TREND ANALYSIS ACROSS THE SLOVAK-POLISH AREA OF THE CARPATHIAN MOUNTAINS

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Abstrakt

Tento príspevok sa venuje trendovej analýze staníc, ktoré sa nachádzajú v slovensko-poľskej časti karpatského oblúka. V rámci analýzy bolo spracovaných 41 vodomerných staníc nachádzajúcich sa v slovenskej časti a 87 vodomerných staníc nachádzajúcich sa v poľskej časti. Pre každú stanicu boli k dispozícii maximálne ročné kulminačné prietoky za obdobie 1960-2010. Analyzované rady maximálnych ročných kulminačných prietokov majú premenlivú dĺžku, ktorá je od 30 do 51 rokov. Plocha povodí k prislúchajúcim vodomerným staniciam je rôzna od 19 km^2 (stanica na rieke Blatina, Slovensko) až po 5649,1 km^2 (stanica na rieke Dunajec, Poľsko). Priemerná nadmorská výška povodí pre analyzované stanice je v rozmedzí od 154,3 m n. m. (stanica na rieke Močiarka, Slovensko) až po 1605,5 m n. m. (stanica na rieke Bialka, Poľsko). Priemerný sklon analyzovaných povodí je 11,5 stupňov.

Trendová analýza časových radov môže byť účinný prostriedok na zisťovanie a porozumenie príčinám zmien v priebehu časového radu, či už ide o zmeny spôsobené klimatickou zmenou alebo inou ľudskou činnosťou. Na analýzu trendov je možné použiť viacero štatistických metód. V príspevku boli použité neparametrické spôsoby detekcie trendu, konkrétne ide o Mann-Kendallov test trendu, Spearmanov test trendu a Cox-Stuartov test trendu. Neparametrické testy sa používajú pre porovnanie súborov štatistických dát, u ktorých sa nepredpokladá normálne rozdelenie pravdepodobnosti sledovaného znaku. V prípade, ak by boli uvažované iba homogénne stanice, na detekciu trendu by postačovala lineárna regresia (Jeneiová a kol., 2015). V našom prípade sme použili neparametrické metódy a teda sme nezohľadňovali homogenitu údajov (bolo uvažované s homogénnymi aj nehomogénnymi vodomernými stanicami).

Pri použití Mann-Kendallovho, Spearmanovho a Cox-Stuartoveho testu boli uvažované nasledovné hladiny významnosti: 5 % (p=0.05) a 1 % (p=0.01). Hladina významnosti 5 % odpovedá 5 % omylu a 95 % istoty. Hladina významnosti 1 % odpovedá 1 % omylu a 99 % istoty. Podľa Mann-Kendallovho testu trendu bolo identifikovaných na hladine významnosti 5 % 25 vodomerných staníc (19 rastúci trend, 6 klesajúci trend). Podľa Mann-Kendallovho testu trendu pre hladinu významnosti 1 % bolo zistených 10 vodomerných staníc (7 rastúci trend, 3 klesajúci trend). Podľa Spearmanovho testu trendu bolo identifikovaných na hladine významnosti 5 % 26 vodomerných staníc (19 rastúci trend, 7 klesajúci trend). Na hladine významnosti 1 % bolo podľa Spearmanovho testu trendu detegovaných 13 vodomerných staníc (10 rastúci trend, 3 klesajúci trend). Výsledky Mann-Kendallovho testu a Spearmanovho testu trendu sú relatívne rovnaké. Podľa Cox-Stuartovho testu bolo detegovaných najmenší počet staníc so štatisticky významných trendom- pre 5 % ide o 11 vodomerných staníc (6 rastúci trend, 5 klesajúci trend), pre 1 % ide o 6 vodomerných staníc (3 rastúci trend, 3 klesajúci trend). V poľskej oblasti je vidieť prevládajúci rastúci trend prietokov za obdobie 1960-2010 pre vybrané vodomerné stanice. V slovenskej oblasti na prítokoch rieky Váh Kľačianke a Štiavnici je pozorovaný klesajúci významný trend za obdobie 1960-2010. Pre potoky, ktoré sa vlievajú do rieky Oravy (Oravica a Zázrivka), je pozorovaný rastúci trend za obdobie 1960-2010.

Cieľom príspevku bolo porovnanie odhadu trendu kulminačných prietokov pomocou troch neparametrických testov. Vo väčšine príspevkov, ktoré sa zaoberajú trendovou analýzou hydrologických časových radov sa využíva len Mann-Kendallov test, no na dosiahnutie podobných výsledkov je možné využiť aj Spearmanov test trendu. Pri využití Cox-Stuartovho testu sú výsledky odlišnejšie, pričom tento test môžeme označiť ako najprísnejší, pretože najmenej staníc bolo detegovaných s významným trendom na hladine významnosti 5 % (p=0,05) a 1 % (p=0,01).

Anotácia

Príspevok je zameraný na trendovú analýzu maximálnych ročných prietokov pomocou neparametrických testov v oblasti slovensko-poľskej časti karpatského oblúka. V príspevku boli spracované maximálne ročné kulminačné prietoky za obdobie 1960-2010 pre 128 vodomerných staníc. Výsledky ukázali rastúci trend prietokov v poľskej časti. Na Slovensku sa vyskytujú obidva trendy, aj rastúci aj klesajúci. Výsledky sa môžu použiť ako súčasť plánov ochrany povodí pred povodňami.

Klúčové slová: neparametrické testy, povodne, slovensko-poľská časť karpatského oblúka

Anotation

The paper is focused on the trend analysis using nonparamteric tests in the area of the Slovak-Polish area of the Carpathian mountains. In the paper, we analyzed annual maximum flow series (peak discharge) for the period 1960-2010 for 128 gauging stations. The results showed increasing trend in polish part. For the Slovakia it is determinated both increasing trend and decreasing trend. Results can be used as part of river basin management plan.

Key words: nonparametric tests, floods, Slovak-Polish area of the Carpathian mountains

Introduction

Trend analysis in annual maximum flood series is an important task for better understanding if changes in hydrologic regimes occur and what is the main cause of these changes (climate change or human activities) Trend analysis are also part of water resources studies. For the trend analysis there is possible to use many statistical tests. Statistical tests for trend analysis are parametric and nonparametric. Parametric statistical methods are based on specific assumptions about probability distributions (e.g. the normal distribution) and involve estimation of the keys parameters of that distribution (e.g., the mean or difference in means) from the sample data. Nonparametric statistical methods are distribution free methods and they do not assume that the outcome is approximately normally distributed. For the trend analysis we used three nonparametric trend tests : Mann-Kendall trend test (Mann, 1945; Kendall, 1975), Spearman trend test (Fieller et al., 1957) and Cox-Stuart test (Cox and Stuart, 1955). Many authors are interested in these statistics tests and they examine e.g. size, power of these tests or their comparing.

Rutkowska (2015) studied size and power properties of the Cox-Stuart test for detection of monotonic deterministic trend in hydrological time series using Monte Carlo method. She assesed that power is high for: length over 60 and strong trend slope, low or medium variation and medium slope. The properities are better for skewed distributions than for symmetrical and test is slightly weaker in comparison to the Mann-Kendall.

Walega et al. (2016) analyzed course and frequency of high water stages in selected catchments of the upper Vistula basin in the south of Poland. They investigated daily flows from the years 1983-2014 for determination of maximum annual flows and maximum flows per summer and winter half-year. For the analysis it was used Mann-Kendall trend test and results show not significant upward trends.

Yue et al. (2002) studied the power of the Mann-Kendall and Spearman’s rho test for detecting monotonic trends in hydrological series by Monte Carlo simulation. Their simulation demonstrates that power depends on the pre-assigned significance level, magnitude of trend, sample size and the amount of variation within a time series.

Methodology

For the analysis we used non-parametric tests (Mann-Kendall trend test, Spearman's trend test and Cox-Stuart test).

The non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975) is commonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data. The null hypothesis, H_0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_A, is that the data follow a monotonic trend. The Mann-Kendall trend is calculated according to:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k), \quad (1)$$

with

$$sgn(x) = \begin{cases} 1 \; if \; x > 0 \\ 0 \; if \; x = 0 \\ -1 \; if \; x < 0 \end{cases} \quad (2)$$

The mean of S is E[S]=0 and the variance σ^2 is

$$\sigma^2 = \{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)\}/18, \quad (3)$$

Where *p* is the number of the tied groups in the data set and t_j is the number of data points in the *j*th tied group. The statistics S is approximately normal distributed provided that the following Z-transformation is employed:

$$Z = \begin{cases} \frac{S-1}{\sigma} \; if \; S > 0 \\ 0 \quad if \; S = 0 \\ \frac{S+1}{\sigma} \; if \; S < 0 \end{cases} \quad (4)$$

The statistics S is closely related to Kendall's τ as given by:

$$\tau = \frac{S}{D}, \quad (5)$$

where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j - 1)\right]^{1/2} \left[\frac{1}{2}n(n-1)\right]^{1/2} \quad (6)$$

Spearman's rank correlation coefficient is a rank-based test for correlation between two variables that can be used to test for a correlation between time and data series (Gauthier, 2001). The Spearman rank correlation coefficient is calculated according to the following equation:

$$r_s = \frac{1 - 6\sum_{i=1}^{n} d_i^2}{n^3 - n},$$

where d_i is the difference between ranks for each x_i , y_i data pair and *n* is the number of data pairs (Gauthier, 2001). Equation is constructed so that it gives r_s =1 when the data pairs have a perfect positive correlation (d_i=0) and r_s =-1 for a perfect negative correlation (Gauthier, 2001).

In 1955 Cox and Stuart introduced a non-parametric test for increasing or decreasing trend that was based on the sign test, which based on the binomial distribution. The basic principle of this method is that a series of observations is said to exhibit an upward trend if the magnitudes of the later observations tend to be greater than those of the earlier observations, the data exhibit a downward trend if the earlier observations tend to be larger that the later of observations. (Li et al., 2014). This method is a robust method to detect the presence of the trend regardless of the distribution of the data. Given the independent data, i.e., X [1], ..., X [*n*], one can divide the data into two sequences with equal number of observations cut in the midpoint and then take the paired difference, i.e., D=X[*i*] -X[*i*+*c*] ,*i*=1,..., floor (n/2), where c is the index of midpoint. The totals of the positive or negative sign in D is defined as S+ or S-. Under null hypothesis, S+ or S- has a binomial distribution with the number of experiment being the number of elements in D after removing elements(s) 0 and probability p=0.5. The exact method (exact=TRUE) is based on binomial distribution of statistic S+ („increasing") or S- („decreasing") or S=min(S+,S-) („two.sided") and one can thus compute the exact p-value. (Qui, 2014) This test was computed in R-studio environment (Rstudio Team, 2016). We used snpar package (Qui, 2014) and function cs.test.

Input data

Carpathian mountains are relatively low mountains in comparison to the Swiss Alps and elevations above 2000 m a.s.l. occur only in the Tatra mountains shared by Poland and Slovakia, with the highest peaks: Rysy (2499 m) in the Polish part and Gerlach (2655 m) in Slovakia. The selected gauging station are located in Slovakia (41 gauging stations) and Poland (87 gauging stations). Together it was processed 128 gauging stations. Length of data for each station is variable (30-51 years) and period is 1960-2010. Examinated data consist of annual maximum series (derived from QP-peak discharges). Catchment area varies from 19 km^2 (station located on the river Blatina, Slovakia) to 5649.1 km^2 (station located on the river Dunajec, Poland). Mean catchment elevation varies from 154.3 m a.s.l. (station located on the river Mociarka) to 1605.5 m a.s.l. (station located on the river Bialka). Mean catchment slope is 11.5 degrees.

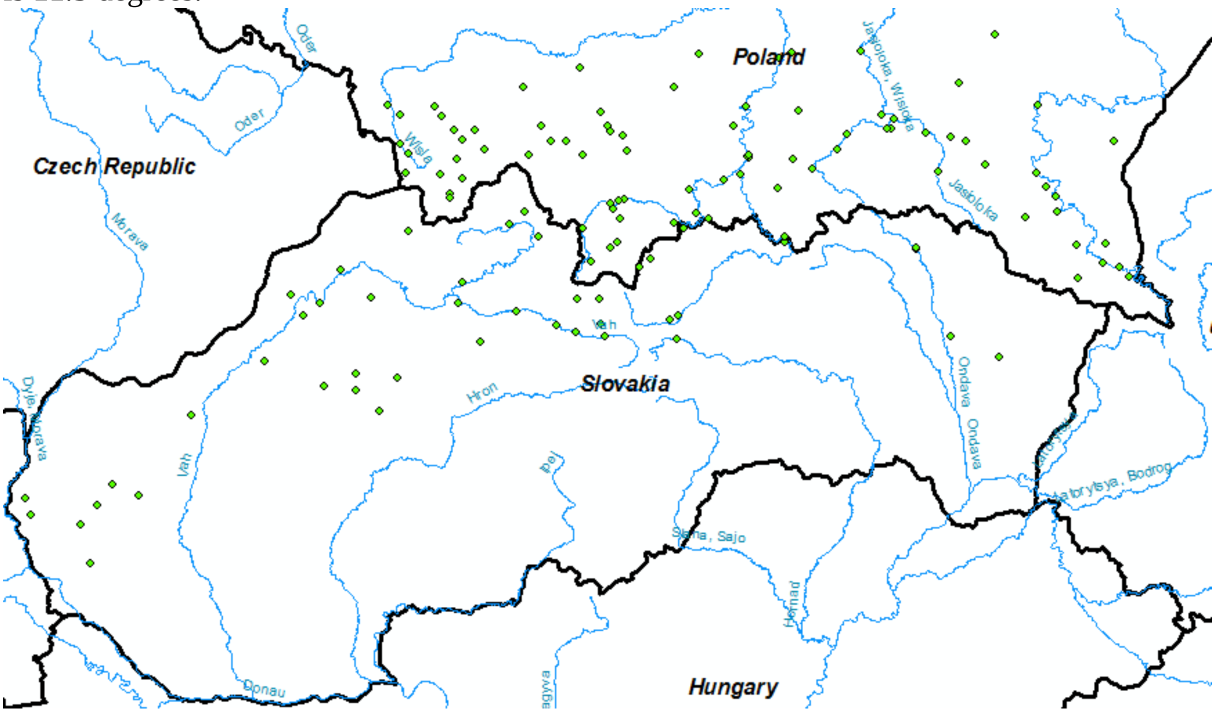

Fig.1 Location of selected gauging stations

Results

Trend analysis of the annual maximum flow series (peak discharge) was processed for 128 gauging stations across the Slovak-Polish area of the Carpathian mountains. According to Mann-Kendall trend test it was detected 25 gauging stations with significant trend at the 5% significance level (19 increasing trend, 6 decreasing trend). According to Spearman's rank correlation trend test it was detected 26 gauging stations with significant trend at the 5% significance level (19 increasing trend, 7 decreasing trend). According to Cox-Stuart test it was detected 11 gauging stations with significance trend at the 5 % significance level (6 increasing trend, 5 decreasing trend). By using Mann-Kendall trend test it was detected 10 gauging stations with significant trend at the 1 % (7 increasing trend, 3 decreasing trend). By using Spearman's rank correlation trend test it was detected 13 gauging stations with significant trend at 1 % (10 increasing trend, 3 decreasing trend). By using Cox-Stuart test it was detected 6 gauging stations with significant trend at 1 % (3 increasing trend, 3decreasing trend).

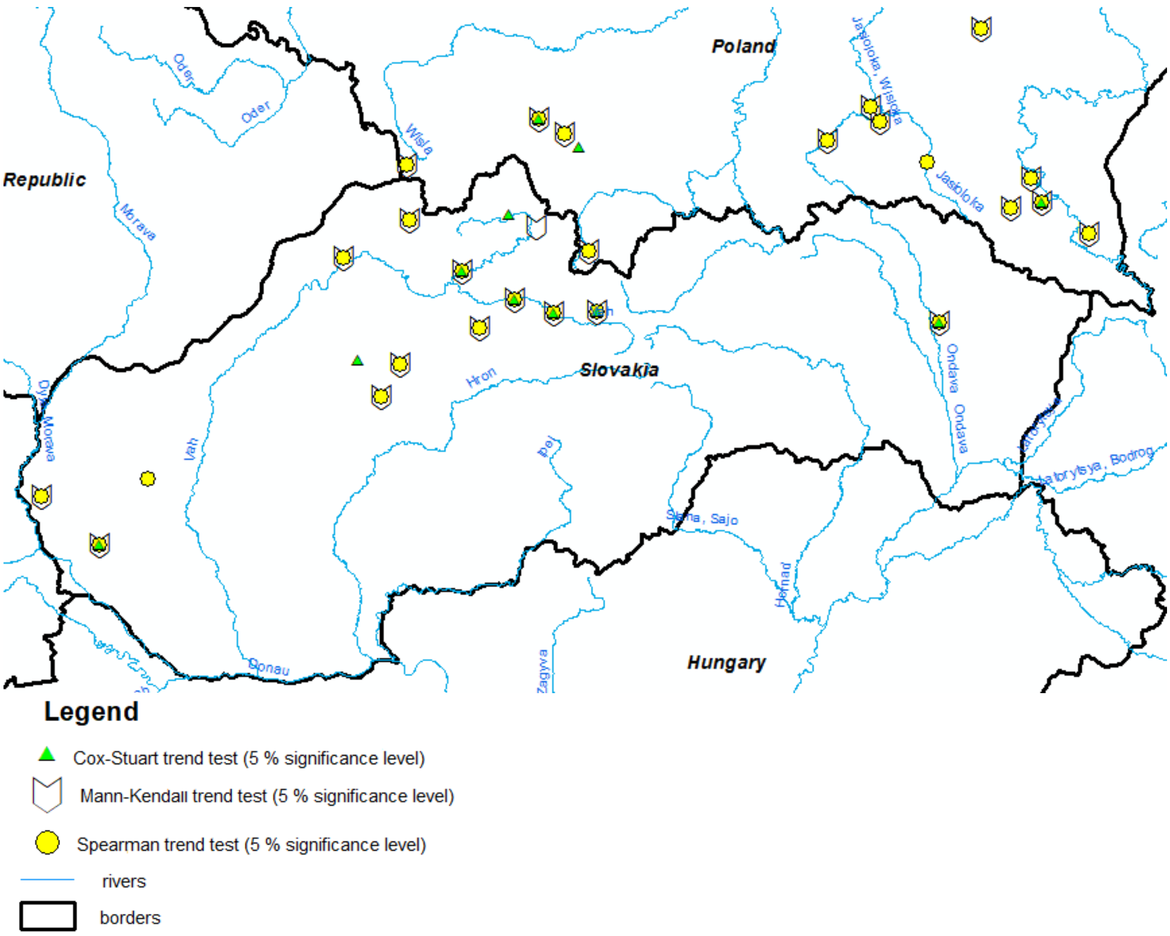

Fig.2 Gauging stations being statistically significant at the 5 % significance level (0.05)

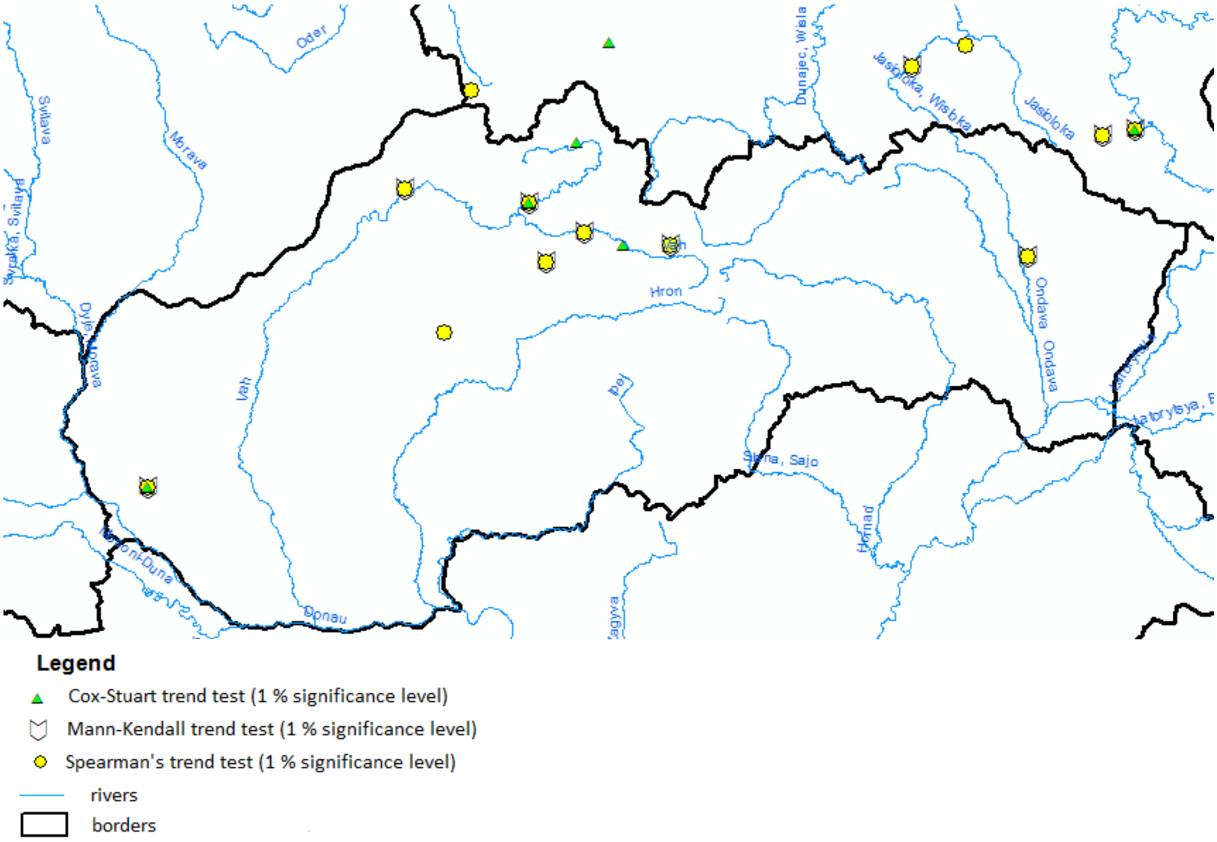

Fig. 3 Gauging stations being statistically significant at the 1 % significance level

Tab. 1 Number of gauging stations with significance trend at the 1% and 5 % significance level

	5 % significance level (P value < 0.05)		1 % significance level (P value <0.01)	
Cox-Stuart trend test	11 gauging stations	6 increasing trend	6 gauging stations	3 increasing trend
		5 decreasing trend		3 decreasing trend
Mann-Kendall trend test	25 gauging stations	19 increasing trend	10 gauging stations	7 increasing trend
		6 decreasing trend		3 decreasing trend
Spearman's trend test	26 gauging stations	19 increasing trend	13 gauging stations	10 increasing trend
		7 decreasing trend		3 decreasing trend

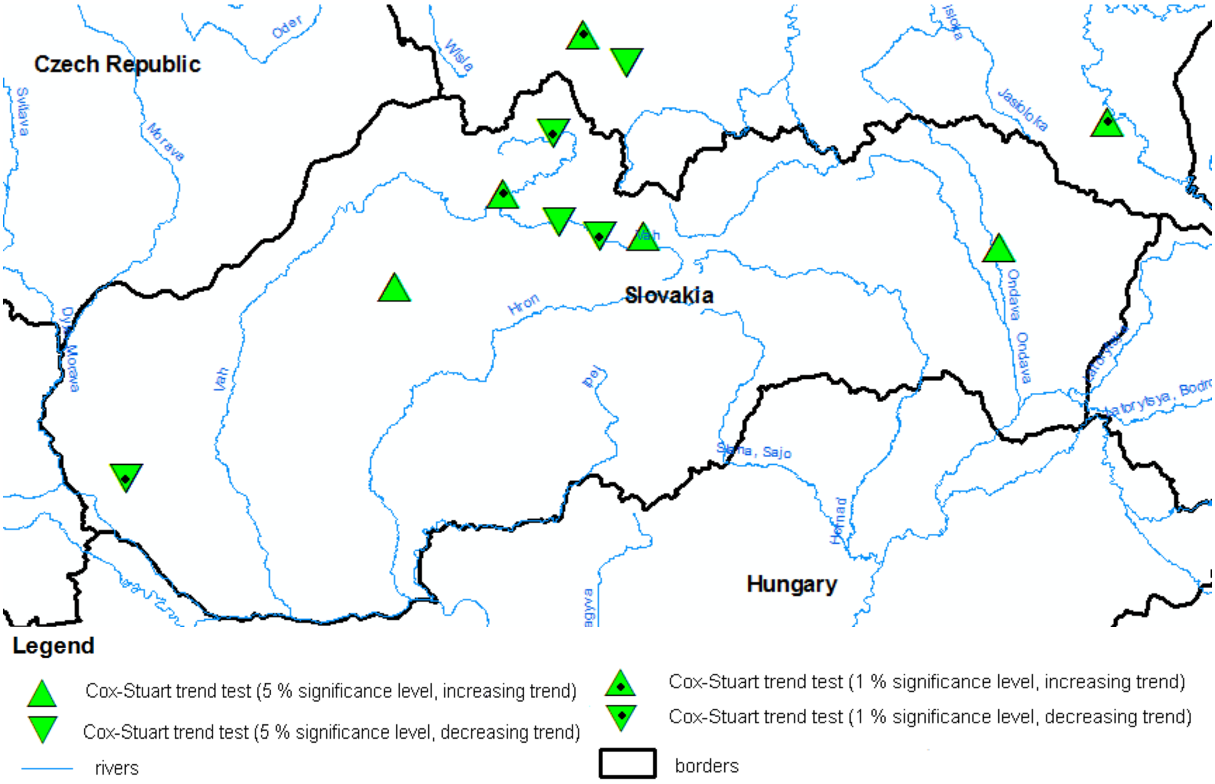

Fig. 4 Gauging stations with significant trend according to Cox-Stuart trend test (significance level 1%, 5%)

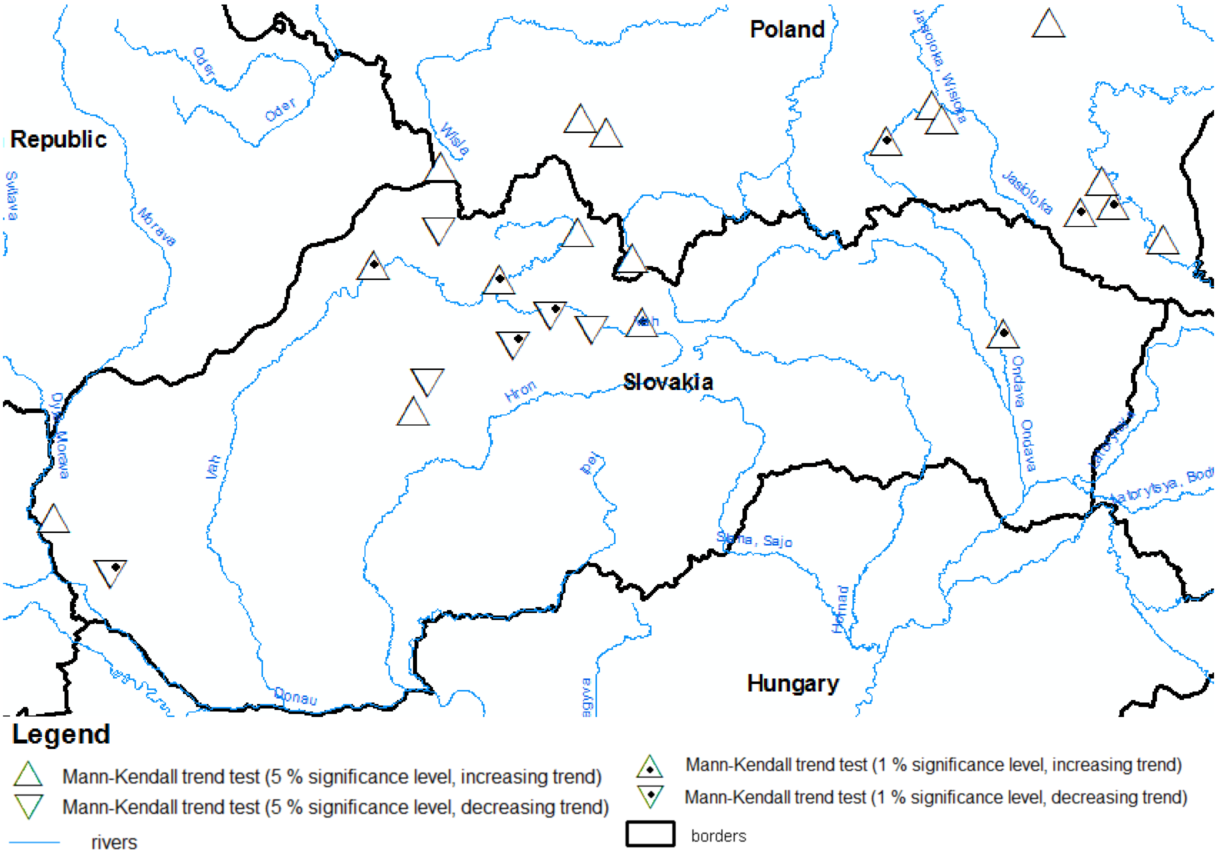

Fig. 4 Gauging stations with significant trend according to Mann-Kendall trendt test (significance level 1%, 5%)

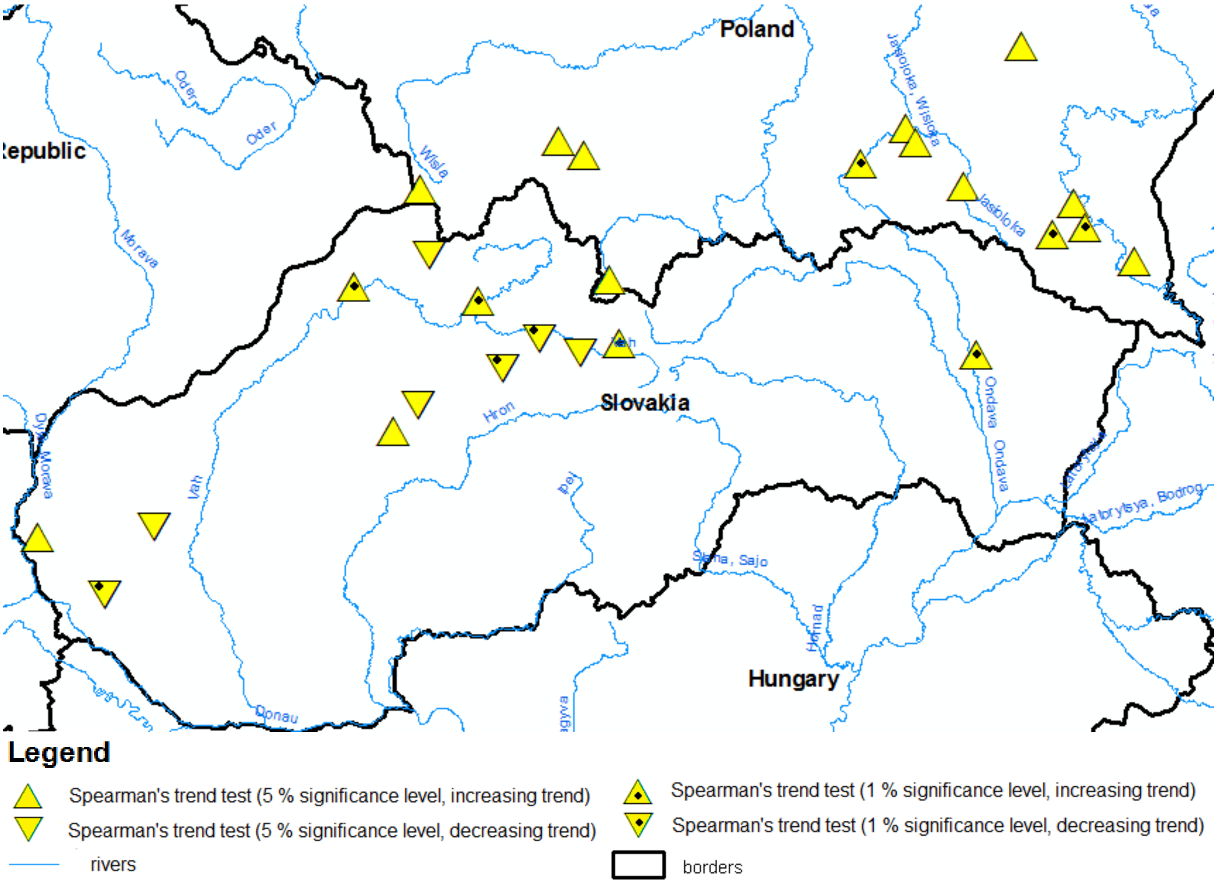

Fig. 4 Gauging stations with significant trend according to Spearman's trend test (significance level 1%, 5%)

Results according to Mann-Kendall trend test and Spearman's trend test are quite similar. For the Polish part it is determinated increasing trend with 3 gauging stations which are significant at the 1 % significance level. For the Slovak part it is determinated both increasing trend and decreasing trend. On the tributaries of river Váh Kľačianka and Štiavnica there is a significant decreasing trend for the period 1960-2010 (significance level at 1 % and 5 %). On the tributaries of river Orava (Oravica and Zázrivka) there is an increasing trend for the period 1960-2010.

Conclusion

The main aim of the article was to test trend analysis according to nonparametric tests. Selected nonparametric tests are Cox-Stuart test, Mann-Kendall trend test and Spearman's trend test. For the analysis we selected 128 gauging stations located in the Slovak-Polish area of the Carpathian mountains. The length of data for each station is variable from 30 to 51 years and duration of observation is 1960-2010. Examinated data consist of annual maximum series (derived from QP-peak discharges). Results show increasing trend in polish part of Carpathian mountains. For the Slovak part it is determinated both increasing trend and decreasing trend. Decreasing trend is located on the tributaries of river Váh and increasing trend is located on the tributaries of river Orava for the period 1960-2010. Results demonstrate that Mann-Kendall trend test and Spearman's trend test are quite similar. According to Cox-Stuart test less gauging stations with significant trend are detected.

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