LONG-TERM TREND CHANGES OF MONTHLY AND EXTREME DISCHARGES FOR DIFFERENT TIME PERIODS
Dana Halmová, Pavla Pekárová, Veronika Bačová Mitková

Nowadays, we are more frequently faced to the information about the extremes in discharge regime (floods and droughts) and their catastrophic consequences. Because of this, the first aim of hydrologists should be to verify these hypotheses and identify sources of mentioned changes. Rating extreme discharges is very important for example for assessing the impact of air temperature on the discharge. The upper parts of river basins are suitable for studying the effect of potential climate change or increased air temperature on drainage conditions in the basin. Analysis of trends in minimum discharges can predict its development and minimize its negative impacts on society and the environment. The contribution deals with the analysis of monthly discharges regime at gauging stations Bela-Podbanske (1929–2014) and Vah-Liptovsky Mikulas (1922–2014) and also analysis the minimum/maximum discharges in Bela River basin. Discharge analysed trends in mean monthly discharges and extreme discharges for selected time period to determine whether there is any significant change in the trend. We used the Mann-Kendall nonparametric test, which is one of the most widely used non-parametric tests to detect significant trends in time series.

KEY WORDS: trend analysis, MANN-KENDALL test, extreme and monthly discharges, Vah River basin, Bela River basin

Introduction
Currently, we are more frequently faced to the information about the hydrological extremes and their catastrophic consequences. Because of this, the first aim of hydrologists should be to verify these hypotheses and identify sources of mentioned changes (e.g. the natural variability of runoff). Analysis of trends in minimum discharges can predict its development and minimize its negative impacts on society and the environment. It is important to note that the minimum discharge is one of the characteristics that can define hydrological drought. So that we can answer these questions, it is necessary to statistically analyse long and high quality time series of hydrological observations from the river basins, which are little affected by anthropogenic activities. The upper part of the Bela River Basin is particularly suitable for studying the effect of potential climate change on drainage conditions in the basin. Regular, continuous evaluation of average daily discharges began in 1927/1928. Attention was also paid to the precipitation, including winter. Based on the measured data originated a number of studies, (Burn et al., 2004; Demeterová and Škoda, 2009; Majerčáková et al., 2007). Analysis of trends in long-term series of hydrological data are an important tool for finding and understanding of the changes in the development of a rainfall-runoff process and the results are useful in the water planning and flood protection. The main reasons for the runoff changes are considered global climate change in combination with different types and degree of human activities. The trend analysis used different methods. Specific examples of analyses of trends in rainfall-runoff time series can be found in several works of authors Falarz (2004), Fu et al. (2004), Franke et al. (2004), Kundzewicz and Robson (2004), Helsel and Frans (2006); Schoner et al. (2009), Onoz, Bayazit, (2003), Pekárová, (2003), etc.

The aim of this article is analysis of monthly discharges regime at gauging stations Bela-Podbanske and Vah-Liptovsky Mikulas for the selected time periods and analysis of minimum discharges in Bela River basin.

Methods and data
At the trend analysis of the time series, generally, the null hypothesis $H_0$ that there is no trend is to be tested against the alternative hypothesis $H_1$, that there is a trend. The parametric and non-parametric tests can be used for this purpose. The parametric test considers the linear regression of the random variable $x_i$ on time. The parameters of the trend line are calculated by using standard method for estimation of the parameters of a simple linear regression model, i.e. by using least square method.
Mann-Kendall nonparametric test

The Mann-Kendall nonparametric test (M-K test) is one of the most widely used non-parametric tests for significant trends detection in time series. The nonparametric tests are more suitable for the detection of trends in hydrological time series, which are usually irregular, with many extremes (Hamend, 2008; Yue et al., 2003; Gilbert, 1987; Blahoušiaková et al., 2016; Lettenmaier et al., 1994; Sonali et al., 2013). The study performs two types of statistical analyses: 1) the presence of a monotonic increasing or decreasing trend, and 2) the slope of a linear trend is estimated with the non-parametric Sen’s method, which uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time.

By M-K test, we want to test the null hypothesis $H_0$ of no trend, i.e. the observations $x_i$ are randomly ordered in time, against the alternative hypothesis $H_1$, where there is an increasing or decreasing monotonic trend. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic $S$ is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, $S$ is decremented by 1. The net result of all such increments and decrements yields the final value of $S$ (Shahid, 2011).

For $n$ (number of tested values) $\geq 10$, the statistic $S$ is approximately normally distributed with the mean and variance as follows

$$E(S) = 0$$

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

where:

$q$ – number of tied groups,
$t_p$ – number of data values in the $p$ group.

The standard test statistic $Z$ is computed as follows

$$Z = \begin{cases} 
\frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S \neq 0 \\
0 & \text{if } S = 0 \\
\frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0
\end{cases}$$

The presence of a statistically significant trend is evaluated using $Z$ value. A positive (negative) value of $Z$ indicates an upward (downward) trend. The statistic $Z$ has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at $\alpha$ level of significance, hypothesis $H_0$ (no trend) is rejected if the absolute value of $Z$ is greater than $Z_{\alpha/2}$, where $Z_{\alpha/2}$ is obtained from the standard normal cumulative distribution tables. The M-K test detects trends at four levels of significance: $\alpha=0.001$, 0.01, 0.05, and $\alpha=0.1$. Significance level of 0.001 means that there is a 0.1% probability that the value of $x_i$ is from a random distribution and are likely to make a mistake if we reject the hypothesis $H_0$. Significance level of 0.1 means that there is a 10% probability that we make a mistake if we reject the hypothesis $H_0$. If the absolute value of $Z$ is less than the level of significance, there is no trend. For the four tested significance levels the following symbols are used in the template:

*** if trend at $\alpha=0.001$ level of significance – $H_0$ seems to be impossible,
** if trend at $\alpha=0.01$ level of significance,
* if trend at $\alpha=0.05$ level of significance – 5% mistake if we reject the $H_0$,
+ if trend at $\alpha=0.1$ level of significance,
Blank: the significance level is greater than 0.1, cannot be excluded that the $H_0$ is true.

Study area and data

River Vah is the biggest left-side Danube River tributary and the second biggest river in Slovakia. The Bela River (93.49 km²), tributary of the Vah River, is situated in the High Tatra Mountains with the highest degree of protection and it can be considered as the basin unaffected by human activity. Gauging station Vah-Liptovsky Mikulas is the final profile above the water reservoir Liptovska Mara, one of the largest reservoirs in Slovakia and the basin are is 1107.21 km². Also for that reasons, it is useful to know the hydrological changes in the discharge profiles, (Fig. 1).

In this study the average daily discharges from above mentioned water gauges were used (Vah River: 1922–2014, Bela River 1929–2014). These basins were selected according of the homogeneity of the discharge time series. In order to perform the homogeneity analyses of data, two different tests of homogeneity were applied on each series, the standard normal homogeneity test (Alexandersson, 1986) and the Mann-Whitney-Pettit test (Pettit, 1979). Software Anclim (Štěpánek, 2007) was used to perform both tests (Pekárová and Miklánek ed., 2019).

The Figure 2 shows the long-term percentiles of daily discharges, which gives a basic overview of the hydrology regime in the area. E.g. green line means the mean of daily discharges, percentile P50. Yellow line represent 99th percentile. According to classification method by Pardé (1947), the Bela River and Vah River have snowmeltwater (nival) runoff regimes, single-peak with a maximum in April-May due to snowmelt and a minimum in winter when the water is retained in form of ice and snow.

Results

Changes of the monthly and extreme discharges from the long-term point of view

Variation in average monthly discharges

We quantify the variation in average monthly discharges from long-term point of view and analysed the monthly discharges regime at both profiles Bela-Podbanske and Vah-Liptovsky Mikulas for the whole selected time periods and for five shorter periods, see Table 1 and...
Fig. 1. Location of the Vah River in Slovakia (left), scheme of the Vah River Basin up to Liptovsky Mikulas gauge; green square represents Bela River basin up to gauging station Bela-Podbanske (right).

Fig. 2. Long-term percentiles of daily discharges, Bela - Podbanske (left), Vah - Liptovsky Mikulas (right).

Table 2, for both profiles, were average monthly discharges subsequently analysed too. The results show that the maximum monthly discharge in each period occurred in May at both river basins. Minimum discharges occurred in February and March at Bela-Podbanske. Minimum discharge occurred in January and February at Vah-Liptovsky Mikulas. This mode of maximum and minimum discharges coincides with the regime discharges in these altitudes. Mean monthly discharge in gauging stations Bela-Podbanske and Vah-Liptovsky Mikulas for selected time periods is in Table 1 and Table 2, maximal and minimal monthly values are highlighted. The shorter time series distribution was chosen with respect to the recommended minimum lengths of time series for hydrological analyses (Viessman et al., 1977).

**Trend analysis of monthly and extreme discharge characteristics**

The results of the slope of trend lines analysis for individual months give us the information about *monthly discharge trend changes* for different periods (Fig. 3). Directive of trend lines for individual months for the selected time periods suggest that a change in trend (from decreasing to increasing trend) occurs in the second half of the year (from July to December) at Bela-Podbanske (Fig. 3a). Conversely, in the month of May, when occurring in those watersheds maximum discharges, trend remains growing for both periods at the Bela River Basin, but during the period of 1960–2014 is three times higher than during the period of 1929–2014. On the contrary at the Vah River Basin trend remains downward. Clearly declare upward or downward trend in the flow, it is necessary to analyse the longest series of observations at any station. In the profile Vah-Liptovsky Mikulas change in trend occurs in different months of the calendar year in the months January, March, August, September and November (Fig. 3b). However, in some months (April, June, July, October) there is a situation where the trend does not change, but in the period 1960–2014 it is several times higher.

Trends changes of monthly discharges for two different time periods and selected months can be clearly seen in Fig. 4; Fig. 4a applies to the station Bela-Podbanske, months: May, September to November and Fig. 4b. applies to the station Vah-Liptovsky Mikulas, months: March, September and November. The upper part of the Bela River Basin is particularly suitable for studying the effect of potential climate change on drainage conditions in the basin. Analysis of *trends in several discharge characteristics* (minimum and maximum, 1-day, 3-day, 7-day and 30-day minimum,
Table 1. Mean monthly discharge for selected time periods at gauging stations Bela-Podbanske (maximal monthly discharge – bold; minimal monthly discharge – grey color)

| Time period       | 1929–2014 | 1960–2014 | 1929–1948 | 1949–1968 | 1969–1988 | 1989–2014 |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| January           | 1.205     | 1.205     | 1.063     | 1.304     | 1.244     | 1.208     |
| February          | 0.988     | 1.017     | 0.777     | 1.120     | 1.018     | 1.027     |
| March             | 1.037     | 1.001     | 1.039     | 1.118     | 0.920     | 1.065     |
| April             | 3.394     | 3.291     | 3.577     | 3.498     | 2.843     | 3.598     |
| May               | **8.432** | **8.418** | **8.207** | **8.211** | **8.372** | **8.823** |
| June              | 6.300     | 6.274     | 6.419     | 6.589     | 6.156     | 6.100     |
| July              | 4.553     | 4.436     | 4.630     | 4.482     | 4.607     | 4.506     |
| August            | 3.401     | 3.240     | 3.720     | 3.382     | 3.415     | 3.160     |
| September         | 2.852     | 2.816     | 3.263     | 2.288     | 2.709     | 3.081     |
| October           | 2.522     | 2.450     | 2.897     | 2.243     | 2.381     | 2.556     |
| November          | 2.338     | 2.072     | 1.945     | 1.802     | 2.412     | 2.430     |
| December          | 1.639     | 1.535     | 1.631     | 1.488     | 1.651     | 1.632     |

Table 2. Mean monthly discharge for selected time periods at gauging stations Vah-L. Mikulas (maximal monthly discharge – bold; minimal monthly discharge – grey color)

| Time period       | 1922–2014 | 1960–2014 | 1922–1941 | 1942–1961 | 1962–1981 | 1982–2014 |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| January           | 9.640     | 9.550     | 10.190    | 9.306     | 9.640     | 9.508     |
| February          | 9.184     | 9.226     | 9.045     | 9.066     | 10.125    | 8.770     |
| March             | 14.772    | 13.954    | 16.950    | 14.560    | 14.829    | 13.545    |
| April             | 30.010    | 30.107    | 26.740    | 32.563    | 33.325    | 28.435    |
| May               | **39.131**| **38.689**| **42.535**| **35.070**| **41.436**| **38.132**|
| June              | 26.762    | 27.380    | 26.815    | 25.035    | 30.872    | 25.287    |
| July              | 20.173    | 20.009    | 19.745    | 21.308    | 20.406    | 19.604    |
| August            | 16.379    | 16.277    | 17.930    | 15.488    | 17.021    | 15.591    |
| September         | 14.128    | 13.934    | 18.028    | 10.423    | 14.199    | 13.967    |
| October           | 14.372    | 14.533    | 16.755    | 11.123    | 17.700    | 12.881    |
| November          | 15.485    | 13.687    | 21.908    | 14.172    | 13.768    | 13.624    |
| December          | 12.377    | 11.477    | 14.316    | 12.488    | 11.883    | 11.095    |

Fig. 3. Slope of trend lines of individual months; a) Bela-Podbanske the time periods 1929–2014 and 1960–2014; b) Vah-L. Mikulas, the time periods 1922–2014 and 1960–2014.

As well as maximum, and day of minimum/maximum discharge occurrence) can predict its development and minimize its negative impacts on society and the environment (fauna and flora of the river basin). It is important to note that the minimum discharge is one of the characteristics that can define hydrological drought.
Trends changes of discharge characteristics for period 1929–2014 in gauging station Bela-Podbanske and period 1922–2014 Vah-Liptovsky Mikulas is shown in Fig. 5a and Fig. 5b. Results clearly declare increasing (Bela-Podbanske) or decreasing (Vah-Liptovsky Mikulas) trend in the Q₁-day minimum or Q₁-day maximum flow. For further analysis it is clear that trend in time period 1960–2014 is decreasing.

The trend of other extreme discharges (Q₁-day min/max, Q₁₀-day min/max, and Q₅₀-day min/max) at gauging station Bela-Podbanske during the longer period 1929–2014 is slightly increasing. While the trend of shorter observation period (1960–2014) suggests that individual extreme discharges remain unchanged or very slightly decreasing. The trend of these characteristics at gauging station Vah-Liptovsky Mikulas during the longer period 1922–2014 remain unchanged or very slightly increasing in minimum and decreasing in maximum values.

According to these differences in trends for shorter and longer measurement periods is necessary to analyse the longest series of observations at any station.

**Non-parametric tests for significant trends detection in time series at Bela and Vah**

Examples of the evaluation of monthly and extreme discharge trends for selected time periods at gauging stations Bela-Podbanske (time periods 1929–2014, 1960–2014, and 1989–2014) and Vah-Liptovsky Mikulas (time periods 1922–2014, 1960–2014, and 1989–2014) are given in Table 3 and Table 4. The results for the Bela River Basin (profile Bela-Podbanske) indicate trends at α=0.05 level of significance (marking symbol – *) in November, and trends at α=0.1 level of significance (marking symbol – +) in December for the time period 1929–2014. Guest shorter period 1960–2014 showed no significant trend. The trend at α=0.1 level of significance in November was established for the Vah River Basin (profile Vah-Liptovsky Mikulas) for the evaluation period 1922–2014. When evaluating a shorter time period 1960–2014 no signify-cant trend was detected, and we cannot reject the hypothesis $H_0$

According to the M-K test, there was a change in the trend at the significance level α=0.05 for both stations in the analysis of whole periods of measurement (Bela-Podbanske 1929–2014, Vah-Liptovsky Mikulas 1922–2014) in the month of November. Figure 6 presents comparison of the long-term trend – as the conclusions of M-K trend test – of discharge in gauging station Bela-Podbanske and Vah-Liptovsky Mikulas in November for two time periods (1929/1922–2014, and 1960–2014) are shown.

**Conclusion and discussion**

In this study the average daily discharges from above mentioned water gauges were used (Vah River: 1922–2014, Bela River 1929–2014). These basins were selected according of the homogeneity of the discharge time series. In order to perform the homogeneity analyses of data, two different tests of homogeneity were applied on each series, the standard normal homogeneity test (Alexandersson, 1986) and the Mann-Whitney-Pettit test (Pettit, 1979). Software Anclim (Štěpánek, 2007) was used to perform both tests (Pekárová and Miklánek ed., 2019).

According to the M-K test, The Mann-Kendall nonparametric test (M-K test), which is one of the most widely used non-parametric tests for significant trends detection in time series, results showed a change in the trend at the significance level α=0.05 for both stations in

---

![Figure 4](https://via.placeholder.com/150)

**Fig. 4.** Linear trend of discharges in selected months: a) Bela-Podbanske: time periods 1929–2014 and 1960–2014; months June, September and November, b) Vah-Liptovsky Mikulas: time periods 1922–2014 and 1960–2014, months March, September and November.
Fig. 5. Linear trend of minimum (left figures) and maximum (right figures) discharge characteristics in particular years, a) station Bela-Podbanske, period: 1929–2014; b) station Vah-L. Mikulas, period 1922–2014.

Julian day means: 1=January 01, 30=January 30, –30 is 336 day=December 06.
the analysis of whole periods of measurement (Bela-Podbanske 1929–2014, Vah-L. Mikulas 1922–2014) in the month of November. Figure 6 presents comparison of the long-term trend – as the conclusions of M-K trend test – of discharge in gauging station Bela-Podbanske and Vah-Liptovsky Mikulas in November for two time periods (1929/1922–2014, and 1960–2014). We quantified the variation in average monthly discharges from long-term point of view and analysed the monthly discharges regime at both profiles Bela-Podbanske (1929–2014) and Vah-Liptovsky Mikulas (1922–2014) for the whole selected time periods and for five shorter periods. The mode occurrence of maximum and minimum discharges coincides with the regime discharges in these altitudes. We analysed the slope of trend lines analysis for individual months. This analysis

| Table 3. Results of monthly and extreme discharge M-K trend tests for selected time periods, gauging station Bela-Podbanske (** – level of significance α=0.01, * – level of significance α=0.05, +α=0.1 level of significance) |
|-----------------|-----------------|-----------------|-----------------|
| Discharge       | 1929–2014       | 1960–2014       | 1989–2014       |
| characteristics | Test Z          | Sen’s A slope   | Test Z          | Sen’s A slope   | Test Z          | Sen’s A slope   |
| January         | -0.31           | 0.000           | -0.70           | 0.000           | 0.14            | 0.002           |
| February        | 1.33            | 0.002           | -0.31           | 0.001           | 0.50            | 0.004           |
| March           | 1.13            | 0.002           | -0.07           | 0.000           | 1.21            | 0.007           |
| April           | 0.99            | 0.009           | 0.70            | 0.012           | 1.57            | 0.072           |
| May             | 1.25            | 0.016           | 1.23            | 0.040           | -0.82           | -0.050          |
| June            | -0.19           | -0.002          | -0.50           | -0.012          | -1.18           | -0.064          |
| July            | -0.44           | -0.004          | -0.91           | -0.017          | 0.96            | 0.036           |
| August          | -1.82           | +0.011          | -0.46           | -0.006          | 1.07            | 0.039           |
| September       | -0.40           | -0.002          | 0.36            | 0.004           | -0.75           | -0.025          |
| October         | -0.93           | -0.004          | -0.10           | -0.002          | 0.32            | 0.011           |
| November        | -2.40           | -0.013          | 1.39            | 0.009           | 0.55            | 0.015           |
| December        | -1.92           | +0.005          | 0.38            | 0.002           | -0.07           | -0.003          |
| 1-day max       | 2.95            | +0.005          | 2.11            | 0.000           | 2.11            | 0.003           |
| 3-day max       | 2.73            | +0.002          | 1.96            | 0.000           | 1.96            | 0.009           |
| 7-day max       | 2.62            | **0.002         | 1.78            | +0.000          | 1.78            | +0.008          |
| 30-day max      | 2.36            | *0.003          | 1.53            | 0.000           | 1.53            | 0.007           |
| 90-day max      | 6.08            | 0.001           | 1.25            | 0.000           | 1.25            | 0.008           |
| 1-day max       | 1.01            | 0.046           | 0.43            | 0.000           | 0.43            | 0.098           |
| 3-day max       | 1.42            | 0.040           | 0.14            | 0.000           | 0.14            | 0.020           |
| 7-day max       | 1.60            | 0.037           | 0.00            | 0.000           | 0.00            | 0.004           |
| 30-day max      | 1.89            | +0.021          | -1.07           | -0.020          | -1.07           | -0.046          |
| 90-day max      | 0.99            | +0.007          | -0.75           | -0.000          | -0.75           | -0.017          |

| Table 4. Results of monthly and extreme discharge M-K trend tests for selected time periods, gauging station Vah-Liptovsky Mikulas (** - level of significance α=0.01, * - level of significance α=0.05, +α=0.1 level of significance) |
|-----------------|-----------------|-----------------|-----------------|
| Discharge       | 1922–1940       | 1960–1980       | 1989–2014       |
| characteristics | Test Z          | Sen’s A slope   | Test Z          | Sen’s A slope   | Test Z          | Sen’s A slope   |
| January         | 0.451           | 0.005           | 0.886           | 0.026           | 1.106           | 0.091           |
| February        | -0.793          | -0.011          | 0.537           | 0.018           | 1.534           | 0.123           |
| March           | -0.704          | -0.018          | 1.031           | 0.043           | 2.070           | *0.213          |
| April           | -0.913          | -0.045          | -0.909          | -0.100          | 0.571           | 0.143           |
| May             | -0.591          | -0.047          | -0.494          | -0.070          | -1.035          | -0.299          |
| June            | -0.813          | -0.028          | -1.016          | -0.090          | -0.856          | -0.157          |
| July            | -0.010          | 0.000           | -0.290          | -0.025          | 1.570           | 0.246           |
| August          | -1.381          | -0.042          | -0.552          | -0.032          | 1.338           | 0.199           |
| September       | -0.803          | -0.021          | -0.138          | -0.014          | -0.303          | -0.052          |
| October         | -1.603          | -0.038          | -0.145          | -0.009          | 1.070           | 0.105           |
| November        | -2.546          | *0.075          | -0.073          | -0.010          | 0.749           | 0.100           |
| December        | -1.646          | +0.033          | -0.508          | -0.020          | -0.660          | -0.063          |
| 1-day max       | -0.853          | -0.006          | -0.719          | -0.010          | 3.055           | **0.159          |
| 3-day max       | 0.428           | 0.002           | -0.327          | -0.005          | 2.035           | *0.064          |
| 7-day max       | 0.156           | 0.001           | -0.421          | -0.005          | 2.248           | *0.071          |
| 30-day max      | -0.571          | -0.004          | -0.116          | -0.001          | 2.034           | *0.091          |
| 90-day max      | -0.999          | -0.012          | 0.987           | 0.023           | 2.570           | *0.111          |
| 1-day max       | -1.640          | -0.252          | -0.937          | -0.280          | 0.357           | 0.431           |
| 3-day max       | -0.959          | -0.113          | -1.263          | -0.306          | 0.036           | 0.061           |
| 7-day max       | -0.451          | -0.039          | -1.314          | -0.264          | 0.500           | 0.227           |
| 30-day max      | -0.438          | -0.020          | -1.307          | -0.178          | 0.321           | 0.056           |
| 90-day max      | -0.949          | -0.033          | -1.336          | -0.102          | 0.000           | 0.002           |
gave us the information about monthly discharge trend changes for the whole year and also for different time periods. We analysed trends of several discharge characteristics (minimum and maximum, 1-day, 3-day, 7-day and 30-day minimum, as well as maximum, and day of minimum/maximum discharge occurrence) for shorter and longer time periods. Results showed that according to differences in trends for shorter and longer measurement periods is necessary to analyse the longest series of observations at any station. We aim to process the longest series of data flow and then evaluate their trends. Then we can evaluate the trend changes in the event of changes in the basin (climate change, water management construction, etc.).

The results of such analysis can be helpful in predicting of their development and minimizing their negative impacts on society and the environment (fauna and flora of the river basin). It is important to note that the minimum discharge is one of the characteristics that can define hydrological drought. In future, trend analysis should be linked to the climate change scenarios. Addressing the observed and potential future changes in runoff will require careful planning by water resource managers and policy makers, that should ensure the sustainable development of water management in the area of interest or mitigate the effects of potential drought periods.

Acknowledgements:

This work was supported by the project VEGA 2/0004/19 and results from the project implementation of the “Centre of excellence for integrated flood protection of land” (ITMS 26240120004) supported by the Research & Development Operational Programme funded by the ERDF.

References

Alexandersson H. (1986): A homogeneity test applied to precipitation data. J. Climatol., 6, 661–675.

Blahušiaková, A., Matoušková, A. (2016): Rainfall and runoff regime trends in mountain catchments (Case study area: the upper Hron River basin, Slovakia). J. of Hydrology Hydromech. 63: 3. 183–192.

Burn, D. H., Cunderlik, J. M., Pietroniro, A. (2004): Hydrological trends and variability in the Liard River basin. Hydrological Science Journal, 49(1), 53–68, doi.org/10.1623/hysj.49.1.53.53994.

Demeterová, B., Škoda, P. (2009): Low flow in selected streams of Slovakia. J. Hydrol. Hydromech., 57(1), 55–69.

Falarz, M. (2004): Variability and trends in duration and depth of snow cover in Poland in the 20th century. International Journal of Climatology, 24, 1713–1727.

Franke, J., Goldberg, V., Eichelmann, U., Freydenk, E., Bernhofer, C. (2004): Statistical analysis of regional climate trends in Saxony, Germany. Climate Research, 27, 2004, 145–150, DOI: 10.3354/cr027145.

Fu, G., Chen, S., Liu, C., Shepard, D. (2004): Hydro-climatic trends of the Yellow River basin for the last 50 years. Climatic Change, 65, 2004, 149–178, doi.org/10.1023/B:CLIM.0000037491.95395.bb.

Kundzewicz, Z., Robson, A. (2004): Change detection in hydrological records – a review of the methodology. Hydrological Science Journal, 49(1), 7–20, doi.org/10.1623/hysj.49.1.7.53993.

Gilbert, R. O. (1987): Statistical Methods for Environmental Pollution Monitoring. John Wiley & Sons, Inc., New York.

Hamed, K. H. (2008): Trend detection in hydrologic data: The Mann-Kendall trend test under the scaling hypothesis. Journal of Hydrology, 349 (3–4), 350–363, doi.org/10.1016/j.jhydrol.2007.11.009.

Helsel, D. R., Frans, L. M. (2006): Regional Kendall Test for Trend. Environmental Science and Technology, 40, 2006, 13 p.

Fig. 6. Long-term trend – conclusions of Mann-Kendall trend test for discharge in November. a) Bela-Podhanske, b) Vah-L. Mikulas; whole period (left side figures) and 1960–2014 (right side figures).
Lettenmaier, D. P., Wood, E. F., Wallis, J. R. (1994): Hydroclimatological Trends in the Continental United States, 1948-1988. Journal of Climate, 7, 586–607.
Majerčáková, O., Škoda, P., Danáčová, Z. (2007): Development of selected hydrological and rainfall characteristics for the periods 1961–2000 and 2001–2006 in the High Tatras. Meteorological Jour. (in Slovak), 10(4), 205–210.
Onoz, B., Bayazit, M. (2003): The power of statistical tests for trend detection. Turkish J. Eng. Environ. Sci., 27, 247–251., <http://journals.tubitak.gov.tr/engineering/issues/muh-03-27-4/muh-27-4-5-0206-6.pdf>
Párducí, M. (1947): Fleuves et Rivières. Paris.
Pekárová, P. (2003): Identification of long-term trends and fluctuations of hydrological time series (Part II, Results). Journal of Hydrol. and Hydromech., 51(2), 2003, 97–108.
Pekárová, P., Miklánek, P., ed: Flood regime of rivers in the Danube River basin. IH SAS, Bratislava, CD ROM, 215 pp. + 450 pp. app., ISBN 978-80-89139-43-9
Pettitt A. N. (1979): A non-parametric approach to the changepoint problem. Appl. Stat., 28, 126–135.
Schoner, W., Auer, I., Bohm, R. (2009): Long term trends of snow depth at Sonnblick (Austrian Alps) and its relation to climate change. Hydrological Processes, 23, 2009, 1052–1063, DOI: 10.1002/hyp.7209.
Shahid, S. (2011): Trends in extreme rainfall events of Bangladesh. Theoretical and Applied Climatology, 104, 489–499, DOI: 10.1007/s00704-010-0363-y.
Sonali, P., Nagesh Kumar, D. (2013): Review of trend detection methods and their application to detect temperature changes in India. Journal of Hydrology, 47: 6, 212–227.
Štěpánek P. (2007): AnClim - software for time series analysis (for Windows). Dept. of Geography, Fac. of Natural Sciences, Masaryk University, Brno. 1.47 MB
Viessman, J. R. W., Knapp, J. W., Lewis, G. L, Harbaugh, T. E. (1977): Introduction to hydrology. New York (Harper and Row), 704 p., ISBN0700224971.
Yue, S., Pilon, P., Phinney, B. (2003): Canadian streamflow trend detection: impacts of serial and cross-correlation. Hydrological Sciences Journal, 48(1), 51–64, doi.org/10.1623/hysj.48.1.51.43478.