Analysis of trends in precipitation time series in selected precipitation stations in eastern Slovakia

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Abstract. One of the most important aspects of climate change is the time distribution of precipitation and its historical changes. In this study, trend analysis of annual precipitation, daily maxims and days without precipitation in three precipitation stations in eastern Slovakia is presented. These are stations Poprad, Košice, and Kamenica nad Cirochou. Individual trends are compared and evaluated. Significant positive trend was observed in maximum daily precipitation in Kamenica nad Cirochou station and in total annual precipitation in Poprad station. Moderate positive trend was observed in maximum daily precipitation in Poprad station and number of days without precipitation in Kamenica nad Cirochou station. No trends were observed in Kosice station.

1. Introduction
Precipitation, and its duration, intensity and frequency are very important in urban hydrology, for example in designing of sewerage or drainage system in cities [1]. Increasing of extreme precipitation is the motivation to study the relationship of extreme precipitation in time. Extreme precipitation events are responsible for river floods and flash floods. High intensity precipitation over short time scale can cause flash flooding and continuous heavy precipitation can cause river flooding [2]. Simulation of GCMs (General Circulation Models), indicates an increase in extreme daily precipitation events in a global [3, 4] and also in regional scale [5, 6]. It is recognized, that changes in daily precipitation regimes are dependent on local factors. On the other hand, there are some studies about the increasing frequency of wet days and increased total precipitation during the heaviest events [7], but there are not a lot of studies about this fact, because high quality data is necessary.

The study of trends in daily intensity of precipitation in Italy from 1951 to 1996 shows that the trend for the number of wet days in the year is significantly negative throughout Italy. In some areas, there is also tendency to an increase of precipitation intensity. The analysis of the evolution of the precipitation events shows that the positive trend of the heaviest events starts in the 1970s [8]. Daily precipitation analysis of a dense data set in the western Mediterranean basin (Valencia Region, eastern coast of Spain), during the second half of the 20th century, indicates that the annual precipitation trend depends on the trend of a very few rainy days. Spatial variability found between annual and daily precipitation trends suggests that annual precipitation trends could depend on local factors that affect extreme events [9]. In northern China region, slightly decreasing trend in daily precipitation from 1956-2000 were observed.
but on the other hand, significant decrease in the number of rainy days and increasing of precipitation events with high intensity were observed [10]. In Romania, the climate has become wetter, but there is decreasing in the total number of precipitation days, and a dominant increasing trend for the number of days with heavy precipitation [11]. The study of trends in daily precipitation over Georgia proved, that the contribution of very heavy and extremely heavy precipitation to total precipitation increased between 1971 and 2010, whereas the number of wet days decreases in Georgia [12].

There are not many studies in that field of study in Slovakia. The first analysis of daily precipitation data in Slovakia was done by Dub in 1950s [13]. The analysis of time series of daily precipitation at selected places in the highest part of the Western Carpathians presents results of the precipitation data for a period 1961–2010. Significant increase of the number of days with daily precipitation 40–60 mm was revealed [14]. The region-of-influence (ROI) method was used for the frequency modelling of heavy precipitation events in Slovakia, where Slovakia was divided into three regions based on the conditions of precipitation [15]. In this study, the trend analysis of selected precipitation parameters in rain station Poprad, Košice and Kamenica nad Cirochou is done.

2. Materials and methods

2.1. Study area

The study area is situated in the eastern part of Slovakia. The location of each precipitation station (Poprad, Košice and Kamenica nad Cirochou) is shown in Figure 1. Poprad city is situated in western part of eastern Slovakia in altitude of 672 m close to the highest mountains of Slovakia, the High Tatras. Climate in this city is affected by topography of the terrain [16]. Košice is city situated in central part of eastern Slovakia near Hornád river in altitude of 208 m, and Kamenica nad Cirochou is situated in eastern part of eastern Slovakia in altitude of 178 m [17].

Figure 1. Location Poprad, Košice and Kamenica nad Cirochou precipitation stations in Slovakia.

Data used for this study consist of daily precipitation data in each station for period of 68 years from 1951 to 2018. These data were obtained from the Slovak Hydrometeorological Institute, regional center Košice. There are no missing data in datasets, precipitation from all days are included. There are a values of daily precipitation data from 7:00 AM to 7:00 AM next day. From daily precipitation data, the annual
precipitation value for each station, number of days without precipitation in each year and maximum daily precipitation in each year was gained and analyzed.

2.2. Data and methodology
There are many statistical methods for data analysing and evaluation. The most useful is the nonparametric Mann-Kendall test. This analysis was carried out for statistical data from mentioned stations. First of all, it was important to find some basic statistical characteristics of the entry statistical data files, especially mean, total, maximum or minimum values.
For trend analysis of time series, Mann-Kendall test was used. A statistical test of the hypothesis is a procedure which is used to find out whether we may “not reject” (“accept”) the hypothesis, that is, act as though it is true, or whether we should “reject” it, that is, act as though it is false. The Mann-Kendall test is a non-parametric statistical test. The data must be ordered chronologically in terms of one or more criteria. This test is based on the calculation of a special statistical value S [18]. All calculations, both of the basic characteristics of the entry data and of the testing of the samples were done using XLSTAT software.

3. Results and discussion

3.1. Basic statistical analysis
Time series of each parameter of precipitation are shown in next graphs (Figure 2, Figure 3 and Figure 4). In the Figure 2 there is time series of total annual precipitation for each station. Time series shows high variability. Average annual precipitation during last 68 years in Poprad is 601.70 mm (maximum is 997.50 mm in 2010 and minimum is 413.50 mm in 1986), in Košice is 614.70 mm (maximum is 958.90 mm in 2010 and minimum is 418.90 mm in 1986) and in Kamenica nad Cirochou is 723.60 mm (maximum is 1089.10 mm in 2010 and minimum is 399.90 mm in 1961). Total precipitation for 68 years was 40 916.40 mm in Poprad, 41 799.50 mm in Košice and 49 204.00 mm. From these results it’s obvious, that Kamenica nad Cirochou is the rainiest locality and Poprad is the locality with lowest precipitation. Kamenica nad Cirochou is also station with the greatest difference between maximum and minimum observed daily precipitation.

![Figure 2. Total annual precipitation from 1951 to 2018 in mm.](image-url)
The time series of number of days without precipitation in a year is shown in the Figure 3. The highest number of days without precipitation during the year is in Košice. During last 68 days, there was average 210.20 days without precipitation in Poprad, 219.90 days without precipitation in Košice and 203.40 days without precipitation in Kamenica nad Cirochou. In Poprad, maximum days without precipitation was 242 days in 2011 and minimum was 183 days in 1965. In Košice, maximum days without precipitation was 254 days in 2003 and minimum was 176 days in 1970. In Kamenica nad Cirochou, maximum days without precipitation was 243 days in 1953 and minimum was 161 days in year 1958.

![Figure 3. Days without precipitation for each year from 1951 to 2018.](image)

Figure 3. Days without precipitation for each year from 1951 to 2018.

The time series of maximum daily precipitation in each year is shown in Figure 4. The maximum daily precipitation 110.50 mm was recorded in Košice in 1963. In Poprad, it was 79.30 mm in 1996 and in Kamenica it was 85.50 mm in 2007. Maximum daily precipitation is also very variable in each year, but from the Figure 4 it seems, that from 1985 there are higher values of maximum daily precipitation.

![Figure 4. Maxims of daily precipitation from 1951-2018 for each year in mm.](image)

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3.2. Trend analysis
The Mann-Kendall trend test was used for trend analysis in time series of total annual precipitation, number of days without precipitation and maximums of daily precipitation in Poprad, Košice and
Kamenica nad Cirochou. This test is based on null hypothesis H0 and alternative hypothesis Ha. Null hypothesis H0 is, that there is no trend in the series and alternative hypothesis Ha is that there is a trend in the series. There are two important parameters in that test, its Kendall’s tau and p-value. When Kendall’s tau is negative, it means decreasing trend and when it is positive, it means increasing trend in time series. When the computed p-value is lower than the significance level alpha=0.05, null hypothesis H0 can be rejected, and the alternative hypothesis Ha can be accepted – there is a trend in time series. When the computed p-value is greater than the significance level alpha=0.05, hypothesis H0 can’t be rejected – there is no trend in time series. We can use also modified greater value of alpha=0.30 for comparing with p-value. Modified Mann-Kendall test can be also used. When p-value is between 0.05 and 0.30, there is a moderately positive/negative trend, when p-value is between 0.30 and 0.50, there is a slightly positive/negative trend in time series, and when p-value is greater than 0.50, there is no trend in time series [19]. The results of calculations of a possible existence of the trend in total annual precipitation, number of days without precipitation and daily maximums using the Mann-Kendall test at all three precipitation stations are presented in Table 1.

Table 1. Results of trend analysis using Mann-Kendall test.

|              | Total annual precipitation | No. of days without precipitation | Maximum daily precipitation |
|--------------|----------------------------|-----------------------------------|-----------------------------|
|              | Kendall’s tau = 0,167      | Kendall’s tau = 0,19              | Kendall’s tau = 0,107       |
| Poprad       | p-value = 0,045            | p-value = 0,828                   | p-value = 0,198             |
|              | SIGNIFICANT                | NO TREND                          | MODERATELY TURNING          |
| Košice       | Kendall’s tau = -0,008     | Kendall’s tau = 0,031             | Kendall’s tau = -0,011      |
|              | p-value = 0,928            | p-value = 0,719                   | p-value = 0,895             |
|              | NO TREND                   | NO TREND                          | NO TREND                    |
| Kamenica nad | Kendall’s tau = 0,042      | Kendall’s tau = 0,096             | Kendall’s tau = 0,228       |
| Cirochou     | p-value = 0,619            | p-value = 0,255                   | p-value = 0,006             |
|              | NO TREND                   | MODERATELY TURNING                | MODERATELY TURNING          |

There have been detecting significant positive trend in total annual precipitation in Poprad station and also in maximum daily precipitation in Kamenica station. Moderately positive trend has been detecting in number of dry days (days without precipitation) in Kamenica station and also in maximum daily precipitation in Poprad. In Poprad station there is no trend in dry days. From these results it’s obvious, that there is increase of extreme precipitation events, which may also cause an increase of total annual precipitation. There is no trend in precipitation in Košice station. In Kamenica station, there is also increase of extreme precipitation events, because we can see that there is positive trend in number of dry days, but on the other hand there is no trend in total annual precipitation, which means, that the same amount of annual precipitation is divided into fewer rainy (wet) days in year. This is also evident from the proven significant increasing (positive) trend in maximum daily precipitation.

4. Conclusion
The paper presents the statistical analysis of daily precipitation of 68 years (1951-2018) in three precipitation stations in eastern Slovakia. These are stations Poprad, Košice and Kamenica nad Cirochou. In the paper, statistical analysis of total annual precipitation, number of days without precipitation in year (dry days) and daily maximum precipitation in year was done. Time series plots were made and average, maximum and minimum values was found. Highest value of total annual precipitation is in Kamenica nad Cirochou station, where average total annual precipitation is 723.60 mm. Greatest maximum annual precipitation was also measured in Kamenica nad Cirochou, it was 1089.10 mm. The lowest average annual precipitation was measured in Poprad station, where it was 601.70 mm. this is because of the location of Poprad in the rain shadow between mountains high Tatras
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and Low Tatras. The average number of days without precipitation is from 203.40 days in Kamenica nad Cirochou to 219.90 days in Košice. The highest daily precipitation during last 68 years was in Košice and it was 110.50 mm in one day on 13.8.1963. In next part of this paper, the Mann-Kendall trend test was used for trend analysis in time series of total annual precipitation, number of days without precipitation and maximums of daily precipitation in Poprad, Košice and Kamenica nad Cirochou. The results show, that there is increase in extreme precipitation events in Poprad station and in Kamenica nad Cirochou station. In Poprad station, there was observed also increase of total annual precipitation. Increasing of number of extreme precipitation events can cause the floods, but on the other hand also dry seasons, because of irregular precipitation distribution in time.

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