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# Analysis of precipitation time series at Keszthely, Hungary (1871–2014)

**Tímea Kocsis**[1*] and **Angéla Anda**[2]

[1] *Budapest Business School College of Commerce,*
*Catering and Tourism Department of Methodology,*
*1054 Budapest, Alkotmány Str. 9–11., Hungary*

[2] *University of Pannonia Georgikon*
*Faculty Department of Meteorology and Water Management,*
*8360 Keszthely, Festetics Str. 7., Hungary*

**Corresponding author e-mail: JakuschneKocsis.Timea@uni-bge.hu*

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**Abstract**—The results in the issue of local signs of global climate change at Keszthely (Hungary) are summarized and presented in this paper. The meteorological measurements at Keszthely have long history, a more than 140-year-long dataset of monthly amount of precipitation, provided by the University of Pannonia, is available for statistical analysis. The long-time series of precipitation amounts of Keszthely (Hungary) meteorological station was analyzed from the beginning of the observation (1871) until 2014, from the point of view of climate change. Simple climate-statistical analysis has been made in purpose to discover local climate alternations. Linear and exponential trends were fitted, and it was concluded that linear trends in every case had lower relative standard error than exponential trends, so linear changes were interpreted. Despite the fact that significant declining tendency was expected, the annual data does not show any modification in the tendency or variability, but other signs of the decreasing trend can be detected. Significant decreasing tendency was found in spring (–31.5 mm/100 years). Among the monthly sums, the precipitation amount of April (–14 mm/100 years) and October (–23.5 mm/100 years) showed statistically proved decreasing tendency. Variability is increasing significantly in September. These tendencies are unfavorable for the agricultural cultivation of the region.

*Key-words:* climate change, Keszthely, Hungary, precipitation, linear and exponential trend, box-plot

## *1. Introduction*

Climate change is one of those serious problems that mankind should face in the 21st century. According to the last *IPCC* report (2013), 95% is the probability that human influence has been dominant on the present changes of climate system. This phenomenon will probably affect all parts of the Earth, and in the heart of Europe, the Carpathian-Basin will be affected too. This region is one of the most vulnerable and less understood areas in Europe. In some cases, the volume and direction of the changes in climate model simulations are not definite. Beside model predictions, it is interesting to search analogies of projected climate during the history of the Earth for better understanding of the processes. *Prista et al.* (2015) worked out chronostratigraphic analogies for IPCC scenarios, and stated that Pliocene (Mid Piacenzian Warm Period) is the best analogue for warming climate in Europe.

Precipitation in average over mid-latitude land areas of the Northern Hemisphere has increased from 1901 (medium confidence) according to *IPCC* AR5 (2013). Heavy precipitation events and increase in intensity and frequency is very likely (90% probability) over mid-latitude land masses (*IPCC*, 2013). This phenomenon can change run-off to lakes that is an income parameter for water budget. *Olichwer* and *Tarka* (2015) investigated water run-off changes in Poland due to climate change, and proved that there were no significant changes in total run-off (but there was reduction in groundwater run-off), and reduction in groundwater run-off in favor of increased surface run-off can be expected. Changing water cycle can strongly affect water balance of vulnerable areas, such as Lake Balaton in Hungary.

The prediction of the effects of climate change on the Carpathian Basin (Hungary) requires regional climate scenarios with adequate temporal and spatial resolution, capable of translating global phenomena to local scale. *Bartholy et al.* (2004) developed a stochastic-dynamic downscaling model to estimate the regional effects of climate change in the Lake Balaton–Sió Canal catchments' area, using ECHAM/GCM outputs. This catchments' area (which also includes Keszthely) is one of the most vulnerable regions in Hungary in terms of climate change. According to *Bartholy et al.* (2005), the amount of precipitation will decline by 25–35% in the summer half-year and by 0–10% in the winter half-year on the Lake Balaton-Sió Canal catchments' area.

The regional model runs for Carpathian Basin (RCMs) using the A2 and B2 global emission scenarios of the *IPCC* AR4 (2007) expect more than 2.5 and less than 4.8 °C temperature rise for all seasons and both scenarios (*Bartholy et al.*, 2007). A 20–33% decrease in precipitation is predicted for the summer half-year, and there is high uncertainty for the rainfall for the winter half-year (*Bartholy et al.*, 2007). The earlier results of the authors harmonizes with their latest projection carried out in PRUDENCE European Project's model application (*Bartholy et al.,* 2009). These statements were enhanced by *Bartholy* *et al.* (2008) and by the *Hungarian Meteorological Service* (2010) according to further regional climate model simulations. According to the results of ENSEMBLES project, increasing tendency of the precipitation can be projected in winter and autumn, but strong decrease can be expected in summer, while the annual sum will not change significantly (*Pongrácz et al.,* 2011). *Kiss et al.* (2014) enhances these future tendencies, that climate circumstances will be drier is summer and wetter in winter. *Pongrácz et al.* (2014) project significant increase in drought-related indices in summer by the end of the 21st century. *Bartholy et al.* (2015) analyzed precipitation indices and project that frequency of extreme precipitation will increase in Central Europe, except of summer, when decreasing tendency is very likely.

The annual precipitation amount decreased by 11% between 1901 and 2004, according to the analysis of the Hungarian Meteorological Service (*Szalai et al.,* 2005). The biggest decline could be experienced in spring; it was 25% in the same period. *Bodri* (2004) suggested slow decrease of precipitation with a noticeable increase in precipitation variability for the 20th century. While the northern and western parts of Europe get more precipitation in parallel with the warming tendency, Hungary, similarly to the region of the Mediterranean Sea, gets less rainfall. The water balance has deficit, the difference between water income and outflow is increasing. Between 1901 and 2009, the highest precipitation decline over the territory of Hungary occurred in the spring, nearly 20% (*Lakatos* and *Bihari,* 2011). *Bartholy* and *Pongrácz* (2007, 2010) examined several precipitation extreme indices and their researches suggested that regional intensity and frequency of extreme precipitation increased in the Carpathian Basin in the second half of the last century, while the total precipitation decreased. The largest extremes for precipitation (monthly precipitation anomalies) tend to occur in summer (*Bartholy* and *Pongrácz,* 2005).

The goal of this study was to analyze the long-term data series of the meteorological measurements of precipitation amount at Keszthely (Trans-Danubia, Hungary, N 46°44’, E 17°14’, *Fig. 1*) from the point of view of climate and statistics. Keszthely is situated in the Lake Balaton catchments’ area sheltered by hills from the north, and its climate is affected also by the lake. It is situated next to the inflow point of Zala stream, at north-western part of the shore. The Zala stream’s sub-basin is the largest between the six sub-basins of the catchment area of Lake Balaton.

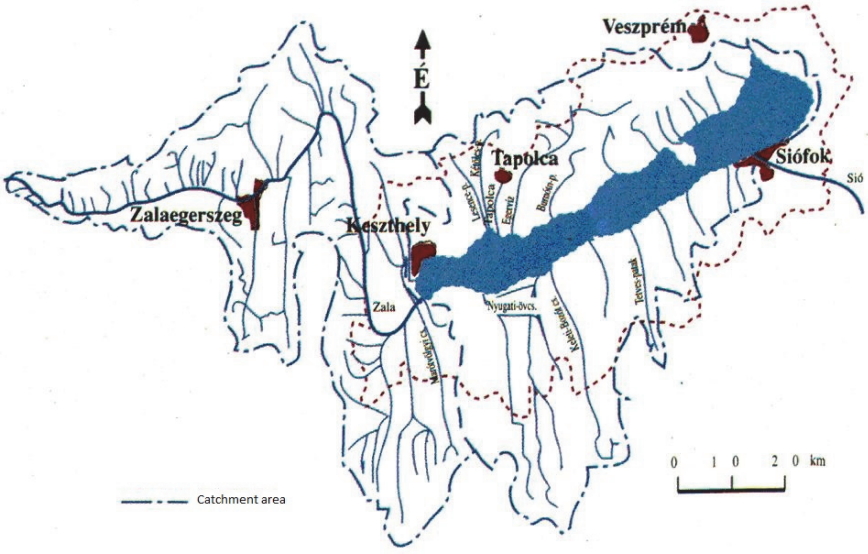

*Fig. 1.* Catchment area of Lake Balaton (source: website of the Hungarian Water Inspectorate, *https://www.vizugy.hu/index.php?module=content&programelemid=42*)

Our goal is to improve the knowledge about the changes in precipitation of Keszthely by expanding the data-set to 2014. *Lakatos* and *Bihari* (2011) detected higher decrease in precipitation sums in the Transdanubian Region than overall Hungary. Keszthely is situated in the center of this region, but precipitation changes cannot be proven clearly, and they are in contradiction to the regional tendencies. Other aim of this study is to highlight the application of some statistical methods in decision-making between the functions describing the tendencies of time series. Local analysis is presented in the paper, and beside the statistical methodological aspects, it highlights the phenomena that, probably in cause of microclimatic conditions, there can be areas that do not show the tendencies of the wider region.

## *2. Data and methods*

Monthly amounts of precipitation were analyzed from 1871 to 2014 measured at first in the territory of the ancient Georgikon Academy of Agriculture at Keszthely, then at the meteorological station of the Hungarian Meteorological Service. The dataset was provided by the Department of Meteorology and Water Management of University of Pannonia Georgikon Faculty (Keszthely). This dataset is special because few stations in Hungary have continuous measurements of more than 140 years with detailed historical background (*Kocsis* and *Anda,* 2006). Data set was analyzed in three sessions: annual amounts, seasonal amounts, and monthly precipitation. Seasons were performed as common in meteorology, e.g., spring: March, April, May.

Trend analysis of time series from single point observations has often been used to define local climate trends (*Boyles* and *Raman,* 2003). During the procession, the data set was analyzed by linear trend analysis and with running averages, which are widespread at the analysis of time series. 10 member-running averages ($k=10$) were used based on computation of climate normal.

Simple statistical methods, such as linear trend, are useful for investigating changes in climatic patters. Slopes of the linear fits to the time series of climatic data provide a simple picture of changes that occurred in the examined period (*Boyles* and *Raman,* 2003). It is well known, that for simplification usually the tendencies in weather elements' time series are described by linear trend, but in reality the tendency is rarely linear. Estimation of the parameters of linear trend was according to the following equitations:

$$\hat{y}_t = b_0 + b_1 t \qquad t = 1, 2, \ldots, 144, \tag{1}$$

$$b_1 = \frac{\overline{t \cdot y} - \bar{t} \cdot \bar{y}}{\overline{t^2} - \bar{t}^2}, \tag{2}$$

$$b_0 = \bar{y} - b_1 \cdot \bar{t}, \tag{3}$$

where

$\hat{y}_t$ is the value estimated by the trend function at $t$ period,

$t$ is the code of time period,

$b_0$ is the value estimated by the trend function at $t=0$,

$b_1$ is the slope of the linear, interpreted as absolute change in the phenomena over a time period unit,

$\bar{y}$ is the mean of the data set and

$\bar{t}$ is the mean of time codes.

*Lakatos* and *Bihari* (2011) stated that precipitation changes are shown better by exponential trend in % than by linear trend in mm. Exponential trend was also used to describe the tendencies in case of the annual and seasonal time series. Estimation of the parameters of exponential trend was according to the following equitations:

$$\hat{y}_t = b_0 \cdot b_1^t \qquad t = 1, 2, \ldots, 144, \tag{4}$$

$$\log b_1 = \frac{\overline{t \cdot \log y} - \bar{t} \cdot \overline{\log y}}{\overline{t^2} - \bar{t}^2}, \tag{5}$$

$$\log b_0 = \overline{\log y} - \log b_1 \cdot \bar{t}, \tag{6}$$

where

$\hat{y}_t$ is the value estimated by the trend function at $t$ period,

$t$ is the code of time period,

$b_0$ is the value estimated by the trend function at $t = 0$ period,

$b_1$ refers to the relative change in the phenomena over a time period unit ($b_1$-1 given in percent shows the relative change per time unit),

$\overline{\log y}$ is the mean of the logarithm of the dataset's values, and

$\bar{t}$ is the mean of time codes.

Sum of square error (SSE) was determined to decide which type of function is fitting the data set better:

$$SSE = \sum_{t=1}^{n} (y_t - \hat{y}_t)^2 , \tag{7}$$

where

$t$ is code of the time period (t=1,2,3,…,144),

$y_t$ is data of the time series at t period,

$\hat{y}_t$ is data of the time series at t period estimated by trend function.

Mean square deviation between real data and trend data is presented as relative standard error ($V_e$) of the trend function in percent:

$$V_e = \frac{\sqrt{\frac{SSE}{n}}}{\bar{y}_t} , \tag{8}$$

where $\bar{y}_t$ is the mean of the time series' dataset.

In case of linear trend, 5% of significance level was used to determine the significancy of the slope ($b_1$) by two tailed t-test. In every case the better fitting function was explained.

The mean values and the dispersion and distribution attributes were also determined. The following ones from the simplest climatic and statistical attributes were applied (*Péczely,* 1998): average, median, standard deviation, maximum and minimum values, upper and lower quartiles, and 5% and 95% percentiles. Distribution of the data is performed by box plot diagrams made by SPSS Statistics.

Climate fluctuation can have two interpretations: one of them is the difference between the certain value and the average of the data series (in an absolute value), the other one is the difference between the values following each other (*Varga-Haszonits,* 2003). Tendency in absolute deviation of the annual data from the mean of the dataset was used to describe changes in the variability.

## *3. Results*

### *3.1. Annual data*

The average of the dataset of the annual precipitation amount is 673 mm which at is a mean value for Hungary. Standard deviation is 138 mm. 25% of the data are higher than 772 mm, and 75% are higher than 580 mm. The lowest amounts (5% percentile is 456 mm) are of the years 2011, 2000, 1971, 1968, 1911, 1898, and 1967, in increasing order. The highest 5% are 1879, 2010, 1905, 1915, 1965, 1940, and 1937, in increasing order (95% percentile is 908 mm). The median is 654 mm, and dominancy of those data that are lower than the mean can be experienced. *Fig. 2* shows the box plot of annual data. Distribution shows slight asymmetry toward lower amounts.

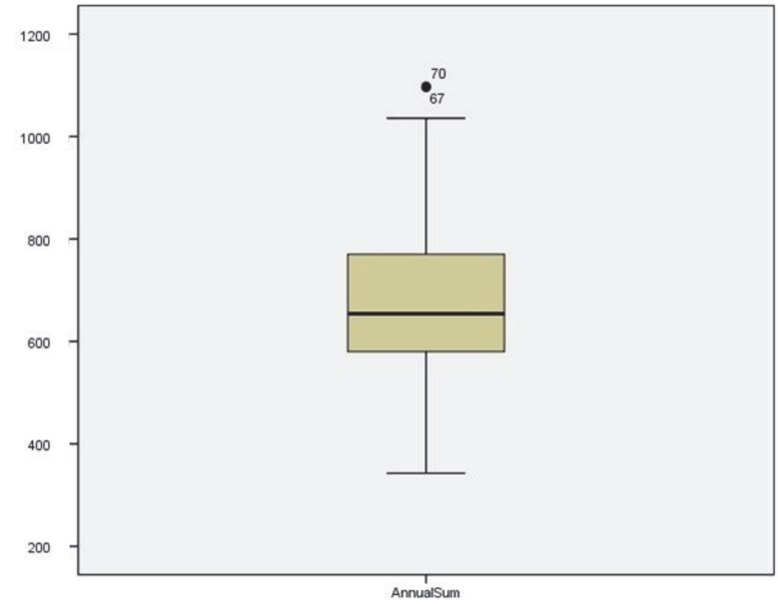

*Fig. 2*. Box plot of annual precipitation data of Keszthely (1871–2014)

(Lower line of the box is the lower quartile (25%), upper line of the box is the upper quartile (75%), the line in the box is the median (50%), upper end of the range is the maximum, and lower end is the minimum according to the box-plot algorithm. Values singed with dots over the range are time codes of outlier data that are more than 1.5 box lengths /interquartile range/ far from the hinge of the box.)

In the course of the analysis of the data series it can be concluded, that in the case of the annual amount of precipitation, neither significant linear decreasing tendency (*Fig. 3*) nor modification in the variability of the annual data (*Fig. 4*) can be shown. The linear trend gave a non-significant decreasing result (linear trend equitation is $\hat{y}_t = 709.2 + 0.4948t$), so the tendency was described also by running averages ($k = 10$). The declining tendency can be seen in *Fig. 3*. Modification of the variability should be expected as an effect of climate change, numbers of extreme values should be enhanced, but the variability of the data did not change.

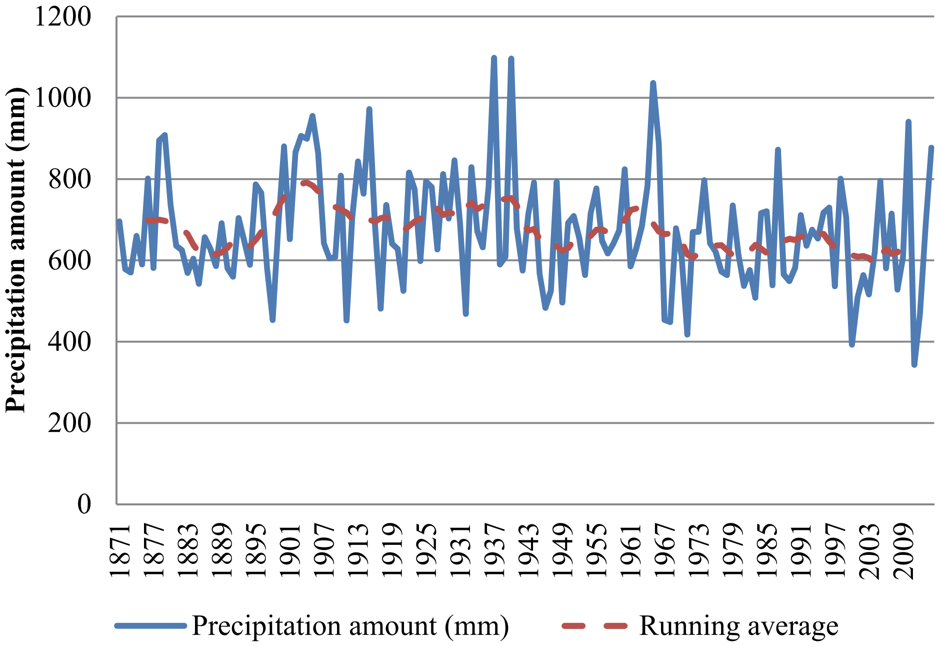

*Fig. 3*. Tendencies of annual precipitation sum at Keszthely (1871–2014) with running average.

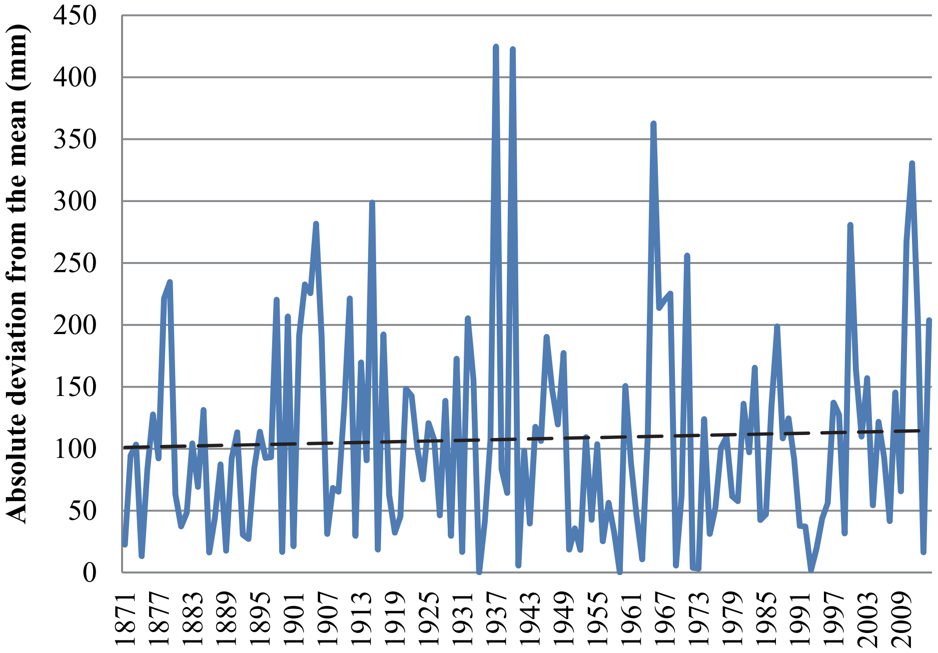

*Fig. 4*. Absolute deviation of the annual data from the mean precipitation and its linear tendency (linear trend equitation is $\hat{y}_t = 101.09 + 0.0949t$)

*Szalai* (2011) showed significant linear declining tendency of the annual precipitation amount in Hungary between 1901 and 2008. The annual rainfall sum decreased by 7% in this period. The declining tendency of the precipitation was enhanced in the Transdanubian Region (*Szalai,* 2011) where Keszthely station is situated, but no decreasing tendency could be found in the dataset of Keszthely.

Exponential trend was also determined (exponential trend equation is $\hat{y}_t = 699.86 * 0.99992^t$). It can be concluded that linear trend is fitting better the dataset, because the relative standard error is lower in case of this function. (Relative standard error is 20.18% for linear trend and 20.29% for exponential trend, respectively.) But linear trend is not significant (p-value is 0.0734), so changing tendency can not be described.

To get more information about the tendency of the annual precipitation sums, climate normals were applied (averages determined for 30 years, shifted by 10 years, following the WMO recommendations). Climate normals show that the amount of precipitation decreased in the second half of the 20th century. This tendency stopped in the first decade of the 21st century (*Fig. 5*).

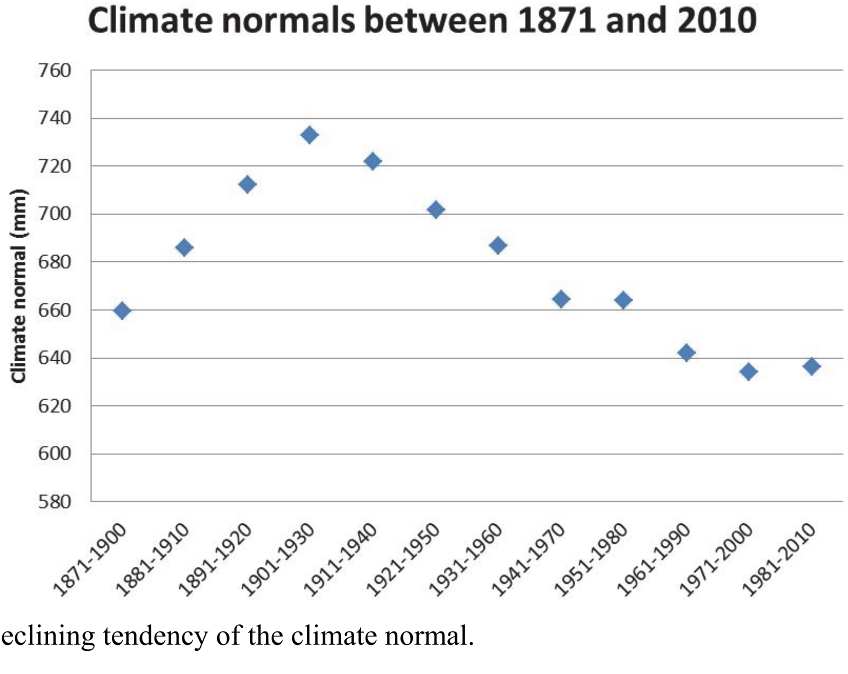

*Fig. 5*. Declining tendency of the climate normal.

### *3.2. Seasonal data*

Mean precipitation sum in spring was 162 mm between 1871 and 2014. The average is 223 mm in summer, 177 mm in autumn, and 111 mm in winter. *Table 1* presents the descriptive statistics of the seasonal amounts. *Fig. 6* shows the distribution of the seasonal data by box plot diagrams. In all seasons, those data have dominancy that are lower than the average.

*Table 1*. Descriptive statistics of the seasonal amounts of precipitation between 1871 and 2014

| **(mm)** | **Spring** | **Summer** | **Autumn** | **Winter** |
|---|---|---|---|---|
| Mean | 162 | 223 | 177 | 111 |
| Standard deviation | 54 | 77 | 68 | 42 |
| Lower quartile | 128 | 166 | 132 | 78 |
| Median | 153 | 216 | 179 | 110 |
| Upper quartile | 195 | 268 | 217 | 138 |
| Range | 302 | 373 | 367 | 198 |
| 5% percentile | 85 | 104 | 65 | 47 |
| 95% percentile | 268 | 374 | 294 | 187 |

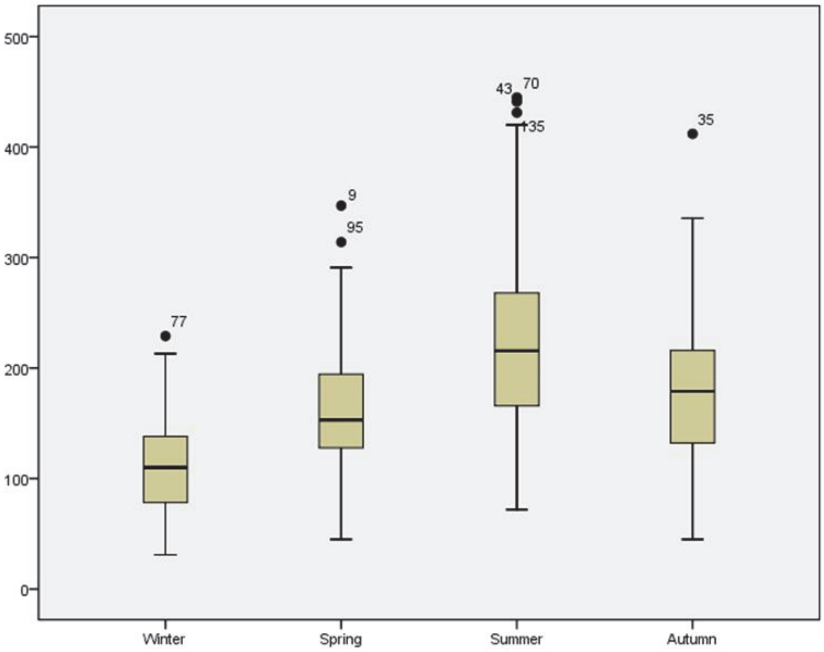

*Fig. 6*. Box-plots of the seasonal sums of precipitation at Keszthely

Linear and exponential trend was determined to analyze the tendencies of the seasonal sums of precipitation. *Table 2* gives the values of relative standard error of the functions. In all cases, linear trend is fitting the data better. *Table 3* contains the slopes of the linear tendencies of the seasons. The only significant change can be found in case of spring precipitation sum. The decreasing tendency is significant at the 5% significance level, and it shows 31.5 mm decline in the precipitation sum in 100 years. Previous researches showed 35 mm significant decrease in 100 years between 1871 and 2000 (*Kocsis,* 2008). This tendency is not favorable for agricultural cultivation, especially for spring crops. No significant changes can be detected in the variability of seasonal amounts.

*Table 2*. Relative standard errors of linear and exponential trends

| **Relative standard error** | **Spring** | **Summer** | **Autumn** | **Winter** |
|---|---|---|---|---|
| Linear trend | 32.54% | 34.54% | 37.87% | 37.10% |
| Exponential trend | 33.00% | 35.06% | 38.69% | 37.89% |

*Table 3*. The slope of the linear tendency and empirical significance level (p-value) of the seasonal data series. * indicates significant modification at the 5% probability level

| | **Spring** | **Summer** | **Autumn** | **Winter** |
|---|---|---|---|---|
| Slope (b1) of linear trend | **–0.315** | –0.075 | –0.241 | 0.136 |
| Empirical significance level of the slope ($b_1$) | **0.4%*** | 63.0% | 7.8% | 10.5% |

### 3.3. *Monthly data*

The mean values of the monthly precipitations sums are shown in *Fig. 7.* In Hungary, the annual evaluation of the monthly precipitation has a minimum in February and a main maximum in June, and a secondary maximum in October. This secondary maximum in the autumn seems to disappear. It is not completely clear that it would be the disappearance of the secondary maximum or a shift in it, but according the averages of the 144-year-long data set, the monthly amounts of precipitation in the fall are nearly the same. The continuous measurements of the further decades will probably answer this question. *Fig. 8* shows the distribution of the monthly data by box plot analyses.

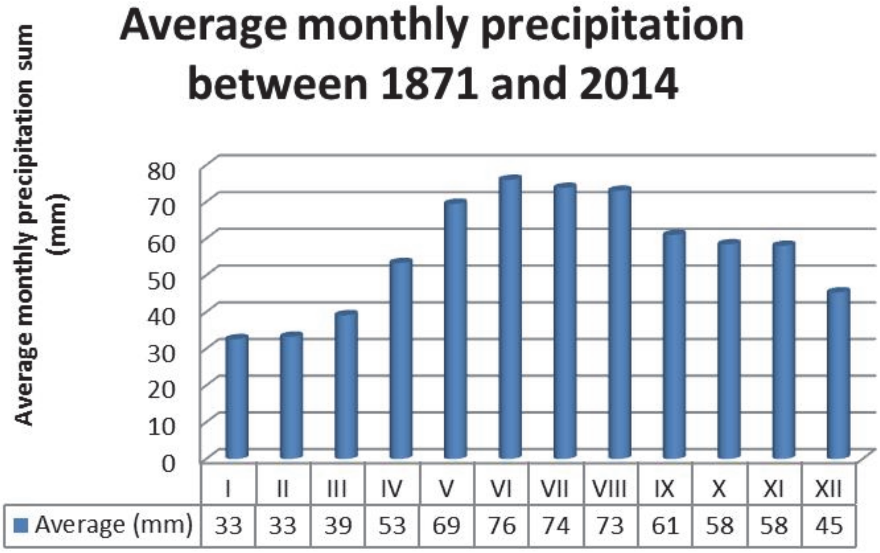

Figure 7. Monthly precipitation sums (1871–2014)

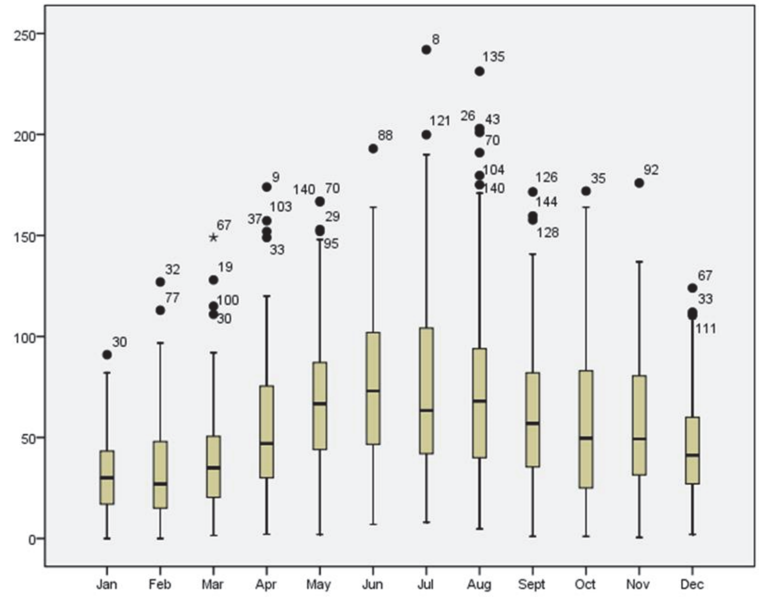

*Fig. 8.* Box-plot of monthly datasets by SPSS.

The amount of precipitation in April and October show a significant decrease between 1871 and 2014 (–14 mm/100 years and 23.5 mm/100 years, respectively), but any other monthly sum does not show significant modification (*Table 4*). In every month, the linear function has lower relative standard error than the exponential trend, so linear trend is fitting the data better. This result enhances the previous researches: between 1871 and 2000, the decreasing tendency was –25.1 mm in 100 years in October (*Kocsis,* 2008). The new finding is that the extended dataset shows significant decrease also in April. This phenomenon might be unfavorable for the agricultural cultivation, because the fall of the precipitation sum could have a critical effect on the germination of the crops.

*Table 4*. The slope of the linear trend and empirical significance level (p-value) of the monthly data series (*indicates significant modification at the 5% probability level) and standard errors of the linear and exponential trends, respectively (For January and February data, exponential trend cannot be fitted)

| Month | Slope (LIN) | p-value (%) | $V_e$ LIN (%) | $V_e$ EXP (%) |
|---|---|---|---|---|
| I | 0.03 | 44.4 | 60.93 | None |
| II | 0.06 | 24.2 | 72.59 | None |
| III | –0.06 | 26.1 | 64.00 | 67.12 |
| IV | **–0.14** | **3.1*** | 59.83 | 62.71 |
| V | –0.12 | 8.9 | 49.03 | 51.00 |
| VI | 0.01 | 90.1 | 48.47 | 50.52 |
| VII | –0.05 | 54.1 | 59.82 | 62.27 |
| VIII | –0.03 | 74.4 | 61.22 | 64.36 |
| IX | –0.02 | 79.3 | 57.99 | 61.26 |
| X | **–0.24** | **0.3*** | 66.54 | 71.66 |
| XI | 0.01 | 85.0 | 59.81 | 62.96 |
| XII | 0.05 | 35.9 | 56.75 | 59.55 |

The monthly analysis of variability gives the evidence that changes can be statistically determined in the absolute deviation of the monthly average values only in September (*Table 5*). Previously, in any cases of monthly variability changes cannot be detected (*Kocsis,* 2008). Between 1871 and 2014, significant increasing variability, can be reported in September. Suspected increase in variability due to the rise of the frequency of extreme weather events cannot be proved clearly.

*Table 5*. The slope of the linear trend of variability and empirical significance level (p-value) of the monthly data series (*indicates significant modification at the 5% probability level)

| **Month** | **Variability (slope LIN)** | **Variability (p-value) (%)** |
|---|---|---|
| I | 0.01 | 69.8 |
| II | 0.03 | 35.1 |
| III | –0.01 | 87.6 |
| IV | –0.04 | 28.9 |
| V | –0.02 | 58.1 |
| VI | 0.04 | 34.4 |
| VII | –0.04 | 48.2 |
| VIII | 0.09 | 10.2 |
| IX | **0.09** | **3.8*** |
| X | –0.07 | 13.5 |
| XI | –0.01 | 70.8 |
| XII | –0.03 | 37.1 |

## *4. Discussion and conclusions*

Our previous and latest results are summarized in *Table 6*, and it can be stated that new analysis enhanced the previous findings. Significant decreasing tendency can be experienced in spring, which is parallel with the findings of *Szalai et al.* (2005) and *Lakatos* and *Bihari* (2011), that highest precipitation decrease occurred in the spring in Hungary. The new result in case of Keszthely is that significant decreasing tendency can be detected also in April, and the variability is significantly increasing in September. Changing tendencies of the meteorological element are rarely linear, but linear trend is the most commonly used method to describe them. Climate normal was used also and showed declining tendency in annual precipitation during the 20th century.

*Table 6.* Summary of the results and previous findings

| | **Significant tendency in 100 years** | | |
|---|---|---|---|
| | 1871–2000 (*Kocsis,* 2008) | 1871–2010 (*Kocsis,* 2015) | 1871–2014 |
| Changes in annual sum | none | none | none |
| Changes in seasonal sums | Spring (–35 mm) | Spring (–29 mm) | Spring (–31.5 mm) |
| Changes in monthly sums | October (–26 mm) | October (–25 mm) | April (–14 mm) and October (–23.5 mm) |
| Changes in variability | none | none | September (+) |

To describe the tendencies in time series, several types of trends can be used, but linear and exponential ones are easily interpretable. In case of linear trend it is easier to decide about significance than in case of exponential one. *Lakatos* and *Bihari* (2011) communicated that changes shown in percent (exponential trend) are more suitable to interpret average changes per time unit in the tendencies of precipitation sums than interpret in mm (linear trend). But no mention can be found about the standard error of the approaches that can prove the decision in favor to exponential trend interpretation. Mathematically it should be more correct to compute the standard errors of the linear and exponential trends, respectively, and interpret the function that has lower error. In this work, relative standard error was counted in all cases, and it can be concluded that linear trend fitted the data sets better, and it had lower error than exponential trends.

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