Seasonal and spatial investigation of trends in precipitation in Slovakia

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Abstract: This paper presents the results of trend analysis applied to monthly precipitation data in Slovakia for the hydrological year (from November to October). Slovakia belongs in the northern moderate climatic zone. There are four seasons during the year – winter, spring, summer and fall. The weather in Slovakia is quite changeable due to the influence of dry continental air from the north and humid ocean air from the west. The topography of Slovakia is very diverse, and altitude is an important factor affecting the temperature and precipitation. The weather is usually warmer in the lowlands than in the mountains. The Mann–Kendall non-parametric test coupled with Sen’s slope was applied to identify the significant long-term climatic trends, as well as the magnitude of those trends. Mainly increasing trends in the investigated variable were found.

Key words: precipitation, trend analysis, Mann Kendall test, Sen estimator

1. INTRODUCTION

In recent years, a number of studies have been published focusing on the trends in precipitation in Europe as well as worldwide. Tomozeiu et al. (2000) examined the spatial and temporal variability of summer precipitation in northern Italy. They found an increasing trend with significant upward shift around 1962 at almost all analysed stations. In contrast Buffoni et al. (1999) identified a decreasing trend in annual precipitation series all over Italy, although it was statistically significant only in the central south. Karpouzos et al. (2010) investigated the temporal variability of precipitation in the Prieria region, located in northern Greece. A downward trend, even though not statistically significant, was identified in the study area, mainly in spring. A comprehensive review of the potential impacts on climate is provided by the Intergovernmental Panel on Climate Change (IPCC, 2012).

Hydroclimatic time series in Slovakia have been investigated in various studies such as Lapin et al. (2001); Gaál (2005); Kriegerová and Kohnová (2005); Parajka et al. (2009); Zelenakova et al. (2012).

In Slovakia, according to the Slovak Hydrometeorological Institute (SHMI, 2015), the average annual precipitation ranges from less than 500 mm in Galanta, Senec and the eastern part of the Žitný Island (south-west part of the country) to about 2 000 mm in the High Tatras (Zbojnícka Hut 2130 mm) (north part of the country). Relatively low rainfall is found in “the rain shadow of the mountains”. For this reason, the basins in the Spiš region are relatively dry, as they are protected from the southwest to the northwest by the High and the Low Tatra mountains and the Slovak Ore Mountains to the south. The Danubian Plain (in the south) is one of the driest areas of Slovakia.

During the year the proportion of precipitation in the summer period (June-August) is about 40%, 25% in the spring, in fall 20% and 15% in winter (thus there is a clear predominance of
rainfall in the summer). The rainiest month is usually June or July, and the least rainfall is from January to March. There is snowfall on the plains from October to April and in locations from 1500 to 2000 meters above sea level throughout the year, so also in the summer months. An extremely strong downpour of 228.5 mm fell on 07/12/1957 in Skalka on Ipeľ.

The objective of this study is to investigate precipitation trends at climatic stations in Slovakia. Annual, half-year, seasonal and monthly trends in precipitation were detected using the Mann-Kendall statistical test.

2. MATERIAL AND METHODS

The daily data for trend analysis were obtained from the Slovak Hydrometeorological Institute (SHMI) in Košice, Slovakia. The network of rain gauge stations over the Slovak Republic is depicted in Figure 1.

![Figure 1. Evaluated rain gauge stations in Slovakia. (SHMI, 2015)](image)

There are 634 rain gauging stations operated by SHMI. For evaluation of trend analysis over the whole of Slovakia we gathered data from 487 stations during the period from 1981 to 2013. We do not have complete data series from the rest of the stations. The selected stations also had some missing data, which were filled in based on linear regression analysis. For that purpose and for each gap in a given rain gauge R1, a nearby rain gauge R2 was identified, provided that: i) R1 and R2 had at least 10 years of simultaneous records in the month where the gap occurred; ii) the correlation coefficient, cc, between the two monthly historical series was the highest from all the possible nearest stations fulfilling condition i) and necessarily higher than 0.7 (cc ≥ 0.7).

Trend analysis for a hydrological time series is an important and popular tool for better understanding the effects of climate variation and anthropogenic activities. Many tests for the detection of significant trends in meteorological time series can be classified as parametric and non-
parametric methods. The Mann–Kendall (MK) test (Kendall, 1975; Mann 1945) is a rank-based non-parametric test for assessing the significance of a trend, and has been widely used in hydro-meteorological trend detection studies (Lettenmaier et al., 1994; Burn, 2002; Partal, Kahya, 2006; Sayemuzzaman and Jha, 2014; Johnes et al., 2015).

In this study the non-parametric Mann-Kendall test is used for the detection of the trend in a time series. This test applies statistics based on standard normal distribution (Z), using Eq. (1).

\[
Z = \frac{S - 1}{\sqrt{Var(S)}} \text{ if } S > 0 \\
0 \quad \text{ if } S = 0 \\
\frac{S + 1}{\sqrt{Var(S)}} \text{ if } S < 0
\]  

(1)

\[
S = \sum_{k=1}^{n-1} \sum_{i=k}^{n} \text{sgn}(x_j - x_i)
\]  

(2)

\[
\text{sgn}(x_j - x_i) = \begin{cases} +1 & \text{ if } (x_j - x_i) > 0 \\ 0 & \text{ if } (x_j - x_i) = 0 \\ -1 & \text{ if } (x_j - x_i) < 0 \end{cases}
\]  

(3)

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

(4)

where n is the number of data points, and m is the number of tied groups (sets of sample data having the same value).

According to this test, the null hypothesis H0 states that the depersonalized data \((x_1, \ldots, x_n)\) form 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 the normal distribution function, in this case \(Z_{0.025} = 1.95996\). 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.

In Mann Kendall test the sign of Z must not be sufficient for trend definition (detection). In case a trend is detected, the existence of autocorrelation in the series will affect the result. The existence of serial autocorrelation will increase the probability of finding a significant trend at the end of the test even if there is no trend (Önöz and Bayazit, 2003; Bayazit and Önöz, 2007; Haktanir and Citakoglu, 2015). The serial autocorrelations of stations was performed in the presented study following Salas et al. (1980), who refer to Andersen (1941).

The magnitude of the trend was determined using Sen’s estimator. Sen’s method assumes a linear trend in the time series and has been widely used for determining the magnitude of trends in hydro-meteorological time series (Sen, 1968). In this method, the median of all possible slopes of the straight lines formed by combining any two points of the \(n\) number of observations is taken as the prospective slope of the trend line, as defined below:

\[
\beta = \text{Median} \left( \frac{x_j - x_k}{j - k} \right)
\]  

(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 the number of all pairs \(x_j\) and \(x_k\). A positive value of \(\beta\) indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.
In this study, a programme developed in Microsoft Excel was used to generate the algorithm of the non-parametric method.

The surface interpolation technique was used to prepare a spatial precipitation data map over Slovakia from the point precipitation measuring stations within the Arc-GIS framework. For spatial distribution of trends in maps, contours are generated using an inverse-distance-weighted (IDW) algorithm with a power of 2.0, 12 grid points, and variable radius location.

Numbers of stations with positive or negative trends at the 95% confidence level are shown in Figure 2, presented as annual and seasonal time scale precipitation data series for the period 1981–2013. The spatial distribution of the magnitude of trends is depicted in Figs. 3–6 for separate seasons.

3. RESULTS

Out of a total of 487 rain-gauging stations, on 93 of them a statistically significant increasing trend, and on only 2 of them a statistically significant decreasing trend has been detected by the Mann–Kendall test at a critical probability level of 5%. That means the rest of the 393 stations, which constitute 81% of all the recorded 33-year-long (from 1981 through 2013) precipitation series, cannot be considered to have ‘trend’ in statistical sense (Fig. 2). Significant decreasing trends were found only in the north part of the study area, near the Orava water reservoir, whereas significant positive trends are identified throughout the all area.

![Graph showing numbers of gauging stations with overall significant positive and negative trends (significant confidence level ≥ 95%) in seasonal and annual time scales.]

Figures 3-6 present the magnitude of trend in precipitation time series in the Slovak Republic.

The Mann–Kendall non-parametric statistical test found much higher numbers of stations with significant increasing trends (77 of 487 stations, 16%) than significant decreasing trends (only 3 stations, 1%) in winter (Fig. 2) at 95% confidence level. Significant negative trends were again found in the north part of the country (Fig. 3).

The Mann–Kendall test found significantly increasing trends in 3% of the stations (16 of 487 stations) in spring (Fig. 2). A significant decreasing trend was not detected (Fig. 2).

Summer precipitation trends show the same nature compared with those of winter and spring, although the significantly increasing trends in precipitation are most obvious in the summer at the gauging stations in Slovakia. In this case, 161 (33%) stations show positive and again none station
shows significantly decreasing trend (Fig. 2). Summer precipitation trend magnitude increased in almost the whole of Slovakia in summer (Fig. 5).

The fall precipitation series demonstrated neither significant increasing nor significant decreasing trends over the study area (Fig. 2). The magnitude of the trends at 95% confidence level can be distinguished in Figure 6 all around the country.

Figure 3. Spatial distribution of precipitation trends (significant confidence level ≥ 95%) in winter.

Figure 4. Spatial distribution of precipitation trends (significant confidence level ≥ 95%) in spring.
4. CONCLUSION

The Intergovernmental Panel on Climate Change provides a comprehensive review of the potential impacts on hydrological variables of human-induced climate changes. It states that such changes are likely to increase runoff in the higher latitude regions because of increased precipitation; moreover, flood frequency is expected to change in some locations and the severity of
drought events could also increase as a result of the changes in both precipitation and evaporation. Observations show that changes are occurring in the amount, intensity, frequency and type of precipitation.

The Mann-Kendall test coupled with Sen’s slope was applied to identify the significant trends, as well as the increasing or decreasing trends and the magnitude of those trends. In the presented research we found some coincidence with the rainiest period, the summer season, although the most decreasing trends were associated with the autumn season, which is a little different from the previous studies (SHMI, 2015).

The application of trend detection in Slovakia resulted in the identification of a few significant increasing trends in precipitation. Temporal differences were noted in the occurrence and the direction of trends as a result of climatic variability. Spatial differences in the trend results can be expected to occur as a result differences in the country characteristics. Slight decrease in precipitation was detected in the fall, while all other seasons showed increasing trends in precipitation. This paper develops a full picture of recent precipitation trends using gauge station data gathered throughout Slovakia, which should be of interest for agriculture and water management.

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