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Effects of climate change on water resources of the Büyük Menderes river basin, western Turkey

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Abstract: Temperature and rainfall changes are both significant components of climate change. This study characterizes the effects of climate change on water resources in the Büyük Menderes river basin in western Turkey, based on hydrology, temperature, and rainfall data from the past 45 years (1963-2007). When analyzed with the Mann-Whitney test, the temperature and precipitation time series exhibited obvious step changes with a 5% level of significance. Both the parametric t-test and nonparametric Mann-Kendall statistical test results showed an increasing trend of the temperature. Over the past 45 years, the temperature increased just about 1 °C. The long-term trend of annual precipitation demonstrated a decreasing trend; however, it was not found to be statistically significant. The spatial distribution of the precipitation pattern showed that the precipitation amount had an increasing trend in the 1970s, especially in the Aydın region, with a value of 5.8%. The precipitation amount started to decrease in the 1980s, especially in the Afyon and Uşak regions, with a value of –6.8%. Serious water scarcity began to appear in the 1990s, especially in the Aydın region, with a value of –14.4%. The streamflow of the Çine and Akçay rivers showed a decreasing trend, especially during the period of 1985-1998. The decreasing trend of the streamflow in the tributaries had a strong correlation with changes in temperature and precipitation. An increasing trend in temperature and decreasing trends in precipitation and streamflow in the Büyük Menderes river basin may be interpreted as climate change.

Key words: Climate change, water resources, Büyük Menderes basin

İklim değişikliğinin Büyük Menderes havzası su kaynaklarına etkileri

Özet: Sıcaklık değerlerindeki yükselme ve yağıştaki belirsizlikler iklim değişiminin önemli göstergelerindendir. Bu çalışma; hidroloji, sıcaklık ve yağış verilerini esas alarak Türkiye'nin batısında bulunan Büyük Menderes havza'sında son 45 yıllık dönem içerisinde iklim değişiminin su kaynakları üzerinde oluşturduğu etkileri incelemektedir. Mann-Whitney testi % 5'lik bir olasılık düzeyi ile sıcaklık ve yağış verilerinde basamak eğilimi olduğunu göstermiştir. Parametrik olmayan Mann-Kendall ve parametrik t-testleri sıcaklık değerlerinde bir yükselme eğilimi olduğunu % 5'lik bir olasılık düzeyi ile önemli bulmuştur. Geçen 45 yıllık dönemde sıcaklığın 1 °C yükseldiği görülmüştür. Yıllık yağışların uzun dönem analizleri yağış miktarında bir azalma eğilimi olduğunu göstermişse de istatistiksel olarak önemli bulunmamıştır. Yağış deseninin konumsal dağılımı yağış miktarının 1970'lerde yükselme eğilimi izlediğini ve bu değerin Aydın'da % 5.8 olduğunu göstermiştir. Yağış miktarı 1980'lerde ortalamanın altına düşmeye başlamış, bu azalma Afyon ve Uşak'ta % –6.8 değerine ulaşmıştır. Yağış miktarında istatistiksel anlamda önemli azalma 1990'larda başlamış ve yağışın en çok azaldığı bölge % –14.4'lük bir değerle Aydın olmuştur. Çine ve Akçay nehirlerindeki akım miktarları azalma eğilimi göstermiş, 1985 ile 1998 yılları arasında bu azalmanın daha belirgin olduğu görülmüştür. Büyük Menderes nehrinin ana kollarında akım değerlerindeki bu düşüşün sıcaklık ve yağıştaki değişimler ile güçlü ilişkileri olduğu tespit edilmiştir. Sıcaklıktaki artış, yağış ve akım verilerindeki azalışlar Büyük Menderes havzasında iklim değişiminin etkileri şeklinde yorumlanabilir.

Anahtar sözcükler: İklim değişikliği, su kaynakları, Büyük Menderes havzası

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Introduction

Increasing atmospheric concentrations of carbon dioxide and other gases are expected to change the heat equilibrium of the earth and result in global climate change. The obvious effect of climate change has been an increase in global temperatures and modified precipitation patterns. This impact, known as the greenhouse effect, as well as its effects on the regional hydrologic cycle and the resultant effects on the quantity and quality of water resources, has attracted widespread interest. Alcamo et al. (2007) indicated that climate change will pose 2 major water management challenges in Europe: increasing water stress, mainly in southeastern Europe where the Büyük Menderes basin is located, and increasing risk of flooding through most of the continent. Precipitation is the main element of variability in the water balance over space and time, and variations in precipitation have very significant implications on hydrology and water resources. Current vulnerabilities to climate are strongly correlated with climate variability, in particular precipitation variability (IPCC 2007). Precipitation trends are more spatially variable in comparison with temperature. Mean winter precipitation is increasing in most of the Atlantic and northern European regions. In the Mediterranean area, yearly precipitation trends are negative in the east. An increase in mean precipitation per wet day is observed in most parts of Europe, even in some areas that are becoming drier (Alcamo et al. 2007). With higher temperatures, the water holding capacity of the atmosphere and the evaporation into the atmosphere increase, and this favors increased climate variability, with more intense precipitation and more droughts (Trenberth et al. 2003). The increasing trend in temperature throughout Europe was +0.90 °C for 1901-2005. However, the recent period shows a trend considerably higher than the mean trend, +0.41 °C per decade for the period of 1979-2005 (Alcamo et al. 2007). In the period of 1977-2005, precipitation trends were higher in central and northeastern Europe and in mountainous regions, while lower trends could be found in the Mediterranean region. Some studies have detected significant trends in some indicators of runoff/streamflow, and some have demonstrated statistically significant links with trends in precipitation or temperature (IPCC 2007). In some parts of the world, variations in flow from year to year have been found to be much more strongly related to precipitation changes than to temperature changes. In large parts of eastern Europe, a major shift in runoff/streamflow from spring to winter has been associated not only with a change in precipitation totals but more particularly with a rise in temperature; in other words, precipitation has fallen as rain, rather than snow, and therefore has reached rivers more rapidly than before (Arnell 1999).

The effects of changes in temperature and precipitation on hydrology have been investigated by many hydrologists all over the world. Chen et al. (2007) investigated the effects of climate change on water resources of the Tarim river basin in China. They found that there was an increasing trend in temperature, precipitation, and streamflow. Bou-Zeid and El-Fadel (2002) studied climate change and water resources in the Middle East. They indicated that climate change was expected to exacerbate existing water shortages. Mizyed (2009) evaluated the impacts of climate change scenarios on water resources availability in the West Bank; he indicated that climate change could potentially increase agricultural water demands by up to 17% and could also result in a reduction of annual groundwater recharge by up to 21% of existing values. Loukas et al. (2007) assessed climate change on drought impulses in Greece and emphasized that frequent, extreme, and spatially extended droughts would be expected in the future. The climate change effect on the water resources of Turkey has been studied by several researchers. Fujihara et al. (2007) evaluated climate change impacts on water resources of the Seyhan river basin located in southern Turkey. They indicated that, compared with the present, precipitation decreased and this resulted in a considerable decrease in streamflow, in which the peak monthly flow occurred earlier than at present. Demir et al. (2007) investigated climate change effects on temperature and precipitation in Turkey. They found that while temperature increased in the summer season, the changes in total annual precipitation amounts had a generally decreasing tendency. Ozkul (2009) studied the generation of climate change scenarios, modeling of basin hydrology, and testing of the sensitivity of runoff to changes in precipitation and temperature in the Büyük Menderes and Gediz basins. Simulation results of the water budget model demonstrated that nearly 20% of the surface waters in the studied basins would be reduced by the year 2030. Mengu et al. (2008) studied climate change effects on agriculture and water resources of Turkey. They concluded that along with an expected increase in temperature of 1-3 °C, rainfall was replaced with snow in winter, annual precipitation showed a significant decrease, and streamflow dramatically dropped. Although these studies discuss the effects of climate change on the water resources of Turkey on a national scale, there are not many studies available on the investigation of the issue on a basin scale, such as the Büyük Menderes river basin.

Examination of the correlation between climate change and the available water resources is beneficial for efficient water resources management. To predict the likely effects of climate change on the hydrological process and water availability is particularly important for any work aimed at supporting the sustainable management and long-term planning of water resources. It is especially significant for the Büyük Menderes river basin, where the supply of water resources is a major problem for further social development and ecological protection. It is therefore significant to examine the hydrological process and water resources availability, understand the causes of water deficiency, and, on the basis of this investigation, formulate a new vision for future water resources in the Büyük Menderes river basin. In the present study, climate and hydrology data from the past 45 years were used, the probable long-term trends of the temperature and precipitation time series were identified, and the vulnerability of streamflow to climate change was studied. The objectives of the present study were to expose the relation between climate change and the variability of hydrological process response, to clarify the impacts of climate change on the hydrological process and water resources, and to offer decisional references for the water resource managers of the Büyük Menderes river basin.

Materials and Methods

Study area

The study area is located in the western part of Turkey (Figure 1). The basin is a plain region surrounded by the Aydın Mountains, Mount Çökelez, and Mount Beşparmak in the north; the West Menteşe Mountains, the East Menteşe Mountains, Mount Karıncalı, Mount Akdağ, Mount Eşler, and Mount

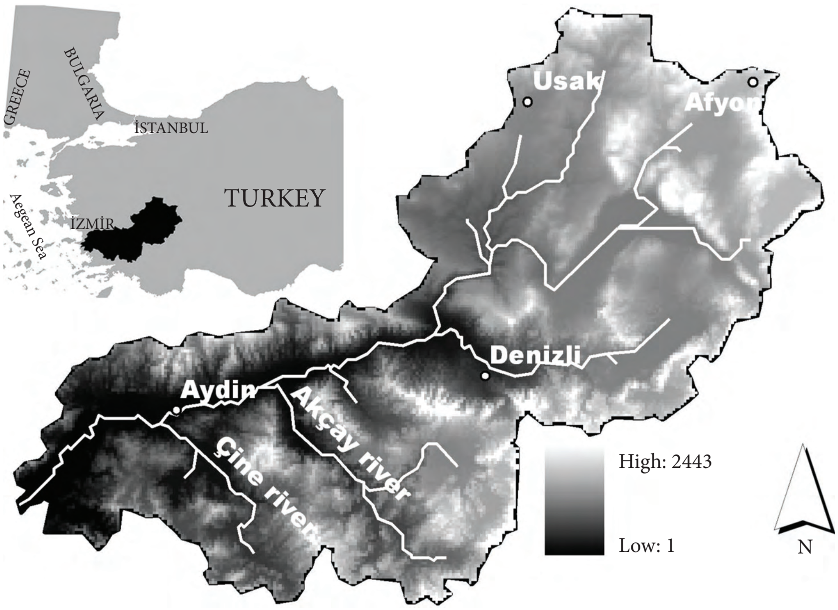

Figure 1. Büyük Menderes river basin.

Söğüt in the south; and the coast of the Aegean Sea in the west. The elevation ranges from sea level at the western coastal area to more than 2400 m at the southern and northern mountains, and the mean elevation of the region is nearly 850 m (Figure 1). On the eastern side of the basin, the climate is continental; the winters are cold and the summers are hot, and the temperature difference between 2 seasons is large. On the western side of the basin, the climate is a typical Mediterranean climate; the summers are usually hot and dry, and in July and August, temperatures can reach 43 °C. The mean annual precipitation over the whole basin is about 635 mm, which is distributed unevenly in space and time. The temporal distribution of precipitation throughout the year is strongly heterogeneous. More than 70% of the total annual precipitation falls between November and May in the high flow season, and less than 30% of the total falls from June to October. The mean annual precipitation varies from about 350 mm on the eastern plains to more than 1000 mm in the western mountain areas. Rainfall is generally rare from June to August. The Büyük Menderes basin is one of the most productive agricultural regions of Turkey. The main crops cultivated in the basin's plain area are maize, cotton, and wheat, whereas olive trees, figs, oranges, peaches, and plums are cultivated in the foothills of the mountain areas. The mainstream of the basin, the Büyük Menderes River, and its tributaries traverse the plain area, and the basin's total drainage area is about 25,000 km^2. Three water systems have a natural hydraulic relationship with the mainstream: the Çine, Akçay, and Çürüksu rivers. Among these three headstreams that flow into the Büyük Menderes River, the Çine River supplies water to the mainstream of the Büyük Menderes River, accounting for 12% of the total. The Akçay River accounts for 30% of the total mainstream discharge. The seasonal runoff is quite poorly distributed. The runoff volume in the flood season from February to April accounts for 60%-80% of the annual runoff volume; this demonstrates that the rivers are mainly fed by rainfall in the basin. The waters of the Büyük Menderes River are used primarily for irrigation and domestic purposes. The intense and extensive cultivation of water-demanding crops has lead to a significant water demand increase, which is usually fulfilled by the overexploitation of groundwater resources. The overexploitation of the groundwater, especially during extended dry periods, has lead to the corruption of the already disturbed water balance and the degradation of water resources.

Data acquisition

Both temperature and precipitation data for the period of 1963-2007 were obtained from the meteorological stations of the Aydın, Denizli, Afyon, and Uşak regions in the basin. These regions were chosen due to the availability of high quality weather data from the meteorological stations and extensive agricultural activities. The data were provided by the State Meteorological Organization. Table 1 provides descriptive statistics of the temperature and precipitation data. Two time series of streamflow during the past 4 decades for the Çine and Akçay rivers were used for the analysis. The streamflow data were provided by State Hydraulic Works and the General Directorate of Electrical Power Resources Survey and Development Administration.

Methods

The objective of trend analysis is to identify if the values of a random variable generally increase or decrease over some period of time in statistical terms. In this study, an attempt was made to produce more reliable estimates of the magnitude and the statistical significance of the trend. In order to detect the trends in the data, both parametric and nonparametric tests

Table 1. Basic statistics of temperature and precipitation data.

Statistics	Mean	Standard deviation	Coefficient of variation	Coefficient of skewness	Maximum value	Minimum value	Range
Temperature (°C)	13.93	0.61	0.04	0.3	15.56	12.75	2.81
Precipitation (mm)	79.36	37.88	0.47	0.53	173.38	5.55	167.82

were used for analysis. Nonparametric tests were developed for use in environmental impact assessment because scientists were concerned that the statistical characteristics of "messy" environmental data would make it difficult to use parametric procedures (Hipel and McLeod 1994). Hirsch and Slack (1984) indicated that natural time series may contain one or more of a number of properties that are undesirable for use with parametric tests. In particular, hydrologic and climate data may be nonnormally distributed and follow a distribution that is usually positively skewed. In the present study, both the parametric t-test and the nonparametric Mann-Kendall test were employed for the monotonic trend test. The rank-based nonparametric Mann-Kendall test has been commonly used to assess the significance of monotonic trends in hydrometeorological time series (Hipel and McLeod 1994). The nonparametric Mann-Whitney test was used for step trend analysis.

Parametric t-test

Student's t-test can be used to test whether a linear trend is statistically significant. In this method, the regression line establishes the differences between the dependent (Y) and independent (X) variables. The intercept and line slopes can be calculated through error minimization. Student's t-test can be calculated as follows (Ghahraman 2006):

$$t = \frac{b}{S_b} \quad \text{where} \quad S_b = \frac{\sum (Y_i - \overline{Y})^2 / (n-2)}{\sum (X_i - \overline{X})^2} \tag{1}$$

where n is the sample size and b is the intercept of the regression line. The hypothesis H_o at the α-level of significance is rejected whenever $|t| > t_{1\frac{\alpha}{2},n-2}$ from the t-Student table. The alternative hypothesis H_1 indicates that there is a trend if the value of b is not equal to 0.

Nonparametric Mann-Kendall test

Mann (1945) presented a nonparametric test for randomness against time, which constitutes a particular application of Kendall's test for correlation commonly known as the Mann-Kendall test. The utility of the Mann-Kendall test is that it is considered robust, being insensitive to outliers and power transformations (Helsel and Hirsch 1992). Letting x_1, x_2,…x_n be a sequence of measurements over time, Mann (1945) proposed to test the null hypothesis, H_o, that the data come from a population where the random variables are independent and identically distributed (Hipel and McLeod, 1994). The alternative hypothesis, H_1, is that the data follow a monotonic trend over time. Under the H_o hypothesis, the Mann-Kendall test statistic is (Chen et al. 2007):

$$s = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad \operatorname{sgn}(x) = \begin{cases} +1, & x > 0 \\ 0, & x = 0 \\ -1 & x < 0 \end{cases} \tag{2}$$

where x_j and x_k are observations from years j and k, respectively, and n is the number of years. If the dataset is identically and independently distributed, then the mean of S is 0 and the variance of S is (Chen and Xu 2005):

$$\operatorname{var}(S) = \frac{\left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j (t_j - 1)(2t_j + 5) \right\}}{18} \tag{3}$$

where p is the number of tied groups in the dataset and t_j is the number of data points in the j_{th} tied group. If the S is significantly different from 0, based upon the available information H_o can be rejected at a chosen significance level and the presence of a monotonic trend, H_1, can be accepted (Hipel and McLeod 1994). For relatively large samples (n > 10), a normally distributed approximation Z can be constructed as:

$$z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & , \text{ if } S > 0 \\ 0 & , \text{ if } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & , \text{ if } S > 0 \end{cases} \tag{4}$$

If a trend is present, the slope can be estimated nonparametrically using the Kendall-Theil method. In this method, the estimate of the slope of the long-term trend is given by the median of all possible pairwise slopes (Gough et al. 2004):

$$\beta = \text{median}\left(\frac{x_k - x_j}{T_k - T_j}\right), \text{ for all possible } j < k \quad (5)$$

where T is the time and $1 < j < k < n$. A positive value of β indicates an upward trend, and a negative value of β indicates a downward trend. The Mann–Kendall test is given as null hypothesis H_o: $\beta = 0$ and rejected H_o: $| Z | > Z_{1-\alpha/2}$, where $\pm Z_{1-\alpha/2}$ is the standard normal deviate and α is the significance level for the test.

The presence of a serial correlation can complicate the identification of trends in that a positive serial correlation can increase the expected number of false positive outcomes for the Mann-Kendall test (Burn and Hag Elnur 2002). In this study, the prewhitening method was used for calculating the serial correlation and removing the correlation if the calculated serial correlation was significant at the 5% level. The prewhitening method is described as (Burn and Hag Elnur 2002):

$$yp_t = y_{t+1} \quad (6)$$

where yp_t is the prewhitened series value for time interval t, y_t is the original time series value for time interval t, and r is the estimated serial correlation coefficient.

Mann-Whitney test for step trend

To further investigate the detailed correlation between hydrological and meteorological variables, the nonparametric Mann-Whitney test was employed. The Mann-Whitney test statistics are described as (Chen and Xu 2005):

$$Z = \frac{\sum_{i=1}^{N} \text{rank}(x_i) - \frac{N_1(N_1 + N_2 + 1)}{2}}{\sqrt{\frac{N_1 N_2 (N_1 + N_2 + 1)}{12}}} \quad (7)$$

where $\text{rank}(x_i)$ is the rank of the observations, N_1 is the number of warm or cold years for the temperature data or the number of wet or dry years for the precipitation data, and N_2 is the number of neutral years for the precipitation or temperature data. The null hypothesis is stated as H_o: $\text{mean}_{wet} = \text{mean}_{neutral} = \text{mean}_{dry}$ for precipitation or $\text{mean}_{warm} = \text{mean}_{neutral} = \text{mean}_{cold}$ for temperature, and H_1: at least 2 of the means are different. Hypothesis H_o is rejected if $| Z | > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is the 1-α/2 point on the standard normal probability distribution and ± is the significance level for the test.

Results

The basic statistics of the temperature and precipitation in the study, including mean, standard deviation, coefficient of variation (CV), skewness, minimum-maximum values, and range, are listed in Table 1. Among these, CV is the most discriminating factor. When the value of CV is less than 0.1, the parameter shows low variability; if the CV is greater than 0.90, it shows great variability. The basic statistical data show that the CV for temperature is less than 0.1. This indicates that while the temperature data present low variability, the precipitation data have moderate variability. Both temperature and precipitation data have low skewness values, but it should be noted that large coefficients of skewness of climate data might be attributed to regional climate variations in the basin. In other words, a high skewness coefficient indicates that the mean and median values are different for the climate data. The mean in such a dataset is probably heavily influenced by the presence of a few extreme values.

Figure 2 demonstrates the standardized average temperature and precipitation data over the years in the study area. Figure 2a shows that both monotonic and step trends occurred in the temperature data. This dataset demonstrates an upward trend. The year 1993 was a cut-off point due to the appearance of significant step change. Figure 2b indicates that the precipitation data also have monotonic and step trend changes. The precipitation data show a downward trend. The year 1992 was a cut-off point due to the sudden decrease in precipitation amount. In the present study, the possible partition points were determined by visual observation. In this visual identification, 2 principles were followed. One was that a large difference between the mean values of the 2 subdivided time series should exist; the other was that either of the 2 subdivided series has to have enough length of record (Xu et al. 2003). According to these rules, the temperature and precipitation datasets

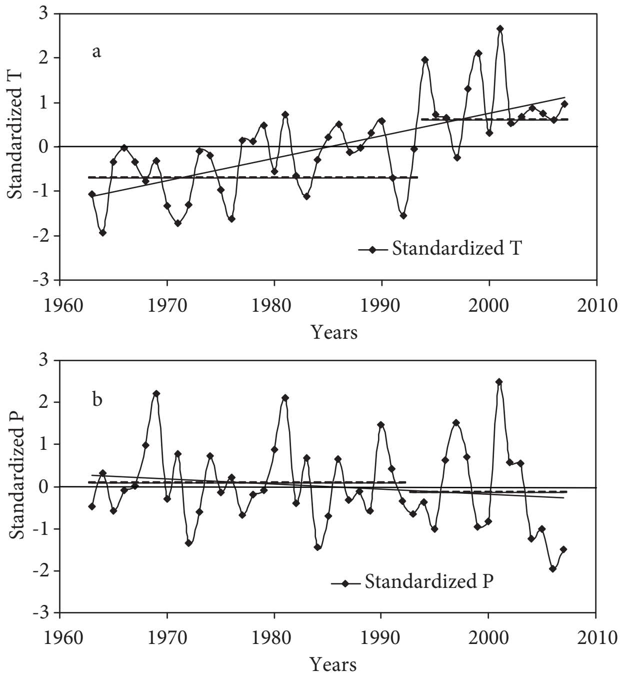

Figure 2. Monotonic and step trends of temperature and precipitation data.

were divided into 2 subseries, as demonstrated in Table 2. The mean temperature before 1993 was 13.65 °C, while this value after 1993 was 14.54 °C.

Table 3 shows the Mann-Whitney test results of step trend for temperature and precipitation data. The test is intended to analyze 2 independent climate datasets. When applying the test to the climate data, a single series of temperature and precipitation data was separated into 2 parts, based on the visual observation mentioned above. According to the Mann-Whitney test, the temperature and precipitation contradicted the null hypothesis. In other words, the 2 time series datasets exhibited an obvious step change. The computed values of Z for temperature and precipitation were –4.732 and 1.396, respectively, with a level of significance of 0.05. Since the computed value of Z for temperature was smaller than the critical value of Z (–1.960), the null hypothesis was rejected. Similarly, the computed value of Z for precipitation was smaller than the critical value of Z (1.960), and so the null hypothesis was rejected.

The long-term trend of annual temperature and precipitation data in the basin was identified by using parametric and nonparametric techniques. The test results are summarized in Table 4. In this table, β_1 is the linear slope obtained from the t-test and β is the Mann-Kendall slope. It was obvious that both the parametric t-test and the nonparametric Mann-Kendall test of the temperature data contradicted the hypothesis H_o. The long-term monotonic trend in annual temperature was strong over time and statistically significant. Table 4 demonstrates that both the β_1 and the Mann-Kendall slope β are greater than 0, meaning that the temperature increased monotonically at the rate of 0.0325. Both the parametric t-test and the nonparametric Mann-Kendall test results for the precipitation data supported the null hypothesis H_o (Table 4). The decreasing trend of the precipitation was not found to be statistically significant. The critical value for the 95% confidence interval of Student's t-distribution with 45 degrees of freedom is 2.014; since the computed t-value for precipitation is less than the critical value, the null hypothesis is accepted with 95% confidence. It can be seen that the β_1 and Mann-Kendall slope β are both less than 0, meaning that they decrease monotonically (Table 4). This determines that the trend still exists, although the decreasing trend of precipitation is not significant. Precipitation decreased at the rate of –0.442.

Table 2. Partitions of the temperature and precipitation data.

Item	No.	Time series	Length of record	Mean value	Standard deviation	Coefficient of variation
Temperature	1 (N_1)	1963-1993	31	13.65	0.442	0.032
	2 (N_2)	1994-2007	14	14.54	0.442	0.030
Precipitation	1 (N_1)	1963-1992	30	83.21	32.66	0.389
	2 (N_2)	1993-2007	15	71.64	46.35	0.636

Table 3. Mann-Whitney test results for the temperature and precipitation data.

Temperature				Precipitation			
Series		Test		Series		Test	
N1	N2	Z	H_o	N1	N2	Z	H_o
31	14	–4.732	Reject	30	15	1.396	Reject

Table 4. Student’s t-test and Mann-Kendall test results for temperature and precipitation.

Item	Student’s t-test				Mann-Kendall test		
	β_o	β_1	t	H_o	Z	β	H_o
Temperature	13.223	0.0309	7.82	Reject	5.077	0.0325	Reject
Precipitation	90.148	–0.4692	–1.91	Accept	–1.575	–0.442	Accept

The spatial distribution of the precipitation pattern in the basin for several distinct periods (the 1970s, 1980s, and 1990s) was further investigated. Figure 3 demonstrates the difference between the average annual precipitation over the period of 1963-2007 and the average annual precipitation over the distinct periods (the 1970s, 1980s, and 1990s). Figure 3a shows that the precipitation amount experienced an increasing trend in the 1970s, especially in the coastal Aydın region, with a value of 5.8%. In the 1980s, the amount of rainfall over the basin started moving below average with a value of –6.8%, which had a serious impact on the mountainous Afyon and Uşak regions (Figure 3b). Serious water scarcity in the basin began to appear in the 1990s; there was a significant decrease in precipitation amount in the Aydın region, with a value of –14.4% (Figure 3c).

To investigate the long-term trend of the streamflow, 2 time series of streamflow from the main tributaries, the Çine and Akçay rivers, were considered. The basic statistics of the streamflow time series are shown in Table 5. The CVs for both time series datasets were less than 0.9 but higher than 0.1. This shows that the data are moderately variable. The data for the Akçay River have a higher skewness coefficient than the data for the Çine River. The large coefficient of skewness of the streamflow data might be attributed to regional climate variation in the basin. The high skewness coefficient indicates that the mean in the dataset is influenced by the existence of a few extreme values.

The annual streamflows of the Çine and Akçay rivers experienced 3 phases of changes during the past 45 years. The period from the 1970s to the mid-1980s represents a high flow phase. From the mid-1980s to the late 1990s, the streamflows in both rivers decreased significantly, representing a low flow phase. The period of the late 1990s to the mid-2000s represents an inconsistent flow phase, in which the precipitation was distributed unevenly in time (Figure 4). In general, the annual streamflows of the Çine and Akçay rivers showed a decreasing trend, especially during the period from 1985 to 1998. To be more accurate in trend analysis, the nonparametric Mann-Kendall test and the parametric t-test were applied to test the streamflow data of both rivers during the past 45 years. In Table 6, β and β_1 represent the Mann-Kendall slope and the linear slope obtained from the t-test, respectively. The t-test for the Çine River rejects the null hypothesis H_o. In other words, the decreasing trend of the streamflow data has a 5% level of significance. The Mann-Kendall test results for the same river support the null hypothesis. The Mann-Kendall slope β has a value of less than 0, meaning

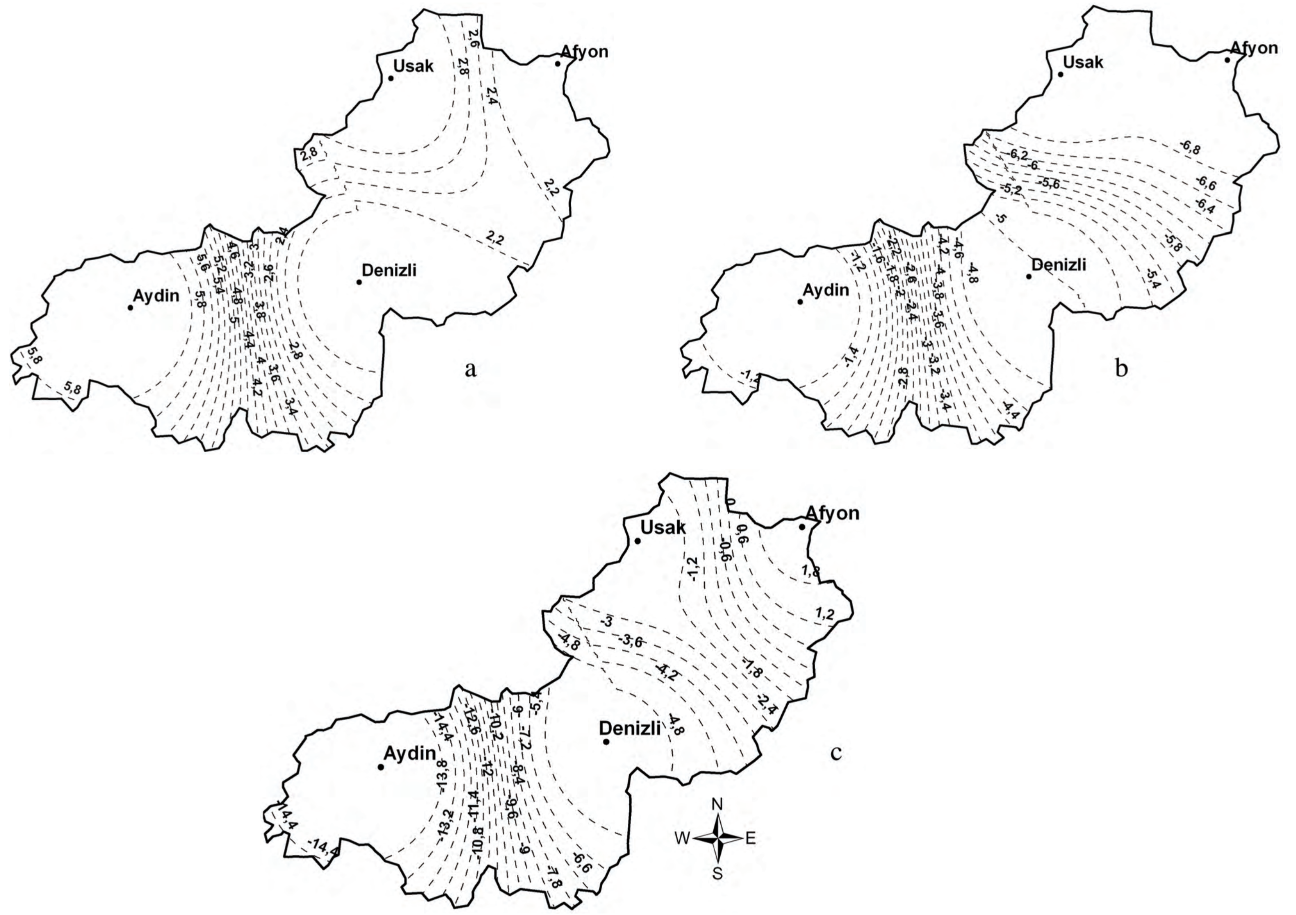

Figure 3. Spatial distribution of average precipitation changes in the (a) 1970s, (b) 1980s, and (c) 1990s.

Table 5. Basic statistics for streamflows of the Çine and Akçay rivers (10^8 m^3).

Statistics	Çine River	Akçay River
Mean	1.690	5.631
Standard deviation	0.920	2.304
Coefficient variation	0.544	0.409
Coefficient of skewness	0.360	0.830
Minimum value	0.277	1.062
Maximum value	3.690	12.172
Range	3.410	11.11

that it decreases monotonically (Table 6). This explains that the trend still exists, although the decreasing trend of the streamflow is not significant. The streamflows of the Çine and Akçay rivers decreased at the rates of –0.301 and –0.322, respectively. Both the t-test and the Mann-Kendall test results for the Akçay River reject the null hypothesis H_o. The decreasing trend of the streamflow data for the Akçay River has a 5% level of significance.

Discussion

The main and most important climate changes in western Turkey are those related to temperature and precipitation. Christensen et al. (2007) emphasized that, although global climate change might result in a small increase in global annual precipitation rates, annual precipitation is very likely to decrease in most of the Mediterranean area. Climate change is likely to cause a decrease in natural water storage capacity, an increase in the vulnerability of the ecosystem, and an increase in water scarcity due to changes in temperature and precipitation patterns.

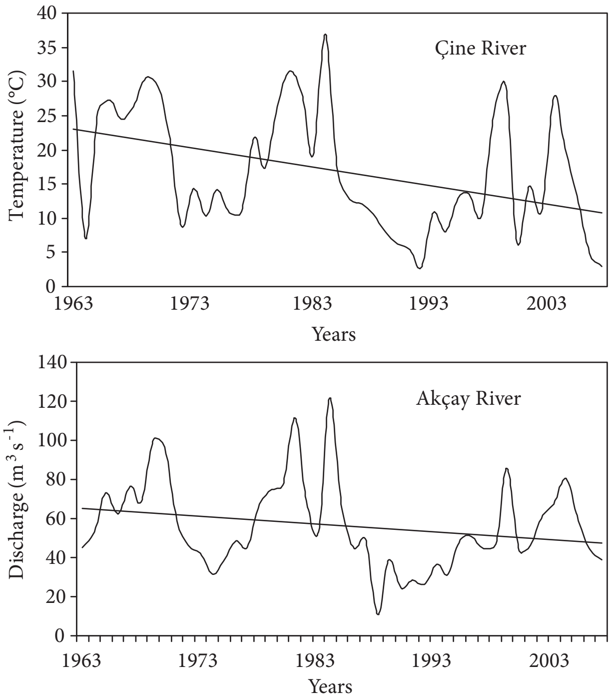

Figure 4. Streamflow distributions of the Çine and Akçay rivers over the years.

The results of trend analysis for temperature correspond well with the report by Alcamo et al. (2007), which indicates that the yearly maximum temperature is expected to increase in southern Europe. The warming of southeastern Europe may be more closely connected to higher temperatures on warm days than to general warming. The report also emphasizes that the warming in the recent period in southeastern Europe shows a trend considerably higher than the mean trend. In other words, the temperature increased with a value of +0.41 °C per decade for the period of 1979-2005. It is important to indicate that one of the reasons for this increase in temperature may be due to urbanization and land use. Urbanization and changing land use influence the minimum temperature. Due to high levels of energy consumption in cities, a significant amount of waste heat is stored in the walls of buildings and streets, which gets released during the night, thereby making the night warmer (Gadgil and Dhorde 2005). As defined in Table 2, the mean precipitation before 1992 was 83.21 mm, whereas it was 71.64 mm after 1992. The coefficient of variation was 0.389 before 1992 and 0.636 after 1992. These findings are also supported by Alcamo et al. (2007), who emphasized that precipitation trends are more spatially variable. In southeastern Europe, yearly precipitation trends are negative. Christensen et al. (2007) indicated that in most of the Mediterranean area, there might be a substantial increase in the intensity of daily precipitation events; however, annual precipitation is very likely to decrease. The combined effects of warmer temperatures and reduced mean summer precipitation would enhance the occurrence of droughts.

Both the parametric t-test and nonparametric Mann-Kendall test were performed in the same manner to identify the long-term trend of annual temperature and precipitation data. The parametric t-test is based on linear regression, and therefore checks only for a linear trend. The Mann-Kendall test is suitable for detecting trends in time series, which are usually skewed and may be contaminated with outliers. The slopes of both tests contradicted the H_o hypothesis for temperature data. The slopes of both tests were also less than 0 for precipitation data. The results of a comparative assessment of the t-test and Mann-Kendall test corresponded well with the findings of Önöz and Bayazıt (2003). They emphasized that the t-test is slightly more powerful when the probability distribution is normal. For

Table 6. Student's t-test and Mann-Kendall test results for the streamflows of the Çine and Akçay rivers.

Rivers	Student's t-test				Mann-Kendall test		
	β_o	β_1	t	H_o	Z	β	H_o
Çine	23.216	–0.274	12.33	Reject	–2.592	–0.301	Accept
Akçay	65.580	–0.403	16.39	Reject	–1.399	–0.322	Reject

moderately skewed distributions, the t-test is almost as powerful as the Mann-Kendall test. Therefore, these 2 tests can be used interchangeably in practical applications.

The results of the t-test and the Mann-Kendall test for analysis of the temperature data correspond well with what has been obtained in previous studies by Sensoy et al. (2008) and Zhang et al. (2005). Sensoy et al. (2008) indicated that the temperature trend increased significantly during the period of 1971-2004 in Turkey. They also found that summer days had increased by about 6 days per decade, and warm days and nights had been increasing all over Turkey while cool days and cool nights had been decreasing. Zhang et al. (2005) investigated trends in Middle Eastern climate extreme indices from 1950 to 2003. They found that there were statistically significant and spatially coherent trends in temperature corresponding to a warming trend in the region. The statistical tests in the present study showed that the decreasing trend in the precipitation data was not significant. Similar results have been observed by Zhang et al. (2005) and Sensoy et al. (2008). Zhang et al. (2005) indicated that trends in precipitation were weak and were not very significant in general in the Middle East. Sensoy et al. (2008) explained that, except in western Turkey, the number of heavy precipitation days had been increasing in some parts of Turkey; however, the trend for annual total precipitation was decreasing. The increased temperatures may be attributed to global warming (Chen and Xu 2005), but the decrease in precipitation may be attributed to global change and possibly a decrease of water surface and the destruction of reservoirs, both resulting in drought, and the hydrological cycles. Since precipitation is a primary factor in the generation of streamflow, its spatial and temporal patterns were further analyzed. Both the parametric and nonparametric tests showed a decreasing trend in precipitation, but this could not explain whether the trend should be attributed to climate change or random fluctuation. Zhang et al. (2005) emphasized that precipitation in the Middle East exhibited increasing and decreasing trends and a lack of spatial coherency. The precipitation in the Büyük Menderes river basin is not uniformly distributed over time and space. During the wet seasons, the precipitation amount is high, whereas it is low in the dry seasons. The study area experiences a precipitation regime during the year, from October to May, with a peak in December. More than 70% of the total annual precipitation falls between October and May. During the dry season, from May to September, there is very little rain. The spatial distribution of the precipitation data shows that the basin area has become somewhat drier in the last 2 decades (Figure 3). The results correspond well with what has been reported by Bates et al. (2008), who emphasized that changes in precipitation are not linear in time, showing significant decadal variability, with a relatively wet period from the 1950s to the 1970s, followed by a decline in precipitation. Bates et al. (2008) demonstrated that the trend of annual precipitation amounts for the period of 1979-2005 in Turkey decreased, with a departure from the average of –3% to –15% per decade.

Climate change has exhibited a significant impact on regional hydrological cycles and water balance. Detecting the relationships among the climate parameters, the hydrologic cycle and anthropogenic impact are important for the sustainable management of water resources in the Büyük Menderes river basin. The annual streamflows of the main tributaries in the Büyük Menderes river basin showed a decreasing trend. Similar results were observed by Alcamo et al. (2007), who emphasized that there was evidence of a broadly coherent pattern, with some regions experiencing an increase in streamflow at higher latitudes and some experiencing a decrease in parts of southern Europe. Kahya and Kalaycı (2004) also indicated that the basins located in western Turkey display completely negative trends, suggesting a decrease in monthly mean streamflow. They concluded that the presence of trends in Turkish streamflow patterns may be attributed to the observed decreases in rainfall and, to some extent, to increases in temperature. The change of streamflow of the rivers in the Büyük Menderes river basin is closely related to the change of correlative climatic factors. Overall, the results in the present study reveal that there was no significant monotonic trend of precipitation in the basin. In other words, the trend was present, although the decreasing trend of precipitation was not significant. However, there was a highly significant increasing trend in temperature. Temperature increase resulted in a decrease in recharge to the rivers. Bates et al. (2008) indicated that trends in streamflow are not always consistent with changes in precipitation. This may be due to data limitations, the effects of human interventions such as reservoir impoundments, or the competing effects of changing temperature and precipitation. In the Büyük Menderes river basin, not only climate factors but also anthropogenic impacts have had a great influence on river discharge. The Akçay and Çine rivers provide water for domestic use to a rapidly increasing population. The increasing agricultural activities and changes in crop patterns also have a significant impact on river flow. Especially in the last 15 years in the basin, the crop pattern has changed from cotton planting to corn planting. Obviously, growing corn consumes more water in comparison to cotton agriculture.

Rising temperature and decreasing precipitation in the Büyük Menderes river basin leads to an intensification of the hydrological cycle, with drier dry seasons and wetter rainy seasons, and subsequently heightened risks of more severe and frequent floods and drought. Climate change in the basin also has serious impacts on the availability of water, as well as the quality and quantity of water that is available and reachable. Since the Büyük Menderes river basin has great productive farm lands, water plays a key role in the development of the region. The basin's agricultural sector is one of the sectors most damaged by climate change. Warmer temperatures lead to an increase in water evaporation, increasing the need for irrigation precisely as water becomes even less available. Shiklomanov (2003) indicated that water consumption for agriculture will increase from 2600 km^3 in 2000 to 3200 km^3 by 2025. Water use for agriculture and industry is significant to fuel economic growth, and competing demands from agriculture, industry, and households can cause conflict over water availability and use. In recent years, the Büyük Menderes river basin has struggled under existing water stress from pressures such as irrigation demand and water pollution. These pressures are significantly exacerbated by climate change, which for many areas results in an increasing temperature and decreasing rainfall, further reducing the availability of water for drinking, domestic use, agriculture, and industry. As these competing demands rise under the influence of climate change, effective management for water demands becomes necessary, specifically in the face of strong pressures to prioritize agricultural and industrial uses over other uses such as drinking supplies. The quality of water becomes a further concern in some regions of the Büyük Menderes river basin. Changes in the quantity or patterns of precipitation in the basin alter the route and residence time of water in the basin, thereby influencing its quality. Furthermore, frequent flooding in the winter raises water tables to the level at which agrochemicals and industrial wastes from soil leach into the groundwater aquifers.

The decision makers in the Büyük Menderes river basin should manage the risks posed by climate change. An adaptation strategy of the basin to climate impacts should be developed to minimize their effects. Irrigation districts should develop a formal water allocation policy that includes contingency plans for different degrees of water shortage. Under both normal and drought conditions, water allocation rules should be understood and accepted by water users. Water allocation decisions should be made at basin and system levels rather than at local distribution levels. Changes in irrigation planning should be taken into account to make water distribution systems less vulnerable to drought. Since the basin has prolonged droughts, decision makers should develop an early warning system that monitors changing conditions and triggers contingency plans at the first sign of water shortage, offering water managers and farmers the best chances of avoiding crop failure. Due to drought conditions, new farming techniques, such as precision irrigation, zero tillage, raised bed planting, and laser leveling of fields, should be suggested to water users to improve the productivity of water.

Conclusions

The consequences of climate change on water resources in the Büyük Menderes river basin in western Turkey, based on hydrology, temperature, and rainfall data from the past 45 years (1963-2007), were investigated. The parametric t-test and nonparametric Mann-Kendall test were used to find the long-term trends of the hydrological time series data. The following conclusions can be drawn from the present study:

(1) Analysis of temperature time series in the Büyük Menderes river basin revealed that the temperature exhibited a monotonic increasing trend during the past 45 years. The mean temperature for the period of 1963-1993 was 13.65 °C, while this value for the period of 1994-2007 was 14.54 °C. The temperature in the basin was increased by almost 1 °C. Both the results of the parametric t-test and of the nonparametric Mann-Kendall test indicated that the long-term monotonic trend in annual temperature was strong over time and statistically significant. According to the results of the Mann-Whitney test, the temperature time series data exhibited an obvious step change with a level of significance of 0.05. Temperature increase affects evapotranspiration, agricultural activities, the hydrological cycle, and drought severity in the river basin.

(2) The test results for the long-term trend of precipitation showed that the decreasing trend of precipitation was not statistically significant. The mean precipitation before the year 1992 was 83.21 mm, whereas it was 71.64 mm after the year 1992. The spatial distribution of the precipitation pattern in the basin showed that the precipitation amount was increasing in the 1970s, especially in the coastal Aydın region. The amount of rainfall started falling below average in the 1980s. Significant water stress began to appear in the 1990s, in which there was a significant loss in precipitation amount in the Aydın region. Analysis of the precipitation time series during the past 45 years revealed that there was no significant interannual variability. However, the precipitation over the basin was distributed unevenly in space and time. This affects the seasonal distribution of the river flow in the Büyük Menderes river basin. Recently, frequent drought and flood seasons have been monitored in the basin.

(3) The streamflow of the Çine and Akçay tributaries showed a decreasing trend, especially during the period of 1985-1998. The results of the t-test and Mann-Kendall test for the Akçay River showed a decreasing trend with a 5% level of significance. The Mann-Kendall test results for the Çine River indicated that the decreasing trend of streamflow data was not significant with a 5% level of significance. The decreasing trend of streamflow data in the tributaries had a strong correlation with changes in temperature and precipitation in the river basin. Not only climatic factors but also human interventions have influences on the discharges of the rivers. Increasing demand for irrigation water, changes in crop patterns, and increases in population are the main sources of negative impacts on the discharges of the rivers.

References

Alcamo J, Moreno JM, Nováky B, Bindi M, Corobov R, Devoy RJN, Giannakopoulos C, Martin E, Olesen JE, Shvidenko A (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Eds. ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson), Cambridge University Press, Cambridge, UK, pp. 541-580.

Arnell NW (1999) Climate change and global water resources. Global Environmental Change 9: S31-S49.

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP, Eds. (2008) Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, p. 210.

Bou-Zeid E, El Fadel M (2002) Climate change and water resources in Lebanon and the Middle East. Journal of Water Resources Planning and Management 128: 343-355.

Burn DH, Hag Elnur MA (2002) Detection of hydrologic trends and variability. Journal of Hydrology 255: 107-122.

Chen YN, Xu ZX (2005) Plausible impact of global climate change on water resources in the Tarim River Basin. Science in China Series D: Earth Sciences 48: 65-73.

Chen Y, Li W, Xu C, Hao X (2007) Effects of climate change on water resources in Tarim River Basin, Northwest China. Journal of Environmental Science 19: 488-493.

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Rueda MV, Mearns L, Menendez CG, Raisanen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Eds. S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor, HL Miller), Cambridge University Press, Cambridge, UK, pp. 847-940.

Demir İ, Kılıç G, Coşkun M (2007) Türkiye ve bölgesi için PRECIS bölgesel iklim modeli çalışmaları. In: Proceedings of I. Türkiye İklim Değişikliği Kongresi, TİKDEK 2007, İTÜ, İstanbul, Turkey, pp. 252-260.

Fujihara Y, Tanaka K, Nagano T, Watanabe T, Kojiri T (2007) Assessing the impact of climate change on the water resources of the Seyhan river basin, Turkey. In: Proceedings of the International Congress River Basin Management, Vol. 1, Antalya, Turkey, pp. 453-463.

Gadgil A, Dhorde A (2005) Temperature trends in twentieth century at Pune, India. Atmospheric Environment 39: 6550-6556.

Ghahraman B (2006) Time trend in the mean annual temperature of Iran. Turkish Journal of Agriculture and Forestry 30: 439-448.

Gough WA, Cornwell AR, Tsuji LJS (2004) Trends in seasonal sea ice duration in southwestern Hudson Bay. Arctic 57: 299-305.

Helsel DR, Hirsch RM (1992) Statistical Methods in Water Resources. Elsevier, Amsterdam.

Hipel KW, McLeod AI (1994) Time Series Modelling of Water Resources and Environmental Systems. Elsevier, Amsterdam.

Hirsch RM and Slack JR (1984) Non-parametric trend test for seasonal data with serial dependence. Water Resources Research 20: 727-732.

IPCC (2007) Climate Change 2007: Impacts, Adaptation, and Vulnerability (Eds. ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson). Cambridge University Press, UK.

Kahya E, Kalaycı S (2004) Trend analysis of streamflow in Turkey. Journal of Hydrology 289: 128-144.

Loukas A, Vasiliades L, Tzabiras J (2007) Evaluation of climate change on drought impulses in Thessaly, Greece. European Water 17/18: 17-28.

Mann HB (1945) Nonparametric test against trend. Econometrica 13: 245-259.

Mengu GP, Sensoy S, Akkuzu E (2008) Effects of global climate change on agriculture and water resources. In: Proceedings of Third International Conference BALWOIS, Ohrid, Republic of Macedonia, pp. 1-10.

Mizyed N (2009) Impacts of climate change on water resources availability and agricultural water demand in the West Bank. Water Resources Management 23: 2015-2029.

Ozkul S (2009) Assessment of climate change effects in Aegean river basins: the case of Gediz and Buyuk Menderes Basins. Climatic Change: doi 10.1007/s10584-009-9589-z.

Önöz B, Bayazıt M (2003) The power of statistical tests for trend detection. Turkish J Eng Env Sci 27: 247-251.

Sensoy S, Demircan M, Alan I (2008) Trends in Turkey climate extreme indices from 1971 to 2004. In: Proceedings of Third International Conference BALWOIS, Ohrid, Republic of Macedonia, pp. 1-9.

Shiklomanov IA (2003) World Water Resources at the Beginning of the 21st Century. Cambridge University Press, Cambridge, UK.

Trenberth KE, Dai AG, Rasmussen RM, Parsons DB (2003) The changing character of precipitation. Bulletin of the American Meteorological Society 84: 1205-1217

Xu ZX, Takeuchi K, Ishidaira H (2003) Monotonic trend and step changes in Japanese precipitation. Journal of Hydrology 279: 144-150.

Zhang X, Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N, Kutaladze N, Rahimzadeh F, Taghipour A, Hantosh TH, Albert P, Semawi M, Ali MK, Al-Shabibi MHS, Al-Oulan Z, Zatari T, Khelet IAD, Hamoud S, Sagir R, Demircan M, Eken M, Adiguzel M, Alexander L, Peterson TC, Wallis T (2005) Trends in Middle East climate extreme indices from 1950 to 2003. Journal of Geophysical Research 110: doi 10.1029/2008JD011010.