DOI: 10.31577/ahs-2021-0022.02.0024

ACTA HYDROLOGICA SLOVACA

Volume 22, No. 2, 2021, 207 – 219

Trend changes analysis of the minimum and average annual discharges in selected Slovak rivers during the two periods 1961–2000 and 1961–2015

Viliam ŠIMOR*, Ľudovít ĽUPTÁK

This paper deals with the development of trends of minimum and average annual discharges for the period 1961–2015 and their comparison with the trends for the period 1961–2000, which have been used by the Slovak Hydrometeorological Institute (SHMI) since 2006 as a reference period.
In assessing both periods, we have dealt with their comparison with each other and subsequent analysis of any change. In general, time series trends can become an important indicator of whether there is a change in selected hydrological characteristics. In this paper, discharge series were processed and statistically analysed using a simple linear trend and the non-parametric Mann-Kendall test.

KEY WORDS: Mann-Kendall test, Sen's slope, Average annual discharge, Minimum annual discharge

Introduction

At the present time of global climate change, the occurrence of periods of extreme weather phenomena is significantly increasing, warm weather without rain for a long time is alternating with local storm activity, the intensity of which creates flood situations in various parts of Slovakia. The impact of a prolonged drought can cause considerable damage not only to property and human life but also to the country's economy. The effects of a long-term drought are dangerous because, unlike a flood situation, the outward signs of a long-term drought are not noticeable for a long time.
In Slovakia and abroad, several authors have dealt with the trend analysis of various hydrological characteristics, as an example we can mention the works of Zeleňáková at al. (2011), in which an analysis of drought in terms of the significance of trends in flow characteristics was carried out. The authors applied their research on the occurrence of the significance of trends and subsequent spatial analysis in a GIS environment in the regions of eastern Slovakia. Bačová Mitková and Halmová (2021) in their work deals with the trend analysis of the extreme flows regime at gauging station Váh –Liptovský Mikuláš. The identification of trends in hydrological data also deals Malik at al. (2020), who identify the long-term trend and magnitude in monthly, seasonal, and annual streamflow by employing three non-parametric approaches conventional Mann-Kendall, Innovative-Sen trend, and Sen-slope at 5% level of significance in the upper Ramganga river catchment in India. A more detailed study of this type of tests is discussed by Dabanlı at al. (2016), the authors also identify the weakness of the Mann Kendall test and explain the principles of the innovative-Sen method, that is based on cluster.
In the present paper, we evaluate by trend analysis the minimum and average annual discharges at selected gauging stations, and we are interested only in those where occurs a change in significance, as determined by the Mann-Kendall test.

Material and methods

The minimum discharge is the lowest immediate discharge in a given profile for the selected period. On natural streams, the minimum discharge is generally the lowest average daily discharge, expressed in $m^3 s^{-1}$ or $l s^{-1}$.
The average discharge is the arithmetic mean of all the discharges in a given profile over the period considered (e.g. day, month, season, year, etc.). It is generally determined by the arithmetic mean of the average daily discharges (average daily, arithmetic mean hourly discharges) or by the ratio of the total amount (volume) of water discharged and the number of seconds over the period considered. It shall be expressed in $m^3 s^{-1}$ or $l s^{-1}$. According to the above definition, the minimum annual discharge is the smallest average daily discharge in a given hydrological year and the average annual discharge represents in the average daily discharge in a given hydrological year (Hydrology. Terminological glossary, 2002).

The discharge data for the period 1961–2015 were taken from the hydrological service database, which allows direct reporting of minimum and average annual discharges. Trends were evaluated in a selection of 65 gauging stations (GS) with long-term observations, which we consider as unaffected 1 in the Bodva basin, 8 in the Bodrog basin, 2 in the Danube basin, 4 in the Hornád basin, 4 in the Ipel basin, 2 in the Morava basin, 7 in the Nitra basin, 3 in the Dunajec and Poprad basins, 7 in the Hron basin, 4 in the Slaná basin and 23 in the Váh basin.
The hydrological datasets were processed and statistically analysed using two methods, the simple linear trend and the non-parametric Mann-Kendall test, which is used to detect significant trends in time series. The advantage of the Mann-Kendall test is that, it is not affected by the actual distribution of the data and it is less sensitive to outliers in the time series (Adámyová, 1989). The test is suitable for larger scale statistical datasets with more than 40 data points (WMO, 2008).
The Mann-Kendall test is based on the statistical value "S", which is calculated by comparing every two values x_i, x_j, (i > j) in a time series, where the statistical value "S" is given by the relationship:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j) \tag{1}$$

where:
n – is the number of values in the time series,
x_i and x_j – are the compared values (discharges).

sign $(x_i - x_j)$ *is:*

$$\begin{cases} +1 & if \;\; x_i - x_j > 0 \\ 0 & if \;\; x_i - x_j = 0 \\ -1 & if \;\; x_i - x_j < 0 \end{cases}$$

The Mann-Kendall statistic (Z) is based on the standard normal distribution and is given by the following relationship:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma_s}} & if \;\; S > 0 \\ 0 & if \;\; S = 0 \\ \frac{S+1}{\sqrt{\sigma_s}} & if \;\; S < 0 \end{cases} \tag{2}$$

where:
σ_s – represents the variance and is defined as:

$$\sigma_s = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t f_t(f_t - 1)(f_t + 5)\right] \tag{3}$$

where:
n – is the number of values in the time series.
t – varies over the set of tied ranks
f_t – is the number of times (i.e. frequency) that the rank t appears.

The sign of the statistic "Z" indicates whether the trend is increasing (Z > 0) or decreasing (Z < 0), and we cannot obtained an estimate of the magnitude of the trends by this test (Santos and Portela, 2007).

Estimating the magnitude of significant trends (Sen's slope):

The magnitude of statistically significant trends of discharges at the gauge stations were calculated using by the slope estimator of Sen (1968). The method is based on a simple non-parametric procedure developed by the mentioned author as follows:
If there is a linear trend in the time series, we can express its real slope using a linear equation:

$$f(t) = Qt + B \tag{4}$$

where:
Q – is a slope,
B – is a constant,
f(t) – is a linear model.

The slope estimate "Q" for all pairs in the time series is calculated as:

$$Q_i \frac{x_j - x_k}{j-k}, i = 1, 2, \dots . N, \; j > k \tag{5}$$

where:
x – are the values in the time series,
N – is the number of estimated slopes while:

$$N = n\,.(n-1) \,/\, 2 \tag{6}$$

where:
n – is the number of values in the original time series.

The resulting estimated slope is the median of these N values of the estimated slopes Q_i (Drápela and Drápelová, 2011). In determining the individual significance of a trend, its increase and decrease, we only evaluate significance at the 95% level (if it has been observed in gauge station, we consider the trend as significant), which is used in most statistical tasks.
We consider trends that occurred at a lower significance level (90%, 85% and below) to be non-significant. When comparing the two periods 1961–2000 and 1961–2015 to each other, we look for those gauge stations at which this significance level has changed. If there is a change in a significance, we also evaluate the size of the trends in the appropriate gauge stations using by a simple linear trend and the Sen's slope as well. All the trend calculations were processed in MS Excel.

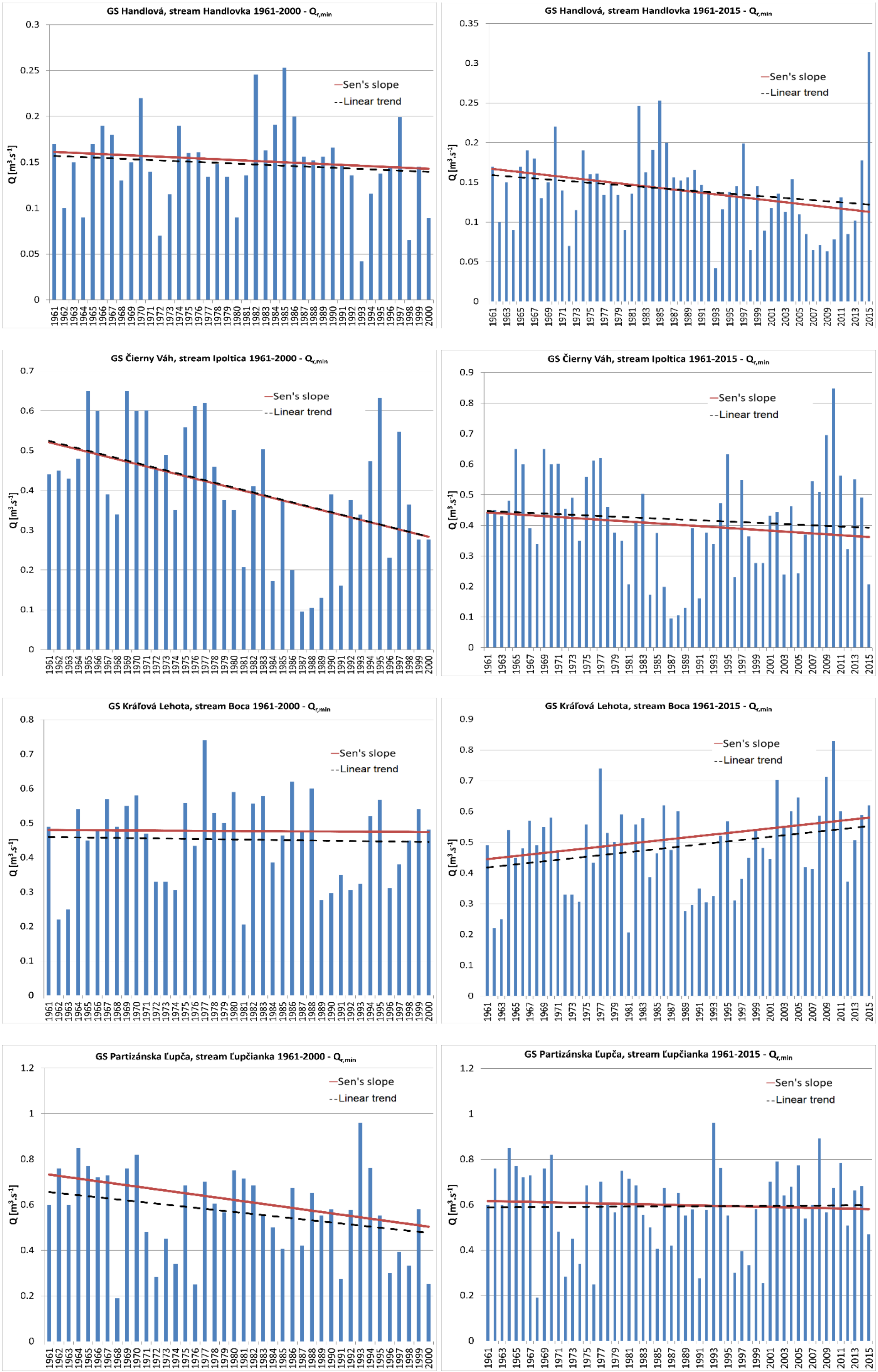
Results

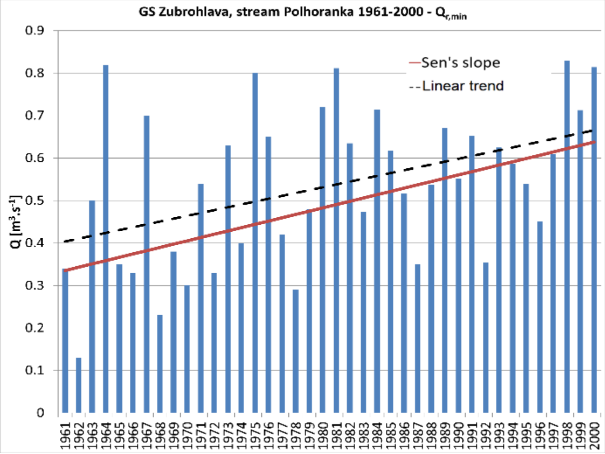
Minimum annual discharges ($Q_{r,min}$)

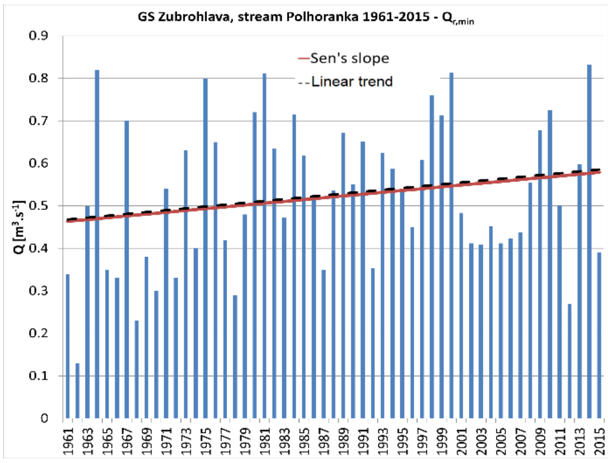
In the period 1961–2000 were at the 95% significance level 7 gauge stations with increasing trends, 13 gauge stations with decreasing trends, and 45 gauge stations (Table 1). In the period 1961–2000 were at the 95%

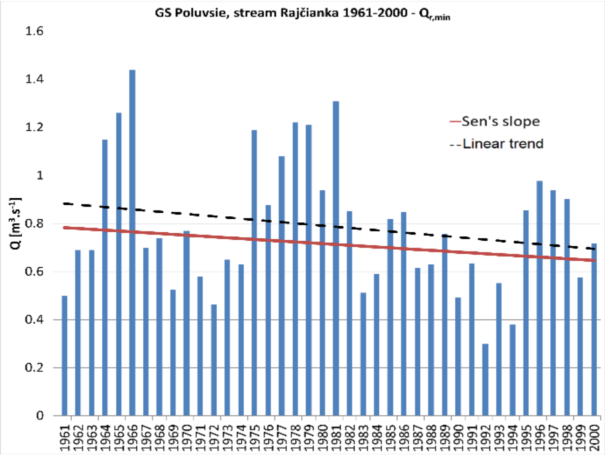
Table 1. Change in the significance of minimum annual discharges ($Q_{r,min}$) at individual gauging stations

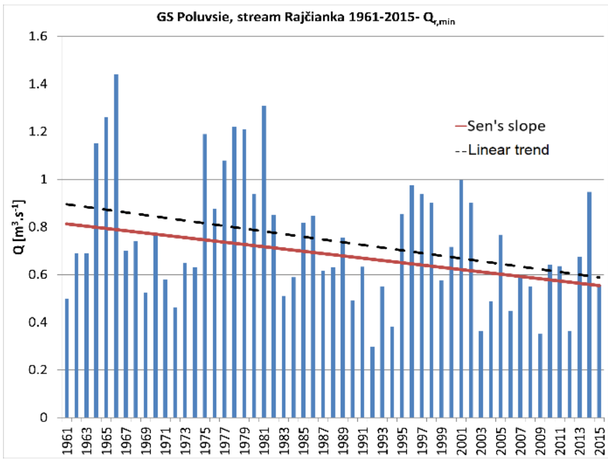
gauge station	stream	catchment area	significance at level 95 %		change of significance
			period for 1961-2000	period for 1961-2015	
Moravský Ján	Morava	Morava	decreasing trend	decreasing trend	no
Láb	Močiarka	Morava	decreasing trend	decreasing trend	no
Spariská	Vydrica	Dunaj	non-significant or no trend	non-significant or no trend	no
Bratislava	Dunaj	Dunaj	non-significant or no trend	non-significant or no trend	no
Pezinok	Blatina	Malý Dunaj	non-significant or no trend	non-significant or no trend	no
Bernolákovo	Čierna voda	Malý Dunaj	non-significant or no trend	non-significant or no trend	no
Horné Orešany	Parná	Malý Dunaj	decreasing trend	decreasing trend	no
Píla	Gidra	Malý Dunaj	non-significant or no trend	non-significant or no trend	no
Nedožery	Nitra	Nitra	decreasing trend	decreasing trend	no
Handlová	Handlovka	Nitra	non-significant or no trend	decreasing trend	yes
Chalmová	Nitra	Nitra	non-significant or no trend	non-significant or no trend	no
Liešťany	Nitrica	Nitra	non-significant or no trend	non-significant or no trend	no
Nadlice	Bebrava	Nitra	decreasing trend	decreasing trend	no
Nitrianska Streda	Nitra	Nitra	non-significant or no trend	non-significant or no trend	no
Vieska n. Žitavou	Žitava	Nitra	non-significant or no trend	non-significant or no trend	no
Čierny Váh	Ipoltica	Váh	decreasing trend	non-significant or no trend	yes
Východná	Biely Váh	Váh	non-significant or no trend	non-significant or no trend	no
Kráľová Lehota	Boca	Váh	non-significant or no trend	increasing trend	yes
Podbanské	Belá	Váh	non-significant or no trend	non-significant or no trend	no
Liptovský Mikuláš	Váh	Váh	non-significant or no trend	non-significant or no trend	no
Partizánska Ľupča	Ľupčianka	Váh	decreasing trend	non-significant or no trend	yes
Podsuchá	Revúca	Váh	non-significant or no trend	non-significant or no trend	no
Ľubochňa	Ľubochnianka	Váh	increasing trend	increasing trend	no
Lokca	Biela Orava	Váh	non-significant or no trend	non-significant or no trend	no
Oravská Jasenica	Veselianka	Váh	decreasing trend	decreasing trend	no
Zubrohlava	Polhoranka	Váh	increasing trend	non-significant or no trend	yes
Trstená	Oravica	Váh	non-significant or no trend	non-significant or no trend	no
Martin	Turiec	Váh	non-significant or no trend	non-significant or no trend	no
Čadca	Kysuca	Váh	non-significant or no trend	non-significant or no trend	no
Poluvsie	Rajčianka	Váh	non-significant or no trend	decreasing trend	yes
Bytča	Petrovička	Váh	increasing trend	increasing trend	no
Vydrná	Petrinovec	Váh	decreasing trend	decreasing trend	no
Dohňany	Biela voda	Váh	non-significant or no trend	decreasing trend	yes
Horné Sŕnie	Vlára	Váh	non-significant or no trend	non-significant or no trend	no
Zlatno	Hron	Hron	non-significant or no trend	non-significant or no trend	no
Brezno	Hron	Hron	non-significant or no trend	non-significant or no trend	no
Hronec	Čierny Hron	Hron	decreasing trend	decreasing trend	no
Bystrá	Bystrianka	Hron	non-significant or no trend	non-significant or no trend	no
Mýto p. Ďumbierom	Štiavnička	Hron	non-significant or no trend	non-significant or no trend	no
Dolná Lehota	Vajskovský potok	Hron	non-significant or no trend	non-significant or no trend	no
Brehy	Hron	Hron	decreasing trend	decreasing trend	no
Holiša	Ipeľ	Ipeľ	non-significant or no trend	non-significant or no trend	no
Plášťovce	Krupinica	Ipeľ	non-significant or no trend	non-significant or no trend	no
Plášťovce	Litava	Ipeľ	non-significant or no trend	non-significant or no trend	no
Lučenec	Krivánsky p.	Ipeľ	non-significant or no trend	non-significant or no trend	no
Dobšiná	Dobšinský potok	Slaná	decreasing trend	non-significant or no trend	yes
Štítnik	Štítnik	Slaná	non-significant or no trend	non-significant or no trend	no
Lenartovce	Slaná	Slaná	non-significant or no trend	non-significant or no trend	no
Lehota nad Rimavicou	Rimavica	Slaná	non-significant or no trend	decreasing trend	yes
Nižný Medzev	Bodva	Bodva	decreasing trend	decreasing trend	no
Stratená	Hnilec	Hornád	non-significant or no trend	non-significant or no trend	no
Jaklovce	Hnilec	Hornád	non-significant or no trend	non-significant or no trend	no
Košické Olšany	Torysa	Hornád	increasing trend	increasing trend	no
Ždaňa	Hornád	Hornád	non-significant or no trend	non-significant or no trend	no
Koškovce	Laborec	Bodrog	non-significant or no trend	non-significant or no trend	no
Lekárovce	Uh	Bodrog	increasing trend	non-significant or no trend	yes
Remetské Hámre	Okna	Bodrog	non-significant or no trend	non-significant or no trend	no
Veľké Kapušany	Latorica	Bodrog	non-significant or no trend	non-significant or no trend	no
Hanušovce nad Topľou	Topľa	Bodrog	non-significant or no trend	non-significant or no trend	no
Svidník	Ondava	Bodrog	non-significant or no trend	non-significant or no trend	no
Jasenovce	Oľka	Bodrog	non-significant or no trend	non-significant or no trend	no
Streda nad Bodrogom	Bodrog	Bodrog	increasing trend	increasing trend	no
Ždiar, Podspády	Javorinka	Poprad	non-significant or no trend	non-significant or no trend	no
Poprad, Matejovce	Slavkovský potok	Poprad	increasing trend	increasing trend	no
Chmelnica	Poprad	Poprad	non-significant or no trend	increasing trend	yes

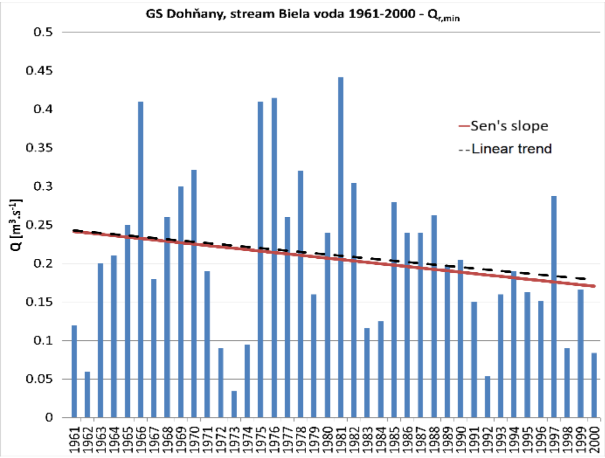

GS Handlová, stream Handlovka 1961-2000 - $Q_{r,min}$
GS Handlová, stream Handlovka 1961-2015 - $Q_{r,min}$
GS Čierny Váh, stream Ipoltica 1961-2000 - $Q_{r,min}$
GS Čierny Váh, stream Ipoltica 1961-2015 - $Q_{r,min}$
GS Kráľová Lehota, stream Boca 1961-2000 - $Q_{r,min}$
GS Kráľová Lehota, stream Boca 1961-2015 - $Q_{r,min}$
GS Partizánska Ľupča, stream Ľupčianka 1961-2000 - $Q_{r,min}$
GS Partizánska Ľupča, stream Ľupčianka 1961-2015 - $Q_{r,min}$
Sen's slope
Linear trend
Q [$m^3.s^{-1}$]

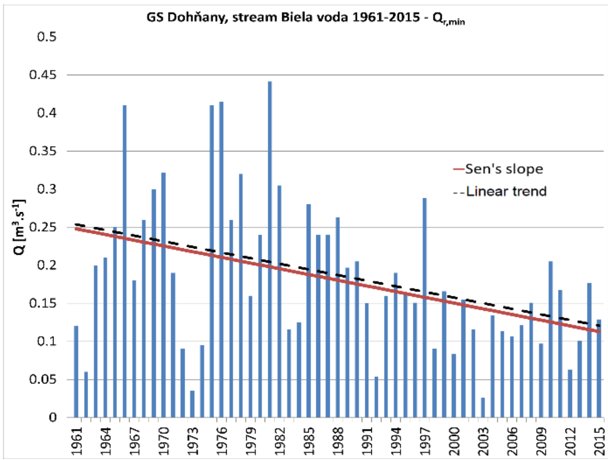

GS Zubrohlava, stream Polhoranka 1961-2000 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]

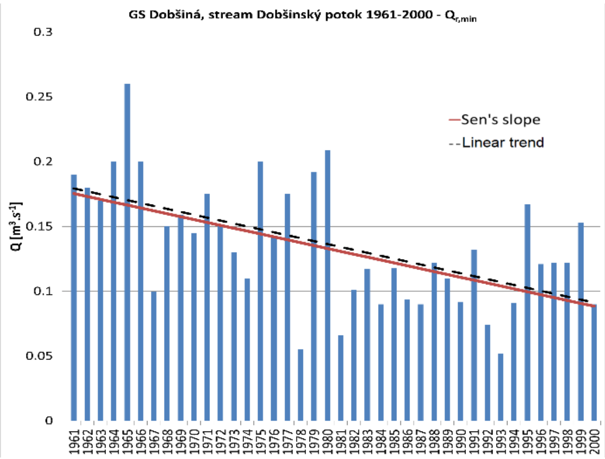

GS Zubrohlava, stream Polhoranka 1961-2015 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]

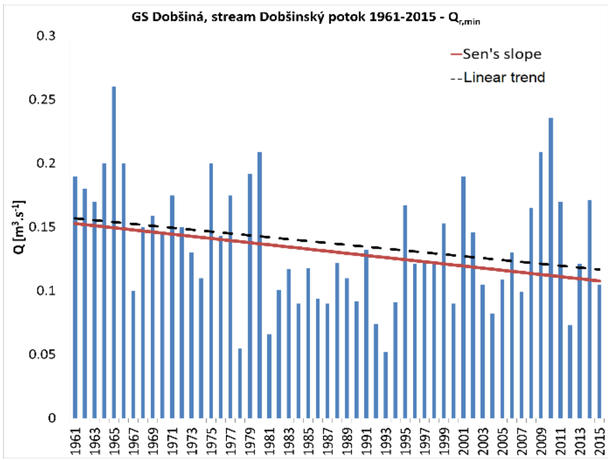

GS Poluvsie, stream Rajčianka 1961-2000 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]


GS Poluvsie, stream Rajčianka 1961-2015- $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]


GS Dohňany, stream Biela voda 1961-2000 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]


GS Dohňany, stream Biela voda 1961-2015 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]


GS Dobšiná, stream Dobšinský potok 1961-2000 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]


GS Dobšiná, stream Dobšinský potok 1961-2015 - $Q_{r,min}$
Sen's slope
Linear trend
Q [m³.s⁻¹]

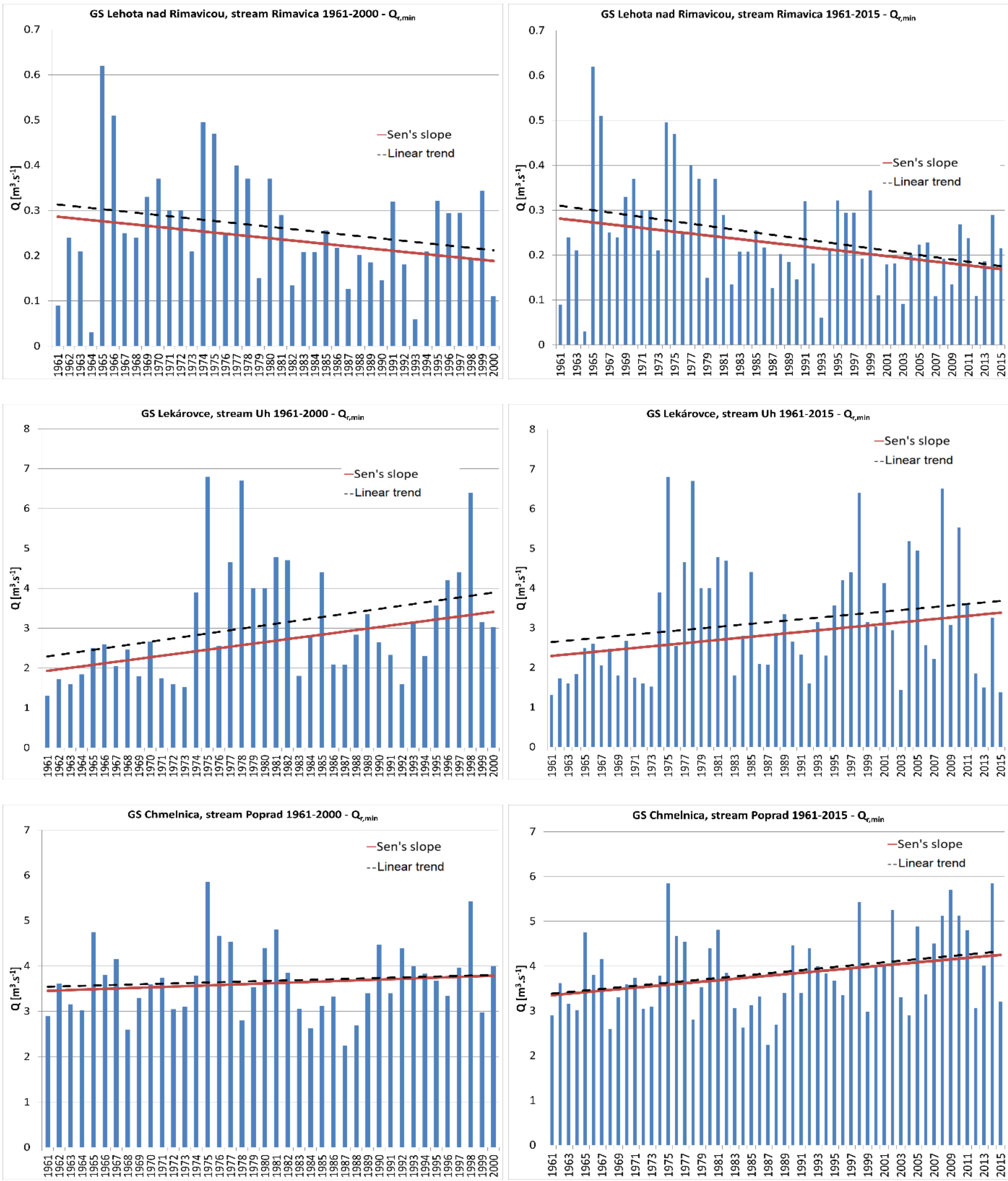


Fig. 1. Magnitude of trends in minimum annual discharges ($Q_{r,min}$) at selected gauging stations (GS) for the period 1961–2000 and 1961–2015.

significance level 7 gauge stations with increasing trends, 14 gauge stations with decreasing trends and 44 gauge stations with insignificant or no trends (Table 1).
The change in trend significance after adding 15 years occurred in 11 gauge stations. The most significant and most cases of changes in the trends of minimum discharges in the compared periods were calculated for the Váh river basin (Table 1).

Figure 1 shows the magnitudes of the trends (both Sen's slope and linear trend) at the gauging stations where occurred the change in significance. More significant differences in slopes occurred only at the gauge station Partizánska Ľupča, Ľupčianka stream in period 1961–2000. The trend in this period is significantly decreasing, but both trends has a different magnitude. The linear trend has a smaller slope than Sen's slope, the change is

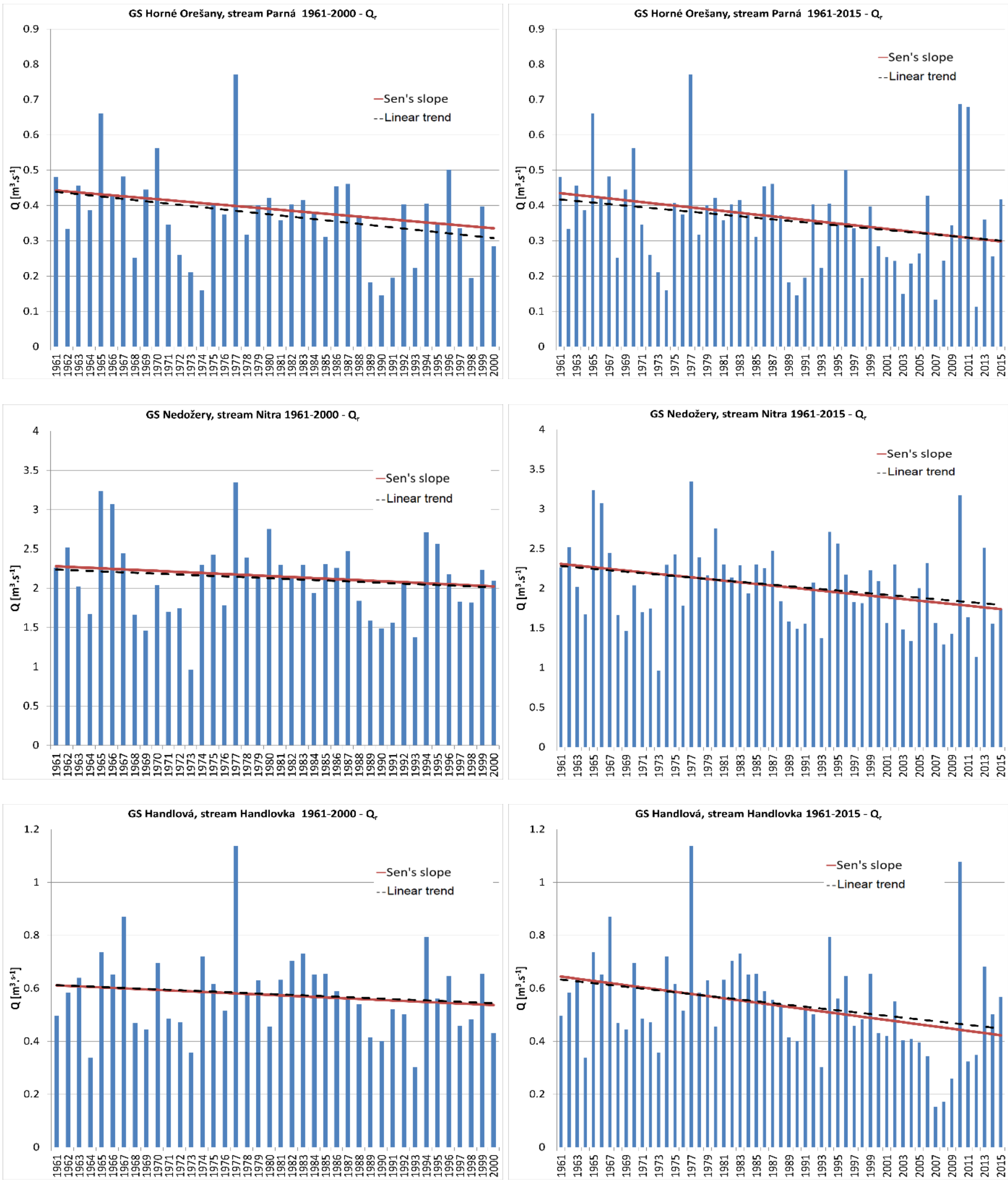
Table 2. Change in the significance of average annual discharges (Q_r) at individual gauging stations

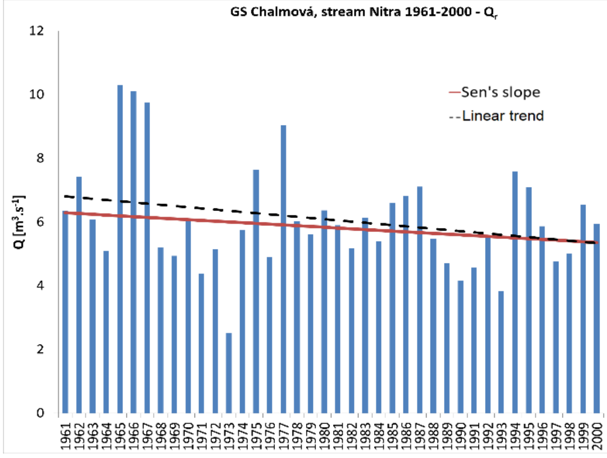
gauge station	stream	catchment area	significance at level 95 %		change of significance
			period for 1961-2000	period for 1961-2015	
Moravský Ján	Morava	Morava	non-significant or no trend	non-significant or no trend	no
Láb	Močiarka	Morava	decreasing trend	decreasing trend	no
Spariská	Vydrica	Dunaj	non-significant or no trend	non-significant or no trend	no
Bratislava	Dunaj	Dunaj	non-significant or no trend	non-significant or no trend	no
Pezinok	Blatina	Malý Dunaj	non-significant or no trend	non-significant or no trend	no
Bernolákovo	Čierna voda	Malý Dunaj	decreasing trend	decreasing trend	no
Horné Orešany	Parná	Malý Dunaj	non-significant or no trend	decreasing trend	yes
Píla	Gidra	Malý Dunaj	non-significant or no trend	non-significant or no trend	no
Nedožery	Nitra	Nitra	non-significant or no trend	decreasing trend	yes
Handlová	Handlovka	Nitra	non-significant or no trend	decreasing trend	yes
Chalmová	Nitra	Nitra	non-significant or no trend	decreasing trend	yes
Liešťany	Nitrica	Nitra	non-significant or no trend	decreasing trend	yes
Nadlice	Bebrava	Nitra	non-significant or no trend	non-significant or no trend	no
Nitrianska Streda	Nitra	Nitra	non-significant or no trend	non-significant or no trend	no
Vieska n. Žitavou	Žitava	Nitra	non-significant or no trend	non-significant or no trend	no
Čierny Váh	Ipoltica	Váh	non-significant or no trend	non-significant or no trend	no
Východná	Biely Váh	Váh	non-significant or no trend	non-significant or no trend	no
Kráľová Lehota	Boca	Váh	decreasing trend	non-significant or no trend	yes
Podbanské	Belá	Váh	non-significant or no trend	non-significant or no trend	no
Liptovský Mikuláš	Váh	Váh	non-significant or no trend	non-significant or no trend	no
Partizánska Ľupča	Ľupčianka	Váh	non-significant or no trend	decreasing trend	yes
Podsuchá	Revúca	Váh	non-significant or no trend	non-significant or no trend	no
Ľubochňa	Ľubochnianka	Váh	non-significant or no trend	non-significant or no trend	no
Lokca	Biela Orava	Váh	non-significant or no trend	non-significant or no trend	no
Oravská Jasenica	Veselianka	Váh	non-significant or no trend	non-significant or no trend	no
Zubrohlava	Polhoranka	Váh	non-significant or no trend	non-significant or no trend	no
Trstená	Oravica	Váh	non-significant or no trend	non-significant or no trend	no
Martin	Turiec	Váh	non-significant or no trend	non-significant or no trend	no
Čadca	Kysuca	Váh	non-significant or no trend	non-significant or no trend	no
Poluvsie	Rajčianka	Váh	non-significant or no trend	non-significant or no trend	no
Bytča	Petrovička	Váh	non-significant or no trend	increasing trend	yes
Vydrná	Petrinovec	Váh	non-significant or no trend	non-significant or no trend	no
Dohňany	Biela voda	Váh	non-significant or no trend	decreasing trend	yes
Horné Srnie	Vlára	Váh	non-significant or no trend	non-significant or no trend	no
Zlatno	Hron	Hron	non-significant or no trend	non-significant or no trend	no
Brezno	Hron	Hron	non-significant or no trend	non-significant or no trend	no
Hronec	Čierny Hron	Hron	decreasing trend	decreasing trend	no
Bystrá	Bystrianka	Hron	decreasing trend	decreasing trend	no
Mýto p. Ďumbierom	Štiavnička	Hron	decreasing trend	non-significant or no trend	yes
Dolná Lehota	Vajskovský potok	Hron	non-significant or no trend	non-significant or no trend	no
Brehy	Hron	Hron	decreasing trend	non-significant or no trend	yes
Holiša	Ipeľ	Ipeľ	decreasing trend	non-significant or no trend	yes
Plášťovce	Krupinica	Ipeľ	non-significant or no trend	non-significant or no trend	no
Plášťovce	Litava	Ipeľ	non-significant or no trend	non-significant or no trend	no
Lučenec	Krivánsky p.	Ipeľ	decreasing trend	decreasing trend	no
Dobšiná	Dobšinský potok	Slaná	non-significant or no trend	non-significant or no trend	no
Štítnik	Štítnik	Slaná	decreasing trend	non-significant or no trend	yes
Lenartovce	Slaná	Slaná	nevýznamný alebo žiadny trend	non-significant or no trend	no
Lehota nad Rimavicou	Rimavica	Slaná	decreasing trend	decreasing trend	no
Nižný Medzev	Bodva	Bodva	non-significant or no trend	non-significant or no trend	no
Stratená	Hnilec	Hornád	decreasing trend	non-significant or no trend	yes
Jaklovce	Hnilec	Hornád	non-significant or no trend	non-significant or no trend	no
Košické Olšany	Torysa	Hornád	non-significant or no trend	non-significant or no trend	no
Ždaňa	Hornád	Hornád	non-significant or no trend	non-significant or no trend	no
Koškovce	Laborec	Bodrog	non-significant or no trend	non-significant or no trend	no
Lekárovce	Uh	Bodrog	non-significant or no trend	non-significant or no trend	no
Remetské Hámre	Okna	Bodrog	non-significant or no trend	non-significant or no trend	no
Veľké Kapušany	Latorica	Bodrog	non-significant or no trend	non-significant or no trend	no
Hanušovce nad Topľou	Topľa	Bodrog	non-significant or no trend	non-significant or no trend	no
Svidník	Ondava	Bodrog	non-significant or no trend	non-significant or no trend	no
Jasenovce	Oľka	Bodrog	increasing trend	increasing trend	no
Streda nad Bodrogom	Bodrog	Bodrog	non-significant or no trend	non-significant or no trend	no
Ždiar, Podspády	Javorinka	Poprad	non-significant or no trend	non-significant or no trend	no
Poprad, Matejovce	Slavkovský potok	Poprad	non-significant or no trend	non-significant or no trend	no
Chmelnica	Poprad	Poprad	non-significant or no trend	non-significant or no trend	no

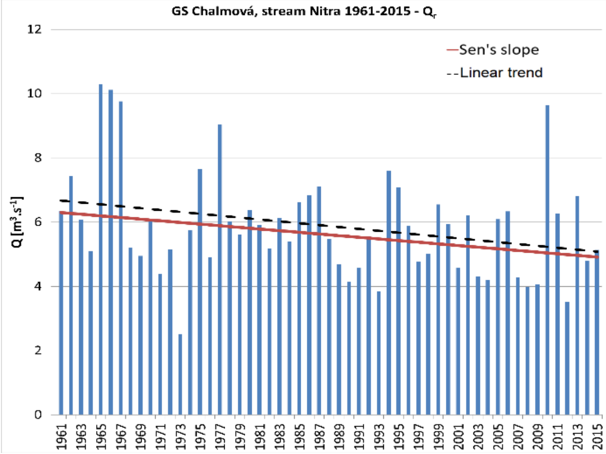
due to the occurrence of an extremely low discharge in 1968, to which the linear trend responds. In gauge station Zubrohlava, Polhoranka stream in period 1961–2000 is a similar case as in gauge station Partizánska Ľupča, however, the difference in slopes is due to the occurrence of an extremely high discharge in 1964. In gauge station Poluvsie, Rajčianka stream, the decreasing insignificant trend of the period 1961–2000 changed to decreasing significant trend after adding 15 years. We can see in both periods the variation in the magnitude of the slopes. This is due to the occurrence of extremely high discharge in 1966.

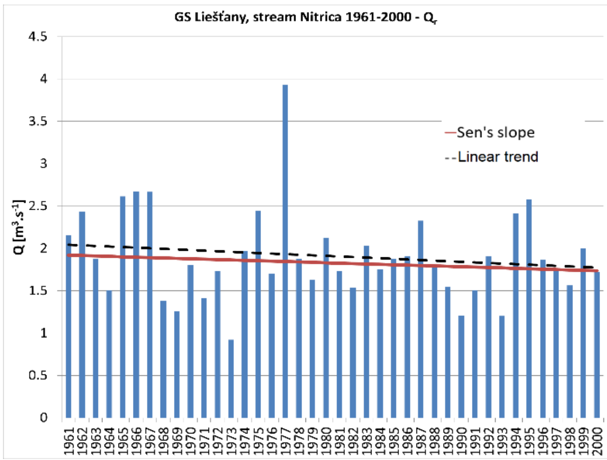
Average annual discharges (Q_r)

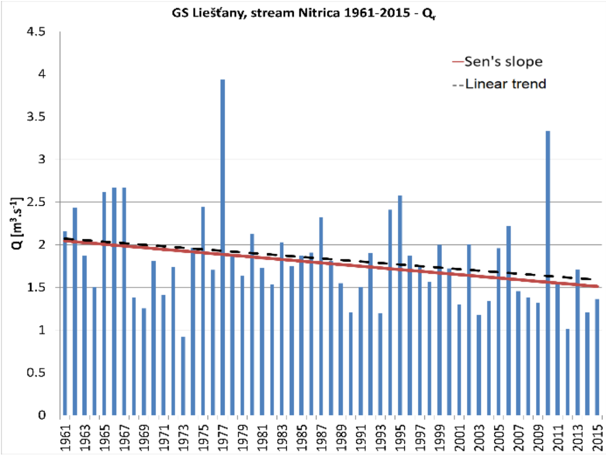
For the period 1961–2000 there was at the 95% significance level 1 gauge station with increasing trend, 12 gauge stations with decreasing trends, and 52 gauge stations with non-significant trends. In the 1961–2015 period there were at the 95% significance level 2 gauge

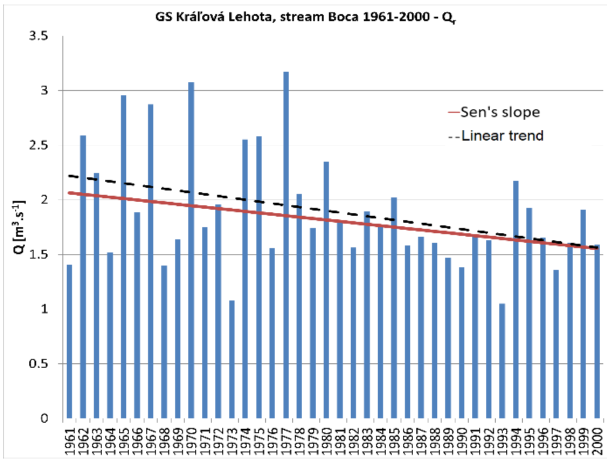


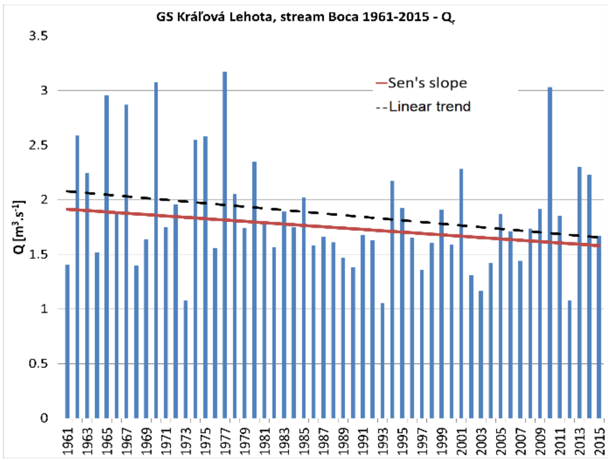

GS Chalmová, stream Nitra 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]

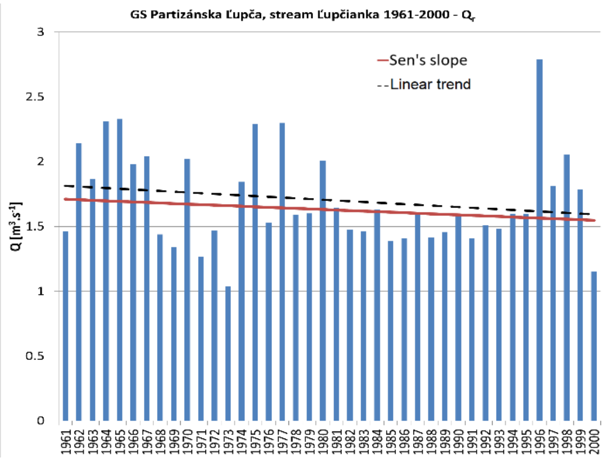

GS Chalmová, stream Nitra 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]

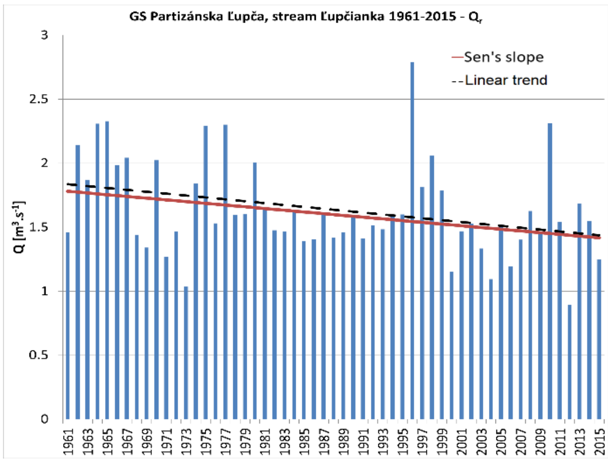

GS Liešťany, stream Nitrica 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]

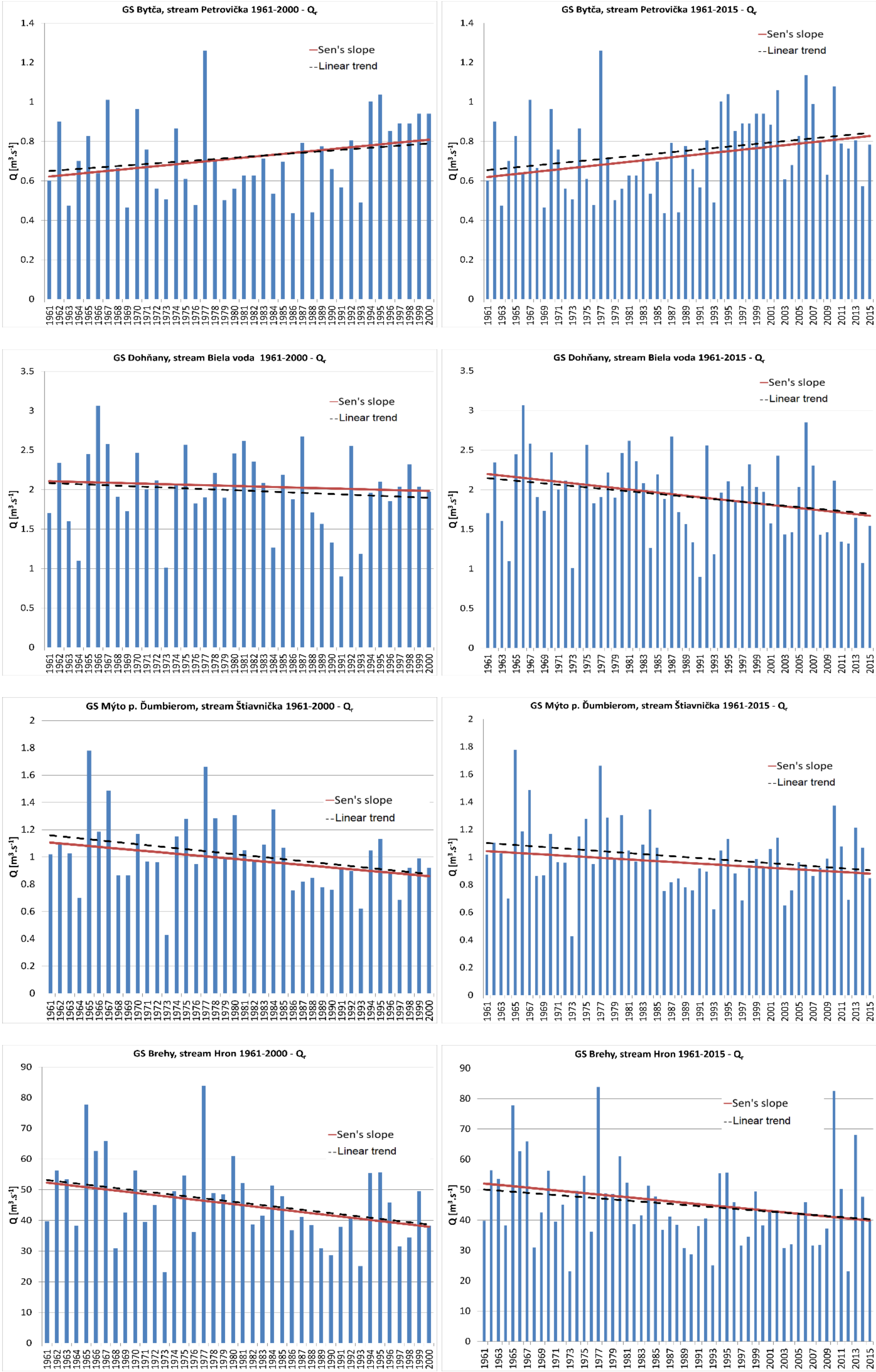

GS Liešťany, stream Nitrica 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]


GS Kráľová Lehota, stream Boca 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]


GS Kráľová Lehota, stream Boca 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]


GS Partizánska Ľupča, stream Ľupčianka 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]


GS Partizánska Ľupča, stream Ľupčianka 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m3.s-1]


GS Bytča, stream Petrovička 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Bytča, stream Petrovička 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Dohňany, stream Biela voda 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Dohňany, stream Biela voda 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Mýto p. Ďumbierom, stream Štiavnička 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Mýto p. Ďumbierom, stream Štiavnička 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Brehy, stream Hron 1961-2000 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]
GS Brehy, stream Hron 1961-2015 - Q_r
Sen's slope
Linear trend
Q [m³.s⁻¹]

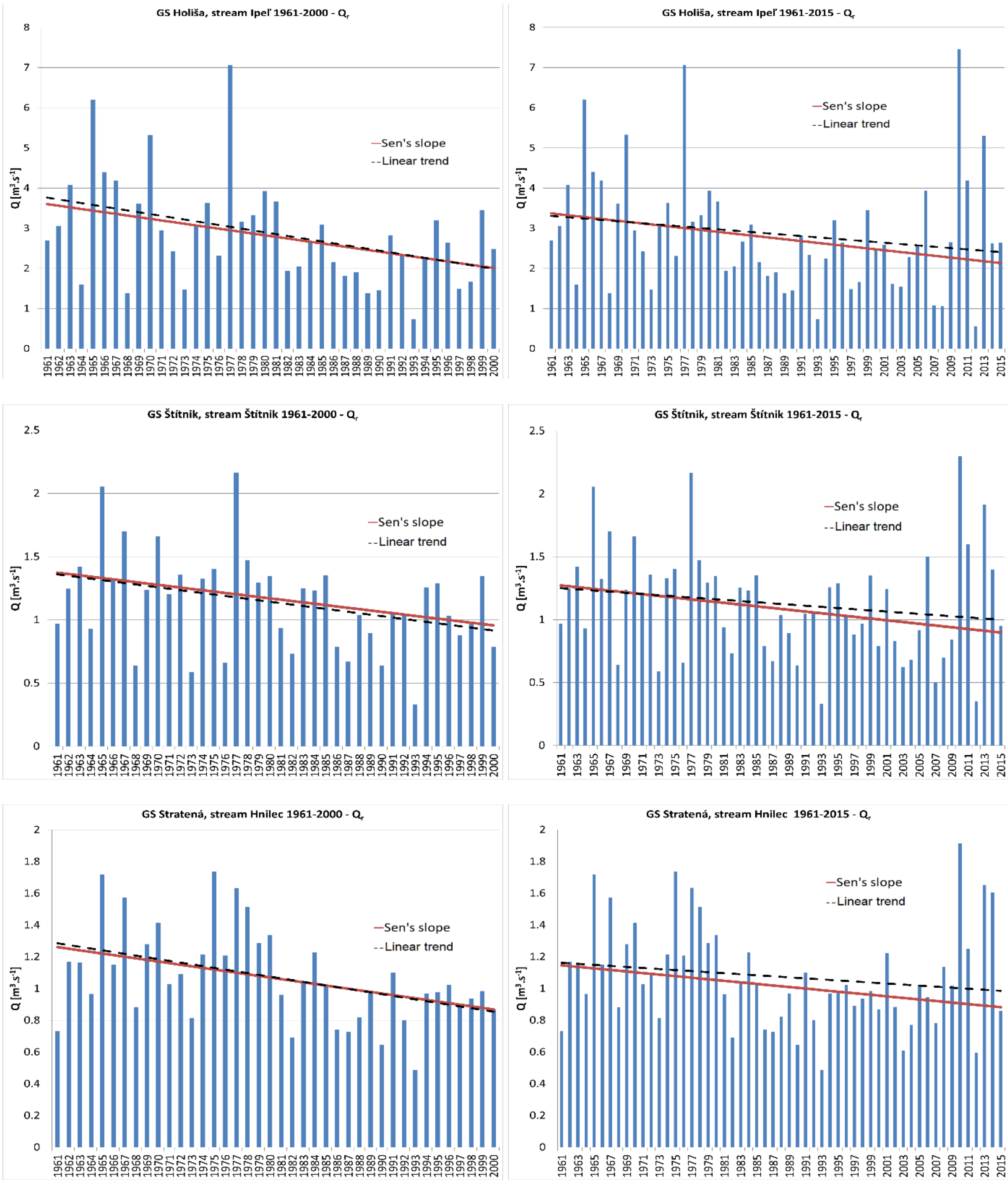


Fig. 2. Magnitude of trends in average annual discharges (Q_r) at selected gauging stations (GS) for the period 1961–2000 and 1961–2015.

stations with increasing trends, 13 gauge stations with decreasing trends, and 50 gauge stations with non-significant trends or no trends (Table 2).

The change in trend significance after adding 15 years occurred in 14 gauge stations. The most significant and most cases of changes in the trends of average discharges in the compared periods were calculated for the Nitra and Váh river basin (table 2).

More significant variation in the magnitude of the slopes was observed in gauge station Chalmová, Nitra River in period 1961–2000, the linear trend has more steepness compared to Sen's slope, this is due to the occurrence of extremely high discharges in 1965 and 1966.

In gauge station Kráľová Lehota, Boca stream, the difference in trend magnitude occurred in both periods, the difference is due to the occurrence of high

discharges in 1965 and 1967.
Gauge station Stratena, Hnilec stream recorded more significant differences in slopes in the period 1961–2015. These are due to the occurrence of high discharges in 2013 and 2014 (Fig. 2).

Discussion

In this paper, we used a non-parametric method to assess the significance of trends and used the chosen significance to determine the trends, in which the magnitude of the slopes were later analysed using the Sen's slope method and the common linear trend method.
The initial significance analysis of the individual trends for the period 1960–2000 determined the number of water gauging stations of interest in which we founded a trend that satisfies the condition of 95% significance level, the remaining trends that occurred at a lower level we consider as insignificant. After adding 15 years to the time series, we again determined the significance of the trends at the same water gauging stations (GS). The change in significance that occurred at the gauging stations indicates to us the occurrence of discharges (low or high) that affect the trend at a given gauging station only at these selected gauging stations we observed the change in trend magnitude using the Sen's slope and linear trend.
In this way, we attempted to speed up the trend analysis, we did not analyse the magnitudes of all trends (using Sen's slope and linear trend) that are located in each water gauging station (which can be a time consuming task with a larger number of GS), but only in those GS where a change in significance accursed. Finally, we included 11 GS at minimum annual flows and 14 GS at average annual flows in the final trend analysis from a total of 65 water gauging stations.
For the individual charts (Fig. 1 and Fig. 2), we were interested in the difference in the magnitude of the Sen's slope and linear trend. This difference was not very pronounced at most gauging stations, however, we recommend using the Sen's slope in addition to the simple linear trend because it is less sensitive to the occurrence of outliers that occur at the end or beginning of the time series. If there are these two trends magnitudes different, we know that an outlier discharge has occurred at the gauging station.

Conclusion

The aim of the present work was to evaluate the trends for the period 1961–2000 in terms of significance and magnitude at selected water gauging stations and their possible change after the addition of 15 years. In both periods, non-significant trends prevail over significant trends in both minimum and average annual discharges, despite the occurrence of two extreme years. The year 2010, which is considered to be an abnormally wet year, and the year 2012, which is considered to be an abnormally dry year in the added period 2001–2015.
In the sub-basins, the change in significance in the minimum annual discharges was mainly in the Váh river basin. In the upper part of the basin, the trends change from significantly decreasing to insignificant, which is due to the higher occurrence of higher minimum discharges in the added period 2001–2015, and conversely in the middle part of the basin, the trends change mainly from insignificant to significantly decreasing, which is due to the higher occurrence of low minimum discharges. In the other basins, the significance of trends did not change at most stations after the 15-year period was added.
In the sub-basins, the change in significance of the mean annual discharges was most pronounced in the upper Nitra basin. Trends change from non-significant to significant decreasing, indicating a greater occurrence of lower flows in the period 2001–2015. In the other basins, the significance of the trends did not change at most stations after the addition of 15 years.
The significance of the trends did not change significantly in either minimum or average annual flows over the entire country with the addition of 15 years, indicating that a large number of low or high annual discharges did not occur in most of the selected gauge stations. The magnitude of the trend slope, both linear and Sen's slope, are also very similar at most stations (where there has been a change in significance), indicating that there are not such extreme low or high discharges in the added time series 2001–2015 that would cause them to be potentially different. In general, the trends in both minimum and average annual flows over the assessment periods can be considered to be balanced to slightly decreasing across the whole of the country.
To assess and better understand the evolution of water bearing is in addition to hydrological characteristic necessary assessment climatological characteristics, in particular air temperature and evaporation.

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Ing. Viliam Šimor, PhD. (*corresponding author, e-mail: viliam.simor@shmu.sk)
Ing. Ľudovít Ľupták
Slovak Hydrometeorological Institute
Jeséniova 17
833 15 Bratislava
Slovak Republic