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, 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
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 track drought cycle in ten meteorological 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:

\[ Y = b + qX \]

where \( Y \) is a dependent variable, \( X \) is an independent variable, and \( b \) and \( q \): 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:

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

\[ f(a) = \int_0^\infty y^{a-1} e^{-y} dy \]

Where:

- \( f(a) \): gamma distribution probability,
- \( x \): Rainfall,
- \( a \): shape parameter,
- \( B \): scale parameter.

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 (Szlepecsényi 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

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard deviation</th>
<th>SLRM</th>
<th>Trend</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Békéscsaba</td>
<td>568</td>
<td>310</td>
<td>836</td>
<td>128</td>
<td>Y= 534.5+ 2.02X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Budapest</td>
<td>525</td>
<td>291</td>
<td>842</td>
<td>130</td>
<td>Y= 492.58+ 1.9X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Debrecen</td>
<td>548</td>
<td>391</td>
<td>845</td>
<td>106</td>
<td>Y= 525.5+ 3.5X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Győr</td>
<td>560</td>
<td>390</td>
<td>906</td>
<td>111</td>
<td>Y= 481.69+ 2.85X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Kékestető</td>
<td>785</td>
<td>489</td>
<td>1111</td>
<td>153</td>
<td>Y= 741.8+ 2.6X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Miskolc</td>
<td>591</td>
<td>334</td>
<td>999</td>
<td>156</td>
<td>Y= 465.5+ 7.6X</td>
<td>+++</td>
<td>99%</td>
</tr>
<tr>
<td>Pápa</td>
<td>593</td>
<td>379</td>
<td>835</td>
<td>135</td>
<td>Y= 545.2+ 2.88X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Pécs</td>
<td>657</td>
<td>405</td>
<td>981</td>
<td>130</td>
<td>Y= 549.9+ 3.7X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Siófok</td>
<td>554</td>
<td>287</td>
<td>894</td>
<td>142</td>
<td>Y= 510.6+ 2.6X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Szeged</td>
<td>524</td>
<td>203</td>
<td>842</td>
<td>141</td>
<td>Y= 457.8+ 3.99X</td>
<td>+</td>
<td>non</td>
</tr>
<tr>
<td>Szolnok</td>
<td>531</td>
<td>319</td>
<td>835</td>
<td>141</td>
<td>Y= 501+ 1.7X</td>
<td>+</td>
<td>non</td>
</tr>
</tbody>
</table>
Table 3
Statistical analysis of average temperature data series (1985–2016)

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

3-2- SPI analyze:
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.

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.


REFERENCES

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