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Detecting Trends in the Annual Maximum Discharges in the Vah River Basin, Slovakia

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Abstract – A number of floods have been observed in the Slovak Republic in recent years, thereby raising awareness of and concern about flood risks. The paper focuses on the trend detection in the annual maximum discharge series in the Vah River basin located in Slovak Republic. Analysis was performed on data obtained from 59 gauging stations with minimum lengths of the observations from 40 years to 109 years. Homogeneity of the time series was tested by Alexandersson test for single shift at 5% level of significance. The Mann-Kendall trend test and its correction for autocorrelated data by Hamed and Rao (1998) were used to analyse the significance of detected changes in discharges. The series were analysed at different lengths of 40, 50, 60 years and whole observation period. Statistically significant rising and decreasing trends in the annual maximum discharge series were found in different regions of the Vah River catchments.

maximum annual discharges / homogeneity / Mann-Kendall trend test

Kivonat – Az évi maximális vízhozamok trend elemzése a Vág (Vah) vízgyűjtőjében, Szlovákiában. Az árhullámok száma igen jelentős napjainkban a Szlovák Köztársaságban, ezért egyre nagyobb az igény az árvízi kockázat elemzésekre. Jelen tanulmány az évi maximális vízhozamok tendenciájának elemzésére koncentrál a Szlovák Köztársaságban található Vág vízgyűjtőjében. Az elemzés alapját 59 vízmérce állomás idősoros adatai adták, amely idősorok hossza 40-től 109 évig változott. Az idősorok homogenitása Alexandersson tesztel lett értékelve 5%-os megbízhatósági szinten. A vízhozamban bekövetkező változások szignifikanciájának elemzésére Mann-Kendall tesztet, illetve annak Hamed és Rao (1998) által továbbfejlesztett, autokorrelált adatokra értelmezett változatát használtuk. Az idősorokat egységes hosszakban, 40, 50, 60 év, és a teljes észlelési időszakra vonatkozóan is értékeltük. Az eredmények alapján statisztikailag szignifikáns emelkedő és csökkenő trendek is kimutathatók voltak a maximális évi vízhozamokban a Vág vízgyűjtőjének különböző régióiban.

évi maximális vízhozam / homogenitás / Mann-Kandall trend teszt

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1 INTRODUCTION

A number of floods have been observed around Europe in recent decades, which have raised awareness of and concerns about flood risks. The observation and detection of changes in long-term hydrological time series is important for scientific and practical reasons, especially when designing water management structures.

There is a need to understand hydrological processes on small and also large temporal and spatial scales, land-atmosphere interactions, land use and climate change impacts (Szolgay, 2011). Further Blöschl et al. (2007) discuss the scales of climate variability and land cover change impact on flooding. In the note they debate, that climate change impact is likely to occur at large scales and to be consistent in both small and large catchments and regions, while land cover change is usually a local phenomenon, which effects are decreasing at larger spatial scale. Therefore the major driving forces behind hydrological phenomenons can vary depending on the factor and spatial scale

Many studies dealing with analyses of trends concerning floods have been published; many of them have found decreasing or increasing trends in their magnitudes and occurrences, and many have also found no changes (Strupczewski et al. 2001, Xiong – Guo 2004, Delgado et al. 2010, Armstrong et al. 2012, Rougé et al. 2013). The Mann-Kendall test (Kendall 1975, Kliment et al. 2011, Armstrong, 2012) is widely used in engineering hydrology to detect trends. When the data do not follow the normal distribution or are autocorrelated, authors have suggested the use of test corrections (Douglas et al. 2000, Burn – Hag Elnur 2001, Zhang et al. 2001, Yue et al. 2002, Lang 2012, Seoane – Lopez 2007, Danneberg 2012).

Strupczewski et al. (2001) investigated trends in 70-year-long observations of the annual maximum flows of Polish rivers. A decreasing tendency in the mean and standard deviations of annual peak flows was found with the use of the maximum likelihood method for estimating parameters and the Akaike Information Criterion for identification of an optimum model. Xiong and Guo (2004) tested maximum annual discharge series, including the mean annual maximum of the Yangtze River during a 120-year-long time period. No significant trend at the 5% significance level was found by the use of the Mann-Kendall test and Spearman’s rho at the tested station. Delgado et al. (2010) examined over 70-year-long annual maximum discharge series from 4 gauging stations in the Mekong river in Southeast Asia with use of Mann Kendal test, ordinary least squares with resampling and non-stationary generalised extreme value functions. The results of the study pointed out increasing likelihood of extreme floods during the last half of century. They also concluded that the absence of detected positive trends was a result of methodological misconception due to simplistic models.

Armstrong et al. (2012) analysed peak over threshold data with a recorded average period of 71 years. An increasing trend was found with the use of the Mann-Kendall trend test in 22 stations out of the 23 investigated, and a hydroclimatic shift towards a rising number of flood occurrences was found. Rougé et al. (2013) studied trend and step-change detection methods in hydrological time series (rainfall, river flows) and applied a combined Mann-Kendall and Pettitt test (1979) on 1217 data sets in the United States during the years 1910–2009.

In Slovakia, a long-term annual time series was investigated by Pekarova et al. (2008). In a IHP UNESCO report (Pekarova et al., 2008), daily discharges of the Danube River from 1976-2005 were analysed, and a rising tendency was detected, but no change was found in the annual and monthly time series. The Mann-Kendall trend test was used in Tegelhoffova (2012) to detect trends in the average annual and monthly discharges in Slovak rivers. However, no thoughtful trend analysis of annual maximum discharges in Slovak catchments has been provided.

This paper focuses on a time series analysis and significance assessment of trends detected in annual maximum discharge series in the Vah River catchment in the Slovak Republic and the lessons learned concerning the occurrence of extreme discharges in the Vah River catchments. The paper is organised as follows: methodology, input data description, results and discussion, and conclusions.

2 METHODS

In engineering hydrology, time series analysis usually operates under the assumption of homogeneity, stationarity and independence of time series. Homogeneity in the time series can be tested by Alexandersson test (Alexandersson – Moberg 1997), which is able to detect abrupt changes in analysed data set. We used Alexandersson test (Standard normal homogeneity test, SNHT) for single shift programmed in AnClim software (Stepanek 2007).

The significance of monotonic linear trend present in the time series is possible to assess by Theil (1950) and Sen (1968) slope defined as:

$$\beta = \text{Median}\left(\frac{x_j - x_l}{j - l}\right) \forall\, l < j, \tag{1}$$

where β is the estimate of slope of the trend and x_j is value of observation from j= 1...l. Positive value of β reveals increasing trend, negative value is sign of decreasing trend.

Changes in a trend can be detected by a rank-based, non-parametric Mann-Kendall trend test for monotonic trends (WMO 2000).

The test statistic S equals to (Yue et al. 2012):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k), \tag{2}$$

where x_j are the values of the data; *n* is the length of the time series and

$$\text{Sign}(x_j - x_k) \begin{array}{l} = 1, \text{ if } x_j - x_k > 0 \\ = 0, \text{ if } x_j - x_k = 0 \\ = -1, \text{ if } x_j - x_k < 0. \end{array} \tag{3}$$

In case the time series has $n \geq 8$, the statistic S has and almost normal distribution, and its variance is computed as:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right], \tag{4}$$

where g is the number of tied groups, and t_p is the amount of data with the same value in the group p=1...g.

The normalised test statistic Z:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{for } S < 0 \end{cases} \tag{5}$$

If the normalised test statistic Z is equal to zero, the data are normally distributed, and the positive values of Z mean a rising trend and negative a decreasing trend (Yue et al. 2012).

The p-value is computed as:

$$p = 0{,}5 - \Phi(|Z|)\ kde\ \Phi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{\frac{t^2}{2}} dt. \qquad (6)$$

If the data are not independent a correction of the MK trend test should be used. Autocorrelation can influence the results of the analysis (Lang 2012, Yue et al. 2002). Hamed and Rao (HR) (1998) correction addresses the issue of autocorrelation in the time series. The modified MK equation for any variance is:

$$\mathrm{V}^*(\mathrm{S}) = \mathrm{VAR}(\mathrm{S}) \frac{\mathrm{n}}{\mathrm{n}^*}, \qquad (7)$$

where VAR(S) is a variance from the original MK test (4); n is the length of the time series; n^* is the effective number of observations and $\frac{n}{n^*}$ is the correction factor in the case of autocorrelation in the sample.

The modified MK statistic:

$$Z^* = \begin{cases} \frac{S-1}{\sqrt{V^*(S)}} & \text{pre S} > 0 \\ 0 & \text{pre S} = 0. \\ \frac{S+1}{\sqrt{V^*(S)}} & \text{pre S} < 0 \end{cases} \qquad (8)$$

The correction factor can be calculated as:

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{j=1}^{n-1} (n-k)(n-k-1)(n-k-2) r_k^R, \qquad (9)$$

where r_k^R is the autocorrelation function of the ranks of the observations. It can also be calculated by the equation by Salas et al. (1980):

$$r_k = \frac{\frac{1}{n-k} \sum_{t=1}^{n-k} (X_t - E(X_t))(X_{t+k} - E(X_t))}{\frac{1}{n} \sum_{t=1}^{n} (X_t - E(X_t))^2}, \qquad (10)$$

where

$$E(X_t) = \frac{1}{n} \sum_{t=1}^{n} X_t, \qquad (11)$$

where r_k is the correction factor for the data X_t; $E(X_t)$ is the average of the input data.

Hamed and Rao (1998) also suggest using only statistically significant values of r_k, because other values have a negative influence on the values of variance S.

The null hypothesis of the MK and HR tests states that there is no perceptible trend in the sample data. If the resulting p-value is lower than level of significance, then we can reject the null hypothesis (Diermanse et al. 2010).

The Sen's slope and trend analysis tests were programmed and performed in the R free software programming language using the fume and Kendall packages (McLeod 2011, Santahter Meteorology Group 2012, R Core Team 2013).

3 INPUT DATA

Annual maximum discharges from 59 gauging stations in the Vah River basin (*Figure 1*) were obtained from the Slovak Hydrometeorological Institute in Bratislava, Slovakia. The annual maximum discharge series for the trend analysis chosen are based on the length of the observations, which is more than 40 years, with a maximum length of 109 years. Annual maximum discharges represent the observed peak maximum values during hydrological year. Mean record length of data set was 53.9 years, median 48 years and mode 41 years. *Table 1* summarised the selected gauging stations with starting year of observation in the Vah River basin.

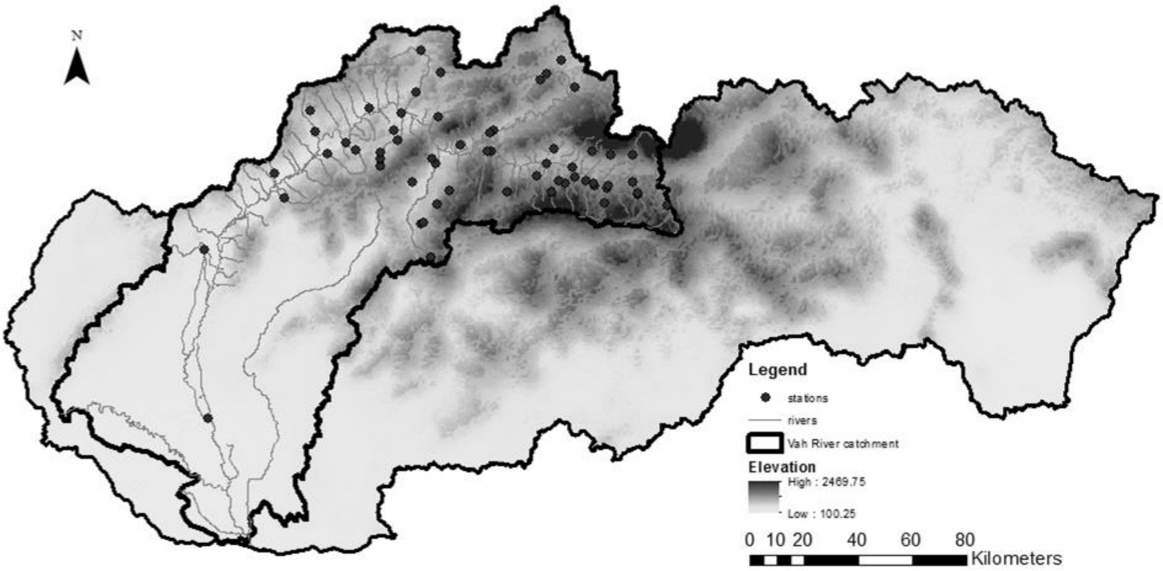

Figure 1. Location of the gauging stations in the Vah River basin, Slovak Republic.

4 RESULTS AND DISCUSSION

The homogeneity was tested on all 59 stations by the SNHT method for a single shift using AnClim software (Stepanek. 2007); 18 stations were found not to be homogeneous at a 5% level of significance (*Figure 2*). *Table 2* gives an insight when the critical values of SNHT were exceeded. It is possible to re-evaluate homogeneity after shortening the time series in 7 cases (5330, 5340, 5350, 5740, 5810, 5880 and 6150). After removing the extreme floods, all of the shortened time series were found to be homogenous at a 5% level of significance. Calculations were further performed with all 59 stations, and the final results were evaluated with an emphasis on the homogeneous stations.

Table 1. List of selected gauging stations in the Vah River basin

Station number	Name of the station	Catchment	Starting year of observations	Station number	Name of the station	Catchment	Starting year of observations
5300	Liptovská Teplička	Čierny Váh	1967	5890	Turany	Čiernik	1970
5310	Čierny Váh	Ipoltica	1961	5930	Turček	Turiec	1967
5311	Čierny Váh	Čierny Váh	1921	5970	Turčianske Teplice	Teplica	1963
5330	Východná	Biely Váh	1923	5980	Háj	Somolan	1969
5336	Malužiná	Boca	1970	6030	Brčna	Sloviansky P.	1969
5340	Kráľova Lehota	Boca	1931	6070	Blatnica	Gaderský P.	1969
5350	Kráľova Lehota	Hybica	1965	6110	Necpaly	Necpalsky P.	1970
5370	Liptovský Hrádok	Váh	1951	6130	Martin	Turiec	1937
5400	Podbanské	Belá	1928	6140	Martin	Pivovarský P.	1969
5460	Račková Dolina	Račkový P.	1963	6150	Stráža	Varínka	1957
5480	Liptovský Hrádok	Belá	1965	6190	Zborov N/Bystricou	Bystrica	1949
5520	Liptovský Ján	Štiavnica	1963	6200	Kysucké Nové Mesto	Kysuca	1931
5530	Žiarska Dolina	Smrečianka	1963	6230	Rajecká Lesná	Lesňanka	1968
5540	Iľanovo	Iľanovianka	1969	6240	Šuja	Rajčianka	1968
5550	Liptovský Mikuláš	Váh	1932	6260	Rajec	Čierňanka	1968
5590	Demänová	Demänovka	1969	6290	Rajecke Teplice	Kunedradsky P.	1969
5650	Prosiek	Prosiečanka	1969	6300	Poluvsie	Rajčianka	1930
5660	Horáreň Hluché	Paludźanka	1970	6330	Lietava, Majer	Lietavka	1969
5680	Liptovský Sv. Kríž	Paludźanka	1969	6340	Závodie	Rajčianka	1967
5720	Liptovské Vlachy	Kľačianka	1962	6360	Bytča	Petrovička	1961
5730	Partizánska Ľupča	Ľupčianka	1961	6370	Prečín	Domanižanka	1969
5740	Podsuchá	Revúca	1929	6380	Považská Bystrica	Domanižanka	1961
5780	Hubová	Váh	1921	6390	Vydrná	Petrinovec	1961
5790	Ľubochňa	Ľubochnianka	1959	6400	Dohňany	Biela Voda	1961
5800	Lokca	Biela Orava	1951	6420	Visolaje	Pružinka	1961
5810	Oravská Jasenica	Veselianka	1951	6450	Horné Srnie	Vlára	1961
5820	Zubrohlava	Polhoranka	1951	6460	Trenčianske Teplice	Teplička	1962
5840	Trstená	Oravica	1961	6470	Čachtice	Jablonka	1961
5870	Párnica	Zázrivka	1963	6480	Šaľa	Váh	1901
5880	Dierová	Orava	1931				

Table 2. Non- homogeneous stations at a 95% level of significance according to the SNHT test (To is the highest computed value of SNHT test statistics for the station; homogeneous stations after the removal of the extreme floods are marked in bold)

Station	Start year of observation	Statistic To	Critical values (Khaliq and Ouarda, 2007)	Critical value exceeded (Years)
5330	**1923**	**14.272**	**9.047**	**1940–1957**
5340	**1931**	**9.303**	**8.951**	**1931**
5350	**1965**	**9.015**	**8.331**	**1965**
5520	1963	8.711	8.382	1985–87
5650	1969	16.409	8.214	2009
5720	1962	17.566	8.382	1972–1984
5740	**1929**	**15.753**	**8.976**	**1938–1963**
5780	1921	19.802	9.067	1958–1995
5810	**1951**	**9.079**	**8.647**	**1960**
5840	1961	21.673	8.432	1999–2008
5870	1963	10.691	8.382	1993–1995
5880	**1931**	**16.197**	**8.951**	**1940–1967**
5890	1970	10.887	8.151	1979–1984
5970	1963	10.479	8.382	2009
6150	**1957**	**11.616**	**8.524**	**1958, 1960**
6360	1961	21.434	8.432	1995–2007
6390	1961	10.089	8.432	1973
6470	1961	15.362	8.432	2000–2005

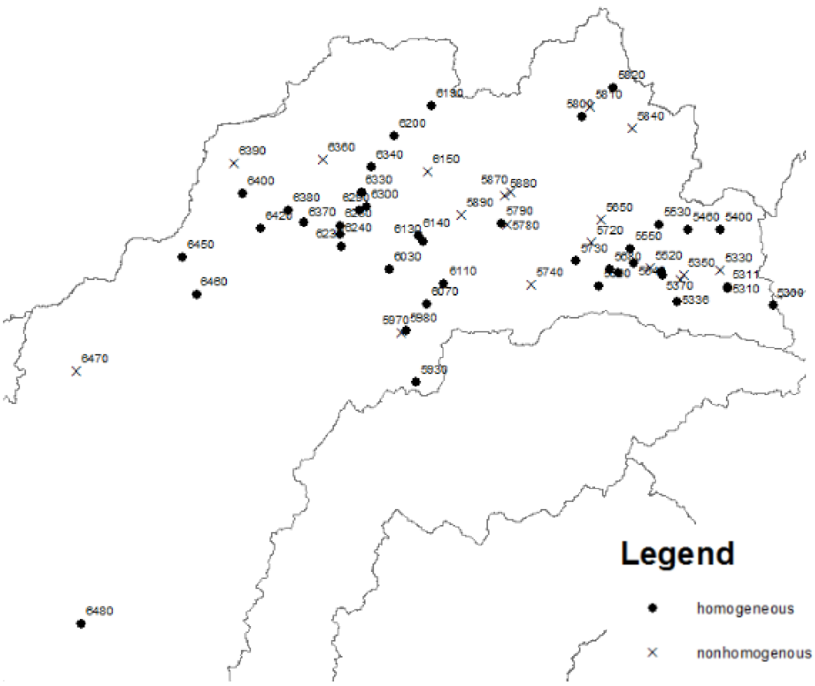

Figure 2. Map with locations and station number of homogeneous and nonhomogeneous stations at a 95% level of significance in the Vah River basin

For each of the 59 stations, the positive or negative direction of the trend was calculated by Sen's slope. The trend detected was positive in 27 cases and negative in 32 cases.

The MK and HR tests were applied to the discharge series in the Vah River catchment to assess the significance of the trend for different observation lengths: 40 years from 1970 to 2010; 50 years from 1960 to 2010; 60 years from 1950 to 2010; and the whole period of time observed at all the stations (40 years was the shortest and 109 years was the longest period). In the case of the autocorrelation in the time series, the test results of the MK and HR tests differ; therefore, there is a need to use the corrected HR test. The results were evaluated at the significance levels of 5, 10 and 20% (*Table 3*).

Table 3. Number of catchments at the levels of significance of 5, 10 and 20% by the MK and HR tests at different lengths of the observations

	Number of gauging stations	59		20		14		59	
	Time period (years)	40		50		60		40–109	
	Trend test	MK	HR	MK	HR	MK	HR	MK	HR
Significance level (number of stations)	5%	8	12	3	3	3	2	16	15
	10%	17	16	4	3	3	3	22	19
	20%	24	23	5	5	4	4	25	24

The null hypothesis (no trend in the time series) could not be rejected at the 20% significance level in 24 cases for the MK and 23 cases for the HR tests in the 40-year-long time period, in 5 cases for both the MK and HR in the 50-year-long time period, in 4 cases for both the MK and HR in the 60-year-long time period; and in 25 cases for the MK and in 24 cases for the HR for the whole time series. At the 10% level of significance, a trend was observed in 17 cases for the MK test and 16 for the HR test in the 40 year-long-period, 4 cases for the MK and 3 cases for the HR in the 50-year-long period, 3 cases for both the MK and HR during the 60-year-long-period; and in 22 cases for the MK and in 19 cases for the HR for the whole available time series. A trend at the 5% significance level was found in 8 cases for the MK and in 12 cases for the HR tests in the 40-year-long time period, in 3 cases for both the MK and HR in the 50-year-long time period, in 3 cases for the MK and in 2 cases for the HR in the 60-year-long time period, and in 16 cases for the MK and in 15 cases for the HR for the whole available time series.

Due to the autocorrelation present in the time series, the results for the MK trend test and HR test differ; therefore, the HR results were chosen for further analysis. The results of the HR trend test are presented in Figure 3, which describes the spatial distribution of rising or decreasing trends detected with significance at the 5%, 10% and 20% levels. The results of the 40 years of observations and the whole observed time period suggest the centralisation of a significant rising trend in the upper parts of the catchment and a decreasing trend in the lower parts of the upper Vah River basin. For the length of 50 years, the number of stations decreased to 20, and a significant trend was found in 5 stations, with a centralised rising trend present in the upper parts of the Vah River catchment. Sixty years of observations were available for 14 stations with a statistically significant trend in 4 stations with no clear spatial pattern.

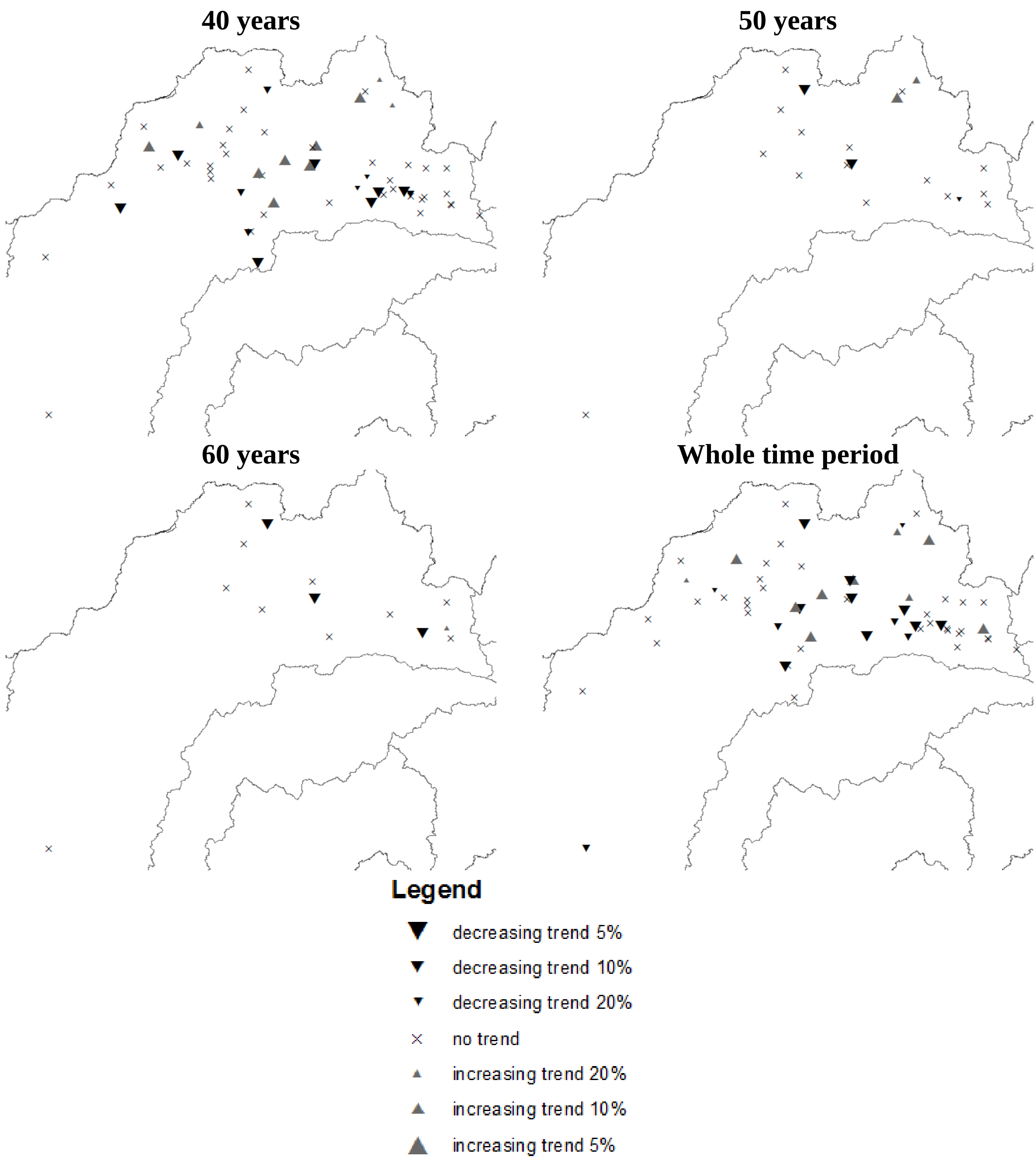

Figure 3. The results of the testing at the 5-, 10- and 20-% significance level

Subsequently, we took a closer look at 13 stations with observation periods longer than 60 years (*Table 3*). In the last column of *Table 4,* it can be seen that in stations with lengths of observations longer than 60 years, a statistically significant decreasing trend was found (Podsuchá, Hubová, Dierová, Martin, Zborov nad Bystricou and Šaľa); three of those time series (Podsuchá, Hubová and Dierová) were found to be non homogeneous by the SNHT test. A statistically significant rising trend was found at the Východná station, no trend was detected at the rest of the stations.

Table 4. Results of the significance analysis for catchments with 60 or more years of observations (the p-value is displayed in %); bold – statistically significant values for a rising trend, bold-italic – statistically significant values for a decreasing trend

Station	Name	Homogeneity	Years of observation	Sen's slope	P-value (%)			
					40y	50y	60y	whole
5311	Čierny Váh	Yes	89	increasing	69.42	70.87	39.38	52.15
5330	Východná	No	87	increasing	93.73	38.04	**15.23**	**0**
5340	Kráľova Lehota	No	79	decreasing	24.73	***19.16***	***2.67***	30.09
5400	Podbanské	Yes	82	decreasing	81.35	94.17	65.41	66.24
5550	Liptovský Mikuláš	Yes	62	decreasing	26.09	58.9	65.57	36.57
5740	Podsuchá	No	81	decreasing	46.53	40.28	49.36	***0.77***
5780	Hubová	No	89	decreasing	***0.53***	***0.3***	***0.03***	***0***
5880	Dierová	No	79	decreasing	87.5	66.92	25.79	***0***
6130	Martin	Yes	73	decreasing	86.62	53.7	62.02	*3.53*
6190	Zborov nad Bystricou	Yes	61	decreasing	***6.74***	***0.17***	***7.42***	***7.15***
6200	Kysucké Nové Mesto	Yes	79	decreasing	94.26	27.58	85.26	47.61
6300	Poluvšie	Yes	80	increasing	62.11	25.89	96.24	98.39
6480	Šaľa	Yes	109	decreasing	62.91	32.97	27.07	***6.48***

5 CONCLUSIONS

The paper was focused on an analysis of changes in annual maximum discharges in the Vah River basin by the use of trend significance analysis methods. The quality of the data set was tested by the Alexandersson SNHT test. The MK and HR trend tests were applied to different observation lengths – 40, 50, 60 and more than 60-year-long time series obtained from 59 gauging stations in the Vah River catchment.

A more detailed analysis of 13 stations with the longest periods of observations revealed that with a prolonged length of observation, the possibility of detecting a statistically significant trend increases. The short length of the time series (in some cases, 40 years) may have influenced the possibility of detecting a significant trend in the Vah River catchment, in that any prolongation of a time series observed can significantly influence the detection of a significant trend at the 5% significance level (Diermanse et al. 2010). When we also took into consideration the homogeneity analysis results of the SNHT method, a statistically significant decreasing trend was present at the Dierová, Martin, Zborov nad Bystricou and Šala stations.

Finally, we can conclude that a significant rising trend was detected in the upper part of the catchment, mainly in the east Tatra Mountain region and a decreasing trend in the lower part of the upper Vah River basin. These results can help when mapping flood risk areas and developing river basin management plans in the Vah River basin.

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REFERENCES

ALEXANDERSSON, H. – MOBERG, A. (1997): Homogenization of Swedish temperature data. Part I: Homogeneity test for linear trends. Int. J. Climatol. (17): 25–34.

ARMSTRONG, W.H. – COLLINS, M.J. – SNYDER, N.P. (2012): Increased Frequency of Low-Magnitude Floods in New England, Journal of The American Water Resources Association. 48 (2): 306–320.

BLÖSCHL, G. – ARDOIN-BARDIN, S. – BONELL, M. – DORNINGER, M. – GOODRICH, D. – GUTKNECHT, D. – MATAMOROS, D. – MERZ, B. – SHAND, P. – SZOLGAY, J. (2007): At what scales do climate variability and land cover change impact on flooding and low flows? (Note). 21 (9): 1241–1247.

BURN, D.H. – HAG ELNUR, M.A. (2002): Detection of Hydrologic Trends and Variability, Journal of Hydrology (255): 107–122.

DANNEBERG, J. (2012): Changes in Runoff Time Series in Thuringia, Germany, Mann-Kendall Trend Test and Extreme Value Analysis, Adv. Geosci. (31): 49–56.

DELGADO, J. M. – APEL, H. – MERZ, B. (2010): Flood trends and variability in the Mekong river, Hydrol. Earth Syst. Sci. (14): 407–418.

DIERMANSE, F.L.M. – KWADIJK, J.C.J. – BECKERS, J.V.L. – CREBAS, J.I. (2010): Statistical Trend Analysis of Annual Maximum Discharges of the Rhine And Meuse Rivers. BHS Third International Symposium, Managing Consequences of a Changing Global Environment, Newcastle 2010, UK

DOUGLAS, E.M. – VOGEL, R.M. – KROLL, C.N. (2000): Trends in Floods and Low Flows in the United States: Inpact of Spatial Correlation, Journal of Hydrology. 240 (1–2): 90–105.

HAMED, K.H. – RAO, A.R. (1998): A Modifed Mann-Kendall Trend Test for Autocorrelated Data, Journal of Hydrology. (204): 182–196.

KENDALL, M.G. (1975) Rank Correlation Methods. London: Griffin.

KHALIQ, M. N. – OUARDA, T. B. M. J. (2007): Short Communication: On the critical values of the standard normal homogeneity test (SNHT), Int. J. Climatol. 27: 681–687

KLIMENT, Z. – MATOUŠKOVÁ, M. – LEDVINKA, O. – KRÁLOVEC, V. (2011): Hodnocení Trend Trendů v Hydro-Klimatických Řadách Napříkladu Vybraných Horských Povodí (Evaluating of trends in hydroclimate time series, for example mountain streams). Středová, H., Rožnovský, J., Litschmann, T. (Eds): Mikroklima a Mezoklima Krajinných Struktur a Antropogenních Prostředí (Microclimate and mezoclimate of landscapes and antropogene landscapes). Skalní Mlýn, 2. – 4.2. 2011.

LANG, M. (2012): Statistical Methods for Detection of Changes Within Hydrological Series. Floodfreq Action, Subgroup WG4-3 “Trend Analysis of Hydrological Extremes”, Vienna, Austria 5.Sept. 2012.

MCLEOD, A.I. (2011): Kendall: Kendall rank correlation and Mann-Kendall trend test. R package version 2.2. http://CRAN.R-project.org/package=Kendall.

PEKÁROVÁ, P. – MIKLÁNEK, P. – ONDERKA, M. – HALMOVÁ, D. – BAČOVÁ MITKOVÁ, V. – MÉSZÁROŠ, I.– ŠKODA, P (2008): Flood Regime of Rivers in the Danube River Basin A case study of the Danube at Bratislava, National report for the IHP UNESCO, Regional cooperation of Danube Countries

PETTITT, A.N. (1979): A Non-Parametric Approach to the Change-Point Detection, Appl.Stat. (28): 126–135.

R CORE TEAM (2013): R a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

ROUGE, C. – GE, Y. – CAI, X. (2013): Detecting Gradual and Abrupt Changes in Hydrological Records, Advances in Water Resources (53): 33–44.

SALAS, J.D – DELLEUR, J.W. – YEVJEVICH, V. – LANE, W.L. (1980): Applied Modeling of Hydrologic Time Series, Water Resources Publications, Littleton, CO, USA.

SANTANDER METEOROLOGY GROUP (2012): fume: FUME package. R package version 1.0. http://CRAN.R-project.org/package=fume

SEN, P.K. (1968): Estimates of the regression coefficient based on Kendall’s tau. J. Am. Statist.Assoc. (63): 1379–1389.

SEOANE, R. – LOPEZ, P. (2007): Assessing the Effects of Climate Change on the Hydrological Regime of the Limay River Basin, Geojournal (70): 251–256.

SZOLGAY, J. (2011): Soil-water-plant-atmosphere interactions on various scales. Contributions to Geophysics and Geodesy 41 (Spec. Issue): 37–56.

STEPANEK, P. (2007): AnClim - software for time series analysis (for Windows). Dept. of Geography, Fac. of Natural Sciences, Masaryk University, Brno. 1.47 MB.

STRUPCZEWSKI, W.G. – SINGH, V.P. – MITOSEK H.T (2001): Non-stationary approach to at-site flood frequency modelling. III. Flood analysis of Polish rivers, Journal of Hydrology 248 (1–4): 152–167.

TEGELHOFFOVÁ, M. (2012): Hodnotenie zmien hydrologického režimu priemerných ročných a mesačných prietokov Slovenských tokov (Evaluation of the changes in hydrologic regime of average annual and monthly discharges in Slovakia), Phd. thesis, Svf STU in Bratislava.

THEIL, H. (1950): A rank-invariant method of linear and polynomial regression analysis, I, II, III. Nederl. Akad. Wetensch. Proc. (53) 386–392, 512–525, 1397–1412.

WMO (2000): Detecting Trend and Other Changes in Hydrological Data. WCDMP-45, WMO/TD 1013.

XIONG, L. – GUO, S. (2004): Trend Test and Change–Point Detection for the Annual Discharge Series of the Yangtze River at the Yichang Hydrological Station, Hydrological Sciences Journal. 49 (1): 99 –114.

YUE, S. – KUNDZEWICZ, Z.W. – WANG, L. (2012): Detection of Changes. Changes in Flood Risk in Europe, Chap. 2, 11–26, IAHS Special Publication 10.

YUE, S. – PILON, P. – PHINNEY, B. – CAVADIAS, G. (2002): The Influence of Autocorrelation on the Ability to Detect Trend in Hydrological Series, Hydrological Processes. 16 (9): 1807– 1829.

ZHANG, X. – HARVEY, K.D. – HOGG, W.D. – YUZYK, T.R. (2001): Trends in Canadian Streamflow, Water Resources Research. 37(4): 987–998.