# Trend Analyses of the Long Time Series of Monthly Mean Temperatures at Keszthely, Hungary

## *A Keszthelyen mért havi középhőmérsékleti idősor trend analízise*

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**Abstract:** Keszthely has one of the longest meteorological measurements in Hungary. The first meteorological station was established in the framework of the Georgikon Academy of Agronomy. From 1871 till nowadays, Keszthely has unbroken records. The town itself has local importance for its tourism and the nearby wetland (natural reserve area of Kis-Balaton). The goal of this study is to examine the long time series of monthly mean temperature data of this meteorological station. The dataset composes 1776 data (from 1871 January to 2018 December), which were undergone to homogenisation method (MASH). Homogeneity was also checked by Pettitt's homogeneity test, and no change-point could be identified. Monthly mean temperatures were not independent from each other, significant autocorrelation could be observed. Thus, linear approach for trend detection couldn't be used, as its requirements for application were not fulfilled. The moving average (12MA, number of tags is 12) showed rising tendency. A modified Mann-Kendall trend test for autocorrelated data was applied to detect the tendency of the time series. Seasonality should be considered as well. The slope was calculated by Sen's slope estimator. Using the autocorrelated (and seasonal) Mann-Kendall trend test, a significant increasing trend can be found (Kendall's tau = 0.047, p-value = 0.013). Sen's slope is estimated to 0.004°C (period=12).

***Keywords**: autocorrelation, Keszthely, moving average, temperature, trend analyses*

**Összefoglalás:** Keszthely meteorológiai állomás hazánk egyik leghosszabb adatsorával rendelkezik. Az első mérőállomás még a régi Georgikon, Közép-Európa első agrár felsőoktatási intézménye keretein belül létesült. 1871 óta napjainkig folyamatos meteorológiai mérések zajlanak Keszthelyen. Maga a város helyi jelentőséggel bír, mivel turisztikai desztináció és a közelben található a Kis-Balaton egyedülálló vizes élőhelye, ami kiemelt természeti érték. A jelen tanulmány célja az állomáson mért havi középhőmérsékleti adatok hosszú idősorának elemzése. Az adatbázis 1776 adatot tartalmazott (1871 januártól 2018 decemberig terjedően). Az adatokat a MASH eljárás segítségével homogenizálták. A homogenitást Pettitt-teszttel is ellenőriztük, töréspontot nem mutattunk ki az idősorban. A havi középhőmérsékleti adatok nem függetlenek egymástól, közöttük szignifikáns autokorreláció figyelhető meg. A lineáris trend illesztésének egyik alkalmazási feltétele, hogy ne legyen jelen autokorreláció. Mivel ez ebben az esetben nem teljesült, az idősor alaptendenciáját először mozgóátlagolással (az átlagolás tagszáma 12 volt), majd az autokorrelált, szezonalitást is figyelembe vevő Mann-Kendall trend teszttel közelítettük. Az átlagos változás mértékét a Sen-féle meredekséggel határoztuk meg. A Mann-Kendall trend teszt szignifikáns emelkedő tendenciát mutatott ki (Kendall tau = 0,047,

p-érték = 0,013). A Sen-féle meredekség az évi átlagos változás mértékét 0,004°C-ra becsülte (időszak=12).

***Kulcsszavak:*** *autokorreláció, Keszthely, mozgóátlag, hőmérséklet, trendszámítás*

## 1. Introduction

Global surface temperature was 1.09°C higher in the period between 2011 and 2020 than between 1850 and 1900, with larger increases over land (IPCC, 2023). Climate change is causing several effects on human life, such as the impacts of extreme weather events, floods, long-term risks associated with changes in temperature and precipitation patterns, sea level rise and influencing human health (Deep, 2023). Many studies were conducted to investigate the modification of the climate in Hungary (Lakatos and Bihari, 2011; Szabó et al., 2024, Kis et al., 2020) and especially at Keszthely (Kocsis et al., 2020; Kocsis et al., 2024). With this paper the authors would like to add an additional part to understanding the past climate at this site.

## 2. Materials and Methods

Monthly temperature time series measured at the long-established Georgikon Academy of Agriculture in Keszthely (E 17°14', N 46°44') and later, at the meteorological station of the Hungarian Meteorological Service spans the period 1871-2018. Keszthely has local importance of tourism and biodiversity reservation in Hungary. The uniqueness of its meteorological dataset lies in its uninterrupted length of 150 years (Kocsis and Anda, 2006). The monthly mean temperature data was provided by the Department of Water Management at Hungarian University of Agriculture and Life Sciences. The dataset composes 1776 data (from 1871 January to 2018 December), which were undergone to homogenisation method (MASH).

The time series was analysed by calculating descriptive statistics and by visualising the distribution of the data, for first. Then the homogeneity of the time series was checked by Pettitt's test. It is a non-parametric approach to change-point analysis that is widely applied. This test detects shifts in the average and calculates their significance (Liu et al. 2012) with a hypothesis test. After, the tendency of the time series was estimated by linear regression, 12-tag moving average was also used to visualize the tendency. In the diagnostic stage of linear trend, the autocorrelation of the data and the normal distribution of the residuals were tested. As significant autocorrelation was detected and the distribution of the residuals couldn't be accepted to be normal according to the Kolmogorov-Smirnov test, a modified version of Mann-Kendall trend test was used that is adjusted to seasonal and autocorrelated data. Mann-Kendall trend test is based upon the work of Mann (1945) and Kendall (1975), and it is closely related to Kendall's rank correlation coefficient. If seasonal cycles are present in the time series, a trend test that removes the effect of seasonality is suggested to be used (Gilbert, 1987). Hirsch et al. (1982) and Hirsch and Slack (1984) developed the method and introduced seasonal Mann-Kendall test for data that are serially dependent. The presence of positive autocorrelation in the data increases the chance of detecting trends when none exist, and vica versa (Hamed and Rao, 1998). This effect of the existence of autocorrelation in data is often ignored. Hamed and Rao (1998) supposed a modified non-parametric trend test, which is suitable for autocorrelated data. After determining the presence of the trend, Sen's slope estimator (Sen, 1968) was applied. It is a non-parametric method that can calculate the change per time unit (direction and volume). Sen's method uses a linear model to estimate the slope of the trend, and the variance of residuals should be constant in time (da Silva et al., 2015). In the case of hypothesis tests decisions were made based on the p-value. Calculations were carried out in MS Excel and Addinsoft's XLSTAT software.

## 3. Results and Discussion

The monthly mean temperature at Keszthely is 10.5°C with a standard deviation of 7.99°C (Table 1). The range of the dataset is 34°C, while the interquartile range is 14.6°C, where the middle half of the monthly mean temperatures is situated (Figure 1). F-score (quartile distribution) is -0.03, skewness can be observed towards the values higher than the average of the dataset.

**Table 1. Descriptive statistics of the monthly mean temperature time series**

| **Descriptive statistics:** | |
|---|---|
| Nr. of observations | 1776 |
| **Statistic** | **monthly mean temperature (°C)** |
| Minimum | -9.500 |
| Maximum | 24.500 |
| 1st Quartile | 3.400 |
| Median | 10.900 |
| 3rd Quartile | 18.000 |
| Mean | 10.500 |
| Sample standard deviation | 7.992 |
| Lower bound on mean (95%) | 10.128 |
| Upper bound on mean (95%) | 10.872 |

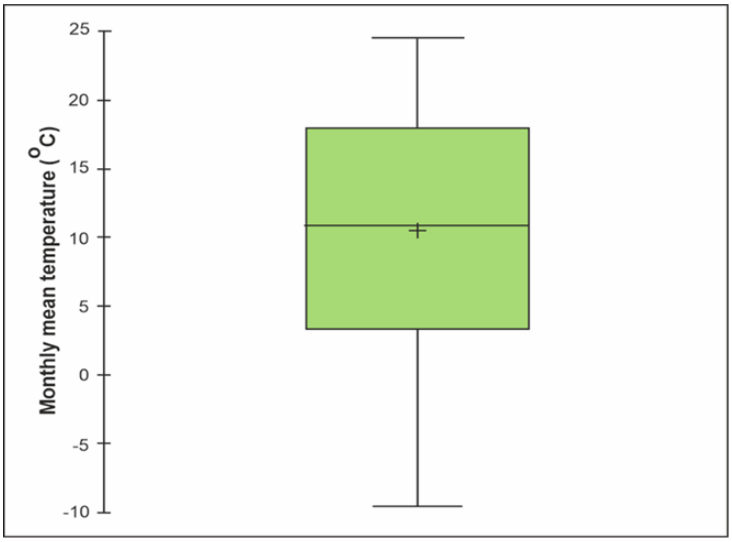


***Figure 1.*** *Box-plot of the monthly mean temperatures (°C)*

*The boxes indicate the interquartile range, the black line in the middle the median, the cross is the mean.*

In purpose to check the homogeneity of the dataset a Pettitt's test was applied based on which the data set can be concluded to be homogeneous (p-value = 0.12). There is no change point in the time series.

To estimate the trend, first linear approach was used, but at the diagnostic stage doubts emerged. The Kolmogorov-Smirnov test confirmed that the distribution of the residuals is not normal (p-value = 0.0001), which is a preliminary requirement for linear trend analysis, so it is not suitable to describe the trend. Based on the 12-month moving average a slight rising tendency could be observed (Figure 2).

The other limitation for using linear trend was the possible autocorrelation of the data. Significant autocorrelation was found (Figure 3, p-value = 0.0001), hence, the modified Mann-Kendall trend test for autocorrelated data was applied to detect the tendency of the time series. Seasonality should be considered as well. The slope was calculated by Sen's slope estimator. A significant increasing trend could be found (Kendall's tau = 0.047, p-value = 0.013). Sen's slope was estimated to 0.004°C (period=12).

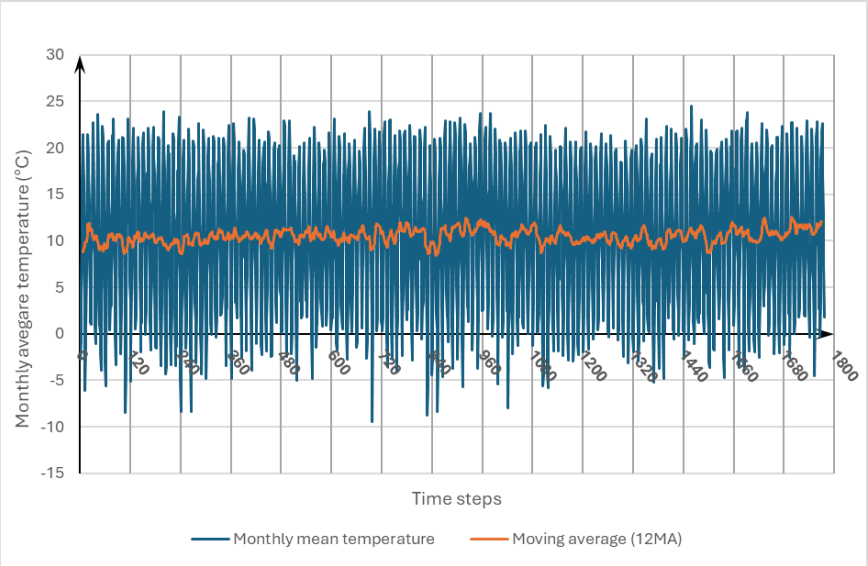


***Figure 2.*** *Time series of monthly mean temperatures and the 12-month moving average*

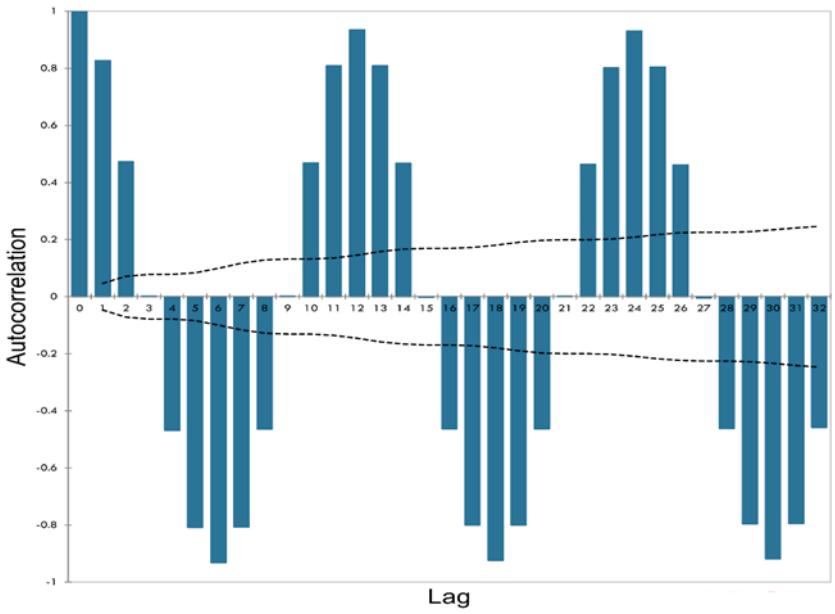


***Figure 3.*** *Autocorrelogram of the dataset*

## 4. Conclusions

A significant rising tendency was detected in the time series of the monthly mean temperatures. This increasing tendency is 0.004°C per year (period =12) on average. It should be interpreted as 0.53°C rise for the whole examined period (148 years). The rising trend of the monthly temperature is evidence in context of climate change, this outcome was expected. Rising monthly mean temperatures have favourable and unfavourable effects, too. It can be favourable for the local tourism industry. But it may be unfavourable for the agricultural cultivation.

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