Carpathian Journal of Earth and Environmental Sciences, August 2016, Vol. 11, No 2, p. 355 - 366

# EXPECTED MID- AND LONG-TERM CHANGES IN DROUGHT HAZARD FOR THE SOUTH-EASTERN CARPATHIAN BASIN

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**Abstract**. In recent decades, the Carpathian Basin in Central Europe has experienced droughts that have had serious socio-economic and environmental consequences. The present study aims to evaluate the mid- and long-term severity and frequency of droughts associated with climate change in the mostly exposed south-eastern part of the Carpathian Basin from an agricultural perspective. To estimate the changes, projected future climate data derived from the ALADIN and REMO regional climate models were used. The Palfai Drought Index (PaDI) was calculated, and the spatial differences and temporal tendencies were analysed. Based on the results, increased drought severity and frequency is expected for the end of the century. At present, drought years are characterised by moderate droughts (PaDI 6-8). In the future, the frequency of such moderate PaDI years might significantly decrease and may be replaced by more serious drought events. In the periods 2021-2050 and 2071-2100, approximately 6-13 years and 9-17 years out of the two 30-year periods, respectively, are expected to be serious (PaDI values >10). The continuous development of the socio-economic system changes the pressure on food production; thus, consumers and producers should have valid, high spatial resolution information on the severity and spatial distribution of drought hazards. Therefore, the development of an early warning system that provides real-time information on agricultural and hydrological aspects at the local or county level would be highly welcomed in this region.

**Keywords**: drought hazard, regional climate model, climate change, Carpathian Basin, PaDI

## 1. INTRODUCTION

Drought is one of the most serious environmental hazards in Southern and Eastern Europe and influences many sectors e.g., agriculture (Fink et al., 2004), energy production (Feyen & Dankers, 2009), nature conservation (Metzger et al. 2008), forest management (Allen et al., 2010), health care (Haines et al., 2006), and tourism (Scott et al., 2012), causing huge economic loss. According to the estimates of the European Commission, at least 11% of Europe's population and 17% of its territory have been affected by water scarcity, resulting in a loss of 100 billion EUR for Europe over the past thirty years (EC, 2007; EEA, 2009). Drought in 2003 highly affected the entirety of Europe, the costs of which were estimated at 13 billion EUR (Eisenreich, 2005). Droughts are predicted to intensify in the future, according to most climate model simulation data; thus, drought is expected to be the most important environmental hazard for the end of the 21st century (IPCC, 2007; IPCC, 2014).

The drought problem is the subject of intensive research worldwide. Drought formation, frequency, future severity for different regions, index approaches and development of early warning systems are being thoroughly investigated. Drought can also be assessed from meteorological, agricultural and hydrological perspectives (Hisdal & Tallaksen, 2003; Niemeyer, 2008; Vogt et al., 2011) due to the different application fields. New indices are published each year; the rate of drought has been quantified by more than 100 indices at present (Zargar et al., 2011). The continuous monitoring of drought phenomenon is available via the European Drought Observatory at a continental scale using maps of indicators derived from different data sources (e.g., precipitation measurements, satellite data and modelled soil moisture content) (Horion et al., 2012).

The occurrence of drought features significant regional differences in Europe (EEA, 2007). In certain areas, e.g., the Mediterranean area, extreme droughts are frequent, occurring every 3 to 5 years (Garcia-Herrera et al., 2007; EEA, 2009; Lopez-Bustins et al., 2013). The Carpathian Basin in Central Europe is also highly influenced by the phenomenon (Spinoni et al., 2013) due to its physical geography. Because the plain areas are primarily covered with agricultural areas, agro-economic losses due to drought are significant. In the case of maize, a crop sensitive to drought, yield losses of 25-50% have been reported in Hungary, Romania and Serbia, depending on drought severity, in recent decades (Dragović et al., 2004; Erdélyi, 2008; Nat. Communication, 2010; Bakonyi, 2010; Mateescu et al., 2013). The most exposed area is the south-eastern part of the Basin, which contains parts of Hungary, Serbia and Romania.

Several detailed regional investigations of drought severity and frequency in this area have been based on indices (Table 1). The Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) have been evaluated in all the three countries, and additional indices, primarily using temperature and precipitation data, have also been applied.

Table 1. Indices used for drought assessment in the most affected countries in the cross-border region of the south-eastern part of the Carpathian Basin.

| | Name of applied indicator | The type of application | Bibliography |
|---|---|---|---|
| **Hungary** | PAI, PaDI | Meteorological, agricultural, hydrological | Pálfai, 2002; Bakonyi, 2010; Pálfai & Herceg, 2011 |
| | PaDI | Hydrological | Mezősi et al., 2014 |
| | SPI, PSDI | Meteorological | Lakatos et al., 2012 |
| | FAI, PDSI, SAI, De Martonne | Meteorological, agricultural | Dunkel, 2009 |
| | SPI, PDSI, PAI | Meteorological, agricultural, hydrological | Szalai et al., 2000 |
| | De Martonne, SAI, PaDI | Meteorological, agricultural | Blanka et al., 2013 |
| **Serbia** | SPI, PDSI | Meteorological, agricultural | Mateescu et al., 2013 |
| | SPI | Meteorological, agricultural | Stricević et al., 2011 |
| | SPI | Meteorological, hydrological | Gocić & Trajković, 2013 |
| | SPI | Hydrological | Gocić & Trajković, 2012 |
| | De Martonne, Pinna | Meteorological | Hrnjak et al., 2014 |
| | MAI | Agricultural | Dragović et al., 2004 |
| | SPI | Meteorological | Spasov et al., 2002 |
| **Romania** | PDSI | Hydrological, agricultural | Nat. Communication, 2010, Mares et al., 2015 |
| | SPA | Meteorological | Croitoru et al., 2011 |
| | scPDSI, DI | Meteorological | Mihăilescu et al., 2009 |
| | scPHDI | Hydrological | Ghoica, 2009 |
| | SPI, AI | Meteorological, agricultural | Sandu & Mateescu, 2009, Mateescu et al., 2013 |

(PAI: Pálfai Index, PaDI: Pálfai Drought Index; SPI: Standardized Precipitation Index, SAI: Standardized Anomaly Index, PDSI: Palmer Drought Severity Index; FAI: Forestry Aridity Index; MAI: Moisture Availability Index, SPA: Standardized Precipitation Anomaly; scPDSI: self-calibrating Palmer Index), DI: Drought Index, scPHDI: self-calibrated Hydrological Drought Index, AI: Aridity Index)

The Pálfai Drought Index (Pálfai, 1989) was developed for the Carpathian Basin climatic conditions using weighted monthly precipitation, temperature data and correction factors (number of heat days, periods without precipitation and groundwater availability). Based on the investigated indices, drought years were observed to be particularly frequent in past decades (Spasov et al., 2002; Djordjević 2008; Bihari, 2012; Fiala et al., 2014). In Serbia the northern part of the country was determined to be the most affected (Spasov et al., 2002; Jovanović et al., 2013; Mateescu et al., 2013). The assessments in Romania determined that the southern, south-eastern and eastern parts of the country are the most vulnerable areas to extreme and severe droughts (Barbu, 2005; Ghioca, 2009; Mihăilescu et al., 2009; Croitoru et al., 2011). In Hungary, the south-eastern plain areas feature the highest risk of serious drought (Pálfai & Herceg, 2011; Spinoni et al., 2013). Due to the ecological, economic and social consequences, the drought hazard is a strategic focus in the environmental policy of the three countries (Barbu, 2005; HDS, 2012; Mateescu et al., 2013).

Increasing frequency and severity of drought events were identified in all three countries and further increase was projected the next decades. To estimate the future tendencies and the consequences, several regional climate models (RCM) were applied to the project climate change in the Central and south-eastern Europe. In Romania, projected climate data for 2100 were calculated by the RegCM model using A2 and B2 scenarios (Boroneanț et al., 2011). In Hungary, future climate data were projected using 4 regional climate models (RegCM, PRECIS, ALADIN and REMO - Krüzselyi et al., 2011). For Serbia, the EBU-POM coupled regional climate model was used for future projections (Djurdjević & Rajković, 2008; Sekulić et al., 2012).

The present study aims to evaluate the mid- and long-term rate and frequency of droughts associated with climate change in the mostly exposed south-eastern part of the Carpathian Basin based on ALADIN and REMO RCM simulation data. The regional analysis and assessment focuses on the spatial and temporal exposure to drought hazard using Palfai Drought Index that characterises drought severity for an agricultural year. The EU assessment (EEA, 2007) confirmed that drought and the resulting agricultural losses are significant problems in the region, and the pressure on European water resources has increased (EEA, 2010). Therefore, providing regional information for spatial planning and agriculture is crucial in order to adapt to the severity of the problem over the long-term.

## 2. STUDY AREA

This assessment focuses on the cross-border area in the south-eastern part of the Carpathian Basin (Fig. 1). The boundary of the study area was delineated by administrative regions in Hungary and Serbia, in which the plain area extends far into each country, and by the boundary of the plain area in Romania. In this region, the environmental conditions, e.g., relief, climate, soils, and land use, are similar. Agriculture is the dominant land use: 63.5% of the area is arable land (CORINE Land Cover 2006 database, code: 211) due to the fertile soils. The soils are primarily Chernozems and Arenosols formed on sand and loess sediments. In depressions and along rivers, Fluvisol, Phaeosem, Solonczak and Solonetz soils are common. The entire area is located in the same climate district (continental steppe climate zone). The mean temperature in July is between 21 and 23°C and the precipitation in the summer half-year is approximately 300 mm (Smailagič et al., 2013; Fiala et al., 2014). Severe droughts in 2000, 2003, 2007 and 2012 were reported for all countries in the study area (Spasov et al., 2002; Djordjević, 2008; Bihari, 2012; Fiala et al., 2014).

## 3. DATA AND METHODS

This study aimed to estimate the potential changes in the spatial pattern and intensity of droughts and to estimate the changes in the frequency of drought events due to climate change. To determine these changes, projected future climate data derived from regional climate models were used, drought indices were calculated, and an analysis of spatial differences and temporal tendencies was applied.

### 3.1. Calculation of drought index

The existing recent and future drought hazard maps of the three countries are difficult to compare, and the affected areas cannot be summarised in an integrative regional map because different drought indices associated with diverse national goals and purposes (hydrological, agricultural, and/or meteorological) were used. To determine which drought index describes the impact of drought on agriculture most effectively, the relationship between crop yields and average drought indices is necessary to be assessed. In the Hungarian Drought Strategy, the average values of the Pálfai Index (PAI) and SPI were compared with the annual yield of maize, a climate-sensitive crop. Both indices showed significant correlation with the annual yield (HDS 2012); however, the PAI exhibited a stronger relationship ($R^2$=0.78) than SPI ($R^2$=0.55).

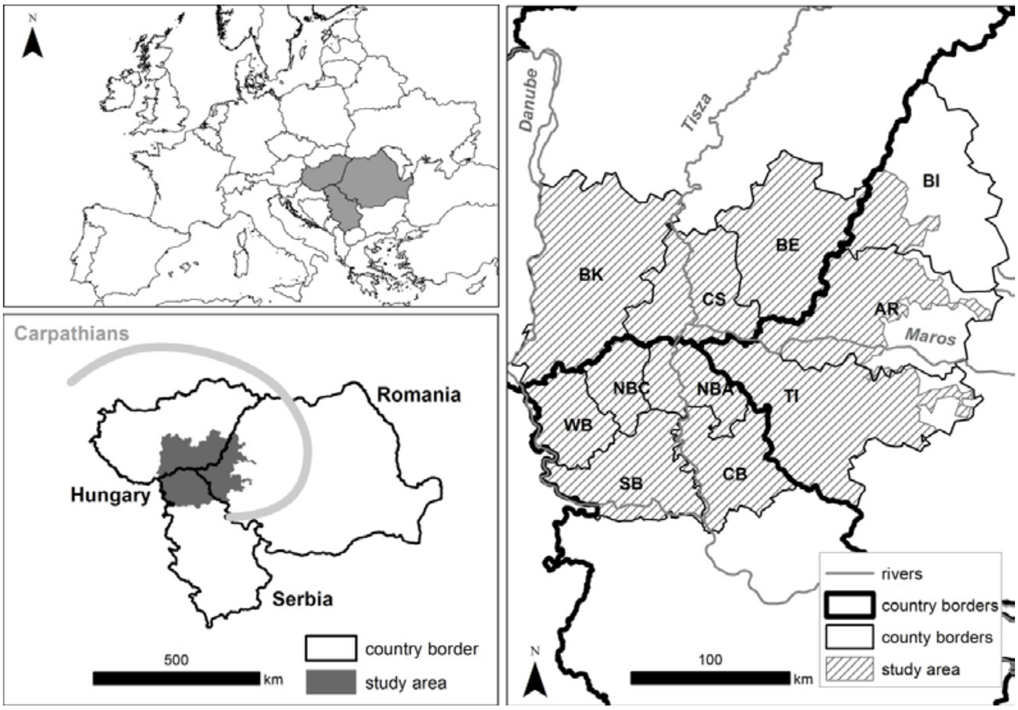


Figure 1. Location of the study area (BK: Bács-Kiskun County; CS: Csongrád County; BE: Békés County; SB: South Backa District; NBC: North Backa District; NBA: North Banat District; CB: Central Banat District; WB: West Banat District; BI: Bihor County; AR: Arad County; TI: Timis County).

The reason for the difference is presumably due to the number of factors involved in the index algorithm: The SPI is based only on precipitation values, whereas the PAI also incorporates temperature and groundwater data. In the PAI formula, the determination of the three correction factors (daily temperature, precipitation values, and groundwater levels) is difficult (Pálfai & Herceg 2011). In the absence of the necessary data for the calculation of the correction factors, the modified Pálfai Drought Index (PaDI) can be used instead of the PAI, especially in case of cross-border investigations, because the PAI and PaDI are highly correlated ($R^2$ = 0.9) (HDS, 2012). Therefore, the PaDI index was used for the spatial and temporal analysis in this study. The PaDI (Pálfai & Herceg 2011) is a relative indicator that uses monthly temperature and precipitation data to characterise the drought in a given agricultural year with a single numerical value. The PaDI was developed in Hungary, and it models drought periods particularly well under the climatic conditions of the Carpathian Basin. The calculation of the PaDI is as follows:

$$\mathrm{PaDI} = \frac{\left[\sum_{i=apr}^{aug} T_i\right] / 5 * 100}{\sum_{i=oct}^{sept} (P_i * w_i)} * k_1 * k_2 * k_3$$

where $T_i$ is the mean monthly temperature from April to August, $P_i$ is the monthly sum of precipitation from October to September, and $w_i$ is a weighting factor. The monthly weighting factors indicate the difference between the moisture accumulation in soil and the water demand of plants. The correction factors are as follows: $k_1$ is a temperature correction factor, $k_2$ is a precipitation correction factor and $k_3$ is a correction factor that characterizes the precipitation conditions of the previous 36 months (Pálfai & Herceg 2011).

### 3.2. Analysis of spatial differences and temporal tendencies

To analyse the spatial differences and temporal tendencies, average values for the 30-year periods (1961-1990, 2021-2050 and 2071-2100) were calculated. The calculation of 30-year averages can conceal large year-to-year fluctuations; however, a long-term average value can reveal the main tendency of the changes and can help to outline the spatial differences in the changes.

To analyse the two future periods (2021-2050 and 2071-2100), REMO and ALADIN RCM data based on the A1B scenario, which models anthropogenic climate forcing (Bartholy et al., 2008), were used. The A1B scenario represents a "middle of the road" emissions scenario, assuming a balance across all sources in economic development (Overland & Serreze, 2012). The climate projections were generated by the Numerical Modeling and Climate Dynamics Division of the Hungarian Meteorological Service. The spatial resolution of the data is 0.22° (approximately 25 km). The model simulations provide changes in daily precipitation and temperature data for the two future periods, relative to the reference period, 1961-1990. For the calculation of PaDI, average monthly values were computed from the daily model data.

To define the size of the area affected by different drought severities in the study area and to delineate the changes in the area affected by serious droughts, the PaDI values were categorised into hazard classes with an interval of 0.5, and the areas (in terms of per cent of the total study area) characterised by different categories of PaDI values were calculated based on the average of REMO and ALADIN model simulations.

More detailed regional differences in the study area were defined by calculating the changes in the minimum, maximum and average values of the PaDI at the county level for the periods 1961-1990, 2021-2050 and 2071-2100 to reveal the tendencies of the drought hazard and the diversity of the hazard in the different counties. The scale of this calculation makes this analysis more applicable for spatial planning purposes.

Because these 30-year averages can conceal notable differences in individual years, the PaDI was also calculated for individual years in the periods 1961-1990, 2021-2050 and 2071-2100. The annual calculation cannot be used directly for assessment because uncertainties of the climate projections. Therefore, the frequency of different drought severities was analysed (Table 2).

The frequency of each class was calculated based on the number of years with drought above a defined PaDI value in the 30-year period. To verify the modelled tendencies, PaDI values for the past 30 years (1983-2012) were also calculated for three locations (Szeged, Becej, Arad) in the countries.

Table 2. PaDI value classes (Pálfai & Herceg 2011)

| PaDI | Description |
|---|---|
| <4 | year without drought |
| 4-6 | mild drought |
| 6-8 | moderate drought |
| 8-10 | heavy drought |
| 10-15 | serious drought |
| 15-30 | very serious drought |
| >30 | extreme drought |

## 4. RESULTS

### 4.1. Spatial and temporal assessment of drought hazard

In the period 1961-1990, the average PaDI values varied between 3.1 and 5.5 in the region (Fig. 2). These PaDI values were not especially high because PaDI values between 6 and 8 represented moderate drought and values above 10 represent serious droughts. However, these value were averages for the 30-year period, which could conceal large fluctuations. The highest PaDI values, indicating the most severe drought, were observed in the north-western part of the region, and the PaDI values decreased toward the south-east. The lowest values occurred in the Romanian part of the region. Based on the average data from the ALADIN and REMO climate model simulations for the period 2021-2050, an increase in the drought hazard was projected for the entire study area (the PaDI values vary between 4 and 6.6), but the spatial pattern of the hazard does not change. For the period 2071-2100, a further increase in the hazard is projected,

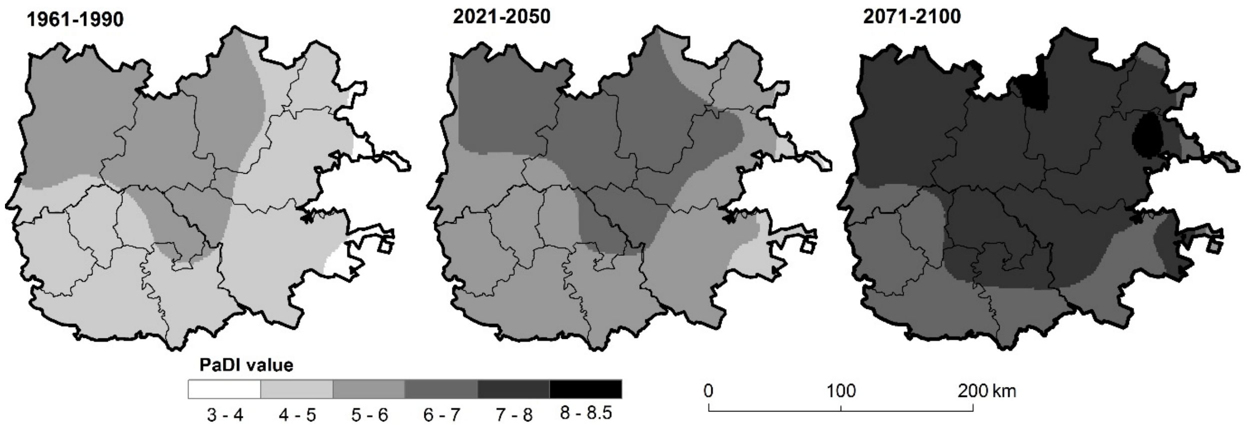


Figure 2. Spatial patterns in the PaDI values based on the average REMO and ALADIN model simulations for the periods 1961-1991, 2021-2050 and 2071-2100.

with PaDI values reaching 8.3. Moreover, the spatial pattern of drought will also change due to an intense increase projected in the eastern part of the region. Therefore, the current NW-SE gradient will be replaced by a N-S gradient. The highest values will occur in Timis, the western part of Arad County, North Banat and in all Hungarian counties.

The PaDI drought classification and the spatial approximation indicated the increasing future drought hazard for the study region. In the 1961-1990 period, the PaDI values were below 5.5 and approximately 90% of the area was characterised by average PaDI values between 4.5 and 5.5 (PaDI values of 4.5-5.0 and 5.0-5.5 were characteristic for 47% and 40% of the area, respectively). For the period 2021-2050, a general increase in drought hazard was characteristic for the whole region: PaDI values of <5.5 values are characteristic for only 15% of the total area, based on the average data of ALADIN and REMO climate model simulations. The dominant PaDI classes are 5.5-6.0 (46% of the area) and 6.0-6.5 (40% of the area) in the 2021-2050 period (Fig. 3).

For the period 2071-2100, the prevailing PaDI classes increase even further, based on the climate simulations. The dominant PaDI class is 7.0-7.5, which represents 36% of the area, and a further 33% of the area features a more serious drought hazard.

The spatial pattern and the general increase in the drought hazard were also linked in our study to county level. In the reference period (1961-1990), the lowest average PaDI values are observed in the Romanian counties, whereas the highest values were observed in the Hungarian counties. Based on the model simulations for the period 2071-2100, the greatest increase in the drought hazard was projected in the Romanian counties, thereby making the average Romanian PaDI values similar to those of the Hungarian counties (Fig. 4a).

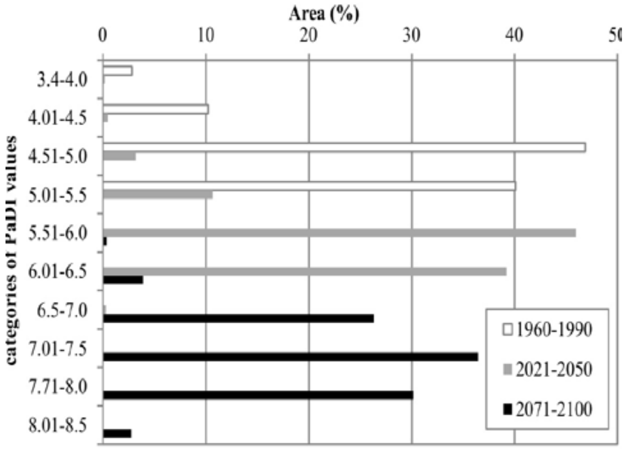


Figure 3 Areas (%) with different categories of PaDI values, based on the averages of the REMO and ALADIN model simulations for the periods 1961-1990, 2021-2050, 2071-2100.

The spatial difference in the hazard within the counties was shown by analysing the minimum and maximum values. The lowest variability was observed in the Serbian counties, and the highest was observed in the Romanian counties.

However, this difference was partly related to the area of the counties. To determine the effects of area on the variability, the relationship between the area and the standard deviation of PaDI values for the counties were analysed (Fig. 4b). In the Hungarian and Serbian counties, the standard deviation and the area of the counties were closely related. In contrast, in the Romanian counties, the standard deviation was very high compared to the area. Hence, the drought hazard in Romania had high spatial variability. The higher variability in this area was likely caused by the proximity to the Carpathian Mountains, where there were large changes in the climate parameters due to orography.

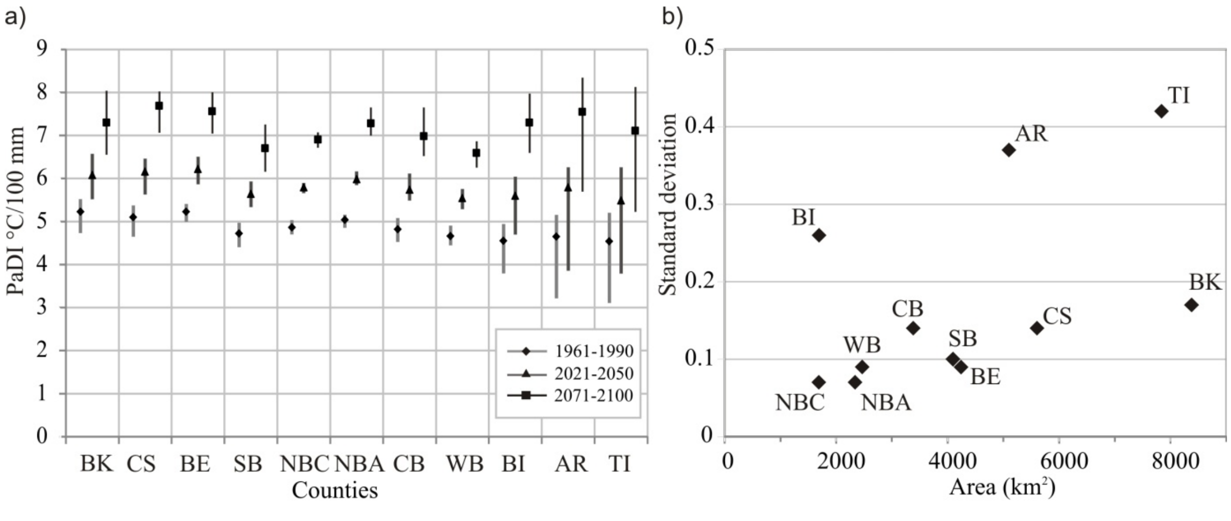


Figure 4.a. Changes in the minimum, maximum and average PaDI values in the investigated periods based on the averages of the REMO and ALADIN model simulation data. b) The relationship between the area and the standard deviation of the PaDI values for different counties.

### 4.2. Number of expected drought years and drought severity analysis

The spatio-temporal increase in the 30-year average drought values did not definitively indicate the seriousness of the economic and ecological problems in the future (2021-2050 and 2071-2100). However, the increase in extremities clearly confirmed its importance (Fig. 5), based on the number of years with expected droughts and the number of years with expected serious drought events (PaDI values >10). A huge increase in severity was projected for both future periods. The northern and eastern parts of the study area were projected to be the most effected (Hungarian and Romanian counties). Serious droughts were expected to occur more frequently in the eastern part of the study area. Figure 7 demonstrates the changes in the frequency of years with different drought severities based on PaDI at Becej (Serbia), Arad (Romania) and Szeged (Hungary) compared to the reference period (1961-1990), when mostly years without drought, furthermore a few years with mild or moderate drought occurred. At all three locations a significant decrease in the number of years without drought or mild drought (PaDI>6) and a significant increase in the extremities (moderate, heavy, serious, very serious or extreme droughts) was projected for the first modelled period compared to the reference period and this tendency was projected to continue in the second period. Heavy and serious (PaDI>8) or even very serious or extreme droughts were projected to occur in almost 50 % of the years in the 30-years-period in the end of the century. The observed data from the past 30 years (between 1983-2012) verify the direction of the projected tendencies, since moderate droughts (6<PaDI<8) occurred more frequently, moreover heavy droughts (8<PaDI<10) and serious droughts (PaDI>10) were also observed.

## 5. DISCUSSION

The results demonstrated that the whole study region was projected to be greatly influenced by serious droughts in the future. The north-eastern part of Serbia, the south-eastern part of Hungary and the south-western counties (Timis and Arad) of Romania face increasing drought hazards in the coming decades. In addition to the increasing drought severity, the frequency of severe droughts was also projected to increase, which clearly confirmed the importance of the problem. In the period 2071-2100, a drought year is expected to occur every second or third year.

Due to the projected increasing drought hazard, agricultural production conditions are expected to worsen throughout the 21st century. Based on the detailed spatio-temporal evaluations of future climatic trends on agriculture, positive consequences were also detected. For example, an increase in yield of approximately 5% is expected when wheat is sown two weeks earlier than usual due to climate change (Erdélyi, 2008). Gaál et al., (2014) concluded that positive changes in maize production conditions would occur in the period 2021-2050. However, these results were calculated on the basis of a 10-year reference period from 2001 to 2011, which was a historically extraordinary decade with two heavy and three moderate drought events in the region; moreover, one year featured a severe inland excess water event. According to our results, the past 30 years fit to the tendency of increasing drought hazard, and more frequent drought years are expected for 2021-2050.

The estimates of drought hazard based on regional climate model simulations have uncertainties, which are normal for future projections (IPCC, 2007, Bartholy et al., 2008). These uncertainties arise in part from the modelling method and from the natural climate variability. The most difficult (thus, the most uncertain) part of the model is the modelling of the social and economic changes, including the adaptation measures undertaken in the future. Therefore, several scenarios were developed to model the anthropogenic climate forcing factors (Nakicenovic & Swart, 2000; Rogelj et al., 2012). Due these uncertainties, the results of our calculations were applied only to outline the tendencies in the changes, and according to the climatological routine the data calculations were performed with 30-year averages.

Future drought hazard projections at the continental level (Jacob et al., 2013) estimate an increasing drought tendency for all of Europe. Thus, EU member states were encouraged to develop national drought strategies until 2012 (EU WFD, 2000). The strategies for each investigated country are now available and include the strategic orientation for drought management, more efficient use of water resources, water quality, modern agro-techniques and potential landscape structure according to changing landscape conditions (Hungarian – HDS, 2012; Romanian- National Communication, 2010; Serbian - Mateescu et al., 2013).

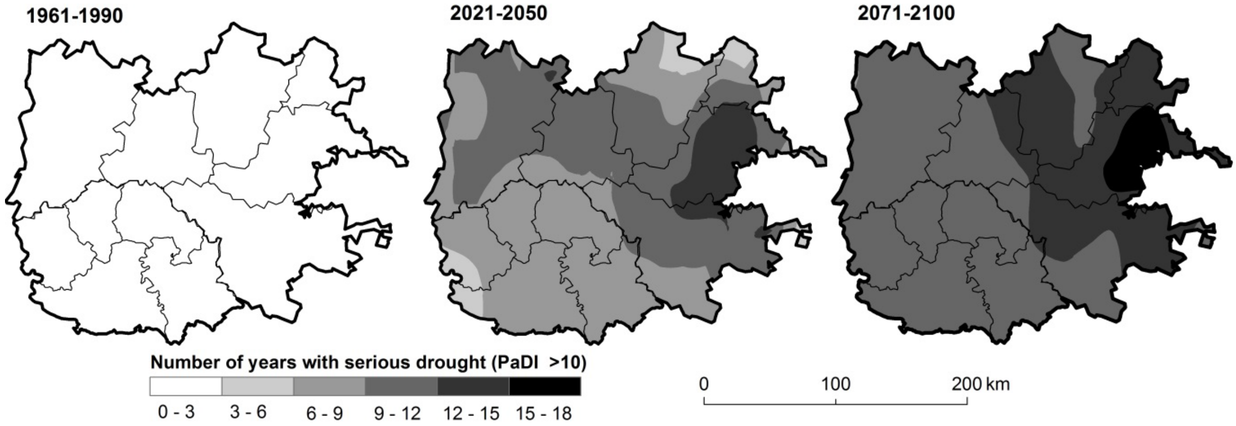


Figure 5. Number of years with serious drought (PaDI values >10) in the periods 1961-1990, 2021-2050 and 2071-2100, based on the averages of the REMO and ALADIN model simulations

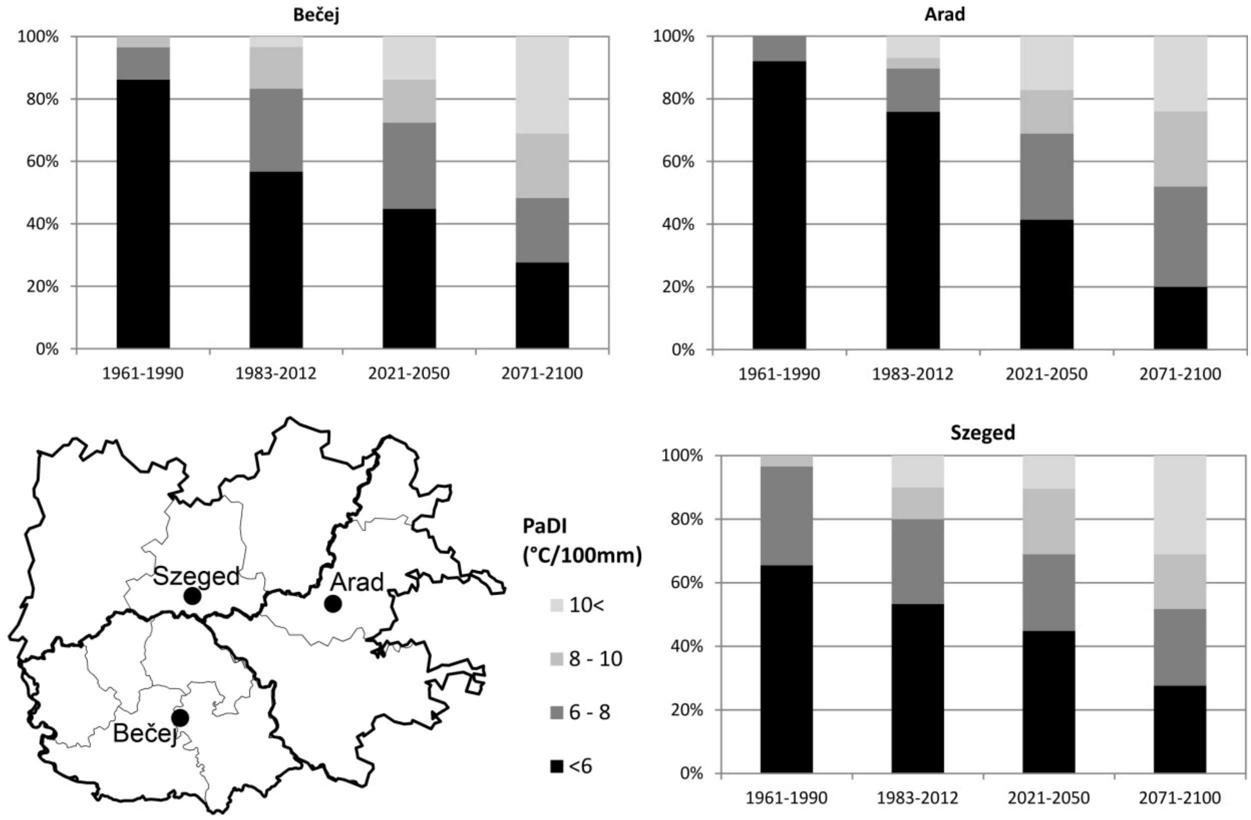


Figure 6. Frequency of years with different drought severities according to PaDI values in the periods 1961-1990, 1983-2012, 2021-2050 and 2071-2100, based on the averages of the REMO and ALADIN model simulations in Bečej (Serbia), Arad (Romania) and Szeged (Hungary).

These national strategies are not harmonised and involve different applied evaluation methods; however, they are all related to the goals of the EU water directives. The drought strategies link multiple goals together (e.g., changing harvest times (Mihăilescu et al., 2009), irrigation needs (Babović & Milić, 2006) and efficient water use (Gayer & Molnár, 2012). Extreme drought damage insurance could broadly support economic stability if it ensures the continuity of individual farmers. In addition, other measures could be undertaken that foster the adaptation of the agricultural sector to increased summer drought risk (Botzen et al., 2010).

The investigated cross-border region has similar environmental conditions, including cross-border catchments, thus, any adaptation measures require a strong cross-border co-operation. Regional thinking is quite important that can be facilitated by high-resolution information on the state of the environment in spatial and temporal aspects as well.

## 6. CONCLUSION

Climate models project increasing drought hazard for the Carpathian Basin in Central Europe. More frequent and severe droughts have already caused significant agricultural yield losses in recent decades. Due to the increasing intensity of the drought problem in the future, as confirmed in our regional cross-border study, the economically viable agricultural production will become more uncertain toward the end of the century.

The continuous development of the socio-economic system changes the pressure on food production. Thus, consumers and producers should have valid, high spatial resolution information on the severity and the spatial distribution of drought hazards in order to mitigate and adapt to the socio-economic vulnerability in their environment. Long-term projections of drought hazard contribute to strategic planning for long-term adaptation to the increasing extreme events (IPCC, 2014). Short-term predictions improve the proper timing of agro-technical measures that prevent and/or mitigate the potential consequences. These short-term predictions can provide the basis for early warning systems that already exist at the continental scale in Europe (European Drought Observatory) and the USA (Drought Monitor) (Wilhite et al., 2007; Vogt et al., 2011; Pulwarty & Sivakumar, 2014).

In the study area, there is no drought-related early warning or real-time information system on e.g., vegetation conditions, soil wetness or drought severity at local or county level at present. The development of a warning system that measures agricultural and hydrological aspects would highly strengthen sustainability and more efficient management implications.

### Acknowledgements

This research was supported by the IPA Cross-border Cooperation Programme of the European Union under the project HUSRB/1203/121/130, entitled WAHASTRAT (Water shortage hazard and adaptive water management strategies in the Hungarian-Serbian cross-border region).

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Received at: 20. 06. 2015
Revised at: 22. 03. 2016
Accepted for publication at: 24. 03. 2016
Published online at: 29. 03. 2016