DETECTING CHANGES IN TRENDS AND SCALING EXPONENTS OF SHORT TERM RAINFALL: CASE STUDY FOR THE ORAVSKÁ LESNÁ STATION

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ABSTRACT

The aim of this study was to test the rainfall trend and scaling exponent changes of different duration at the Oravská Lesná climatological station during the observation period 1964 to 2009. Trends of rainfall intensities were tested for the durations of 5, 10, 15, 30, 40, 50, 60, 120, 180, 240 and 1440 minutes from April till October and for the whole warm period. To analyze the significance of rainfall trends Mann-Kendall trend test (Kendall, 1975) was used. Trend analysis of the short-term rainfall was performed for 90% significance. In the next step, the simple scaling methodology was applied to derive scaling exponents and compared changes in their values in different observation periods. Finally, the impact of changes in trends on scaling exponents at the selected station in Slovakia was discussed.

Key words: rainfall intensities, scaling exponents, Mann-Kendall trend test (Kendall, 1945)

1 INTRODUCTION

Over the last decades extreme rainfall events become one of the most frequent natural hazards around the world. In the last twenty years the increased rainfall amounts are visible also in the central European countries. The storms with extremely high short-term rainfall become more frequent, and in the last decades the occurred events reached overall observation maxima of daily and hourly precipitation totals. Increasing of the temperature in the atmosphere increases the intensity of convective origin precipitation across faster than of stratiform precipitation (Berg et al., 2013). More amount of the water vapor content in the atmosphere is causing increase in global average temperature of the atmosphere and the ocean surface, with higher likelihood of extreme rainfall. The average increase in temperature of the planet in the future will also influence higher probability of extreme rainfalls. Analysis of changes and trends in daily rainfall has recently devoted several scientific studies (eg. Vaes et al. 2002, p. 55-61; Velpuri, Senay, 2013; Adamowski and Bougado 2003, p. 17; Santos and Fragoso 2013, p. 34-45; Romano and Preziosi 2013, p. 33), but the analysis of short-term rainfall is confined to a few authors. In recent decades, hydrological research has devoted considerable attention to improving the representation of precipitation fields both in time and space. One of the most important issues is the development of various simple and multiscaling models. They recognize rainfall organization at different scales through the concept of mesoscale precipitation areas and the clustering of cells in space and time; see e.g. Waymire and Gupta (1981), Waymire et al. (1984), Rodriguez-Iturbe et al. (1984), Marien and Vandewiele (1986), Sivapalan and Wood (1987), Veneziano et al. (1996).

In Slovakia the scaling properties of extreme rainfall were first tested in the studies of Bara (Bara 2010, p.74; Bara 2009, p.25-32). In these studies, the simple scaling method was adopted in order to derive the rainfall intensities of sub-daily durations for places without observation. Later Látečková et al. (Látečková 2011, p.47-54) presented scaling exponents derived for the individual months and for the whole warm season and estimated IDF curves for the warm season (April to September) in analysed staions.

The aim of this study was to test the trend changes of short term rainfall intensities at the Oravská Lesná climatological station. Subsequently, using a simple scaling methodology scaling exponents were determined and compared according to the changing trends of specific rainfall intensities.

2 METHODOLOGY

For the testing of trends in time series as precipitation, flows, water quality indicators etc., Mann-Kendall trend test (Kendall, 1975) is often used. The Mann-Kendall trend test is nonparametric test based on the correlation between the alignment of the time series and their time arrangement. For series X = {x_1, x_2, ..., x_n}, a test statistic is given by (Yue et al. 2012, p. 11-26):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sign}(x_j - x_k), \tag{1}$$

where *n* is the length of the data series x_j and x_k are the sequential data in the series and

$$\mathrm{Sign}(x_j - x_k) = \begin{cases} 1, & x_j - x_k > 0 \\ 0, & x_j - x_k = 0, \\ -1, & x_j - x_k < 0 \end{cases} \tag{2}$$

The test statistic *S* shall approximately normal distribution with time series $n \geq 8$, variance is given by:

$$\mathrm{VAR}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right], \tag{3}$$

where t_p is the number of ties for the p_{th} value and q is the number of tied values. The second term in the variance formula is for tied censored data. Standardized test statistic *Z* is computed by

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{pre } S > 0 \\ 0 & \text{pre } S = 0. \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{pre } S < 0 \end{cases} \tag{4}$$

To test for monotonic trend at a significance level, the null hypothesis of no trend is rejected if the absolute value of standardized test statistic Z is greater than $Z_{1-\propto/2}$ obtained from the standard normal cumulative distribution tables.

To test the statistical significance of the trends reflects the conditions listed below while in hydrological practice, to determine the statistical significance test trends levels 90% significance (80% <1.28; -1.28>; 85% <1.44; -1, 44>; **90% <1.64, -1.64>** 95% <1.96, -1.96>).

A simple scaling method was adopted in order to derive relationship between the intensity, duration and frequency (the IDF characteristics) of rainfall. Let I_d and $I_{\lambda d}$ denote annual maximum rainfall intensity series for the time durations *d* and *λd*, respectively. The two random variables I_d and $I_{\lambda d}$ have the scaling property as (Menabde et al. 1999, p. 335-339; Yu et al. 2004, p. 11-26):

$$I_d \overset{dist}{=} l^{-b} I_{ld}, \tag{5}$$

The equality of variables I_d and $I_{\lambda d}$ is mean in the sense of equality of probability distributions of both variables and β represents the scaling exponent.

Scaling coefficient β we determined the complete, unabridged observation period at the Oravská Lesná station, and then we use it to estimate the design values of rainfall for different frequencies and duration.

3 INPUT DATA

For the analysis in this study, Oravská Lesná climatological station located in the northern mountainous part of Slovakia with long observation period of short-term rainfall (from 1964 to 2009), was selected, see Figure 1. The input data were collected from the database of the Slovak Hydrometeorological Institute. The input data consists of maximum rainfall intensities of the durations 5, 10, 15, 30, 40, 50, 60, 120, 180, 240 and 1440 minutes, separately for months April to October and for the whole warm season. To compare changes in trends and scaling exponents, the observation period was analysed as "complete" from 1985 to 2009 and "shortened” from 1985-2009 and 1964 to 1984, respectivelly.

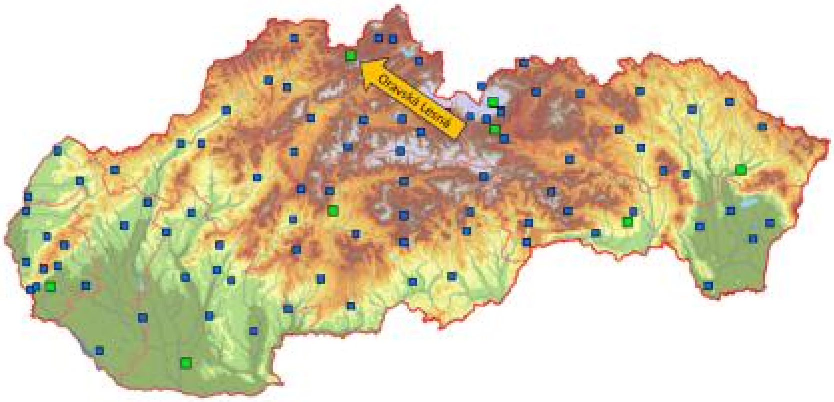

Fig. 1 Location of the Oravská Lesná station in the climatological network of Slovakia.

4 RESULTS

In the first step the trend analysis of the rainfall intensities of duration from 5 to 1,440 minutes from April till October, and for the whole period at the Oravská Lesná station was performed. To determine the statistical significance of the trends in the rainfall time series, the Mann-Kendall trend test (Kendall, 1975) was applied. The results proved that none of the trends detected in the time series was significant on the 90% significance level. The decreasing "+" or increasing trend "-"for all durations and analysed months for "complete" and shortened observation periods are summarised in the Table 1.

Tab. 1 Summary of rainfall intensities trends during a) 1984-1964; at the Oravská Lesná station b) 1985-2009, c) whole (1964-2009) and shortened observation period

Month		Duration [min]											Month		Duration [min]										
		5	10	15	30	40	50	60	120	180	240	1440			5	10	15	30	40	50	60	120	180	240	1440
April	a	-	-	-	-	-	-	-	-	-	-	-	August	a	+	+	+	+	+	+	+	+	+	+	+
	b	-	-	-	-	-	-	-	-	-	-	-		b	-	-	-	+	+	+	+	+	+	+	-
	c	-	-	-	-	-	-	-	-	-	-	-		c	+	+	+	+	+	+	+	+	+	+	+
May	a	-	-	-	-	-	-	-	-	-	-	+	September	a	+	+	+	+	+	+	+	-	+	+	-
	b	-	-	-	-	-	-	-	-	-	-	-		b	-	+	+	+	+	+	+	-	-	-	-
	c	-	-	-	-	-	-	-	-	-	-	-		c	-	-	-	-	-	-	-	-	-	-	+
Jun	a	+	+	+	+	+	+	+	+	-	-	-	October	a	-	-	-	-	-	-	-	-	-	-	-
	b	+	+	+	+	+	+	+	-	-	-	+		b	+	+	+	+	+	+	+	+	+	+	+
	c	+	+	+	+	+	+	+	+	+	+	+		c	+	+	+	+	+	+	+	+	-	+	-
July	a	-	-	-	-	-	-	-	-	-	-	-	Warm season	a	+	+	+	+	+	+	+	+	+	+	+
	b	-	-	+	+	+	+	+	+	+	+	+		b	-	+	+	+	+	+	+	-	+	-	+
	c	-	-	-	-	-	-	-	+	+	+	+		c	-	-	+	+	+	+	+	+	+	+	+

Table 1 shows that in the climatological station for all the durations and analysed months mainly the increasing trend prevailed. Climatological station Oravská Lesná represents the northern region of Slovakia, which is characterised by decreasing rainfall trend for all observation periods in April and May. Significant decreasing trend was also observed in the months of July and October for the 1984 to 1964 observation period. Increasing trends were observed during the observation period 1964 to 1984 in August and in the whole warm season, in the period 1985 to 2009 in October and in observation period 1964 to 2009 in April and May. Important is the increasing trend in the last 15 years is dominant in the months June, August and October. This could be a result of more intensive convective precipitation fields which are formed more frequently in this region during last years. In the next step a simple scaling methodology was used to derive scaling exponents for all the stations analysed in the months April to October and whole warm season as for "complete" and "shorter" observation periods.

Overview of the values of scaling exponents for individual months and periods of observations is summarized in the Fig. 2.

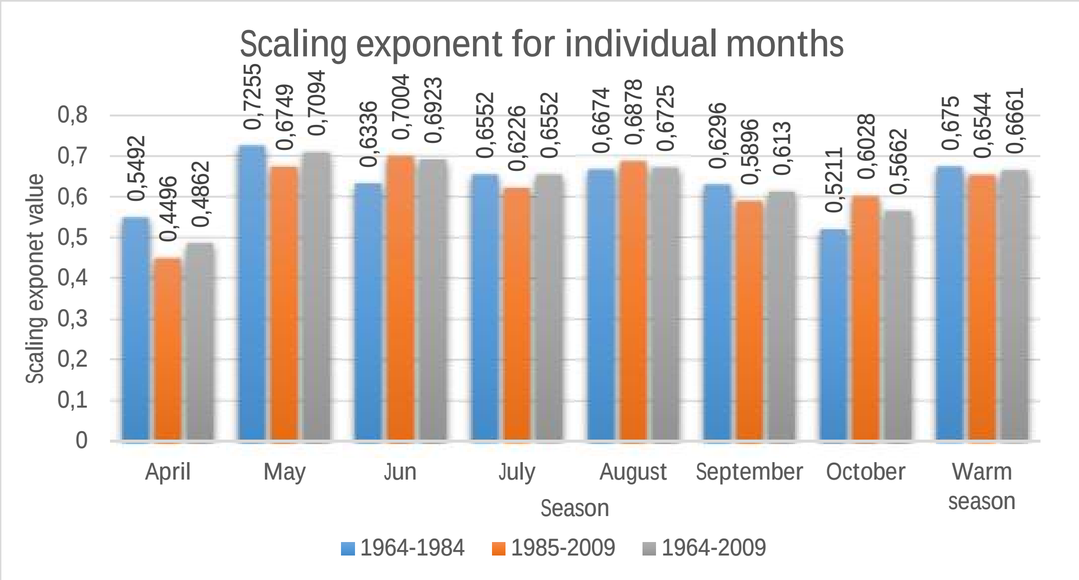

Fig. 2 Scaling exponents for individual months, and the analyzed observation

From the results of the scaling exponents presented, we can conclude that the values of scaling exponents are depending on the length of observations series. The highest values were estimated for the months May, June and August, lowest values in April and October. Differences in maximum, minimum and average values of scaling exponents are throughout each observation period very low, see statistics in the Fig. 3.

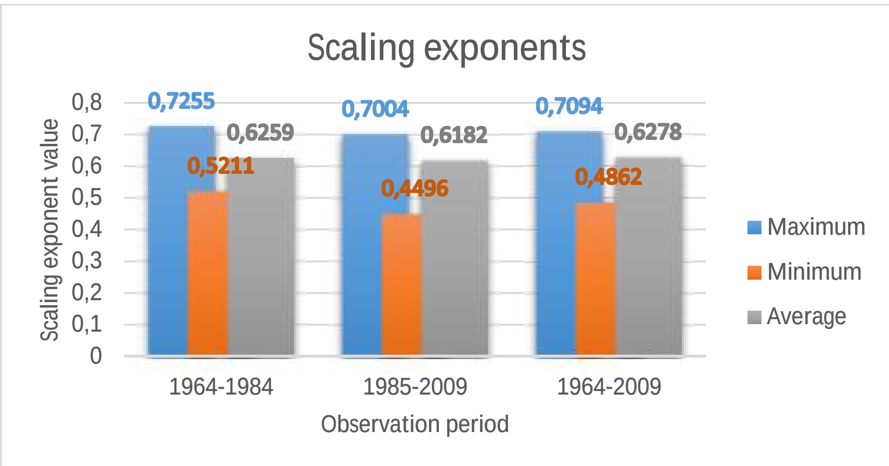

Fig. 3 Statistics of the scaling exponents for the analysed observation periods

We also observed that the impact of decreasing rainfall intensities trends throughout all rainfall duration caused increase in scaling exponents for the analysed observation periods mainly in April and May.

5 CONCLUSION

The aim of this study was to test the trend and scaling exponent changes of rainfall intensities at the Oravská Lesná climatological station. The significance of trends of maximum annual rainfall intensities was tested by the non-parametric Mann-Kendall test (Kendall, 1975). At the climatological station during all the duration of each month and the observation period the trend has prevailing increasing character. Significant decreasing trend for all observation periods we observed in duration from 5 to 1,440 minutes in July and October for 1984 to 1964 observation period. Increasing trend were observed in August and whole warm season during the observation period 1964 to 1984, in October in the period 1985 to 2009 and in April and May in the period 1964 to 2009. The increasing trend in the last 15 year is dominant in the months June, August and October. This could be a result of more intensive convective precipitation fields which are formed more frequently in this region during last years. From the results of estimated values of scaling exponents we can conclude that the values of scaling exponents are depending on the length of observations periods. In general, however, it was not possible to detect a clear impact of rainfall intensities trends on the scaling exponents' changes.

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