AIR TEMPERATURE AND PRECIPITATION EVOLUTION IN THE AREA OF KESZTHELY

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Abstract

In this brief study some local signs of global climate modification are presented based on the statistical analysis of long-term air temperature and precipitation data for Keszthely (Hungary). In the Agrometeorological Research Station in Keszthely continuous meteorological measurements have been recorded since 1871, therefore an adequate length of data is available for analysis. Based on our results, a significant warming tendency is dominant, an increasing trend in air temperature can be established especially from the 1980s. Over the 116-year study period, statistically significant increase of 0.1°C per decade was found with 9.94±0.77°C annual average. Regarding to rainfall a downward trend of 47 mm per 100 years was observed.

Keywords: air temperature, rainfall, climate change, time-series analysis, Keszthely (Hungary)

Összefoglalás

Tanulmányom célja a globális klímaváltozás helyi megnyilvánulásainak bemutatása a keszthelyi hosszú idősoros léghőmérséklet és csapadék adatok éghajlati statisztikai elemzése alapján. A keszthelyi Agrometeorológiai Kutatállomáson már 1871 óta végeznek folyamatos meteorológiai méréseket, így kellő hosszúságú adatsor áll rendelkezésünkre. Az eredmények alapján elmondható, hogy jelentős felmelegedési tendencia figyelhető meg a térségben, főképpen az 1980-as évektől kezdődően. A 116 éves vizsgált időszakban évtizedenként 0.1°C-os, statisztikailag szignifikáns hőmérséklet-emelkedés mutatható ki, az átlaghőmérséklet 9.94±0.77°C. A csapadékösszegek tekintetében 47 mm/100 év csökkenő tendencia tapasztalható.

Kulcsszavak: léghőmérséklet, csapadék, éghajlatváltozás, idősorelemzés, Keszthely (Magyarország)

Introduction

Global climate change has accompanied the history of Earth. Recent developments are fundamentally different from changes due to natural causes (Kertész, 2001). Human emissions of greenhouse gases have changed the composition of the atmosphere over the last two centuries and caused global climate modification on Earth. Climate change is the best reflected by the evolution of air temperature. During the 20th century, warming occurred in two phases. The first was from the 1910s to the 1940s and 1950s followed by a mild cooling until the 1970s. From the beginning of the last quarter of the century a rapid, intense warming has begun (Folland et al., 2018). Warming is not gradual, it varies by different locations and seasons (IPCC, 2007). The national average is also reflecting to the global changes, but shows slightly higher warming tendencies (Szalai et al., 2005). In Hungary, spatial change is not uniform, vary by region, distribution is mainly determined by the zonality and the relief. In most parts of the country the average annual temperature is between 10 and 11°C. Relief is well reflected in the annual mean temperature. The lowest values usually appear in higher areas, in the regions of Bakony and Alps, or in the North Hungarian Mountains, where the average temperature is usually below 8°C. Values higher than 11°C are located on the south-southwest slopes and south of the country. The spatial distribution of the average temperature from southwest to northeast is decreasing due to the effect of the Mediterranean Sea and the Siberian anticyclone. Air temperature characteristics are well suited to global trends, but due to Hungary is a small country, its variability is higher.

The extent and distribution of precipitation in Hungary has also changed. This process is most likely due to higher temperatures. Hydrological cycle may become more intense, with an increasing proportion of precipitation in the form of heavy rainfall. Hungary's water balance shows a deficit. According to Domonkos (2003) a slow precipitation decrease was observed during the 20th century. Regarding to the Carpathian Basin Bartholy and Pongrácz (2007, 2010) found an increased frequency and intensified tendency in the extreme values and decreasing precipitation amounts in the second half of the 20th century. The most extreme events occurred during the summer months (Bartholy et al., 2005). Lakatos and Bihari (2011) revealed stronger decrease in precipitation sums in the Transdanubian region than in other parts of the country. The largest precipitation decline occurred in springs, nearly 20% of the total between 1901-2009. Despite of the small area, Hungary also has a significant difference in precipitation by region. The western and south-western parts of the country are more humid, while as well as the higher-lying areas where the precipitation in some small spatial spots exceeds the 800 mm. The most arid region is located in the Great Plain on a long-term average of less than 500 mm. The annual rainfall decreases from southwest to northeast. Most precipitation falls between May and July. In a significant part of the country, especially in the southern part of Transdanubia, on the south-eastern slopes of the Transdanubian Mountains and the Dunazug Mountains, a secondary rainfall may occur in Autumn (October-November). According to Szalai et al., (2005) there were more humid years in the first half of the century, and over the 1901-2004 period an 11% of decrease in precipitation was reached.

The regional impact of global warming appears in the manifestation and enhancement of extreme climatic events. In addition to this, a considerable change in the intensity of temperature or precipitation extremities can be observed as well. The decrease in the number of frosty days and the increase of hot days clearly show an accelerated warming process. Extreme weather phenomena may become more common and according to IPCC (2011), it is very likely that the number of hot extremities and heat waves will increase. The frequency, intensity and duration of hot waves are expected to increase throughout Europe, while the occurrence of winter extremes of cold and frosty days is expected to decrease. A considerably increased number of summer days (T_{max}>25°C) and tropical nights (T_{min}≥20°C) were observed in Hungary, in recent decades (Lakatos et al., 2007). According to Spinoni et al. (2015a) in the period of 1961-2010 a general tendency of a more frequent, longer, more severe and intense heat wave events was found in the Carpathian region in every season. The tendency of cold waves was generally less frequent, shorter, less severe and less intense. Drought variables show a moderate increase in Carpathian regions in the period 1950-2012. The frequency, duration, and severity of drought increased in the past decades, in particular from 1990 onwards. This region is one of the highest drought risk areas (Spinoni et al., 2013, 2015b). Briffa et al. (2009) also found a significant clustering of dry summers in the most recent decades. Analyzing in a very long-term context, trend displays towards wetter summer conditions from the end of the 17th century until the beginning of the 19th century, followed by a continuous trend towards drier conditions. Drying summers are found obvious in the latter part of the 20th century, especially in central Europe.

Materials and methods

Keszthely (Hungary, N 46°44', E 17°14') is located in Transdanubia, near Keszthely Bay, in the catchment area of Lake Balaton surrounded by hills from the north. Its weather is influenced by the unique microclimate of the lake, as well as the wind changing influence of Keszthely Hills. These hills are located in the western part of the Bakony, which is in the way of the Mediterranean, Atlantic and Continental air masses. This area is very sensitive for climate change. The southern slopes of the mountains are particularly affected by the Mediterranean effect, which is enhanced by the climate change of the water mass of Lake Balaton. It also has an effect on the air humidity, and its surface plays an important role in the reflection of solar radiation (Antal, 1974).

The aim of this study was to analyze the long-term data series of the meteorological measurements of air temperature and precipitation at Keszthely from the point of view of climate modification and statistics. Meteorological observations at Keszthely have a long detailed historical background, measurements of the meteorological elements are continuous from 1871. For the air temperature analysis monthly homogenized mean data from 1901 to 2016 were used. Homogenization of air temperature data was done using MASH software (Szentimrey, 1999). After homogenization, the data were analyzed on an annual, seasonal and monthly scale. Development of precipitation was examined based on a monthly precipitation sums from the beginning of the observation until 2016 and on a daily scale from 1971.

Results

Changes in air temperature

The results derived from the observed data showed a significant rising trend in the air temperature for Keszthely. The annual average was found 9.94±0.77°C during the period of 1901-2016 (*Fig. 1*). This value was corresponded to the mean value in Hungary. For this entire period a temperature rise of 0.1°C per decade was resulted. Calculating from the most intense warming phase from the 1980s, the average temperature in the 1981-2010 period was already 10.31°C, with an intense rise of 0.36°C. Extended this interval to 2016, the average was 10.46°C with a rise of 0.43°C per 10 year.

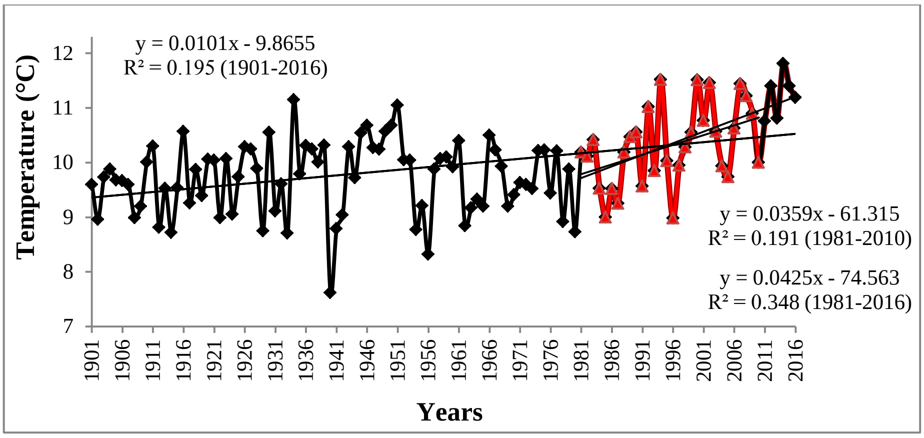

Fig. 1 Tendency of annual mean air temperatures between 1901-2016 ($p<0.001$), 1981-2010 ($p=0.016$) and 1981-2016 ($p<0.001$), in Keszthely

The mean annual temperature range is 21°C. 1940 proved to be the coldest year in Keszthely with an average annual temperature of 7.6°C, the hottest one was 2014 with 11.8°C. The absolute minimum monthly average was -9.96°C, which occurred in February 1929, the maximum average in 1992 August with 23.89°C. In *Fig. 2* the past changes and the increasing intensity of warming were shown. Annual mean temperature in the entire period were compared to the climate norm of the 1981-2010. The anomaly is clearly showing the recent intensive warming process.

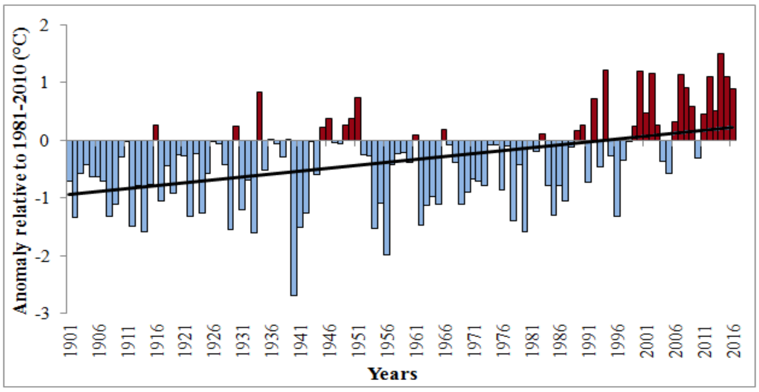

Fig. 2 Anomalies of the annual average temperatures of Keszthely (from 1901 to 2016) compared to 1981-2010 climate norm

Changes in ten-year averages of homogenized annual mean temperatures was presented in *Fig. 3*. After the warming period of 1901-1950, three decade long cooling period turned into a steadily warming phase especially from the 1980s. Based on the characteristics of the temperature evolution, Keszthely fits well with the global tendencies.

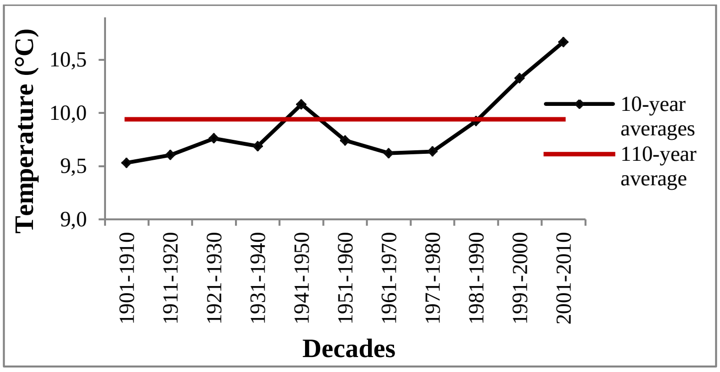

Fig. 3 The relationship of ten-year averages of homogenized annual mean air temperatures to the average of 110 years

Applying 10-year-moving averages was highlighted the upward trend in the air temperature in the last decades. (*Fig. 4*).

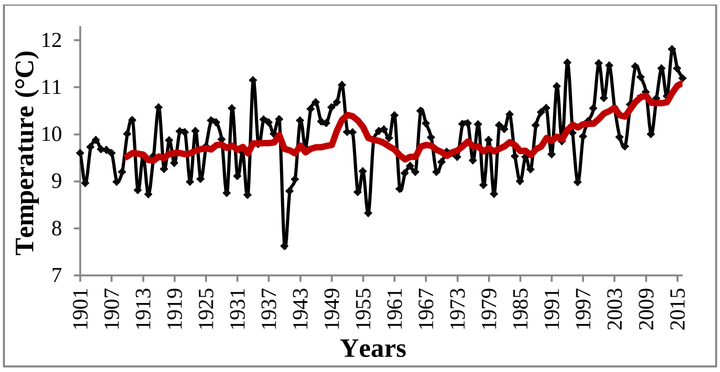

Fig. 4 Annual air temperature tendency (1901–2016) with moving average (k=10)

Regarding to the most recent climate from 2001 with the exception of the years 2004 and 2005, the average temperature of each year was exceeded the normal value (9.96°C) of 1971-2000 (*Fig. 5*). The average temperature of 2001-2016 period was 10.9 which was 0.9°C higher than the 30-year average of the last century.

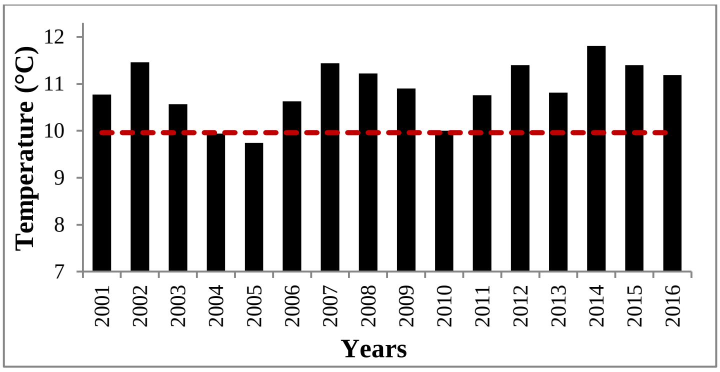

Fig. 5 The trend of changes in most recent annual temperatures (2001-2016) in comparison to the mean value of 1971-2000

A trend alignment for seasonal analysis was also prepared. The seasonal air temperature was investigated for the entire data set and from the beginning of the intensively warming period of 1981 (*Table 1*). Spring was proved to be the most warming season for the whole period, the changes were proved to be significant with the exception of autumn and winter of the last climate normal. The average temperature of each season has increased in the 1981-2010 period. Springs and summers represented the highest temperature rises for both intervals.

Table 1 Summary of seasonal mean temperatures and temperature rises

Season	**1901-2016**		**1981-2010**	
	Mean temp. (°C)	**Temp. rise (°C)**	**Mean temp. (°C)**	**Temp. rise (°C)**
Spring	10.24	1.38	10.76	1.35
Summer	19.37	1.26	19.82	1.51
Autumn	10.08	1.01	10.20	0.68
Winter	1.47	0.87	1.74	0.88

The ten-year average of the homogenized seasonal average temperatures was compared to the average of 110 years. Changes in 10-year averages was reflected to the modifications which occurred in the last decades and also showed clearly that spring and summer are the most warming seasons.

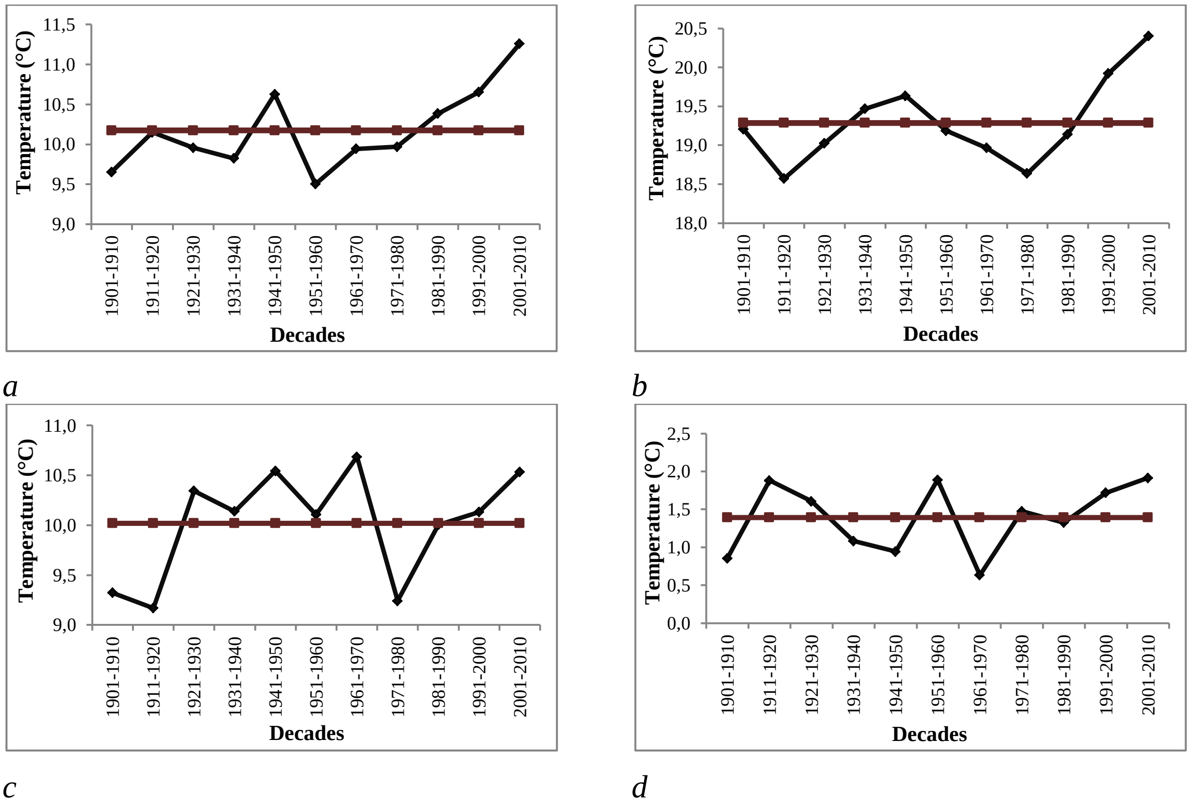

Fig. 6 The relationship between the ten-year averages of the mean temperatures and its 110 years average (a springs; b summers, c autumns, d winters)

On a monthly scale the hottest period of the year was the end of July and the beginning of August, while the coldest average was in January. The monthly temperature distribution is illustrated in *Fig. 7*.

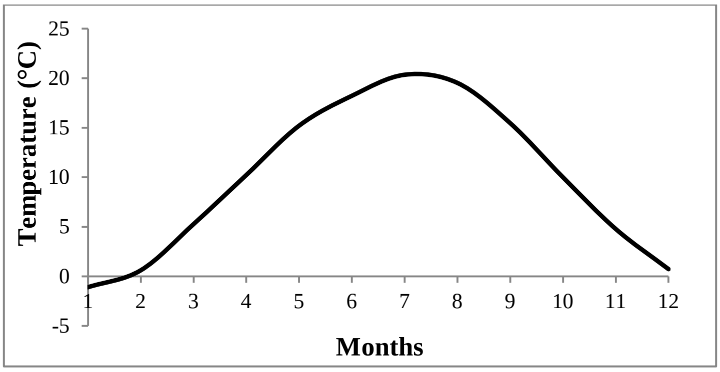

Fig. 7 The average monthly temperatures in Keszthely between 1901 and 2016

The air temperature was more balanced in the warmer months, the annual variability in summer was usually lower than in the colder seasons. (*Fig. 8*).

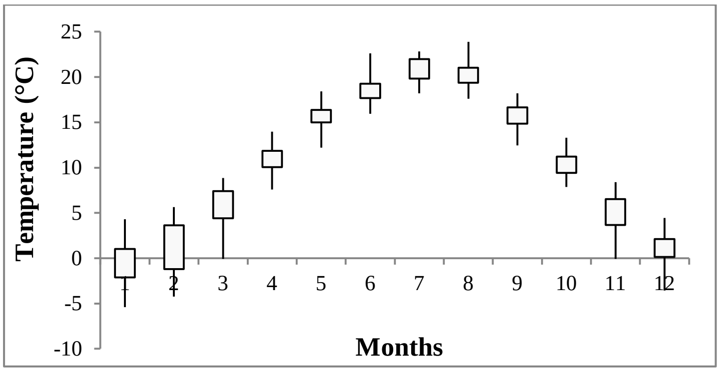

Fig. 8 The average monthly values of lower, upper quartile and extreme temperatures of Keszthely in the period of 1981-2010

Changes in precipitation

The 146-year annual average rainfall of Keszthely was 673±137 mm. Based on the entire dataset the precipitation decreases by 0.47 mm per year which resulted a total of 47 mm less rainfall in 100 years (*Fig. 9*). The range of data was 755 mm and the average absolute difference was 108 mm. According to Szász (1994), the risk of less precipitation is threatening Hungary.

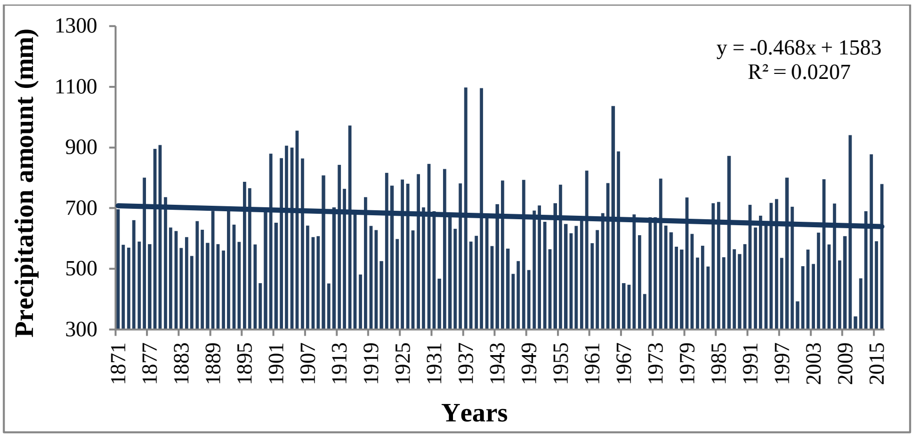

Fig. 9 The development of annual precipitation sums in Keszthely (1871-2016), p=0.083

Based on the linear trend, a significant downward tendency was fitted to the data. The decrease was also apparent from the average annual rainfall in the period from 1981 to 2010 which was resulted only 637 mm. Examined the annual precipitation amounts, these values was fluctuated on a wide scale, with a relatively large variation. Over the 146-year study period there were 16 years when the annual rainfalls were over 850 mm, moreover in three cases they were higher than 1000 mm (1098 mm in 1937, 1096 mm in 1940 and 1036 mm in 1965). There were 12 years, when the annual amounts remained below 500 mm, from which 2 years were extremely dry (393 mm in 2000 and 343 mm in 2011). The difference was more than twice between the lowest and the highest measured rainfall. Thirty-year standard climatic normal values were generated for ten-year slid periods presented in *Fig. 10*. From the beginning of the second third of the 20th century a significant decrease was observed.

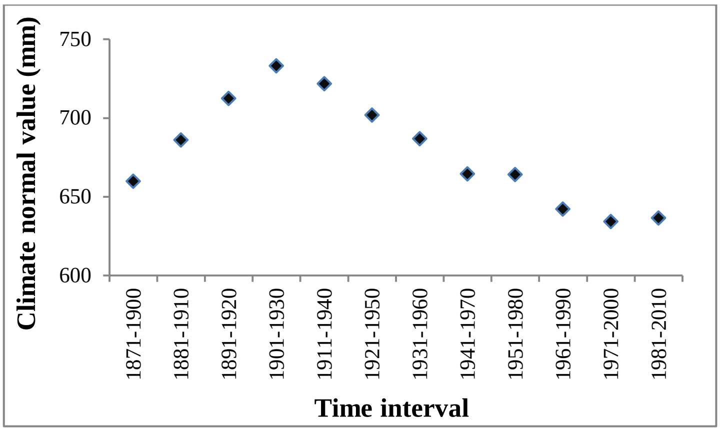

Fig. 10 Ten years slid climate normal values between1871-2010

The driest period was January-March, and in the rest of the year the precipitation was relatively evenly distributed (*Fig. 11*). For the whole period the rainiest month was June and the driest one was January. From March, the rainfall gradually increased until June. Among the monthly sums, the precipitation amounts of April (-15.9 mm per 100 years) and October (-18.9 mm per 100 years) showed statistically decreasing trends. These tendencies are unfavourable for the agricultural cultivation in this region. With the exception of August, September and December, a downward trend in precipitation was observed in comparison to the entire period.

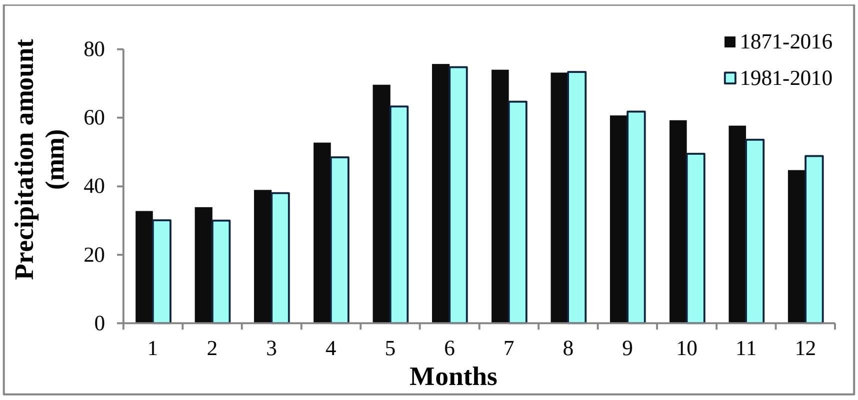

Fig. 11 The monthly average rainfalls between 1871-2016 and 1981-2010

The incidence and change in the occurrence of events and periods with more abundant precipitation or persistent drought also characterize the climate change. Days with precipitation of more than 20 mm showed a slight increasing tendency (*Fig. 12*). The upward trend in average daily precipitations suggests that precipitation was increasingly falling in the form of short-term, intense showers and thunderstorms.

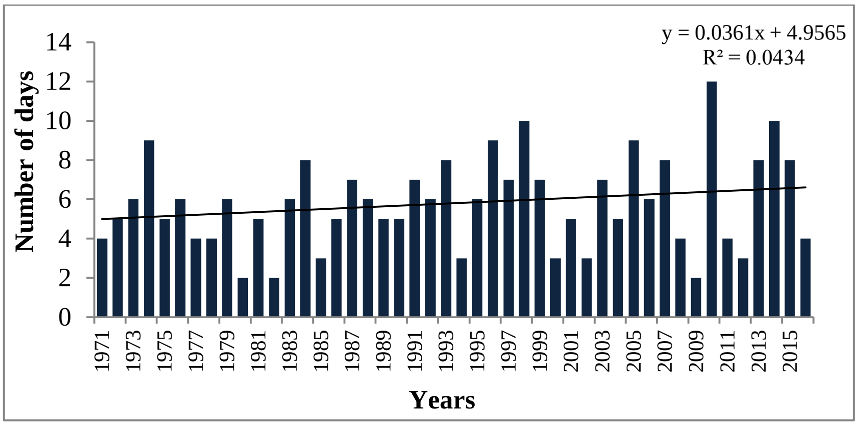

Fig. 12 The number of days with ≥20 mm precipitation between 1971 and 2016

Most arable is hard to tolerate rainless periods of 5-10 or more days and suffer irreversible damage (Szász, 1994). *Fig. 13* shows the length of dry periods in two different time intervals: from 10 to 14 days and over 15 days without precipitation. Between 1971 and 2016, on average there were two 15-day and three 10-14-day periods without precipitation yearly. In Keszthely, less rainy day were observed as we approached to the present. The longest period when the daily rainfall was less than 1 mm, had increased in the last decades.

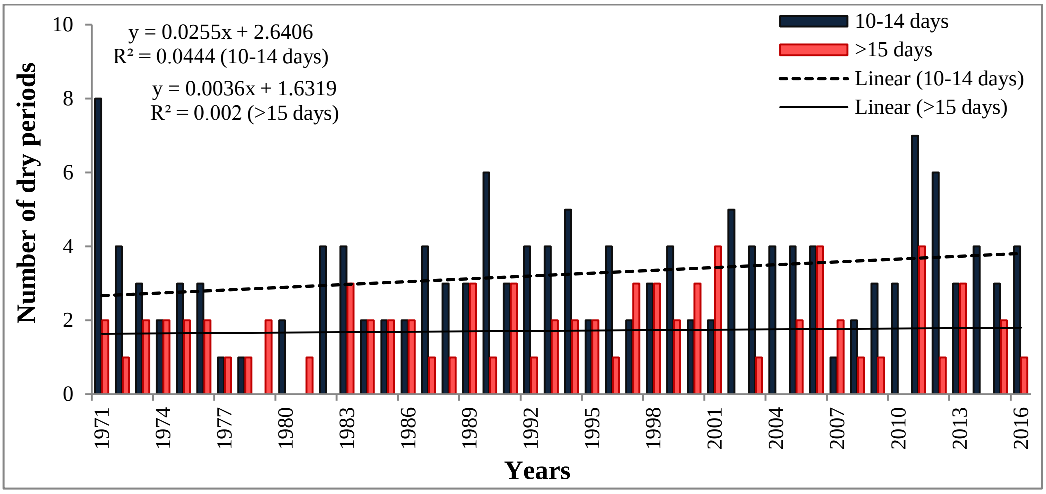

Fig. 13 The number of dry periods between 1981-2016

Discussion

Local scale study on the air temperature and precipitation trends showed the modification of the climate in Keszthely region. The results obtained a significant warming and downward precipitation tendency. The climate analysis highlights that information from development of these variables for short to long term planning in different sectors of economy is indispensable. Water management, agriculture, food production, biodiversity, forestry, tourism and human health can be the most affected sectors in the future. Increasing number of hot days during summers will have impacts towards higher energy consumption, as well. Due to warming and decreasing precipitation the rate of evaporation will be higher than the incoming amounts, which can affect on the water mass of Lake Balaton and its catchment area. If this trend continued in a long-term, the water level would decline. As a short-term positive effect, the water mass heats up sooner (in spring) and cools down later (in autumn), which could have beneficial on tourism and beaching by extending the holiday season. In accordance with other studies, for adjacent territories the trend of increasing risk of summer draughts needs to be taken into account. From the point of view of risk assessment it is very important to mapping this very vulnerable region and contributes to prioritization of measures for mitigation and adaptation of negative impacts. Climate warming has resulted in a significant upward shift in species optimum elevation and location, besides natural migration is proved slower than the climate spatial shifts. Therefore, projecting the climate change may likely drive major part of Hungarian agriculture to irreversible transformation. Shift of varieties is expected and variety selection is required. For planning of agro-technical measures are needed for a short and long term planning in struggle with the draught and high temperatures damage, and consequently risks from diseases and pests. Because of the drought and rising temperatures, the risk from forest fires may also grow. As a positive effect, the prolongation of the growth season is expected.

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