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Long-Term Precipitation Trends in Eastern Slovakia

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Authors' contributions

This work was carried out in collaboration between all authors. Author MZ designed the study, managed the literature searches and managed the analyses of the study. Author PP performed the statistical analysis. Author HH managed the data for research from Slovakia. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

The objective of this study was to investigate precipitation trends in climatic stations in eastern Slovakia. We investigated 20 climatic stations in Slovakia. The studied period was from 1981 to 2010. Monthly precipitation trends were detected by nonparametric Mann-Kendall statistical test. Positive trends of annual as well as monthly precipitation were found in the analyzed rainfall gauging stations in eastern Slovakia. March was observed to have the highest decreasing trends. All other months displayed mostly increasing trends. In quartile research mostly the summer period shows positive trends in precipitation. In conclusion, Slovakia has an increasing trend of precipitation time series.

Keywords: Monthly precipitation data; mann-kendall test; Slovakia; climatic stations; trend.

1. INTRODUCTION

Climatic change is considered likely to increase runoff in the higher latitude regions because of increased precipitation on the other hand flood frequencies are expected to change also in

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some locations and the severity of drought events could increase as a result of those changes in both precipitation and evaporation. In all these considerations 'the issue' then becomes the effect of global warming and its impacts on the environment and water resources in particular. The Intergovernmental Panel on Climate Change [1] provides a comprehensive review of the potential impacts on climate. IPCC studies suggests an increase in the probability of occurrence of more frequent droughts, as well as floods, in the Atlantic Ocean and Caribbean Sea, the Mediterranean Sea, and the Indian and Pacific Oceans. Observations show that changes are occurring in the amount, intensity, frequency and type of precipitation. Pronounced long-term trends from 1900 to 2005 have been observed in precipitation amount in some places: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia. For most of North America, and especially over high-latitude regions in Canada, annual precipitation has increased during the 105-year period. The primary exception is over the southwest USA, northwest Mexico and the Baja Peninsula, where the trend in annual precipitation has been negative (1 to 2% per decade) as drought has prevailed in recent years. Across South America, increasingly wet conditions were observed over the Amazon Basin and southeastern South America, including Patagonia, while negative trends in annual precipitation were observed over Chile and parts of the western coast of the continent. Widespread increases in heavy precipitation events have been observed, even in places where total amounts have decreased. These changes are associated with increased water vapor in the atmosphere arising from the warming of the world's oceans, especially at lower latitudes. There are also increases in some regions in the occurrences of both droughts and floods [2].

Several studies have given a great deal of attention to the potential impacts of climatic change and variability in several fields at international level. Trend analysis for meteorological time series is an important and popular tool for better understanding the effects of climate variation [3].

Many tests for the detection of significant trends in climatic time series can be classified as parametric and non-parametric methods [4,5]. Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. In comparison, non-parametric trend tests require only that the data be independent and can tolerate outliers in the data. On the other hand, they are insensitive to the type of data distribution [5,6].The Mann–Kendall (MK) test Kendall [7]; Mann [8] is a rank-based nonparametric test for assessing the significance of a trend, and has been widely used in hydro-meteorological trend detection studies [8]. The Mann-Kendall (MK) test is example of non-parametric tests that are applied for the detection of trends in many studies e.g. [3,4], [5,6,9-17]. Recent studies of climate change have focused mainly on long-term variability of precipitation.

Hydrometeorological time series and rainfall distribution in Slovakia were investigated by [18-21]. The detection of trends in meteorological data, in particular rainfall is essential for the assessment of the impacts of climate variability and change on the water resources of a region. The study of precipitation trends is performed with goal to reduce impacts of droughts and floods.

2. MATERIALS AND METHODS

The territory under this study in Slovakia lies in the eastern part of the country, particularly in the Bodrog and Hornád river basins. The morphological type of terrain in the Hornád valley is dominated by rolling hills, higher and lower uplands. The southern sub-basin is part of a plain and the Slovakian Karst and is formed by moderately higher uplands [22]. The Bodrog river valley has varied climatic conditions. Precipitations are highly differentiated. The highest annual totals are mainly in the eastern border mountains and Vihorlat where rainfall totals are about 1000 mm. Decrease in total precipitation is quite marked directly to the south, where annual totals fall to below 800 mm. The Michalovce, Lastomír and Medzibodrožie lowlands rank among the driest in the eastern region (550 mm rainfall per year) [23].

Monthly precipitation data recorded at 20 stations operated by Slovak Hydrometeorological Institute with data length from 1981 to 2010 were collected for this study. Geographical location of climatic stations in Slovakia is listed in Table 1. The distribution of stations is shown in Fig. 1. Data of 30 years were set up to study precipitation trend in the east part of Slovakia. Although the data sets for climate trend analysis are quite short it was impossible to investigate a longer period because 75% of this stations start precipitation measurements in 1981.

Table 1. Stations under the study in Slovakia

Station	Altitude (m)	Latitude (N)	Longitude (E)
V. Kapušany	103	48°33'	22º04'
Humenné	160	48°55'	21º54'
Michalovce	110	48°44'	21º56'
Snina	235	48°58'	22º08'
Svidník	218	49°18'	21º34'
Tisinec	216	49°12'	21º39'
Horovce	106	49°02'	21º45'
Bardejov	305	49°17'	21º16'
Hanušovce	165	49°02'	21º31'
Moldava N. Bodvou	218	48°36'	21º00'
Turňa N/B	180	48°36'	20º52'
Spiššská Nová Ves	456	48°56'	20º33'
Spišské Vlachy	380	48°56'	20º48'
Kysak	262	48°51'	21º13'
Čaňa	173	48°36'	21º20'
Mníšek n/Hnilcom	410	48°48'	20º49'
V. Folkmar	379	48°51'	21°00'
Jakubovany	410	49°06'	21º08'
Vyšný Čaj	230	48°41'	21º24'
Chmeľnica	515	49°17'	20º43'

Fig. 1. Stations under the study in eastern Slovakia

In this study non-parametric Mann-Kendall test is used for the detection of the trend in a time series. Mann-Kendall test [7,8] is following statistics based on standard normal distribution (Z), by using Eq. (1).

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

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

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

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

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 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 trend in hydro-meteorological time series e.g. [16,17,24,25]. In this method, the slopes (β) of all data pairs are first calculated by

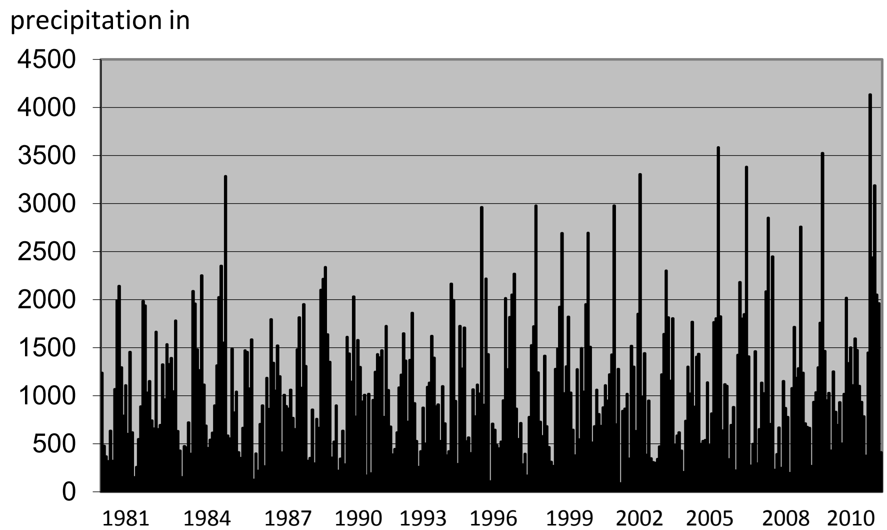
$$\beta = Median\left((x_j - x_k)/(j - k)\right) \tag{5}$$

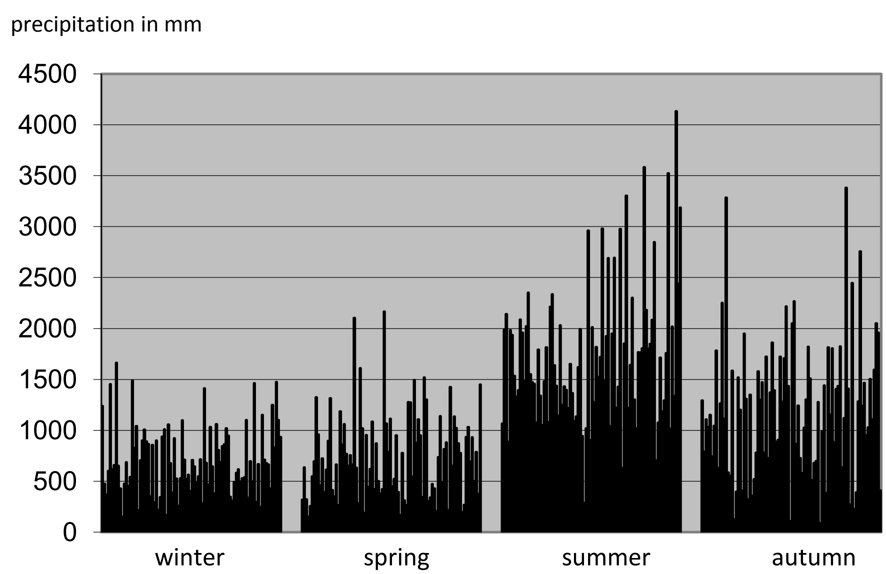
For i = 1, 2, ..., N, where x_j and x_k are data values at time *j* and *k* ($j>k$), respectively and *N* is a number of all pairs x_j and x_k. A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Analysis of variance (ANOVA) analyzes the differences between group means and their associated procedures. ANOVA is the useful tool in comparing (testing) three or more means (groups or variables) for statistical significance.

3. RESULTS AND DISCUSSION

The statistical analysis of precipitation time series has been done as a first step of the research. Time series plots in statistical graphs are showed in Figs. 2-4 to demonstrate the variability and trends during the period 1981–2010 separately for each year, each season and each month.





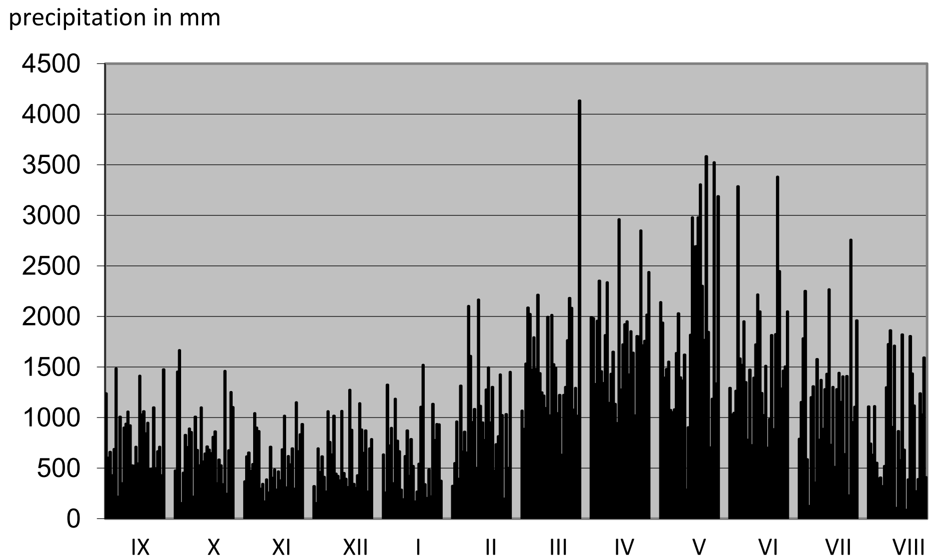


Fig. 2. Time series plots during the period 1981–2010

The results of trend analysis for the precipitation data are discussed in the following. Results of precipitation analysis are presented for annual (Table 2), quartile periods (Table 3) and monthly data (Table 4). The evaluation was done for the time period from November to October. Data series for the 30years period was considered for trend detection. In the Sen's method the slope of all the data points are calculated and their median value is the Sen's estimator of slope.

Table 2. Sen's estimator for annual precipitation

No	Station	*β*
1	V. Kapušany	0,024017
2	Humenné	0,004219
3	Michalovce	0,022973
4	Snina	-0,0027
5	Svidník	0,018135
6	Tisinec	0,018974
7	Horovce	0,029054
8	Bardejov	0,013953
9	Hanušovce	0,01102
10	Moldava n/B	0,014198
11	Turňa n/B	0,036813
12	Sp. NováVes	0,030745
13	Sp. Vlachy	0,024306
14	Kysak	0,009486
15	Čana	0,024651
16	Mníšek n/H	0,057214
17	V. Folkmár	0,041694
18	Jakubovany	0,016535
19	V. Čaj	0,024409
20	Chmeľnica	0,034146

Table 3. Sen`s estimator for precipitation in periods

No	Station	Period			
		XI-I	**II-IV**	**V-VII**	**VIII-X**
		winter	**spring**	**summer**	**autumn**
1	V. Kapušany	0.063333	0.075	0.034426	**0.263636**
2	Humenné	0.005797	-0.00759	-0.015	0.115254
3	Michalovce	0.078261	0.091667	0.18	0.06
4	Snina	0.004348	-0.01818	0.012821	0.05
5	Svidník	-0.04805	0.113514	0.309091	0.026316
6	Tisinec	-0.03651	0.050909	0.282857	0.153968
7	Horovce	0.082143	0.2	0.258696	-0.00462
8	Bardejov	-0.01875	0.04	0.239744	0.052
9	Hanušovce	0.009524	0.081818	0.117241	0.009677
10	Moldava n/B	0.048214	0.053571	0.061404	0.08
11	Turňa n/B	0.152273	0.107407	0.25	0.112
12	Sp. NováVes	0.1	0.044444	0.3	0.202439
13	Sp. Vlachy	0.034286	0.076923	0.330233	0.186957
14	Kysak	0.034884	-0.07027	0.172581	0.13
15	Čana	0.06087	0.051563	0.317391	0.096774
16	Mníšek n/H	0.204918	0.143333	0.50625	0.241176
17	V. Folkmár	0.136667	0.078261	0.255	0.20119
18	Jakubovany	-0.06	0.06129	0.167164	0.171429
19	V. Čaj	0.1	0.053061	0.188889	0.047619
20	Chmeľnica	-0.03636	0.188235	0.296667	0.225581

Rainfall trends show variability in magnitude and direction of trend from one station to another. It depends upon many factors, e.g. latitude, altitude. Significant positive trend is in stations – Veľké Kapušany, Turňanad Bodvou, Spišská Nová Ves, Spišské Vlachy, Mníšek nad Hnilcom (January, June, July), Veľký Folkmár. Decreasing trend of precipitation was found only in March all other months prove increasing trend of precipitation. The trend slope is increase of annual precipitation e.g. in Mníšek nad Hnilcom it is 0.057mm/year. In conclusion, trend analysis of rainfall data series for 1981–2010 showed increasing trend in Slovakia.

The results of ANOVA analysis (Tables 5 and 6), to sort out the spatiotemporal patterns of precipitation, are presented in the following.

In both cases we have made the same result p = 0.0001. F ratio is “large”, especially for monthly precipitation, which might indicate a location effect. It means that null hypothesis is rejected, or there is a statistically significant difference between the average values of the trends in all the considered groups of data.

Table 4. Sen`s estimator for monthly precipitation in Slovakia

No	Station	Month					
		XI	XII	I	II	III	IV
1	V. Kapušany	0,376923	0,23	0,245455	**0,913333**	-0,075	0,04
2	Humenné	0,071429	-0,22083	0,12963	0,26875	-0,47	0
3	Michalovce	0,066667	0,216667	0,236364	0,504545	-0,05789	0,3375
4	Snina	0,557143	-0,36667	-0,21111	0,1	-0,32857	-0,08667
5	Svidník	0,091667	-0,67273	0,094444	0,3	-0,05	0,66
6	Tisinec	0,058824	-0,6	0,1	0,236364	-0,03684	0,288889
7	Horovce	0,328571	0,222222	0,28	1,25	0,285714	0,388889
8	Bardejov	-0,02917	-0,61	0,518182	0,088889	-0,03077	0,05
9	Hanušovce	-0,4625	0,066667	0,441176	0,256522	-0,125	0,52
10	Moldava n/B	-0,46	0,6	0,331818	0,316667	-0,31071	0,286957
11	Turňa n/B	0,095455	0,557143	0,595455	0,5125	-0,13478	0,808333
12	Sp. NováVes	-0,32083	0,35	0,58	0,027273	-0,0375	0,566667
13	Sp. Vlachy	-0,4	0,1375	0,416667	0,266667	0,15	0,284615
14	Kysak	-0,23125	0,542857	0,133333	0,142857	-0,415	-0,73333
15	Čana	0,125	0,088889	0,4	0,48125	-0,46429	0,366667
16	Mníšek n/H	0,63	0,642857	0,8	0,4	0,075	0,973333
17	V. Folkmár	0,4125	0,466667	0,638095	0,25	0,056522	0,46
18	Jakubovany	-0,3381	-0,6625	0,254545	0,152941	-0,02222	0,54
19	V. Čaj	0,425	-0,07857	0,469565	0,457143	-0,28571	0,208696
20	Chmeľnica	0,486667	-0,56	0,247826	0,53125	0,66	0,255556
No	**Station**	**Month**					
		V	**VI**	**VII**	**VIII**	**IX**	**X**
1	V. Kapušany	0,042857	-0,1619	0,7	**1,392593**	0,764706	0,253846
2	Humenné	0,3	-0,25	0,806667	0,55	0,474074	-0,14286
3	Michalovce	1,030435	0,329167	0,62	-0,04	0,41	-0,28125
4	Snina	-0,02	-0,6	1,075	0,5	0,052941	0,126923
5	Svidník	0,257895	0,6125	3,248148	0,111111	-0,26667	0,246154
6	Tisinec	0,425	0,7	2,2	0,754545	0,392593	0,273333
7	Horovce	1	0,664286	1,08	-0,43913	0,559091	-0,10833
8	Bardejov	0,414286	0,457143	2,47	0,314286	-0,04444	0,4
9	Hanušovce	-0,12273	-0,1	1,189474	0,64	0,385714	-0,25455
10	Moldava n/B	-0,65926	-0,06667	1,7	0,54	0,364706	-0,29167
11	Turňa n/B	-0,63125	0,525	2,209524	0,67	0,428571	-0,03846
12	Sp. NováVes	-0,26	0,583333	2,67619	1,157143	0,268182	0,46
13	Sp. Vlachy	-0,25294	0,855556	4,051852	1,275	0,717647	0,39
14	Kysak	-0,2	-0,24286	2,3	0,214286	1,1375	-0,11
15	Čana	0,685	0,745	1,47	0,1	0,746667	0,033333
16	Mníšek n/H	-0,44	1,864286	3,511111	1,25	0,914286	0,472727
17	V. Folkmár	-0,27273	0,593333	2,74	0,866667	0,96875	0,374074
18	Jakubovany	-0,33	0,4	1,691667	0,855556	0,305882	0,4
19	V. Čaj	0,228571	0,1875	1,686957	-0,06154	0,280952	0,069565
20	Chmeľnica	0,041667	1,12	1,9	1,072	0,304545	0,883333

Table 5. ANOVA analysis for monthly precipitation

Source of variation	Sum of squares	Degrees of freedom	Mean squares	*F*
between	63.39	11	5.762	26.69
error	49.22	228	0.2159	
total	112.6	239		

Table 6. ANOVA analysis for precipitation in season

Source of variation	Sum of squares		Mean squares	*F*
between	0.3231	3	0.1077	8.517
error	0.9609	76	1.2644E-02	
total	1.284	79		

4. CONCLUSION

This paper deals with the research of monthly precipitation trends in climatic stations in Slovakia. The non-parametric Mann-Kendall statistic test was applied to detect trends and to assess the significance of the trends in the time series. The evaluation was done for the time period from November to October.

Trends analysis in precipitation data in eastern Slovakia was carried out in the time period 1981–2010. Data used in the present study were acquired from Slovak Hydrometeorological Institute. Almost all the gauging stations in Slovakia show positive trend of monthly precipitation. The increase of precipitation – significant positive trend – was proved in stations Turňa nad Bodvou, Mníšek nad Hnilcom, Veľký Folkmár. Monthly rainfall data series show increasing trend for eastern Slovakia's stations. Significant positive trend in precipitation is proved in July. Decreasing trend is demonstrated only in March.

It proves results of IPCC studies regarding pronounced long-term trends from 1900 to 2005. It has been observed in precipitation amount in northern Europe significantly wetter conditions. Our research was oriented more locally – to small region – eastern part of Slovakia.

We can also conclude that the rainfall of a certain place depends upon many factors and some weather conditions. These include latitude, altitude, topography, and distance from water bodies or other wet areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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