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Research Article

Analysis of precipitation in the Danube Lowland (Slovakia) in 1921–2020

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Abstract Climate change is increasingly occurring not only in Slovakia and Europe, but worldwide. One of the consequences is frequent droughts alternating with extreme rainfall. Drought, especially in the spring months, causes water shortages in the soil and limited crop growth. Extreme rainfall causes frequent floods and destroys crops and property. The aim of this work was to statistically evaluate precipitation during January–December for the period 1921–2020 in the most fertile part of Slovakia – the Danube Lowland. The results show a statistically significant (p <0.10) decrease in precipitation in April and an increase in September, with the annual total precipitation from 535 to 600 mm (except for extremes in some years). The work provides a statistical analysis of changes and rainfall distributions over 100 years, which can help identify and address drought problems.

Keywords: precipitation, Mann-Kendall test, drought, Danube Lowland

1 Introduction

Climate change is one of the biggest challenges to the world in present times. It is defined as significant changes in the average values of meteorological elements, such as precipitation and temperature, for which averages have been computed over a long period (World Meteorological Organization (WMO), 1992; Malhi, Kaur & Kaushik, 2021). Among the most critical impacts of climate change are their effects on the system of hydrology and water management (Zeleňáková & Fendeková, 2018; Koutroulis et al., 2018; Betts et al., 2018). An increase in extreme precipitation is projected for many areas worldwide in the coming decades (Eekhout et al., 2018). While precipitation levels were averaged for the year as a whole, there was a wide range of anomalies between regions and between different times of year (European state of the climate, 2020). Several episodes of extreme precipitation or extreme lack of precipitation (and high temperature) leading to dramatic and high-impact floods and droughts have occurred in Europe in recent years (Kundzewicz, Radziejewski & Pínskwar, 2006). The attention paid to drought periods occurrence is going to be more and more pronounced in both – scientific research community and governmental economy sector (Fendeková et al., 2018).

Slovakia does not currently have a drought management strategy, although the Ministry of the Environment considered several documents for drought to be strategic. However, the issue of drought is not addressed comprehensively and systemically. Drought was for the first time identified as a significant water management problem in the Water Plan of Slovakia for the years 2021 to 2027. According to the "Methodological Manual for the preparation of drought management plans", a drought policy based on risk management should be developed, as well as a strategy for its implementation. The strategy paper should be prepared as a framework document containing the main principles of the drought policy, together with a general plan for its implementation, including all necessary steps to develop a drought management plan (NKÚ, 2021).

In Slovakia, over the last 100 years, we have seen a trend of increasing the average annual air temperature by 1.1 °C and a decrease in annual total atmospheric precipitation by 5.6% on average (in the south of the Slovak Republic there was also a decrease of ≥10%, in the north and northeast rarely also growth of up to 3% for the whole century). The amount of precipitation in the summer half-year decreased by about 20% in the south and by about 10% in the north, the relative humidity

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decreased by 2–6%, especially in the spring months (Sobocká, 2005). The aim of this work is the statistical evaluation of monthly precipitation (January–December) in the period from 1921 to 2020.

2 Material and methods

2.1 Study area

The Slovak Republic is a country in Central Europe. It has an area of 49,035 km^2. It borders the Czech Republic in the northwest, Austria in the southwest, Poland in the north, Ukraine in the east, and Hungary in the south. The landscape is mostly mountainous. The largest and most fertile lowland in Slovakia is the Danube Lowland. It is located in the southwest of Slovakia.

Based on long-term air temperature measurements from several regions of Slovakia, the Danube Lowland is on average the warmest area with an average air temperature of -1 to -2 °C in January, 18 to 21 °C in July and 9 to 11 °C on an annual average. The Danube Lowland is one of the driest areas in Slovakia, because it has the smallest precipitation totals (even less than 500 mm per year), but also there is low rainfall in summer and it is also the warmest and relatively windiest area, due to which there is a high potential evapotranspiration (Slovenský hydrometeorologický ústav, 2022).

In the Danube Lowland, a warm climatic area prevails with climatic districts (from south to north) – warm, very dry with a mild winter; warm, dry with mild winter; warm, slightly dry with mild winter (Lapin et al., 2002). Onset and duration of certain average temperatures – the main growing season with an average daily temperature of 10 °C or more started in southern Slovakia by April 21th and ended after October 11th. The stated temperature characteristics apply to the periods between 1931–1990 (Slovenský hydrometeorologický ústav, 2022). In the current period (1990–2020), the onset of the main vegetation period is until April 10th and ends after October 16th (Kišš et al., 2022).

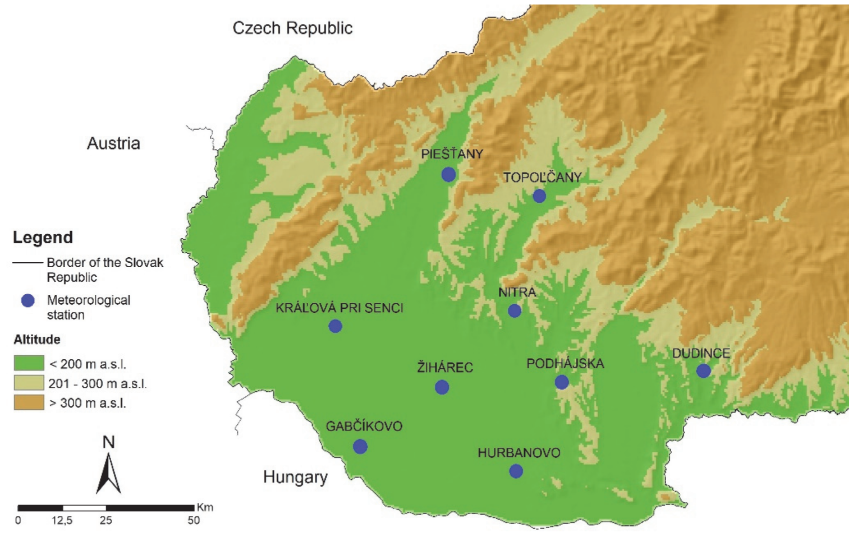

Figure 1 Meteorological stations (Danube Lowland)

The recent soil cover of the Danube Plain is specific within Slovakia. The fluvial relief dominates here, and extensive areas of chernozems, fluvisols and their soil complexes are located on its surface. The most widespread chernozems and their complexes are found along the main watercourses and wetlands. The second most widespread soil type are fluvisols, which occur in the region in the floodplains of rivers and streams (Šefčík et al., 2019).

Data of the precipitation were provided from the Slovak Hydrometeorological Institute at selected localities (Fig. 1). In Table 1 there is longitude, latitude, and altitude of meteorological stations.

2.2 Data analysis

Rainfall is unevenly distributed, and it was not possible to determine the correlation between the data. That's why there was used the Mann–Kendall (MK) test. It is the most widely used nonparametric method for trend detection. That means, it can be applied to data no matter what the probability distribution is (Önöz & Bayazit, 2012). The basic principle of MK tests for trend is to

Table 1 Location of meteorological stations

Station	Longitude	Latitude	Altitude (m a. s. l.)
Kráľová pri Senci	48° 12´ 00´´	17° 16´ 29´´	124
Gabčíkovo	47° 53´ 45´´	17° 33´ 56´´	113
Žihárec	48° 04´ 13´´	17° 52´ 55´´	112
Piešťany	48° 36´ 47´´	17° 49´ 58´´	163
Topoľčany	48° 33´ 50´´	18° 09´ 22´´	180
Podhájska	48° 06´ 27´´	18° 20´ 21´´	140
Nitra	48° 16´ 50´´	18° 08´ 08´´	135
Hurbanovo	47° 52´ 24´´	18° 11´ 40´´	115
Dudince	48° 10´ 09´´	18° 52´ 34´´	139

examine the sign of all pair wise differences of observed values (Libiseller & Grimvall, 2002; Gocic & Trajkovic, 2013; Hamed, 2008; Buhairi, 2010).

The Mann-Kendall test statistic S (Mann, 1945; Kendall, 1975) is calculated as:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j) \quad (1)$$

where: n – the length of the data set; x_i and x_j – two generic sequential data values, and the function sign $(x_i - x_j)$ assumes the following values:

$$sign(x_i - x_j) \begin{cases} 1, if (x_i - x_j) > 0 \\ 0, if (x_i - x_j) = 0 \\ -1, if (x_i - x_j) < 0 \end{cases} \quad (2)$$

The S statistic represents the number of positive differences minus the number of negative differences found in analysed time series. Under the null of that there is no trend in the data no correlation between considered variable and time, each ordering of the data set is equally likely. Under this hypothesis the statistic S is approximately normally distributed with the mean $E(S)$ and the variance Var (S) as follows:

$$E(S) = 0 \quad (3)$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n=5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \quad (4)$$

where: n – the length of the times-series; t_p – the number of ties for the *pth* value and q – the number of tied values i.e., equals values. The second term represents an adjustment for tied or censored data. The standardized test statistic Z is given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \quad if \; S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} \; if \; S < 0 \end{cases} \quad (5)$$

The presence of a statistically significant trend is evaluated using the Z value. This statistic is used to test the null hypothesis such that no trend exists. A positive Z indicates an increasing trend in the time-series, while a negative Z indicates a decreasing trend. To test for either increasing or decreasing monotonic trend at p significance level, the null hypothesis is rejected if the absolute value of Z is greater than $Z(1 - p/2)$; where $Z(1 - p/2)$ is obtained from the standard normal cumulative distribution tables.

It is also possible to obtain a non-parametric estimate for the magnitude of the Sen's slope of trend. Sen Slope estimator test (Sen, 1968) is applied to the whole time series to detect the direction and magnitude of a trend:

$$b = median\left[\frac{(X_j - X_i)}{(j-i)} \right] \quad (6)$$

for all $i < j$

where: b – the slope between data points X_j and X_i; measured at times j and i; respectively

In this work, Excel XLSTAT was used for Mann-Kendall statistical test to detect if there are any statistically significant trends existing in the data. The significance level p <0.10 was applied for analysed time-series 1921–2020.

3 Results and discussion

From the results of the Mann-Kendall trend analysis for the months (January – December) for 100 years (Table 2 and 3) we found a statistically significant decrease in precipitation in April (except for Gabčíkovo and Žihárec stations, where a decrease is visible, but not statistically significant at p <0.10). The decreasing trend is from -0.09 $mm.year^{-1}$ to -0.21 $mm.year^{-1}$, which represents a 100-year decline of 9–21 mm of precipitation in April. There is also a statistically significant decrease in precipitation at the stations Piešťany, Topoľčany, Nitra and Dudince in November (at other stations there is a decrease without statistical significance at the level p <0.10). In November, the decrease ranges from -0.06 $mm.year^{-1}$ to -0.18 $mm.year^{-1}$. In 100 years, this represents a decrease from 6 to 18 mm in November. On the contrary, a statistically significant increase in precipitation occurred in September when the increase is about 0.16–0.27 $mm.year^{-1}$ (except for the Topoľčany station, where the increase is only 0.08 mm.year 1). This is an increase in September for 100 years from 8 to 27 mm. We also observe a statistically significant increase in July at the Dudince station and in August at the Žihárec station.

From the perspective of the whole year, there is a decrease in precipitation, especially in the autumn and spring, which results in a lack of water in the soil for the growth of agricultural crops (Čimo et al., 2021; Šurda, Vitková & Rončák, 2020). Also in the Danube Lowland area, there has been no long-term continuous snowfall in recent years, from which moisture would get into the soil. Also, due to climate change, snowfall has changed from solid to liquid (Markovič, Pecho & Faško, 2020).

Table 2 Results of the Mann-Kendall test (*Z*) with Sen's slope estimator for monthly precipitation time series 1921–2020 (January – June)

1921–2020	I.		II.		III.		IV.		V.		VI.	
	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope
Kráľová pri Senci	0.26	0.01	-0.94	-0.06	-0.01	0.00	-1.71*	-0.12	-0.27	-0.02	-0.38	-0.05
Gabčíkovo	0.09	0.00	-0.99	-0.07	0.16	0.01	-1.27	-0.11	-0.64	-0.06	0.35	0.05
Žihárec	1.30	0.07	-0.51	-0.03	0.36	0.03	-1.23	-0.09	0.38	0.03	0.84	0.10
Piešťany	-1.30	-0.08	-0.39	-0.02	-0.06	-0.01	-2.09*	-0.17	0.68	0.06	-0.28	-0.04
Topoľčany	-0.76	-0.05	-0.61	-0.05	-0.44	-0.04	-1.87*	-0.15	0.78	0.08	-0.66	-0.08
Podhájska	-0.19	-0.01	0.06	0.00	-0.46	-0.04	-1.92*	-0.16	0.51	0.06	0.87	0.11
Nitra	-0.26	-0.02	-0.80	-0.05	0.22	0.01	-2.42*	-0.21	-0.34	-0.04	-0.28	-0.03
Hurbanovo	-0.17	-0.01	-1.33	-0.09	0.02	0.00	-2.28*	-0.17	-0.60	-0.07	0.51	0.06
Dudince	1.19	0.10	-0.24	-0.01	0.19	0.01	-1.76*	-0.14	-0.01	0.00	1.16	0.13

* *p* <0.10; green colour – increase of precipitation; yellow colour – decrease of precipitation; bold number – statistically significant increase/decrease

Table 3 Results of the Mann-Kendall test (Z) with Sen's slope estimator for monthly precipitation time series 1921–2020 (July – December)

1921–2020	VII.		VIII.		IX.		X.		XI.		XII.	
	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope	Z index	Sen´s slope
Kráľová pri Senci	0.34	0.04	1.15	0.13	2.07*	0.19	-1.14	-0.10	-1.13	-0.09	0.05	0.00
Gabčíkovo	0.10	0.01	1.04	0.11	2.54*	0.22	-0.31	-0.04	-0.69	-0.06	-0.90	-0.06
Žihárec	0.85	0.11	2.40*	0.31	2.91*	0.27	-0.83	-0.07	-0.69	-0.06	0.27	0.03
Piešťany	-0.25	-0.03	-0.08	-0.01	1.80*	0.18	-0.97	-0.11	-1.91*	-0.18	-0.63	-0.05
Topoľčany	-0.54	-0.05	-0.72	-0.09	0.85	0.08	-1.64	-0.19	-2.09*	-0.18	-0.76	-0.06
Podhájska	0.84	0.10	0.75	0.09	2.52*	0.24	-0.77	-0.08	-1.27	-0.11	-0.09	-0.01
Nitra	0.23	0.03	0.63	0.08	2.23*	0.23	-1.31	-0.12	-1.85*	-0.18	0.03	0.00
Hurbanovo	1.17	0.14	0.55	0.07	2.17*	0.21	-0.94	-0.09	-1.17	-0.12	-0.47	-0.03
Dudince	1.70*	0.19	0.78	0.10	1.67*	0.16	-1.01	-0.10	-1.72*	-0.17	0.07	0.00

* *p* <0.10; green colour – increase of precipitation; yellow colour – decrease of precipitation; bold number – statistically significant increase/decrease

Fig. 2 shows the maximum, minimum and average annual precipitation values in the period 1921–2020 from the monitored stations on the Danube Lowland. The lowest annual precipitation was most often at the stations Kráľová pri Senci (24x), Gabčíkovo (13x) and Hurbanovo (13x). The highest annual precipitation was reached in the stations Dudince (31x), Topoľčany (21x) and Piešťany (15x). In the monitored period, the highest values were reached at the Dudince station above 1000 mm in 1944 and 2010. The lowest at the Žihárec station in 1921 (308 mm) and at the Gabčíkovo station in 2003 (319 mm). The 100-year average at stations ranges from 535 mm to 600 mm.

Precipitation patterns change and the frequency and intensity of climatic extremes increase not only in Europe (decreases in spring or summer precipitation) (Riedel & Weber, 2020; Karpouzos, Kavalieratou & Babajimopoulos, 2010), but worldwide (higher heavy precipitation event frequencies) (Kunkel, Andsager & Easterling, 1999; Kunkel et al., 2003; Kim et al., 2022; Wang, 2005; Mukherjee et al., 2018).

Several authors are currently working on changes in the distribution of precipitation and drought in Slovakia (Zeleňáková et al., 2017; Vido & Nalevanková, 2020; Brezianska & Vitková, 2015; Šútor, Šurda & Štekauerová, 2011). They discuss the issue of uneven distribution of precipitation during the year, the frequent occurrence of dry periods and lack of water in the soil. There are no big differences in the annual total precipitation (except for some extreme years). The difference is mainly in the uneven distribution of precipitation and extreme precipitation intensities. At such intensities, most of the

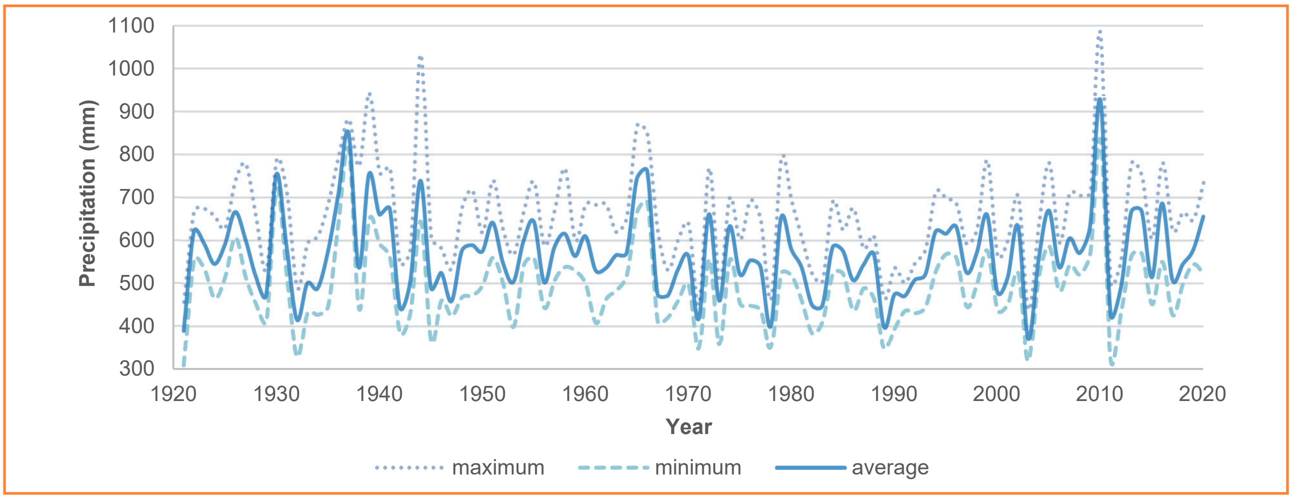

Figure 2 Maximal, minimal, and average precipitation value for the stations in the Danube Lowland (1921–2020)

water does not have time to infiltrate and drains like surface runoff. This results in water shortages in the basin and frequent floods and property damage. In the future, therefore, in addition to examining the distribution of precipitation over months, it would be interesting to compare the intensity of precipitation in the past and in the present.

4 Conclusions

In this work, we focused on the statistical analysis of the distribution of precipitation during the year in the period from 1921 to 2020 in the Danube Lowland. Currently, this issue is interesting in terms of climate change and frequent droughts alternating with extreme precipitation. The results show a statistically significant (p <0.10) decrease in precipitation in April and an increase in September, with the annual total ranging from 535 to 600 mm (except for extremes in some years). In the future, in addition to the distribution of precipitation, it would be interesting to extend this issue to the intensity of precipitation and evaluate it from the perspective of the past and present. Meteorological parameters, mainly average air temperature and precipitation, influence also agricultural crops. Other research of our scientific team (Čimo et al., 2020) showed that we can expect earlier start of the vegetation period in spring and a longer duration in autumns months. This trend is observable in past 30 years. These changed conditions could lead to higher yields of crops or to using of second vegetation. Precipitation is crucial factor to take advantage of this as our results shows.

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