Multi-annual analysis and trends of the temperatures and precipitations in West Anatolia
Turgay Partal

ABSTRACT
This study has been carried out to analyze the historical precipitation and temperature data for West Anatolia (Turkey) to understand the annual and multi-annual changes. The wavelet transform technique was used for time–frequency representation of the data. The trends in the data were estimated with the non-parametric Mann–Kendall test. A change point in the time series was determined by the Pettitt test. According to the wavelet analysis, some strong short-term periodical events at the scale levels of 1–4 were determined. The application of the Mann–Kendall test resulted with the identification of some decreasing trends in the observed annual precipitations and also in some periodic components, such as in 32 yearly periodic components. As well, 16 yearly periodic components of the temperature data showed very strong increasing trends at the 5% significance level.

Key words | Mann–Kendall test, Pettitt test, precipitation, temperatures, Turkey, wavelet analysis

INTRODUCTION
Multi-decadal analysis of hydro-climatic time series (such as precipitation, temperatures, etc.) is of great importance because many scientists are working to prove the existence of climate change. This is also crucial for determining the long-term needs of water management.

Non-stationarities in hydro-climatic data are essentially present to past climate changes (Koutsoyiannis 2005). Razavi et al. (2015) indicate that stationarity might never have existed in the nature of climate processes. Therefore, the statistical parameters such as mean and variance change continuously with time. At this point, trend analysis is generally used to determine the non-stationary and changes in time series.

Previous studies generally used the Mann–Kendall test to determine the existence of trends and climate change (Zhang et al. 2000; Burn & Elnur 2002; Ma et al. 2008; Tabari et al. 2011; Gocic & Trajkovc 2013; Westra et al. 2013). Partal & Kahya (2006) identified the regions of West and South Anatolia (Turkey) as an area of significant decreasing trends. They analyzed Turkish annual mean precipitation data for 91 stations with a recording length period from 1929 to 1993. Kahya & Kalayci (2005) investigated decreasing trends in the streamflow data of West Anatolia. Türkeş (1996) investigated some significant decreasing trends in Turkey’s rainfall data. Kadioglu (1997) investigated some increasing trends in Turkey’s temperature data. Previous studies summarize that the trends investigated in the precipitation data of West Turkey are generally downward.

There has been growing interest about wavelet transform in hydrology (Drago & Boxall 2002; Coulibaly & Burn 2004; Ozger et al. 2010). Wavelet transform was studied to investigate the possible trends in recent studies (Pisoft et al. 2004; Adarsh & Janga Reddy 2014; Paul & Birthal 2016). Partal & Küçük (2006) suggested wavelet trend analysis, which combines the discrete wavelet transformation and the Mann–Kendall (M-K) test. They show that certain periodical components are mainly responsible for the trends determined in the observed data. The purpose of

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Nalley et al.’s (2012) study was to determine trends in the average streamflow and precipitation data over Canada by wavelet analysis and M-K tests. Their results showed that inter-annual events are significant in the observed trends. Zhang & Liu (2013) researched changes in some hydrological variables such as flows, blue water and green water in Northwestern China using wavelet and M-K trend analysis. They found increasing trends from 1960 to 2010 throughout Northwestern China. On the other hand, the relation between trends and long-term periodicity of hydro-climatic records is an important study point. Some studies describe the influences of long-term periodicities on trends in hydrological data (Bordi et al. 2009; Stojković et al. 2014). Bordi et al. (2009) found that long-term periodicity of monthly precipitation in Europe was characterized by a negative trend. Stojković et al. (2014) showed that the downward trends in streamflow data of the Danube River Basin are influenced by the long-term periodicity of annual streamflows. Hanna- ford et al. (2013) presented a detailed study on decadal-scale variability of long-term trends in European streamflow data. Their research emphasizes that the power and direction of short-term trends are heavily influenced by interdecadal variability.

This study aims to determine the periodicities and investigate trends in the precipitations and temperatures of West Anatolia in Turkey, which has the most highly populated and industrialized cities, using wavelet trend analysis. The findings of this study were compared with the findings of past studies. As well, western Turkey precipitation data were analyzed to determine their characteristics in long-term changes. Also, the temperature data of western Turkey were investigated by wavelet-based trend analysis. The long-term periodical relationships between precipitation and temperature data were determined. Lastly, the wavelet components of the precipitation and temperature were analyzed in association with some global indices. The Pettitt test was also used to determine a main change point in the time series.

**CASE STUDY**

The precipitation data used in this study, which consist of eight stations in West Anatolia in Turkey, is for the period of 1929 to 2008. The annual mean temperature data employed in this study for 55 years, extending from 1951 to 2005. These data are collected and managed by the Turkish State Meteorological Service. The locations of the stations are shown in Figure 1 and the main features of the data are presented in Table 1. West Anatolia has the most highly populated and industrialized cities in Turkey, such as Izmir, Istanbul, and Bursa. This region lies between the Mediterranean Sea, the Aegean Sea, and the Black Sea. The coastal areas of the region are generally

![Figure 1 | Location of the stations.](https://iwaponline.com/jwcc/article-pdf/8/3/456/375495/jwc0080456.pdf)
associated with a Mediterranean climatic type (a subtropical climatic regime with a moist and rainy winter and a hot dry summer). On the other hand, the interior parts of the region have a continental climate type with hot summers and cold winters.

The mean of the annual total precipitation for Turkey is 646 mm. The mean annual precipitation at İzmir station is 686.7 mm, while the mean annual total precipitation at Bursa station is 692 mm (Table 1). For this study, the highest average annual total precipitation is at Muğla station (925.5 mm), while the minimum of the average annual total precipitations is at Eskisühir station (332.5 mm). The highest average annual temperature is at İzmir station (17.8 °C), while the lowest average annual temperature is at Eskisühir station (10.9 °C).

### METHODS

#### Mann–Kendall test

Most of the trend analysis on hydro-meteorological data is based on the nonparametric Mann–Kendall test. The test is based on a rank-based procedure, therefore, normality of the distribution is not required (Lins & Slack 1999).

The Mann–Kendall’s statistic $S$ is calculated as follows (Douglas et al. 2000):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k)$$  \hspace{1cm} (1)

where $n$ is the number of a data sample, $x_k$ and $x_j$ are the data values in time series $k$ and $j$ ($j > k$). Variance of $S$ which is asymptotically normally is computed as below:

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \Sigma_t(t-1)(2t+5)}{18}$$  \hspace{1cm} (2)

Here, $t$ is the extent of any given tie and $\Sigma_t$ denotes the summation over all ties. Then, the standard normal variable $z$ (with zero mean and unit standard deviation) is computed as (Douglas et al. 2000):

$$z = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases}$$  \hspace{1cm} (4)

A positive value of $z$ indicates an increasing trend while a negative value of $z$ indicates a decreasing trend. Statistical significance of $z$ is evaluated by the critical $z$ value at the $\alpha$ level of significance. The critical value at the 0.05 significance level is ±1.96, while the critical value at the 0.10 significance level is ±1.64.

The sequential values $z(t)$ obtained from the progressive analysis of the Mann–Kendall test show change of $z$ with time. Calculation of $z(t)$ is the same as the $z$ values

<table>
<thead>
<tr>
<th>Stations</th>
<th>Average of the annual total precipitations (mm)</th>
<th>Average of the annual mean temperatures (°C)</th>
<th>Average elevation (m)</th>
<th>Lag 1 autocorrelation – precipitation</th>
<th>Lag 1 autocorrelation – temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muğla</td>
<td>846</td>
<td>14.9</td>
<td>646</td>
<td>0.22</td>
<td>0.06</td>
</tr>
<tr>
<td>İzmir</td>
<td>686</td>
<td>17.8</td>
<td>30</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Aydın</td>
<td>645</td>
<td>17.6</td>
<td>70</td>
<td>0.11</td>
<td>0.22</td>
</tr>
<tr>
<td>Manisa</td>
<td>846</td>
<td>16.9</td>
<td>42</td>
<td>0.14</td>
<td>−0.06</td>
</tr>
<tr>
<td>Edirne</td>
<td>589</td>
<td>13.6</td>
<td>48</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Bursa</td>
<td>692</td>
<td>14.4</td>
<td>100</td>
<td>0.13</td>
<td>0.04</td>
</tr>
<tr>
<td>Afyon</td>
<td>433</td>
<td>11.1</td>
<td>1,013</td>
<td>0.18</td>
<td>0.00</td>
</tr>
<tr>
<td>Eskisühir</td>
<td>332</td>
<td>10.9</td>
<td>732</td>
<td>−0.10</td>
<td>−0.00</td>
</tr>
</tbody>
</table>
calculated from the first to the last data point (Partal & Kahya 2006). The test statistic is computed as below:

\[ t_j = \sum_{i=1}^{j} n_j \quad (j = 2, 3, \ldots, n) \]  

(5)

\[ t_j \text{ is normally distributed and its statistics are given as:} \]

\[ E(t) = \frac{n(n-1)}{4} \]  

(6)

\[ \text{Var}(t_j) = \frac{j(j-1)(2j+5)}{72} \]  

(7)

The sequential values of \( z(t) \) are computed as below:

\[ z(t) = \frac{t_j - E(t)}{\sqrt{\text{Var}(t_j)}} \]  

(8)

**Wavelet transformation**

Wavelet transform is an effective and useful method for periodic analysis of hydro-climatic time series.

A wavelet function \( \psi(t,s) \) can be written as translation and dilation of a mother wavelet:

\[ \psi(t,s) = s^{-1/2} \psi\left(\frac{t-\tau}{s}\right) \]  

(9)

Here, \( t \) is time function, \( s \) is scale parameter, and \( \tau \) is the time translation (Meyer 1995). The continuous wavelet transform coefficients are obtained by the convolution of \( x(t) \) with \( \psi(t,s) \):

\[ W(t,s) = s^{-1/2} \int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-\tau}{s}\right) dt \]  

(10)

Here, \( \psi^* \) is the complex conjugates (Labat et al. 2000). \( W(t,s) \) presents a two-dimensional picture of wavelet power spectrum. The Morlet wavelet was used as the mother wavelet function in this study. The Morlet main wavelet presents a good definition of a signal in the spectral-space (Coulibaly & Burn 2004).

The discrete signals of the data can be determined by discrete wavelet transform (DWT). DWT is computed as:

\[ \psi_{m,n}(\frac{t-\tau}{s}) = s_0^{-m/2} \psi\left(\frac{t-n\tau_0 s_0^m}{s_0^m}\right) \]  

(11)

in which \( m \) is decomposition level and \( n \) is time translation factor. \( s_0 \) is a specified fixed dilation step greater than 1; and \( \tau_0 = 1 \) (Daubechies 1990). For a discrete time series \( x_i \), where \( x_i \) occurs at discrete time \( i \) (i.e., here integer time steps are used), the DWT becomes as below:

\[ W_{m,n} = 2^{-m/2} \sum_{i=0}^{N-1} x_i \psi(2^{-m} i - n) \]  

(12)

Here, \( W_{m,n} \) is wavelet coefficients for the DWT. DWT is the most efficient solution for practical purposes. The DWT process includes two types of coefficient sets, as an approximation series and a detail series at different scales. More details on DWT processing can be founded in Mallat (1989).

If the wavelet coefficients at each scale are summed throughout the length of a time series, the time-averaged wavelet spectrum, which is known as the global wavelet spectrum (GWS), is obtained (Torrence & Compo 1998). The GWS can be computed as:

\[ \overline{W^2}(s) = \frac{1}{T} \sum_{t=0}^{T-1} |W(t,s)|^2 \]  

(13)

where \( T \) is the number of points in the time series. The GWS is similar to the smoothed Fourier spectrum in many ways. The GWS shows effective periodic cycles in the time series and provides a consistent estimation of the power spectra.

**Pettitt test**

The Pettitt test developed by Pettitt (1979), was used to find the existence of a main change point in the time series. This test determines a significant change in the general tendency
of a time series. Test statistic, $K$ is given as:

$$K = \max_{1 \leq k \leq N} |U_k|$$

(14)

where $U_k$ is equivalent to a Mann–Whitney statistic using for testing two samples $(x_1, x_2, \ldots, x_k)$ and $(x_{k+1}, x_{k+2}, \ldots, x_N)$. $U_k$ can be acquired as below:

$$U_k = 2 \sum_{i=1}^{k} r_i - k(N + 1)$$

(15)

where $r_i$ is the rank of the $i$th observation. A change point occurs in the series where $U_k$ reaches a maximum (Tarhule & Woo 1998). If a change point exists, then $U_k$ increases up to this change point, then begins to decrease. This point may occur several times in a time series, indicating several local change points. Significance level of the $K$ value is computed approximately as:

$$K_{\alpha} = \left[ \frac{-\ln a(N^3 + N^2)}{6} \right]^{0.5}$$

(16)

If $K$ exceeds $K_{\alpha}$, then the change point is statistically significant.

### Wavelet-based analysis of precipitation data

**Methodological procedures**

The methodological procedures used in this study are essentially as follows:

1. Each of the observed time series was decomposed into an approximation (A) and more periodic components (D) by the DWT.
2. The Mann–Kendall test was applied on the observed data and the wavelet components (D, A).
3. The sequential values of the Mann–Kendall statistics ($z$) were computed and compared for the observed and the periodic series.
4. A change point of the observed annual precipitation time series was computed and presented by the Pettitt test.
5. The continuous wavelet transforms and GWS were applied to the observed precipitation series for understanding annual, decadal, and multi-decadal changes.

**Wavelet-based trend analysis of the precipitation data**

DWT presents an approximation series and a detail series at different scales. Thus, the wavelet components at different periods can be used for time series analysis. In this study, Mallat’s algorithm was used for obtaining discrete wavelet coefficients (Mallat 1989).

The observed data were decomposed into an approximation and five detail components. The detail components represent the 2-yearly periodicity (D1), 4-yearly periodicity (D2), 8-yearly periodicity (D3), 16-yearly periodicity (D4), and 32-yearly periodicity (D5) which is the lowest frequency component of the data. The approximation (A) component represents the approximation series at the fifth level of decomposition. Table 2 presents calculated correlation coefficients ($r$) between the observed data and the wavelet component for each station’s data. It can be seen that the D1 component shows the highest $r$ value among all stations.

### Table 2 | The correlations between wavelet components (D, A) and the observed precipitations for all the stations

<table>
<thead>
<tr>
<th></th>
<th>Mugla</th>
<th>İzmir</th>
<th>Aydın</th>
<th>Manisa</th>
<th>Edirne</th>
<th>Bursa</th>
<th>Aşaf</th>
<th>Eskişehir</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>0.62</td>
<td>0.72</td>
<td>0.71</td>
<td>0.70</td>
<td>0.75</td>
<td>0.69</td>
<td>0.69</td>
<td>0.78</td>
</tr>
<tr>
<td>D2</td>
<td>0.64</td>
<td>0.68</td>
<td>0.55</td>
<td>0.63</td>
<td>0.66</td>
<td>0.54</td>
<td>0.62</td>
<td>0.51</td>
</tr>
<tr>
<td>D3</td>
<td>0.62</td>
<td>0.51</td>
<td>0.50</td>
<td>0.47</td>
<td>0.45</td>
<td>0.44</td>
<td>0.47</td>
<td>0.30</td>
</tr>
<tr>
<td>D4</td>
<td>0.44</td>
<td>0.36</td>
<td>0.45</td>
<td>0.41</td>
<td>0.36</td>
<td>0.48</td>
<td>0.28</td>
<td>0.32</td>
</tr>
<tr>
<td>D5</td>
<td>0.22</td>
<td>0.17</td>
<td>0.25</td>
<td>0.29</td>
<td>0.20</td>
<td>0.35</td>
<td>0.32</td>
<td>0.37</td>
</tr>
<tr>
<td>A</td>
<td>0.12</td>
<td>0.09</td>
<td>0.26</td>
<td>0.29</td>
<td>0.14</td>
<td>0.20</td>
<td>0.34</td>
<td>0.36</td>
</tr>
</tbody>
</table>
After the wavelet decomposition, the M-K test was applied to the annual precipitation data. Table 3 presents the results of the M-K test. All of the observed precipitations have a decreasing tendency. Moreover, two precipitation stations showed a statistically significant decreasing trend: Afyon (\(z = -1.98\), significant at the 5% level) and Aydın (\(z = -1.80\), significant at the 10% level). These results are also consistent with those of Partal & Kahya (2006), who found significant downward trends in western Turkey precipitations, such as for Aydın and Afyon stations, with data spanning from 1929 to 1993. However, the significance of the decreasing trends found in the previous study seems to have slightly reduced. For example, the \(z\) values of the Aydın precipitation have changed from \(-2\) to \(-1.80\).

The M-K test was used to determine trends on wavelet series (D components) at different scales. Table 3 presents trend analysis results for eleven different combinations of the D components. It is interesting that only D5 (32-yearly trend analysis results for eleven different combinations of series (D components) at different scales. Table 3 presents the results of the M-K test. All of the observed precipitations have a statistically significant decreasing trend: Aydın (\(z = -1.98\), significant at the 5% level) and Afyon (\(z = -1.80\), significant at the 10% level). These results are also consistent with those of Partal & Kahya (2006), who found significant downward trends in western Turkey precipitations, such as for Aydın and Afyon stations, with data spanning from 1929 to 1993. However, the significance of the decreasing trends found in the previous study seems to have slightly reduced. For example, the \(z\) values of the Aydın precipitation have changed from \(-2\) to \(-1.80\).

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The M-K test was used to determine trends on wavelet series (D components) at different scales. Table 3 presents trend analysis results for eleven different combinations of the D components. It is interesting that only D5 (32-yearly periodicities) shows clearly stronger trends than the decreasing trends found in the observed data. For instance, the \(z\) value of the observed precipitations is \(-1.80\), while the \(z\) value of D5 is \(-5.52\) for Aydın. Generally, the D1, D2, and D3 components do not show a trend in any direction. Also, it is important to note that the approximation series (A) showed very strong decreasing trends at the 5% significance level. Namely, the approximations carry most of the trend component. As seen in Table 3, D1 + A presents the nearest trend values to the observed trend value for all the stations. Trend analysis on the periodic components shows that the D5 component can be seen as affecting the observed trend.

Figure 2 shows the sequential values of \(z(t)\) at Aydın station. It shows changes in sequential \(z(t)\) values of the observed data and the periodic components. The \(z(t)\) values for both the observed data and the D component are illustrated by solid and bold dashed lines, respectively. The sequential M-K values show that the decreasing tendency in the observed precipitations may visually have been starting at the beginning of the 1950s. It is seen from Figure 2 that the harmony between \(z\) values of D1 (with approximation) and the observed data is strong. As well, the sequential M-K values of D4 (with approximation) are very inharmonious with observed precipitation data. It is important to note that the fluctuations in the low periodic components such as D1 and D2 can be considered as noise and hardly reflect the significant periodic changes. Thus, these components without approximation are not significant. Moreover, the fluctuations in the higher periodic components such as D5 are significant for showing a sign of trend changing in the multi-decadal periodicity. As seen in Figure 2, the \(z\) values of D5 (with approximation), which denotes the trend found in the observed precipitation

<table>
<thead>
<tr>
<th>Data</th>
<th>Muğla</th>
<th>İzmir</th>
<th>Aydın</th>
<th>Manisa</th>
<th>Edirne</th>
<th>Bursa</th>
<th>Afyon</th>
<th>Eskişehir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>(-1.40)</td>
<td>(-1.16)</td>
<td>(-1.80)*</td>
<td>(-1.40)</td>
<td>(-0.98)</td>
<td>(-1.16)</td>
<td>(-1.98**)</td>
<td>(-1.42)</td>
</tr>
<tr>
<td>D1</td>
<td>(-0.07)</td>
<td>(-0.31)</td>
<td>(-0.27)</td>
<td>(-0.46)</td>
<td>(-0.11)</td>
<td>(0.22)</td>
<td>(-0.33)</td>
<td>(-0.38)</td>
</tr>
<tr>
<td>D2</td>
<td>(-0.61)</td>
<td>(-0.62)</td>
<td>(-0.75)</td>
<td>(-0.65)</td>
<td>(-0.28)</td>
<td>(0.33)</td>
<td>(-0.67)</td>
<td>(0.63)</td>
</tr>
<tr>
<td>D3</td>
<td>(0.69)</td>
<td>(-1.00)</td>
<td>(-0.45)</td>
<td>(-0.79)</td>
<td>(1.01)</td>
<td>(0.05)</td>
<td>(-0.31)</td>
<td>(0.60)</td>
</tr>
<tr>
<td>D4</td>
<td>(0.34)</td>
<td>(1.40)</td>
<td>(1.20)</td>
<td>(1.32)</td>
<td>(0.35)</td>
<td>(0.76)</td>
<td>(2.17**)</td>
<td>(0.17)</td>
</tr>
<tr>
<td>D5</td>
<td>(-4.30**)</td>
<td>(-2.76**)</td>
<td>(-5.52**)</td>
<td>(-3.22**)</td>
<td>(-1.40)</td>
<td>(-4.94**)</td>
<td>(-0.63)</td>
<td>(-3.98**)</td>
</tr>
<tr>
<td>A</td>
<td>(-5.50**)</td>
<td>(-5.88**)</td>
<td>(-6.65**)</td>
<td>(-3.63**)</td>
<td>(-6.59**)</td>
<td>(-6.33**)</td>
<td>(-5.88**)</td>
<td>(-1.98**)</td>
</tr>
<tr>
<td>D1 + A</td>
<td>(-1.08)</td>
<td>(-1.05)</td>
<td>(-2.31**)</td>
<td>(-1.70*)</td>
<td>(-1.45)</td>
<td>(-1.42)</td>
<td>(-2.48**)</td>
<td>(-1.05)</td>
</tr>
<tr>
<td>D2 + A</td>
<td>(-2.33**)</td>
<td>(-1.70*)</td>
<td>(-4.52**)</td>
<td>(-2.56**)</td>
<td>(-1.98**)</td>
<td>(-2.27**)</td>
<td>(-3.97**)</td>
<td>(-0.98)</td>
</tr>
<tr>
<td>D3 + A</td>
<td>(-1.10)</td>
<td>(-2.17**)</td>
<td>(-4.80**)</td>
<td>(-2.57**)</td>
<td>(-1.62)</td>
<td>(-2.72**)</td>
<td>(-4.13**)</td>
<td>(-0.72)</td>
</tr>
<tr>
<td>D4 + A</td>
<td>(-1.61)</td>
<td>(-0.25)</td>
<td>(-2.94**)</td>
<td>(-0.99)</td>
<td>(-2.35**)</td>
<td>(-1.51)</td>
<td>(-3.66**)</td>
<td>(-1.76*)</td>
</tr>
<tr>
<td>D5 + A</td>
<td>(-5.97**)</td>
<td>(-5.29**)</td>
<td>(-8.81**)</td>
<td>(-1.80*)</td>
<td>(-4.49**)</td>
<td>(-6.94**)</td>
<td>(-2.98**)</td>
<td>(-1.60)</td>
</tr>
</tbody>
</table>

*Indicates significant trend values at \(p = 0.05\).
**Indicates significant trend values at \(p = 0.01\).
Figure 2 | The sequential Mann-Kendall values for the Aydin precipitation data. The solid line is the Mann-Kendall values of the observed precipitation and the bold dashed progressive line is the Mann-Kendall values of the wavelet components of the observed data.
data, clearly shows a decreasing period starting around the 1950s and ending at the beginning of the 2000s. The same periodicities can be seen clearly in the $z$ values of D5 (without approximation), with a short-term increasing tendency between 1970 and 1985. As a result, the D5 component may be considered as representing the trend found in the observed annual precipitations.

The sequential values of the $z(t)$ statistics of D5 (with approximation) are shown in Figure 3 for the other stations. The sequential M-K values for Afyon station, which has a statistically significant decreasing trend, show that the decreasing tendency in the observed precipitations started in the 1950s. On the other hand, the $z$ values of D5 show clearly a decreasing period from
the end of the 1950s to 1980 (z values changes from +6 to −4). After the year 1980, there is a wetter period up to the 2000s, and immediately after a decreasing mode for the rest of the periods. Similar modes can also be seen in the z values of the other stations. The İzmir, Muğla and Bursa stations show clearly a decreasing period from the end of the 1940s to 2000. After the year 2000, again there is an increasing mode for the rest of the periods. The meaningful long-term decreasing modes in z values of D5 (with approximation) may be identified as commencing in the 1970s for the Manisa and Eskişehir stations. For instance, the z values of D5 (with approximation) at Eskişehir station show clearly an increasing period up to the 1970s (z values changes from 0 to +10). After the 1970s, there is a strong decreasing mode for the rest of the periods (z values change from +10 to −2).

In summary, a decreasing tendency starts in the years between 1940 and the 1950s at six stations and between 1970 and the 1980s at two stations. Analysis of the sequential z values of D5 (32-yearly periodicity) demonstrated the main change points for the long-term trends of precipitation time series. Analyzing the multi-decadal periodical component of the precipitation data presented valuable information about past climate change.

**Change point analysis**

The change point of the annual precipitation data was determined for the years with the main change points. The main change point in the time series was computed by the Pettitt test. The results in Table 4 show that precipitations at three stations (Eskişehir, Manisa, and Afyon) have change points with a significance level of 5%. All of them may be seen in Figure 4. The change points for Eskişehir and Manisa stations occurred in the period of 1970–1980s. It is worth mentioning that similar results had already been achieved by the trend analysis of the D5 component of the annual precipitation at the same stations. On the other hand, the significant change point is 1963 for Afyon station (Figure 4). Three stations (İzmir, Muğla, and Bursa) have change points between 1940 and the 1950s. The change points are in the 1980s for Aydın and Edirne stations, but they are not statistically significant. The results confirm the sequential M-K results of the D5 component demonstrating the main change points for the long-term trends in hydrological data.

### Table 4 | Results of Pettitt test for change point analyses of the annual precipitation data

<table>
<thead>
<tr>
<th>Stations</th>
<th>Change point (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eskişehir</td>
<td>1978</td>
</tr>
<tr>
<td>İzmir</td>
<td>1955 and 1981</td>
</tr>
<tr>
<td>Afyon</td>
<td>1963</td>
</tr>
<tr>
<td>Aydın</td>
<td>1987</td>
</tr>
<tr>
<td>Bursa</td>
<td>1950</td>
</tr>
<tr>
<td>Muğla</td>
<td>1986</td>
</tr>
<tr>
<td>Manisa</td>
<td>1980</td>
</tr>
<tr>
<td>Edirne</td>
<td>1981</td>
</tr>
</tbody>
</table>

**Multi-annual periodicities of the precipitation data**

The continuous wavelet spectrum (CWS) and GWS were applied to the observed precipitation data (Figures 5–8). Generally, the inter-decadal periodicities (light regions) are located between a 1- and 4-year scale level. These periodic events are similar for all stations but are more clear for İzmir station. The 32-year periodic events are one of the most significant multi-decadal events and continuous through the time period for all the stations. These strong periodicities located from the 16- to 32-year scale range occur strongly after the 1970s and reach a maximum in the 1990s (strong light region) for Aydın and İzmir stations. It can be noted that the sequential M-K values of the D5 component of the Aydın and İzmir precipitations show that the decreasing tendency beginning in the 1950s reaches clearly its maximum in the 1990s. That is to say, that the power of long-term decreasing trends may be demonstrated in the CWS. The 32-yearly periodicity is also very powerful for the Eskişehir, Bursa and Edirne stations.

As a result, the brightness in the 1- to 4-year periodicity shows the probability of the short-term mode having high precipitations or drought terms. However, the brightness in the multi-decadal scales such as the 32-yearly periodicity presents power and variability over time of long-term trends.
Figure 4 | Pettitt’s test results for detecting a change point in the annual precipitation. Dashed lines represent significance levels of 5%.
Wavelet transformation-based trend analysis of the temperature data

Before applying trend analysis, the observed temperature data were decomposed into an approximation and five detail components as described in the section above. After the wavelet decomposition, the M-K test results were obtained for the eight stations’ data.

The test results for the observed data and the different combinations of D components are presented in Table 5. The M-K trend analysis of the observed temperature data shows increasing tendencies at all the stations except one. Moreover, two stations (İzmir and Eskişehir) show a
significance trend at the 10% significance level. The results demonstrate that the average annual temperature data in Western Turkey have a warming tendency for the 1951 to 2005 period. This was confirmed by the decreases in the precipitation data as found in the section above. It can be said that an increase in temperature coincides generally with a decrease in precipitation. On the other hand, it is interesting that the Eskişehir station presents a strong decreasing trend at the 10% significance level.

Table 5 presents M-K trend results for the different combinations of D components. Generally, the D1, D2, and D3 components do not show a trend in any direction as similar to the precipitation data. However, D4 presents statistically significant increasing trends by contrast with the observed data for the seven stations. For instance, the z value of the observed temperature data is 0.90, while the z value of D4 is 2.77 for Mugla station. As well, the D5 and A components showed very strong
trends at the 5% significance level for two stations, one of them being Eskişehir station (the \( z \) value of D5 is \(-6.70\)). For Bursa station, the \( z \) value of the D5 component is 2.25, but its real trend value is 1.09. The periodic wavelet components explain that the real trend of the data is well represented by the D4 and D5 components. It is also seen that the D4 component is the main contributor to the trend production in the temperature data even if trends do not appear in the real data. Namely, the long-term periodical components carry most of the trend component.

The sequential values of the \( z(t) \) statistics of the D5 component (with approximation) are shown in Figure 9 for six stations. The sequential M-K values show that the increasing tendency in the observed temperature data may visually have been starting between 1970 and 1980. These increasing modes continue for the rest of the periods. On the other hand, the sequential M-K values

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**Figure 7** | CWS (left) and GWS (right) of the Muğla and Manisa stations.
show that the decreasing tendency in the observed temperature data of Eskişehir station started in the 1960s and finished at the end of the 1990s. After the 1970s, there is an increasing mode for the rest of the period. It is worth mentioning that the sequential $z$ values of the D5 component of temperature data are connected with the sequential $z$ values of the D5 component of the precipitation data. Namely, a decreasing tendency in the precipitation data starts after the 1950s (after the 1970s at some stations). Similarly, an increasing tendency in the temperatures data starts after the 1970s.

**The multi-annual relationship of precipitation and temperature data**

The periodic components of the precipitation and temperature data are analyzed in association with each other in this section. Table 6 shows the cross correlations between the D

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**Figure 8** | CWS (left) and GWS (right) of the Bursa and Edirne stations.
component of the precipitation data and the D component of the temperature data for the period 1951–2005. The larger correlation indicates the stronger relationship between the variables. The significance of a correlation was determined by the Student t-test at the significance level of \( p = 0.01 \). The correlations between the observed annual average temperature and the annual precipitation data do not generally have a significant value at the 1% significance level (for instance, its value is 0.27 for the Aydın data). On the other hand, the cross correlations of the long-term periodical components (such as D4, D5) show that 14 out of 16 data have a significant correlation (most of them are positive) at the 1% significance level. For example, the cross correlation between the D4 component of the precipitation data and the D4 component of the temperature data is 0.70 for İzmir data. The D4 component shows clearly stronger positive correlation than the correlations found in the observed data. On the other hand, it is worth noting that the D5 component shows very strong negative correlation at five out of eight stations. For instance, the correlation value of the D5 component at Muğla station is −0.82. Contrary to the D5 component, the correlation between the observed precipitation and air temperature data at Muğla station is positive (its value is 0.24). Similarly, the significance relationship between the approximate series is emphasized. These results show that there is a meaningful relationship between the long-term periodicity of the precipitation and temperature data.

**THE EFFECTS OF THE SOI AND NAO**

Mann–Kendall analysis of the annual data shows that the decreasing tendency in the precipitations and the increasing tendency in the temperatures of some stations may have been starting in the 1970s. This timing is important because the NAO (North Atlantic Oscillation), which is commonly known as the predominant mode of atmospheric variability in the North Atlantic, has been in a positive phase since the end of the 1960s (Anctil & Coulibaly 2004). Evidence of the NAO on Turkey’s precipitation data has already been demonstrated by Kara-bork et al. (2005). The wavelet spectra of the precipitation data indicate also some evidence of the SOI (South Oscillation Index). The short-term periodicities in the precipitation data may be associated with strong El Niño or La Niña events. For instance, the brightness in 2- to 4-yearly scales of the İzmir precipitation data can be referenced to the 1933, 1942, 1958, 1977, 1992, and 2005 El Niño events. As well, the powerful short-term periodicities in 1956 and the 1988s in the precipitation data of Aydın station may be explained by the 1956 and 1988 strong

<table>
<thead>
<tr>
<th>Data</th>
<th>Muğla</th>
<th>İzmir</th>
<th>Aydın</th>
<th>Manisa</th>
<th>Edirne</th>
<th>Bursa</th>
<th>Afyon</th>
<th>Eskişehir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>0.90</td>
<td>1.73*</td>
<td>0.47</td>
<td>0.81</td>
<td>0.57</td>
<td>1.09</td>
<td>1.35</td>
<td>−1.72**</td>
</tr>
<tr>
<td>D1</td>
<td>0.20</td>
<td>0.27</td>
<td>0.01</td>
<td>0.20</td>
<td>0.01</td>
<td>0.08</td>
<td>0.23</td>
<td>−0.13</td>
</tr>
<tr>
<td>D2</td>
<td>−0.11</td>
<td>−0.05</td>
<td>−0.02</td>
<td>−0.14</td>
<td>−0.47</td>
<td>−0.11</td>
<td>0.33</td>
<td>−0.37</td>
</tr>
<tr>
<td>D3</td>
<td>1.26</td>
<td>1.66</td>
<td>1.49</td>
<td>1.65</td>
<td>1.66</td>
<td>0.75</td>
<td>0.33</td>
<td>−0.36</td>
</tr>
<tr>
<td>D4</td>
<td>2.77**</td>
<td>2.71**</td>
<td>2.25**</td>
<td>2.72**</td>
<td>2.29**</td>
<td>2.25**</td>
<td>3.00**</td>
<td>−0.49</td>
</tr>
<tr>
<td>D5</td>
<td>−0.59</td>
<td>1.37</td>
<td>−0.50</td>
<td>0.71</td>
<td>−1.36</td>
<td>4.10**</td>
<td>0.82</td>
<td>−6.70**</td>
</tr>
<tr>
<td>A</td>
<td>−0.58</td>
<td>1.65</td>
<td>−0.55</td>
<td>0.58</td>
<td>−1.30</td>
<td>3.15**</td>
<td>0.90</td>
<td>−5.47**</td>
</tr>
<tr>
<td>D1 + A</td>
<td>0.21</td>
<td>2.09**</td>
<td>0.46</td>
<td>1.07</td>
<td>0.27</td>
<td>1.45</td>
<td>1.07</td>
<td>−2.26**</td>
</tr>
<tr>
<td>D2 + A</td>
<td>−0.23</td>
<td>0.92</td>
<td>−0.72</td>
<td>0.01</td>
<td>−1.59</td>
<td>0.94</td>
<td>0.53</td>
<td>−3.65**</td>
</tr>
<tr>
<td>D3 + A</td>
<td>0.72</td>
<td>1.56</td>
<td>0.49</td>
<td>0.52</td>
<td>−0.04</td>
<td>1.78*</td>
<td>0.66</td>
<td>−4.84**</td>
</tr>
<tr>
<td>D4 + A</td>
<td>1.17</td>
<td>1.94**</td>
<td>0.50</td>
<td>1.69*</td>
<td>−0.52</td>
<td>2.39**</td>
<td>−0.33</td>
<td>−4.98**</td>
</tr>
<tr>
<td>D5 + A</td>
<td>−0.53</td>
<td>1.49</td>
<td>−0.55</td>
<td>0.75</td>
<td>−1.32</td>
<td>3.92**</td>
<td>0.90</td>
<td>−6.41**</td>
</tr>
</tbody>
</table>

*Indicates significant trend values at \( p = 10\% \).
**Indicates significant trend values at \( p = 5\% \).
Figure 9 | The sequential Mann-Kendall values for the annual mean temperature data. The solid line is the Mann-Kendall values of the observed temperature and the bold dashed progressive line is the Mann-Kendall values of the D5 component (with approximation) of the observed data.

Table 6 | Cross correlations between precipitation and temperature data for the period 1951–2005

<table>
<thead>
<tr>
<th>Data</th>
<th>Mugla</th>
<th>Izmir</th>
<th>Aydin</th>
<th>Manisa</th>
<th>Edirne</th>
<th>Bursa</th>
<th>Afyon</th>
<th>Eskisehir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>0.24</td>
<td>0.24</td>
<td>0.27</td>
<td>0.27</td>
<td>0.49*</td>
<td>0.07</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>D1</td>
<td>0.45*</td>
<td>0.20</td>
<td>0.48*</td>
<td>0.37*</td>
<td>0.34</td>
<td>0.11</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>D2</td>
<td>0.04</td>
<td>0.07</td>
<td>−0.20</td>
<td>0.08</td>
<td>−0.20</td>
<td>−0.32</td>
<td>−0.39*</td>
<td>−0.43*</td>
</tr>
<tr>
<td>D3</td>
<td>−0.15</td>
<td>0.10</td>
<td>−0.27</td>
<td>0.32</td>
<td>−0.61*</td>
<td>0.08</td>
<td>0.33</td>
<td>0.44*</td>
</tr>
<tr>
<td>D4</td>
<td>0.77*</td>
<td>0.70*</td>
<td>0.45*</td>
<td>0.73*</td>
<td>0.41*</td>
<td>0.46*</td>
<td>0.66*</td>
<td>−0.34</td>
</tr>
<tr>
<td>D5</td>
<td>−0.82*</td>
<td>−0.59*</td>
<td>−0.55*</td>
<td>−0.67*</td>
<td>0.31</td>
<td>−0.65*</td>
<td>0.60*</td>
<td>0.55*</td>
</tr>
<tr>
<td>A</td>
<td>0.13</td>
<td>0.75*</td>
<td>0.48*</td>
<td>−0.32</td>
<td>0.56*</td>
<td>0.38*</td>
<td>0.82*</td>
<td>0.82*</td>
</tr>
</tbody>
</table>

*Indicates significant correlation coefficients at p = 1%.
La Niña events. Similar periodicities can also be seen in the CWS of the Afyon and Eskişehir stations. As a result, influences of the SOI and NAO can be seen in the precipitations and temperatures of western Turkey. Namely, the periodicities and changes observed in the hydro-meteorological time series could be associated with the global atmospheric indexes which orchestrate large variations in climate.

DISCUSSION AND CONCLUSION

The wavelet-based trend analysis presented short- or long-term variability of the precipitations and temperatures in West Anatolia (Turkey). The results show that there is a decreasing tendency at all the stations for precipitation, but some of them are statistically significant. On the contrary, the mean annual temperature data present generally an increasing tendency for the 1951–2005 period. The decreasing tendency in the observed precipitations and the increasing tendency in the observed temperatures may generally have been starting at the beginning of the 1970s. Besides, this timing is important because the NAO has been in a positive phase since the ending of the 1960s.

The short-term periodicities can also be seen as being related to the strong El Niño or La Niña events. On the other hand, the major multi-decadal periodic events are seen approximately at 16- to 32-year scale level. This suggests that the probability of long-term decrease in the precipitation data of West Anatolia has been clearly demonstrated in the wavelet spectrum.

The Mann–Kendall test of the D components demonstrates that D5 (32-year periodicity) denotes the trend seen in the precipitation data. Moreover, the fluctuations in the D5 component are significant to show the long-term trend variability. The sequential z values of D5 show clearly decreasing modes starting around the 1940s or the 1970s for the precipitation data. The results of the D5 components were confirmed by the change point test. As well, the D4 components of the temperature data present very strong increasing trends even if these do not appear in real data. Namely, trend test of the wavelet components reveals hidden trends in the observed temperature data. Also, a very meaningful relationship between the long-term periodical components of the hydro-climatic data was investigated.

The results of this study approve previous trend analysis studies on the western part of Turkey. The decreasing trends found in the precipitation data and the increasing trends found in the temperature data are harmonious with the studies of Partal & Kahya (2006) and Kadioğlu (1997).

The wavelet analysis discovers hidden trends in data. Future studies are needed to address the issue of wavelet trend analysis to prove the existence of climate change.

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First received 16 June 2016; accepted in revised form 3 March 2017. Available online 20 April 2017.