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Drought cycle tracking in Hungary using Standardized Precipitation Index (SPI)

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SUMMARY

Drought is one of the natural hazard risks which badly affects both agricultural and socio-economic sectors. Hungary, which is located in Eastern Europe has been suffering from different drought cycles; therefore, the aim of this study is to analyse the rainfall data obtained from ten metrological stations (Békéscsaba, Budapest, Debrecen, Győr, Kékestető, Miskolc, Pápa, Pécs, Szeged, Siófok, Szolnok) between 1985 and 2016, by using the Standardized Precipitation Index (SPI).

The results showed that 2011 was recorded as the worst drought cycle of the studied period, where the SPI ranged between -0.22 (extreme drought) in Siófok, and 0.15 (no drought) in Miskolc. In a similar vein, the study highlighted the year 2010 to be the best hydrological year, when the SPI reached 0.73 (mildly wet) on average. Interestingly, the Mann-Kendall trend test for the drought cycle showed no positive trends in the study area. Finally, more investigation should be conducted into the climate change spatial drought cycle in Europe.

Keywords: *Drought Cycle, Standardized Precipitation Index (SPI), Hungary*

INTRODUCTION

Day by day, clues to the existence of climate change (CC) and global warming have become more and more of a reality. In the last decade many parts of the world have started to suffer from the consequences of CC, effects which include floods, drought, sea-level rise and conflict (Khedun et al., 2014; Hsiang et al., 2013; Smith and Katz, 2013; Allen et al., 2010; Mundetia and Sharma, 2015; Hoang et al., 2018).

On a global scale, agricultural activities are the main source of CC, where more than 14% of greenhouse gas (GHG) emissions come from agricultural sectors and approximately 17% from land use changes (Paul et al., 2018). This rapid increase in GHG emissions has altered global climate and led to more extreme weather events (Alter et al., 2018; Bento et al., 2018; IPCC, 2007; Snyder et al., 2009; Hoerling and Kumar, 2004; Spinoni et al., 2018).

Recently, many parts of the world have been affected by global warming, which has had a catastrophic impact on natural resources, resulting in decreasing rainfall, and more intense and frequent dry spells, which worsen droughts in many regions of the globe (Naumann et al., 2018; Touma et al., 2015; Prudhomme et al., 2014)

Drought is one of the phenomena that is affected rapidly by CC, due to the complex factors that lead to it (Spinoni et al., 2018; Wilhite et al., 2007), and it has started to affect new terrestrial ecosystems, especially in the last few years (Allen et al., 1998). Interestingly, as CC progresses, future drought will occur under warmer temperature conditions (Breshears et al., 2005; Hoerling and Kumar, 2004; IPCC, 2001) and will have massive effects on vegetation cover (Allen et al., 1998; Kelly and Goulden, 2008; IPCC, 2007; He et al., 2018).

Globally, drought is considered to be one of the most costly natural disasters, having killed more than 11 million people and affected more than 2 billion people from 1900 to 2011; in particular, it affected more than 900 million people worldwide from 1999 to 2010 (EMDAT, 2011; Wilhite, 2000; Ivits et al., 2014; EM-DAT, 2013; Spinoni et al., 2014). Historically, Europe has been hit by the drought cycle many times as a consequence of CC and global warming, causing approximately 100 billion Euros of damage from 1976 to 2006 (Vogt et al., 2011a; van Lanen and Tallaksen, 2008; Feyen and Dankers, 2009; Lindner et al., 2010; Dai, 2011). However, the future climate for Europe is predicted to be higher temperatures with extreme climate events, changing precipitation patterns and a higher probability of drought cycles (Rowell, 2005; Beniston et al., 2007).

On a regional scale, southern Europe is subjected to increasing drought frequency and severity, with a remarkable increase noticeable in the Carpathian region (Spinoni et al., 2013, 2014; Spinoni et al., 2015a, 2015b; Spinoni et al., 2018); in contrast, northern regions recorded a wetter and cooler climate (Kingston et al., 2015). Feyen and Dankers (2009) concluded that CC will badly affect river basins in Europe, particularly in the southern parts of Europe, due to water stress, which is an increasing drought hazard. Similarly, Ivits et al. (2014) indicate that ecosystems in the Western Atlantic regions and Eastern Europe are vulnerable to climate change, and increases in drought frequency or intensity may result in great impacts on these ecosystems.

Hungary, which is located in the Carpathian Region, is subjected to climate change, as are other countries in Europe (Gálos et al., 2007). Spinoni et al. (2015a) emphasize the positive trends of heat wave events in the entire Carpathian Region, while cold waves tend to be less frequent and shorter. Similarly, Gálos et al. (2007) predicted a drying tendency until the end of 21st century, especially in summer (Bartholy et al., 2013; Pongrácz et al., 2014;). Many other studies have been conducted in Hungary in order to track CC; Blanka et al. (2013) reported an expected

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an increase in the drought hazard due to climate change, using regional climate models (REMO and ALADIN). Domonkos (2003) analysed the monthly precipitation data from 14 Hungarian stations (1901–1998) and reported an important main change in the mean summer precipitation with an increase in summer drought frequency, In the same context, Kocsis and Anda (2017) detected a significant decreasing tendency of rainfall in Keszthely, which will make it unfavourable for agricultural cultivation.

The principal aim of this study is to the track drought cycle in ten metrological stations (Békéscsaba, Budapest, Debrecen, Győr, Kékestető, Miskolc, Pápa, Pécs, Szeged, Siófok, Szolnok) from 1985 to 2016 by using the Standardized Precipitation Index (SPI).

MATERIALS AND METHODS

Monthly precipitation and yearly average temperature series covering the period 1985–2016 from 10 Hungarian observing stations were used in this research. The data was obtained from The Hungarian Central Statistical Office (1985–2016).

The Simple Linear Regression Model (SLRM), which can be defined as follows:

Y= ß+ ąX

where **Y** is a dependent variable, **X** is an independent variable, and **ß** and **ą**: are regression coefficients, has been applied to estimate the trend of climate data (temperature and rainfall) from 1900 to 2015.

The Standard Precipitation Index (SPI) (McKee et al., 1995) has been used as an indicator of drought. SPI statistically converts the gamma distribution probability into a series of linear data with natural distribution, where the mean value is equal to zero (*Table 1*). Positive values mean an increase in rainfall and negative values mean a decrease in rainfall, according to the following equation:

$$g(x) = \frac{1}{B^{a}\acute{\Gamma}a} x^{a-1} e^{-x/B}$$

$$\acute{\Gamma}(a) = \int_{0}^{\infty} y^{a-1} e^{-y}\, dy$$

Where:

$\acute{\Gamma}$(a): gamma distribution probability, **x** Rainfall, **a**: shape parameter, **B**: scale parameter.

Table 1

Drought categories from SPI

SPI Value	Drought category
0 to – 0.99	Mild drought
-1.00 to –1.49	Moderate drought
-1.5 to –1.99	Severe drought
-2.00 or less	Extreme drought

After calculating the SPI Index, the trends were checked using the Mann-Kendall test (Mann, 1945; Kendall, 1975) to detect the presence or absence of an increasing or decreasing trend within a time series (Szelepcsényi et al., 2018).

RESULTS AND DISCUSSION

3-1- Trends of observed climate data:

The statistical analysis showed a general positive trend in both rainfall and temperature, although in most of the cases these changes are not significant, as can be seen in *Tables 2* and *3*.

Rainfall has shown no significant changes, except for the Miskolc station, where the changes were significant; the average rainfall ranges between 525 and 785 mm. The temperature showed a positive trend (nonsignificant; P > 0.001), and some changes were significant, i.e. in Győr, Kékestető, Pápa, and Pécs, over the period between 1985 and 2015.

Table 2

Statistical analysis of rainfal data series (1985–2016)

	Mean	Minimum	Maximum	Standard deviation	SLRM	Trend	Sig
Békéscsaba	568	310	836	128	Y= 534.5+ 2.02X	+	non
Budapest	525	291	842	130	Y= 492.58+ 1.9X	+	non
Debrecen	548	391	845	106	Y= 525.5+ 3.5X	+	non
Győr	560	390	906	111	Y= 481.69+ 2.85X	+	non
Kékestető	785	489	1111	153	Y= 741.8+ 2.6X	+	non
Miskolc	591	334	999	156	Y= 465.5+ 7.6X	+**	99%
Pápa	593	379	835	135	Y= 545.2+ 2.88X	+	non
Pécs	657	405	981	130	Y= 549.9+ 3.7X	+	non
Siófok	554	287	894	142	Y= 510.6+ 2.6X	+	non
Szeged	524	203	842	141	Y= 457.8+ 3.99X	+	non
Szolnok	531	319	835	141	Y= 501+ 1.7X	+	non

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Table 3

Statistical analysis of avareg temprature data series (1985–2016)

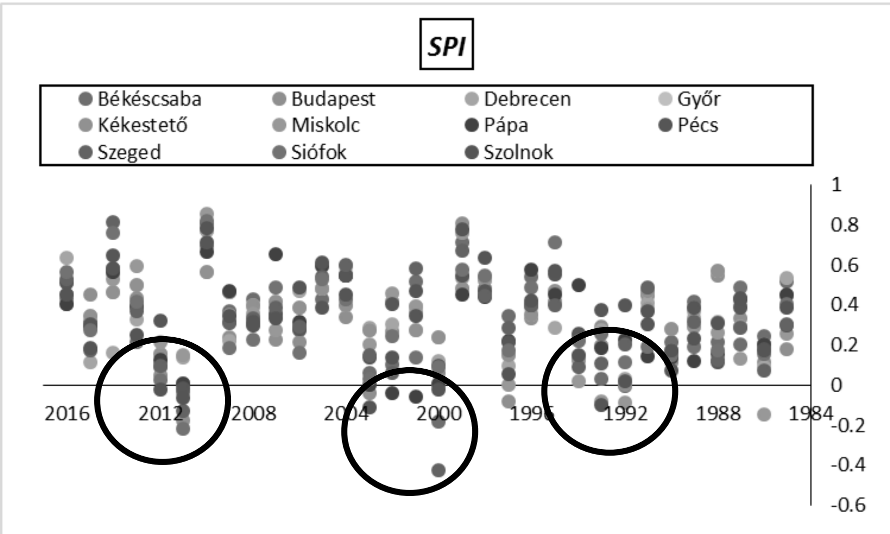
	Mean	Minimum	Maximum	Standard deviation	SLRM	Trend	Sig.
Békéscsaba	10.919	9.200	12.400	0.873	Y= 9.8+ 0.06X	+	non
Budapest	11.878	10.400	13.300	0.824	Y= 10+ 0.05X	+	non
Debrecen	10.613	8.700	12.200	0.809	Y= 9.6+ 0.06X	+	non
Győr	10.769	9.100	11.900	0.796	Y= 9.9+ 0.05X	+**	99%
Kékestető	10.900	9.400	12.300	0.819	Y= 5.2+ 0.05X	+**	99%
Miskolc	6.088	4.700	7.400	0.780	Y= 8.86+ 0.07X	+	non
Pápa	10.688	9.100	11.800	0.715	Y= 9.9+ 0.04X	+**	99%
Pécs	10.075	8.100	11.700	0.901	Y= 10.33+ 0.05X	+**	99%
Siófok	10.813	9.500	12.200	0.797	Y= 10.36+ 0.6X	+	non
Szeged	10.638	9.100	11.900	0.756	Y= 10.16+ 0.05X	+	non
Szolnok	11.163	9.600	12.300	0.806	Y= 9.97+ 0.06X	+	non

3-2- SPI analyse:

As can be seen from *Figure 1*, the SPI (drought) has changed over time from 1985 till 2015, which reflects the characteristics of precipitation changes through the years. The results show that Békéscsaba; Budapest, and Miskolc were affected by 3 drought events (with an SPI of less than 0), while Pápa and Siófok were affected by 2 drought events (an SPI of less than 0), and 5 drought events (an SPI of less than 0). The results also showed that the years 2000 and 2011 were the worst in the studied time series, in which most of the stations recorded a negative SPI value. Interestingly, the Mann-Kendall trend test for the drought cycle showed no positive trends in the study area.

Principle component analysis showed a potential drought in Debrecen, Győr, Kékestető, and Miskolc, while the correlation matrix showed a good agreement between SPI for all the studied locations, as can be seen in *Table 4.*

Figure 1: **Distribution of Standardized Precipitation Index (SPI) in the study area**



Our results are in accord with other researchers, including Matyasovszky et al. (1999), who reported a warmer and drier temperature over the last century in Hungary due to increased atmospheric greenhouse gases, a finding supported by many researchers, e.g. Hanssen-Bauer et al. (2005), Bartholy et al. (2007), Havril et al. (2018). Similarly, many scholars have indicated drought trends in Hungary, especially in 2011, due to climate change and a lack of precipitation e.g. Bartholy et al. (2014), Móricz et al. (2018). On the contrary, there are no records in the research of increased rainfall along Hungary, although our positive trend was not statistically significant.

In conclusion, further studies should be conducted with an emphasis on drought trends in Hungary, and the SPI should be calculated on a different scale in order to track drought changes through the seasons.

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Table 4

Correlation matrix within studied locations (SPI)

	Bék	Budt	Deb	G	Kék	Misk	Páp	Pé	Szeg	Sió
Budt	0.709									
Deb	0.667	0.638								
G	0.654	0.787	0.679							
Kék	0.654	0.787	0.679	1.000						
Misk	0.735	0.769	0.739	0.772	0.772					
Páp	0.606	0.524	0.454	0.495	0.495	0.478				
Pé	0.669	0.693	0.559	0.512	0.512	0.682	0.634			
Szeg	0.897	0.706	0.647	0.598	0.598	0.754	0.625	0.798		
Sió	0.699	0.751	0.595	0.689	0.689	0.660	0.796	0.852	0.746	
Szo	0.858	0.818	0.729	0.757	0.757	0.780	0.674	0.703	0.821	0.804

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