Modelling vulnerability of drought in the Great Plain of Hungary

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Abstract The Carpathian Basin is characterized by varying hydrological extremes, both in space and time. In fact, that the drought is significant and growing risk factor for Hungary, particularly in the Great Hungarian Plain, but in the other parts of the country signs of desertification are also found. Severe or moderate droughts occur in Hungary almost every year. However, the frequency of drought has increased, especially in recent decades.

The aim of the study was to research drought phenomenon with calculation different drought indexes and based on this develop a drought vulnerability model to identifying and monitoring this phenomenon.

In this study we calculated Reconnaissance Drought Index (RDI), Standardised Precipitation Index (SPI), Precipitation Deciles (PD) using DrinC software and Palfai Drought Indices (PaDI) to identifying and monitoring drought in our sample area (Karcag) which are situated in the Great Hungarian Plain.

The result of drought indices calculation showed different types of drought in different years, however there were correlation between the indices and the input parameters were also simular. Thus using the all values of indices, a new drought categories were created using centroid defuzzification methods. Thus a new drought classification method were worked for the evalution of drought. We created 5 new categories: year without drought, mild drought, moderate drought, drought, heavy drouht and based on these categories we evaluated the drought phenomenon in our sample area.

Keywords: drought indices (RDI, SPI, PD, PaDi), defuzzyfication, modelling drought vulnerability

1. Introduction

Drought is a complex phenomenon, which has no generally accepted definition. Wilhite and Glantz (1985) the discussion of the disciplinary perspectives of drought which follows is the result of a review of more than 150 published definitions. For purposes of discussion these definitions of drought are clustered into four types: meteorological, agricultural, hydrologic, and socio-economic.

During our reseach, we dealt with in more detail in meteorological drought. Meteorological definitions of drought are the most prevalent. They often define drought solely on the basis of the degree of dryness and the duration of the dry period. For example, meteorological drought has been defined as a "period of more than some particular number of days with precipitation less than some specified small amount". In connection with the meteorological drought debate about when to begin a drought, that is, how long is the period which has been considered to be permanently numerically low rainfall periods.

In Hungary, in avarage 10 years are considered dorught in every 3-4 year. One of the main sources of uncertainty in drought-related studies in spatial, temporal and intensity demarcation. The Carpathian Basin weather, such as drought appearance of Hungary was determine by a large regional processes fundamentally.

According to the 2071-2100 regional climate models onto the major regions of the Carpathian Basin will be typical of the semi-arid nature, and as a result of this, the frequency and extent of drought will also increase (Bartholy et.al., 2007).

In the dorught prevention is an important step to more accurately explore the relation between the local and global hydrological process (Lehner et.al, 2006).

Among the research objectives included examination of the most currently used meteorological drought indices calculation and application of our sample area. As a basis for the Global Water Partnership Handbook of Drought Indicators and Indices (2016) (Internet1).

There are three main methods for monitoring drought and guiding early warning and assessment:

1. Using a single indicator or index
2. Using multiple indicators or indices
3. Using composite or hybrid indicators.

The WMO-GWP (34) are separeted different groups of indices as meteorological, hidrological, remotly sensed and modell indicators (Sivakumar el.al, 2011). Based on the GWP Handbook, the following indices were calculated: Deciles, RDI, SPI.

Precipitation deciles

One of the simplest meteorological drought indices is the method of Deciles which was introduced by Gibbs and Maher (1967). The precipitation totals for the preceding 3 months are ranked against climatologic records and if the sum falls within the lowest decile of the historical distribution of 3-month totals, then the region is considered to be under drought conditions (Kininmonth *et al*. 2000). The drought ends when: (i) the precipitation measured during the past month already places the 3-month total in or above the fourth decile, or (ii) the precipitation total for the past 3 months is in or above the eighth decile. The advantage of the method of deciles is its computational ease, but its simplicity can lead to conceptual difficulties. The deciles are grouped into five classes as presented in Table 1.

Table 1: Classification of drought conditions according to deciles

Decile Class	Description
deciles 1–2: lowest 20 %	much below normal
deciles 3–4: next lowest 20 %	below normal
deciles 5–6: middle 20 %	near normal
deciles 7–8: next highest 20 %	above normal
deciles 9–10: highest 20 %	much above normal

(Source: Tigkas, 2014).

Reconnaissance drought index (RDI)

The Reconnaissance Drought Index (RDI) was developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system (Tsakiris and Vangelis 2005; Tsakiris *et al*. 2007c). It is based both on cumulative precipitation (P) and potential evapotranspiration (PET), which are one measured (P) and one calculated (PET) determinant.

Positive values of RDIst indicate wet periods, while negative values indicate dry periods compared with the normal conditions of the area. Drought severity can be categorised in mild, moderate, severe and extreme classes, with corresponding boundary values of RDIst (−0.5 to −1.0), (−1.0 to −1.5), (−1.5 to −2.0) and (< −2.0), respectively.

Standardized precipitation index (SPI)

For the SPI calculation, the long-term precipitation record for a desired period is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (McKee *et al*. 1993; Edwards and McKee 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Since SPI is normalised, wetter and drier climates can be represented in the same way. Generally, monthly precipitation is not normally distributed so a transformation is performed such that the derived SPI values follow a normal distribution. The SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. One interpretation of the resultant values is presented in Table 2 (Tsakiris and Vangelis 2004).

Table 2: Classification of drought conditions according to the SPI

SPI values	Classification
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
−2.0 or less	Extremely dry

(Source: Tigkas, 2014).

Palfai Drought Indices (PaDI)

The Palfai drought index (PAI) developed in Hungary for users in agriculture and in water management has been used for numerical characterization of droughts since the beginning of the 1980s. This index characterizes the strength of the drought for an agricultural year with one numerical value, which has a strong correspondence with crop failure.

The calculation of the base-value of PAI is essentially simple because data requirements can be easilly met, only monthly mean air temperature and sum of precipitation are needed for calculations. However, in the formula of PAI the determination of three correction factors, based on daily temperature and precipitation values, as well as groundwater levels is difficult. For easier practical use we have developed a new, simpler method for the calculation of these factors, which is based on monthly mean air temperature and monthly sum of precipitation.

The equation for the new method, base-value of the modified index, named Palfai's Drought Index (PaDI) is:

$$PaDI_0 = \frac{\left[\sum_{i=apr}^{aug} T_i\right] / 5 * 100}{c + \sum_{i=okt}^{szept}(P_i * w_i)}$$

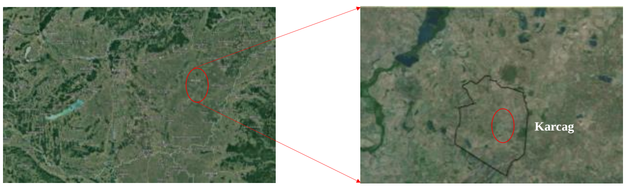
where

PaDI0 – base-value of drought index, °C/100 mm

Ti – monthly mean temperature from April to August, °C,

Pi – monthly sum of precipitation from October to September, mm,

wi – weighting factor,



c – constant value (10 mm).

The weighting factors (wi) of precipitation in Table x show the difference between the soil moisture accumulation and the water demand of plants.Weighting factors are the following : October 0,1; November, December 0,4; January-April 0,5; May 0,8; June 1,2; July 1,6; August 0,9; September 0,1.

Calculation of PaDI

$$PaDi = PaDI_0 * k_1 * k_2 * k_3$$

PaDI – Palfai Drought Index, °C/100 mm k1 – temperature correction factor, k2 – precipitation correction factor k3 – correction factor, which characterizes the precipitation circumstances of the previous 36 month From the correction factors the temperature factor k1 represent the relation between examined and annual summer mean temperature, the precipitation factor k2 represent the relation between examined and annual summer precipitation sum and k3 represent the effect of precipitation circumstances of previous 36 month.The drought categories are in Table 3.

Table 3. Drought categories

PaDI	ºC/100 mm 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

(Source: Internet 2).

Material and methods

2.1 Introduction of the sample area

During our research, our sample area was Karcag and surrounding areas. Karcag is located in (Coordinates: latitude 47° 18′ 40″, longitude. 20° 54′ 58″) in the Northern Great Plain, within that Jász-Nagykun County, the flat of Szolnok-Túr (Figure 1).

Figure 1: Location of our sample area

This is the driest area of Hungary. Furthermore, 80% of the total area of the sub-region is agricultural land, in which the percentage of the arable land is dominated (70% of the total area).

2.2 Calculation drought indices

The temperature and precipitation data which were reqiured for the calculation have been provided by the Research Institute of Karcag of the University of Debrecen.

During in our reseach, the choosen indices (Deciles, SPI, RDI) from the GWP Handbook of Drought Indicator and Indices were calculated using DrinC (Drought Indices Calculator) software in our sample area. The general knowledge and methodological foundation of the software was published by Tigkas et.al in 2014.

DrinC can be used for the calculation of two recently developed indices, the Reconnaissance Drought Index (RDI) and the Streamflow Drought Index (SDI), as well as two widely known indices, the Standardised Precipitation Index (SPI) and the Precipitation Deciles (PD). Moreover, the software includes a module for the estimation of potential evapotranspiration (PET) through temperature based methods, useful for the calculation of RDI. The software may be used in a variety of applications, such as drought monitoring, assessment of the spatial distribution of drought, investigation of climatic and drought scenarios, etc. The applications of DrinC in several locations, especially in arid and semi-arid regions, show that it is gaining ground as a useful research and operational tool for drought analysis.

The data can be monthly, annual and seasonal period, and these can be directly imported from MS Excel files (.xls). In addition, it is possible to transform the effective precipitation from the precipitation data using the USA Bureau of Reclamation Method (Stamm, 1967) or FAO method (Brouwer and Heibloem, 1986).

The calculation was made on a monthly scale, relative to the hydrological year (from october to september) from 2002 until 2013.

Processing the calculation, the input parameters and coordinates should be necessary to give. The potencial evapotranspiration values were processed by Thornthwaite-method.

After that, the different drough indices were calculated. The input parameters of the indices were different (Table 4).

Table 4: Input parameters of the indices

Name of the indices	Input parameters
Deciles	Precipitation
RDI	Precipitation, PET (or temperature data)
SPI	Precipitation

(Source: Tigkas, 2014)

The PaDi were calculation in MS Office Excel using precipitation and temperature values for our sample area.

2.3 Fuzzyfication

The reuslts of calculation of drought indices shows different type of drought, thus a new drought classification method were worked for the evalution of drought. We created 5 new categories: year without drought, mild drought, moderate drought, drought, heavy drouht. The fuzzyfication method were processed, when we fuzzified all input values into fuzzy membership functions (blur value was 5 %), then executed all applicable rules in the rulebase to compute the fuzzy output functions. Finally de-fuzzified the fuzzy output functions to get the new values. De-fuzzification were made by centroid method.

3. Results

First of all, the calculated values of drought indices were presented (Table 5). As we mentioned earlier, we calculated Deciles, SPI, RDI and PaDi to our sample area.

Table 5: Values of the drought indices 2002-2013

Years	Deciles	SPI	RDI	PaDi
2002-2003	1,00	-0,31	-0,03	9,08
2003-2004	9,00	0,91	0,37	3,17
2004-2005	10,00	0,82	0,72	2,71
2005-2006	9,00	0,09	-0,04	3,60
2006-2007	3,00	-1,41	-0,61	6,44
2007-2008	9,00	1,17	0,98	3,68
2008-2009	4,00	0,15	0,43	5,33
2009-2010	10,00	1,81	0,95	2,60
2010-2011	5,00	1,32	0,87	5,10
2011-2012	1,00	-0,51	-1,00	7,90
2012-2013	8,00	0,06	-1,00	5,11

In case of deciles, the 20% threshold value was 416,4 mm. Based on the Deciles value we can established that in the year of 2002-2003, 2011-2012 the values were below normal, thus the subregion was drought. Furthermore in the year of 2006-2007, 2008-2009 the deciles values were above normal, thus in these years there were also drought, but these were milder.

Based on the evaluation of RDI values, the year of 2006-2007, 2011-2012 and 2012-2013 were dry period.

Based on the results of SPI values, milder drought was obrserved in the year of 2002-2003, in the year of 2011-2012 was normal year and in 2006-2007 was moderately dry.

Based on the PaDi values there was drought in the year of 2002-2003, 2006-2007,2008-2009, 2011-2012.

Our result showed different types of drought in different years, however there were correlation between the indices and the input parameters were also simular. Thus using the all values of indices, a new drought categories were created using defuzzification methods (Table 6).

Table 6: Values of the new categories

Years	Mean fuzzy membership values (%)	Categories
2002-2003	36,99	mild drought
2003-2004	76,62	drought
2004-2005	75,22	drought
2005-2006	57,06	moderate drought
2006-2007	25,00	mild drought
2007-2008	80,74	heavy drought
2008-2009	83,38	heavy drought
2009-2010	75,07	drought
2010-2011	95,66	heavy drought
2011-2012	25,00	mild drought
2012-2013	60,22	drought

Based on the table 6., we could said that in the examination period there weren't year without drought. However, in the year of 2002-2003, 2006-2007 and 2011-2012 were mild drought, in the year of 2005-2006 was moderate drought, in the year of 2003-2004, 2004-2005, 2009-2010 and 2012-2013 were drought and in the year of 2007-2008, 2008-2009, 2010-2011 were heavy drought.

Summary

The aim of our study was to research drought phenomenon with calculation different drought indexes and based on this develop a drought vulnerability model to identifying and monitoring this phenomenon. and evaluated the drought based on these new categories.

In this study we calculated Reconnaissance Drought Index (RDI), Standardised Precipitation Index (SPI) and Precipitation Deciles (PD) and Palfai Drought Indices (PaDI) to identifying and monitoring drought in our sample area (Karcag) which are situated in the Great Hungarian Plain.

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Internet 2:

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