Trend Detection in Precipitation Data in Climatic Station

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Abstract. Trends and changes in precipitation extremes have been a focus of research over the past decade. Observations show that changes are occurring in the amount, intensity, frequency and type of precipitation. Climate variability has created the need to study subsequent changes in hydroclimatic variables (e.g. rainfall, streamflow and evapotranspiration) to understand the regional effects of climate change. Mainly agricultural activities and water management activities – water supply, urban drainage, and hydraulic structures management are patterned according to rainfall seasonality. Trend detection in precipitation time series is crucial for water resources management. Many researchers all over the word have investigated hydrologic variables trends at various temporal scales. In this paper we investigate the trends in precipitation time series in climatic station Košice, Slovakia in the period 1981–2013. We address the topic of trend detection in precipitation time series combining novel and traditional tools in order to simultaneously tackle the issue of seasonality and interannual variability, which usually characterize natural processes. The analysis proves that, in the case study area, statistically significant trends in precipitation have been undergoing in the last decades, although they have no significant impacts on water resources.

Keywords: precipitation, trend analysis, Mann-Kendall test.

Conference topic: Water engineering.

Introduction

Spatial distribution of average annual precipitation totals in Slovakia points to several regions with relatively low amount of rainfall (Fig. 1). The most extensive region is located within a large part of the Podunajská nížina lowland and in the south of Považie region. Likewise dry, but smaller areas, are also at the far northwest of Záhorie region and also at the boundary of basins Hornádska kotlina and Popradská kotlina, where the values of this precipitation characteristic are less than 550 mm. However less precipitation in Spiš region does not have such a big impact on potential drought, as in the west and southwest regions of Slovakia. The average annual precipitation totals above the 1,500 mm occur in the highest locations of the mountains Malá Fatra, Veľká Fatra, Oravské Beskydy, Nízke Tatry and Tatra Mountains. In peak position of the Tatra Mountains these values reach up to about 2,000 mm. The fields of average monthly precipitation for individual months of the year are affected by specific variations in the annual precipitation regime. This regime is influenced by sentimentality of climate in Slovakia and also by the orientation of the mountain ranges towards the flow of humid air masses bringing precipitation. Contrast between northern and southern regions of Slovakia in the average rainfall is also visible. The average monthly precipitation totals are lowest in January and partially in February, mainly in the Hornádska kotlina basin in Spiš region. Their values do not reach 20 mm in certain locations of these regions. In May and the first two summer months, in the highest mountains of Slovakia, the most exposed areas to precipitation, the average monthly precipitation totals exceed the value of 200 mm. In October and November there are relatively high average monthly precipitation totals mainly in the southern and south-eastern windward mountain slopes, especially in the southern half of central Slovakia. This is related to the above mentioned increased seasonal activity of low pressure centres bringing precipitation from the Mediterranean. In December there is a similar effect in the far northwest of Orava region, associated with a stronger flow of humid air masses from the west respectively northwest. The above mentioned peculiarities are manifested more or less strongly in the fields of average precipitation totals for different seasons (spring, summer, autumn, winter), respectively in the warm half-year (April–September) and a cold half-year (October–March). Average monthly precipitation totals calculated over the period of 30 years are based on the set of individual monthly precipitation totals. The values of this time series may differ significantly in each year. The month of October is the typical example of such an unbalanced variation of monthly precipitation totals in climatic conditions of Slovakia. It's entirely possible that certain precipitation station records minimum monthly total or even no precipitation during October of any particular year while in the following year the October monthly precipitation total at the same station could reach an extraordinary high value. It is caused by the influence of semi-permanent pressure systems in Europe, and is the nature of the weather in Slovakia. This nature of

weather associated with precipitation anomalies can be manifested more frequently in the middle of autumn than in any other months of the year. At the same time, however, it should be noted that the relatively large variability of monthly precipitation totals exist also in other months of the year. In these months, either extremely low or extremely high monthly precipitation totals were registered more frequently in the late 20 and early 21 century than in the previous periods. Values of monthly totals in some cases exceeded even historic extremes, both in minimum and maximum values (SHMI 2015).
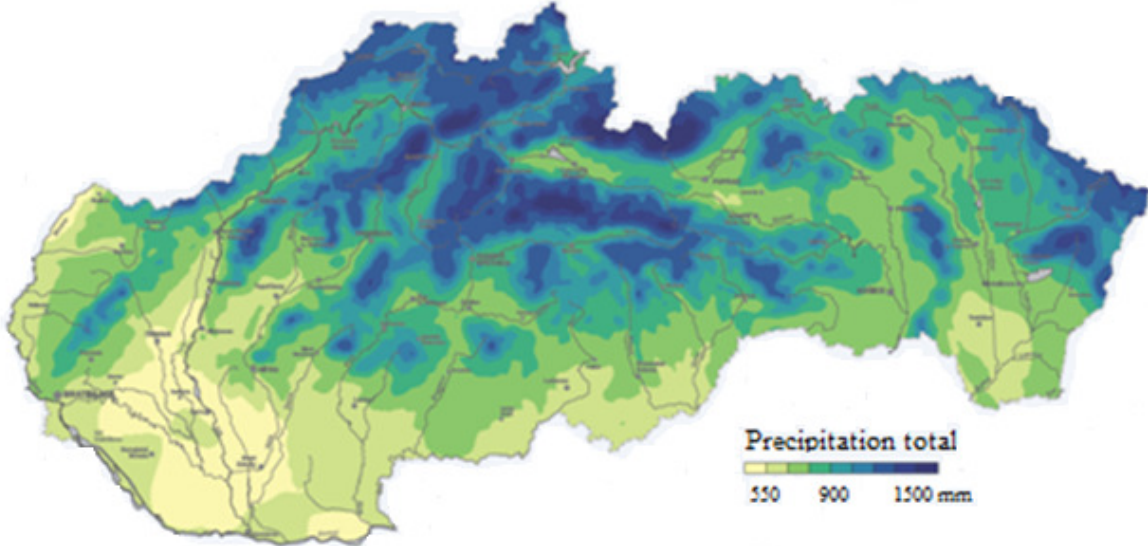

Fig. 1. The average annual precipitation in Slovakia (source: SHMI 2015)

Trend detection in precipitation time series is crucial for planning and designing regional water resources management (Karpouzos *et al*. 2010; Zeleňáková 2009). Many researchers all over the word have investigated hydrologic variables trends at various temporal scales (Burn, Hag Elnur 2002; Lanzante 1996; Lettenmaier *et al*. 1994; Önöz, Bayazit 2003; Partal, Kahya 2006; Sarkar *et al*. 2012; Sayemuzzaman, Jha 2014; Zeleňáková *et al*. 2013, 2014; Zhang *et al*. 2006; Johnes *et al.* 2015).

Methodology

In this paper we investigate the trends in precipitation time series in climatic station Košice, eastern Slovakia in the period of hydrological year from November 1981 to October 2013. We address the topic of trend detection in precipitation time series combining novel and traditional tools in order to simultaneously tackle the issue of seasonality and interannual variability, which usually characterize natural processes.

Mann-Kendall test

We applied the widely used Mann-Kendall test (Mann 1945; Kendall 1975) to the daily precipitation time series to identify trends. Mann-Kendall test is following statistics based on standard normal distribution (Z) calculated following Eq. (1):

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\[2em] 0 & if \quad S = 0 \\[1em] \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \qquad (1)$$

in which

$$S = \sum_{k=}^{n-1}\sum_{k+i}^{n} sgn(x_j - x_k) ; \qquad (2)$$

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$$sgn\left(x_j - x_k\right) = \begin{cases} +1 & if\left(x_j - x_k\right) > 0 \\ 0 & if\left(x_j - x_k\right) = 0; \\ -1 & if\left(x_j - x_k\right) < 0 \end{cases} \tag{3}$$

$$Var\left(S\right) = \left[n\left(n-1\right)\left(2n+5\right) - \sum_{i=1}^{m} t_i\left(t_i-1\right)\left(2t_i+5\right)\right]/18, \tag{4}$$

where: n is the number of data points; m is the number of tied groups (a set of sample data having the same value).

According to this test, the null hypothesis H0 states that the depersonalized data $(x_1, \ldots, x_n)$ is a sample of n independent and identically distributed random variables. The alternative hypothesis H1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \leq n$ with $k \neq j$. The significance level is chosen as $\alpha = 0.05$ and $Z_{\alpha/2}$ is the value of normal distribution function, in this case $Z_{\alpha/2} = 1.95996$. Hypothesis H0 – no trend is if $(Z < Z_{\alpha/2})$ and H1 – there is a trend if $Z > Z_{\alpha/2}$. Positive values of Z indicate increasing trends, while negative values of Z show decreasing trends.

The magnitude of the trend can be assessed by Sen's method (Sen 1968; Theil 1950). Sen's method assumes a linear trend in the time series. The trend slope (b) of all data pairs are calculated following Eq. (5)

$$b = Median\left(\left(x_j - x_k\right)/\left(j-k\right)\right) \tag{5}$$

for $i = 1, 2, \ldots, N$, where x_j and x_k are data values at time j and k $(j > k)$, respectively and N is a number of all pairs x_j and x_k.

A positive value of b indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

All mathematical relationships (1)–(5) were programmed in Visual Basic in Microsoft Excel 2003.

Moving Average over Shifting Horizon

We used also a novel tool to be applied in time series data analysis, named Moving Average over Shifting Horizon (MASH) (Anghileri *et al.* 2014). It allows simultaneously investigating the seasonality in the data and filtering out the effects of interannual variability, thus facilitating trend detection. The seasonal pattern is represented by the 365 values of daily precipitation over the year. We consider data over consecutive days in the same year, and over the same days in consecutive years. However, the horizon of consecutive years is progressively shifted ahead to allow for any trend to emerge. The MASH is thus a matrix (Anghileri *et al.* 2014):

$$MASH = \begin{bmatrix} \mu_{1,1} & \cdots & \mu_{1,Nh} \\ \vdots & \ddots & \vdots \\ \mu_{365,1} & \cdots & \mu_{365,Nh} \end{bmatrix} \tag{6}$$

where: the columns are the daily precipitation computed over N different horizons. More precisely $\mu_{t,h}$ is the daily precipitation on the t-th day of the year in the h-th horizon, computed as

$$MASH = \underset{y \in [h, h+Y-1]}{mean}\left[\underset{d \in [t-w, t-w]}{mean} x_{d,y}\right] \tag{7}$$

where $x_{d,y}$ is the precipitation on the d-th day of the y-th year of the time series, $2w+1$ is the number of days and Y is the length (years) of the shifting horizon. The number N_h of horizons is univocally related to Y by the equation $N_h = N_y - Y + 1$, where N_y is the number of years in the original time series.

Results

We describe how to combine the MASH with statistical trend detection tests, like the Mann–Kendall test, and Sen's method, to quantify the trends occurring in different time series

Figure 2. provides a visual representation of the MASH of precipitation with $w = 21$ days and $Y = 1$ year. Since the original time series covers a period of $N_y = 33$ years, from 1981 to 2013, the MASH is composed of $N_h = 32$ precipitation patterns. The line labelled as $h = 1$ is the moving daily precipitation computed over the horizon 1981–1982, the line labelled as $h = 2$ is the moving daily precipitation over 1982–1983, etc. Older horizons are plotted with blue lines and more recent horizons with red lines. The results in Fig. 2 are consistent with the trends reported in Fig. 3 – a precipitation decrease in April, the increase in all other months and the significant increase in January detected by the Mann–Kendall test. These results were obtained using $w = 21$. The choice of this value comes from the following considerations. Parameter w filters out the day-to-day variability: small values may be insufficient to smooth out such variations and let the seasonal pattern emerge, on the other hand very large values of w may smooth out also seasonal variations. In our case study, manual tuning proved that $w = 21$ days is a reasonable compromise, although slightly smaller or larger values provide qualitatively similar results (not shown). Parameter Y filters out the year-to-year variability.
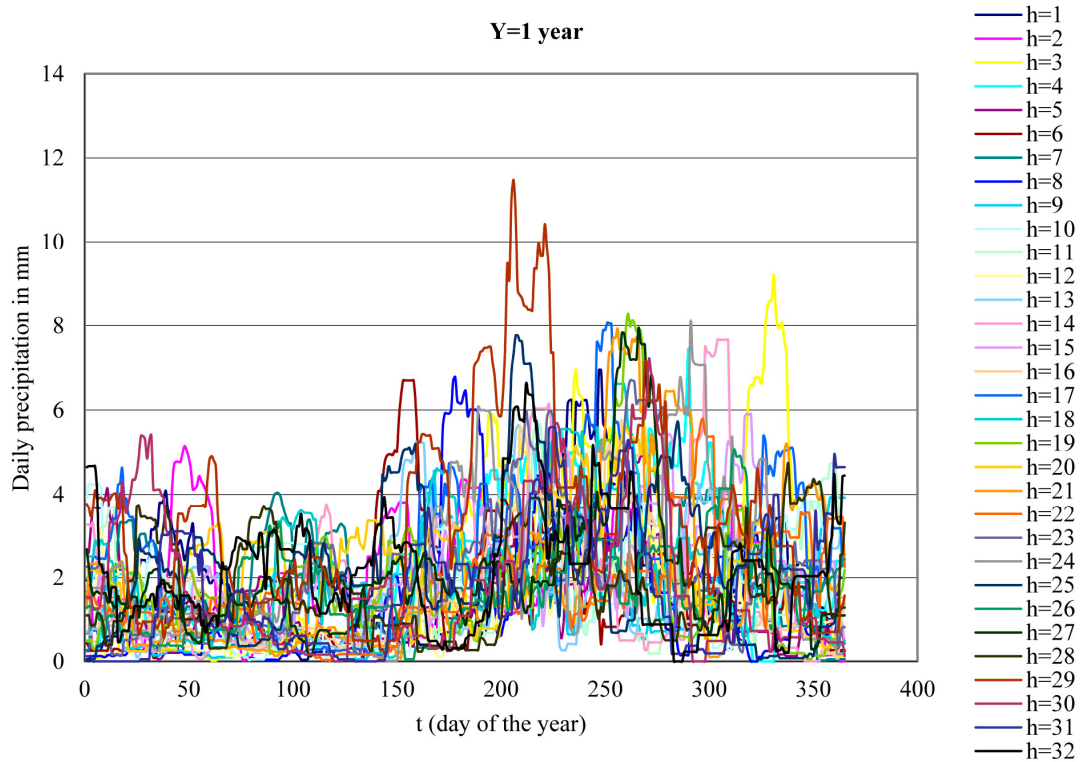

Fig. 2. MASH of daily inflows ($w = 21$ days, $Y = 1$ year, time horizon 1981–2013). The line labelled as $h = 1$ is the moving average computed over the horizon 1981–1982, the line labelled as $h = 2$ is the moving average computed over 1981–1983, etc.
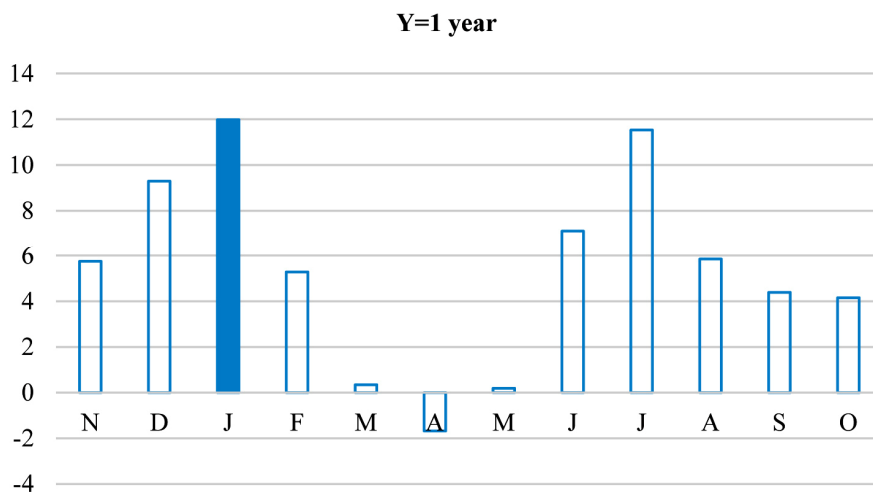

Fig. 3. Sen's slope of the Mann-Kendall applied MASH for $Y = 1$ year

Conclusions

There are two distinct types of regimes in the annual precipitation regime of Slovakia, these are the one-modal and the bi-modal regime. The frst is typical for the northwestern, northern and northeastern regions of Slovakia, where the rainfall maximum occurs dur- ing the peak summer period. Afterwards, the precipitation declines and the rainfall has its minimum in the second half of the winter. The second type of annual precipitation regime is characteristic of the rest of the territory. It is clearly refected in southwestern Slovakia, in the south of Ponitrie region, Pohronie region and in the southeast Slovakia. It's linked with the activity of the Mediterranean low-pressure areas, which causes increase of rainfall in the second half of the spring and during the second half of the autumn (SHMI 2015).

The plotted MASH allows however to have a concise and informative representation of how the precipitation pattern has changed in time. The analysis proves that, in the case study area, statistically significant trends in precipitation have been undergoing in the last decades, although they have no significant impacts on water resources.

Funding

References

Anghileri, D.; Pianosi, F.; Soncini-Sessa, R. 2014. Trend detection in seasonal data: from hydrology to water resources, *Journal of Hydrology* 511: 171–179. https://doi.org/10.1016/j.jhydrol.2014.01.022

Burn, D. H.; Hag Elnur, M. A. 2002. Detection of hydrologic trends and variability, *Journal of Hydrology* 255: 107–122. https://doi.org/10.1016/S0022-1694(01)00514-5

Johnes, J. R.; Schwartz, J. S.; Ellis, K. N.; Hathaway, J. M.; Jawdy, C. M. 2015. Temporal variability of precipitation in the Upper Tennessee Valley, *Journal of Hydrology: Regional Studies* 3: 125–138. https://doi.org/10.1016/j.ejrh.2014.10.006

Karpouzos, D. K.; Kavalieratou, S.; Babajimopoulos, C. 2010. Trend analysis of precipitation data in Pieria region (Greece), *European Water* 30: 31–40.

Kendall, M. G. 1975. *Rank correlation measures*. Charles Griffin, London.

Lanzante, J. R. 1996. Resistant, robust and non-parametric techniques for the analysis of climate data: theory and examples, including applications to historical radiosonde station data, *International Journal of Climatol*ogy 16(11): 1197–1226. https://doi.org/10.1002/(SICI)1097-0088(199611)16:11<1197::AID-JOC89>3.0.CO;2-L

Lettenmaier, D. P.; Wood, E. F.; Wallis, J. R. 1994. Hydro-climato-logical trends in the continental United States, 1948–88, *Journal of Climate* 7: 586–607. https://doi.org/10.1175/1520-0442(1994)007<0586:HCTITC>2.0.CO;2

Mann, H. B. 1945. Non-parametric tests against trend, *Econometrica* 13: 245–259. https://doi.org/10.2307/1907187

Önöz, B.; Bayazit, M. 2003. The power of statistical tests for trend detection, *Turkish Journal of Engineering and Environmental Sciences* 27: 247–251.

Partal, T.; Kahya, E. 2006. Trend analysis in Turkish precipitation data, *Hydrological Processes* 20: 2011–2026. https://doi.org/10.1002/hyp.5993

Sarkar, A.; Singh, R. D.; Sharma, N. 2012. Climate variability and trends in part of Brahmaputra river basin, in *India Water Week 2012 – Water, Energy and Food Security: Call for Solutions*. New Delhi.

Sayemuzzaman, M.; Jha, M. K. 2014. Seasonal and annual precipitation time series trend analysis in North Carolina, United States, *Atmospheric Research* 137: 183–194. https://doi.org/10.1016/j.atmosres.2013.10.012

Sen, P. K. 1968. Estimates of the regression coefficient based on Kendall's tau, *Journal of the American Statistical Association* 63: 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

SHMI. 2015. *Climate atlas of Slovakia*. Banská Bystrica: Slovak Hydrometeorological Institute. 228 p.

Theil, H. 1950. A rank-invariant method of linear and polynomial regression analysis, *Nederlandse Akademie Van Wetenschappen Series A* 53: 386–392.

Zeleňáková, M. 2009. Preliminary flood risk assessment in the Hornád watershed, in *River Basin Management 5*, 7.-9.9.2009 Ramla Bay Resort, Malta. Southampton: Wessex Institute of Technology, 15–24. ISBN 9781845641986. https://doi.org/10.2495/RM090021

Zeleňáková, M.; Gargar, I.; Purcz, P. 2013. Evaluation of hydrological series in Libya, in *SGEM 2013: 13th International Multidisciplinary Scientific Geoconference: Water resources, forest, marine and ocean ecosystems: conference proceedings*, 16–22 June 2013, Albena, Bulgaria. Albena: STEF92 Technology Ltd., 125–132.

Zeleňáková, M.; Purcz, P.; Soľáková, T.; Simonová, D; Ondrejka Harbuľáková, V. 2014. Trends in minimal stream flows at eastern Slovakia, in *Environmental Engineering 2014: the 9th International Conference: selected papers*, 22–23 May 2014, Vilnius, Lithuania. Vilnius: Gediminas Technical University, 1–7.

Zhang, Q.; Liu, C.; Xu, C. Y.; Xu, Y.; Jiang, T. 2006. Observed trends of annual maximum water level and streamflow during past 130 years in the Yangtze River basin, China, *Journal of Hydrology* 324(1): 255–265. https://doi.org/10.1016/j.jhydrol.2005.09.023