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Long-Term Analysis of Precipitation in Slovakia

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Abstract: Precipitation and its development over time is an important indicator of climate change. Research on long-term precipitation totals is absent in the Slovak Republic. This paper deals with the statistical analysis of daily precipitation from 48 precipitation stations in Slovakia. The paper evaluates the spatial distribution of precipitation in Slovakia and also presents analyses of stationarity and trends using the Mann-Kendall test. Emphasis is placed especially on the evaluation of the trends in total annual precipitation, maximum daily precipitation and also the number of days without precipitation in the year. By evaluating the trends in these three indicators, it is possible to assess the impact of potential change in the temporal and spatial distribution of precipitation on hydrological drought and floods. The results show that there are currently no significant changes in precipitation in Slovakia. The problem of floods and hydrological drought seems to be more complex and is mainly due to surface water drainage from the landscape and the change in its use in connection with the increase in the average annual temperature.

Keywords: precipitation; long-term analysis; trend analysis; Mann-Kendall trend test

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1. Introduction

The effects of climatic changes and variability have been analyzed by many researchers in a variety of geophysical fields. Climate change and its impact on water management can be characterized mainly as a change in temperature and a change in precipitation [1]. Changes in temperature are easily detectable, as many studies of global temperature have shown. Global surface temperature has increased around 0.2 °C per decade over the past 30 years, similar to the warming rate predicted in the 1980s in initial global climate model simulations with transient greenhouse gas changes [2]. A rising trend in temperatures has also been observed in many stations in eastern Slovakia [3]. Temperature, together with precipitation, has a significant effect on the occurrence of dry periods, and in recent years we have observed an increase in the number of dry days and periods in Slovakia [4]. While the evaluation of temperature is essentially simple and appears in many studies, the evaluation of precipitation over time is more difficult [5–7]. Precipitation is highly variable depending on many factors including terrain, altitude and geographical location. It is very difficult and incorrect to analyze the time series of precipitation data globally because the spatial distribution of precipitation is very variable and it significantly depends on the geographical location, altitude or the surrounding environment [8]. There are many studies worldwide which evaluate and analyze long-term precipitation data [9–11], including trend analysis of time series and spatial analysis. These studies show significantly different results, depending mainly on the geographical location. In some parts of the world an increase in the amount of precipitation is observed, while in other localities it is decreasing. Similar results are provided by analyses of various variables related to precipitation. In India, the precipitation trends show large variability. In a 2012 study six river basins showed an increasing trend in annual precipitation, whereas 15 river basins showed decreasing annual precipitation. Furthermore, four river basins showed an increasing trend in rainy days, and 15 river basins showed the opposite trend. In trend analysis studies, the results significantly depend upon the period of data collection and the stations whose data are used. This shows the variability of precipitation [12]. The application of a trend detection framework to Turkish precipitation data resulted in the identification of some significant trends. From the monthly precipitation variables, January, February and especially September were found to have strong decreasing trends, as opposed to other months showing either positive or negative trends in a minority of stations [13]. A mix of positive and negative trends was observed at various stations and sub-basins in Pakistan as well [14]. In Greece, statistical exploration and tests indicate no statistically significant climatic changes in extreme precipitation during the last 136 years. This is the longest precipitation record available in Greece and its analysis is required for the prediction of intense precipitation in Athens, where currently major flood protection works are under way [15]. In Europe, there are many other studies presenting the variability of precipitation, and their results show a mix of positive, negative or no trends for different precipitation indicators [16–18]. These results effectively demonstrate that precipitation analysis cannot be performed globally because of spatial variability, so it is necessary to focus on a specific area when analyzing precipitation data.

In addition to precipitation, anthropogenic activity and changes in land use also contribute to changes in the hydrological regime of the landscape [19–21]. Figure 1 shows changes in land use in the lowland territories of Slovakia over the last few hundred years, where the natural landscape has been largely replaced with agricultural and anthropogenically altered land [22].

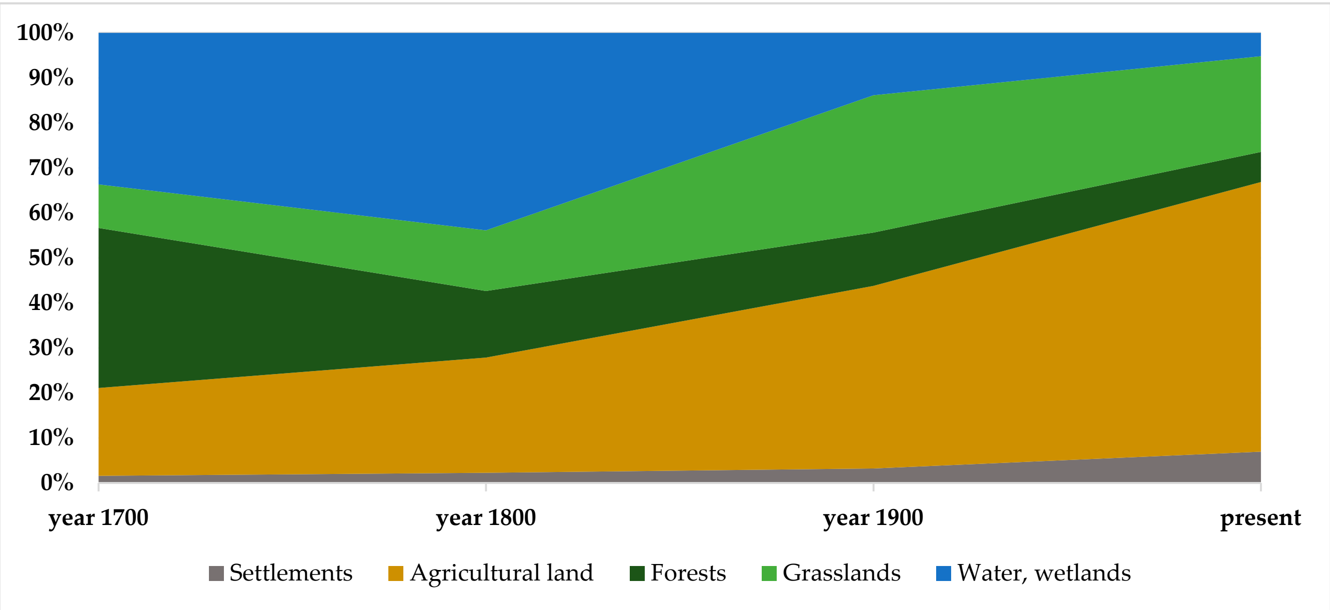

Figure 1. Changes in land use in the lowland territories of Slovakia from 1700.

Hydrological extremes (floods, droughts) are seemingly random natural phenomena which not only occur in specific regions, but also occupy large areas of countries, and thus significantly affect people's lives and activities [23]. The extremes of the hydrological regime include periods of drought and, on the other hand, flood situations on watercourses. At present, increased frequency in the occurrence of extreme meteorological situations is expected, and thus also increased occurrence of hydrological phenomena, i.e., floods and droughts, which are a problem not only for the Slovak Republic and Europe as their effects are manifested on a global scale. Regions in northern and north-eastern Europe are most prone to increasing flood frequencies, while southern and south-eastern Europe show significant increases in drought frequency [24]. The risk of floods and droughts is growing, and issues related to protection against these risks are becoming increasingly topical and are taking on an increasing international dimension. The analysis of precipitation totals helps us to locate these situations and thus reduce the consequences of the mentioned risks.

This paper focuses on analysis of long-term data from precipitation stations over the whole territory of Slovakia. The aim of the paper is to identify changes in precipitation occurring in Slovakia over time and to evaluate these changes. The paper consists of a basic statistical analysis, descriptive analysis and evaluation of trends in several indicators of precipitation.

2. Materials and Methods

2.1. Study Area

Slovakia is located in central Europe, spreading over a geographical area of 49,035 km^2. As presented in the topographical map in Figure 2, the landscape relief is very diverse. The terrain of Slovakia passes from low altitudes in the south-west and south-east to mountain areas in the north. The lowest altitude is located in the south-eastern part of a country in the East Slovakian lowlands (94.3 m) and the highest altitude is in the High Tatras in the north of the country (2655 m). The northern regions are more typical for colder climate than the central and southern regions of the country.

Figure 2. Location of Slovakia and the topography of Slovakia.

In terms of global climate classification, the territory of Slovakia lies in the northern temperate climatic zone with regular alternation of four seasons and variable weather, with the highest number of precipitation events in the summer periods. On the other hand, the driest are the winter periods. Average annual precipitation is around 600 mm, and the rainiest season is summer. The average duration of snow cover is from 40 days in the lowlands to 120 days in the mountain ranges. Precipitation data present rainfall as well as snow together.

In Slovakia, the average annual precipitation varies from less than 500 mm in the south-west to approximately 2000 mm in the High Tatras. Relatively low total precipitation occurs in the rain shadow of the mountains. During the year, the summer period (June–August) accounts for about 40%, spring around 25%, autumn about 20% and winter 15% of the annual precipitation, and thus the predominance of precipitation in summer is clear. The rainiest month is June or July, and the least precipitation is in January to March. In winter, much of the precipitation, especially in medium and high mountain locations, falls in the form of snow [25]. There are not many studies focusing on precipitation analysis in Slovakia. There are several studies dealing with local evaluation of short-term data, for example, the analysis of extreme precipitation events in 2010, which were characterized by their exceptional intensity and overall quantity, and moreover, they hit repeatedly at the most flood-vulnerable river basins in Slovakia [26]. The authors of the study focused on maximum multi-day total precipitations in Slovakia, and constructed maps of 1-, 2- and 5-day precipitation totals in Slovakia for the period 1951–2000. The results of the study confirm the direct dependence between altitude and extreme precipitation [27]. Monthly precipitation trends were detected by means of non-parametric Mann-Kendall testing in statistical analysis of monthly data from 487 stations in the period 1981–2014. Precipitation trends show high variability. The precipitation time series in Slovakia at gauging stations in particular have an increasing trend, especially in the month of July [28]. For the Poprad station in the north of the country, the temporal analysis of daily and ten-minute precipitation events was performed. The results of the basic statistics outlined trend behavior in the data, meaning that the annual total precipitation for the period 1951–2018 slightly increased. The number of rainy days decreased but maximum precipitation intensity increased year by year, indicating that total precipitation happens in fewer and fewer days, with an increase in the number of zero-precipitation days. The results demonstrate no presence of a trend or only a weak trend in daily time steps, but a significant increasing trend in annual precipitation [29]. Similar results were produced from the analysis of daily precipitation for the Košice station in eastern Slovakia, with no trend in daily precipitation for the period 1951–2018 [30]. In an analysis of total annual precipitation, the number of days without precipitation and maximum daily precipitation for three stations in eastern Slovakia, we observed a significant positive trend just in total annual precipitation at one station and in maximum daily precipitation at another station. The number of dry days was without trend in these three stations [31]. The results of the analysis of ten-minute precipitation in eastern Slovakia show that the design intensities which are currently in use in Slovakia are not satisfactory, especially for precipitation with a duration of more than 30 min [32].

2.2. Input Data

Daily precipitation data from 48 climatic stations were used for the analysis of precipitation in Slovakia. Locations of all stations are shown in Figure 3. There are 12 stations in western Slovakia, 17 stations are located in central Slovakia, and in eastern Slovakia there are 19 stations. A list of all stations with corresponding altitudes and coordinates is given in Table 1. Data from all stations are without daily gaps. Observation time varies through the stations from 34 years to 119 years. The observation time ends with the year 2019 at every station. Data for analysis were collected from the Slovak Hydrometeorological Institute (SHMI). Annual precipitation amount, number and percentage of days without precipitation in each year, daily maximum precipitation and average daily precipitation for each station were derived and evaluated from the daily precipitation data. In the next steps, statistical analysis using Mann-Kendall trend tests, stationarity tests and others were performed.

Table 1. List of observed stations with their altitude and location.

Station	Observed Period	Number of Observed Years	Altitude (m asl.)	Latitude	Longitude
Bratislava-Koliba	1950–2019	69	287	48°10′7″	17°6′38″
Bratislava-airport	1951–2019	68	182	48°9′8″	17°4′13″
Dudince	1977–2019	42	139	48°10′9″	18°52′34″
Hurbanovo	1900–2019	119	115	47°52′23″	18°11′39″
Jaslovské Bohunice	1961–2019	58	176	48°29′12″	17°40′15″
Kráľová pri Senci	1961–2019	58	124	48°12′0″	17°16′29″
Malý Javorník	1982–2019	37	586	48°15′21″	17°9′14″
Piešťany	1951–2019	68	163	48°36′47″	17°49′58″
Podhájska	1961–2019	58	145	48°6′27″	18°20′21″
Prievidza	1973–2019	46	260	48°46′11″	18°35′38″
Veľké Ripňany	1966–2019	53	188	48°30′38″	17°59′26″
Žihárec	1961–2019	58	111	48°4′13″	17°52′55″
Banská Štiavnica	1970–2019	49	575	48°26′58″	18°55′18″
Boľkovce	1951–2019	68	214	48°20′20″	19°44′11″
Bzovík	1978–2019	41	355	48°19′9″	19°5′38″
Dolné Plachtince	1965–2019	54	228	48°12′24″	19°19′12″
Dolný Hričov	1976–2019	43	309	49°13′56″	18°36′51″
Chopok	1955–2019	64	2005	48°56′38″	19°35′32″
Liptovský Hrádok	1950–2019	69	640	49°2′21″	19°43′31″
Lom nad Rimavicou	1980–2019	39	1018	48°39′38″	19°39′57″
Oravská Lesná	1951–2019	68	780	49°22′6″	19°10′59″
Ratková	1968–2019	51	311	48°35′34″	20°5′37″
Rimavská Sobota	1951–2019	68	215	48°22′26″	20°0′38″
Sliač	1951–2019	68	313	48°38′33″	19°8′31″
Štrbské Pleso	1951–2019	68	1322	49°7′10″	20°3′48″
Telgárt	1951–2019	68	901	48°50′55″	20°11′21″
Vígľaš-Pstruša	1972–2019	47	368	48°32′39″	19°19′19″
Žiar nad Hronom	1984–2019	35	275	48°35′10″	18°51′8″
Žilina	1981–2019	38	365	49°12′19″	18°44′48″
Červený Kláštor	1961–2019	58	469	49°23′14″	20°25′27″
Jakubovany	1973–2019	46	410	49°6′32″	21°8′27″
Kamenica nad Cirochou	1951–2019	68	176	48°56′20″	22°0′22″
Košice-airport	1951–2019	68	230	48°40′20″	21°13′21″
Lomnický štít	1951–2019	68	2635	49°11′43″	20°12′54″
Medzilaborce	1961–2019	58	305	49°15′12″	21°54′50″
Michalovce	1968–2019	51	110	48°44′24″	21°56′43″
Milhostov	1961–2019	58	105	48°39′47″	21°43′26″
Orechová	1978–2019	41	122	48°42′19″	22°13′31″
Plaveč	1961–2019	58	485	49°15′35″	20°50′45″
Podolínec	1982–2019	37	573	49°15′20″	20°31′58″
Poprad	1951–2019	68	694	49°4′8″	20°14′44″
Prešov	1985–2019	34	307	49°1′55″	21°18′31″
Silica	1974–2019	45	520	48°33′17″	20°31′15″
Skalnaté pleso	1961–2019	58	1778	49°11′22″	20°14′9″
Somotor	1961–2019	58	100	48°25′17″	21°49′6″
Spišské Vlachy	1965–2019	54	380	48°56′35″	20°48′8″
Tatranská Javorina	1970–2019	49	1013	49°15′47″	20°8′37″
Tisinec	1963–2019	56	216	49°12′56″	21°39′0″

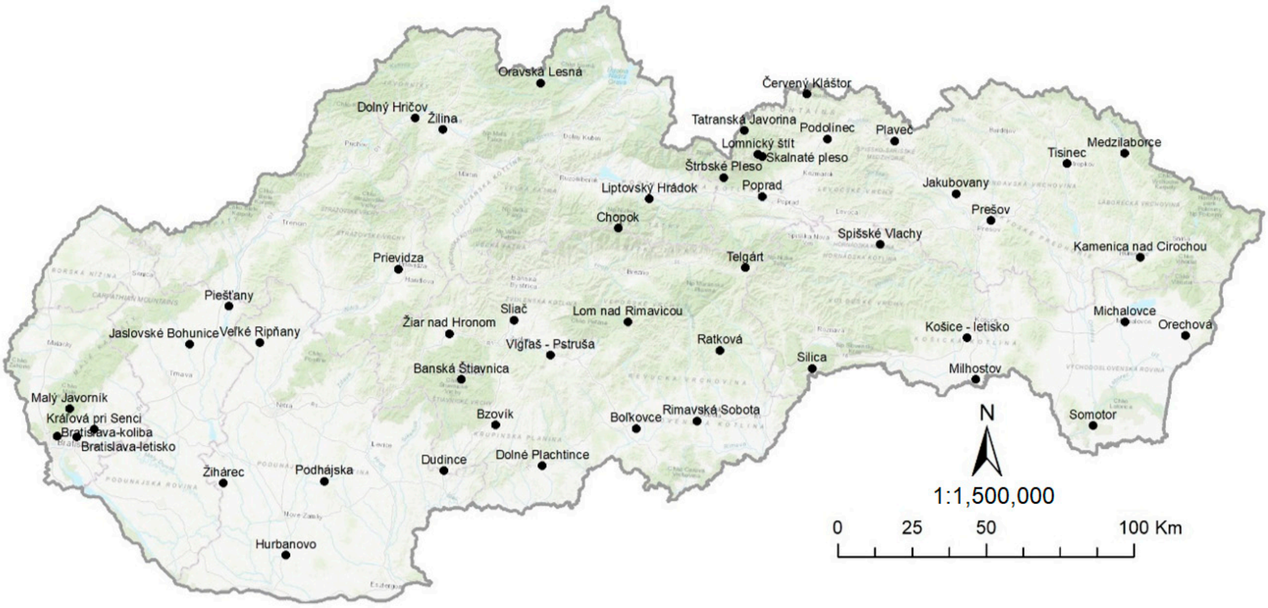

Figure 3. Location of precipitation stations in Slovakia.

2.3. Statistical Analysis

First of all, daily precipitation series for each station were used to determine annual precipitation, the number of days without precipitation, maximum daily precipitation, average daily precipitation and average monthly precipitation. For each set of data, the mean, standard deviation, skewness, kurtosis maximum and minimum were evaluated. For each station, the characteristic indicators of the temporal and spatial distribution of precipitation were evaluated. Secondly, the temporal variation in the precipitation data time series was analyzed using a series of statistical tests of stationarity and periodicity. The stationarity of time series was tested using the Augmented Dickey-Fuller (ADF) test, Phillips–Perron test and Kwiatkowski, Phillips, Schmidt, Shin (KPSS) test.

The Dickey-Fuller (ADF) test [33] is one of the best-known and most widely-used unit root tests. It is based on the model of the first-order autoregressive process [34]. Phillips and Perron [35] proposed an alternative (nonparametric) method of checking for serial correlation when testing for a unit root [36]. The Kwiatkowski, Phillips, Schmidt, Shin (KPSS) test [37] is built on the idea that a time series is stationary around a deterministic trend and is calculated as the sum of the deterministic trend, random walk and stationary random error [38]. These tests are widely used in hydrological time series analysis [39–44].

Spectral analysis was used for determining the periodicity of the precipitation time series. The periodic behavior of a time series is observed by utilizing the sine wave function of the time series. The periodicity which gives the strength of the time series at a given frequency is presented in a periodogram. The peak value of the periodogram is the dominant frequency [45]. All the tests were carried out at a 5% significance level. In all the tests the p-value is calculated, and if the p-value is less than 0.05 (5% significance level), then the null hypothesis is rejected and the alternative hypothesis is accepted.

Subsequently, trends in the average annual precipitation totals, the maximum daily precipitation and the number of days without precipitation were evaluated for each station for the whole observation period, depending on the observation time at each station. These variables were evaluated because comparing them can show the evolution and changes in precipitation over the years. The Mann-Kendall (MK) trend test was used for analyzing these trends. This trend test [46,47] is based on a nonparametric method and it is frequently used to quantify the significance of trends in time series, especially in environmental science [48], and also for trend detection analysis in rainfall time series [39–44]. Based on the above steps of statistical analysis, the development of precipitation in recent years was ultimately evaluated.

2.4. Spatial Distribution

The spatial distribution of precipitation in the map (Figure 4) was generated using CoKriging, an interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement of the measured points. CoKriging shows the best performance among the univariate methods [49,50].

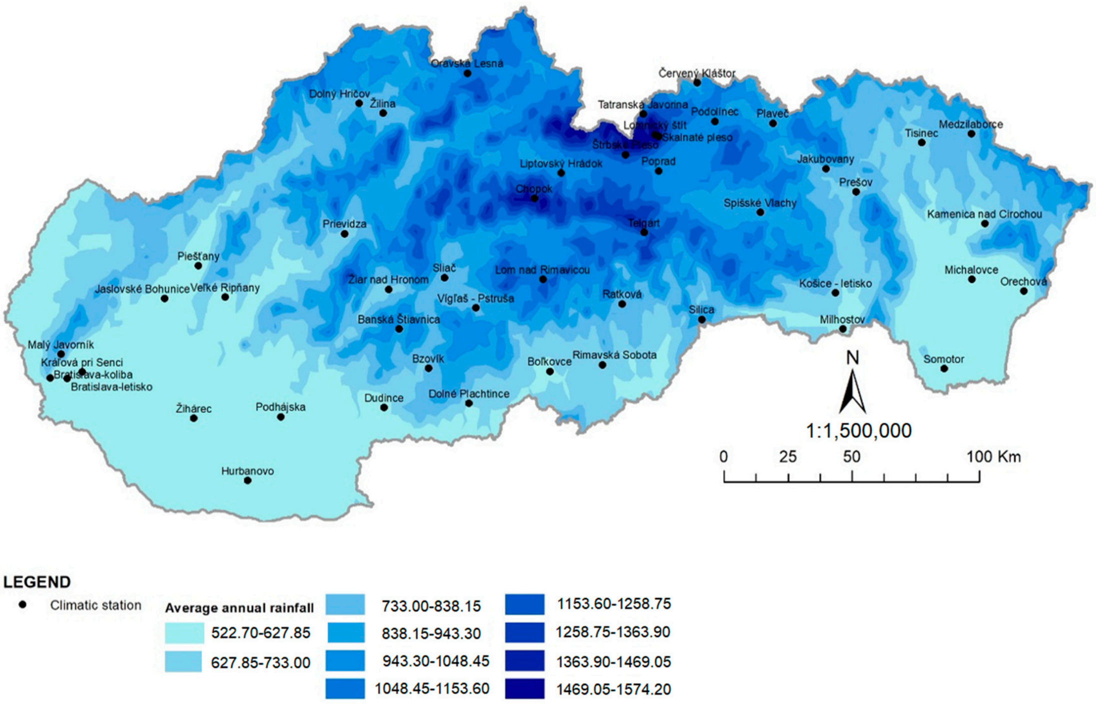

Figure 4. Average annual precipitation in Slovakia using CoKriging method.

3. Results

The results are presented in three subsections, namely basic statistics of precipitation, descriptive statistics and trend analysis of precipitation in Slovakia. The basic characteristics consist of the evaluation of basic precipitation parameters, such as average daily precipitation, average annual precipitation, maximum daily precipitation or average number of days without precipitation for each station. Descriptive analysis consists of stationarity, homogeneity and periodicity testing of daily precipitation time series for each station. Trend analysis focuses on trend assessment in annual precipitation, maximum daily precipitation and dry days.

3.1. Basic Statistics of Precipitation in Slovakia

The results of basic statistics are shown in Table 2. Data for each station include observed period, average daily and annual precipitation, maximum daily precipitation and average number of days without precipitation. Climatic stations were divided into three groups according their location within Slovakia: western, central and eastern.

The rainiest station in Slovakia is Lomnický štít (Lomnicky Peak) in the High Tatras in the north of the country, with an average annual precipitation of 1574.2 mm. The least rainy locations are the lowland areas, specifically the Kráľová pri Senci station in south-western Slovakia with an average annual precipitation of 522.7 mm. During the entire observation period, the highest daily precipitation was recorded at the Oravská Lesná station with 163.2 mm per day. Most days without rain occurred at the Silica station located in eastern Slovakia, whereas the lowest number of days without rain occurred at the Lomnický Peak station.

Table 2. Basic statistics of precipitation in Slovakia.

Station	Observed Period	Average Annual Precipitation (mm)	Maximum Daily Precipitation (mm)	Average Number of Days without Precipitation in a Year
		Western Slovakia		
Bratislava-Koliba	1950–2019	673.3	86.4	215
Bratislava-airport	1951–2019	572.7	78.4	224
Dudince	1977–2019	592.5	91	233
Hurbanovo	1900–2019	565.7	90.2	228
Jaslovské Bohunice	1961–2019	555.7	73.1	226
Kráľová pri Senci	1961–2019	522.7	106.1	235
Malý Javorník	1982–2019	768.9	108	216
Piešťany	1951–2019	577.5	83.6	225
Podhájska	1961–2019	557.9	74.2	228
Prievidza	1973–2019	655.5	74.9	219
Veľké Ripňany	1966–2019	553.1	73.4	240
Žihárec	1961–2019	573.8	94.4	222
		Central Slovakia		
Banská Štiavnica	1970–2019	752	70.8	215
Boľkovce	1951–2019	596.1	105	233
Bzovík	1978–2019	615.2	63	235
Dolné Plachtince	1965–2019	615.8	62.6	240
Dolný Hričov	1976–2019	737.2	65.5	199
Chopok	1955–2019	1134	116.7	158
Liptovský Hrádok	1950–2019	688.3	62.7	209
Lom nad Rimavicou	1980–2019	883.9	89	220
Oravská Lesná	1951–2019	1125.7	163.2	172
Ratková	1968–2019	725.2	92	227
Rimavská Sobota	1951–2019	620.2	82.7	238
Sliač	1951–2019	698	93.8	220
Štrbské Pleso	1951–2019	1011.9	100.8	162
Telgárt	1951–2019	860.1	94.6	191
Vígľaš-Pstruša	1972–2019	621	74.8	228
Žiar nad Hronom	1984–2019	658.6	90.2	220
Žilina	1981–2019	761.5	68.2	200
		Eastern Slovakia		
Červený Kláštor	1961–2019	803.7	106	212
Jakubovany	1973–2019	637.7	73.2	223
Kamenica nad Cirochou	1951–2019	724.1	85.5	204
Košice-airport	1951–2019	615.8	110.5	220
Lomnický štít	1951–2019	1574.2	141.2	149
Medzilaborce	1961–2019	846.6	86.2	196
Michalovce	1968–2019	635.4	61.9	219
Milhostov	1961–2019	560.8	82.5	221
Orechová	1978–2019	692.3	67.8	225
Plaveč	1961–2019	709	119.2	196
Podolínec	1982–2019	724.1	92.4	185
Poprad	1951–2019	602.8	79.3	210
Prešov	1985–2019	648.4	65.8	217
Silica	1974–2019	709.6	70.8	240
Skalnaté pleso	1961–2019	1374.8	144.5	160
Somotor	1961–2019	557.7	74	227
Spišské Vlachy	1965–2019	620	77	212
Tatranská Javorina	1970–2019	1336.1	144.6	174
Tisinec	1963–2019	679.1	70.2	200

Extreme precipitation events with a total daily precipitation of more than 60 mm were also analyzed for each station. Analysis of the occurrence of such events showed that they occurred in the past as well as in the present.

Available data were used to create a map of average annual precipitation over the whole Slovak Republic using the CoKriging method.

It is clear from Figure 4 that the lowest annual precipitation is in the south of the country, especially in the East Slovakian and West Slovakian lowlands. The amount of precipitation per year gradually increases with altitude. The highest annual precipitations are recorded in the High Tatra and Low Tatra mountain ranges.

The average number of days without precipitation also depends on altitude and geographical location. The number of days without precipitation for each station is shown graphically in Figure 5.

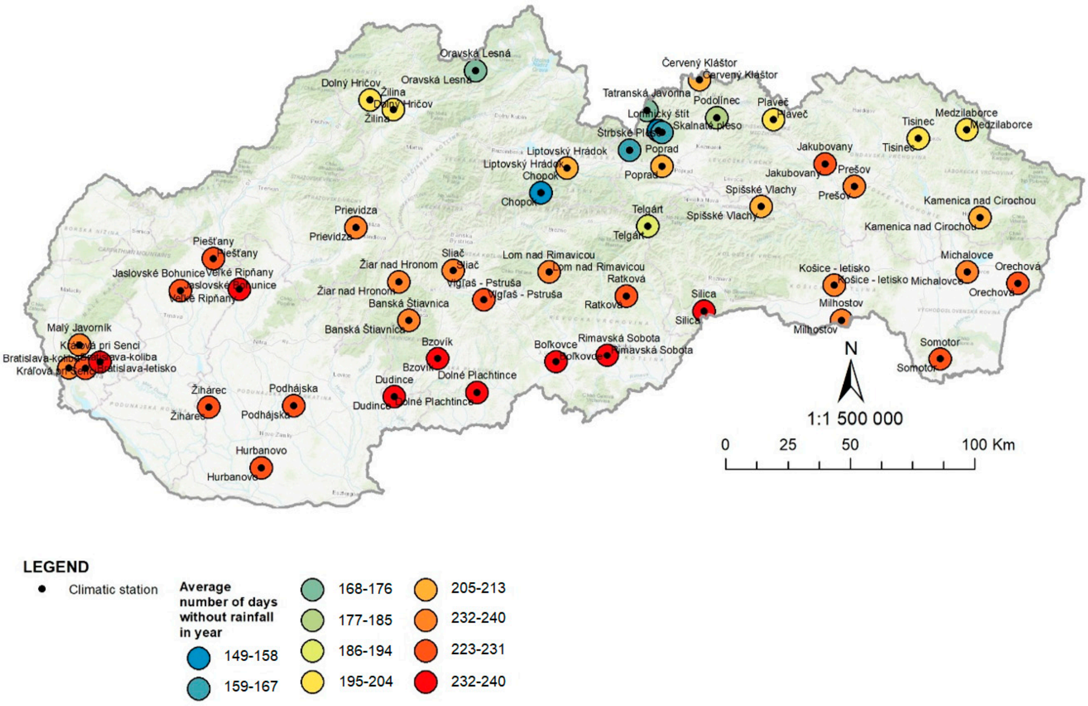

Figure 5. Average number of days without precipitation.

Most days without precipitation occur again in the whole of southern Slovakia, where the average number of days without precipitation per year is around 230. The least rainy stations are Veľké Ripňany, Dolné Plachtince and Silica, where the average number of days without precipitation is 240. At the other extreme there is the station at Lomnický Peak in the High Tatras with just 149 days without precipitation. The areas in the north-east and north-west of the country, where the average number of days without precipitation per year is up to 200, are also relatively rainy compared to the rest of Slovakia.

3.2. Descriptive Statistics

Descriptive statistics consist of stationarity, homogeneity and periodicity tests. The stationarity of time series was checked using ADF, Phillips-Perron and KPSS tests. Spectral analysis was used for determining the periodicity of time series. In general, a stationary time series has no predictable patterns in the long term. Time plots show the series to be roughly horizontal (although some cyclical behavior is possible), with constant variance. A stationary process has the characteristic that the mean, variance and autocorrelation structure do not change over time [51].

Stationarity and periodicity tests were carried out using XLSTAT software (Paris, France). The stationarity of daily precipitation time series was evaluated for all stations. Based on the results of the tests, daily precipitation series in all stations were stationary, which means that there was no long-term trend in daily precipitation totals. Spectral analysis showed the periodicity of time series as being around 365 days. This means that there was regular alternation of the time distribution of precipitation over the years.

3.3. Trend Analysis

Trend analysis was carried out for the listed stations using the Mann-Kendall trend test. The results are presented in Table 3, with positive trends marked with green color, while negative trends are marked with orange color and results showing no trend in the time series are marked with grey color. In the table there are also values of coefficients of MK trend analysis.

Table 3. Trend analysis of precipitation in Slovakia

Stations	Number of Days without Precipitation	Annual Precipitation	Maximum Daily Precipitation
Bratislava-koliba	T = −0.021, p = 0.803	T = 0.095, p = 0.248	T = −0.023, p = 0.788
Bratislava-letisko	T = 0.235, p = 0.005	T = −0.004, p = 0.970	T = 0.088, p = 0.290
Dudince	T = 0.111, p = 0.308	T = 0.201, p = 0.062	T = 0.176, p = 0.104
Hurbanovo	T = 0.212, p = 0.001	T = −0.077, p = 0.213	T = 0.024, p = 0.698
Jaslovské Bohunice	T = 0.145, p = 0.114	T = 0.068, p = 0.452	T = 0.205, p = 0.023
Kráľová pri Senci	T = −0.201, p = 0.028	T = 0.108, p = 0.232	T = 0.084, p = 0.355
Malý Javorník	T = −0.029, p = 0.814	T = 0.213, p = 0.065	T = 0.156, p = 0.178
Piešťany	T = −0.042, p = 0.619	T = −0.112, p = 0.179	T = 0.053, p = 0.525
Podhájska	T = −0.154, p = 0.095	T = 0.123, p = 0.179	T = −0.019, p = 0.842
Prievidza	T = 0.042, p = 0.690	T = 0.096, p = 0.353	T = 0.105, p = 0.311
Veľké Ripňany	T = −0.430, p = 0.001	T = 0.132, p = 0.165	T = 0.067, p = 0.485
Žihárec	T = 0.539, p = 0.001	T = 0.130, p = 0.151	T = 0.119, p = 0.191
Banská Štiavnica	T = −0.340, p = 0.001	T = 0.185, p = 0.061	T = 0.206, p = 0.038
Boľkovce	T = −0.015, p = 0.861	T = 0.017, p = 0.845	T = 0.073, p = 0.385
Bzovík	T = −0.253, p = 0.022	T = 0.227, p = 0.038	T = −0.033, p = 0.770
Dolné Plachtince	T = −0.368, p = 0.001	T = 0.154, p = 0.101	T = −0.164, p = 0.082
Dolný Hričov	T = 0.082, p = 0.451	T = 0.017, p = 0.884	T = 0.041, p = 0.706
Chopok	T = −0.348, p = 0.001	T = 0.162, p = 0.060	T = 0.143, p = 0.096
Liptovský Hrádok	T = −0.267, p = 0.001	T = 0.221, p = 0.007	T = 0.047, p = 0.576
Lom nad Rimavicou	T = 0.366, p = 0.001	T = 0.341, p = 0.002	T = 0.374, p = 0.001
Oravská Lesná	T = 0.023, p = 0.791	T = 0.186, p = 0.025	T = 0.180, p = 0.031
Ratková	T = 0.109, p = 0.269	T = 0.096, p = 0.322	T = 0.051, p = 0.603
Rimavská Sobota	T = −0.166, p = 0.047	T = 0.040, p = 0.630	T = 0.067, p = 0.421
Sliač	T = −0.080, p = 0.340	T = 0.056, p = 0.501	T = 0.072, p = 0.391
Štrbské Pleso	T = 0.006, p = 0.945	T = 0.284, p = 0.001	T = 0.127, p = 0.129
Telgárt	T = −0.145, p = 0.083	T = 0.124, p = 0.137	T = 0.021, p = 0.804
Vígľaš-Pstruša	T = −0.221, p = 0.030	T = 0.164, p = 0.107	T = 0.092, p = 0.369
Žiar nad Hronom	T = 0.010, p = 0.943	T = 0.129, p = 0.280	T = 0.024, p = 0.853
Žilina	T = −0.105, p = 0.365	T = 0.073, p = 0.530	T = −0.071, p = 0.538
Červený Kláštor	T = −0.272, p = 0.003	T = 0.304, p = 0.001	T = −0.194, p = 0.032
Jakubovany	T = 0.059, p = 0.576	T = 0.129, p = 0.211	T = 0.172, p = 0.094
Kamenica nad Cirochou	T = 0.143, p = 0.088	T = 0.054, p = 0.515	T = 0.248, p = 0.003
Košice-letisko	T = −0.031, p = 0.711	T = 0.021, p = 0.804	T = 0.007, p = 0.937
Lomnický štít	T = −0.211, p = 0.012	T = 0.332, p = 0.001	T = 0.216, p = 0.009
Medzilaborce	T = 0.046, p = 0.615	T = 0.131, p = 0.147	T = 0.132, p = 0.147
Michalovce	T = 0.145, p = 0.139	T = 0.139, p = 0.153	T = 0.129, p = 0.186
Milhostov	T = −0.015, p = 0.877	T = 0.061, p = 0.502	T = 0.028, p = 0.758
Orechová	T = 0.426, p = 0.001	T = −0.010, p = 0.937	T = −0.045, p = 0.686
Plaveč	T = −0.454, p = 0.001	T = 0.263, p = 0.004	T = 0.133, p = 0.142
Podolínec	T = −0.223, p = 0.056	T = 0.132, p = 0.255	T = −0.087, p = 0.456
Poprad	T = −0.015, p = 0.861	T = 0.183, p = 0.028	T = 0.130, p = 0.120
Prešov	T = 0.206, p = 0.093	T = 0.180, p = 0.138	T = 0.128, p = 0.293
Silica	T = −0.280, p = 0.007	T = 0.012, p = 0.914	T = 0.039, p = 0.710
Skalnaté pleso	T = −0.030, p = 0.742	T = 0.274, p = 0.002	T = 0.004, p = 0.973
Somotor	T = −0.236, p = 0.009	T = −0.030, p = 0.742	T = −0.039, p = 0.668
Spišské Vlachy	T = −0.359, p = 0.001	T = 0.277, p = 0.003	T = 0.144, p = 0.126
Tatranská Javorina	T = −0.225, p = 0.024	T = 0.267, p = 0.007	T = 0.268, p = 0.007
Tisinec	T = −0.152, p = 0.102	T = 0.121, p = 0.191	T = −0.005, p = 0.961

Positive trend, Negative trend, No trend, *T*—Kendall's Tau, *p*—Two-tailed *p*-value.

For more than 56% of stations, there was no trend in time series for the number of days without rain, which means that there was no significant change in that number during the observation period. For 33% of stations, there was a negative trend in the number of days without rain, meaning that there was an increase in the number of rainy days, and only in 10% of stations there was an increase in days without rain during the observation period. The annual precipitation for the majority of stations did not show any trend, and for only 25% of stations there was a positive trend in annual precipitation, which means that the amount of rain per year increased during the observation period. No negative trend was recorded for any station. Trend analysis for time series in maximum daily precipitation again showed no trend for the majority of stations, and a positive trend for only eight stations, so there were only eight places in Slovakia where there was an increase in maximum daily precipitation during the observation period. The results of the trend analysis suggest that the number of days without rain is not increasing globally, and at the same time the amount of annual precipitation is not decreasing.

4. Discussion and Conclusions

While extreme meteorological and hydrological events are stochastic and ultimately unavoidable in nature, in recent decades they seem to have started occurring more frequently and their consequences appear to be more devastating. Those that most affect human lives, property and the natural environment include excessive rainfall, which generates floods, and hydrological droughts. Design values of extreme hydrological phenomena such as floods and droughts are a common criterion used in the construction of civil engineering structures and water supply systems. Two different parameters are considered in the analysis of extreme hydrological phenomena: on the one hand, intense precipitation, the effects of which are most serious in urban environments, and on the other hand, droughts, which are much less spectacular but whose impact is correspondingly more invidious.

Floods and droughts are unavoidable natural phenomena. However, some human activities (such as growing settlements and economic assets across floodplains and the reduction in natural water retention in the ground) and climate change are contributing to increased likelihood and adverse effects of extreme hydrological events. Droughts and floods can be considered as the most serious natural disasters with economic, environmental and social impacts, which depend on the duration, severity and extent of the reduction (increase) in precipitation, but also on the vulnerability of the area. The degree of vulnerability can be determined by identifying the degree of risk in particular areas and its trends over time; investigating the causes of historical droughts (floods); and by ranking the significant effects of the risk. While extreme hydrological risks (droughts and floods) are accidental natural phenomena, they show an increasing tendency due to climate change. Knowing the occurrence of historical events supports the study of their manifestations in time and space, as well as their impacts on nature and human society. Understanding these developments should lead to proper planning and risk management in river catchments. In this context, statistical mathematical evaluation is recommended, including the processing of trend lines, which will contribute to the evaluation of the impacts of climate change on the hydrological regime in specific areas.

The analysis of precipitation and the evaluation of changes in it over time are highly necessary for engineering practice. This paper deals with long-term analysis of precipitation in Slovakia using data from 48 precipitation stations throughout the country. The trend analysis shows that there have been no significant changes in the total annual precipitation in Slovakia. There has also been no significant increase in extreme precipitation events, which have been observed in the past as well as now. A declining trend in the number of days without precipitation has even been demonstrated at some precipitation stations. The problem of floods and droughts seems to be more complex and is related to changes in temperature, but especially to changes in land use. Water retention measures, land use change and a return to a nature-friendly economy appear to be the most appropriate measures to mitigate the effects of floods and droughts.

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