall test. Plots of the selected stations that are the same in Figure 8 are shown in Figure 9. When the curve of $u(ti)$ values exceeded the absolute value of the critical value on a time-series graph, which is 1.96 at the 0.05 significance level, a significant trend was indicated (e.g., Figure 9.6 and 9.8). On the plots of Balıkesir, Akhisar, Dikili and Bodrum, few values of $u(ti)$ exceeded the 0.05 significance level, although the $u(t)$ statistics of these stations indicated a significant decreasing tendency in their *AI* series. Thus, as pointed out by Sneyers (1990), it may be assumed that, if the trend is real, its effect is very recent, and it is recommended to wait for later observations to confirm the trend. For an abrupt change, or for the beginning point of a secular trend, $u(ti)$ and $u'(ti)$ curves would exhibit the same behaviour at the change point over the series. The two lines should also intersect at that point. This clearly shows up on the plots of the Afyon, Ankara and Merzifon stations. Upward trends in the *AI* series of Ankara and Merzifon began in 1957 and 1970, and become significant during the periods 1971-1993 and 1979-1993, respectively.

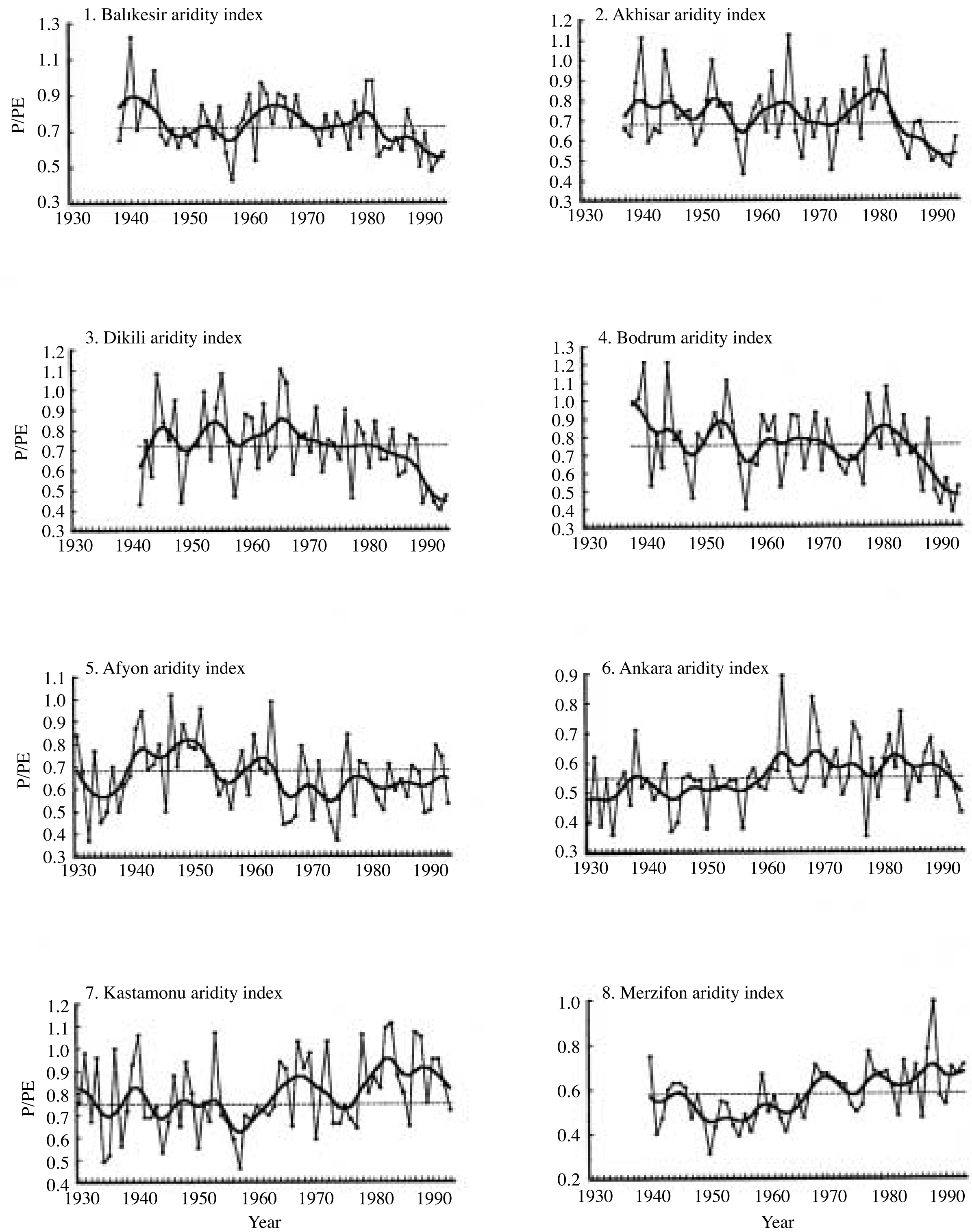


**Figure 8.** Variations in annual series of selected stations, with smoothed line by the Gaussian filter (———) and median (– – – – –).

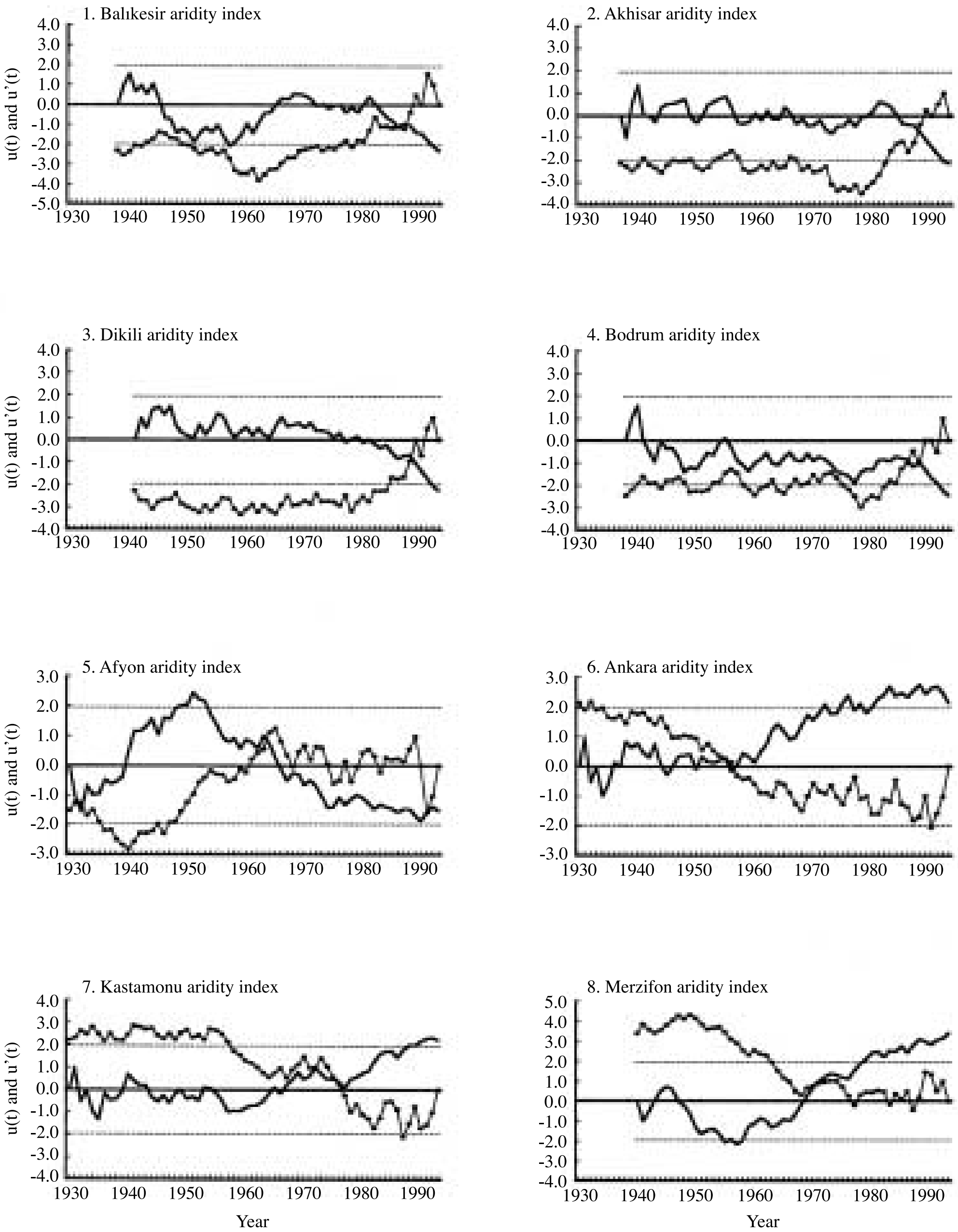


**Figure 9.** Trends in annual *AI* series of selected stations from sequential values of the statistics $u(t)$ (———) and $u'(t)$ ($-\bullet-$) of the Mann-Kendall test, with the critical significance value of ± 1.96 at the 0.05 level (– – – – –).

**Persistence:** According to the Wald-Wolfowitz serial correlation analysis performed by Türkeş (1996a, b) for normalized precipitation anomalies, significant persistence from year to year variations was one of the dominant characteristic of long-term variations in annual series, and particularly in winter series, whereas high year to year oscillation showed up in spring precipitation series. Türkeş (1998) has recently shown the existence of a simple Markov type persistence in the winter precipitation anomaly series. In the present study; by applying the L-1SC test to annual and seasonal precipitation totals and $AI$ values, similar results were found (Table 1). Series of annual precipitation totals have a significant positive correlation at seventeen stations (results of seasonal series are not given in Table 2). By considering the exponential relationships $r_2 \cong r_1^2$ and $r_3 \cong r_1^3$, a simple Markov type persistence is found in the annual precipitation totals for four stations. The $AI$ series of seven stations show a significant positive L-1SC, although most $AI$ series are dominated by a positive serial correlation. Only the $AI$ series is that of Konya station is characterized by a simple Markov type persistence.

**Periodicity:** The desired exponential relationships for the Markov-type persistence were found only at one station, Konya. Hence, the appropriate 'null' hypothesis continuum to the spectrum was assumed to be Markov 'red' noise only for Konya. The rest of the series of 55 stations, having non-significant positive L-1SC or significant positive L-1SC without Markov-type persistence and significant but negative L-1SC, was formulated by a 'white' noise continuum, which is a horizontal straight line and its value varies according to the length of the record. For a 64 year aridity series, it is 0.046 with the confidence level values of 0.082 and 0.098, at significance levels of 0.90 and 0.95 levels of significance, respectively.

The 'white' noise continuum and its 0.90 and 0.95 confidence levels that are plotted superposed on the spectrum are shown in Figure 10 for annual $AI$ series of selected stations. In the Figure 10, the significant spectral peaks are also specified by their period values in years. The period value of the spectral estimates can be found by:

$$Period = 2m/lag$$

where m is the maximum lag for a series. Results of the estimated spectral peaks that exceed the 0.90 and 0.95 confidence limits of the 'white' noise continuum of the spectrum are not shown in a table, but can be summarized as follows:

Stations of the Black Sea Region are mostly characterized by spectral peaks with cycles shorter than 3 years. Spectral peaks having 2.5 year quasi-biennial oscillation (QBO) deviate from the 'white' noise continuum at the 0.95 confidence level at the Rize, Samsun and Bolu stations. In case of significant spectral peaks, relatively frequent peaks occur at shorter periods of 2.2-2.3 years (QBO) at Adana and 2.5-2.6 years at Dörtyol, and at longer periods of 15-20 years in rest of the Aegean and Mediterranean stations with the Mediterranean climate. At the stations in the Marmara Region, shorter cycles of 2.5-3.5 years, in which 3.0-3.3 year periods are significant at the 0.95 confidence level, and longer cycles of 18-19 years generally dominate within the observed variations of the aridity index series. Stations in the Central, Eastern and South-eastern Anatolia regions have different periodicity in their aridity series. QBOs with cycles of 2.5-2.6 years at Eskişehir and 2.1-2.2 years at Diyarbakır exceed the 0.95 confidence limits of the 'white' noise continuum. Diyarbakır also has significant biennial oscillation at the 0.90 confidence level.

**Table 2.** Correlations between annual aridity index ($AI$) series and annual precipitation ($P$) and potential evapotranspiration ($PE$) series for selected stations. Italics and bolds indicate significance at the 0.01 and 0.001 levels, respectively.

| Station | $AI$ | Station | $AI$ | Station | $AI$ |
|---|---|---|---|---|---|
| Bolu P | **0.96** | Zonguldak P | **0.94** | Akhisar[d] P | **0.97** |
| Bolu PE | *-0.41* | Zonguldak PE | *-0.38* | Akhisar PE | -0.19 |
| Çorum[i] P | **0.96** | Balıkesir [d] P | **0.98** | Aydın[d] P | **0.98** |
| Çorum PE | **-0.51** | Balıkesir PE | -0.04 | Aydın PE | 0.02 |
| Kastamonu[i] P | **0.96** | Edirne P | **0.98** | Bodrum[d] P | **0.99** |
| Kastamonu PE | **-0.46** | Edirne PE | *-0.37* | Bodrum PE | 0.00 |
| Merzifon[i] P | **0.97** | Göztepe P | **0.97** | Dikili[d] P | **0.99** |
| Merzifon PE | **-0.52** | Göztepe PE | **-0.40** | Dikili PE | 0.15 |
| Rize P | **0.95** | Tekirdağ P | **0.98** | Isparta[d] P | **0.97** |
| Rize PE | **-0.41** | Tekirdağ PE | 0.02 | Isparta PE | -0.05 |
| Sinop P | **0.98** | Afyon P | **0.98** | Ankara[i] P | **0.96** |
| Sinop PE | -0.23 | Afyon PE | -0.26 | Ankara PE | -0.15 |

**([d]):** Stations with a significant decreasing trend in $AI$ series; ([i]) stations with a significant increasing trend in $AI$ series.

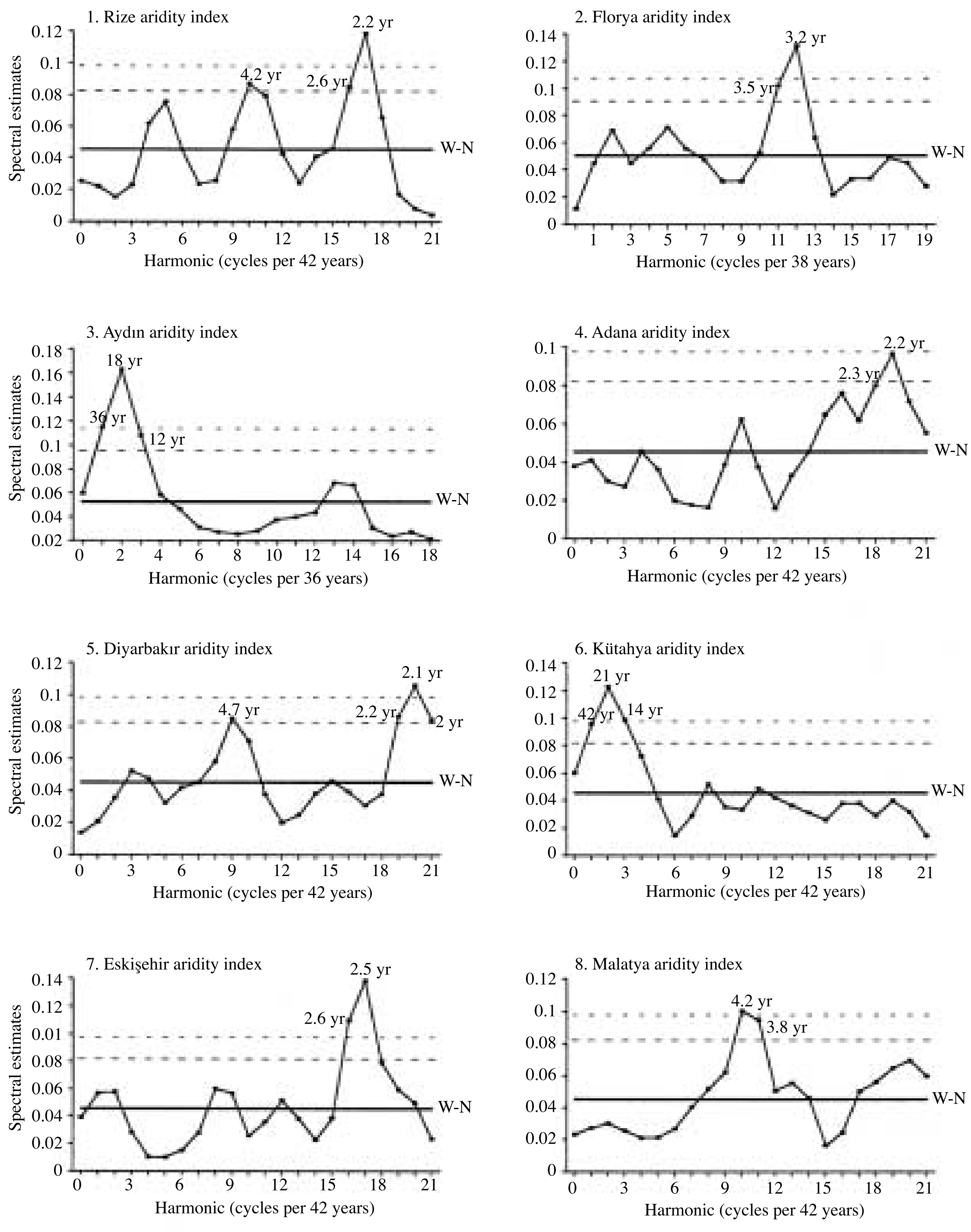


**Figure 10.** Power spectrum of annual *AI* series of selected stations. (——), 'white' noise (W-N) continuum with the 0.90 (– – – – –) and 0.95 (..............) confidence limits of the spectrum.

**Role of precipitation and $PE$ on variations of $AI$ series:** In order to detremine possible causes of variations in $AI$ series, simple correlation analysis was done between $AI$ series and precipitation and $PE$ series by parametric Pearson's $r$ and non-parametric Spearman's $r_s$. Because values from the Pearson's correlation agree very well with values from Spearman's rank correlation, only the Pearson's r values are shown in Table 2. Variations in $AI$ series in Turkey are related perfectly to variations of precipitation. $AI$ values of all stations are positively correlated with precipitation amounts at the 0.001 significance level (Table 2). On the other hand, variations of $AI$ series in some stations are related closely (but negatively) to variations of $PE$ series, whereas $AI$ series in many stations show very weak or no relationships with $PE$ series. Significant negative relationships are found especially at stations in the Black Sea Region. Similar relationships are also found among smoothed series by the nine-point Gaussian filter of the $AI$, precipitation and $PE$ values (not given here). Thus, variations and trends in the $AI$ series are likely to have been dominated by the variations and trends in the precipitation series.

## Discussion and Conclusions

Dry sub-humid climatic conditions extend over most of the Central Anatolia and South-eastern Anatolia regions, some parts of the eastern Mediterranean, and some parts of the Eastern Anatolia Region. Semi-arid climatic conditions are dominant over the Konya Sub-region, and over the eastern part of the Eastern Anatolia, in which mean annual precipitation totals are below 400 mm. In the arid lands of Turkey, values of coefficient of variations are generally above 20 percent annually and 30 percent in winter and spring, and above 45-50 percent in autumn and summer. Characteristic vegetation formations of semi-arid and dry sub-humid regions of Turkey are generally steppe, steppe with sparse trees, and steppe with trees and dry forests, respectively (Atalay, 1994). Anthropogenic steppes with dry forests are the dominant vegetation formations over the semi-arid and dry sub-humid parts of the continental Eastern Anatolia Region. These sparse vegetation covers protect and stabilize the land surface and soil, except where the land is completely degraded, and when climatic changes result in significant increase of aridity conditions, or decrease of precipitation amounts, and water resources.

Annual and winter precipitation totals have decreased at many stations, particularly at those in the Aegean and Mediterranean regions. Severe and widespread dry conditions occurred, especially in 1973, 1977, 1984, 1989 and 1990 (Türkeş, 1996c). The decrease of winter precipitation may have resulted in a degradation of the soil moisture content and a depletion of the ground water level, over most of the country. There has also been a general tendency of a shift from humid conditions during the 1960s to the dry sub-humid climatic conditions of the early 1990s, in the aridity index series of Turkey. Significant downward trends in the $AI$ series show up at the stations of the Marmara and Aegean regions. At some stations of the Aegean Region, there is a significant change from humid conditions to dry sub-humid or semi-arid conditions. The original and smoothed $AI$ series showed only weak and medium-size negative relationships with variations of $PE$ at some stations and no relationships at many stations, but were related positively and most strongly to variations of precipitation series at all stations. Thus, decreases in the $AI$ values are likely to have been controlled by decreased amounts of precipitation at these stations. Increased frequencies and intensities of the drier conditions in the last twenty years or so may have been related to the dominance of the anticyclonic circulation during the same time period, due to mainly increased atmospheric geopotential heights and decreased cyclone activity over the Turkish region (Türkeş, 1998). Furthermore, various climate models predict a decrease in precipitation totals for future changes over many parts of the subtropics including the eastern Mediterranean Basin and Turkey, particularly in the winter or generally during cool part of the year (ECSN, 1995; UKMO, 1995; Jacobeit, 1996). In addition to the long-lasting summer dryness of the Mediterranean type climate, considerable persistent dry conditions during last two decades and secular decreasing trends in the annual and particularly in the winter precipitation totals make the natural and socio-economic system of Turkey more vulnerable to the projected changes in the mean climate. Projected changes in the climatic variability in addition to the mean climate and changes in land-use, which should be considered in the future especially with respect to the land-use management, regional planning, forestry and agricultural activities, would also make the existing conditions progressively worse.

The South-eastern Anatolia and the continental interiors of Turkey could be aridlands that are affected by desertification processes, owing to the climatic factors that may lead to the desertification. Climatic factors would include existing semi-arid and dry sub-humid climatic conditions, long-lasting summer dryness of the air and soil, particularly in Southeastern Anatolia with high temperature, high precipitation variability, variations in precipitation and aridity, and low and erratic rainfall amount. Significant trends towards drier than normal conditions in annual and winter precipitation, and towards dry sub-humid or semi-arid climatic conditions have been increasing climatic factors that lead to desertification in the Mediterranean and Aegean regions of Turkey. When other natural (especially geomorphologic and pedologic) and anthropogenic factors, such as forest fires, recent misuse of agricultural lands, are also taken into account, these regions could be considered as areas that may be more vulnerable to desertification processes in the future.

The quantity and quality of water and land supplies, especially agricultural lands, in Turkey have already been affected by rapid population growth and industrialization, as well as by changes in demands, technology, and socio-economic and legislative conditions, as in other developing countries. Thus, options for dealing with the possible impacts of climate change on water resources, drought and desertification should include efficient management of existing water and land supplies, and forecasting systems for droughts and monitoring of desertification processes, including soil erosion and changes in vegetation formations and/or covers.

## Acknowledgements

The author is very grateful to Şükriye Öz of the TSMS, for helping to derive the $APE$ values from the WATBUG, and to the referee for the valuable comments.

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