Analysis of trends in reference evapotranspiration data in a humid climate

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Abstract Statistically significant FAO-56 Penman-Monteith (FAO-56 PM) and adjusted Hargreaves (AHARG) reference evapotranspiration (ET0) trends at monthly, seasonal and annual time scales were analysed by using linear regression, Mann-Kendall and Spearman’s Rho tests at the 1 and 5% significance levels. Meteorological data were used from 12 meteorological stations in Serbia, which has a humid climate, for the period 1980–2010. Web-based software for conducting the trend analyses was developed. All of the trends significant at the 1 and 5% significance levels were increasing. The FAO-56 PM ET0 trends were almost similar to the AHARG trends. On the seasonal time scale, for the majority of stations significant increasing trends occurred in summer, while no significant positive or negative trends were detected by the trend tests in autumn for the AHARG series. Moreover, 70% of the stations were characterized by significant increasing trends for both annual ET0 series.

Key words trend analysis; reference evapotranspiration; linear regression; Mann-Kendall test; Spearman’s Rho test

1 INTRODUCTION

Trends in climate changes are important environmental issues that have a significant impact on hydrological parameters such as soil moisture, groundwater and evapotranspiration (ET). ET is one of the major components in the hydrological cycle, and its reliable estimation is essential to water resources planning and management. It is a physical process in which water passes from the liquid to gaseous state while moving from the soil to the atmosphere, and refers both to evaporation from the soil and vegetative surfaces and to transpiration from plants. The two separate processes, evaporation and transpiration, occur simultaneously, and there is no easy way of distinguishing one from the other.

A common procedure for estimating ET is to estimate reference evapotranspiration (ET0) and then apply an appropriate crop coefficient. ET0 is a complex nonlinear process for which accurate estimation is needed for many studies, e.g. hydrological water balance, irrigation system design, irrigation scheduling and water resources planning and management.
In recent years, many scientists have compared and analysed trends in ET₀. Xu et al. (2006) calculated, compared and regionally mapped the Penman-Monteith ET₀ and pan evaporation (E_p) at 150 meteorological stations during 1960–2000 in the Changjiang region of China. They concluded that there is a significant decreasing trend in both the annual ET₀ and E_p. Wang et al. (2007) found that E_p and ET₀ decreased during the summer months in the upper and mid–lower Yangtze River basin of China from 1961 to 2000. Yin et al. (2010) analysed the trends in ET₀ across China during the period 1961–2008. The results showed decreasing trends of ET₀ in most regions and increasing trends in the cold temperate humid region and the tropical humid region. Li et al. (2012) examined the present (1961–2009) and future (2011–2099) spatio-temporal characteristics of ET₀ on the Loess Plateau of China to understand the present and future changes in hydrology.

The results presented in Bandyopadhyay et al. (2009) show a significant decreasing trend in ET₀ estimated by the FAO 56 Penman-Monteith method over different agro-ecological regions of India during the period 1971–2002. In another study, Jhajharia et al. (2012) investigated the trends in ET₀ estimated using the Penman-Monteith method for the humid region of northeast India by using the Mann-Kendall test. They found that ET₀ decreased significantly at annual and seasonal time scales for six stations in northeast India.

A few studies have been conducted on the variability of ET₀ and E_p in Iran. Tabari and Marofi (2011) investigated, among other things, temporal variations in E_p for 12 stations in Hamedan province in western Iran for the period 1982–2003. In another study, Tabari et al. (2011a) analysed the annual, seasonal and monthly trends of the ET₀ series for 20 stations in the western half of Iran during 1966–2005. They concluded that the increasing trends in winter and summer ET₀ were greater than those for the spring and autumn series. Furthermore, the results of the monthly ET₀ analysis indicated that the highest numbers of stations with significant trends were found in February. In addition, Tabari et al. (2012) used the Mann-Kendall test, Theil-Sen’s estimator and the Spearman test to identify trend in ET₀ series with serial dependence in Iran. They found that the Mann-Kendall test was more sensitive than the Spearman test to the existence of positive serial correlation in the ET₀ series. Shadmani et al. (2012) analysed temporal trends of ET₀ values in arid regions of Iran. Their results showed that increasing and decreasing trends were found for monthly ET₀. On a seasonal scale, the highest numbers of significant trends were found in the summer and autumn series.

In trend analysis in southern Spain, Espadafor et al. (2011) detected a statistically significant increase in Penman-Monteith ET₀. Chauouche et al. (2010) focused on the western part of the French Mediterranean area and reported an increase trend in monthly potential ET mainly in the spring.

The objectives of this study are: (a) to consider the trends in FAO-56 Penman-Monteith (FAO-56 PM) and adjusted Hargreaves (AHARG) ET₀ time series in a humid climate, analysed using the linear regression, Mann-Kendall and Spearman’s Rho test methods, and (b) to use the trend analysing component of recently developed Web services to examine monthly, seasonal and annual ET₀ trend analysis.

2 MATERIALS AND METHODS

2.1 Study areas and data collection

Serbia is located in the central part of the Balkan Peninsula with an area of 88,407 km². 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.

Series of monthly meteorological data of maximum (T_max) and minimum (T_min) air temperatures, maximum (R_H_max) and minimum (R_H_min) relative humidities, actual vapour pressure (e_a) and wind speed (U_2) from 12 humid stations in Serbia (Fig. 1), for the period 1980–2010 were obtained from the Republic Hydrometeorological Service of Serbia (http://www.hidmet.gov.rs/). The 12 locations were chosen because: (a) they cover all the latitudes in Serbia (from 42° 30’ N to 46° 10’ N) and (b) they are situated at different elevations above sea level. The selected weather stations are described in Table 1.

Mean values and standard deviations (SDs) of the variables used in this study for the 31-year period are summarized in Table 2. All the selected weather stations had good-quality data sets for estimating ET₀ using the FAO-56 PM and AHARG equations. 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°C and 17.9°C, and between 3.8°C and 8.4°C, respectively, while the mean R_H_max and
RH_{min} ranged from 78.0% to 86.0% and from 53.9% to 65.5%, respectively. The range of mean annual $e_d$ is 0.9 to 1.4 kPa. The mean annual $U_2$ was lowest at Loznica (0.6 m s$^{-1}$). It varied from 0.9 to 1.9 m s$^{-1}$ at the other stations.

The data sets were investigated for randomness, homogeneity and absence of trends. The Kendall autocorrelation test, the Mann-Kendall trend test and the homogeneity tests of Mann–Whitney for the mean and the variance, were used for this purpose.

### 2.2 Methods for estimating $ET_0$

Numerous equations, classified as temperature-based, radiation-based, pan evaporation-based and combination-type, have been developed for estimating $ET_0$ (Gocic and Trajkovic 2010, Trajkovic 2010, Tabari et al. 2011b). In this study, the FAO-56 PM and AHARG equations are used for estimating $ET_0$ as a part of an approach based on a service-oriented paradigm (Gocic and Trajkovic 2011).

#### 2.2.1 FAO-56 Penman-Monteith equation

The FAO-56 Penman-Monteith equation (FAO-56 PM) is recommended by the Food and Agriculture Organization of the United Nations (FAO), as the
standard equation for estimating \( ET_0 \). It assumes the \( ET_0 \) is that from a hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance (70 s m\(^{-1}\)) and albedo (0.23), closely resembling the \( ET \) from an extensive surface of green grass cover of uniform height, actively growing and not short of water, which is given by Allen et al. (1998):

\[
ET_0 = 0.408\Delta R_n - G + \gamma \frac{900}{T + 273} U_2 (e_a - e_d)
\]

where \( ET_0 \) is reference evapotranspiration (mm d\(^{-1}\)); \( \Delta \) is the slope of the saturation vapour pressure function (kPa °C\(^{-1}\)); \( R_n \) is net radiation (MJ m\(^{-2}\) d\(^{-1}\)); \( G \) is soil heat flux density (MJ m\(^{-2}\) d\(^{-1}\)); \( \gamma \) is the psychometric constant (kPa °C\(^{-1}\)); \( T \) is mean air temperature (°C); \( U_2 \) is average 24-h wind speed at 2 m height (m s\(^{-1}\)); and VPD is vapour pressure deficit (kPa).

### 2.2.2 Adjusted Hargreaves equation

The lack of weather data motivated Hargreaves et al. (1985), to develop a simpler approach where only minimum and maximum air temperature values are required. The Hargreaves equation (HARG) can be written as:

\[
ET_{0,\text{harg}} = HC \cdot R_a \cdot (T_{\text{max}} - T_{\text{min}})^{HE} \cdot \left( \frac{T_{\text{max}} + T_{\text{min}}}{2} + HT \right)
\]

where \( ET_{0,\text{harg}} \) is \( ET_0 \) estimated by the Hargreaves equation (mm d\(^{-1}\)); \( R_a \) is extraterrestrial radiation (mm d\(^{-1}\)); \( T_{\text{max}} \) is daily maximum air temperature (°C); \( T_{\text{min}} \) is daily minimum air temperature (°C); \( HC \) is the empirical Hargreaves coefficient, \( HE \) is the empirical Hargreaves exponent and \( HT \) is an empirical temperature coefficient (HC = 0.0023, \( HE = 0.5 \) and \( HT = 17.8 \); Hargreaves 1994).

Allen et al. (1998) proposed that when sufficient data to solve the FAO-56 PM equation are not available, and then the Hargreaves equation can be used. However, this equation generally overestimates \( ET_0 \) at humid locations (Jensen et al. 1990). These results motivated Trajkovic (2007) to develop the adjusted Hargreaves equation that provides close agreement with FAO-56 PM estimates at humid Serbian locations.

The adjusted Hargreaves (AHARG) equation can be written as (Trajkovic 2007):

\[
ET_{0,\text{aharg}} = 0.0023 \cdot 0.408 \cdot R_a \cdot (T_{\text{max}} - T_{\text{min}})_{0.424} \cdot \left( \frac{T_{\text{max}} + T_{\text{min}}}{2} + 17.8 \right)
\]

where \( ET_{0,\text{aharg}} \) is \( ET_0 \) estimated by the adjusted Hargreaves equation (mm d\(^{-1}\)). The AHARG equation requires temperature and latitude data for estimating \( ET_0 \).

### 2.3 Trend analysis methods

Many statistical techniques have been developed to detect trends within time series, such as the Bayesian procedure, Spearman’s Rho test, Mann-Kendall test and Sen’s slope estimator. In this study, one parametric method (linear regression) and two non-parametric methods (Mann-Kendall and Spearman’s Rho) were used to detect the \( ET_0 \) trends.
2.3.1 Linear regression method A linear regression method attempts to explain the relationship between two or more variables using a straight line. Regression refers to the fact that although observed data are variable, they tend to regress towards their mean, while linear refers to the type of equation we use in our models. A linear regression line has an equation of the form:

\[ y = a + b \cdot x \]  

(4)

where \( x \) is the explanatory variable, \( y \) the dependent variable, \( b \) the slope of the line and \( a \) is the intercept.

The slope indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends. Linear regression analysis is used for detecting and analysing trends in time series.

2.3.2 Mann-Kendall trend test The Mann-Kendall statistical test (Mann 1945, Kendall 1975) has frequently been used to quantify the significance of trends in hydro-meteorological time series (Douglas et al. 2000, Yue et al. 2002a, Partal and Kahya 2006, Modarres and Silva 2007, Hamed 2008, Tabari and Marofi 2011, Tabari et al. 2011a). The Mann-Kendall test statistic \( S \) is calculated using:

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i)
\]  

(5)

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 determined as:

\[
\text{sgn}(x_j - x_i) = \begin{cases} 
+1, & \text{if } x_j - x_i > 0 \\
0, & \text{if } x_j - x_i = 0 \\
-1, & \text{if } x_j - x_i < 0 
\end{cases}
\]  

(6)

The variance is computed as:

\[
\text{var}(S) = \frac{n \cdot (n - 1) \cdot (2 \cdot n + 5)}{18}
\]  

(7)

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 the absence of ties between the observations, the variance is computed as:

\[
\text{var}(S) = \frac{n \cdot (n - 1) \cdot (2 \cdot n + 5)}{18}
\]  

(8)

In cases where the sample size \( n > 10 \), the standard normal test statistic \( Z_S \) is computed as:

\[
Z_S = \begin{cases} 
\frac{S-1}{\sqrt{\text{var}(S)}}, & \text{if } S > 0 \\
0, & \text{if } S = 0 \\
\frac{S+1}{\sqrt{\text{var}(S)}}, & \text{if } S < 0 
\end{cases}
\]  

(9)

Positive values of \( Z_S \) indicate increasing trends while negative \( Z_S \) values show decreasing trends.

Testing of trends is done at a specific significance level, \( \alpha \). In this study, significance levels of \( \alpha = 0.01 \) 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 \( p \)-value (local significance level or probability value, \( p \)) for the Mann-Kendall trend test can be obtained from Yue et al. (2002b):

\[
p = 0.5 - \Phi(|Z_S|)
\]  

(10)

where:

\[
\Phi(|Z_S|) = \frac{1}{\sqrt{2\pi}} \int_0^{\sqrt{2}} e^{-\frac{t^2}{2}} dt
\]  

(11)

denotes the cumulative distribution function of a standard normal variable.

Given the significance level (\( \alpha \)), if the value \( p < \alpha \), then a trend is considered to be statistically significant. For example, at the significance level of 0.05, if \( p \leq 0.05 \), then the trend is assessed to be statistically significant.
2.3.3 Spearman’s Rho test

This is a non-parametric method commonly used to verify the absence of trends. The null hypothesis (H₀) is that all the data in the time series are independent and identically distributed, while the alternative hypothesis (H₁) is that increasing or decreasing trends exist (Yue et al. 2002b).

The Spearman’s Rho test statistic \( D \) and the standardized test statistic \( Z_D \) are expressed as follows (Lehmann 1975, Sneyers 1990):

\[
D = 1 - \frac{6 \sum_{i=1}^{n} (R(X_i) - i)^2}{n(n^2 - 1)} \quad (12)
\]

\[
Z_D = D \sqrt{\frac{n-2}{1 - D^2}} \quad (13)
\]

where \( R(X_i) \) is the rank of \( i \)th observation \( X_i \) in the time series, and \( n \) is the length of the time series. The sample size in this study is \( n = 31 \).

Positive values of \( Z_D \) indicate increasing trends while negative values of \( Z_D \) show decreasing trends. At the 5% significance level, the null hypothesis of no trend is rejected if \( |Z_D| > 2.08 \) and rejected if \( |Z_D| > 2.831 \) at the 1% significance level.

2.3.4 Serial autocorrelation test

To remove serial correlation from a series, von Storch and Navarra (1995) suggested pre-whitening of the series before applying the Mann-Kendall test. This study incorporates this suggestion in both the Mann-Kendall and Spearman’s Rho tests and computes the lag-1 serial correlation coefficient (designated by \( r_1 \)) as:

\[
r_1 = \frac{\sum_{i=1}^{n-1} (x_i - \bar{x}_{(1)}) \cdot (x_{i+1} - \bar{x}_{(2)})}{\sqrt{\sum_{i=1}^{n-1} (x_i - \bar{x}_{(1)})^2} \cdot \sqrt{\sum_{i=2}^{n} (x_i - \bar{x}_{(2)})^2}} \quad (14)
\]

where \( \bar{x}_{(1)} \) is the mean of the first \((n - 1)\) observations and \( \bar{x}_{(2)} \) is the mean of the last \((n - 1)\) observations.

2.4 Trend analysis using web-based services

Trend analysis software based on Web services was developed to investigate trends in FAO-56 PM and AHARG ET₀ time series. The architecture of the software component for ET₀ trend analysis is shown in Fig. 2. This architecture is a follow-up to the study of Gocic and Trajkovic (2011). The first step is data entry using the Input Data Provider. The data from the measuring stations are parsed and stored in an SQL database (hydrological database) using the web-based storage service.

The main input data are: date (format dd/mm/yy), daily maximum temperature (°C, \( T_{max} \)), daily minimum temperature (°C, \( T_{min} \)), wind speed, latitude (°), elevation (m), daily minimum and maximum relative air humidities (RH_{min}, RH_{max}), daily dew-point temperature (°C, \( T_{dew} \)) and vapour pressure (VP). Information on the latitude and elevation of the measuring station and the date are required for the estimation of extra-terrestrial solar radiation (\( R_a \)) and the maximum sunshine hours (\( N \)).

The ET₀ model consists of two components: model equation and numerical estimator. Model equation contains the following ET₀ equations: temperature-based, radiation-based, pan evaporation-based and combination-type. This study is based on the FAO-56 PM and AHARG equations.

The numerical estimator calculates the output data. It contains the logic for selection of the appropriate ET₀ equation according to the choice of input parameters.

The Trend Analyser component contains the logic for selecting parametric or non-parametric methods for monthly, seasonal and annual trend analyses. The present study uses linear regression, Mann-Kendall and Spearman’s Rho methods. Each trend method is
Table 3 Statistics: mean, SD and CV, of the estimated FAO-56 PM and AHARG ET₀, for the 12 weather stations during the period 1980–2010.

| Station   | FAO-56 PM |          |          |          | AHARG   |          |          |
|-----------|-----------|----------|----------|----------|---------|----------|----------|
|           | (mm d⁻¹)  | (mm d⁻¹) | (%)      | (mm d⁻¹) | (mm d⁻¹) | (%)      |          |
| Belgrade  | 2.501     | 0.220    | 8.81     | 2.171    | 0.104    | 4.77     |
| Dimitrovgrad | 2.416    | 0.161    | 6.68     | 2.317    | 0.110    | 4.76     |
| Kragujevac | 2.134     | 0.152    | 7.14     | 2.313    | 0.111    | 4.81     |
| Kraljevo  | 2.184     | 0.160    | 7.31     | 2.303    | 0.109    | 4.74     |
| Loznica   | 2.054     | 0.143    | 6.96     | 2.280    | 0.109    | 4.77     |
| Negotin   | 2.258     | 0.152    | 6.73     | 2.290    | 0.114    | 4.97     |
| Nis       | 2.292     | 0.205    | 8.94     | 2.405    | 0.131    | 5.46     |
| Novi Sad  | 2.363     | 0.207    | 8.76     | 2.197    | 0.142    | 6.46     |
| Palic     | 2.405     | 0.216    | 8.99     | 2.145    | 0.109    | 5.07     |
| Sombor    | 2.320     | 0.205    | 8.85     | 2.246    | 0.115    | 5.11     |
| Vranje    | 2.552     | 0.216    | 8.47     | 2.372    | 0.109    | 4.59     |
| Zlatibor  | 1.975     | 0.156    | 7.89     | 1.820    | 0.127    | 6.96     |

Fig. 3 Lag-1 serial correlation coefficient for the FAO-56 PM and AHARG ET₀ series at the weather stations during the period 1980–2010.
implemented as a web service, which is written in C#. The end-user can select the appropriate study period, weather station and statistical method. After selection, the results are published as a table. This component can be used to facilitate the trend analysis process.

The trend analysis web services and accompanying WSDL and SOAP 1.2 documentation are available for free download from http://www.gaf.ni.ac.rs/mgocic/TrendWebServices.htm. More information about web services can be found in Staab et al. (2003), Alonso et al. (2004), Papazoglou et al. (2007) and Papazoglou and Heuvel (2007).

The output data from this component can be obtained from the output data provider. The output data are: ET₀, Rₐ, N, daily net radiation (Rₙ), estimated missing weather data and monthly, seasonal and annual trend analyses results for the data.

3 RESULTS

Statistical characteristics of the FAO-56 PM and AHARG ET₀ estimated for the 12 weather stations for the period 1980–2010 are summarized in Table 3. The mean daily estimates of the FAO-56 PM and AHARG methods range from 1.975 to 2.552 and 1.820 to 2.405 mm d⁻¹, respectively. The highest coefficient of variation (CV) of the FAO-56 PM ET₀ values was 8.99% observed at the Palic station located in northern Serbia, while the highest CV of 6.96% was observed at Zlatibor for the AHARG ET₀ values. The lowest CV, 6.68%, was found at Dimitrovgrad for the FAO-56 PM ET₀, while the lowest CV of 4.59% was observed at Vranje for the AHARG ET₀ values.

Autocorrelation plots for the FAO-56 PM and AHARG ET₀ at the 12 weather stations are presented in Fig. 3. Both FAO-56 PM and AHARG ET₀ series had a positive lag-1 serial correlation coefficient at all stations. The highest serial correlations of 0.59 and 0.62 were obtained at Negotin (FAO-56 PM) and Zlatibor (AHARG) stations, respectively. The lowest serial correlations of 0.01 and 0.03 were detected at Loznica (AHARG) and Dimitrovgrad (FAO-56 PM), respectively.

3.1 Trends of ET₀

Trends of ET₀ are considered statistically at the 1 and 5% significance levels. When a significant trend is
identified by three statistical methods, the trend is presented in bold character in the table.

3.1.1 Monthly analysis The results of the three statistical tests for the monthly FAO-56 PM ET₀ over the period 1980–2010 are summarized in Supplementary Material, Table S1. The Mann-Kendall and Spearman’s Rho tests for trend analysis of monthly ET₀ produced similar results. All stations exhibited no significant trends in the months of January, February, March, September, October and December. The results show that the only the significant trends were increasing trends. However, the Nis and Vranje weather stations exhibited no significant trends. The magnitude of the significant increasing trends in the FAO-56 PM ET₀ series varied from 0.114 mm/month at Loznica station in November to 0.990 mm/month at the Belgrade station in July.

The results of the three statistical tests for the monthly AHARG ET₀ over the period 1980–2010
are summarized in Supplementary Material, Table S2. All stations had no significant trends in the months of January, February, March, September, October and December, which is similar to FAO-56 PM ET$_0$ series. The slope of the significant increasing trends in the AHARG ET$_0$ series ranged from 0.148 mm/month at the Vranje station in November to 0.872 mm/month at the Zlatibor station in May.

Figure 4 shows the percentage of stations with significant positive trends for the monthly FAO-56 PM and AHARG ET$_0$ during 1980–2010. The largest numbers of stations with significant trends were found in the AHARG ET$_0$ series at the 5% significance level in August and November (66.67%), while the lowest numbers of stations with significant trends were found in the FAO-56 PM ET$_0$ series at the 1% and 5% significance levels in June and July (8.33%), respectively.

The spatial distribution and rate of the Mann-Kendall trend at the 1 and 5% significance levels for monthly FAO-56 PM ET$_0$, 1980–2010, are presented in Fig. 5. The size and significance of the trends in FAO-56 PM ET$_0$ are greater in northern and central Serbia, with one exception in the south in November.

3.1.2 Seasonal analysis Results of the statistical tests for seasonal FAO-56 PM and AHARG ET$_0$ for 1980–2010 are presented in Tables 4 and 5, and clearly show that significant increasing trends occur in the FAO-56 PM and the AHARG ET$_0$ series.

Analysis of the ET$_0$ series revealed that there were significant increasing trends in spring at Negotin, Palic and Sombor for FAO-56 PM, and at Nis and Zlatibor for AHARG. In summer, the significant increasing trends were significant at the 1% level for FAO-56 PM ET$_0$ series, except at Dimitrovgrad, Nis and Vranje, where there were no significant trends. It is apparent that all stations except Loznica had significant increasing trends for summer in the AHARG ET$_0$ series.

The results also indicate that there were no increases or decreasing trends in autumn in the AHARG ET$_0$ series, while there was significant

| Station name | Spring | Summer |
|--------------|--------|--------|
|              | p-value | Z$_S$ | Z$_D$ | b (mm/year) | p-value | Z$_S$ | Z$_D$ | b (mm/year) |
| **FAO-56 PM** |         |      |      |            |         |      |      |            |
| Belgrade     | 0.0427* | 1.734 | 1.863 | 5.409      | 0.0006**| 3.229**| 3.821**| 9.766      |
| Dimitrovgrad | 0.4522  | –0.136| –0.285| –0.017     | 0.0901  | 1.360 | 1.386 | 4.712      |
| Kragujevac   | 0.0375* | 1.785 | 1.888 | 2.879      | 0.0004**| 3.348**| 4.328**| 7.410      |
| Kraljevo     | 0.1075  | 1.258 | 1.208 | 2.312      | 0.0006**| 3.263**| 3.749**| 8.449      |
| Loznica      | 0.0526  | 1.632 | 1.694 | 2.907      | 0.0031**| 2.753**| 3.214**| 5.540      |
| Negotin      | 0.0119* | 2.278*| 2.581*| 4.153      | 0.0003**| 4.045**| 5.320**| 9.810      |
| Nis          | 0.2420  | 0.714 | 0.723 | 1.423      | 0.0427* | 1.734 | 1.626 | 4.931      |
| Novi Sad     | 0.1271  | 1.156 | 1.136 | 3.896      | 0.0055**| 2.579**| 2.936**| 7.889      |
| Palic        | 0.0024**| 2.821**| 3.036**| 6.147      | 0.0014**| 2.991**| 3.228**| 10.430     |
| Sombor       | 0.0047**| 2.600**| 2.840**| 6.343      | 0.0003**| 4.028**| 5.240**| 9.584      |
| Vranje       | 0.3745  | –0.340| –0.283| –0.442     | 0.0594  | 1.564 | 1.509 | 5.691      |
| Zlatibor     | 0.1490  | 1.054 | 1.164 | 2.314      | 0.0010**| 3.093**| 3.569**| 7.133      |
| **AHARG**    |         |      |      |            |         |      |      |            |
| Belgrade     | 0.0643  | 1.530 | 1.518 | 2.461      | 0.0013**| 3.025**| 3.350**| 4.590      |
| Dimitrovgrad | 0.0427* | 1.734 | 1.794 | 2.638      | 0.0005**| 3.297**| 3.922**| 5.968      |
| Kragujevac   | 0.1003  | 1.285 | 1.014 | 2.024      | 0.0002**| 3.543**| 4.325**| 6.037      |
| Kraljevo     | 0.0901  | 1.360 | 1.319 | 1.626      | 0.0107* | 2.312* | 2.567* | 4.458      |
| Loznica      | 0.0694  | 1.496 | 1.526 | 1.600      | 0.0694  | 1.496 | 1.302 | 1.899      |
| Negotin      | 0.1003  | 1.292 | 1.465 | 2.527      | 0.0020**| 2.889**| 3.671**| 6.119      |
| Nis          | 0.0125* | 2.243*| 2.552*| 3.470      | 0.0007**| 3.807**| 4.747**| 7.941      |
| Novi Sad     | 0.0594  | 1.564 | 1.661 | 3.665      | 0.0181* | 2.413* | 2.815* | 4.640      |
| Palic        | 0.1075  | 1.258 | 1.291 | 2.056      | 0.0227* | 2.006* | 2.277* | 3.800      |
| Sombor       | 0.0570  | 1.581 | 1.722 | 2.526      | 0.0035**| 2.702**| 2.861**| 4.015      |
| Vranje       | 0.0392* | 1.768 | 1.978 | 2.458      | 0.0031**| 2.753**| 3.211**| 5.383      |
| Zlatibor     | 0.0001**| 3.637**| 4.666**| 4.770      | 0.0006**| 3.841**| 5.903**| 7.527      |

$b$: slope of linear regression, $Z_S$: Mann-Kendall test, $Z_D$: Spearman’s Rho test.
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.
Bold characters represent trends identified by the three statistical methods together.
increasing trend at Sombor at the 5% significance level in autumn for the FAO-56 PM ET₀ series. In addition, significant increasing trends were obtained at Loznica and Sombor (FAO-56 PM ET₀) and at Nis and Zlatibor (AHARG ET₀), at the 5% significance level in winter.

Figure 6 shows the spatial distribution of seasonal FAO-56 PM ET₀ trends at the 1% and 5% significance levels using the Mann-Kendall test. The stations with significant positive trends are mainly distributed in southern and central Serbia in summer. The significant positive trends are located in the north in spring, autumn and winter, with two exceptions: in the east in spring and in the west in winter.

### 3.1.3 Annual analysis

Results of the Mann-Kendall, Spearman’s Rho and the linear regression analysis for the annual FAO-56 PM and AHARG ET₀ series, 1980–2010, are shown in Table 6. All trends significant at the 1% and 5% levels were increasing. The significant increasing trends in annual FAO-56 PM ET₀ varied from 3.772 mm/year at Negotin station to 5.163 mm/year at the Sombor station. In the annual AHARG ET₀ series, the significant increasing trends ranged from 1.810 mm/year at Sombor to 3.623 mm/year at Zlatibor. The results also indicated that 41.67% and 25% of stations had no significant annual trends for FAO-56 PM and AHARG ET₀ series, respectively.

The spatial distribution of annual FAO-56 PM ET₀ trends (1% and 5% significance) from the Mann-Kendall test for 1980–2010 is presented in Fig. 6. The significant increasing trends were located in northern and central Serbia, while there were no significant trends in southern Serbia.

### Table 5 Results of the statistical tests for autumn and winter FAO-56 PM and AHARG ET₀ over the period 1980–2010.

| Station name | Autumn | Winter |
|--------------|--------|--------|
|              | p-value | Zₛ    | Z_Do  | b (mm/year) | p-value | Zₛ    | Z_Do  | b (mm/year) |
| **FAO-56 PM** |         |       |       |             |         |       |       |             |
| Belgrade     | 0.2177  | 0.782 | 0.921 | 1.865       | 0.4920  | -0.034| -0.152| 0.314       |
| Dimitrovgrad | 0.4364  | -0.170| -0.348| -0.338      | 0.2877  | -0.578| -0.632| -0.471      |
| Kragujevac   | 0.4602  | 0.119 | 0.227 | 0.476       | 0.1075  | 1.241 | 1.050 | 0.707       |
| Kraljevo     | 0.3446  | 0.408 | 0.539 | 0.272       | 0.0694  | 1.496 | 1.369 | 0.936       |
| Loznica      | 0.1401  | 1.088 | 1.118 | 0.622       |         |       |       |             |
| Negotin      | 0.4207  | -0.204| -0.176| -0.509      | 0.3300  | 0.442 | 0.596 | 0.800       |
| Nis           | 0.4207  | -0.204| -0.315| -4.932      | 0.2546  | 0.680 | 0.568 | 0.384       |
| Novi Sad     | 0.4207  | -0.204| -0.274| -0.010      | 0.452   | -0.136| -0.342| -0.142      |
| Palic        | 0.0465* | 1.700 | 1.851 | 1.690       | 0.3300  | 0.442 | 0.453 | 0.350       |
| Sombor       | **0.0191*** | **2.363*** | **2.501*** | **2.574** | **0.0170*** | **2.125*** | **2.087*** | **2.152**  |
| Vranje       | 0.0526  | -1.632| -1.719| -2.195      | 0.1894  | -0.884| -0.867| -0.337      |
| Zlatibor     | 0.4973  | 0.001 | 0.122 | 0.314       | 0.1844  | 0.884 | 1.035 | 0.438       |

| **AHARG** |         |       |       |             |         |       |       |             |
| Belgrade    | 0.1112  | 1.224 | 1.113 | 0.573       | 0.3085  | 0.510 | 0.455 | 0.251       |
| Dimitrovgrad| 0.2546  | 0.680 | 0.761 | 0.563       | 0.0694  | 1.496 | 1.669 | 0.670       |
| Kragujevac  | 0.4761  | -0.069| -0.187| -0.146      | 0.2236  | 0.764 | 0.770 | 0.489       |
| Kraljevo    | 0.4973  | 0.001 | 0.141 | 0.124       | 0.2177  | 0.782 | 0.837 | 0.398       |
| Loznica     | 0.4207  | 0.204 | 0.052 | 0.039       | 0.1401  | 1.088 | 1.023 | 0.589       |
| Negotin     | 0.3228  | -0.476| -0.605| -0.031      | 0.4207  | 0.204 | 0.154 | 0.288       |
| Nis          | 0.0571  | 1.598 | 1.782 | 1.326       | **0.0227*** | **2.006*** | **2.081*** | **1.011**  |
| Novi Sad     | 0.1401  | 1.088 | 1.058 | 0.854       | 0.2611  | 0.646 | 0.625 | 0.411       |
| Palic        | 0.3974  | -0.272| -0.217| -0.042      | 0.4129  | 0.238 | 0.259 | 0.189       |
| Sombor       | 0.2358  | 0.731 | 0.626 | 0.418       | 0.3300  | 0.459 | 0.400 | 0.280       |
| Vranje       | 0.4973  | 0.001 | 0.089 | 0.270       | 0.0643  | 1.530 | 1.669 | 0.761       |
| Zlatibor     | 0.0392* | 1.768 | 1.897 | 1.192       | **0.0179*** | **2.108*** | **2.105*** | **0.841**  |

| b | slope of linear regression, Zₛ: Mann-Kendall test, Z_Do: Spearman’s Rho test. |
|**Statistically significant trends at the 5% significance level.**|
|**Statistically significant trends at the 1% significance level.**|
|**Bold characters represent trends identified by all three statistical methods together.**|

Analysis of trends in reference evapotranspiration data
2.211 mm/year at Vranje to 3.623 mm/year at Zlatibor station.

4 DISCUSSION

ET\textsubscript{0} depends on changes in air temperature (minimum and maximum), solar radiation, RH and wind speed (Gocic and Trajkovic 2010, Tabari et al. 2011a, Liu and McVicar, 2012). We investigated the relationship between these meteorological variables and the ET\textsubscript{0} trends.

According to Türkes and Sümer (2004) and Dhorde et al. (2009), the local physical geographic and atmospheric circulation features can impact on the nature and magnitude of maximum and minimum temperature trends. These factors may also influence the changes of ET\textsubscript{0} that can be seen at the seasonal scale between the flatlands of northern Serbia (Novi Sad, Palic, Sombor) and the highlands in central and southern Serbia (Kragujevac, Zlatibor, Nis, Vranje).

Djordjevic (2008) and Gocic and Trajkovic (2013) found that the most significant increasing trends in the T\textsubscript{min} and T\textsubscript{max} series, and the significant decreasing trend in the RH series occurred in summer. This could explain the significant increasing trend in ET\textsubscript{0} in summer (Table 4 and Fig. 6).

Moreover, Ducic et al. (2008) found that the air temperature increases in northern Serbia are approximately 1.5 times greater in the near-surface layer, compared to the lower and middle layers of the troposphere. According to the present results, the most significant increasing trends of ET\textsubscript{0} occurred in spring and summer. As addressed in Table 4, the significant increasing trend in summer was observed for both FAO-56 PM and AHARG ET\textsubscript{0} series at 75 and 92% of the stations, respectively.
The Mann-Kendall test detected that approximately 70% of the stations showed a significant decreasing trend in wind speed at the seasonal and the annual scale (Gocic and Trajkovic 2013). Similar results were detected by Jiang et al. (2010), who concluded that the fundamental reason for the decreasing trend in wind speed is the change of atmospheric circulation. A significant trend of increasing wind speed was found only at Palic station. The decreasing trend in wind speed may lead to an increase in ET₀ (Table 6).

### 5 CONCLUSIONS

The linear regression, Mann-Kendall and Spearman’s Rho tests were applied to analyse monthly, seasonal and annual trends in the FAO-56 PM and AHARG ET₀ series. Monthly weather data for this study were used from 12 weather stations in Serbia for the period 1980–2010.

The statistical analysis methods were developed as web services and are presented as the part of the trend analyser component. In general, this study showed that there is a great similarity between the statistical results from the three statistical methods. Similar conclusions were confirmed by Yue et al. (2002b), Tabari et al. (2011a) and Shadmani et al. (2012).

In general, all of the trends in the ET₀ series significant at the 1 and 5% levels were increasing. Furthermore, none of the stations exhibited any significant trends in the months of January, February, March, September, October and December, for both the FAO-56 PM and AHARG ET₀ series. According to the Mann-Kendall test results, the highest numbers of stations with significant trends were found in the monthly FAO-56 PM ET₀ series in July and August, while the lowest numbers of stations with significant trends were found in April.

The positive ET₀ trends were significant at the 1 and 5% significance levels, according to the statistical tests in the spring, summer and winter seasons at about 25%, 75%, 8.33% and 16.67% of the stations (FAO-56 PM) and about 16.67%, 91.67%, 0% and 16.67% of the stations (AHARG), respectively. Moreover, the highest significant

### Table 6 Results of the statistical tests for the annual FAO-56 PM and AHARG ET₀ over the period 1980–2010.

| Station name | p-value | Zₘ | Z₅ | b (mm/year) |
|--------------|---------|----|----|-------------|
| **FAO-56 PM** |         |    |    |             |
| Belgrade     | 0.0055** | 2.549* | 2.913** | 4.301       |
| Dimitrovgrad | 0.2877   | 0.578 | 0.418 | 0.980       |
| Kragujevac   | 0.0066** | 2.498* | 2.889** | 2.910       |
| Kraljevo     | 0.0062** | 2.515* | 2.714* | 2.995       |
| Loznica      | 0.0091** | 2.379* | 2.644* | 2.579       |
| Negotin      | 0.0003** | 3.467** | 4.371** | 3.772       |
| Nis           | 0.0526   | 1.632 | 1.492 | 2.891       |
| Novi Sad     | 0.0392*  | 1.768 | 1.959 | 2.948       |
| **Palic**    | 0.0006** | 3.263** | 3.546** | 4.562       |
| **Sombor**   | 0.0001** | 3.756** | 4.859** | 5.163       |
| Vranje       | 0.4602   | 0.102 | 0.076 | 0.884       |
| Zlatibor     | 0.0274*  | 1.938 | 2.255* | 2.409       |
| **AHARG**    |         |    |    |             |
| Belgrade     | 0.0082** | 2.413* | 2.683* | 1.936       |
| Dimitrovgrad | 0.0013** | 3.025** | 3.473** | 2.460       |
| Kragujevac   | 0.0082** | 2.414* | 2.680* | 2.174       |
| Kraljevo     | 0.0287*  | 1.904 | 2.105* | 1.592       |
| Loznica      | 0.1190   | 1.190 | 1.326 | 1.028       |
| Negotin      | 0.0062** | 2.515* | 2.781* | 2.167       |
| Nis           | 0.0003** | 3.433** | 4.316** | 3.419       |
| Novi Sad     | 0.0125*  | 2.244* | 2.522* | 2.377       |
| Palic        | 0.0643   | 1.530 | 1.709 | 1.453       |
| Sombor       | 0.0113*  | 2.295* | 2.443* | 1.810       |
| Vranje       | 0.0017** | 2.923** | 3.368** | 2.211       |
| Zlatibor     | 0.00002** | 4.079** | 5.308** | 3.623       |

b: Slope of linear regression, Zₘ: Mann-Kendall test, Z₅: Spearman’s Rho test
* Statistically significant trends at the 5% significance level.
** Statistically significant trends at the 1% significance level.
Bold characters represent trends identified by all three statistical methods together.
increasing trend was detected in the summer season at Palic station.

On the annual time scale, the significant increasing trends varied from 3.772 mm/year at the Negotin station to 5.163 mm/year at Sombor station, for FAO-56 PM ET₀, and from 1.810 mm/year at the Sombor station to 3.623 mm/year at the Zlatibor station, for the AHARG ET₀ series. The increasing trends were significant for 70% of the stations at the 1% and 5% significance levels.

Fig. 7 Time series and linear trends of annual FAO-56 PM (a) and AHARG ET₀ (b) at the stations with significant trends at $\alpha = 0.01$. 

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The analysed results will be helpful for planning the efficient use of water resources to improve agricultural production. Further research in analysing relationships between meteorological variables and ET₀ trends is recommended.

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SUPPLEMENTARY MATERIAL

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