Innovative and successive average trend analysis of temperature and precipitation in Osijek, Croatia

Abstract: The paper examines monthly, seasonal, and annual trends in temperature and precipitation time series in Osijek during the period between 1900–2018. Two new methods, including Innovative Trend Analysis (ITA) and Successive Average Methodology (SAM) together with the classic Mann-Kendall (M-K) and Sen's Slope methods, have been applied to determine potential trends in the variables at different time scales. Moreover, time series decomposition using locally estimated scatterplot smoothing (STL) was conducted to determine trend, seasonality, and the relationship in the components of each variable. Regarding the air temperature, ITA showed a monotonic positive trend at relatively low (T≤10°C) and high (T≥13°C) temperature ranges in all seasons, excluding spring. A positive trend was also found in the medium temperature range in this season which agrees with the results of M-K test. The highest Sen's slope was obtained in January, followed by April. According to the results acquired for the observed precipitation time series, it was discovered that Osijek has experienced decreasing trend in spring precipitation. However, there is no trend in annual precipitation at 5% significance level. Differing from the M-K results, the ITA showed decreasing trend in both spring and autumn seasons. Summer precipitation increases with a significant change in the high precipitating amounts ($P \geq 100$ mm). Comparing successive pair of partial trends in both historical temperature and precipitation, our results showed that trends in peak and trough change-points are very close to each other, indicating a slight positive (negative) trend for annual temperature (precipitation) during the past century.

Keywords: Innovative Trend Analysis, Successive Average Methodology, Mann-Kendall test, temperature, precipitation, Osijek

1. Introduction

Trend analysis is an important part of environmental monitoring that allows identification of the primary question about the variation of environmental variables over time. Many researchers have explored temperature and precipitation trend at local and regional scales (Kadioğlu 1997; Jones

1999; Jain 2012; Gocic and Trajkovic 2013; Addisu et al. 2015; Yao and Chen 2015; Tosunoğlu 2017; Nourani et al. 2018; Panda and Sahu 2019; Yacoub and Tayfur 2019; Güçlü 2020). Focusing on the Pannonian region, a large flat alluvial basin in Central Europe, also known as the Carpathian Basin, several studies reported the rise in the temperature across the region (Bartholy and Pongrácz 2007; Koprivšek et al. 2012; Bonacci 2010, 2012; Melo 2013; Zhu et al. 2019). Regarding climate change, and more frequent extreme weather and climate disasters, especially droughts, fertile Pannonian lowland belongs to the endangered areas. It is necessary to make strategic plans to mitigate its consequences on agriculture, which should be based on the analyses of long-lasting air temperature and precipitation time series. The Osijek station is one of the oldest meteorological stations in the Pannonian lowland, and the analysis of its climatological data can be of special regional importance. In the time of climate change, mostly global warming, this region should be prepared for an unknown, yet threatening future. According to the 6th National Communication of the Republic of Croatia under the UN Framework Convention on Climate Change, greater warming, between 1.5°C and 2°C, is projected over the eastern and central parts of the country in the winter. In the eastern part of Slavonia where the Osijek station is located, the statistically significant increase (more than 12%) of precipitation is projected (Tadić et al. 2019a).

Different aspects of the time series of climatological parameters monitored at the Osijek meteorological station have already been investigated in a few papers. For example, the historical series of annual precipitation in Osijek during the 1891-1990 period has been studied by Gajić-Čapka (1993). A noteworthy decreasing trend in annual precipitation was found in this continental lowland meteorological station. Kovačević et al. (2009) concluded that the relation between maize yield and weather changes became more tightened in 1996-2003 period due to extremely arid conditions. The aridity index has been proved as a useful tool for characterizing impacts of rainfall and temperature pattern on maize yield in southeast Europe. Using the method of rescaled adjusted partial sums (Garbrecht and Fernandez 1994), Bonacci (2010, 2012) revealed a statistically significant jump in the Western Balkans region that started in the early 1980s. A recent study on the historical air temperature at 67 meteorological stations (including Osijek station) showed that warming started during the period between 1987-1997 in the Western Balkans region (Bonacci 2010). At Osijek station, warming started in 1988. The difference between the mean annual temperature before and after the warming is about 0.83 °C (Bonacci 2010, 2012). Precipitation data from the period between 1961–2010 in Osijek was analyzed for spatial characteristics of trends in the precipitation amounts and precipitation indices (Gajić-Čapka et al. 2015). The results revealed that the changes in the annual and seasonal amounts are predominantly weak. A significant trend was only detected for autumn precipitation. Gajić-Čapka (2013) analyzed daily and multi-day (two and five days) precipitation at the Osijek meteorological station in the period of 1949-2009. During the year, the daily variability is high. The study demonstrated that there are no changes regarding the intensity and frequency of the one-day, two-day, and five-day precipitation amounts during the historical period. Tadić et al. (2019a) applied principal components analysis to evaluate climate change impacts on the variation of precipitation and air temperature at the Osijek station. The study indicated that principal components analysis can be satisfactorily used for detecting trends in hydro-climatological variables.

Using measured precipitation and temperature data from 13 stations distributed across Croatia (Osijek station included), Tadić et al. (2019b) explored the meteorological drought in the region. The results showed that a positive trend in the air temperature during the period of 1981–2018 strongly affected the occurrence and intensity of meteorological drought in the country. Despite several studies on temperature and precipitation trend in the Pannonian region, our review discovered that only a few studies explored temperature/precipitation trends in the region considering long-lasting (a century or more) observations. Likewise, most of the studies have been confined to classical trend analyzing methods such as Mann-Kenall (M-K) test, or linear regression analysis. To the best of our knowledge, potential advantages of new methods such as innovative trend analysis (ITA: Şen 2012; 2014) and successive average methodology (SAM: Şen 2019) have not yet been explored for the Pannonian region. Therefore, in this study, we aimed at trend analysis and partial trend identification in temperature and precipitation using these new methods. Moreover, the method of seasonal and trend decomposition using Loess (STL) was applied to explore the relationship between different components of the temperature/precipitation time series. Data collected at the Osijek meteorological station from the beginning of the twentieth century to the recent time (1900-2018) is used in the present study, thus providing us with crucial information about climate variation in this region.

2. Study area and data

The city of Osijek is in the northeastern part of the Croatian Pannonian lowland near the Hungarian and Serbian border. It is also a river port along the Drava River, a rapidly growing urban area. The population increased from 25,550 inhabitants in 1880 to 129,792 in 1999. After the war (1991-1995) and according to the 2011 census, the total population of the city decreased to 108,048 inhabitants.

The Osijek station (Figure 1) is one of the oldest meteorological stations in Croatia. Thus, the analyses of measured data in this station is of special importance for the region. It is operated by Croatian state national network of meteorological stations, for which air temperature data are homogenized. Although its location was changed three times during the period between 1900-2018, there is no missing data. In the first period (1900-1943) its coordinates were 45º 33' N and 18º 40' E, while altitude was 91 m a.s.l. In the second period (1944-1991) its coordinates were 45º 12' N and 18º 44' E, and altitude was 91 m a.s.l. During these two time periods, the station was in the urban area of Osijek. Recent location, which began its work in 1992 (Figure 1 right) has the following coordinates: 45º 30' 09" N and 18º 33' 41" E with altitude 89 m a.s.l.

Broader Osijek area, located in the Pannonian lowland is a part of northeastern Croatia and experiences a temperate, continental climate, which is considered as Dfb according to the Köppen-Geiger climate classification. This indicates warm and moist summer and cold, often snowy, winters with no significant precipitation difference between seasons. (Cvitan and Patarčić 2018). Mean monthly, seasonal, and annual temperature, and total monthly, seasonal, and annual precipitation time series for the period 1900-2018 are shown in Figures 2 and 3, respectively.

3. Methods

3.1.Mann-Kendall trend analysis

Most previous trend analyses of environmental data have been performed using non-parametric Mann-Kendall trend test that makes no assumption about the underlying distribution of that data (e.g., Allen et al. 2015; Hori et al. 2017). This is a rank-based method which cares about the relative magnitudes of a given variable in its time series. The test is performed by calculating three different metrics: *S* statistic (Kendall, 1962), variance of S, and *Z* statistic, or test statistic.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (x_i - x_j) \tag{1}$$

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

$$Z = \left\{ \begin{array}{cc} \frac{S-1}{\sigma} & for\ \ S > 0 \\ \frac{S-1}{\sigma} & for\ \ S < 0 \\ 0 & for\ \ S = 0 \end{array} \right\} \tag{3}$$

where x_i and x_j are the data points (in this case, a temperature or precipitation value) at times i and j, respectively. $sign\ (x_i - x_j)$ equals +1 if $x_i$is greater than x_j and -1 if x_i is less than x_j.

The test statistics indicates if trend is increasing (+) or decreasing (-). The null hypothesis for M-K test is that there is no trend, and the alternative hypothesis is that there is an upward trend or downward trend. The trend is considered insignificant if Z is less than the significance levels (e.g., α=5%), but significant if Z ≥ |±1.96|. On the other hand, hypothesis for the significant trend rejection is valid, whereas acceptance is considered for no trend case.

3.2. Sen's slop

Sen’s slope (Sen 1968) is used to identify the magnitude of trend in a dataset. The method in non-parametric and insensitive to outliers. For a dataset with x_i and x_j as the sample data points, Sen’s slope is calculated using Equation (4).

$$Sen's\ slope = Median\ \left\{\frac{x_i - x_j}{j-i} : i < j\right\} \tag{4}$$

For confidence level of 95%, we calculated lower and upper intervals ($x_L and\ x_U$) with respect to the number of pairs of time series elements (N) and standard deviation of M-K test (σ).

$$x_L = \frac{N-k}{2} \tag{5}$$

$$x_U = \frac{N+k}{3} \tag{6}$$

Where k is the product of critical Z statistics and standard deviation of M-K test.

3.3. Seasonal and Trend decomposition using Loess (STL)

The Seasonal and Trend decomposition using Loess (STL) is a popular method for decomposing time series (Sanchez-Vazquez, et. al., 2012; Hrnjica & Mehr, 2020). The Loess is the method for determining the relationship between different components of a time series. It is a generalization of the moving average and the polynomial regression called **LO**cal r**E**gre**SS**ion (LOESS). The STL method begins with the well-known time series component model by decomposing the time series (Y_t) into a trend (t_t), a seasonal (s_t) and noise (ϵ_t) or remainder components by using Loess regressor (Cleveland et al., 1990).

$$Y_t = t_t + s_t + \epsilon_t. \tag{7}$$

By using Loess regressor, each observation is multiplied with the weight which is calculated in terms of distance (in time) between the time series value and the value to be smoothed. The weight value tends to be zero while the distance tends to be infinity. For any point in time t, the neighborhood weight value $v_i(t)$ related to observation t_i can be calculated using tricube weight function W:

$$v_i(t) = W\left[1 - \left(\frac{|t_i - t|}{\lambda_k(t)}\right)\right], \tag{8}$$

where $\lambda_k(t) = |t_i - t_k|$ represents the distance between kth farthest t_i and t. The parameters k determine the number of time series values included in the regression. The tricube weight function W is defined as:

$$W(x) = \begin{cases} (1-x^3)^3 \, for \; 0 \leq x \leq 1 \\ 0 \qquad\quad for \; x \geq 1. \end{cases} \tag{9}$$

The STL method uses two loops, inner and outer to decompose the given hydrometeorological time series. The inner loop is used to calculate trend and seasonal components using the Loess regressor. The outer loop is used to determine the robustness weight which is used in the next inner loop to reduce the influence of transient and deviant behavior of trend and seasonal components. Once the trend and the seasonal components are determined in the inner loop, the outer loop calculates the corresponding remainder component. Comparing to traditional time series decomposition, the STL has the following advantages (Hyndman and Athanasopoulos 2018), which motivated us to include it in this study.

- In addition to monthly and quarterly, the STL supports any type of seasonality. This means that the decomposed seasonal component can consist of different cycles through time. With such ability, one can analyze different values of positive and negative peak amplitude.
- It allows the season component to be changed over time, which is very handy for dynamics time series. However, it cannot handle the date variable automatically.
- STL is robust to outliers so that they do not affect the approximations of the trend and seasonal components.
- STL only support additive decomposition (see Equation 7), while multiplicative decomposition can be achieved by taking the logs of the data.

3.4. Innovative Trend Analysis (ITA)

The ITA (Şen 2012, 2014) is a simple and effective method for trend detection by means of graphical distribution of historical data. In ITA approach, the historical time series of observed data is split into two subseries of equal length called serials. Then, the serials are sorted in ascending order and plotted against each other (Figure 4). As illustrated in Figure 4, the 45° diagonal line is passed through the scatter diagram that divides the plot into the trend-free zone along the 1:1-line, with an upper triangular area indicating the increasing trend zone, and a lower triangle area indicating the decreasing trend zone. The ITA approach attracted many researchers in recent years (e.g., Dabanlı et al. 2016; Tosunoglu and Kisi. 2017; Ay et al. 2018 among others).

3.5. Successive average methodology (SAM)

Most of the trend analyzing methodologies in the literature discuss monotonic trends within a given hydrological time series. For long-term data, monotonic analysis holistically over the whole recording duration may lead to losing successive trends of different durations and slopes within the same time series. To manage the problem, Şen (2019), proposed a new partial trend methodology called successive arithmetic average methodology (SAM) in which peak and trough change-points, initial and ending points of partial trend durations and slopes are identified.

The SAM starts with searching for the change-points among the potential and natural change-point occurrences in a long-term hydrological time series. Firstly, for the given time series with the length of n and the data points of $x_1, x_2, \ldots, x_n$, the vector of successive arithmetic average is calculated according to the following formulation,

$$\overline{X}_i = \sum_{i=1}^{n} \left(\frac{1}{i} \sum_{j=1}^{i} x_j \right), \quad (10)$$

Then, the following statements are used to determine the position of local peak/trough change-points along time axis.

$$\begin{cases} if \quad \overline{X}_{i-1} < \overline{X}_i > \overline{X}_{i+1} \quad then \quad fix\ \boldsymbol{x_i\ as\ peak - change\ position} \\ if \quad \overline{X}_{i-1} > \overline{X}_i < \overline{X}_{i+1} \quad then \quad fix\ \boldsymbol{x_i\ as\ trough - change\ position} \end{cases} \tag{11}$$

Finally, successive two change-points are connected by linear lines indication partial duration trends. The corresponding slope (S_{ij}) is calculated by the following expression in which Y_i and Y_j denote the corresponding position (e.g. year for annual time series) of the two successive averages $\overline{X}_i$ and $\overline{X}_j$, respectively.

$$S_{ij} = \frac{\overline{X}_j - \overline{X}_i}{Y_j - Y_i} \tag{12}$$

4. Results and discussion

4.1. M-K test results

Table 1 presents the results of the M-K trend analysis for monthly observed temperature and precipitation. The M-K statistics Z value in each month was calculated and the associated significance level (p-value) was obtained. As previously mentioned, the null hypothesis for this test is that there is no trend. If the p-value of the test is less than the significant level of the test (α=5%), the test rejects the null hypothesis. According to the table, the M-K test for the historical precipitation showed that the p-values are greater than α in all months, excluding April, indicating there is insufficient evidence to reject the null hypothesis. The corresponding Z statistics in April is -2.42 far from critical Z = ±1.96, indicating a significant decreasing trend. Regarding the results for the air temperature, the M-K test does not show a significant increasing trend from April to June and August.

The results of the M-K test for observed temperature and precipitation at the seasonal and annual level were presented in Table 2. A significant increasing trend is obvious in mean seasonal temperature in spring and summer seasons that yields in a positive trend in annual temperature. By contrast, there is no trend in annual precipitation at 5% significance level even though spring precipitation decreases over time.

4.2.Sen's slope test results

The Sen's slope, along with the lower and upper limits of 95% confidence interval, were presented in Tables 3 and 4 for monthly and seasonal observations, respectively. The results showed a slightly positive trend for temperature in all months, seasons, and annual levels, excluding September and December. The highest slope is observed in January, followed by April. This is not in agreement with the results of M-K test that showed that the most significant trend appeared in August. Considering the Sen's slopes for precipitation series, it is obvious that Osijek experienced a decreasing trend in the period March to June and September to November. The highest decreasing trend is seen in April. According to Table 4, the summer temperature increased faster than other seasons. Notably, annual precipitation demonstrated a decrease with the slope of 0.33.

4.3. STL results

The STL decomposition was performed on the observed historical temperature and precipitation data to detect any seasonal or trend changes. The decomposition was performed for both monthly and seasonal (winter, spring, summer, and autumn) levels. Generally, the obtained results show changes in trends and seasonality on monthly and seasonal levels that can be considered as a signal of global climate change.

4.3.1. STL temperature decomposition results

The trend and seasonality analysis by using STL was performed by using *stlsplus* R package (Hafen 2016) which is based on original *stl* R package with some advancement in plotting. Figure 5 shows the time series components of the monthly temperature at Osijek in the period 1900-2018. Figure 6 shows the time series decomposition of the quarterly (winter, spring, summer, and autumn) temperature values at Osijek in the period 1900-2018. Monthly and quarterly based time series components show some changes during the time in the seasonal and the trend components. The seasonal component shows some minor changes in the magnitude. It can be stated that the lower magnitude change has greater values than the upper change. The changes are less than 1°C, and mostly depend on the loess window for seasonal extraction.

Very important changes come from trend components. From both time series decompositions, it is seen that a trend components have demonstrated some increasing trend in the past 19 years (2000-2018). It is the longest period with the trend above the average value. Figure 7 shows precisely the trend component with the average trend values. The increasing behavior of the trend for the past 19 years can clearly be observed.

Besides an increasing trend, the figure shows some anomalies (peaks and troughs) of the trend component in the past century. One can identify a decreasing trend during World War II. In addition, lower values of trend can be identified at the beginning of the 20th century, as well as in the 60s and 70s. The troughs are reflected in the remainder component in more quantities than in the seasonal component. This indicates that such anomalies are more likely due to noise in the data, rather than seasonal variations.

Figure 8 shows temperature changes in a specific period of the year during the observed period. The temperature changes in winter and autumn (Nov., Dec., Jan., Feb., and Mar.) are slightly higher than in spring and summer. This implies that winters and autumns are much different than summers and springs in terms of temperature. This could indicate that climate change has affected winter and autumn more than spring and summer. In other words, seasonal variations of the temperature were not significantly changed during the period even though the temperature changes can be identified on a seasonal basis.

4.3.2. STL precipitation decomposition results

Figures 9 and 10 illustrate the results of STL analysis for the observed precipitation time series. From the decomposition point of view, one cannot detect any trend at any time period that indicates water balance in Osijek station. However, the seasonal component for the precipitation was changed over the time (see Figures 9 and 10). The precipitation range in seasonal component is smaller than that of the remainder. Thus, the seasonal component has less influence on the time series than the remainder component. Comparing different components of precipitation, it can be concluded that reminder (error components) is the most dominant component in the observed precipitation time series.

The seasonal component can be identified as a pattern of fluctuation (i.e., increase or decrease) that reoccurs across periods of time, i.e. it is a periodic function with amplitude and period values. To analyze the seasonal component changes, the negative peak amplitude (NPA), positive peak amplitude (PPA), and the peak-to-peak amplitude (PTPA) were identified. The NPA and PPA represent the magnitude of a seasonal component in the positive and negative side of a cycle, respectively. Magnitude of the seasonal component of quarterly precipitation in Osijek is shown in Figure 11. The first marked values (PPA, NPA) are at the beginning of the century. The point is also identified as the biggest amplitude in the observed period (PTPA=35 mm). Since then, a decreasing trend for both PPA and NPA amplitudes is seen until the second critical point having a minimum PTPA of 10 mm. This indicates that the influence of the seasonal changes on the total precipitation is decreasing. Moving forward, an increasing behavior for the PTPA was identified, until it reaches the 26 mm of PTPA which is marked at beginning of the seventies of the last century. Since then, there is no uniform trend in the seasonal component. However, in the last 20 years, one can see a decreasing trend of the NPA. In fact, current NPA is four times less than 120 years ago, while the PPA is more or less constant. This indicates that the seasonal changes of the precipitation have less influence in the summer then 120 years ago.

The seasonal component period starts in 1900, when the PTPA is 35 mm, so that the NPA is –23 mm, and PPA is 12 mm. Since then, the trend is constantly decreasing till the middle of the 20th century when it reaches the minimum PTPA of 9 mm with NPA= –3 and PPA=6 mm. From 1950 to 1970 the PTPA increases to 26 mm with NPA= –6 mm and PPA=20 mm. Ever since, the seasonal component is decreasing, and the minimum value reached in the 2018 is PTPA=18 mm with NPA = –6 mm and PPA=12mm. However, the changes in the seasonal component of the precipitation have less influence in the whole time series than the corresponding remainder values. This also indicates that STL decomposition of the precipitation time series is remainder dominant. The complex behavior of the seasonal component is clearly seen in Figure 12, where precipitation variations of each month or season in a year are shown. The variation changes can be detected in any month or season of the year in certain amount.

4.4. ITA results

Figures 13 and 14 illustrate the results of the ITA for the historical temperature and precipitation time series, respectively. Besides the general insight, the ITA represents the trend (positive or negative) in the "low," "medium," and "high" values of each variable. In Figures 13 and 14, the entire time series of each variable at seasonal and annual levels were split temporally into two halves (1900-1959 and 1960-2018), with each half sorted in ascending order, and subsequently plotted against each other. Şen's temperature plots show a monotonic positive trend at relatively low and high temperatures in all seasons, excluding spring where the decreasing trend in low ($T \leq 10°C$) and high ($T \geq 13°C$) temperature is observed in spring. By contrast, a positive trend is shown in medium temperature in this season. From the annual perspective, the figure clearly shows that the low, medium, and high temperatures in Osijek have increased during the period between 1960–2018, as compared to the period between 1900-1959. The increasing rate in the high and low temperatures is higher than that of a medium temperature.

Figure 14 shows the seasonal and annual trends of precipitation in the Osijek station. The figure demonstrates that there is not a significant change in winter medium precipitation ($30\ mm \leq P \leq 60\ mm$) during the past century. A similar pattern is also seen for annual medium precipitation ($600\ mm \leq P \leq 800\ mm$). The different monotonic trend is seen in other seasons. While the figure implies decreasing trend in the spring and autumn seasons, summer precipitation increases with a significant change in the high precipitating amounts ($P \geq 100\ mm$).

4.5.SAM results

Figure 15 illustrates the change-points and partial trends of the mean annual temperature and total annual precipitation time series. On the top panels, the graphs demonstrate the SAM series together with change-points, whereas the bottom panels of the graphs show the corresponding values at the change-points and the trends of irregular durations in the original observations. The number of peak and trough change-points at temperature and precipitation series are 23 and 27 change-points, respectively.

The figure shows that peak and trough change-points follow each other alternatively. It is obvious that in both cases (temperature and precipitation), the time duration between two change-points is unequal, which implies the existence of a natural partial trend within itself. Again, comparing successive pairs of the partial trends in both cases shows that trends in peak and trough change-points are very close to each other. However, a significant difference in their slope appears at the outset of the records (~1915) which might be owing to the bias effect of the initial warm-up portion as described by Şen (2019). Since 1920, partial trends are very close to each other on the slope, with slight positive (negative) values for temperature (precipitation). Therefore, the partial trends can together be considered as a single trend.

5. Summary and conclusion

The paper explores the trends in long-term (118 years) temperature and precipitation records in Osijek, located in the Pannonian lowland, Croatia. Osijek meteorological station represents one of the crucial regional control points of climatological changes and variabilities in this broad and very important agricultural region. To perform trend analysis, four different methods were applied: the conventional M-K and Sen’s slope test as well as the new ITA and SAM approaches. While the conventional methods were applied at monthly, seasonal, and annual levels, ITA was applied at seasonal and annual scales and the use of SAM approach was confined to annual observations as suggested by Şen (2019). In addition, seasonal and annual records were decomposed using STL technique to identify relationships between trend and seasonality components of the observed time series. Each of these methods provided several insights into the temperature and precipitation pattern in the study region.

The results presented in this paper show statistically significant increasing trends of air temperatures during the hot and dry part of the year from April to August (during spring and summer). Statistically decreasing trend of precipitation is found only in April. It should be noted that decreasing trend (statistically not significant but relatively high, p=0,031) exists during the spring. Precipitation falling in this month and season is of crucial importance for tillage. Pandžić et al (2020) noted that a significant correlation was discovered between drought damages in agriculture in Croatia and drought indices for the Zagreb-Grič Observatory for the period 2000-2012, and that the maize grain yield was most affected at times of severe droughts in August. The major conclusion is that trends of air temperature and precipitation indicate a very dangerous process for regional agricultural production, which should prepare for the uncertain future. The other conclusions are summarized below:

- Summer temperature increases faster than in other seasons in the region. The highest Sen slope was observed in January, followed by April. This is not in agreement with the results of the M-K test that showed that the most significant trend appears in August.

- There is a significant decrease in annual precipitation with a slope of 0.33. Osijek experienced decreasing trend mainly in the period March to June and September to November. The highest decreasing trend was obtained in April.
- From the annual perspective, ITA showed that all observed low, medium, and high temperatures have increased in the second half of the past century. The increasing rates in high and low temperatures are greater than that of a medium temperature.
- Based on the SAM results, there is a natural partial trend with unequal durations within the annual temperature and precipitation time series. Trends in peak and valley change-points are close to each other, indicating a slightly positive trend for temperature and negative trend for precipitation.
- Based on the STL decomposition, there is an increasing trend in the temperature over the last few decades. However, an increasing or decreasing trend was not detected in the precipitation series, which is perhaps due to the complex nature of this meteorological parameter. The method indicated certain amounts of change in the seasonal component.

This study was limited to the use precipitation and temperature series directly. The effects of change in climatologic characteristics of Osijek could be analyzed by mixed or ancillary indices such as standard precipitation index, precipitation concentration index, or seasonality index in future studies.

Declarations

Funding: Not applicable

Conflicts of interest/Competing interests: The author states that there are no conflicts of interest.

Availability of data and material: The data that support the findings of this study are available by the corresponding author upon the request.

Code availability: Not applicable

Authors' contributions:

Ali Danandeh Mehr: conceptualization, methodology, formal analysis, validation, writing original draft, writing-review and editing, visualization, supervision.

Bahrudin Hrnjica: methodology, formal analysis, writing original draft, writing-review and editing, visualization.

Ognjen Bonacci: data preparation, data curation, writing original draft, validation.

Ethics approval Not applicable

Consent to participate: Not applicable

Consent for publication Not applicable

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Figures Caption:

Figure 1. Osijek meteorological station

Figure 2. Observed (s) monthly and (b) seasonal and annual air temperature time series in Osijek (1900-2018)

Figure 3. Observed (s) monthly, (b) seasonal, and (c) total annual precipitation in Osijek (1900-2018)

Figure 4. ITA scatter plot illustrating increasing (squares), decreasing (triangles), and trendless time series (circles)

Figure 5. STL time series components for monthly temperature in Osijek (1900-2018)

Figure 6. STL time series components for quarterly temperature in Osijek (1900-2018)

Figure 7. The trend component and average trend value

Figure 8. Variation in the seasonal component of the historical temperature time series at monthly (left panel) and quarterly (right panel) levels

Figure 9. STL time series components for monthly precipitation in Osijek (1900-2018)

Figure 10. STL time series components for quarterly precipitation in Osijek (1900-2018)

Figure 11. Magnitude of the seasonal component of quarterly precipitation in Osijek (1900-2018) at different time periods.

Figure 12. Monthly (left) and quarterly (right) seasonal component changes for precipitation in Osijek (1900-2018)

Figure 13. Seasonal and annual trends in temperature during the period 1900-2018

Figure 14. Seasonal and annual trends in precipitation during the period 1900-2018

Figure 15. SAM and trend graphs for a) mean annual temperature and b) total annual precipitation in Osijek (1900-2018)

Table 1. Results of the Mann-Kendall trend for monthly temperature and precipitation (1900-2018)

	Temperature			**Precipitation**		
Month	**Z**	**p-value**	**Trend**	**Z**	**p-value**	**Trend**

Jan.	1.64	0.10	No	0.420	0.674	No
Feb.	1.30	0.20	No	1.128	0.259	No
Mar.	0.87	0.38	No	-0.393	0.694	No
Apr.	2.66	0.01	Yes	-2.421	0.015	Yes
May	2.31	0.02	Yes	-0.639	0.523	No
Jun.	2.71	0.01	Yes	-0.094	0.925	No
Jul.	1.96	0.05	No	0.583	0.560	No
Aug.	2.90	0.00	Yes	0.606	0.544	No
Sep.	0.31	0.75	No	-0.269	0.788	No
Oct.	1.26	0.21	No	-1.314	0.189	No
Nov.	1.32	0.19	No	-0.243	0.808	No
Dec.	-0.21	0.84	No	-0.002	0.998	No

Table 2 Results of the Mann-Kendall trend test at seasonal and annual level

	Temperature	**Precipitation**

Season	Z	p-value	Trend	Z	p-value	Trend
Winter	1.500	0.134	No	0.682	0.495	No
Spring	3.113	0.002	Yes	-2.159	0.031	Yes
Summer	3.345	0.001	Yes	0.455	0.649	No
Autumn	1.493	0.135	No	-0.859	0.390	No
Annual	3.59	0.00	Yes	-0.972	0.331	No

Table 3. Results of the Sen's slope test at monthly level

	Temperature			Precipitation		
Month	**Slope**	**Lower**	**Upper**	**Slope**	**Lower**	**Upper**

Jan.	0.014	-0.002	0.029	0.035	-0.102	0.159
Feb.	0.010	-0.006	0.027	0.080	-0.063	0.228
Mar.	0.005	-0.007	0.017	-0.030	-0.187	0.120
Apr.	0.012	0.003	0.020	-0.200	-0.364	-0.036
May	0.010	0.001	0.019	-0.071	-0.269	0.126
Jun.	0.010	0.003	0.019	-0.008	-0.236	0.210
Jul.	0.007	0.000	0.014	0.043	-0.113	0.188
Aug.	0.011	0.004	0.020	0.065	-0.124	0.256
Sep.	0.000	-0.007	0.009	-0.021	-0.200	0.138
Oct.	0.005	-0.003	0.013	-0.134	-0.357	0.068
Nov.	0.008	-0.003	0.020	-0.017	-0.200	0.140
Dec.	-0.001	-0.013	0.011	0.000	-0.161	0.158

Table 4. Results of the Sen’s slope test at seasonal and annual level

	Temperature			**Precipitation**		
Season	**Slope**	**Lower**	**Upper**	**Slope**	**Lower**	**Upper**

Winter	0.007	-0.002	0.016	0.032	-0.057	0.118
Spring	0.010	0.004	0.016	-0.122	-0.222	-0.012
Summer	0.010	0.004	0.015	0.025	-0.094	0.147
Autumn	0.005	-0.002	0.011	-0.056	-0.190	0.075
Annual	0.008	0.004	0.012	-0.330	-1.121	0.332