METEOROLOGICAL DROUGHT FREQUENCY ANALYSIS USING SPI IN RIVER BASIN HORNÁD, SLOVAKIA

SOĽÁKOVÁ T.[1], ZELENAKOVA M.[1], PURCZ P.[2] and HLAVATÁ H.[3]

[1] Technical University of Košice, Civil Engineering Faculty, Institute of Environmental Engineering, Vysokoškolská 4, 042 00 Košice, Slovakia,
[2] Technical University of Košice, Civil Engineering Faculty, Institute of Construction Technology and Management, Vysokoškolská 4, 042 00 Košice, Slovakia
[3] Slovak Hydrometeorological Institute, Ďumbierska 26, Košice, Slovakia
E-mail: martina.zelenakova@tuke.sk

ABSTRACT

Meteorological drought occurrences are diagnosed using monthly rainfall form 10 gauging stations by calculating Standardized Precipitation Index for the period of years 1981–2011. In this study the Standardized Precipitation Index is calculated by non-parametric approach: the Weibull plotting position is used to obtain the cumulative frequency of precipitation deficiency in 3, 6, 12 months' time scales. The results obtained herein demonstrated that short-term meteorological drought occurred in 4-8 month duration, whereas the duration of intermediate meteorological drought was 6-12 months and long-term meteorological drought lasted 9-18 months.

Keywords: Meteorological drought, Standardized Precipitation Index (SPI), Drought monitoring.

1. Introduction

Drought is slow-moving environmental phenomenon that occurs in virtually all countries of the world affects natural ecosystems as well as socioeconomic systems and human lives (Blain, 2012). In the past many drought indices have been developed, as an useful and simple method for monitoring and assessment various categories of drought (Mishra *et al*., 2010). The comprehensive lists of drought indices are described in some review papers: Mishra *et al*. (2010) and Dai (2011). Meteorological drought is a sustained period of below normal precipitation that is classified with spatial and temporal parameters (Beran and Rodier, 1985). In order to identify the dynamics of precipitation variability, the SPI has been developed by MeKeen *et al*. (1993) to evaluate drought events according to precipitation. The SPI is a probability index that gives a better representation of abnormal wetness and dryness condition as well as it is a fundamental tool to assessing the effects of dryness condition and defining its parameters including duration, severity (intensity) and interarrival time between two successive droughts. (Guttman, 1999; Mishra *et al*, 2010).

The computation of drought SPI indicator can be made using parametric or non-parametric methods. Differences between them are in the method of determination the probability density function $f_{(x)}$ able to describing the long-term observed precipitation. Then the its cumulative probability function is transformed to standard normal random variable Z with mean zero and variance of one, which is the value of the SPI (MeKeen *et al*, 1993). The parametric methods have been preferred to non-parametric methods for the calculation of SPI because the precipitation is usually not normally distributed. Consequently, the meteorological variables can be described by the most appropriate distribution function selected by goodness-of-fit test: Kolmogorov-Smirnov test (Kottegoda and Rosso, 1997) or L-moment ratio diagrams (Peel *et al*, 2001). The SPI is a powerful, flexible index that is simple to calculate for any time scales that functionally reflect meteorological, agricultural and hydrological droughts (Blain, 2012). The short time scales of SPI (SPI 3) reflect deficiency of soil moisture. The long-time scales of SPI

(SPI 6, SPI 9, SPI 12 or SPI 24) reflect deficiency of groundwater, snowpack, streamflow and reservoir storage (McKee *et al*, 1993).

The purpose of drought frequency analysis is to quantify a dryness anomaly for different time scales. Understanding of historical behaviour of physical droughts has important role in planning management of water resources and helps predict and avoid the potential damage of future droughts (Mishra *et al*, 2010). Frequency analysis by SPI has many advantages:

- The SPI is easily comparable with others drought indices.
- It is spatially and temporally invariant drought indicator that allows comparison among different regions and among different periods.
- It is allowed to understand another type of drought, as well as its characterization: duration, severity and frequency.

Disadvantages of frequency analysis of drought by SPI are following:

- It is only univariate analysis, in terms of duration, severity or intensity and inter-arrival time of drought events. The bivariate and multivariate analysis are the best for understanding relationships between them (for example: duration - severity, duration - intensity, duration – inter-arrival time and etc.) using a joint probability distribution.

Drought identification and characterisation is the major interest for drought monitoring systems. The computation of drought characteristics is the first step for assessment of its impacts and for selecting the necessary measures for minimizing its consequences.

The research focuses on the study to distinguish deficiency of precipitation amounts over a season and a longer period of time. It helps to understand the impact of precipitation deficiency on the availability of the different water resources. The objective of this paper is to identify episodes of extreme historical climate droughts and their recurrence probability for purpose to improve monitoring, prediction and preparedness of this hazard. The determination of drought events is important for decision makers for planning and management of water resources in Hornád river sub-basin.

2. Material and methods

2.1. Place specifications and data used

To calculate SPI values for drought analysis, monthly observed precipitation data from 1981 to 2011 are retrieved from the Slovak Hydrometeorological Institute (SHMI) at 10 rain gauge stations located at the sub-basin Hornád. This area is 4 414 km^2, and represents 9% of the total area of Slovakia.

The river Hornád stems at west of the village Vikartovce on the eastern slopes of Kráľová hoľa at an altitude of about 1050 m a. m. Along the river are located rain gauge stations (shown in Table 1).

Table 1: Position of measurement rain gauge stations

Precipitation stations	Latitude	Longitude
Moldava nad Bodvou	48°36'55''N	20°59'56''E
Turňa N/B	48°35'55''N	20°52'50''E
Spišská Nová Ves	48°36'34''N	20°34'22''E
Spišské Vlachy	48°36'54''N	20°47'37''E
Kysak	48°51'12''N	21°13'17''E
Čaňa	48°36'25''N	19°29'53''E
Mníšek nad Hnilcom	48°48'41''N	20°48'54''E
Jakubovany	49°06'26''N	21°08'32''E
Vyšný Čaj	48°41'10''N	21°24'41''E
Chmelnica	49°17'45''N	20°43'53''E

All the chosen rain gauge stations exhibit good data quality, according to the existence of minimal or non-data gaps in all-time series, which can be considered homogeneous. Their homogeneity was controlled by Pettit's test (Pettit, 1979) over the period 1981-2011.

2.2. SPI calculation

The non-parametric approach Weibull plotting position, the empirical frequency gives an estimation of $F(x)$ that is the cumulative distribution of the mean precipitation X_d in the monthly moving windows d = 3, 6, 12 calculated as:

$$X_d(t) = \frac{1}{d}\sum_{\tau=t-d+1}^{t} X(\tau). \tag{1}$$

The Weibull plotting position has been implemented to calculate the cumulative frequency of precipitation deficiency over the time scales d (Kottegoda and Rosso, 1997). According to the time scale, the index is indicated as SPI3 for a time scale of 3 month, SPI6 for 6 months, and so on.. The cumulative frequency $F(x)$ is determined by order statistics: let $x_1, x_2..., x_N$ be the sequence of N observations of the variable X_d and with $x_{(1)} \leq x_{(2)} \leq ..... \leq x_{(N)}$ the relative order statistics. For the i-th order statistics $x_{(i)}$ the cumulative frequency is

$$F_N(x_{(i)}) = i/(N+1) \tag{2}$$

Than the standardized drought index SPI is defined as the inverse of cumulative standard Normal distribution (Φ^{-1}) of $F(x)$ (McKee *et al*. 1993):

$$\mathrm{SPI} = \Phi^{-1}(F(X_d)) \tag{3}$$

According to Madadgar *et al*. (2011), as threshold level of drought we use SPI=-1 in order to estimate moderately dry spell. Thus if $Z_d \leq -1$ then we are in drought conditions, while if $Z_d > -1$ we are in normal, or wet, conditions. Consequently it is possible to define the duration of a drought, D, as the period during which the drought index is continuously below the threshold level. The interarrival time, T, is defined as the continuous period the index persists above the threshold. The severity of a drought is defined as the cumulative value of the index in the drought period.

3. Results

Here we evaluate SPI indices at different time scales: 3, 6, 12 months, using nonparametric approaches, and we estimate the short-term and long-term severe and extreme historical drought episodes at 10 rain gauge stations situated in the eastern part of Slovakia from year 1981 to 2011. The assessment shows in Table 2 that the short time scales drought becomes more frequent then longer time scales drought. Drought characteristics are changed when the time scales is changed (McKee *et al*, 1993).

The frequency analysis of droughts is carried out in order to determine the likelihood of their occurrence. In a Tab. 3, the average interarrival times of severe drought events for each rain gauge stations are shown.

The three-month cumulative deficit of rainfall occurs after every 10-13 month. The maximum duration of short-term meteorological drought was recorded in Chmelnica and in May 1986 to December 1986. The six-month cumulative deficit rainfall occurs every 16-28 month. From December 1981 to November 1982, in the precipitation stations Spišská Nová Ves was noted intermediate drought with maximum duration. The twelve-month cumulative deficit rainfall occurs every 22-33 month. The maximum duration of long-term drought was observed in Čaňa and in August 1986 to January 1988.

Table 2: Frequency analysis of meteorological drought in Hornád river basin

Precipitation stations	Years	Drought events		
		SPI 3	SPI 6	SPI 12
Moldava nad Bodvou	1981-1990	8	8	3
	1991-2000	11	7	5
	2001-2010	5	5	4
	1981-2011	**26**	**20**	**12**
Turňa N/B	1981-1990	11	10	8
	1991-2000	12	6	2
	2001-2010	7	4	1
	1981-2011	**32**	**20**	**11**
Spišská Nová Ves	1981-1990	10	7	5
	1991-2000	10	3	2
	2001-2010	6	3	5
	1981-2011	**28**	**13**	**12**
Spišské Vlachy	1981-1990	9	9	9
	1991-2000	9	3	4
	2001-2010	7	5	1
	1981-2011	**27**	**17**	**14**
Kysak	1981-1990	9	9	9
	1991-2000	9	3	4
	2001-2010	7	5	1
	1981-2011	**25**	**15**	**16**
Čaňa	1981-1990	10	7	3
	1991-2000	13	6	5
	2001-2010	7	5	3
	1981-2011	**32**	**18**	**12**
Mníšek nad Hnilcom	1981-1990	10	10	4
	1991-2000	9	6	3
	2001-2010	7	3	4
	1981-2011	**28**	**19**	**11**
Jakubovany	1981-1990	9	10	5
	1991-2000	9	6	4
	2001-2010	7	3	4
	1981-2011	**26**	**19**	**13**
Vyšný Čaj	1981-1990	12	8	3
	1991-2000	11	8	9
	2001-2010	8	5	3
	1981-2011	**33**	**21**	**16**
Chmelnica	1981-1990	12	6	9
	1991-2000	8	9	5
	2001-2010	7	4	2
	1981-2011	**28**	**20**	**16**

Table 3: The return period of drought occurrence.

Precipitation stations	Average interarrival time		
	SPI 3	SPI 6	SPI 12
Moldava nad Bodvou	13,3	17,6	29,9
Turňa N/B	10,6	17,6	32,7
Spišská Nová Ves	12,3	27,5	29,9
Spišské Vlachy	12,7	20,8	25,5
Kysak	13,8	23,7	22,2
Čaňa	10,6	19,6	29,9
Mníšek nad Hnilcom	12,3	18,5	32,7
Jakubovany	13,3	18,5	27,5
Vyšný Čaj	10,2	16,7	22,2
Chmelnica	12,3	17,6	22,2

4. Conclusions

An analysis of drought characteristics in 10 gauging stations located in the Eastern part of Slovakia has been carried out, by SPI that is being used in more than 70 countries as part of drought monitoring and early warning efforts. The main aim of this paper was showed the availability of SPI to determine severe and extreme drought in river sub-basin: Hornád during the years 1981-2010.

AKNOWLEGMENT

The contribution is written thanks to support of project VEGA 1/0609/14.

REFERENCES

1. Beran M., Rodier J. (1985), Hydrological aspects of drought: a contribution to the International Hydrological Programme of Studies and Reports in Hydrology, Paris: Unesco-WMO, **39**.
2. Blain G. C. (2012), Revising the probabilistic definition of drought: strengths, limitations and an agrometeorological adaptation. Brasil. Bragantia, **71/1**, 132-141.
3. Dai A. (2011),. Drought under global warming: a review, Wiley Interdisciplinary Reviews: Climate Change, **2/1**, 45–65.
4. Guttman G. B. (1999), Accepting the Standardized Precipitation Index: a calculation algorithm index, Journal of the American Water Resources, **35/2**, 311-322.
5. Kottegoda N. and Rosso R. (1997), Statistics, Probability and Reliability for Civil and Environmental Engineers, McGraw-Hill, New York.
6. Madadgar S., Moradkhani H. (2011), Drought Analysis under Climate Change using Copula, Journal of Hydrologic Engineering, **18/7**, 746-759.
7. McKee T.B.N., Doesken J., Kleist J. (1993), The relationship of drought frequency and duration to time scales, Conference on Applied Climatology, Boston, AMS, 179-184.
8. Mishra K., Singh P. (2010), A review of drought concepts, J of Hydrology, **391/1-2**, 202-216.
9. Peel M.C. Wang Q.J., Vogel R.M. and McMahon, T.A. (2001), The utility of L-moment ratio diagrams for selecting a regional probability distribution, Hydrol. Sci. J., .**46/1**, 147–155.
10. Pettit A.N. (1979), A non-parametric approach to the change-point detection. Applied Statistics 28, 126–135.