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Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia

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ABSTRACT

The annual and seasonal trends of seven meteorological variables were analyzed for twelve weather stations in Serbia during 1980–2010. The non-parametric Mann-Kendall and Sen's methods were used to determine whether there was a positive or negative trend in weather data with their statistical significance. The occurrence of abrupt changes was detected using cumulative sum charts and bootstrapping. In the present study, the increasing trends were indicated in both annual and seasonal minimum and maximum air temperatures' series. The relative humidity decreased significantly in summer and autumn, while the vapor pressure had a significant increasing trend in spring, summer and autumn. Besides, no significant trends were detected in summer and winter precipitation series. In general, the results of using the Mann-Kendall and Sen's tests demonstrated the good agreement of performance in detection of the trend for meteorological variables.

1. Introduction

Climate change is referred to as large variations in climate averages which exist for decades or even longer periods. Although climate change occurred on a global scale, its impacts often vary from region to region (Trajkovic and Kolakovic, 2009). Therefore, the analysis of changes in meteorological variables represents an important task in climate change detection.

In recent years, various studies have been done for detecting possible climate trends and changes across the world. However, most of these studies have focused on changes in temperature (maximum, minimum or mean) and precipitation only.

Yunling and Yiping (2005) analyzed climate change trends and characteristics during 1960–2000 at 19 stations along the Lancang River (China) according to the archival data of monthly air temperature and precipitation series. They found increases in temperature and decreases in precipitation. Karaburun et al. (2011) analyzed the evolution of annual, seasonal and monthly mean, minimum and maximum temperatures in Istanbul from 1975 to 2006 by using Mann-Kendall test and Sen's method.

Temperature changes in the Kingdom of Saudi Arabia for 29 years using data obtained from 29 meteorological stations were investigated by ElNesr et al. (2010). They found that a warming trend was in the maximum, minimum and average temperatures throughout the year except in the winter months of November to January where non-significant cooling trends were observed.

In Switzerland, Ceppi et al. (2012) performed the trend analysis of temperatures from 1959 to 2008, using a 2×2 km gridded dataset. They found that the seasonal trends are all positive and mostly significant with an annual average warming rate of 0.35 °C/decade.

Trends of streamflow in the Tarim River Basin during the past 50 years are analyzed by Tao et al. (2011). The results indicated that temperature, precipitation, relative humidity and actual vapor pressure show positive trends, while wind speed, sunshine duration and potential evapotranspiration show negative trends. The similar results were obtained by Xu et al. (2010). They concluded that both mean annual air temperature and precipitation had an increasing trend for the Tarim River Basin during the past five decades.

Singh et al. (2008) examined the trend and variability of seasonal and annual rainfall and relative humidity on the basin scale for the northwest and central parts of India using Mann-Kendall statistical test. In this research, they concluded that the majority of river basins in India had an increasing trend in the relative humidity both on seasonal and annual scales. The similar results were achieved by Vincent et al. (2008) who analyzed surface temperature and relative humidity trends in Canada for the period 1953–2005.

Jiang et al. (2010) analyzed wind speed changes based on two observational datasets in China from 1956 to 2004 and concluded that they all show decreasing trends over broad areas of China.

Some researchers analyzed the water vapor and concluded that there was an increase in atmospheric water vapor (Philipona et al., 2005; Trenberth et al., 2005; Willett et al., 2007).

In Iran numerous studies have examined the changes in meteorological variables (Modarres and Silva, 2007; Tabari and Hosseinzadeh Talaee, 2011a, 2011b; Tabari et al., 2011a). In general, their results

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showed a significant change in meteorological variables at many stations in Iran.

The purpose of this paper is to analyze the variability of seven meteorological variables at 12 stations in Serbia during 1980–2010. Besides, the objectives of this study are: (1) to analyze and discuss the trend characteristics of meteorological variables in detail; (2) to quantify the significance of changes by using the Mann-Kendall test and the Sen's slope estimator after removing the influence of significant lag-1 serial correlation from the time series; and (3) to detect the occurrence of abrupt changes by using cumulative sum charts and bootstrapping.

2. Materials and methods

2.1. Study areas and data collection

The study area is Serbia which is located in the central part of the Balkan Peninsula with an area of 88.407 km^2. Northern Serbia is mainly flat, while its central and southern areas consist of highlands and mountains. Its climate is temperate continental, with a gradual transition between the four seasons of the year.

In the present study, series of monthly maximum (T_{max}) and minimum (T_{min}) air temperatures, maximum (RH_{max}) and minimum (RH_{min}) relative humidities, actual vapor pressure (e_a), wind speed (U_2) and precipitation (P) were analyzed. The weather data included daily values of the above mentioned parameters averaged over each month. The full weather datasets were collected from 12 weather stations from Serbia for the period 1980–2010 and were obtained from the Republic Hydrometeorological Service of Serbia (http://www.hidmet.gov.rs/). Spatial distribution of the selected stations in the Serbia map is shown in Fig. 1, while their geographic description is given in Table 1. These locations were chosen according to three parameters: (1) each of them should have good quality datasets; (2) the data should be reliable; and (3) the data should have adequate record length.

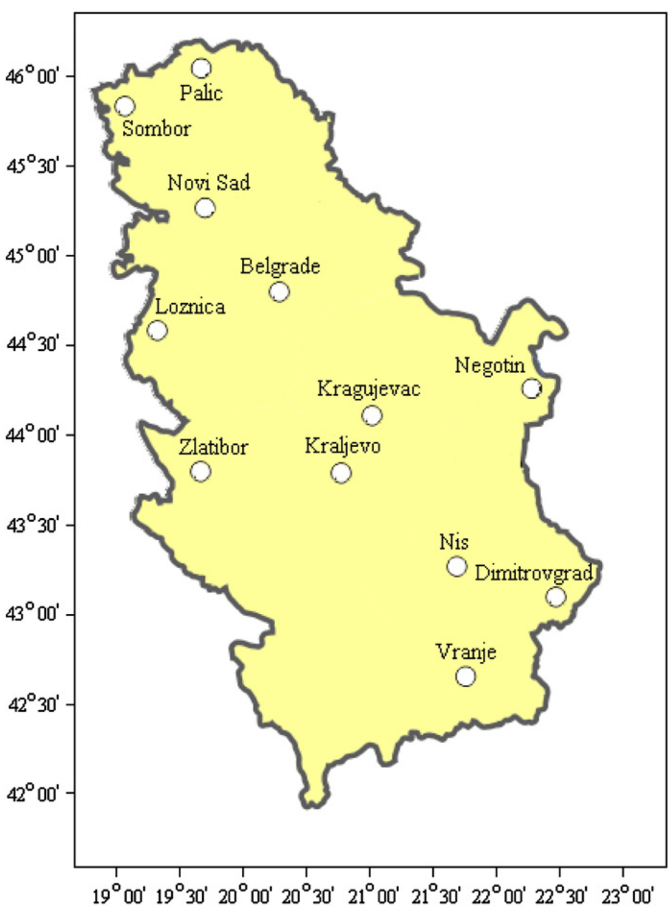

Fig. 1. Spatial distribution of the synoptic stations in the Serbia map.

Mean values with standard deviation of the variables used in this study for the observed period are summarized in Table 2. Differences in the mean weather data for these locations are not very significant. The mean annual T_{max} and T_{min} for most locations varied between 12.3 and 17.9 °C and 3.8 and 8.4 °C, respectively, while the mean RH_{max} and RH_{min} for these locations ranged from 78.0 to 86.0% and from 53.9 to 65.5%, respectively. The mean annual e_a ranged from 0.9 to 1.4 kPa. The mean annual U_2 was the lowest in Loznica (0.6 m s^{-1}). It varied for all other locations between 0.9 and 1.9 m s^{-1}. The mean monthly P ranged from 48.6 to 84.9 mm.

Monthly values were averaged to obtain seasonal temperature for each of the 12 weather stations. Seasons were defined as follows: winter = December, January, February; spring = March, April, May; summer = June, July, August and autumn = September, October, November.

The methods and techniques developed for detecting non-homogeneities in the data series and description of different approaches involved in adjusting climate data have been investigated by many researchers (Peterson et al., 1998; Aguilar et al., 2003; Ducré-Robitaille et al., 2003; Reeves et al., 2007; Costa and Soares, 2009). In this study, both the double-mass curve analysis (Kohler, 1949) and autocorrelation analysis were applied to the climatic variables' time series of each station. The points plotted for all stations in a double-mass curve fit closely without changes in slope, which indicates that there were no errors in the data processing or changes in the method of data observation.

2.2. Trend analysis methods

Tests for the detection of significant trends in climatologic time series can be classified as parametric and non-parametric methods. Parametric trend tests require data to be independent and normally distributed, while non-parametric trend tests require only that the data be independent. In this study, two non-parametric methods (Mann-Kendall and Sen's slope estimator) were used to detect the meteorological variables' trends.

2.2.1. Mann-Kendall trend test

The Mann-Kendall test statistic S (Mann, 1945; Kendall, 1975) is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \quad (1)$$

Table 1
Geographic characteristics of the weather station sites used in the study.

Station name	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
1. Belgrade	20°28′	44°48′	132
2. Dimitrovgrad	22°45′	43°01′	450
3. Kragujevac	20°56′	44°02′	185
4. Kraljevo	20°42′	43°43′	215
5. Loznica	19°14′	44°33′	121
6. Negotin	22°33′	44°14′	42
7. Nis	21°54′	43°20′	204
8. Novi Sad	19°51′	45°20′	86
9. Palic	19°46′	46°06′	102
10. Sombor	19°05′	45°47′	87
11. Vranje	21°55′	42°33′	432
12. Zlatibor	19°43′	43°44′	1028

Table 2
Mean values with standard deviation of the meteorological variables used in this study at twelve weather stations during the period 1980–2010.

Station	T_{min} (°C)	T_{max} (°C)	RH_{min} (%)	RH_{max} (%)	e_a (kPa)	U_2 (m s^{-1})	P (mm)
Belgrade	8.409 ± 0.802	17.179 ± 1.082	55.484 ± 3.123	78.030 ± 3.037	1.058 ± 0.053	1.670 ± 0.214	60.064 ± 12.505
Dimitrovgrad	4.667 ± 0.540	16.403 ± 0.949	55.366 ± 3.082	85.145 ± 2.201	0.962 ± 0.062	1.816 ± 0.060	53.602 ± 10.223
Kragujevac	6.421 ± 0.662	17.350 ± 0.998	55.441 ± 3.516	83.575 ± 2.519	1.054 ± 0.054	1.144 ± 0.225	53.649 ± 10.086
Kraljevo	6.264 ± 0.598	17.068 ± 0.971	57.890 ± 3.151	85.753 ± 1.501	1.061 ± 0.052	1.529 ± 0.170	62.280 ± 9.749
Loznica	6.857 ± 0.700	17.393 ± 1.067	58.944 ± 3.555	86.016 ± 1.932	1.109 ± 0.054	0.619 ± 0.147	71.496 ± 13.075
Negotin	6.679 ± 0.748	16.928 ± 1.018	57.508 ± 3.503	81.151 ± 2.498	1.067 ± 0.046	1.040 ± 0.170	52.249 ± 11.049
Nis	6.643 ± 0.637	17.874 ± 1.163	53.965 ± 2.857	82.446 ± 2.003	1.028 ± 0.054	0.944 ± 0.196	49.247 ± 8.308
Novi Sad	6.417 ± 0.756	16.520 ± 1.305	59.583 ± 3.945	84.530 ± 2.606	1.078 ± 0.067	1.893 ± 0.260	55.748 ± 13.966
Palic	6.595 ± 0.689	16.231 ± 1.035	56.497 ± 5.078	84.065 ± 2.335	1.027 ± 0.054	1.904 ± 0.366	48.592 ± 11.172
Sombor	5.905 ± 0.752	16.712 ± 1.104	54.828 ± 4.651	85.484 ± 3.131	1.029 ± 0.043	1.646 ± 0.087	51.211 ± 11.639
Vranje	5.553 ± 0.548	17.023 ± 0.943	54.680 ± 2.863	84.645 ± 2.302	0.975 ± 0.049	1.796 ± 0.387	48.828 ± 10.736
Zlatibor	3.778 ± 0.676	12.358 ± 1.175	65.460 ± 3.108	83.056 ± 1.946	0.862 ± 0.031	1.416 ± 0.237	84.858 ± 12.362

where n is the number of data points, x_i and x_j are the data values in time series i and j ($j>i$), respectively and $\text{sgn}(x_j-x_i)$ is the sign function as:

$$\text{sgn}\left(x_j-x_i\right)=\begin{cases}+1, & \text{if } x_j-x_i>0\\ 0, & \text{if } x_j-x_i=0\\ -1, & \text{if } x_j-x_i<0\end{cases}. \tag{2}$$

The variance is computed as

$$Var(S)=\frac{n(n-1)(2n+5)-\sum_{i=1}^{m}t_i(t_i-1)(2t_i+5)}{18} \tag{3}$$

where n is the number of data points, m is the number of tied groups and t_i denotes the number of ties of extent i. A tied group is a set of sample data having the same value. In cases where the sample size $n>10$, the standard normal test statistic Z_S is computed using Eq. (4):

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

Positive values of Z_S indicate increasing trends while negative Z_S values show decreasing trends. Testing trends is done at the specific α significance level. When $|Z_S|>Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, significance levels $\alpha=0.01$ and $\alpha=0.05$ were used. At the 5% significance level, the null hypothesis of no trend is rejected if $|Z_S|>1.96$ and rejected if $|Z_S|>2.576$ at the 1% significance level.

The Mann-Kendall statistical test has been frequently used to quantify the significance of trends in hydro-meteorological time series (Douglas et al., 2000; Yue et al., 2002; Partal and Kahya, 2006; Modarres and Silva, 2007; Tabari and Marofi, 2011; Tabari et al., 2011b).

2.2.2. Sen's slope estimator

Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i=\frac{x_j-x_k}{j-k}\quad \text{for } i=1,\ \dots, N, \tag{5}$$

where x_j and x_k are the data values at times j and k ($j>k$), respectively.

If there is only one datum in each time period, then $N=\frac{n(n-1)}{2}$, where n is the number of time periods. If there are multiple observations in one or more time periods, then $N<\frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as

$$Q_{med}=\begin{cases}Q_{[(N+1)/2]}, & \text{if } N \text{ is odd}\\ \dfrac{Q_{[N/2]}+Q_{[(N+2)/2]}}{2}, & \text{if } N \text{ is even}\end{cases}. \tag{6}$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability.

The confidence interval about the time slope (Hollander and Wolfe, 1973; Gilbert, 1987) can be computed as follows:

$$C_\alpha=Z_{1-\alpha/2}\sqrt{Var(S)}, \tag{7}$$

where $Var(S)$ is defined in Eq. (3) and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, the confidence interval was computed at two significance levels ($\alpha=0.01$ and $\alpha=0.05$).

Then, $M_1=\frac{N-C_\alpha}{2}$ and $M_2=\frac{N+C_\alpha}{2}$ are computed. The lower and upper limits of the confidence interval, Q_{min} and Q_{max}, are the M_1th largest and the (M_2+1)th largest of the N ordered slope estimates (Gilbert, 1987).

The slope Q_{med} is statistically different than zero if the two limits (Q_{min} and Q_{max}) have similar sign.

Sen's slope estimator has been widely used in hydro-meteorological time series (Lettenmaier et al., 1994; Yue and Hashino, 2003; Yunling and Yiping, 2005; Partal and Kahya, 2006; ElNesr et al., 2010; Tabari and Marofi, 2011; Tabari et al., 2011a).

2.3. Serial correlation effect

To remove serial correlation from the series, von Storch and Navarra (1995) suggested to pre-whiten the series before applying the Mann-Kendall test. This study incorporates this suggestion in both Mann-Kendall test and Sen's slope estimator.

Possible statistically significant trends in sample data ($x_1, x_2, \dots, x_n$) are examined using the following procedures:

(1) Compute the lag-1 serial correlation coefficient (designated by r_1). The lag-1 serial correlation coefficient of sample data x_i can be computed by (Kendall and Stuart, 1968; Salas et al., 1980)

$$r_1=\frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i-E(x_i))\cdot(x_{i+1}-E(x_i))}{\frac{1}{n}\sum_{i=1}^{n}(x_i-E(x_i))^2}, \tag{8}$$

$$E(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{9}$$

where $E(x_i)$ is the mean of sample data and n is the sample size.

(2) If the calculated r_1 is not significant at the 5% level, then the Mann-Kendall test and Sen's slope estimator are applied to the original values of the time series.

(3) If the calculated r_1 is significant, prior to application of the Mann-Kendall test and Sen's slope estimator, then the 'pre-whitened' time series may be obtained as $(x_2 - r_1\ x_1, x_3 - r_1\ x_2, \ldots, x_n - r_1\ x_{n-1})$.

The critical value of r_1 for a given significance level depends on whether the test is one-tailed or two-tailed. For the one-tailed hypothesis, the alternative hypothesis is usually that the true r_1 is greater than zero, while for the two-tailed test, the alternative hypothesis is that the true r_1 is different from zero, with no specification of whether it is positive or negative. According to Anderson (1942) and Salas et al. (1980), the probability limits on the correlogram of an independent series for r_1 can be computed by

$$r_1 = \begin{cases} \dfrac{-1+1.645\sqrt{n-2}}{n-1}, & \text{one} - \text{tailedtest} \\ \dfrac{-1\pm1.96\sqrt{n-2}}{n-1}, & \text{two} - \text{tailedtest} \end{cases} \tag{10}$$

where n is the sample size.

Which alternative hypothesis to use depends on the problem. If there is some reason to expect positive autocorrelation, the one-tailed test is the best. Otherwise, the two-tailed test is the best.

2.4. Cumulative sum charts and bootstrapping

Cumulative sum charts (CUSUM) and bootstrapping (Efron and Tibshirani, 1993) are used for abrupt change point detection in climate series. All the analysis performed in this study are based on 1000 bootstrap samples. The cumulative sums $S_0, S_1, \ldots, S_n$ of sample data $(x_1, x_2, \ldots, x_n)$, where n is the sample size, are calculated iteratively as follows: (1) calculate the average of sample data $(\bar{x})$; (2) set $S_0 = 0$; and (3) calculate S_i recursively as $S_i = S_{i-1} + (x_i - \bar{x}), i = 1, 2, \ldots, n$.

A period where the CUSUM chart follows a relatively straight line indicates a period where the average does not change, while an abrupt change in the direction of the CUSUM indicates an abrupt shift in the average. The confidence level can be determined by performing bootstrap analysis. First, the magnitude of change S_{diff} is calculated by $S_{diff} = S_{\max} - S_{\min}$, where $S_{\max} = \max_{i=1,\ldots,n} S_i$ and $S_{\min} = \min_{i=1,\ldots,n} S_i$, and then, the bootstrap analysis can be performed as illustrated in the following steps:

(1) Generate a bootstrap sample of n units, denoted as $x_1^0, x_2^0, \ldots, x_n^0$, by randomly reordering the original n values.
(2) Based on the bootstrap sample, calculate the bootstrap CUSUM, denoted as $S_1^0, S_2^0, \ldots, S_n^0$.
(3) Calculate the maximum, the minimum and the difference of the bootstrap CUSUM, $S_{\max}^0$, $S_{\min}^0$ and S_{diff}^0, respectively.
(4) Determine whether the bootstrap difference S_{diff}^0 is less than the original difference S_{diff} or not.
(5) Iterate the above procedure (1)–(4) n times.
(6) Let X be the number of bootstraps for which $S_{diff}^0 < S_{diff}$, then, the confidence level (CL) at which a change point occurred is $CL = 100 \cdot \frac{X}{n}\%$.

To estimate the location of the change point, define m such that: $|S_m| = \max_{i=1,\ldots,n} |S_i|$, which is the point furthest from 0 in the CUSUM chart. The point m estimates the last point before the occurrence of the change point.

3. Results and discussion

The Mann-Kendall test and Sen's slope estimator were applied to the time-series 1980–2010 for the seven meteorological variables: T_{min}, T_{max}, RH_{min}, RH_{max}, e_a, U_2 and P. Each of trend methods is implemented as a Web service, which is written in C#. The Web services and accompanying WSDL and SOAP 1.2 documentation are available for free download from the website http://www.gaf.ni.ac.rs/mgocic/TrendWebServices.htm.

3.1. Serial correlation of the meteorological variables

Autocorrelation plots for the meteorological variables at the 12 weather stations are presented in Fig. 2. As shown, positive serial correlations were obtained for the T_{min} and T_{max}, while all other meteorological variables had both positive and negative serial correlations. The strongest and the weakest serial correlations were found at the T_{min} (Negotin) and P (Sombor) series, respectively. The negative serial correlations were significant at Loznica (RH_{min}), Zlatibor (RH_{max}), Palic, Novi Sad and Sombor (P), while the majority of the stations had the significant positive serial correlations for all the variables.

3.2. Trends in the meteorological variables

3.2.1. Analysis of T_{min} and T_{max}

Results of applying statistical tests for seasonal and annual T_{min} over the period 1980–2010 are presented in Table 3. As shown, all of the significant trends at the 1% and 5% significance levels were increasing. On the annual time scale, the significant increasing trends were detected at the 5% significance level at 66.67% of all stations and varied between 0.279 °C/year at Dimitrovgrad station and 0.388 °C/year at the Zlatibor station.

On the seasonal scale, neither significant positive or negative trends were detected by the trend tests in winter. Moreover, the Vranje and Zlatibor stations showed insignificant increasing trends in all seasons. On the contrary, the statistical tests detected a significant increasing trend at about 41.67%, 25% and 66.67% of the stations in spring, summer and autumn, respectively.

Analysis in Table 4 indicated increasing trends in both annual and seasonal T_{max} series. The magnitudes of the significant increasing trends in annual T_{max} ranged between 0.529 °C/year at the Palic station and 0.696 °C/year at the Negotin station. On the seasonal scale, the percentage of stations characterized by the significant increasing trends of T_{max} was about 25% for spring, 16.67% for summer, 25% for autumn and 8.33% for winter. However, the Dimitrovgrad, Kragujevac, Negotin and Vranje stations showed insignificant increasing trends in all seasons.

The results obtained for T_{min} and T_{max} series are in line with Tabari and Marofi (2011) and Türkes and Sümer (2004) who detected increasing of air temperature in the western part of Iran and in Turkey, respectively. The increasing trends in air temperature series have been caused by several factors such as global warming, increased urbanized area and changes in atmospheric circulation (Smadi, 2006; Tabari et al., 2011a). Significant increasing trends in both T_{min} and T_{max} series will increase reference evapotranspiration and dry conditions in Serbia.

3.2.2. Analysis of RH_{min} and RH_{max}

The output of the analyzed RH_{min} series was summarized in Table 5. Both increasing and decreasing trends were identified by the two statistical tests in the annual and seasonal RH_{min} data. The significant decreasing trend in annual RH_{min} series was found at four of the observed stations and varied from −1.289% per year at the Sombor station to −1.833% per year at the Palic station. On the seasonal time scale, the significant decreasing trends were found at the Sombor station in spring, summer and autumn. Moreover, the

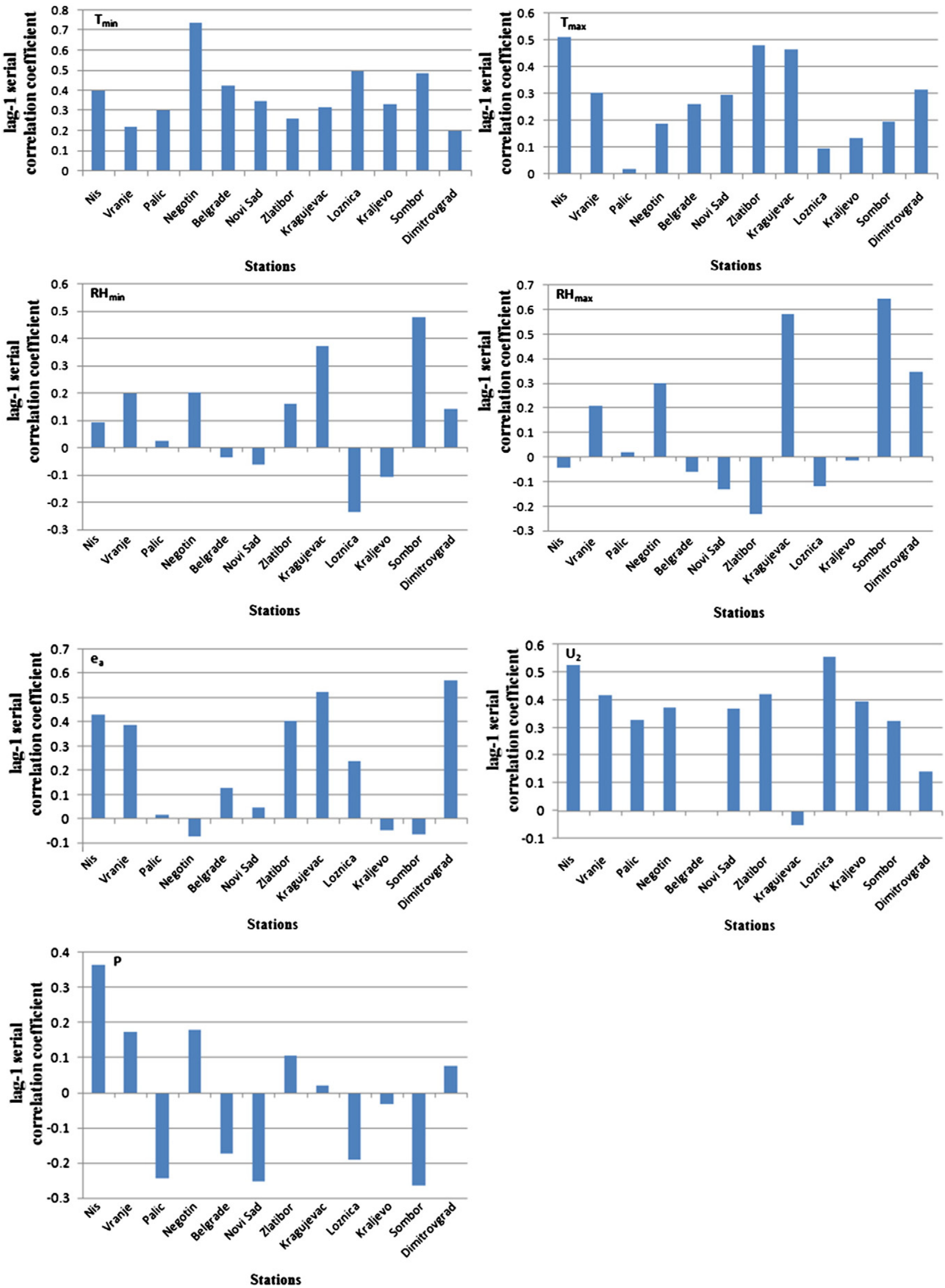

Fig. 2. Lag-1 serial correlation coefficient for the meteorological variables at the weather stations.

Table 3
Results of the statistical tests for seasonal and annual T_{min} over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	1.938	1.360	2.606**	0.851	1.836
	Q_{med}	0.467	0.446	0.583**	0.267	0.425
Dimitrovgrad	Z_S	0.955	2.142*	1.513	0.136	2.447*
	Q_{med}	0.200	0.348*	0.167	0.030	0.279*
Kragujevac	Z_S	2.606**	1.802	2.364*	1.077	2.278*
	Q_{med}	0.533**	0.321	0.433*	0.300	0.376*
Kraljevo	Z_S	1.460	1.666	2.380*	1.477	2.346*
	Q_{med}	0.333	0.296	0.367*	0.333	0.364*
Loznica	Z_S	1.564	2.142*	2.555*	1.581	2.176*
	Q_{med}	0.413	0.504*	0.533*	0.400	0.383*
Negotin	Z_S	2.210*	1.768	3.484**	1.859	1.700
	Q_{med}	0.435*	0.419	0.450**	0.433	0.278
Nis	Z_S	1.122	1.700	2.937**	0.817	2.447*
	Q_{med}	0.318	0.417	0.333**	0.200	0.339*
Novi Sad	Z_S	2.744**	1.836	1.790	0.868	1.598
	Q_{med}	0.500**	0.326	0.383	0.233	0.386
Palic	Z_S	2.108*	2.481*	2.120*	0.799	1.904
	Q_{med}	0.394*	0.486*	0.433*	0.333	0.254
Sombor	Z_S	2.176*	1.734	2.399*	1.841	2.074*
	Q_{med}	0.470*	0.486	0.450*	0.533	0.372*
Vranje	Z_S	0.952	1.904	0.904	0.510	2.432*
	Q_{med}	0.193	0.306	0.010	0.102	0.329*
Zlatibor	Z_S	1.685	1.734	1.651	1.025	2.244*
	Q_{med}	0.383	0.435	0.333	0.217	0.388*

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

Table 5
Results of the statistical tests for seasonal and annual RH_{min} over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	−0.696	−1.199	−0.573	1.217	−0.834
	Q_{med}	−0.667	−1.500	−0.667	1.333	−0.583
Dimitrovgrad	Z_S	2.957**	−0.921	0.382	2.091*	0.969
	Q_{med}	0.303**	−1.000	0.667	0.733*	0.583
Kragujevac	Z_S	1.026	−0.452	1.269	2.156*	0.612
	Q_{med}	1.167	−0.667	1.000	1.135*	0.520
Kraljevo	Z_S	0.986	−1.546	−0.556	0.001	−1.038
	Q_{med}	0.896	−2.000	−0.667	0.010	−0.917
Loznica	Z_S	2.447*	0.453	0.442	1.548	0.238
	Q_{med}	0.751*	0.333	0.306	1.333	0.167
Negotin	Z_S	−2.417*	−2.520*	−0.226	−0.904	−2.364*
	Q_{med}	−0.333*	−0.667*	−0.333	−1.000	−1.792*
Nis	Z_S	1.462	−1.408	−0.244	−0.157	−0.595
	Q_{med}	1.782	−1.667	−0.333	−0.001	−0.458
Novi Sad	Z_S	−0.069	−0.156	−0.383	0.905	−0.034
	Q_{med}	−0.167	−0.333	−0.333	1.000	−0.167
Palic	Z_S	−1.634	−1.287	−1.530	−0.609	−2.074*
	Q_{med}	−2.333	−1.667	−1.667	−0.500	−1.833*
Sombor	Z_S	−2.989**	−2.074*	−2.447*	−1.462	−2.210*
	Q_{med}	−1.000**	−1.171*	−1.216*	−1.962	−1.289*
Vranje	Z_S	−0.544	−1.129	−0.782	−1.586	−1.701
	Q_{med}	−0.435	−1.833	−0.667	−1.000	−0.917
Zlatibor	Z_S	−0.442	−2.590**	−0.834	−1.791	−2.466*
	Q_{med}	−0.545	−1.000**	−0.667	−1.667	−1.750*

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

significant decreasing trends in spring RH_{min} were larger than the other seasonal series. The highest and lowest significant increases of RH_{min} values were detected over Kragujevac in winter and Dimitrovgrad in spring at the rates of 1.135% per year and 0.303% per year, respectively.

Results of the applied Mann-Kendall and Sen's slope estimator statistical tests for seasonal and annual RH_{max} over the period 1980–2010 are presented in Table 6. As shown, the majority of the trends in the annual RH_{max} series were not significant, while the significant decreasing trend was found only at the Negotin station. On the seasonal time scale, the significant increasing trend was detected at the Dimitrovgrad station in spring and winter, at the Zlatibor station in spring and at the Palic station in autumn. However, the negative RH_{max} trends were significant at the 1% and 5% significance levels according to the statistical tests in the spring, summer, autumn and winter seasons in about 16.67%, 41.67%, 16.67% and 8.33% of the

Table 4
Results of the statistical tests for seasonal and annual T_{max} over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	1.751	1.734	2.084*	0.486	1.462
	Q_{med}	0.767	0.677	0.567*	0.233	0.479
Dimitrovgrad	Z_S	1.479	1.904	1.667	1.442	1.768
	Q_{med}	0.567	0.618	0.500	0.433	0.401
Kragujevac	Z_S	1.546	1.734	1.234	0.646	1.428
	Q_{med}	0.517	0.683	0.367	0.156	0.449
Kraljevo	Z_S	1.164	3.266**	1.390	0.938	2.787**
	Q_{med}	0.367	0.633**	0.400	0.333	0.583**
Loznica	Z_S	1.581	2.676**	1.389	1.181	2.142*
	Q_{med}	0.500	0.617**	0.467	0.417	0.604*
Negotin	Z_S	1.771	1.768	1.460	0.442	2.923**
	Q_{med}	0.700	0.661	0.333	0.167	0.696**
Nis	Z_S	1.928	1.632	2.345*	2.050*	1.700
	Q_{med}	0.867	0.809	0.767*	0.617*	0.526
Novi Sad	Z_S	2.125*	1.326	1.841	0.521	1.394
	Q_{med}	0.717*	0.582	0.483	0.200	0.505
Palic	Z_S	2.136*	1.428	0.903	0.434	2.244*
	Q_{med}	0.567*	0.495	0.217	0.117	0.529*
Sombor	Z_S	2.172*	1.292	1.755	0.764	2.532*
	Q_{med}	0.667*	0.473	0.433	0.300	0.675*
Vranje	Z_S	1.563	1.666	0.935	1.528	1.530
	Q_{med}	0.550	0.592	0.333	0.417	0.318
Zlatibor	Z_S	2.884	1.870	2.102*	1.702	1.666
	Q_{med}	0.383	0.613	0.667*	0.650	0.489

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

Table 6
Results of the statistical tests for seasonal and annual RH_{max} over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	−1.599	−2.329*	−1.967*	0.001	−1.819
	Q_{med}	−1.333	−2.667*	−1.334*	0.010	−1.458
Dimitrovgrad	Z_S	1.972*	0.001	0.544	2.142*	1.428
	Q_{med}	1.015*	0.000	0.477	0.838*	0.759
Kragujevac	Z_S	−2.006*	−2.210*	−1.836	−0.122	−1.836
	Q_{med}	−1.650*	−2.418*	−0.978	0.000	−0.832
Kraljevo	Z_S	1.744	−2.022*	0.850	0.918	0.272
	Q_{med}	1.000	−1.333*	0.433	0.320	0.167
Loznica	Z_S	−0.104	−0.993	0.087	1.677	0.102
	Q_{med}	−0.001	−0.333	0.001	0.667	0.042
Negotin	Z_S	−2.889**	−2.955**	−2.422*	0.017	−3.180**
	Q_{med}	−2.667**	−3.000**	−1.000*	0.000	−1.583**
Nis	Z_S	−0.644	−0.956	−0.958	−0.340	−0.953
	Q_{med}	−0.333	−1.000	−0.567	−0.195	−0.417
Novi Sad	Z_S	−0.374	−0.017	0.192	0.576	−0.663
	Q_{med}	−0.313	0.000	0.000	0.333	−0.417
Palic	Z_S	0.608	0.609	2.021*	0.717	1.377
	Q_{med}	0.333	0.500	1.000*	0.333	0.667
Sombor	Z_S	−1.734	−2.108*	−1.904	−2.244*	−1.870
	Q_{med}	−2.263	−2.360*	−1.349	−1.498*	−1.810
Vranje	Z_S	1.166	−0.087	1.156	0.244	0.408
	Q_{med}	0.667	−0.333	0.789	0.000	0.208
Zlatibor	Z_S	3.264**	−1.131	0.939	1.184	0.324
	Q_{med}	2.889**	−0.667	0.667	0.667	0.083

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

stations, respectively. On the contrary, no significant trends were detected at Loznica, Nis, Novi Sad and Vranje in all seasons.

3.2.3. Analysis of e_a

As shown in Table 7, about 25% and 33.33% of the stations had the significant increasing trends at the 1% and 5% significance levels in annual e_a series, respectively. The rates of the significant increasing trends in annual e_a varied from 0.024 kPa/year at the Zlatibor station to 0.045 kPa/year at the Novi Sad station. The positive e_a trends were significant at the 1% and 5% significance levels according to the statistical tests in the spring, summer and autumn seasons in about 50%, 66.67% and 25% of the stations, respectively. Moreover, the highest significant increasing trend of 0.073 kPa/year was detected in the summer season at the Dimitrovgrad station. However, no significant trends were detected in winter e_a series and in about 33% of the stations in all seasons.

The results indicated inverse trends at the two nearby stations of Nis (significant increasing trend) and Negotin (no trend). According to Türkes and Sümer (2004) and Tabari et al. (2011b) this can be explained by the natural factors and the different microclimates.

3.2.4. Analysis of U_2

Table 8 lists the results of the statistical tests for seasonal and annual U_2 over the period 1980–2010. Most of the trends were insignificant at the 1% and 5% significance levels for both the seasonal and annual scales. Based on the results of the statistical methods, the significant decreasing trend was at Nis station in annual U_2 series. However, the other stations had no significant trends. On the seasonal scale, the decreasing trends were significant at two stations at the 1% significance level (at the Vranje station in autumn and winter and at the Novi Sad station in summer). The significant increasing trend was detected only at the Palic station in summer. On the contrary, no significant trends were detected by the trend tests in spring U_2 series.

Similar results are detected by Jiang et al. (2010), which concluded that the fundamental reason for the decreasing trend in wind speed is the change of atmospheric circulation.

Table 7
Results of the statistical tests for seasonal and annual e_a over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	1.938	1.738	1.598	1.687	2.482*
	Q_{med}	0.034	0.038	0.027	0.013	0.036*
Dimitrovgrad	Z_S	2.176*	2.923**	2.313*	0.612	2.889**
	Q_{med}	0.032*	0.073**	0.027*	0.009	0.034**
Kragujevac	Z_S	3.059**	3.144**	2.173*	1.869	1.938
	Q_{med}	0.048**	0.050**	0.033*	0.017	0.030
Kraljevo	Z_S	1.972*	1.980*	0.713	0.918	2.329*
	Q_{med}	0.035*	0.037*	0.010	0.010	0.027*
Loznica	Z_S	2.210*	3.300**	2.276*	1.930	3.468**
	Q_{med}	0.040*	0.067**	0.035*	0.020	0.040**
Negotin	Z_S	1.237	1.234	0.521	1.237	1.258
	Q_{med}	0.010	0.028	0.010	0.010	0.016
Nis	Z_S	2.685**	2.433*	1.825	0.748	2.176*
	Q_{med}	0.032**	0.055*	0.017	0.010	0.031*
Novi Sad	Z_S	1.700	2.923**	1.407	1.235	2.906**
	Q_{med}	0.032	0.065**	0.023	0.017	0.045**
Palic	Z_S	1.529	1.910	0.400	0.382	1.445
	Q_{med}	0.020	0.040	0.007	0.003	0.015
Sombor	Z_S	−0.156	−0.677	−1.373	−0.272	−1.343
	Q_{med}	−0.003	−0.020	−0.017	−0.002	−0.013
Vranje	Z_S	1.982*	2.189*	1.755	1.772	1.870
	Q_{med}	0.030*	0.050*	0.017	0.020	0.030
Zlatibor	Z_S	1.802	3.978**	1.878	1.949	2.379*
	Q_{med}	0.026	0.063**	0.017	0.013	0.024*

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

Table 8
Results of the statistical tests for seasonal and annual U_2 over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	0.818	0.645	0.017	0.818	0.306
	Q_{med}	0.067	0.033	0.000	0.067	0.008
Dimitrovgrad	Z_S	−0.071	−0.001	−0.646	−0.272	0.256
	Q_{med}	−0.001	−0.001	−0.033	−0.013	0.001
Kragujevac	Z_S	−0.418	1.275	1.171	1.517	1.056
	Q_{med}	−0.033	0.083	0.033	0.133	0.075
Kraljevo	Z_S	1.394	1.167	0.296	1.802	1.428
	Q_{med}	0.010	0.067	0.000	0.120	0.062
Loznica	Z_S	1.190	1.866	1.326	1.666	1.632
	Q_{med}	0.047	0.010	0.056	0.073	0.056
Negotin	Z_S	−1.341	0.313	−0.731	−0.272	−0.544
	Q_{med}	−0.067	0.000	−0.067	−0.020	−0.021
Nis	Z_S	−1.088	−1.117	−1.870	−0.816	−2.210*
	Q_{med}	−0.069	−0.100	−0.118	−0.057	−0.122*
Novi Sad	Z_S	−1.564	−1.972*	−1.496	−1.535	−1.802
	Q_{med}	−0.201	−0.164*	−0.169	−0.117	−0.166
Palic	Z_S	1.688	3.289**	1.394	1.690	1.564
	Q_{med}	0.167	0.233**	0.167	0.133	0.148
Sombor	Z_S	−1.621	−0.925	−0.510	0.749	−0.816
	Q_{med}	−0.067	−0.033	−0.026	0.033	−0.024
Vranje	Z_S	−1.700	−1.584	−2.278*	−2.142*	−1.666
	Q_{med}	−0.254	−0.233	−0.290*	−0.212*	−0.218
Zlatibor	Z_S	−1.904	−1.396	−1.802	−1.462	−1.598
	Q_{med}	−0.156	−0.067	−0.130	−0.103	−0.141

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

3.2.5. Analysis of P

Seasonal and annual trends of precipitation obtained by Mann-Kendall test and Sen's slope estimator are given in Table 9.

According to these results, the significant increasing trend in annual precipitation series was detected at the Sombor station at the 5% significance level, while other stations had no significant trends.

Table 9
Results of the statistical tests for seasonal and annual precipitation over the period 1980–2010.

Station	Test	Trends				
		Spring	Summer	Autumn	Winter	Annual
Belgrade	Z_S	−1.343	−0.476	1.003	0.136	−0.085
	Q_{med}	−2.333	−2.256	2.317	0.609	−0.333
Dimitrovgrad	Z_S	−0.573	−0.612	1.806	1.274	1.292
	Q_{med}	−1.050	−3.817	3.050	4.683	3.442
Kragujevac	Z_S	−1.173	−0.765	1.407	0.272	−0.051
	Q_{med}	−2.983	−2.600	2.367	0.875	−0.350
Kraljevo	Z_S	0.306	0.238	0.816	0.408	0.068
	Q_{med}	1.026	1.350	3.633	2.833	0.010
Loznica	Z_S	−0.001	0.646	1.241	1.802	1.870
	Q_{med}	−0.050	4.950	3.217	6.633	5.017
Negotin	Z_S	1.972*	0.136	0.935	1.122	0.340
	Q_{med}	2.550*	1.000	2.750	1.867	1.117
Nis	Z_S	0.357	−0.538	0.816	0.714	0.544
	Q_{med}	1.733	−2.433	3.133	3.367	1.055
Novi Sad	Z_S	0.612	0.417	2.532*	0.612	1.802
	Q_{med}	3.257	3.917	2.550*	2.583	4.579
Palic	Z_S	1.054	0.748	1.513	0.527	1.802
	Q_{med}	4.917	4.833	4.467	1.617	4.421
Sombor	Z_S	0.578	1.615	1.172	0.868	1.989*
	Q_{med}	2.070	3.700	3.800	3.300	4.183*
Vranje	Z_S	0.357	−0.382	1.394	0.544	1.309
	Q_{med}	1.850	−2.683	2.376	1.550	3.383
Zlatibor	Z_S	0.578	0.068	1.479	0.731	1.207
	Q_{med}	2.933	0.300	3.450	2.633	3.363**

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.

On the seasonal scale, there were the increasing trends in autumn and winter precipitation series. However, the significant increasing trends were found only at one station in spring and autumn. No significant trends were detected in summer and winter precipitation series.

3.3. Spatial distribution of trends

Spatial distribution of weather stations with increasing, decreasing and no trends for the annual data series during the period 1980–2010 is presented in Fig. 3. As shown, the significant increasing trends in annual T_{min} and e_a were detected at seven of the observed stations located in the central and southern parts of Serbia. The T_{max} had the significant increasing trends in the northern, central and eastern parts of Serbia. Only a significant increasing trend for precipitation was presented at the Sombor station north of Serbia. Significant decreasing trends were found at one station south of Serbia in the U_2 and at one station east of Serbia in the RH_{max}. The RH_{min} had the significant decreasing trends north of Serbia, with one exception in the east and south.

The location of weather stations and the direction of trends for seasonal data series during the period 1980–2010 are displayed in Fig. 4. The spatial occurrence of the trends for T_{min} is quite similar to that of e_a. A warming trend in T_{max} was found at the majority of the stations in the northern regions. The RH_{max} and RH_{min} had the significant decreasing trends in the central region of Serbia and the significant increasing trends in the southern region of Serbia. Stronger significant decreasing trends were identified in U_2 data in autumn and winter in the southern region of Serbia. The significant increasing trends were found for P series in the eastern and northern region of Serbia in spring and autumn, respectively. On the contrary, no significant increasing or decreasing trends were detected in P series in summer and winter.

3.4. Identification of change points in time series

Results of the change point analysis in the meteorological variables during the period 1980–2010 are summarized in Table 10. As shown, change point can be detected for all seven variables. Change from positive to negative direction was detected in the time series of precipitation, while the other variables had the change from negative to positive direction.

Based on the results of the bootstrap analysis, the confidence level for the change point in precipitation and relative humidity is 98%. The confidence level for temperature, vapor pressure and wind speed is 99%. Quite similar results are obtained by Tao et al. (2011).

3.5. Comparison of the Mann-Kendall and Sen's methods for detection changes in meteorological variables

The results obtained using Sen's slope estimator for annual and seasonal meteorological variables' series during the period 1980–2010 are given in Table 11. In general, this study showed that there is the great similarity between the statistical results from the Mann-Kendall and Sen's statistical methods at the 1% and 5% significance levels. A similar conclusion has been confirmed by Partal and Kahya (2006) and Tabari and Hosseinzadeh Talaee (2011a, 2011b).

4. Conclusions

The climate variability has not been greatly investigated in Serbia. Because of that, the main aim of this study was to perform an analysis of the seasonal and annual trends of seven meteorological variables in Serbia from 1980 to 2010. The analysis was obtained by the non-parametric Mann-Kendall and Sen's methods after eliminating the effect of significant lag-1 serial correlation from the time series. The meteorological

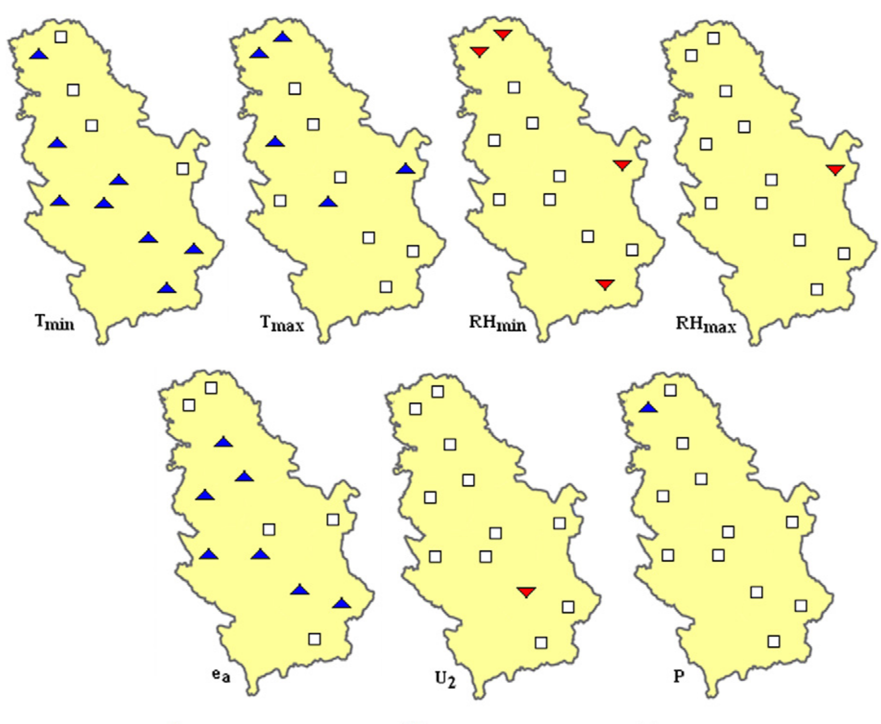

Fig. 3. Spatial distribution of weather stations with increasing, decreasing and no trends by the Mann-Kendall and Sen's tests for the annual data series during the period 1980–2010.

data are used from twelve stations which had good quality datasets with reliable data and adequate record length.

The given results indicated that there was a significant increasing trend in T_{min} and T_{max} in both annual and seasonal time series. The magnitudes of the significant increasing trends in annual T_{max} ranged between 0.529 °C/year at the Palic station and 0.696 °C/year at the Negotin station, while in annual T_{min} varied between 0.279 °C/year at the Dimitrovgrad station and 0.388 °C/year at the Zlatibor station. However, the significant decreasing trend in annual RH_{min} series was found at four of the observed stations, while the majority of the trends in the annual RH_{max} series were not significant. The annual e_a series showed the significant increasing trends at 60% of the stations, but no significant trends were detected in the winter series. Based on the results of the statistical methods, most of the trends were insignificant at the 1% and 5% significance levels for both the seasonal and annual U_2 series. The significant increasing trend in annual precipitation series was detected at the Sombor station at the 5% significance level and only at one station in spring and autumn.

Besides, the results of the change point analysis in the meteorological variables during the period 1980–2010 showed that the change point can be detected for all seven variables. Based on the results of the bootstrap analysis, the confidence level for precipitation and relative humidity is 98%, while for temperature, vapor pressure and wind speed is 99%.

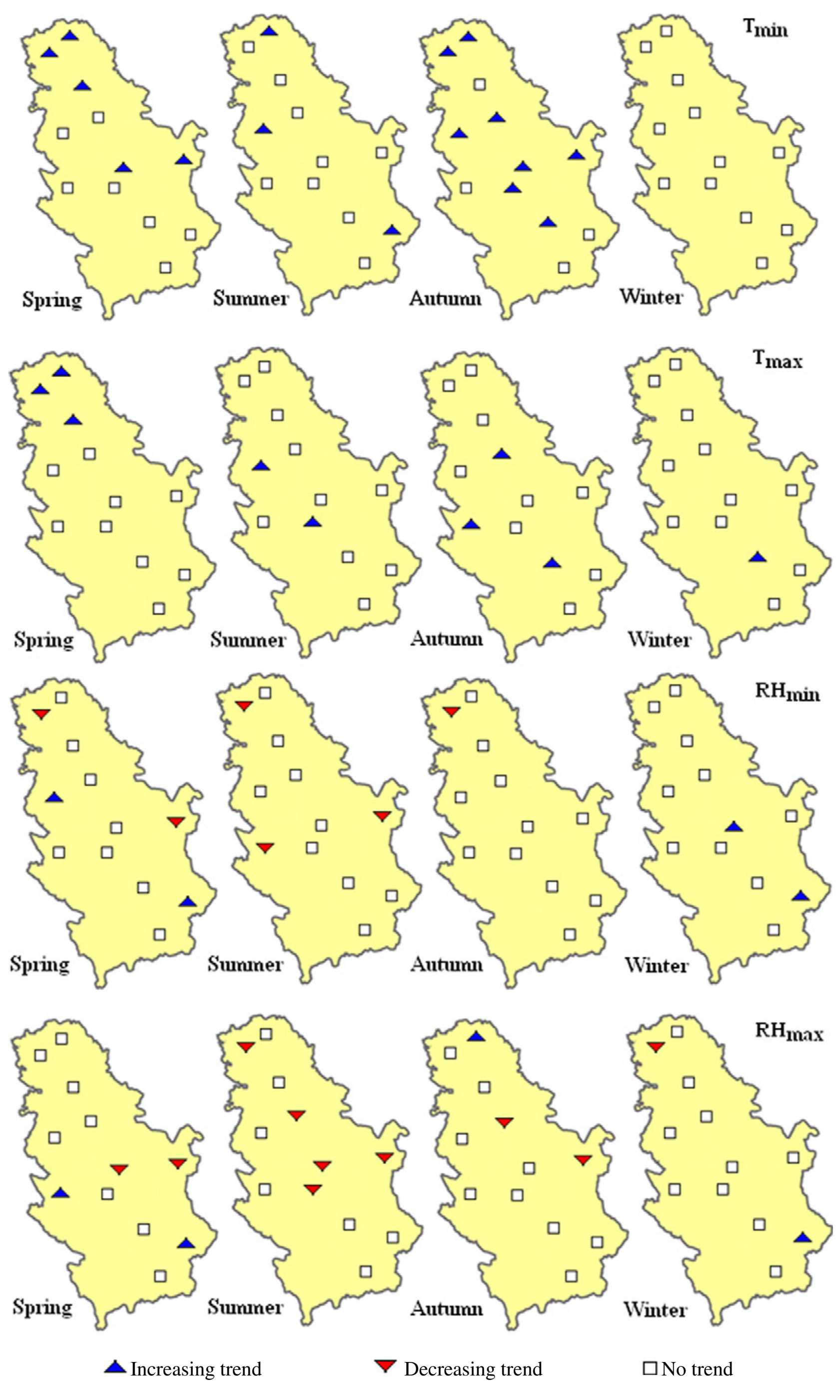

Fig. 4. Spatial distribution of weather stations with increasing, decreasing and no trends by the Mann-Kendall and Sen's tests for the seasonal data series during the period 1980–2010.

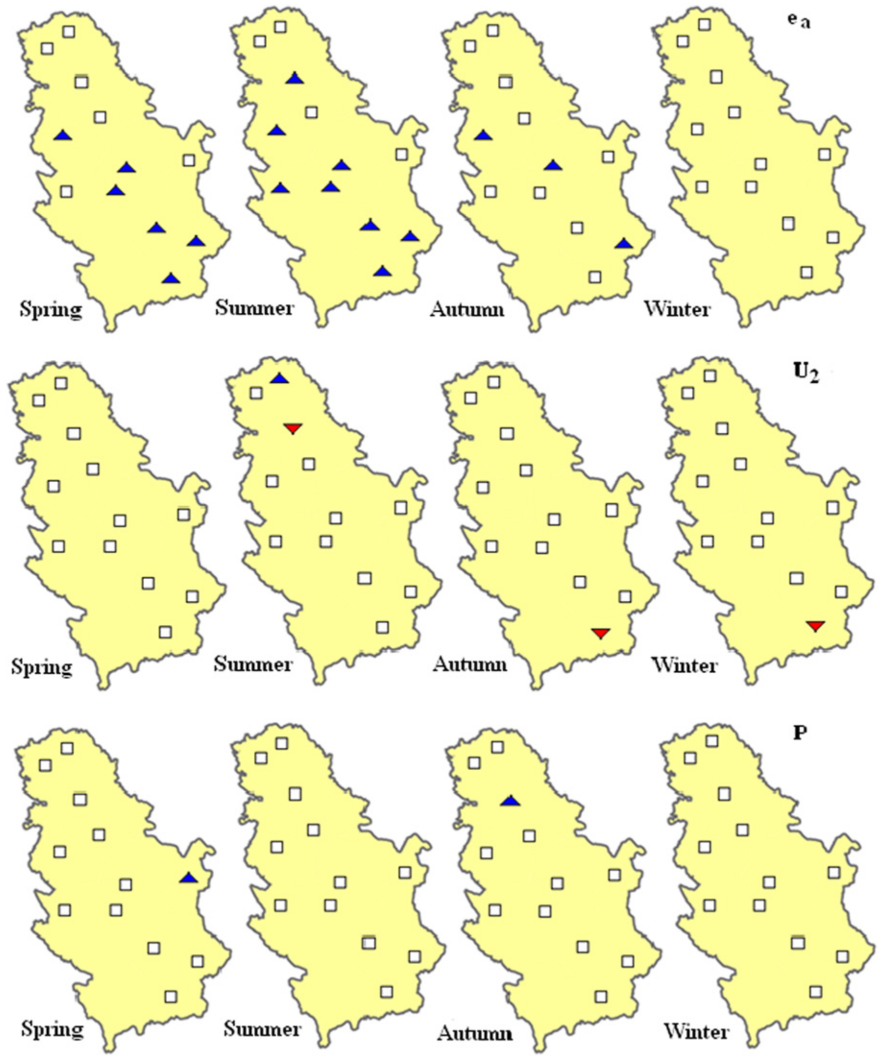

Fig. 4 (*continued*).

In general, the results of using Mann-Kendall and Sen's slope estimator statistical tests pointed out the agreement of performance which exists in the detection of the trend for the meteorological variables.

The findings of this study can help in further analysis of possible causes of the increase or decrease in the reference evapotranspiration. Besides, further research in comparing between Mann-Kendall and another trend identification test is recommended.

Table 10
Change point analysis in the meteorological variables during the period 1980–2010.

Station	T_{min}	T_{max}	RH_{min}	RH_{max}	e_a	U_2	P
Belgrade	1994 (− → +)	1992 (− → +)	1993 (− → +)	1991 (− → +)	1992 (− → +)	1991 (− → +)	1986 (+ → −)
Dimitrovgrad	1994 (− → +)	1993 (− → +)	1995 (− → +)	1994 (− → +)	1993 (− → +)	1992 (− → +)	1986 (+ → −)
Kragujevac	1992 (− → +)	1993 (− → +)	1993 (− → +)	1993 (− → +)	1993 (− → +)	1993 (− → +)	1986 (+ → −)
Kraljevo	1994 (− → +)	1993 (− → +)	1992 (− → +)	1993 (− → +)	1991 (− → +)	1993 (− → +)	1984 (+ → −)
Loznica	1993 (− → +)	1994 (− → +)	1993 (− → +)	1991 (− → +)	1993 (− → +)	1991 (− → +)	1987 (+ → −)
Negotin	1993 (− → +)	1992 (− → +)	1993 (− → +)	1992 (− → +)	1990 (− → +)	1993 (− → +)	1988 (+ → −)
Nis	1994 (− → +)	1991 (− → +)	1993 (− → +)	1993 (− → +)	1994 (− → +)	1991 (− → +)	1987 (+ → −)
Novi Sad	1992 (− → +)	1993 (− → +)	1993 (− → +)	1992 (− → +)	1994 (− → +)	1992 (− → +)	1986 (+ → −)
Palic	1992 (− → +)	1993 (− → +)	1991 (− → +)	1993 (− → +)	1995 (− → +)	1996 (− → +)	1987 (+ → −)
Sombor	1993 (− → +)	1993 (− → +)	1993 (− → +)	1992 (− → +)	1993 (− → +)	1991 (− → +)	1986 (+ → −)
Vranje	1994 (− → +)	1993 (− → +)	1993 (− → +)	1993 (− → +)	1996 (− → +)	1992 (− → +)	1986 (+ → −)
Zlatibor	1991 (− → +)	1995 (− → +)	1992 (− → +)	1993 (− → +)	1996 (− → +)	1992 (− → +)	1986 (+ → −)

− → + = change from negative to positive direction.
+ → − = change from positive to negative direction.

Table 11
The percentage of stations with significant trends by Sen's slope estimator for annual and seasonal meteorological variables' series during the period 1980–2010.

Variable	Trend	Significance level	Annual	Spring	Summer	Autumn	Winter
T_{min}	Positive	$\alpha = 0.05$	66.67	25.00	25.00	41.67	–
		$\alpha = 0.01$	–	16.67	–	25.00	–
	Negative	$\alpha = 0.05$	–	–	–	–	–
		$\alpha = 0.01$	–	–	–	–	–
T_{max}	Positive	$\alpha = 0.05$	25.00	25.00	–	25.00	8.33
		$\alpha = 0.01$	16.67	–	16.67	–	–
	Negative	$\alpha = 0.05$	–	–	–	–	–
		$\alpha = 0.01$	–	–	–	–	–
RH_{min}	Positive	$\alpha = 0.05$	–	8.33	–	–	16.67
		$\alpha = 0.01$	–	8.33	–	–	-
	Negative	$\alpha = 0.05$	33.33	8.33	16.67	8.33	–
		$\alpha = 0.01$	–	8.33	8.33	–	–
RH_{max}	Positive	$\alpha = 0.05$	–	8.33	–	8.33	8.33
		$\alpha = 0.01$	–	8.33	–	–	–
	Negative	$\alpha = 0.05$	–	8.33	33.33	16.67	8.33
		$\alpha = 0.01$	8.33	8.33	8.33	–	–
e_a	Positive	$\alpha = 0.05$	33.33	33.33	25.00	25.00	–
		$\alpha = 0.01$	25.00	16.67	41.67	–	–
	Negative	$\alpha = 0.05$	–	–	–	–	–
		$\alpha = 0.01$	–	–	–	–	–
U_2	Positive	$\alpha = 0.05$	8.33	–	–	–	–
		$\alpha = 0.01$	–	–	8.33	–	–
	Negative	$\alpha = 0.05$	–	–	8.33	8.33	8.33
		$\alpha = 0.01$	–	–	–	–	–
P	Positive	$\alpha = 0.05$	8.33	–	–	8.33	–
		$\alpha = 0.01$	–	–	–	–	–
	Negative	$\alpha = 0.05$	–	8.33	–	–	–
		$\alpha = 0.01$	–	–	–	–	–

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References

Aguilar, E., Auer, I., Brunet, M., Peterson, T.C., Wieringa, J., 2003. Guidelines on climate metadata and homogenization. WMO-TD No. 1186, WCDMP No. 53. World Meteorological Organization, Geneva, Switzerland.
Anderson, R.L., 1942. Distribution of the serial correlation coefficients. Annals of Mathematical Statistics 13 (1), 1–13.
Ceppi, P., Scherrer, S.C., Fischer, A.M., Appenzeller, C., 2012. Revisiting Swiss temperature trends 1959–2008. International Journal of Climatology 32 (2), 203–213.
Costa, A.C., Soares, A., 2009. Homogenization of climate data: review and new perspectives using geostatistics. Mathematical Geosciences 41, 291–305.
Douglas, E.M., Vogel, R.M., Kroll, C.N., 2000. Trends in floods and low flows in the United States: impact of spatial correlation. Journal of Hydrology 240, 90–105.
Ducré-Robitaille, J.-F., Vincent, L.A., Boulet, G., 2003. Comparison of techniques for detection of discontinuities in temperature series. International Journal of Climatology 23 (9), 1087–1101.
Efron, B., Tibshirani, R.J., 1993. An Introduction to the Bootstrap. Chapman & Hall.
ElNesr, M.N., Abu-Zreig, M.M., Alazba, A.A., 2010. Temperature trends and distribution in the Arabian Peninsula. American Journal of Environmental Sciences 6, 191–203.
Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring. John Wiley & Sons, New York.
Hollander, M., Wolfe, D.A., 1973. Nonparametric Statistical Methods. John Wiley & Sons, New York.
Jiang, Y., Luo, Y., Zhao, Z., Tao, S., 2010. Changes in wind speed over China during 1956–2004. Theoretical and Applied Climatology 99 (3–4), 421–430.
Karaburun, A., Demirci, A., Kara, F., 2011. Analysis of spatially distributed annual, seasonal and monthly temperatures in Istanbul from 1975 to 2006. World Applied Sciences Journal 12 (10), 1662–1675.
Kendall, M.G., 1975. Rank Correlation Methods. Griffin, London, UK.
Kendall, M.G., Stuart, A., 1968. The Advanced Theory of Statistics: Design and Analysis, and Time-series, vol. 3. Charles Griffin & Company Limited, London.
Kohler, M.A., 1949. Double-mass analysis for testing the consistency of records and for making adjustments. Bulletin of the American Meteorological Society 30, 188–189.
Lettenmaier, D.P., Wood, E.F., Wallis, J.R., 1994. Hydro-climatological trends in the continental United States, 1948–88. Journal of Climate 7, 586–607.
Mann, H.B., 1945. Nonparametric tests against trend. Econometrica 13, 245–259.
Modarres, R., Silva, V.P.R., 2007. Rainfall trends in arid and semi-arid regions of Iran. Journal of Arid Environments 70, 344–355.
Partal, T., Kahya, E., 2006. Trend analysis in Turkish precipitation data. Hydrological Processes 20, 2011–2026.
Peterson, T.C., Easterling, D.R., Karl, T.R., Groisman, P.Y., Nicholis, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Førland, E., Hanssen-Bauer, I., Alexandersson, H., Jones, P., Parker, D., 1998. Homogeneity adjustments of in situ atmospheric climate data: a review. International Journal of Climatology 18, 1493–1517.
Philipona, R., Durr, B., Ohmura, A., Ruckstuhl, C., 2005. Anthropogenic greenhouse forcing and strong water vapor feedback increase temperature in Europe. Geophysical Research Letters 32, L19809. http://dx.doi.org/10.1029/2005GL023624.
Reeves, J., Chen, J., Wang, X.L., Lund, R., Lu, Q., 2007. A review and comparison of changepoint detection techniques for climate data. Journal of Applied Meteorology and Climatology 46, 900–915.
Salas, J.D., Delleur, J.W., Yevjevich, V.M., Lane, W.L., 1980. Applied Modeling of Hydrologic Time Series. Water Resources Publications, Littleton, Colorado, USA.
Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63, 1379–1389.
Singh, P., Kumar, V., Thomas, T., Arora, M., 2008. Changes in rainfall and relative humidity in river basins in northwest and central India. Hydrological Processes 22 (16), 2982–2992.
Smadi, M.M., 2006. Observed abrupt changes in minimum and maximum temperatures in Jordan in the 20th century. American Journal of Environmental Sciences 2 (3), 114–120.
Tabari, H., Hosseinzadeh Talaee, P., 2011a. Analysis of trends in temperature data in arid and semi-arid regions of Iran. Global and Planetary Change 79 (1–2), 1–10.
Tabari, H., Hosseinzadeh Talaee, P., 2011b. Temporal variability of precipitation over Iran: 1966–2005. Journal of Hydrology 396 (3–4), 313–320.
Tabari, H., Marofi, S., 2011. Changes of pan evaporation in the west of Iran. Water Resources Management 25, 97–111.
Tabari, H., Shifteh Somee, B., Rezaeian Zadeh, M., 2011a. Testing for long-term trends in climatic variables in Iran. Atmospheric Research 100 (1), 132–140.
Tabari, H., Marofi, S., Aeini, A., Hosseinzadeh Talaee, P., Mohammadi, K., 2011b. Trend analysis of reference evapotranspiration in the western half of Iran. Agricultural and Forest Meteorology 151 (2), 128–136.
Tao, H., Gemmer, M., Bai, Y., Su, B., Mao, W., 2011. Trends of streamflow in the Tarim River Basin during the past 50 years: human impact or climate change? Journal of Hydrology 400 (1–2), 1–9.
Trajkovic, S., Kolakovic, S., 2009. Wind-adjusted Turc equation for estimating reference evapotranspiration at humid European locations. Hydrology Research 40 (1), 45–52.
Trenberth, K.E., Fasullo, J., Smith, L., 2005. Trends and variability in column-integrated atmospheric water vapor. Climate Dynamics 24, 741–758.
Türkes, M., Sümer, U.M., 2004. Spatial and temporal patterns of trends and variability in diurnal temperature ranges of Turkey. Theoretical and Applied Climatology 77 (3–4), 195–227.
Vincent, L.A., Wijngaarden, W.A., Hopkinson, R., 2008. Surface temperature and humidity trends in Canada for 1953–2005. Journal of Climate 20 (20), 5100–5113.
von Storch, H., Navarra, A., 1995. Analysis of Climate Variability — Applications of Statistical Techniques. Springer-Verlag, New York.
Willett, K.M., Gillett, N.P., Jones, P.D., Thorne, P.W., 2007. Attribution of observed surface humidity changes to human influence. Nature 449 (7163), 710–713.
Xu, Z., Liu, Z., Fu, G., Chen, Y., 2010. Trends of major hydroclimatic variables in the Tarim River Basin during the past 50 years. Journal of Arid Environments 74 (2), 256–267.
Yue, S., Hashino, M., 2003. Temperature trends in Japan: 1900–1996. Theoretical and Applied Climatology 75, 15–27.
Yue, S., Pilon, P., Phinney, B., Cavadias, G., 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrological Processes 16, 1807–1829.
Yunling, H., Yiping, Z., 2005. Climate change from 1960 to 2000 in the Lancang River Valley, China. Mountain Research and Development 25 (4), 341–348.