Carpathian Journal of Earth and Environmental Sciences, May 2015, Vol. 10, No. 2, p. 77 - 84

SEASONAL AND ANNUAL PRECIPITATION TRENDS IN TURKEY

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Abstract: The Mediterranean Basin is a region where global climate change will be most evident. Located in the Eastern Mediterranean Basin, Turkey is a potential area of risk, too. Climate change will significantly affect the high precipitation variability in the Mediterranean Basin. This study used seasonal and annual precipitation data from 1975-2008 from 83 meteorology stations to identify the precipitation trends in Turkey. Seasonal and annual precipitation analysis is performed with two types of statistical analyses. First, the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and, secondly, the slope of a linear trend is estimated with the nonparametric Sen's method. These analyses revealed a decreasing trend in all seasonal and annual precipitation other than those in autumn, during which an increasing trend prevails throughout the country. While the northern coast of Turkey seems to have an increased precipitation trend other than in summer, a decrease can be observed in southern and central regions. The overall semi-arid qualities of these regions where precipitation rates fall call for a sustainable irrigation management.

Keywords: Turkey, precipitation trend, climate change, Mann-Kendall test, Sen's slope test

1. INTRODUCTION

It is a scientifically shown fact that greenhouse gas emissions caused by human activity lead to increased global mean surface temperatures and global climate change. The IPCC 4th Assessment Report (IPCC, 2007) shows that global mean surface temperature has increased by 0.74°C between 1906-2005. The last 50 years witnessed extensive changes in extreme temperatures throughout the world, and the increase in atmospheric water vapour due to warming has led to changes in the frequency and severity of precipitation. The regional and temporal changes observed in climatic elements will likely continue in the future. The latest report by the IPCC issued in September 2013 states that no ten-year global surface temperature noted ever since 1850 was higher than the last 30 years and that the period between 1983-2012 is probably the warmest 30-year period of the last 1,400 years in the Northern Hemisphere. All scenarios for the end of the 21st century envision a higher global surface temperature change from the 1850's by 1.5°C (IPCC 2013). Various modelling results given in the IPCC 4th Assessment Report predict an increase between 1.1 and 6.4°C in mean surface temperature from 1980-1999 to 2090-2099, as well as a decrease in precipitation as one moves closer to the poles but an increase in it in most subtropical lands (by 20% in 2100). More extreme temperatures, heat waves, severe precipitation and tropical storms are all envisioned.

The Mediterranean Basin is a region that will be most severely affected by global climate change. Several studies conducted in the region have found significant changes in precipitation trend analyses and model output, and foresaw an acceleration in the severity and frequency of these changes.

Global precipitation was relatively stable, or slightly increased from 1900 to the early 1940s. It then increased sharply from the mid-1940s to the mid-1950s and has stayed relatively high since then throughout most areas except the tropics where land precipitation went below the 1900–1988 mean in the 1970s and 1980s. The 40°– 60°N increasing trend is most pronounced in March– May precipitation, whereas the 0°–20°N decreasing trend is most evident in June–August precipitation and least in December–February (Dai et al., 1997).

Goubanova & Li (2007) analyzed the changes in extreme precipitation and temperatures in the Mediterranean Basin by using global modelling. They found that the Mediterranean and Southern Europe are characterized by a significant decrease in winter, spring and summer precipitation. An increase prevails in extreme precipitation in all seasons other than summer. Overall, it is predicted that severe precipitation is on the increase, total precipitation is on the decrease, and a warmer climate will prevail in the Mediterranean Basin.

Hertig & Jacobeit (2008) analyzed the precipitation changes due to increased greenhouse gases in the Mediterranean Basin between 1990-2100 by using the statistical scale minimizing technique. A shorter but wetter wet season is predicted for the western and northern Mediterranean regions, including precipitation increases in winter and decreases in the transitional seasons for the period 2071–2100 compared to 1990–2019. Eastern and southern Mediterranean exhibit mainly negative precipitation changes from October to May due to increased greenhouse gases.

Kotroni et al., (2008) analyzed "current" climate (1961-1990) simulations by using the regional climate change model PRECIS. It was found that the model underestimates seasonal rainfall during DJF and SON, mainly in the stations of the Mediterranean coast which receives most of its annual rainfall during autumn and, mainly, winter. It is worth noting that, during JJA, the model was able to quite efficiently reproduce seasonal rainfall in central Balkans which receives as much rain in summer as in winter.

Longobardi & Villani (2010) analyzed precipitation time series over a wide time interval and region, detecting potential trends and assessing their significance. For this purpose, 211 gauged stations mainly within the Campania region in southern Italy were analysed for the period 1918–1999. Statistical analysis of the database highlighted that the trend appears predominantly negative, both on an annual and seasonal scale, except for summer when it appears to be positive. For the entire reference period, positive and negative trends are significant for 9% and 27% of all stations, respectively, and a negative trend is instead significant for 97% of all stations over the last 30 years.

Türkeş et al., (2007, 2009) studied precipitation series and found a significant decreasing trend for winter precipitation, and an overall increasing trend for spring, summer and autumn precipitation.

Demir et al., (2008a) researched precipitation, maximum and minimum and mean temperature trends in Turkey, and concluded that a slight increase was the case in precipitation in Black Sea and Eastern Anatolian Steppe regions, whereas a slight decrease was the case in the Mediterranean, Mediterranean Transitional and Mediterranean Steppe regions. Throughout Turkey, significant changes in precipitation are most evident during winter.

Demir et al., (2008b) emphasize in their estimations for 2071-2100 in Turkey made with the Precis climate model that precipitation will decrease from east to west. In winter, precipitation will fall in the south and west. This will be reversed in summer. Regarding water budget, snow thickness will fall in Eastern Anatolia and Eastern Black Sea.

Önol et al., (2009) found an increase in winter precipitation along the Eastern Black Sea mountain range in an analysis based on evidence from 1961-1990 by using the RegCM3 model and the A2 scenario by the IPCC. Serious decreases occurred in winter precipitation in Turkey’s Aegean, Mediterranean and Southeastern Anatolian regions (between 20% and 50%).

Partal & Kahya (2006) indicated, from monthly precipitation variables, that January, February and particularly September were found to have strong decreasing trends, as opposed to other months showing either a positive or negative trend in fewer stations. The results of trend analyses 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 Turkey, but several upward trends were found in central Turkey.

2. DATA AND METHOD

This study utilized data obtained between 1975-2008 from 83 Turkish meteorological stations analyzed for homogeneity (Fig. 1). The sums of monthly mean precipitation rates of these stations yielded seasonal and annual mean precipitation.

Seasonal and annual precipitation is studied by two types of statistical analyses. First, the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and, secondly, the slope of a linear trend is estimated with the nonparametric Sen’s method. To this end, a program developed by the Finnish Meteorological Institute was used (Salmi et al., 2002). The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series with no seasonal or other cycle. The Sen’s method uses a linear model for the trend.

Figure 1. Distribution of study stations (BSR: Black Sea Region, MR: Marmara Region, ER: Aegean Region, MEDR: Mediterranean Region, CAR: Central Anatolian Region, EAR: Eastern Anatolian Region, SEAR South-eastern Anatolian Region)

2.1. Mann-Kendall Test

Possible decreasing and increasing precipitation trends were identified by using the Mann-Kendall test (Mann, 1945; Kendall, 1975). As it is a non-parametric test, it is independent of the distribution of random variables. The test checks whether there is a trend in a time series by using the null hypothesis; ": no trend" (Bayazıt, 1996). In the time series where the test is to be used, pairs are divided into two groups. In the time series x_1, x_1... x_n, where the test will be performed, x_i, x_j pairs are divided into two groups. If the number of pairs where $x_i<x_j$ for i<j is shown by P, and the number of pairs where $x_i>x_j$ is shown by M, the test statistics can be defined as S=P-M. Kendall correlation coefficient:

$$\tau = \frac{S}{\frac{n(n-1)}{2}}$$

For n≥10, μ_s=0 and

$$\sigma = \sqrt{\frac{[n(n-1)(2n+5)-\sum t_i(t_i-1)(2t_i-5)]}{18}}$$

Here, the number of reobservations in the r data set show the observations repeated in a series where the t_i value is of i length. Thus, the distribution of the statistics defined as below is standard normal distribution.

$$Z = \begin{cases} (S-1)/\sigma_s \text{ if } S>0 \\ 0 \quad\quad \text{if } S=0 \\ \frac{S+1}{\sigma_s} \quad \text{if } S<0 \end{cases}$$

If the α which is the absolute value of *Z* calculated as above is smaller than the $Z_{a/2}$ of the normal distribution value corresponding to the selected significance level, the null hypothesis is accepted and the conclusion follows that there is no trend in the examined time series. If the value is bigger, a trend is existent. A positive S value indicates an increasing trend while a negative one indicates a decreasing one. It is particularly convenient as the data are not required to fit a certain distribution (Yue et al., 1993).

2.2. Sen's Trend Method

If a linear trend exists in the series, real trend (change in unit time) can be reached with a non-parametric method that is not affected by data errors or extreme values and that can be conducted on records with missing data (Sen 1968, Yu et al., 1993). Here, provided that the data at times j and k are x_j and x_k Where $k_{(j>k)}$

$$N = \frac{n(n-1)}{2} \text{ (n: number of time periods)}$$

$$Q_i = \frac{(x_j - x_k)}{j-k} \text{ (i=1,...,N)}$$

values are calculated and are ordered from low to high. The Sen's estimator of slope is the median of these N values of Q_i. When N is an odd number, equation

$Q=Q_{(N+1)/2}$ is used, and when it is an even number

$Q=1/2$ ($Q_{[N/2]}+Q_{[(N+2)/2]}$ is used to find the change of observations in unit time. The Q_{median} value found is tested with a bidirectional test in the confidence interval 100(1-α)% by using a non-parametric technique proposed by Sen in order to make decisions about the real trend (Yu et al., 1993, Kalaycı & Kahya, 1998). Practically, the Q_{median} values between -0.01 and 0.01 were taken as zero in this study. The trends were tested in two different confidence intervals at the levels 99% and 95%.

3. RESULT

3.1. Seasonal Precipitation Trends

Figure 2 shows that precipitation tends to decrease throughout most of Turkey. A decreasing trend was found in 64 stations, and an increasing one in 17. No trend was observed in 2 stations (Sivrihisar & Bursa). Stations with an increasing trend were mostly located in the Marmara region and coastal Central and Eastern Black Sea. However, the trend for the increase was not significant in any station but Sinop, where a significant increase existed at the level 0.05. In winter, there are non-significant decrease trends throughout Turkey. This trend is significant in Ağrı, Elazığ and Alanya at the level 0.01, and in Konya and Kırşehir at the level 0.05 (Fig. 2).

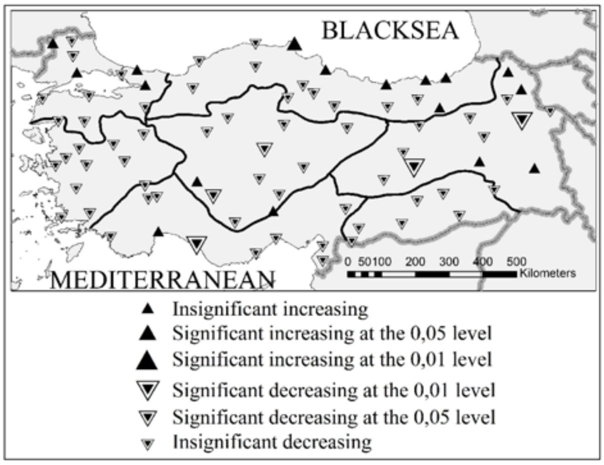

Figure 2. Winter precipitation trends according to the Mann Kendall test

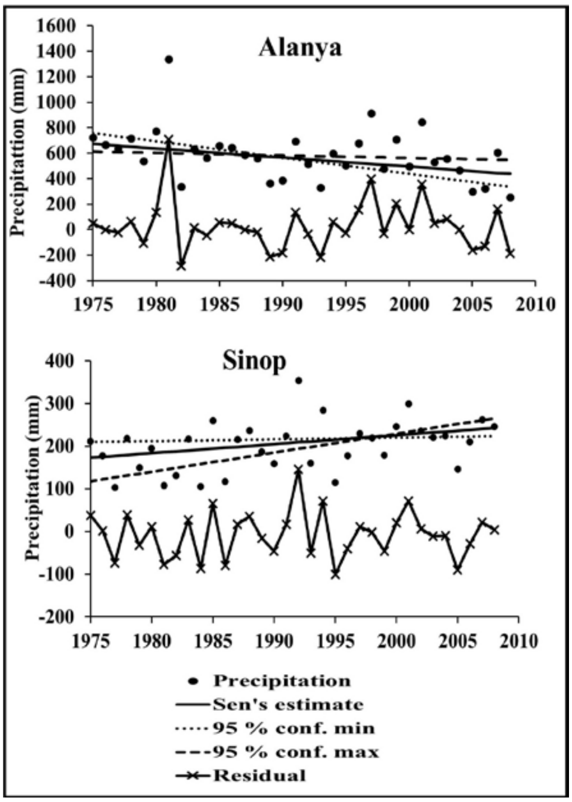

Figure 3. Winter precipitation trends of Alanya and Sinop according to the Sen's method

The figure drawn in accordance with Sen's results obtained in Alanya, which has a strong decrease trend, reveals an expansion in precipitation data band from 1995 onwards and represents the randomness in precipitation data (Fig. 3). On the other hand, a significant precipitation increase can be observed in Sinop. Shrinking residual values after 2000 shows the consistency of the estimation.

The spring precipitation trend in coastal Black Sea, North-eastern Anatolia and to the west of Bursa-Antalya is increasing, albeit insignificantly. The increasing trend is prevalent in 28 stations, but is only significant in Ardahan (at level 0.05).

Outside these areas (55 stations), spring precipitation displays an insignificant decreasing trend on the whole (Fig. 4). However, it is worth noting that even though annual precipitation is low, spring instability precipitation is high and a significant decrease is observed in southern Central Anatolia and Malatya at the level 0.05.

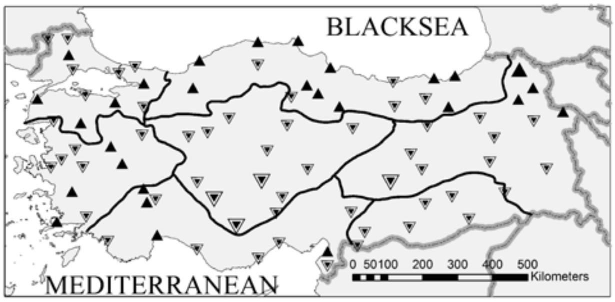

Figure 4. Spring precipitation trends according to the Mann Kendall test (See Figure 2 for explanations)

According to Sen's test results, it is understood that the slope estimator for Ardahan (Q value) is -1.858, and small residual values indicate the accuracy of model estimations except for 1990-1995(Fig. 5).

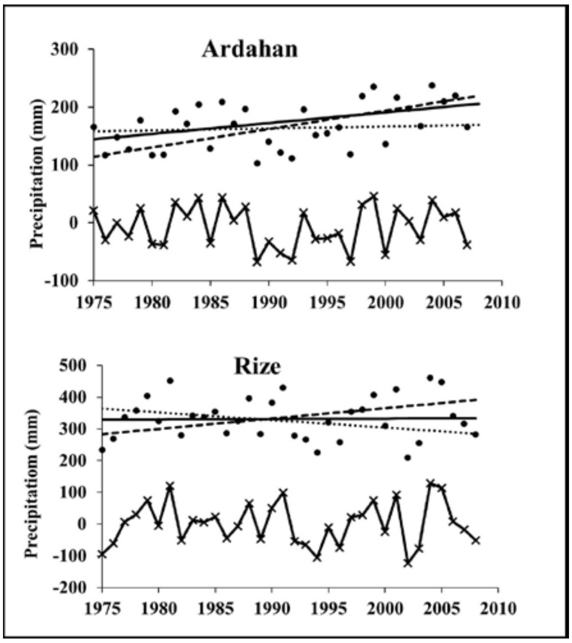

Figure 5. Spring precipitation trends in Ardahan and Rize according to the Sen's method)See Figure 3 for explanations)

The decrease in precipitation data after 1995 is notable. Rize's estimator value of 0.135, i.e. high residual values in the model, indicate the randomness of the increase in precipitation (Fig. 5).

No significant clustering is evident in the distribution of precipitation trends in Turkey in the summer. An increasing trend is seen in 27 stations. These stations are located mostly in Central Black Sea and North-eastern Central Anatolia, Eastern Mediterranean and South-eastern Anatolia. The increase was insignificant in all stations where an increasing precipitation trend was observed. Precipitation rates are falling in most of Eastern Anatolia and the Aegean and the southern parts of Southern Marmara and Central Anatolia. This trend was seen in 52 stations. A significant decreasing trend was evident in Tekirdağ, Simav & Bodrum at the level 0.05. An increasing trend, on the other hand, existed in North-eastern Anatolia, northern part of Central Anatolia, and most of the Mediterranean and South-eastern Anatolia, though not significant (Fig. 6).

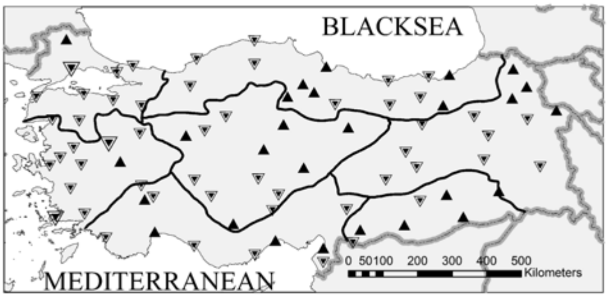

Figure 6. Summer precipitation trends according to the Mann Kendall test (See Figure 2 for explanations)

Owing to the precipitation characteristics of the Mediterranean climate, variability is high during summer. The differences that exist between the residual values of the two stations examined and the estimations of the model are evidence for this variability. Further, the expansion in the precipitation band in Tekirdağ after 1995 shows that variability is on the rise. Antalya, on the other hand, is a station where summer precipitation displays an increasing trend. Even though insignificant, an increase in summer precipitation may be taken as an indicator of heavier showers and floods (Fig 7).

When compared to the other seasons, autumn is different regarding the direction and distribution of the trend. A decreasing trend in precipitation prevails in autumn in Iğdır, Ağrı, Hınıs and Muş in the Eastern Anatolia region; in Siirt and Mardin in the South-eastern Anatolian region; in the triangle between Antalya, Konya and Karaman; around Manisa-Simav in the Aegean region; and in Lüleburgaz in Thrace. However, this trend is not significant. In other stations, the trend is for an increase (69 stations). Particularly in coastal Black Sea and North-eastern Anatolia, there are significant precipitation increases (Fig. 8). Autumn is noted for the big number of stations that only display an increase in precipitation. Of the 69 stations where an increase was noted, 41% experienced it only in autumn.

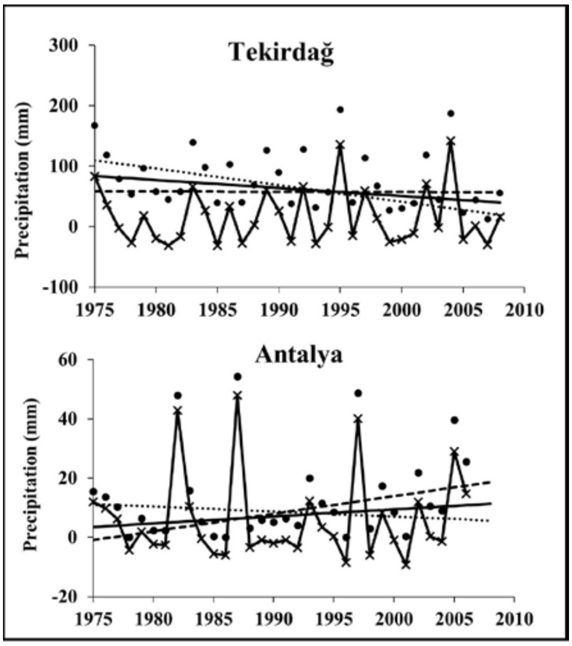

Figure 7. Summer precipitation trends in Tekirdağ and Antalya according to the Sen's method (See Figure 3 for explanations)

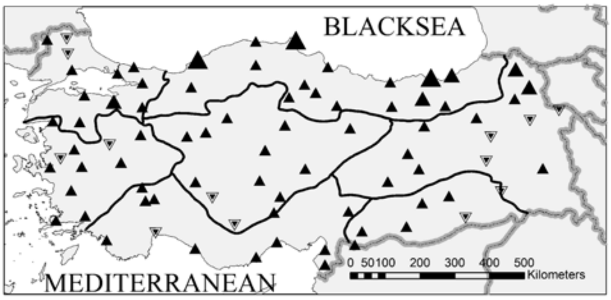

Figure 8. Autumn precipitation trends according to the Mann Kendall test (See Figure 2 for explanations)

Figure 9 presents Sen's test results for Trabzon where a significant increase was found at level 0.01 and in Fethiye where an insignificant increase was seen. While precipitation in Trabzon was clustered around Sen's estimator, huge differences existed in Fethiye between Sen's estimator and precipitation distribution. This is also evident from the size of the residual. Such a distribution reveals that the increase in Fethiye was random.

3.2. Annual Precipitation Trends

Annual precipitation in Turkey displays an increasing trend in central and eastern Black Sea and

North-eastern Anatolia, and in the Şile-Antalya line in Western Anatolia. Even though several other stations also display a trend for increase, they are not clustered. Sinop, Rize and Kars display significant increase at level 0.05, and Giresun and Ardahan at level 0.01. On the other hand, decreasing precipitation was noted in 52 stations (63%). These were focussed in Southern and Western Black Sea (Fig. 10).

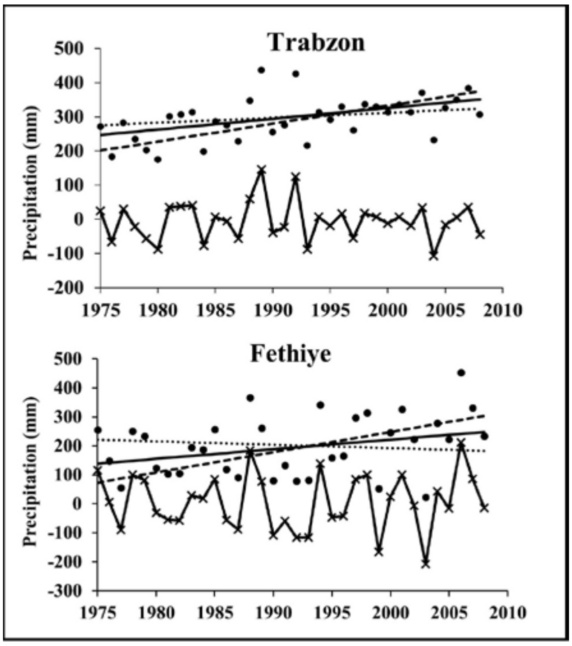

Figure 9. Autumn precipitation trends in Trabzon and Fethiye according to the Sen's method (See Figure 3 for explanations)

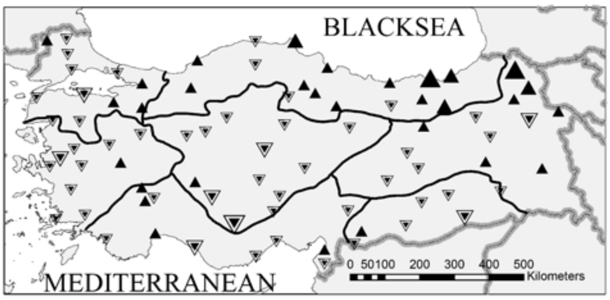

Figure 10: Annual total precipitation trends according to the Mann Kendall test (See Figure 2 for explanations)

4. DISCUSSION

According to the results of the study, the 7 stations that display an increasing precipitation trend in all seasons are clustered in the Black Sea coastal belt and North-eastern Anatolia. These stations are Ardahan, Kars, Bayburt, Rize, Samsun, Sinop and Kocaeli. These are the wettest regions in the country. On the other hand, there were only 4 stations with decreasing precipitation in all seasons (Manisa, Konya, Ağrı and Hınıs) and there was no spatial correlation in their distribution.

This study identified a decrease in winter precipitation in places other than the Black Sea coastal belt. Of the stations examined, 77% displayed a decreasing trend. This finding is in accord with those of Goubanova & Li (2007), Partal & Kahya (2006), Türkeş et al., (2007, 2009), Demir et al., (2008a, 2008b), Önol et al., (2009). In spring, 67% of Turkey experiences a decreasing trend, except the insignificant increases in the Black Sea coastal belt and Western Anatolia. A significant decrease was found in this season, particularly in Southern Central Anatolia. In summer, 33% of the stations display an increasing trend. This is most evident in the driest parts of the country, other than North-eastern Anatolia. Most studies on the precipitation trends in Turkey suggest an increase in autumn precipitation. In this study too, an autumn increase was noted in 83% of the stations examined (69 stations). The increase in precipitation only occurred in autumn in 41.4% of the stations that revealed an increase (28 stations). The trends in total annual precipitation in Turkey show that stations with an increasing trend focus in coastal Black Sea and North-eastern Anatolia. Outside these areas, 64% of the stations display insignificant decreasing trends. The decrease becomes significant particularly in semi-arid regions.

5. CONCLUSION

Owing to its location, Turkey's precipitation regime includes more precipitation in the cold season, and decreasing precipitation and meteorological drought in the hot season. Therefore, changes in seasonal precipitation distribution may have serious ecological outcomes.

As Turkey's Mediterranean coast lies in a macroclimate zone, winter is the wettest season. The 40% precipitation rate in winter and the majority of this being snowfall, especially in high altitudes, plays a major role in feeding ground and surface water sources, and meeting the water needs of agriculture and industry. If Turkey's winter precipitation falls, so will the effectiveness of the South-eastern Anatolian Project, a major electricity and irrigation initiative. At the same time, having the stations with the steepest decrease in Eastern Turkey may lead to international problems by affecting the regime of rivers that flow across borders, such as the Tigris and Euphrates. Throughout most of Turkey, spring is the second wettest season after winter. Together, decreased precipitation in these two seasons will lead to even more serious problems. If the trend continues, the problems will be exacerbated. The decreasing trend in spring will have a particularly negative effect on the instability precipitation in semi-arid regions. In many stations with increased precipitation, summer is the driest season. In summer, increased precipitation in places such as South-eastern and Central Anatolia will lead to increased showers, which will in turn cause land erosion and sudden floods. Considering the role of autumn with its high precipitation rate in annual precipitation, it is obvious that any increase in this season will not compensate for the decrease in winter and spring. Therefore, the water deficiency in the land due to decreased precipitation will not be compensated for by an increase in this season.

The decreasing trend in annual precipitation, particularly in the semi-arid regions of Turkey (Central and South-eastern Anatolia) will cause serious ecological problems. The decrease in semi-arid regions calls for more agricultural irrigation in these areas. This may lead to the emergence of ecologically problematic projects such as importing water from different basins (such as drawing water from River Manavgat to irrigate the Çumra Plain) and end up with more water withdrawal from the ground. The number of resulting collapse dolines, particularly to the south of Central Anatolia will rise. In response to these problems, new techniques need to be launched in agriculture where water is most precious; the produce pattern needs to be varied; and drawing ground water from illegal wells must be stopped.

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Received at 18. 08. 2014
Revised at: 12. 12. 2014
Accepted for publication at: 03. 03. 2015
Published online at: 26. 03. 2015