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Trend analysis in Turkish precipitation data

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Abstract:

This study aims to determine trends in the long-term annual mean and monthly total precipitation series using non-parametric methods (i.e. the Mann–Kendall and Sen's *T* tests). The change per unit time in a time series having a linear trend was estimated by applying a simple non-parametric procedure, namely Sen's estimator of slope. Serial correlation structure in the data was accounted for determining the significance level of the results of the Mann–Kendall test. The data network used in this study, which is assumed to reflect regional hydroclimatic conditions, consists of 96 precipitation stations across Turkey. Monthly totals and annual means of the monthly totals are formed for each individual station, spanning from 1929 to 1993. In this case, a total of 13 precipitation variables at each station are subjected to trend detection analysis. In addition, regional average precipitation series are established for the same analysis purpose. The application of a trend detection framework resulted in the identification of some significant trends, especially in January, February, and September precipitations and in the annual means. A noticeable decrease in the annual mean precipitation was observed mostly in western and southern Turkey, as well as along the coasts of the Black Sea. Regional average series also displayed trends similar to those for individual stations. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS precipitation; Mann–Kendall; Sen's *T*; trend analysis; Turkey

INTRODUCTION

The effects of climatic change and variability have been analysed by many researchers in a variety of geophysical fields. Most previous studies concerning long-term climatologic trends have focused on surface air temperature and precipitation. Reviews of relevant recent researches include, for example: Hirsch *et al*., (1982), Van Belle and Hughes (1984), Yu *et al*. (1993), Kalayci and Kahya (1998) and Kahya *et al*. (1998) for water quality variables; Zhang *et al*. (2001), Burn and Hag Elnur (2002), Kahya and Kalayci (2004), Kalayci and Kahya (2004) and Cıgızoglu *et al*. (2003) for streamflow; Lettenmaier *et al*. (1994), Türkeş (1996) and Zhang *et al*. (2000) for precipitation; and finally Cengiz *et al*. (2003) for lake levels. From these and other studies, a range of potential climatic impacts on the hydrologic regime for various geographic areas can be hypothesized. Correlations between hydrologic variables and meteorological variables were evaluated by Burn and Hag Elnur (2002), who documented similarities in trends and hydrologic patterns in two different variables at selected locations. They utilized only the Mann–Kendall test to detect trends for 18 hydrologic variables that reflect different parts of the hydrologic cycle from a network of 248 Canadian streamflow catchments.

Most previous studies have used Kendall's test to identify hydroclimatologic trends and possible climatic variations. Van Belle and Hughes (1984) described two classes of procedures in detail: (i) intrablock methods (procedures that compute a statistic, such as Kendall's τ, for each block or season and then sum these to produce a single overall statistic) and (ii) aligned ranks method (procedures that first remove the block effect from each datum, second sum the data over blocks, and finally produce a statistic from these sums).

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They found that aligned rank methods are asymptotically more powerful than intrablock methods; however, intrablock methods are more adaptable. Lettenmaier *et al.* (1994) looked for evidences of long-term trends in precipitation, mean temperature, temperature range, and streamflow over the continental USA by adopting the Mann–Kendall test. They also tried to investigate seasonal and spatial characteristics of climatic variables using large data sets of 1009 streamflow stations and 1036 stations, a subset of the Historical Climatologic Network throughout the continental USA. Increase in precipitation during autumn was found in a quarter of the entire stations, mostly located in the central part of the USA. Yue and Hashino (2003) studied long-term trends in Japanese annual and monthly precipitation and generally found significant negative trends. Zhang *et al.* (2000) analysed precipitation totals and ratios of snowfall to total precipitation in Canada during the 20th century and pointed out a prevailing wetter pattern in Canadian climate. They also emphasised significant increasing trends in annual precipitation totals and decreasing trends in winter precipitation. As a follow-up study, Zhang *et al.* (2001) searched trends in 11 hydrometric variables in Canadian catchments by first applying a method proposed by Von Storch and Navarra (1995) to eliminate the effects of serial correlation prior to performing the Mann–Kendall test and noted, in general, decreasing streamflow trend characteristics. In fact, Hirsch and Slack (1984) were the first to propose an extension of the Mann–Kendall test for trend (especially robust against serial correlation effects). When there is no serial correlation, this test is less powerful than a related simpler test that is not robust against serial correlation. Lins and Slack (1999) evaluated 395 streamflow records in the USA for the presence of trends in selected quantiles of discharge. They made a general statement to the effect that the USA streamflow climatology is getting wetter but having less extreme events.

When it comes to reviewing germane studies in Turkey, a limited number appear to be available. For streamflow variables, Kahya and Kalayci (2003) identified the regions of western and southeastern Turkey as an area of significant decreasing trends. These streamflow trends were said to be all season-wise homogeneous; at the same time, some of those were noted to be homogeneous station-wise as well. Cıgızoglu *et al.* (2003) investigated trend existences in maximum, mean and low flows in Turkish rivers using daily mean values for nearly 100 stations. They detected trends in the majority of rivers located in western and southern Turkey, as well as in some parts of central and eastern Turkey. The number of trends in the mean and low flow data was larger than that of maximum flow data. For temperature variables, Türkeş *et al.* (1995) applied four statistical tests to the annual mean temperature series over Turkey and concluded that these series were generally dominated by a cooling tendency in the last two decades. Kadıoğlu (1997) used the seasonal Kendall test to detect temperature trends across Turkey and observed that there was a tendency for a warming trend over the period 1939–89, in contrast to a tendency for a cooling trend lasting from 1955 to 1989. However, these implied temperature trends were not statistically significant. Karaca *et al.* (1995) applied the Mann–Kendall test and the method of linear regression to the monthly mean temperatures to detect the urban heat-island effects in Istanbul, which is the largest metropolis in Turkey. They found positive trends for southern stations and negative trends for northern stations, reflecting the importance of densely populated districts in Istanbul.

Finally, for precipitation, Toros (1993) examined seasonal and annual rainfall data of the western part of Anatolia using 68 stations for the period 1930–92, finding a decrease in rainfall after 1982 and concluding that this decrease did not result from climatic change, but rather was only due to rainfall fluctuations. In the context of climatic variability, Türkeş (1996) analysed the spatial and temporal characteristics of Turkish annual mean rainfall data for long-term trends, for fluctuations and changes in runs of dry and wet years, and rainfall-regime regions at 91 stations with a recording length ranging from 54 to 64 years. Annual rainfall series of 17 stations exhibited a significant trend in the mean, and the majority of trends had a downward direction.

The trend-related studies concerning Turkey may have one or more of the following shortcomings:

1. Some did not cover the entirety of Turkey as a study domain.
2. All did not include an analysis for the serial correlation effect on the statistical testing for the test statistic of the Mann–Kendall test.

3. All used an intrablock procedure (such as the Mann–Kendall test), but not an aligned procedure (such as Sen's T test) to obtain extra confidence in their results (except for Kahya and Kalayci (2003)).
4. A few were concerned with the starting time of trends.
5. None examined trend characteristics for different time intervals at the same time, such as monthly, seasonal and annual bases, to see whether or not a dramatic change occurs.

Taking all the points indicated above into consideration, we thus decided to analyse precipitation trends using a satisfyingly large and long data set in Turkey based on both a monthly and an annual basis by applying two categorically different non-parametric tests. Additionally, we aimed to pay attention not only to the serial correlation effect on statistical testing, but also to locating the start of trends in this study.

DATA

The data network used in this study, which is assumed to reflect regional hydroclimatic conditions, consists of 96 precipitation stations (Figure 1), each spanning from 1929 to 1993. All stations have continuous observations over 55 years with a maximum sample size of 65 years. More specifically, 39 out of 96 stations have a sample size between 55 and 59 years, and the remaining stations have a sample size between 60 and 65 years. Daily precipitation totals compiled by the Turkish State Meteorological Service (DMI) have been used to obtain monthly totals, so we were able to arrange two different categorical data sets, namely monthly totals and annual means of monthly totals. As a result, 13 precipitation variables at each station are subjected to trend detection analysis. Homogeneity analysis of a large portion of the data network had been performed by Özçelik (1996), who used the Kruskal–Wallis test, the Swed–Eisenhart runs test and graphical analysis. In addition, regional average precipitation series are established for the same analysis purpose. Readers are referred to Ünal *et al.* (2003) for a general description of the climate conditions prevailing over Turkey.

METHODOLOGY

The study analysis is carried out not only for the time series of each individual station, but also for that of the regional averages; the methodological procedures are summarized in Figure 2. These steps essentially involve: (i) testing the serial correlation effect; (ii) applying the Mann–Kendall test; (iii) applying the sequential Mann–Kendall test; (iv) applying Sen's T test; (v) in a particular region, computing Sen's estimator; and (vi) transforming monthly total values into modular coefficients which will be then used in the Mann–Kendall and Sen's T tests.

Station basis trend analysis

Serial correlation effect. One of the problems in detecting and interpreting trends in hydrologic data is the confounding effect of serial dependence. Specifically, if there is a positive serial correlation (persistence) in the time series, then the non-parametric test will suggest a significant trend in a time series that is, in fact, random more often than specified by the significance level (Kulkarni and Van Storch, 1995). For this, Von Storch and Navarra (1995) suggest that the time series should be 'pre-whitened' to eliminate the effect of serial correlation before applying the Mann–Kendall test. This study incorporates this suggestion, and thus possible statistically significant trends in a precipitation observations ($x_1, x_2, \ldots, x_n$) are examined using the following procedures:

1. Compute the lag-1 serial correlation coefficient (designated by r_1).
2. If the calculated r_1 is not significant at the 5% level, then the Mann–Kendall test is applied to original values of the time series.

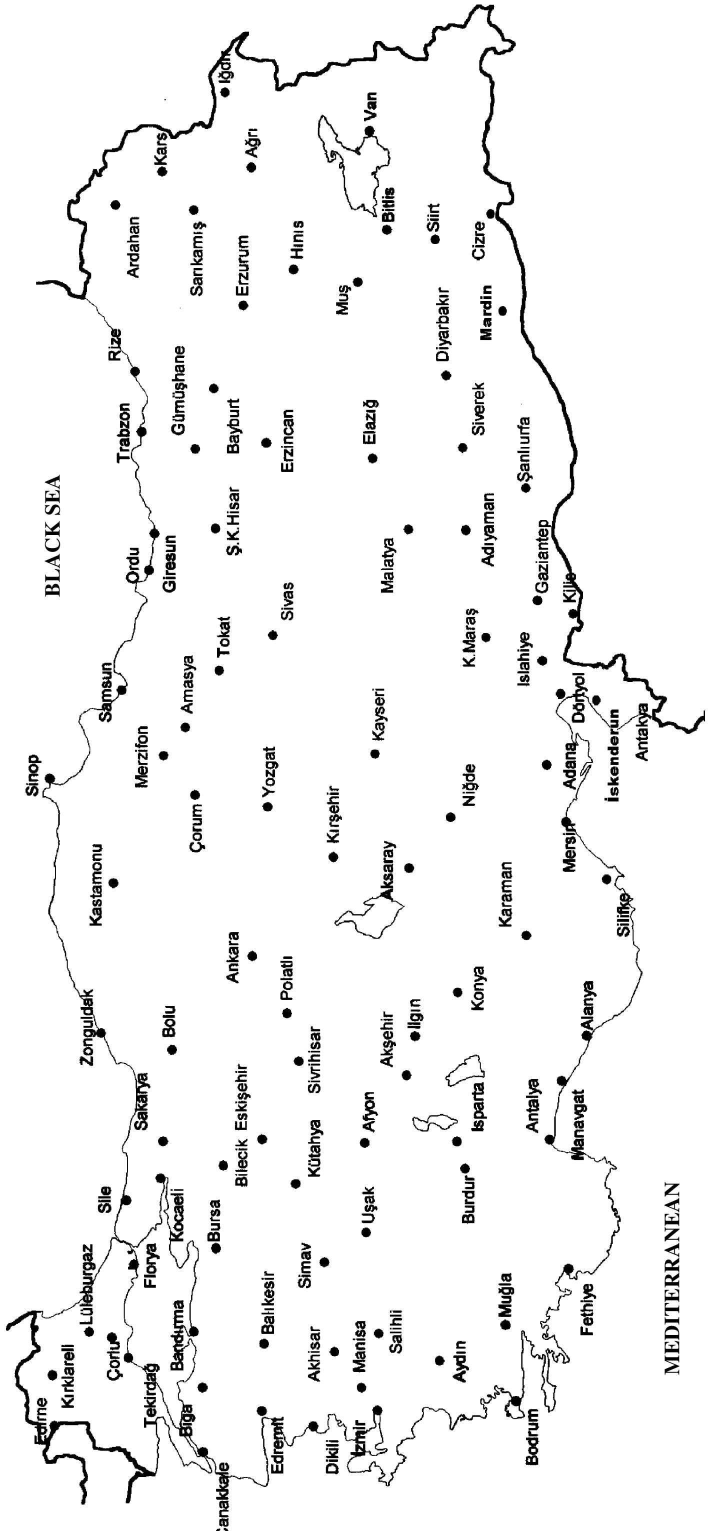

Figure 1. Distributions of precipitation stations used in the study

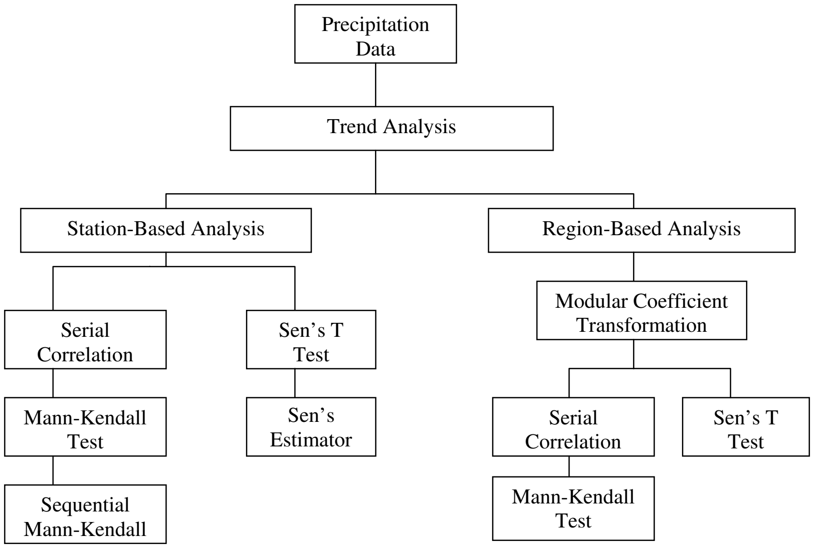

Figure 2. Procedures of analysis methodology used in this study

3. If the calculated r_1 is significant, prior to application of the Mann–Kendall test, then the 'pre-whitened' time series may be obtained as $(x_2 - r_1x_1, x_3 - r_1x_2, \ldots, x_n - r_1x_{n-1})$.

Mann–Kendall test. This test, which is usually known as Kendall's τ statistic, has been widely used to test for randomness against trend in hydrology and climatology. It is a rank-based procedure, which is robust to the influence of extremes and good for use with skewed variables. According to this test, the null hypothesis H_0 states that the deseasonalized data $(x_1, \ldots, x_n)$ is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all k, $j \leq n$ with $k \neq j$. The test statistic S, which has mean zero and a variance computed by Equation (3), is calculated using Equations (1) and (2), and is asymptotically normal (Hirsch and Slack, 1984):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \tag{1}$$

$$\operatorname{sgn}(x_j - x_k) = \left\{ \begin{array}{lll} +1 & \text{if} & (x_j - x_k) > 0 \\ 0 & \text{if} & (x_j - x_k) = 0 \\ -1 & \text{if} & (x_j - x_k) < 0 \end{array} \right\} \tag{2}$$

$$\operatorname{Var}(S) = \left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \right] \Big/ 18 \tag{3}$$

The notation t is the extent of any given tie and $\sum_t$ denotes the summation over all ties. In cases where the sample size $n > 10$, the standard normal variate z is computed by using Equation (4) (Douglas *et al.*, 2000). In a two-sided test for trend, H_0 should thus be accepted if $|z| \leq z\alpha/2$ at the α level of significance. A positive value of S indicates an 'upward trend'; likewise, a negative value of S indicates 'downward trend':

$$z = \left\{ \begin{array}{lll} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{if} & S > 0 \\ 0 & \text{if} & S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{if} & S < 0 \end{array} \right\} \tag{4}$$

Sequential Mann–Kendall test. Sequential values *u(t)* and $u'(t)$ from the progressive analysis of the Mann–Kendall test were determined in order to see change of trend with time (Sneyers, 1990). Herein, *u(t)* is a standardized variable that has zero mean and unit standard deviation. Therefore, its sequential behaviour fluctuates around the zero level. *u(t)* is the same as the z values that are found from the first to last data point. This test considers the relative values of all terms in the time series ($x_1, x_2, \ldots, x_n$). The following steps are applied in sequence:

1. The magnitudes of x_j annual mean time series, ($j = 1, \ldots, n$) are compared with x_k, ($k = 1, \ldots, j - 1$). At each comparison, the number of cases $x_j > x_k$ is counted and denoted by n_j.
2. The test statistic t is then given by equation

$$t_j = \sum_{1}^{j} n_j \tag{5}$$

3. The mean and variance of the test statistic are

$$E(t) = \frac{n(n-1)}{4} \quad \text{and} \quad \mathrm{Var}(t_j) = [j(j-1)(2j+5)]/72 \tag{6}$$

4. The sequential values of the statistic *u(t)* are then calculated as

$$u(t) = \frac{t_j - E(t)}{\sqrt{\mathrm{Var}(t_j)}} \tag{7}$$

Similarly, the values of $u'(t)$ are computed backward, starting from the end of the series. The sequential version of the Mann–Kendall could be considered as an effective way of locating the beginning year(s) of a trend.

Sen's T test. This technique is an aligned rank method having procedures that first remove the block (season) effect from each datum, then sum the data over blocks, and finally produce a statistic from these sums. The aligned rank test is more powerful than its counterpart (namely, intrablock procedures, such as the Mann–Kendall test). It is distribution free and not affected by seasonal fluctuations (Sen 1968a; Van Belle and Hughes, 1984). Following Van Belle and Hughes' description, the data might be displayed as shown in Table I.

Then the procedure steps are:

Table I. Matrix display of analysis variables used in the Sen's T test

Year	Season (i.e. month)						
	1	2	3	·	·	m	Mean
1	X_{11}	X_{12}	X_{13}	·	·	X_{1m}	X_1
2	X_{21}	X_{22}	X_{23}	·	·	X_{2m}	X_2
·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·
n	X_{n1}	X_{n2}	·	·	·	X_{nm}	X_n
Mean	X_1	X_2	X_3	·	·	X_m	X

1. $X_{.j}$ and X_i are computed for averages of jth month and ith year as

$$X_j = \frac{\sum_{i}^{n} X_{ij}}{n} \quad \text{and} \quad X_i = \frac{\sum_{i}^{m} X_{ij}}{m} \tag{8}$$

2. Subtract the monthly average from each of the corresponding months in the n years of data (i.e. calculate $X_{ij} - X_j$ for $i = 1, \ldots, n$ and $j = 1, \ldots, m$ to remove monthly or seasonal effects).
3. All differences obtained from step 2 are replaced by its ranks, resulting in a similar table with the notation of R instead of X. It is important to note that the integer 1 would be assigned to the smallest difference, whereas the integer nm would correspond to the rank of the highest difference. Hence, R_j refers to the rank of $(X_{ij} - X_{.j})$, where $i = 1, \ldots, n$ and $j = 1, \ldots, m$. For each of the t tied values, the average of the next t ranks is assigned.
4. Calculate the test statistic:

$$T = \left[\frac{12m^2}{n(n+1)\sum_{i,j}(R_{ij} - R_j)^2}\right]^{1/2} \left[\sum_{i=1}^{n}\left(i - \frac{n+1}{2}\right)\left(R_i - \frac{nm+1}{2}\right)\right] \tag{9}$$

The test statistic T follows an $N(0, 1)$ distribution under the null hypothesis of no trend. If $|T| > z\alpha$, then a significant trend exists in the time series under consideration. Positive values of T indicate an 'upward trend' and negative values the opposite.

Sen's estimator. If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968b). The slope estimates of N pairs of data are first computed by

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1, \ldots, N \tag{10}$$

where x_j and x_k are data values at times j and k ($j > k$) respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by $Q_{\text{med}} = Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by $Q_{\text{med}} = [Q_{N/2} + Q_{(N+2)/2}]/2$. Finally, Q_{med} is tested by a two-sided test at the $100(1 - \alpha)\%$ confidence interval and the true slope may be obtained by the non-parametric test.

Regional trend analysis

The use of regional average, in general, provides a time series that is a better representation of large-scale climatic processes, and it is easier to deal with one index series that is a spatially averaged series in a region (Kahya and Dracup, 1993). We have redone the tests above using the index time series that is assumed to represent all individual time series in a region under interest. For this purpose, prior to trend analyses, the original precipitation series are converted to modular coefficient series by dividing original monthly values by the long-term mean (calculated over the entire years) at each station in order to put all stations on an equal footing without changing cyclic features of data at the same time. The regional average (index) time series were established based on Turkish climatic zones defined by Ünal *et al*. (2003). Applying cluster analysis, they redefined climate zones in Turkey based on monthly temperature and precipitation totals data (spanning from 1951 to 1998) at 113 climate stations and consequently determined seven main clusters. They named these clusters as Marmara, Aegean–western Mediterranean, Black Sea, central Anatolian, eastern Anatolian, southeastern Anatolian, and eastern Mediterranean regions and designated these by A, B, C, D, E, F, and G zones respectively. The geographical extents of these climatic regions are not displayed here due to limited space. Consequently, monthly and annual modular index time series are obtained for each climatic region and then are subjected to the non-parametric tests.

RESULTS AND DISCUSSION

Station basis trend analysis

Serial correlation effect. The majority of the monthly series in the data set appear to have no significant lag-1 serial correlation coefficient; however, the series for January (November) reveal a significant correlation value in 18·7% (12·5%) of 96 series. The locations of the stations with a significant serial correlation were, for the most part, in western Turkey, especially in the Marmara region, in which the large industrialized cities are situated. They are subjected to pre-whitening procedures before applying the two non-parametric tests. In addition, we have carried out a similar analysis for annual data and found that annual series in most stations show a significant serial correlation at the 5% level.

Mann–Kendall test. This section presents the results of the non-parametric Mann–Kendall test at the 5% significance level in tabular and map fashions. Thirteen precipitation variables (i.e. 12 monthly totals and the annual mean series) are subjected to the Mann–Kendall test at each station. Table II summarizes the total numbers of significant serial correlations, as well as significant decreasing and increasing trends, for each variable during the study period 1929–93. Detailed interpretations will be made in the following sections.

Monthly total precipitation: The spatial distribution of significant trends in monthly precipitation is shown in Figure 3. Monthly precipitation totals generally have a decreasing trend, with the strongest magnitude in September and the winter months. During January, only negative trends are detected in stations along the southwest–northeast direction. During February, a lesser number of stations, mostly located on the northern side of country, show either positive or negative trend. Downward trends are observed at stations located over the eastern Black Sea coast, the southern Marmara Sea coast and the lakes region, whereas opposite trends at fewer stations are marked in eastern Turkey.

During March, the sense of the arrows (Figure 3) is quite like the two preceding months, indicating that the implied trend behaviour continues. When it comes to April, the trend behaviour is totally changed in such a way that upward trends become dominant with a smaller number of occurrences compared with the preceding months. Looking over the outcomes during the following spring and summer months, April may

Table II. Trend test results and significant lag-1 serial correlations at the 5% level

Variable	No. of significant serial correlation	No. of decreasing trends	No. of increasing trends	Significant trends (%)
January	18	14	—	14·6
February	4	7	3	10·4
March	6	8	1	9·3
April	4	—	6	6·2
May	6	—	2	2·0
June	4	—	4	4·2
July	3	1	2	3·1
August	4	1	1	2·0
September	4	13	—	13·5
October	3	2	1	3·1
November	—	—	4	4·2
December	12	2	3	5·2
Annual mean	17	19	3	22·9

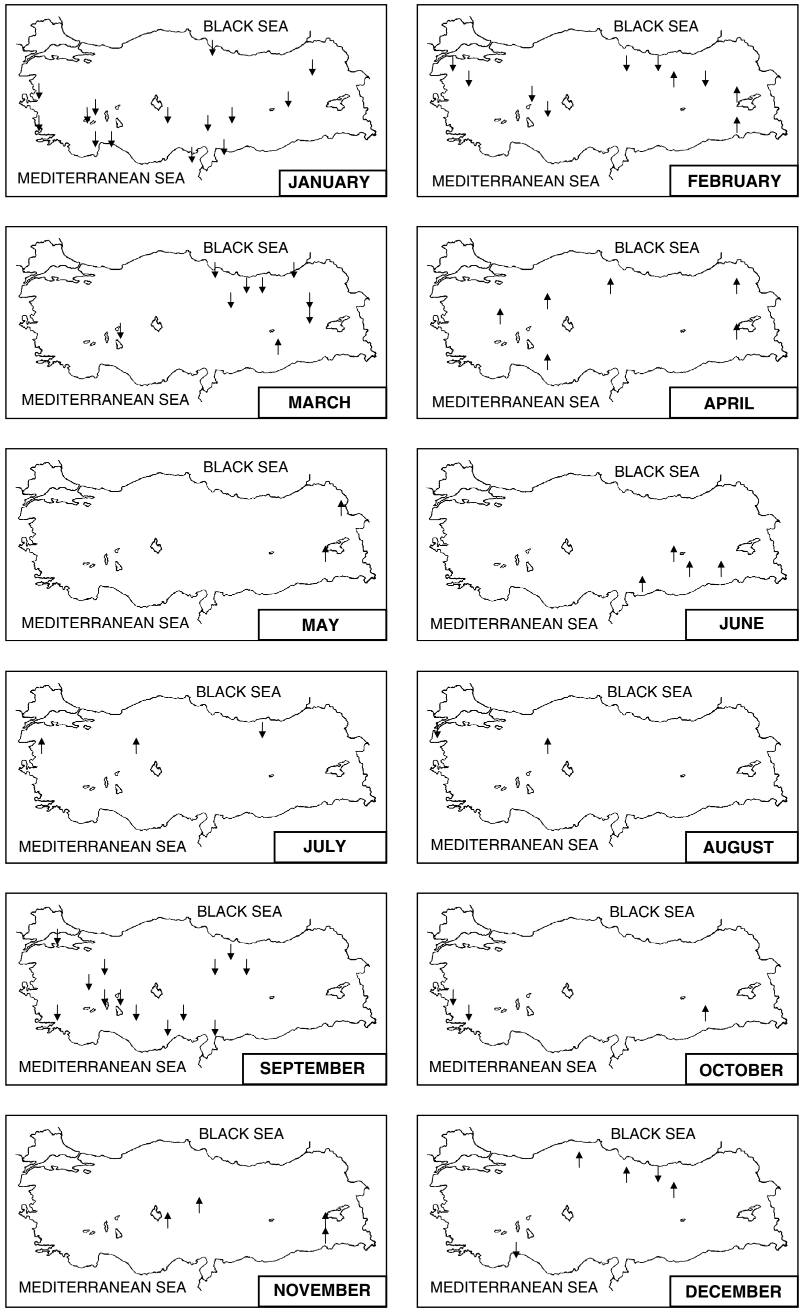

Figure 3. Spatial distribution of significant monthly precipitation trends at the 5% level. Downward trend is marked by '↓' and upward trend by '↑'

be considered as the time of change in trend direction. Only two (four) stations exhibit an increasing trend in May (June). During July and August, three and two stations demonstrate significant trends respectively. In general, that the trends are negative in winter and positive in the spring and summer seasons may indicate a shift in the annual cycle of the hydrologic regime (Zhang *et al.*, 2001). September is the one of the months showing most trends with homogeneity of direction across the country. October and November might be considered as a period of trend transition with respectively few decreasing and increasing significant trends. In spite of these few occurrences in Figure 3, it is worthwhile to point out that a tendency for a change in trend direction is apparent during the months of September and December.

In summary, there appears to be a more apparent seasonal pattern in trends. The number of negative trends exceeds that of positive trends during January, February, March, September and October. In other words, the greatest predominance of negative trends is in late winter and September. Their distribution seems scattered across the country, together with fewer opposite trends in western and southern Turkey and along eastern Black Sea coasts.

Annual mean precipitation: Figure 4 shows the spatial distribution of significant trends for annual mean precipitation data in Turkey. The majority of precipitation stations have a negative trend at the 5% significance level. Stations showing a negative trend are Balıkesir, Edremit, Aydın, Akhisar, Dikili, Afyon, Akşehir, Bodrum, Fethiye, Isparta, Manavgat, Dörtyol, Niğde, Ulukışla, Ordu, Rize, Kilis, Kars, and Muş; stations having a positive trend are Ankara, Çorum, and Bitlis. From a regional perspective, the decreasing trends are observed in western and southern Turkey as few increasing trends in the central Turkey. In addition, some stations in northeast and eastern Turkey demonstrated a decreasing trend. The former region, where the highest amount of precipitation is often measured (based on the precipitation climatology of Turkey), includes two stations exhibiting a tendency to diminish with respect to the annual basis.

Türkeş (1996) found significant trends in the 17 stations for annual rainfall data in Turkey, and 15 of these stations show a downward trend, predominantly in southern and western regions of Turkey. We detected a significant trend at the following stations: Edremit, Akhisar, Akşehir, Dörtyol, Ordu, Kilis, Ankara, and Bitlis, where Türkeş (1996) did not identify any. However, he claimed the existence of a trend at Bursa, Merzifon, and Ilgın stations, where we were not able to find any. We believe that this inconsistency between the two studies is partly caused by the use of different periods. In addition, we utilized a larger data network and extensive analysis procedures that took the serial correlation effect into consideration.

Visual inspection of map patterns in Figures 3 and 4 inspired us to examine the contribution of each month to the annual trend at 22 stations in Figure 4. Four of these stations interestingly have no trend in every month of the year, although they exhibited a significant trend in their annual series (Table III). It is more likely that this results from the heterogeneity of trend in seasons noted first by Van Belle and Huges (1984). Similarly, 10 stations (five, one and two stations) have a significant trend only in 1 month (two, three and four months respectively). Total precipitation amount during the particular months having a significant trend and its ratio to the annual total amount (given in the second column of Table III) are computed to distinguish the dominance of the months with trend over the annual. At Aksehir, Bodrum, Manavgat, Ordu, Bitlis, and Muş stations, the ratio of average precipitation totals to average annual total during the months with trend (column 4 divided

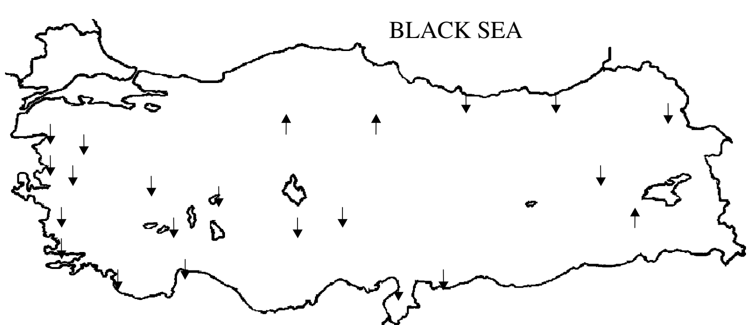

Figure 4. As Figure 3, except for annual total precipitation trends

Table III. The contribution of each month to the annual trend at 22 stations in Figure 4

Station (1)	Annual total precipitation (mm) (2)	Months with trend (3)	Total precipitation in months with trend (mm) (4)	Proportion of column (4) to column (2) (%) (5)	Mann–Kendall test statistic (6)	Mann–Kendall test statistic, after removing the months with trend (7)
Balıkesir	579	February	68	11·7	−2·30	−1·67
Aydın	647	October	46·4	7·2	−2·02	−1·54
Akhisar	588	—	—	—	−2·03	—
Dikili	630	January	123·6	19·7	−2·87	−1·91
Edremit	713	June	5·4	0·7	−1·98	−2·06
Afyon	434	September	19·3	4·4	−2·58	−2·16
Aksehir	642	February, March, September	162·4	25·3	−2·26	−1·73
Bodrum	725	January	175·5	24·2	−2·47	−1·39
Fethiye	895	—	—	—	−2·19	—
Isparta	574	January, September	98·6	17·2	−2·74	−2·08
Manavgat	1204	January, December	578·3	48	−2·56	−1·20
Dörtyol	982	September	54·7	5·5	−2·66	−2·02
Ankara	382	April	41·5	10·8	1·96	1·36
Çorum	419	—	—	—	2·28	—
Niğde	335	January, September	43·6	13·1	−2·18	−0·85
Ulukışla	334	—	—	—	−2·05	—
Ordu	1137	February, March, September, December	423·4	37·2	−2·55	−1·57
Rize	2308	March	165·9	7·2	−2·63	−2·40
Bitlis	1091	February, April, May, October	509·1	46·6	−2·47	−1·27
Kars	487	January	22·1	4·5	−3·17	−2·50
Kilis	526	January, July	103·4	19·7	−2·11	−1·59
Muş	841	January, March	231·6	27·5	−3·39	−1·45

by column 2) is found to be greater than 24%; thus, it may not be so surprising to encounter similar trend characteristics in both monthly and annual precipitation series. However, this does not apply to the series of precipitation stations containing only 1 month with significant trend (e.g. Balıkesir and Aydın). To understand what causes this contradiction, we tried to establish new series by subtracting the sum of precipitation total amounts during the months with trend from the annual total amount at each year in all stations listed in Table III and carried out the Mann–Kendall test using these new series. The results of this analysis (given in column 7) reveal a dramatic decrease in the test statistic at all stations (except six stations marked in bold), indicating strong effects of those months on the annual trend. A reasonable explanation for the six contrary stations could be made through either insignificant opposing trend behaviours or approximately dominant uniform fluctuations in the remaining months, or both.

Sequential Mann–Kendall test. Among the 96 stations, we present only the results of Isparta station in detail. In the upper panel of Figure 5, a least-squares line is drawn to illustrate a possible linear trend appearance in the annual precipitation data. It apparently shows a decreasing linear trend over the study period at Isparta station. In addition, the sequential values of the $u(t)$ and $u'(t)$ statistics, both derived from a progressive analysis of the Mann–Kendall rank correlation, are depicted respectively by solid and dashed lines in the lower panel of Figure 5. Horizontal dashed lines correspond to confidence limits at the 5% significance level. When inspecting the plots of $u(t)$ and $u'(t)$ in Figure 5, meaningful long-term trends may be identified in increasing mode commencing in the early 1930s and ending in 1945, and immediately after in the decreasing

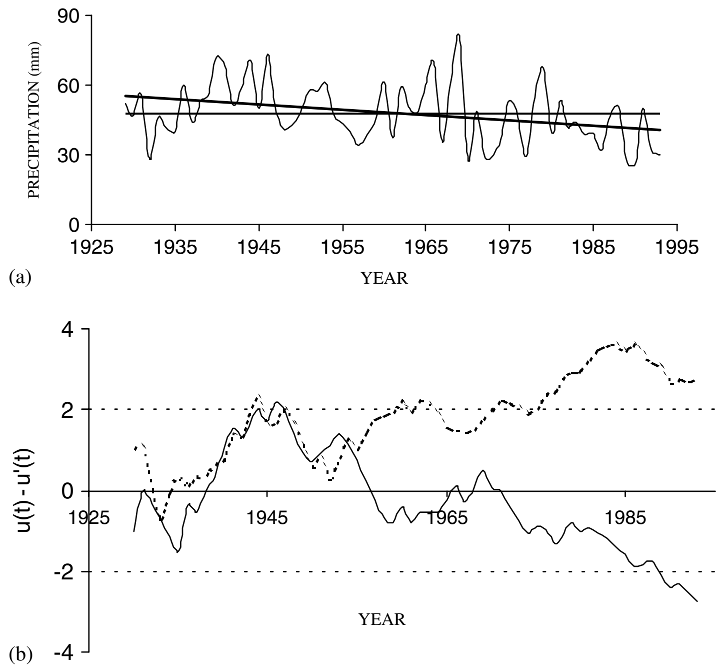

Figure 5. (a) Annual mean precipitation series in Isparta station. (b) Sequential values of the statistics $u(t)$ (———) and $u'(t)$ (- - - -) from the Mann–Kendall test for Isparta station

Table IV. Beginning of the detected trend in the annual mean series

Station	Direction of trend	Beginning of trend	Station	Direction of trend	Beginning of trend
Balıkesir	Downward	1945	Kilis	Downward	1954
Edremit	Downward	1945	Aksehir	Downward	1940
Dikili	Downward	1940	Ankara	Upward	1962
Aydın	Downward	1955	Çorum	Upward	1964
Akhisar	Downward	1955	Niğde	Downward	1935
Afyon	Downward	1963	Ulukışla	Downward	1965
Bodrum	Downward	1945	Ordu	Downward	1960
Fethiye	Downward	1945	Rize	Downward	1952
Isparta	Downward	1950	Bitlis	Upward	1955
Manavgat	Downward	1943	Kars	Downward	1954
Dörtyol	Downward	1953	Muş	Downward	1954

mode for the rest of the period. It should also be noted that two functions begin to diverge in the early 1950s, indicating the starting point of the trend. Similar results for the remaining stations are given in detail elsewhere (Partal, 2003). In summary, a significant trend starts in a year between 1940 and 1950 at eight stations (predominantly located along the western and southern coasts of Turkey); between 1950 and 1960 (inclusive) at 10 stations; and after 1960 at four stations, generally located in the central part of Turkey (Table IV).

Sen's T test. Using monthly precipitation totals we adopted the Sen's T test to detect trend and noticed that its outcomes appear to be quite consistent with the Mann–Kendall test. Differing from the Mann–Kendall test results, the series of January showed a downward trend in Edremit, Fethiye, Akşehir, and Ulukışla stations

Table V. Sen's estimator of the slope of significant trend

Station	Q_{med}	Station	Q_{med}
Balıkesir	−0·220	Ankara	0·070
Edremit	−0·216	Çorum	0·098
Dikili	−0·303	Niğde	−0·118
Aydın	−0·175	Ulukışla	−1·550
Akhisar	−0·151	Ordu	−0·444
Afyon	−0·133	Tokat	−0·037
Bodrum	−0·380	Rize	−0·469
Fethiye	−0·562	Bitlis	1·110
Isparta	−0·242	Kars	−0·143
Manavgat	−0·886	Muş	−0·443
Dörtyol	−0·332	Sarıkamış	0·054
Kilis	−0·162	Akşehir	−0·484

as an upward trend in Balıkesir station; and the series of February showed a decreasing trend in Sivrihisar and Ulukışla stations. Moreover there was an upward trend in Kırşehir station during April; in Iğdır station during May; in Gümüşhane station during June; in İzmir station during September; and in Bitlis station during December. Two stations (Eskişehir and Muğla) exhibited a trend only according to the Mann–Kendall test. Care must be taken in interpreting annual trends because they may obscure large seasonal differences. For the annual data, stations having a negative trend were identified as Dikili, Afyon, Bodrum, Fethiye, Isparta, Manavgat, Dörtyol, Akşehir, Niğde, Ulukışla, Ordu, Tokat, Rize, Kars, and Muş while stations showing a positive trend were Bitlis and Sarıkamış. The results of the Sen's T test seemed to be fairly similar to those obtained from the Mann–Kendall test.

Sen's estimator. Table V summarizes the results of change per unit time of the trends detected. For the negative trends, the highest (lowest) slope value was computed at Ulukışla (Tokat) station, with a value of $-1·55$ mm year^{-1} ($-0·037$ mm year^{-1}). On the other hand, Sen's estimator value ranges from $-0·037$ mm year^{-1} at Sarıkamış station to 1·11 mm year^{-1} at Bitlis station for the positive trends.

Regional trend analysis

Based on the procedures described in the 'Regional trend analysis' section, we first transformed the original precipitation data into modular coefficients in a predetermined region and then repeated the trend analysis to discover a possible regional behaviour. Following the definition of climatic regions in Turkey by Ünal *et al.* (2003), we took the following regions into consideration: the Marmara, Aegean, Mediterranean, central Anatolia, Black Sea, east-central Anatolia, and southeast-central Anatolia. An index series was formed for each region before applying the Mann–Kendall and Sen's T tests. As done in the previous section, the pre-whitening procedure was adopted prior to the application of the Mann–Kendall test if the first serial correlation coefficient was statistically significant (marked by an asterisk in Table VI). In the averaging procedure, the number of stations varied from one region to another, e.g. 10 precipitation station records are used to obtain the index series in the Marmara region. Table VI presents the trend analysis results of monthly and annual data for the aforementioned seven climatic regions.

The pre-whitening procedure was carried out only for the January and December index series in the Marmara region, for the January index series in the Aegean region, and finally for the August index series in the central Anatolia, Mediterranean and southeast Anatolia regions. There was no significant persistence in any of monthly index series in the Black Sea and east Anatolia regions. These findings are not surprising for precipitation variables, which typically have low interannual persistence characteristics. An overall inspection of Table VI indicates that the regional Mann–Kendall statistic was mostly found to be significant in September

Table VI. Results of regional trend analysis[a]

		January	February	March	April	May	June	July	August	September	October	November	December	Annual mean
Marmara	X	1·39	1·12	1·02	0·86	0·80	0·77	0·52	0·42	0·71	1·18	1·48	1·67	1·00
	r_1	0·34*	0·04	−0·09	−0·16	−0·11	0·06	−0·03	0·04	−0·03	0·15	−0·02	0·24*	0·01
	z	0·21	−1·44	0·60	0·35	0·60	0·43	0·49	1·10	−1·70	−0·88	0·82	−0·15	−0·51
	T													−0·70
Aegean	X	2·05	1·60	1·24	0·84	0·69	0·34	0·17	0·12	0·33	0·86	1·47	2·27	1·00
	r_1	0·29*	−0·08	−0·19	−0·21	−0·16	−0·07	−0·10	−0·04	0·01	0·00	−0·09	0·22	0·12
	z	−0·81	−1·35	−0·14	1·00	−1·05	0·50	0·49	0·04	**−2·28**	−1·12	1·14	0·10	−1·87
	T													−1·65
Black Sea	X	1·25	1·00	0·92	0·75	0·63	0·71	0·68	0·78	1·11	1·41	1·44	1·32	1·00
	r_1	0·06	0·09	0·07	−0·17	−0·04	−0·14	−0·11	−0·19	−0·10	0·06	−0·02	−0·04	−0·03
	z	−1·19	**−2·34**	**−2·44**	−0·84	0·87	1·00	−1·04	−0·56	−1·72	0·54	−0·31	−0·96	**−2·85**
	T													**−2·12**
Central Anatolia	X	1·30	1·14	1·18	1·34	1·56	1·07	0·36	0·24	0·48	0·85	1·06	1·40	1·00
	r_1	0·16	0·12	−0·10	−0·18	−0·27	0·01	−0·07	0·28*	0·00	0·06	0·06	−0·01	−0·04
	z	−0·42	−1·20	−0·48	1·14	−0·29	−0·14	0·74	0·28	−1·91	1·14	0·50	0·34	−0·37
	T													−0·30
Mediterranean	X	2·13	1·71	1·23	0·83	0·63	0·30	0·11	0·14	0·34	0·95	1·40	2·25	1·00
	r_1	0·09	−0·04	−0·08	−0·02	−0·30*	0·01	−0·19	0·26*	−0·08	0·02	−0·11	−0·07	0·04
	z	−0·87	−1·34	0·37	−0·76	−0·07	−0·63	−0·02	−1·89	**−2·40**	−0·28	0·86	−0·62	−1·54
	T													**−2.32**
East Anatolia	X	0·99	1·01	1·15	1·47	1·68	1·16	0·58	0·44	0·47	1·04	1·08	0·96	1·00
	r_1	0·11	−0·09	−0·14	−0·19	−0·24	−0·08	−0·21	−0·03	−0·02	0·10	−0·10	0·04	−0·10
	z	−0·76	0·03	−0·43	−0·94	0·57	−0·34	−1·77	−0·87	**−2·07**	0·34	0·78	0·06	−0·94
	T													−1·19
Southeast Anatolia	X	1·87	1·70	1·56	1·41	0·97	0·27	0·04	0·04	0·11	0·76	1·32	1·78	1·00
	r_1	0·00	0·00	0·01	−0·18	−0·19	−0·05	−0·13	0·28*	0·04	0·10	−0·03	0·18	0·14
	z	−0·69	0·60	1·44	−0·23	0·99	0·61	0·03	0·32	**−2·45**	1·11	1·20	0·84	0·59
	T													−1·05

[a] X is the ratio of monthly mean precipitation to annual mean precipitation; r_1 is the lag-1 serial correlation coefficient; z is the Mann–Kendall test statistic; T is Sen's T test statistic. *: pre-whitening procedure was adopted. Bold figures indicate significant values at the 5% significance level.

(shown in bold). It is worth noting that the Mann-Kendall test statistic was about to exceed the critical value (zc = +1·96), for the Marmara, Black Sea and Central Antaolia regions. However, the Black Sea region had 2 months with a significant decreasing trend and appeared as a unique region from the viewpoint of trend existence in the annual index series. The indication from the Sen's T test seemed to verify the outcomes of the Mann–Kendall test in the same region. It should be noted that the former assertion is also true for the other regions. As a result, the regional precipitation trend analysis in Turkey has not provided better results than those for the station-based analysis.

CONCLUSIONS

Trend analysis of precipitation records at the 96 stations in Turkey has been carried out using monthly total series, annual mean series and regional index series. Analysis of the serial correlation effect showed that most of the data did not reveal a significant lag-1 correlation coefficient, except the series of January and November. The application of a trend detection framework to Turkish precipitation data has resulted in identification of some significant trends. As Burn and Hag Elnur (2002) indicated, spatial and temporal differences were noted in the occurrence and the direction of trends in this study, implying that a systematic framework is critical for detecting trends that may arise from climatic change. The direction of precipitation trends was, in general, downward across Turkey. Both the aligned (i.e. Sen's T) and intrablock (i.e. Mann–Kendall) methods yielded more or less similar conclusions.

From the monthly precipitation variables, January, February and especially September were determined to have strong decreasing trends, as opposed to other months showing either positive or negative trend in less stations. The results of trend analysis of monthly total precipitation especially in January, February and September affected the results of annual series. There were downward trends in the annual mean precipitation series, predominantly in western and southern of Turkey, but a few upward trends were founded in the central part of Turkey. Our results were also consistent with those of previous studies for Turkish streamflow data. For example, Kahya and Kalayci (2003) found that river basins located in western Turkey exhibited downward trends, whereas basins located in eastern Turkey showed no trend. It is now reasonable to postulate that decreases in mean streamflow in western Turkey were due most likely to decreases in precipitation in the same region.

The similarities in trends between individual stations and the regional index series (including seven regions) implied that the local effects influencing trend characteristics at each individual station in a region were not strong enough to mask the large-scale climatic effects in that region. It is worthwhile emphasising that the trend results presented in this study were not sufficient to approve climatic change in Turkey. Future studies are needed to address the issue of trend attribution and to attempt to establish a linkage between climatic change and the observed hydrologic trends.

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