RAINFALL AND RUNOFF REGIME TRENDS IN MOUNTAIN CATCHMENTS (CASE STUDY AREA: THE UPPER HRON RIVER BASIN, SLOVAKIA)

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Abstract: This paper presents an analysis of trends and causes of changes of selected hydroclimatic variables influencing the runoff regime in the upper Hron River basin (Slovakia), complemented by assessment of floods. Different methods for identifying trends in data series are evaluated and include: simple mass curve analysis, linear regression, frequency analysis of flood events, use of the Indicators of Hydrological Alteration software, and the Mann-Kendall test. Analyses are performed for data from 1931 to 2010. The changes in runoff are significant, especially in terms of lower Q_{Max} and 75 percentile values. This fact is also confirmed by the lower frequency and extremity of flood events. The 1980s are considered a turning point in the development of all hydroclimatic variables. The Mann-Kendall test shows a significant decrease in runoff in the winter period. The main causes of runoff decline are: the considerable increase in air temperature, the decrease in snow cover depth and changes in seasonal distribution of precipitation amounts.

KEY WORDS: Trend analysis, Mann-Kendall test, IHA software, Hron River basin, flood

TRENDY ZRÁŽKO-ODTOKOVÉHO REŽIMU HORSKÝCH POVODÍ. V príspevku sú prezentované výsledky analýz hodnotenia trendov a príčin zmien hydroklimatických parametrov ovplyvňujúcich zrážko-odtokový režim horného Hrona, doplnené o hodnotenie povodní. Na identifikáciu trendov sú použité viaceré metódy: jednoduché súčtové čiary, lineárna regresia, frekvenčná analýza povodňových udalostí, IHA softvér a Mann-Kendallov test. Do analýz vstupujú údaje z obdobia 1931–2010. Signifikantný pokles nastáva v hodnotách Q_{Max} a 75 percentilu. Tento fakt potvrdzuje i nižšia frekvencia a extremita povodňových udalostí. Osemdesiate roky môžeme považovať za zlomové obdobie vo vývoji všetkých hydroklimatických ukazovateľov. Mann-Kendallov test preukázal signifikantný pokles odtoku v zimnom období. Hlavnými príčinami poklesu sú: významný vzrast teploty vzduchu, pokles snehovej pokrývky a zmeny v sezónnom rozložení zrážok.

KĽÚČOVÉ SLOVÁ: trendové analýzy, Mann-Kendallov test, IHA softvér, Hron, povodeň

Introduction

Assessment of climate change impacts on the hydrological regimes of water courses is of great significance. As a rule, analyses of the consequences of climatic change for the hydrological regimes of water courses are conducted 1) by modelling expected changes in the hydrological regime based on knowledge of the relationships between the characteristics of the climate and the hydrological regime; 2) by analyzing the hydrological regime using data from the instrumental period and proxy data, and determining indicators of changes in runoff formation. Both approaches require consideration of the relationships between climate variables on the one hand and the hydrological regime on the other hand.

The first group of research includes climate projections for Slovakia, which typically indicate an increase of air temperature of 2°C to 4°C by 2075 (Lapin et al., 2012) and depending on climate model and emission scenario a change in precipitation typically ranging from -15% to 10% (Szolgay et al., 2008). The modelling of impacts of such projections then translates into a general tendency of decreasing future annual runoff and a change of runoff regime, particularly in the mountains. However, the uncertainty of these model scenarios is rather large. Models of long-term mean annual runoff in Slovakia predict an increase in runoff throughout the winter and its decrease in the summer until 2075 (Hlavčová et al., 2008; Szolgay et al., 1997).

The second group of studies includes the assessment of changes and trend detection based on the observed data. Often, these variables are studied separately and the study of mutual relationships between individual hydroclimatic variables is missing. We can observe a decreasing trend in mean annual runoff using a linear trend analysis of the measured data. Minďáš et al. (2011) report that the smallest decrease in period 1961–2009 has occurred in northern Slovakia (13%); in the basins of central and southern Slovakia the decrease is more noticeable (between 16% and 24%, in period 1931–2009). The decrease of the mean annual runoff was also reported by Šipikalová et al. (2006). With the exception of the northern areas of Slovakia, mean annual runoff values in 1961–2000 are lower than in 1931–1980.

Runoff change scenarios on the upper Hron have been modelled by Danihlík et al. (2004), Pekárová and Szolgay (2005), Szolgay et al. (2008). The runoff change scenarios were developed for time horizons 2010, 2030, and 2075 by using data from the reference period 1951– 1980. The results show the decrease in the long-term mean annual runoff and changes in the seasonal runoff distribution. The southern part of the basin and lowland areas should be more sensitive to the decrease in runoff. The changes in the seasonal runoff distribution are shown also by Hlavčová et al. (2008). Based on analyses of recorded values, the Hron River basin is categorized as a basin with a decreasing to significantly decreasing long-term discharge trend (Poórová et al., 2013).
The changes in snow cover, characterized by simulated snow water equivalent (*SWE*) in the upper Hron River basin were examined by Juričeková et al. (2013). The results indicate a decrease in simulated *SWE* in the period of 1961–2000. Estimation of climate change impacts on the snow cover in the Hron River basin was carried out also by Holko et al. (2005). Possible snowmelt-runoff scenarios for the upper Hron were constructed by Hrušková (2006).
The seasonality, frequency and extremity of floods in the upper Hron River basin were assessed by Blahušiaková and Matoušková (2012). A review of methods for understanding flood regime changes and preparation of scenarios for predicting future changes in floods is described in Hall et al. (2014).
The main objective of this paper is to complement existing studies by detection and analysis of key factors controlling changes in runoff regime in the upper Hron River basin. The main contribution is to study the mutual relationships between individual water balance components and link and compare existing results of climate scenarios with trend detection and attribution studies.

Methods and data sources

The general guidance to the methodology of trend detection in time series of hydrological data is offered by Kundzewicz and Robson (2004) or Pilon and Yue (2002). The examination of the different statistical tests and their power was conducted by Helsel and Hirsch (1992) or Önöz and Bayazit (2003). Several methods were applied in this study. Simple mass curves of annual precipitation amounts and discharges were used as first step to identify changes in the rainfall-runoff regime. Trends of mean annual discharges (Q_r), annual air temperatures (T_r), annual precipitation amounts (P_r) and mean annual snow cover conditions were assessed using linear regression. Furthermore, the evaluation of a trend in annual and monthly time data series of all studied hydroclimatic factors has been done using a seasonal non-parametric Mann-Kendall test (Bawden et al., 2014; Kendall, 1975; Kliment and Matoušková, 2009; Mann, 1945; Yue et al., 2012). The test has two parameters important for the trend detection: a significance level (p), which represents the power of the test, and a slope magnitude estimate (Mann-Kendall statistics *MKS*), which represents the direction and volume of the trend. The trend significance level of 0.05 has been set for all statistical analysis.
The Indicators of Hydrological Alteration (IHA) software (Richter et al., 1998) and IHA 7.1 statistics software (TNC, 2009) were used to identify changes in hydrological time series of mean daily discharges (Q_d). We compared two selected data periods 1951–1980 and 1981–2010. The IHA software calculates 67 statistical parameters, e.g. coefficient of dispersion (*COD*) → (75-25)/50*pct* (*pct*→percentile), extreme water conditions: the 3-, 7-, 30-, and 90-day minimums and maximums (Q_{Min} and Q_{Max}), base flow index, frequency, timing and duration of high and low pulses.
Attention was paid also to the frequency, extremity and seasonality of floods. *N*-year flood events were used as the basin selection criterion, while a flood was defined as a hydrological situation where the mean daily discharge achieved or exceeded the value Q_1 (one-year flood). Evaluated flood events ≥ Q_5, Q_{20}, Q_{50}, Q_{100} were included in the assessment. In order to analyze the frequency and seasonality of floods, peak discharge values were used as source data. Seasonality was assessed using data on mean Q_d that exceeded the value of Q_1. Three days preceding the day with Q_1 occurrence determined the boundaries between individual flood events. If a flood began in one month and subsided in the next, the month in which the peak flow occurred was recorded.
All data provided by the Slovak Hydrometeorological Institute (SHMI) in Banská Bystrica was homogenized. Values of Q_d (mean daily discharge), Q_m (mean monthly discharge) and Q_r (mean annual discharge) from three gauging stations: Zlatno, Brezno and Banská Bystrica in the period 1931–2010 (Table 1) were used. Mean monthly and annual climatic data from 12 climate stations and daily data from 1 climate station (Telgárt) available from the beginning of measurements: 1931 and 1961, respectively, until 2010 (Table 2), were used as well. The analyzed dataset included mean monthly air temperature (T_m) from 6 stations and mean daily air temperature (T_d) from 1 station, monthly precipitation amounts (P_m) from 12 stations and monthly snow cover conditions from 12 stations. Snow cover conditions were evaluated for days with permanent snow cover, i.e. period in which the snow cover was not interrupted for more than three consecutive days and a minimum height of snow cover was 1 cm. We processed data on daily snow cover depth (SCD_d) for one station, and mean monthly snow cover depth (SCD_m), and number of days with snow cover in the month (SCN_m) for each station. Mean snow cover depth SCD_m was calculated as a ratio of sum of snow depths and number of days with snow in particular month. For annual analyses, mean snow cover depth (SCD_r) values were used along with the number

of days with snow cover (SCN_r). The SCD_r was calculated for a winter season (November–April) as the ratio of the sum of snow cover depth (SCS_r) and number of days with permanent snow cover (SCN_r).

Table 1. Gauging stations in the study basin.
Tabuľka 1. Vodomerné stanice v záujmovom povodí.

DB	Gauging site	Area [km^2]	Altitude [m a.s.l.]	Q_a [m^3.s^{-1}]	q [l.s^{-1}.km^{-2}]	□ [%]	Q_{rMax} [m^3.s^{-1}]	Q_{rMin} [m^3.s^{-1}]
6950	Zlatno	83.7	733	1.4	16.4	0.55	3.27 (1945)	0.72 (1947)
7015	Brezno	582.1	491	7.6	14.0	0.43	15.47 (1945)	3.48 (1943)
7160	B. Bystrica	1766.5	334	26.1	15.9	0.47	46.14 (1965)	12.93 (1943)

DB – database number (databázové číslo); Q_a – long-term mean annual discharge (dlhodobý priemerný ročný prietok) (1931–2010); q – specific runoff (špecifický odtok) for the period 1961–2000 (Zlatno) and 1931–1980 (Brezno, Banská Bystrica); φ – annual runoff coefficient (ročný odtokový koeficient) for the period 1961–2000 (Zlatno) and 1961–1980 (Brezno, Banská Bystrica); Q_{rMax} – maximum of mean annual discharge (maximálny priemerný ročný prietok) and Q_{rMin} – minimum of mean annual discharge (minimálny priemerný ročný prietok) (1931–2010)

Table 2. Climatic stations in the study basin.
Tabuľka 2. Klimatické stanice v záujmovom povodí.

Station	Altitude	Data from			Mean			Median			Maximum			Minimum		
	[m a.s.l.]	T	P	SC	T [°C]	P [mm]	SCD [cm]	T [°C]	P [mm]	SCD [cm]	T [°C]	P [mm]	SCD [cm]	T [°C]	P [mm]	SCD [cm]
Sliač	313	1961	1961	1961	8.2	705	12	8.2	705	11	9.7	1076	24	5.4	496	3
B. Bystrica	343, 427*	1931	1931	1961	8.2	828	16	8.3	827	14	9.7	1388	39	5.7	541	5
Staré Hory	475		1961	1961		1024	28		1030	27		1482	82		674	5
Dolný Harmanec	481		1961	1961		1066	27		1056	24		1585	78		727	6
Brezno	487	1931	1931	1961	6.9	751	15	6.8	747	12	8.6	1236	37	4.4	482	4
Jasenie	540		1961	1961		848	19		830	16		1272	49		533	4
Králiky	627		1961	1981		1060	26		1036	23		1685	67		731	6
Mýto pod Ďumbierom	630		1961	1961		883	20		886	18		1235	50		554	3
Motyčky	688		1961	1961		1031	35		1052	36		1481	81		755	7
Telgárt	901	1931	1961	1961	5.0	853	24	5.0	853	20	6.4	1282	67	3.2	528	5
Lom nad Rimavicou	1018	1961	1961	1961	5.2	928	33	5.2	908	32	7.0	1793	98	2.9	607	6
Chopok	2005	1961	1961	1961	-0.9	1072	96	-0.9	1055	89	0.4	1421	187	-2.2	832	19

* Data from two stations in Banská Bystrica (údaje z dvoch staníc v Banskej Bystrici), *T* – air temperature (teplota vzduchu), *P* – precipitation amount (úhrn zrážok), *SC* – snow cover (snehová pokrývka), *SCD* – snow cover depth (výška snehovej pokrývky)

Study area

The Hron River (basin area of 5.465 km^2) is the second longest river in Slovakia. It springs under the Kráľova hoľa Mountain in the Low Tatras at 934 m a.s.l. and flows into the Danube near Štúrovo at 103 m a.s.l. The upper Hron River basin up to Banská Bystrica has an area of 1.766 km^2 and was selected as the study basin (Figure 1). The Ďumbier Mountain (2043 m a.s.l.) is the highest point of the basin, and the gauging station in Banská Bystrica (334 m a.s.l.) is its outlet. Maximum mean monthly discharges (Q_m) occur in April, minimum ones in January, February and September. The long-term (1931–2010) mean annual discharge (Q_a) of the Hron River in Zlatno is 1.4 m3.s^{-1}, in Brezno 7.6 m3.s^{-1}, and in Banská Bystrica 26.1 m3.s^{-1}.

Results

Trend detection in the annual data series

From the perspective of mass curve analysis, changes in the Q_r are not particularly significant. The period of increased runoff occurred approximately from the second half of the 1960s until the beginning of the 1980s, when it began to gradually decrease with a more marked decrease after 1990. The Mann-Kendall test results (Table 3) also indicate an apparent declining trend of Q_r in 1931–2010, namely for the stations Zlatno, Brezno

and Banská Bystrica. For the period 1961–2010, the statistically significant declining trend of Q_r is only in Banská Bystrica.
A rising trend of T_r by 1.1°C (Lapin et al., 2012) was observed in Slovakia in the last 100 years. This trend could also be seen in the upper Hron River basin. This trend has been most pronounced at low and middle altitudes and south located stations. The highest increase was detected for stations Lom nad Rimavicou and Brezno. The T_r rose about 1.2 °C between 1961–1980 and 1981–2010 at the most southern station, Lom nad Rimavicou. The T_r at Brezno rose about 0.8°C between 1931–1980 and 1981–2010.
No evidence of statistically significant changes was found in the assessment of P_r. A slight decrease in precipitation totals in the cold half of the year (September–February) could be observed at the Brezno and Banská Bystrica stations.
In terms of SCD_r, its gradual decrease can be seen at most stations. This trend was recorded at lower and middle altitudes, being most pronounced at stations Dolný Harmanec (481 m a.s.l.), Motyčky (688 m a.s.l.), Staré Hory (475 m a.s.l.) and Telgárt (901 m a.s.l.). The trend could not be detected at the higher located stations Chopok (2005 m a.s.l.) and Lom nad Rimavicou (1018 m a.s.l.). It was indicated only by a lower SCN_r such as at the station Lom nad Rimavicou. In the past 30 years, the most abundant mean SCD_r was observed in the winter season of 2004–2005 (44 cm) and 2005–2006 (64 cm). These winter periods (November–April) could be classified as above average. The average SCD_r value for the upper Hron River basin (1981–2010) is 27 cm. Winters of 1988–1989 and 1997–1998 were below average; SCD_r was only 13 and 12 cm (SHMI, BB). In Telgárt SCD_r value decreased by approximately 10 cm (when 1961–1980 and 1981–2010 are compared). The highest SCD_r values at Telgárt station were recorded in 1963, 2006 and 1970 (Figure 2).

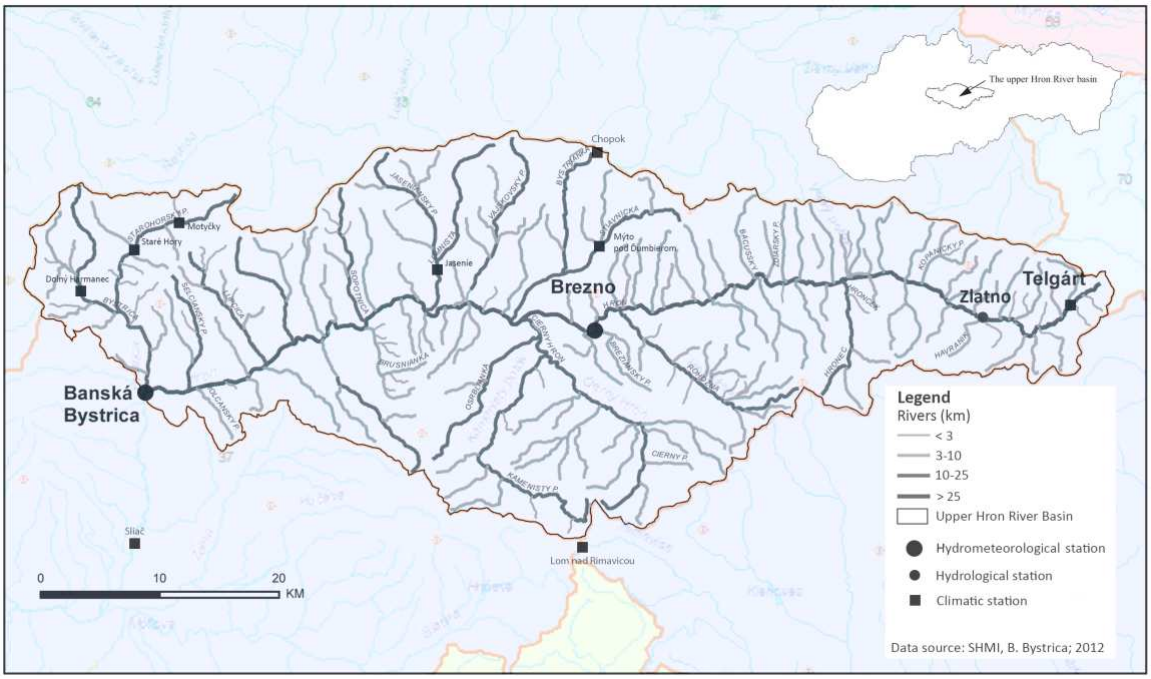


Fig. 1. Study area – the upper Hron River basin, Slovakia.
Obr. 1. Záujmové povodie – povodie horného Hrona, Slovensko.

Trend detection in the monthly and seasonal data series
From the results of the Mann-Kendall test, the reduced runoff in winter months (November to February) is significant for the period 1931–2010, being most pronounced in the upper course (Zlatno), in November and February (Brezno – Figure 3) and in November and December (Banská Bystrica). Almost no trend was registered for the summer months (only for Banská Bystrica – a decrease in June).
The most significant trends were found in the series of T_m. In the cold half of the year, the highest increase in T_m was recorded in January. A significant increase in T_m in this month was recorded at all stations with the exception of the station at the highest elevation (Chopok). In other winter months, the increase in T_m is generally not significant except Lom nad Rimavicou in December and Brezno in February. In the warm half of the year, this trend was reconstructed from April to August with the highest increase in August; the greatest increases occurred at Lom nad Rimavicou and at Brezno.
Seasonal fluctuations in P_m can be observed with a greater percentage of spring and summer precipitation amounts since 1990. Overall, P_m in observed climate stations indicates a slightly rising trend with the greatest share in growth occurring during the warmer half of the year, primarily in July, August, and May. In the cooler

half of the year, P_m at the Brezno and Banská Bystrica stations has a slightly decreasing tendency. In the months of November and February, P_m decreases at most stations. Statistically, using the Mann-Kendall test, no evidence of pronounced changes was found in P_m.

A more profound decrease in both SCD_m and SCN_m was confirmed by the Mann-Kendall test. A decrease in SCD_m is clear approximately from the 1980s. The most profound decrease of SCD_m was recorded in December at most stations and in February and April at others. At the Telgárt, Brezno and Banská Bystrica stations, this decrease is reflected in the *SCD*, although on *SCN*, this trend was not confirmed. In 1989–2010 mainly the months of January through March contributed to snow totals in Telgárt, whereas in 1961–1980 snow totals in December were significant as well. The duration of snow cover has reduced gradually (snow disappears in April), and there has been a shift in the beginning of snow cover from December to January.

Table 3. Results of MK test for mean annual discharge (Q_r), mean anuual air temperature (T_r), annual precipitation amount (P_r), mean annual snow cover depth (SCD_r) and number of days with snow cover in the year (SCN_r).

Tabuľka 3. Výsledky MK testu pre priemerný ročný prietok (Q_r), priemernú ročnú teplotu vzduchu (T_r), ročný úhrn zrážok (P_r), priemernú ročnú výšku snehovej pokrývky (SCD_r) a počet dní v roku so snehovou pokrývkou (SCN_r).

	Q_r (1931-2010)			Q_r (1961-2010)	
Station	*MK-S*	*p*	**Station**	*MK-S*	*p*
Zlatno	-2.65	0.01	Zlatno	-1.28	0.20
Brezno	-1.89	0.06	Brezno	-1.61	0.11
B. Bystrica	-3.00	0.00	B. Bystrica	-2.65	0.01
	T_r (1931-2010)			T_r (1961-2010)	
Station	*MK-S*	*p*	**Station**	*MK-S*	*p*
Telgárt	2.54	0.01	Chopok	2.87	0.00
Brezno	4.41	0.00	Lom n/Rimavicou	5.35	0.00
B. Bystrica	2.46	0.01	Sliač	2.88	0.00
	P_r (1931-2010)			P_r (1931-2010)	
Station	*MK-S*	*p*	**Station**	*MK-S*	*p*
Brezno	0.88	0.38	B. Bystrica	0.03	0.98
	Pr (1961-2010)			**Pr (1961-2010)**	
Station	*MK-S*	*p*	**Station**	*MK-S*	*p*
Telgárt	1.28	0.20	Sliač	-0.20	0.84
Dolný Harmanec	0.48	0.63	Lom n/Rimavicou	-1.08	0.28
Králiky*	2.43	0.01	Mýto p/Ďumbierom	1.07	0.28
	SCD_r (1961-2010)			SCD_r (1961-2010)	
Station	*MK-S*	*p*	**Station**	*MK-S*	*p*
Telgárt	-2.58	0.01	Lom n/Rimavicou	-1.80	0.07
Brezno	-1.97	0.05	Mýto p/Ďumbierom	-2.45	0.01
B. Bystrica	-1.52	0.13	Chopok	-0.33	0.74
Dolný Harmanec	-3.45	0.00	Staré Hory	-2.65	0.01
Králiky*	-1.95	0.05	Motyčky	-2.81	0.00
	SCN_r (1961-2010)			SCN_r (1961-2010)	
Station	*MK-S*	*p*	**Station**	*MK-S*	*p*
Telgárt	-1.36	0.17	Lom n/Rimavicou	-2.48	0.01
Brezno	-1.82	0.07	Mýto p/Ďumbierom	-3.39	0.00
B. Bystrica	-0.51	0.61	Chopok	-0.39	0.69
Dolný Harmanec	-3.35	0.00	Staré Hory	-2.50	0.01
Králiky*	0.54	0.59	Motyčky	-1.21	0.23

MK-S – Mann-Kendall statistics (Mann-Kendallova štatistika), *p* – a significance level (úroveň významnosti), (+ values) rising trend (rastúci trend), (- values) decreasing trend (klesajúci trend); * data period 1981 –2010

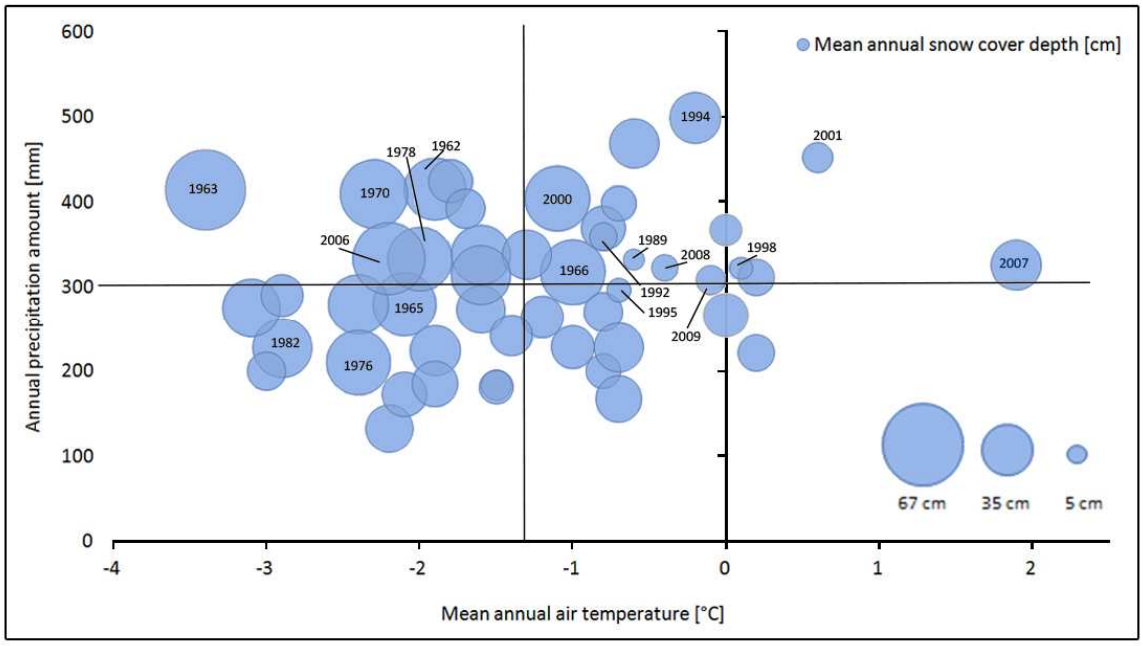


Fig. 2. The relationship between selected hydroclimatic variables at Telgárt station (1961–2010, November – April). Bubble diameter expresses snow cover depth, and the black lines represent mean annual air temperature or annual precipitation amount values in 1961–2010.
Obr. 2. Vzťah medzi vybranými hydroklimatickými premennými v Telgárte (1961–2010, november–apríl). Bubliny vyjadrujú výšku snehovej pokrývky, čierne čiary reprezentujú priemernú ročnú teplotu vzduchu a ročné zrážkové úhrny v rokoch 1961–2010.

Trend detection in the daily data series using IHA

Changes in discharge series were confirmed using the IHA software. The entire 1951–2010 period was assessed and was divided into two equally 30-year-long time periods: 1951–1980 and 1981–2010. During the 1951–1980 period, runoff was overall higher; higher values were recorded for all hydrological indicators Q_{Min}, Q_{25pct}, Q_{Med}, Q_{75pct} and Q_{Max} in the months of December, February, March, and June–August. The greatest difference in the *COD* was between the months of December and January. During the first period, the values for 1-, 3-, and 7-day peaks were significantly higher. A significant decrease in Q_{75pct} in the month of December is depicted in Figure 4. The decrease in minimum discharge values was practically unnoticeable. The primary causes of changes in runoff were the Q_{Max} and 75_{pct} values.

Trend detection in the extreme data series

The most events during which the N_1 value was exceeded in the 1931–2010 period occurred in the month of April (35 events), followed by May (20 events). A reduction in the frequency of discharge $\geq Q_1$ can be observed, which is also documented by comparing the 1951–1980 and 1981–2010 periods (Figure 5). The frequency of the occurrence of Q_1 events shifted from April to May to late summer. A higher frequency of flood events was observed approximately until the beginning of the 1980s, associated with a period of increased runoff. A considerable decrease of flood events $\geq Q_1$ from October until April occurred in 1981–2010. Rising air temperatures have an effect on the decreasing number of winter-spring floods. Finally, modification of the channel (especially after the flood in 1974), its deepening and less ice-cover formation also contributed to the decrease of their incidence. These reasons could explain the reduced incidence of floods with a peak discharge above Q_1, i.e. Q_5, Q_{20}, Q_{50}, and Q_{100}. The most extreme flood event occurred in Banská Bystrica in October 1974. The maximum flow achieved during the flood was 560 $m^3.s^{-1}$ which is an equivalent to Q_{100} (SHMI, BB).

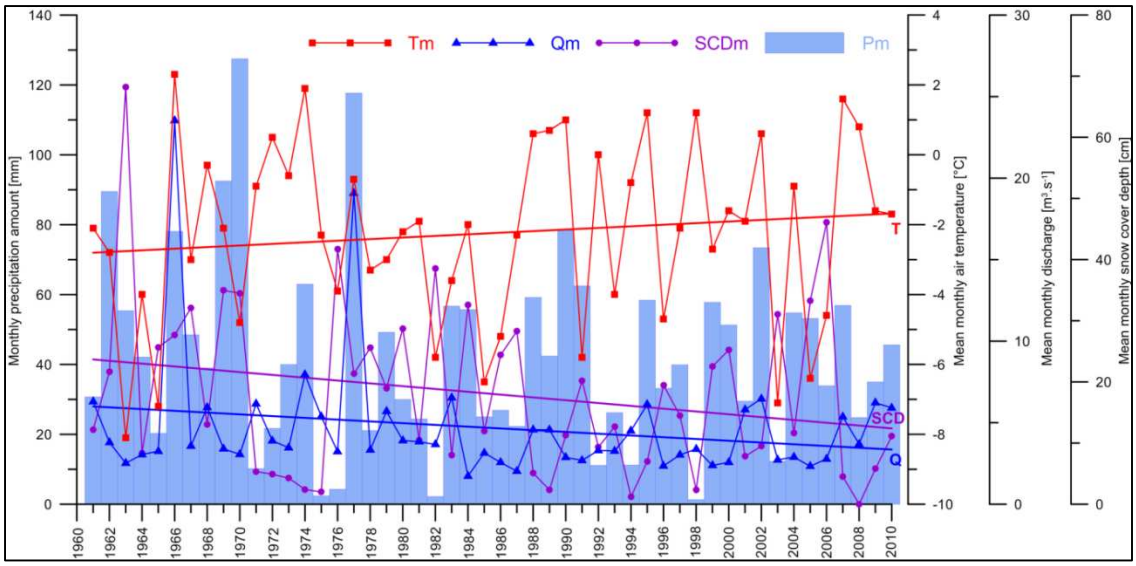


Fig. 3. Trends of hydroclimatic parameters in February (mean monthly values) in Brezno (1961–2010).
Obr. 3. Trendy hydroklimatických parametrov vo februári (priemerné mesačné hodnoty) v Brezne (1961–2010)

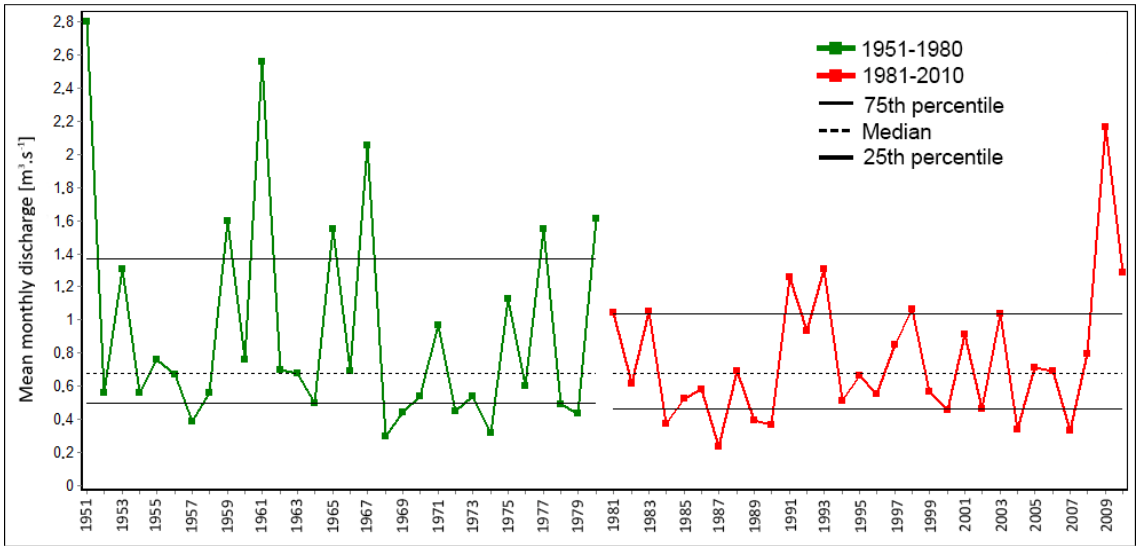


Fig. 4. The mean monthly discharge for December in Zlatno in periods 1951–1980 and 1981–2010.
Obr. 4. Priemerný mesačný prietok v decembri v Zlatne v období 1951–1980 a 1981–2010.

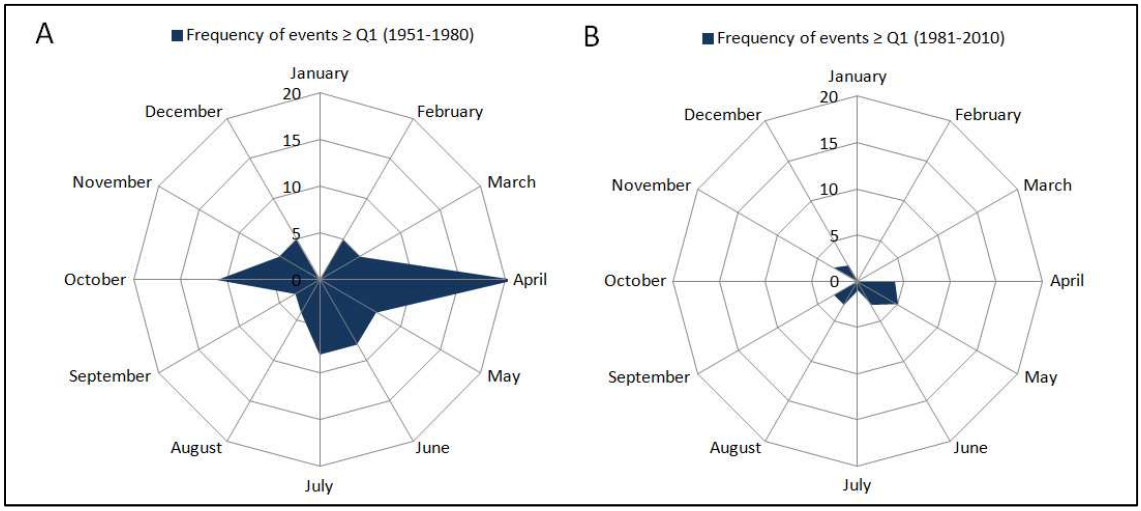


Fig. 5. Frequency of events ≥ Q_1 in the study basin, a comparison of periods A) 1951–1980 and B) 1981–2010.
Obr. 5. Frekvencia udalostí ≥ Q_1 v záujmovom povodí, porovnanie období A)1951–1980 a B) 1981–2010.

Discussion

From the results of our analyses and also other studies (Poórová et al., 2013; Tegelhoffová, 2010), it is clear that on the upper Hron there is a significant declining trend in discharges in cold half of the year during the period 1931–2010. Based on the findings of each hydroclimatic indicator, it seems as if the greatest change took place in the 1980s. Analyses and statistic tests have discovered a decrease in both Q_r and Q_m values in 1931–2010. At the Zlatno station, the decrease in Q_m was detected for the longest period, from November to February. Results for the upper Hron River basin confirm the significant rising tendency of air temperature at all the stations observed, which is similar to results of Danihlík et al. (2004), Lapin et al. (2012), Pekárová and Szolgay (2005), and Szolgay et al. (2008). This increase is most obvious from April to August and also in the winter period, particularly in December and January. The increase in observed T_r at the all stations ranges between 0.4°C and 1.2°C (comparing 1961–1980 and 1981–2010). The Mann-Kendall test did not provide any evidence of pronounced changes in P_r. Similar result was obtained also by Faško and Šťastný (2001). Further analyses have demonstrated a particular greater fluctuation in P_m and their distribution over the year. A slight increase occurs in the warmer half of the year (July, August, May). In the cold period, P_m has a slightly decreasing tendency.
Parajka et al. (2009) indicate the same shift in the seasonality of floods in mountainous areas of central Slovakia. The factors that probably most likely influence the decrease in flood occurrence in the upper Hron River basin are the increase in air temperature and lower *SCD*. Changes in snow conditions can be observed since the 1980s by our analysis; these changes include a decrease as well as greater variability in *SCD*. Since the end of the 1980s Holko et al. (2005) observed repeated weak winters in the southern part of the Hron River basin. As a rule, several years with low snow precipitation are followed by an above average year. Snow cover has decreased primarily in the month of December and is significant for most climatic stations. As for trend detection using statistical tests, a disadvantage is posed by the rather short duration of the data series and by being limited to the cold period of the year with snow cover.
The duration of observations plays an important role in the assessment of trends in hydroclimatic factors. If the goal of research is to identify the changes of the hydrological regime, then it is justifiable to use a time series that is as long as possible. Runoff trends in the upper Hron River basin were also tested for different data period sets. From our point of view, at least 30 years of data is needed to obtain statistically meaningful test trends.

Conclusion

The main results of our study are:
1) The upper Hron River basin is very sensitive, both to climate warming and changes in precipitation distribution, which have a significant effect on the runoff.
2) The 1980s can be considered a turning point in the development of all assessed hydroclimatic variables.
3) Significant declining trends in Q_r and Q_m were detected for period 1931–2010 period. In the cold half of the year Q_m decreases from November to February.
4) A considerable significant increase in air temperature was observed at all stations. The most significant increase was detected for December and January and April to August.
5) There are no statistically significant changes in annual precipitation amounts. Seasonal fluctuations in P_m can be observed with a greater percentage of spring and summer monthly precipitation since 1990. In November and February, P_m decreased at most stations.
6) Runoff decrease seems to be influenced by the decrease in snow cover depth (*SCD*) and the decrease in the number of days with snow cover (SCN_r). A decrease in mean monthly snow cover depth (SCD_m) and number of days with snow cover in the month (SCN_m) is significant mainly in December, February and April.
8) The changes in the runoff regime are significant, especially the drop in Q_{Max} and 75_{pct} values. The fact of decreasing runoff is also confirmed by the higher frequency and extremity of flood events in the period before 1980. At the same time a shift in the seasonality of flood events has occurred.

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TRENDY ZRÁŽKO-ODTOKOVÉHO REŽIMU HORSKÝCH POVODÍ (POVODIE HORNÉHO HRONA, SLOVENSKO)

V príspevku sú prezentované výsledky analýz hodnotenia trendov a príčin zmien hydroklimatických parametrov ovplyvňujúcich zrážko-odtokový režim horného Hrona. Na identifikáciu trendov sú použité viaceré metódy: jednoduché súčtové čiary, lineárna regresia, frekvenčná analýza povodňových udalostí, IHA softvér a Mann-Kendallov test. Do analýz vstupujú údaje z obdobia 1931–2010.

Z výsledkov analýz vyplýva, že povodie horného Hrona je veľmi citlivé na otepľovanie klímy, ako aj na zmeny v rozložení zrážok, ktoré majú významný vplyv na odtok. Za zlomový bod vo vývoji všetkých hydroklimatických ukazovateľov možno považovať osemdesiate roky minulého storočia.

Signifikantný klesajúci trend v období 1931–2010 je detekovaný v hodnotách priemerných ročných a mesačných prietokov. Významný je pokles odtoku v chladnej polovici roka (november–február). Na všetkých sledovaných staniciach zaznamenávame značný rast teploty vzduchu. Najsignifikantnejší vzrast je detekovaný v chladnej polovici roka v mesiacoch december a január, v teplej polovici roka v období apríl až august. Mann-Kendallov test nepreukázal signifikantné zmeny ročných zrážkových úhrnov. Sledujeme ale sezónne výkyvy mesačných zrážkových úhrnov, s väčším podieľom jarných a letných zrážok od deväťdesiatych rokov. V novembri

a februári dochádza na väčšine staníc k poklesu zrážok. Zmeny odtoku v chladnom polroku sú ovplyvnené poklesom výšky snehovej pokrývky a dní so snehovou pokrývkou. Tento pokles je badateľný hlavne v mesiaci december, február a apríl.
Väčšia frekvencia povodňových udalostí je zaznamenaná do začiatku osemdesiatych rokov. V porovnaní s obdobím 1951–1980, došlo v rokoch 1981–2010 k poklesu udalostí s hodnotou 1-ročného prietoku. Značný je ich pokles hlavne od októbra do apríla. Frekvencia výskytu týchto udalostí sa pritom posunula z apríla na máj a koniec leta. Tento fakt potvrdzuje i vývoj hodnôt maximálnych prietokov a 75 percentilu. IHA analýza i Mann-Kendallov test preukázali signifikantný pokles týchto ukazovateľov.

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