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Research Article

Precipitation Regime and Temporal Changes in the Central Danubian Lowland Region

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The aim of this paper is to investigate the statistical aspects of multiannual variability of precipitation at the Hurbanovo station, Slovakia, over 140 years (1872–2011). We compare the long-term variability of annual precipitation for Hurbanovo (Slovakia), Brno (Czech Republic), Vienna (Austria), and Mosonmagyarovar (Hungary) stations using autocorrelation and spectral analysis methods. From the long-term point of view, there is no consistent trend in the annual precipitation; only a multiannual variability has been detected. Consequently we identify changes in the distribution of annual maximum daily precipitation for Hurbanovo during different periods for winter-spring and summer-autumn seasons using histograms, empirical exceedance curves, and frequency curves of daily precipitation. Next, we calculate the periods of days without precipitation exceeding 29 days between 1872 and 2011. The longest period of days without precipitation was 83 days in 1947. The statistical analysis does not confirm our initial hypothesis that neither high daily precipitation (over 51.2 mm per day) nor long dry periods (more than 50 days without precipitation) would occur more frequently nowadays. We assume that the decrease in annual precipitation over the period 1942–2011 (compared to 1872–1941) is caused by the less frequent occurrence of daily precipitation between 0.4 and 25.6 mm.

1. Introduction

The issue of hydrological and meteorological extremes (floods and droughts) has received much attention in recent years. After catastrophic floods in Central Europe during the last 15 years (1997—Morava River, 2002, Czech Republic and Upper Danube River, 2008, Ukraine, 2010, Slovakia, 2013, Danube River) we need to focus on precipitation and flood risk assessment in this region [1–4]. On the other hand, in the course of the last decade 2001–2010, the year 2003 was extremely dry, with Central, South-Eastern, and Northern Europe being affected the most (Slovakia, Spain, Portugal, Switzerland, France, Italy, Netherlands, and Norway). This drought led to economic losses in agricultural production and extensive forest fires. The summer of 2010 was extremely dry in Russia, attended by a high number of wild fires directly around the capital Moscow. Simultaneously, the summer of 2010 was extremely wet in Slovakia. The regions of Central and South-Eastern Europe (including the whole Danube River basin) were affected by the extreme drought in the autumn of 2011 again. Mean annual precipitation from territory of Slovakia in the year 2003 was 573 mm while in the year 2010 was 1255 mm.

It is globally observed that air temperature parallels the increasing concentration of greenhouse gasses in the atmosphere, which is consequently reflected in the extremality in meteorological and hydrologic data. According to IPCC 2013 [5], in the long term, global precipitation will increase with increased globalmean surface temperature. Global mean precipitation will increase at a rate per degree celsius smaller than that of atmospheric water vapour. Changes in average precipitation in a warmer world will exhibit substantial spatial variation. Some regions will experience increases, other regions will experience decreases, and yet others will not experience significant changes at all. There is high confidence that the contrast of annual mean precipitation between dry and wet regions and that the contrast between wet and dry seasons will increase over most of the globe as temperature increases. For example Hanel et al. [6] analyzed changes in seasonal precipitation extremes using a number of transient regional climate models in the Czech Republic. Their results substantiate the hypothesis that climate change will be accompanied with a considerable increase in 1-day precipitation maxima and therefore also with the increasing severity of floods caused by precipitation of this duration. Klein Tank et al. [7] presented a dataset of climatic time series with a daily resolution that had been compiled for the European Climate Assessment & Dataset project (ECA&D). This ECA&D dataset contains 199 series of daily mean, minimum, and maximum temperature; 195 series of daily precipitation were observed at meteorological stations throughout Europe and the Middle East. Almost all series cover the standard normal period 1961–1990, and about 50% of them extend back to at least 1925. The study shows that the winter (October–March) warming in Europe between 1976 and 1999 was accompanied by a positive trend in the number of warm-spell days at most stations, but not by a negative trend in the number of cold-spell days. Instead, the number of cold-spell days increases over entire Europe. As for precipitation changes concerned, the mean precipitation depth per wet day predominantly increases over Europe between 1946 and 1999, both at stations with positive and negative trends in total winter precipitation amount. Boni et al. [8] analyzed the historical records of annual rainfall maxima recorded in Northern Italy, cumulated over time windows (durations) of 1 hr and 24 hrs, and considered paradigmatic descriptions of storms of both short and long durations and the probability of occurrence of extraordinary events over a period of one year. Their results confirmed the existence of a four-month dominant season that maximizes the occurrences of annual rainfall maxima. Their results also show how the seasonality of extraordinary events changes whenever a different duration of events is considered.

When evaluating long-term trends the used time series should be as long as possible. The study of Brunetti et al. [9] is aimed at describing precipitation behaviour over the last two centuries in a wide region centered on the European Alps. Moreover, it describes what can be analyzed if the full capacity of existing instrumental data is used, for a relatively small but climatologically interesting region at the border between different continental-scale European climate regimes. Auer and Böhm [10] and Auer et al. [11, 12] observed for Austria an increase in wet conditions in winter over the last 150 years and no uniform behaviour in the other seasons. On a yearly basis, they observed two separate tendencies in western and eastern parts of Austria; the former being characterized by an increase in wet conditions, while the latter being characterized by an increase in dry conditions. This behaviour is consistent with our results, since Austrian stations are split into both northern (NE) and southern (SW, and SE) regions, which have opposite precipitation tendencies.

Törnros [13] investigated how the detection of precipitation trends depends on the length of the chosen time period. Dahamsheh and Aksoy [14] analyzed annual precipitation data in Jordan, but did not find any trends at the 13 stations investigated for the years 1953–2002. Zhang et al. [15] concluded that precipitation trends in the Middle East are weak and not very significant. Samaj et al. [16] estimated the relationships between the North Atlantic Oscillation (NAO) index and precipitation and river flow over Northeast Turkey. It has been suggested that NAO may have a noticeable influence further east over the Mediterranean region. In Europe, a signal of disproportionately large changes in precipitation extremes has been apparent at stations where the annual mean precipitation increased during the latter half of the 20th century [17]. On the larger scale, in recent decades, those areas of the Earth's continents suffering from either very dry or very wet conditions have been increasing. According to New et al. [18], trends in observed annual and seasonal precipitation in Europe differ between northern and southern parts of the continent. Over the 20th century, the mean annual precipitation has increased in northern Europe and has decreased in southern Europe. They studied the precipitation variability and changes in the greater Alpine region over the 1800–2003 period, too. Pronounced increase in autumn and winter precipitation in the latter part of the 20th century has been observed over northern Europe and western Russia.

The research presented in this paper is motivated by the fact that the last complex nation-wide frequency analyses of precipitation in Slovakia were presented in the 1960s and mid-1980s [16, 19, 20]. Since then, much broader and reliable records of daily precipitation have become available and accessible in the database of the Slovak Hydrometeorological Institute (SHMI). In the last couple of years, several studies of precipitation frequency have been published applying the new regional statistical methods and mostly focusing on larger catchments in Slovakia, [21–25]. Those authors used data since 1950, rarely since 1901. For that reason we decided to complete the daily data series at Hurbanovo station since 1872.

2. Materials

2.1. Description of Study Area and Data. The meteorological station at Hurbanovo (with its former name Ógyalla) is a representative station for the relatively arid region of the Danubian lowland region (Figure 1). The Hurbanovo station (latitude 47.9°N; longitude 18.2°E, $H = 115$ m a.s.l.) ranks among the best meteorological stations in Central Europe providing sufficiently long, high quality, and homogenous observations. The meteorological observatory is situated in the large garden on the northern edge of the small city of Hurbanovo. Regular measurements of the air temperature T [°C] and precipitation P [mm] started in 1876 at this station [26]. The period 1871–1875 was completed according to the Komarno station (distance of 20 km from Hurbanovo). According to Petrovic [26], precipitation totals were measured by different devices within the limits of observation errors. Precipitation series since 1871 to 1900 for this study were acquired from historical archives of the SHMI. The data covering the period after 1901 (up to 2011) were obtained from current SHMI database. Additional data series of annual and

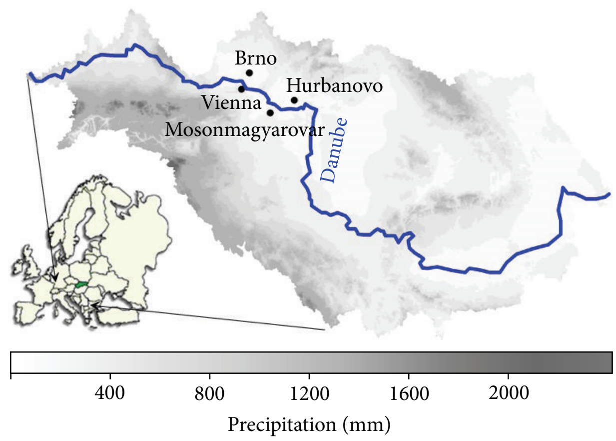

Figure 1: The Danube River basin, location of the meteorological stations at Hurbanovo, Mosonmagyarovar, Vienna, and Brno. Average annual precipitation depths throughout the Danube River basin during the period 1960–1990 according to Petrovic et al. [19].

monthly precipitations were used for the long-term trend and spectral analysis from other three stations within the Central Danube region: Brno (1803–2011), Czech Republic; Vienna (1841–2011), Austria; and Mosonmagyarovar (1861–2011), Hungary. The historic monthly precipitation data series were obtained from the HISTALP database [27].

3. Methods

3.1. Homogeneity Testing. Homogenization of time series is widely recognized to be an important step in the process of constructing reliable long-term data sets from original climate observations. The Hurbanovo meteorological station is one of the oldest stations in Europe. From among all the stations with long series of observations in Slovakia published in the Catalogue of WMO [28], the Hurbanovo station is now the only station with an unaltered original location [29].

We used the AnClim software [30, 31] to test the absolute homogeneity of the annual precipitation series at the Hurbanovo station (1872–2011). Changes in the mean values and variance were tested with different tests (Student's t-test, Worsley Likelihood Ratio Test, Mann-Whitney-Pettit Test, and Standard Normal Homogeneity Test). In Figure 2(a) the test characteristics *Ti* of the Standard Normal Homogeneity Test (SNHT) for shift in mean [32, 33] is shown. The test characteristic *Ti* is just above its critical value 9.35 on the 95% confidence level in year 1966. The test characteristics of the changes in standard deviation are similar. Actually, "absolute homogeneity" of long time series is always questionable. The nonhomogeneity may result from change in the long-term trend, as it is shown in Figure 2(b).

The relative homogeneity was tested using the Standard Normal Homogeneity Test for two stations [30, 34, 35]. In our case, the precipitation series from Mosonmagyarovar, Vienna, and Brno stations were used as a reference station; Hurbanovo precipitation series was used as candidate stations. The test characteristics *Ti* of the changes did not exceed in any case the critical value of 9.35 on the confidence level 95% (Figure 2(c)). Based on the results of homogeneity testing, we can declare that the annual precipitation series of Hurbanovo is homogeneous.

The statistical processing in this study was done using the software packages EXCEL, STAGRAPHICS, CTPA, and BestFit [36].

The aim of this study is to apply long-term trend, autocorrelation, and spectral analysis to annual precipitation series and frequency analysis to daily precipitation series observed at the meteorological station Hurbanovo during the period 1872–2011 in order to investigate their long-term trend and multiannual variability.

3.2. Trends versus Long-Term Variability of Dry and Wet Periods of Annual Precipitation. Already more than 50 years ago, during the Nasser (Aswan) dam design on the Nile-Hurst, [37] expressed the opinion that the whole Earth climatic system is subject to long-term oscillations. By studying more than 900 time series of various data (Nile water levels of more than 790 years, dendrochronological series, sediments of seas and lakes, etc.), he observed a particular behaviour of these geophysical time series, which has become known as the "Hurst phenomenon." This term refers to the tendency of the dry and wet years to cluster together into multiannual dry and wet periods. The basic mathematical expression of this phenomenon can be written as

$$\frac{R_n}{S_n} = \left(\frac{n}{2}\right)^h, \tag{1}$$

where R_n is the range of partial sums of deviations from the arithmetic mean of a time series, and S_n is the standard deviation of the time series with length n. Coefficient h denotes the Hurst coefficient. The Hurst exponent of 0.5 will correspond to a time series that is truly random. On the basis of a study of several annual time series, Hurst found h to have an average value of 0.73 [38].

3.3. Frequency Analysis of the Hurbanovo Daily Precipitation Series in Different Periods. Frequency analysis is a technique that is often used to estimate the design values of extreme hydrological or climatologic events (extraordinary floods, precipitation depths, drought-meteorological, and hydrological), and it has intensively been discussed in the environmental literature for the last decades.

In the study we are focused on

(i) comparison of daily precipitation for different time periods,

(ii) analysis of maximum annual 24-hour precipitation series,

(iii) the assessment of periods without precipitation longer than 29 days.

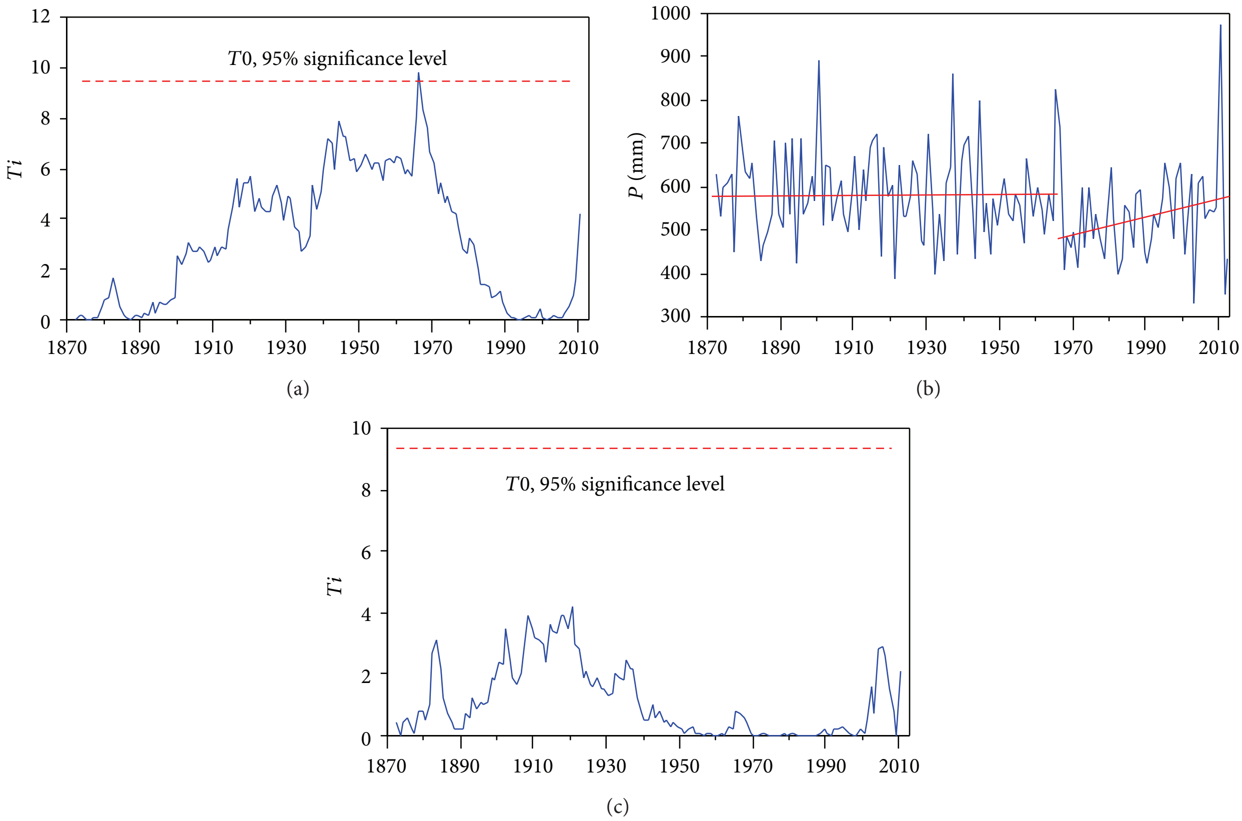

FIGURE 2: (a) Absolute homogeneity test of annual precipitation series for the Hurbanovo station, changes in the mean level, and values of the test statistics *Ti* on *y*-axis. (b) Long-term trend for two periods 1872–1966 and 1967–2011. (c) Relative homogeneity test, SNHT for Hurbanovo and Mosonmagyarovar.

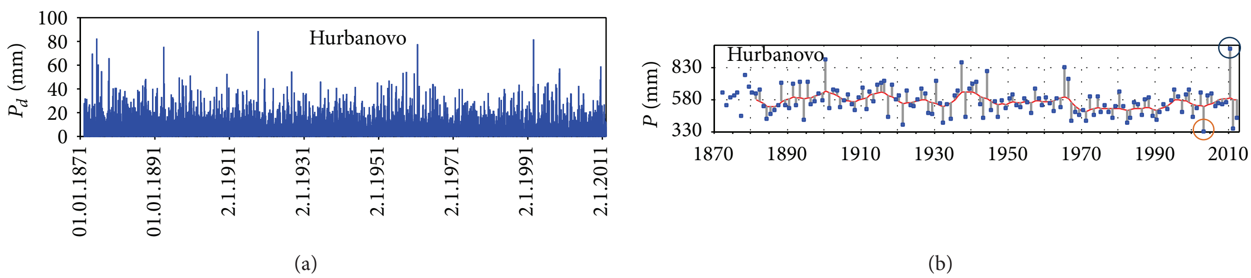

FIGURE 3: (a) Daily precipitation measured at the Hurbanovo station, period 1872–2011; (b) deviations from 7-year moving averages of the annual precipitation.

4. Results

4.1. Trends versus Long-Term Variability of Dry and Wet Periods of Annual Precipitation. The daily precipitation series for the Hurbanovo station are shown in Figure 3(a). The graphical depiction of filtered annual precipitation (Figure 3(b)) shows multiannual cycles of dry and wet periods in the series. Hurst coefficient of the precipitation series for the Hurbanovo station is 0.697, which endorses the hypothesis of the existence of a significant long-term periodic component (Table 1).

The period 1981–1990 was the driest decade in the history of the precipitation observed at the Hurbanovo station (Figure 4). The nearby meteorological stations (Mosonmagyarovar, Vienna, and Brno) testify that low precipitation periods occurred before the year 1871 as well. The best example of precipitation long-term trend is visible in the series from the meteorological station at Brno (Czech Republic). The time period between 1803 and 1830 was most likely exceptional in terms of precipitation in the Danubian lowland region. We approximated the long-term trend by the linear function and by polynomial of the 4th degree. Markedly drier periods occurred after 120–140 years. Comparing to the other three stations, one could suppose that the precipitation was lower at the Hurbanovo station before 1870, too. In Slovakia, there were no observations of precipitation made prior to 1870, and

Table 1: Basic characteristics of the annual precipitation series at the Hurbanovo station, P_a—mean annual precipitation in mm, st. dev.—standard deviation, P_{min}—minimum annual precipitation, P_{max}—maximum annual precipitation, cs—coefficient of asymmetry, and cv—coefficient of variation.

	P_a	St. dev	P_{min}	P_{max}	cs	cv	Median	Hurst coeff.
1872–2011	567	105	333	972	0.73	0.19	553	0.697

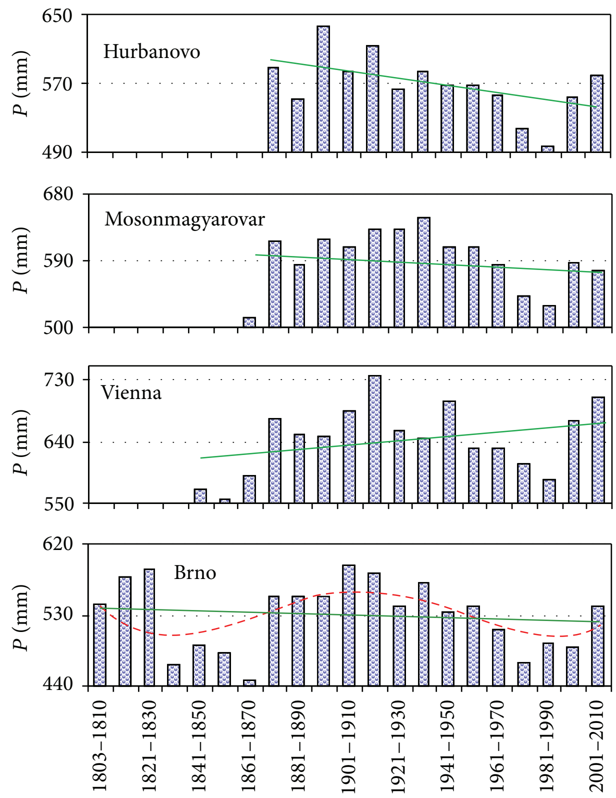

Figure 4: 10-year average of precipitations at Hurbanovo (1872–2010), Mosonmagyarovar (1861–2009), Vienna (1841–2009), and Brno (1803–2010); green line is the long-term trend of precipitation and red curve is the long-term trend by a polynomial of the 4th degree.

hence we can only speculate if the precipitation was also as low as at the other three stations in the region. However, we can support this hypothesis only with the assistance of historical archives providing information on the occurrence of especial events.

Generally, while floods occur in wet periods more frequently, a higher number of fire events is noticed in drought periods. Historical records of fire events in the territory of Slovakia confirm that the time period 1850–1875 was exceptionally dry. After the year 1860, as a consequence of frequent fire events, voluntary fire brigades in the Austria-Hungary Empire were established. In 1863, after the large fire events, additional fire brigades were established in the cities of Bratislava, Trnava (1868), and Nitra (1869).

4.1.1. Autocorrelation and Spectral Analysis. Multiannual variability within the annual precipitation series was studied by means of autocorrelation and spectral analysis [37, 39]. Long periods were identified using Blackman-Tukey power spectrum, MESA method, and combined periodograms (Figures 5(a)-5(b)). It is clear from Figure 5(c) that multiannual wet and dry periods take turns in the series of precipitation. Significant multiannual cycles of durations 2.35-; 3.64-; 5-; 7-; 12.8-; 21–23; and 60 years were identified in the precipitation series for the Hurbanovo station. These cycles were identified in several other data series in Slovakia, Europe, and elsewhere around the globe [9, 40, 41]. The 22-year cycle is probably related to the activity of the Sun [42] and 2.35-year cycle can be related to the QBO (Quasi-Biennial Oscillation) phenomenon.

4.1.2. Changes in the Variation of Intra-Annual Precipitation. Changes in the intra-annual distribution of precipitation at the Hurbanovo station for two time periods, 1871–1940 and 1941–2010, are depicted in Figure 6(a) (left). In [43] we identified the changes in daily precipitation distribution at Hurbanovo observatory in different 30-year periods for winter-spring and summer-autumn seasons using daily precipitation time series 1901–2005. In this study we compare 20-year periods rather then 30-year ones as usual, in order to analyze the last 20-year period from 1992 to 2011. Concurrently we verify whether we have ever experienced a similar 20-year period. The shift of monthly precipitation by one month is apparent between the two periods at Hurbanovo station. Maximal monthly precipitation did not occur in May, as was the case for the period 1871–1940, but rather occurred in June. Monthly average precipitation for two time periods at the Mosonmagyarovar station is different as opposed to monthly precipitation in Vienna, which is similar. At the Brno station, on the other hand, the intra-annual distribution of precipitation is nearly identical for two 100-year periods (1806–1905 and 1906–2005). Although the changes at this station are not significant, the occurrence of maximum monthly precipitation seems to have changed slightly (from August in the first 100-year period to July in the second 100-years period). 200-year series of precipitation at the Brno station was used because it is the longest available time series in this region.

Next, we divided each of the precipitation time series from the four meteorological stations into two seasons: cold half-year (October to March—X–III) and warm half-year (April to September—IV–IX). The seasonal moving averages of precipitation are shown in Figure 6(b) (right), for summer-autumn and winter-spring seasons. It is evident that from the long-term point of view there are some cycles in the precipitation series, which are identical in all selected stations.

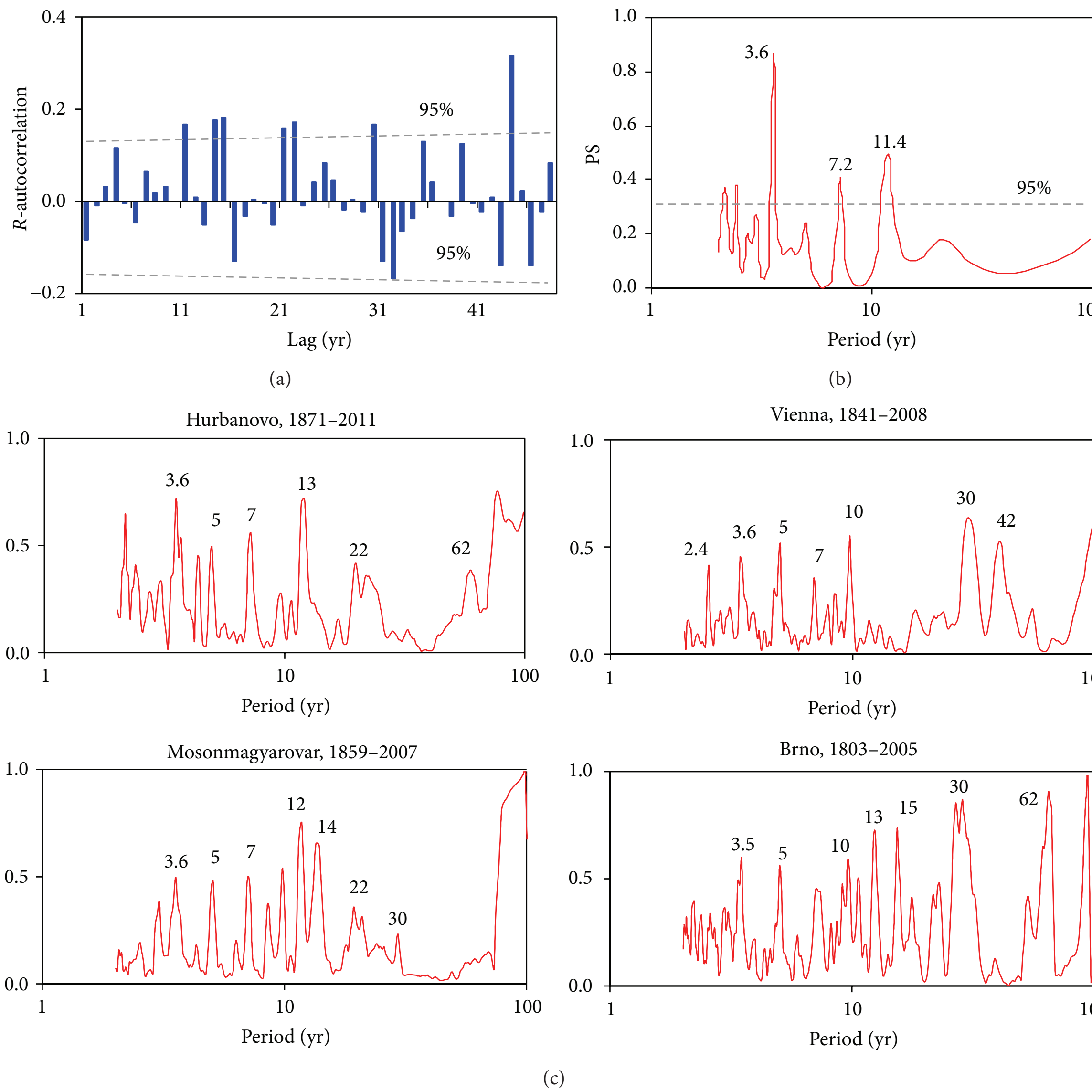

Figure 5: (a) Autocorrelation coefficients R, confidence limits 95%; (b) Normalized power spectrum, method MESA, confidence limit 95%. Hurbanovo 1872–2011 (output by AnClim). (c) Normalized power spectrum, PS, combined periodogram of the annual precipitation series for the analyzed stations.

4.2. Frequency Analysis of the Hurbanovo Daily Precipitation Series in Different Periods

4.2.1. Comparison of Daily Precipitation for Different Time Periods. We analyzed the time series of daily precipitation for the Hurbanovo station in terms of the number of days with no precipitation and days with precipitation depth above 0.1 mm and then with respect to the number of days with various precipitation depths (Figure 7). Two time periods of daily precipitation were considered (1872–1941 and 1942–2011). The total number of days with precipitation per year in the individual classes for the two different time periods is presented in Table 2. Boundaries (in mm) of each class were determined according the function: $n_{i+1} = 2 \cdot n_i$ where $n_0 = 0.1$; $i = 0, 1, 2, \ldots, 10$. The differences between periods are minimum. We used the Kolmogorov-Smirnov test to compare the distributions of the two samples. Since the P value was greater than 0.05, there is no statistically significant difference between the two samples at the 95.0% confidence level.

A comparison of the frequency curves of daily precipitation for two time periods is given in Figure 8 for the Hurbanovo station in the cold half-year and the warm half-year. The distributions of maximum annual precipitation change neither in the winter nor in the summer season.

In Table 3 we compare the statistical characteristics of the period 1992–2011 to other twenty-year periods: 1872–1891; 1892–1911; . . ., 1972–1991. From these characteristics it follows that the period 1882–1901 has similar characteristics as the period 1992–2011.

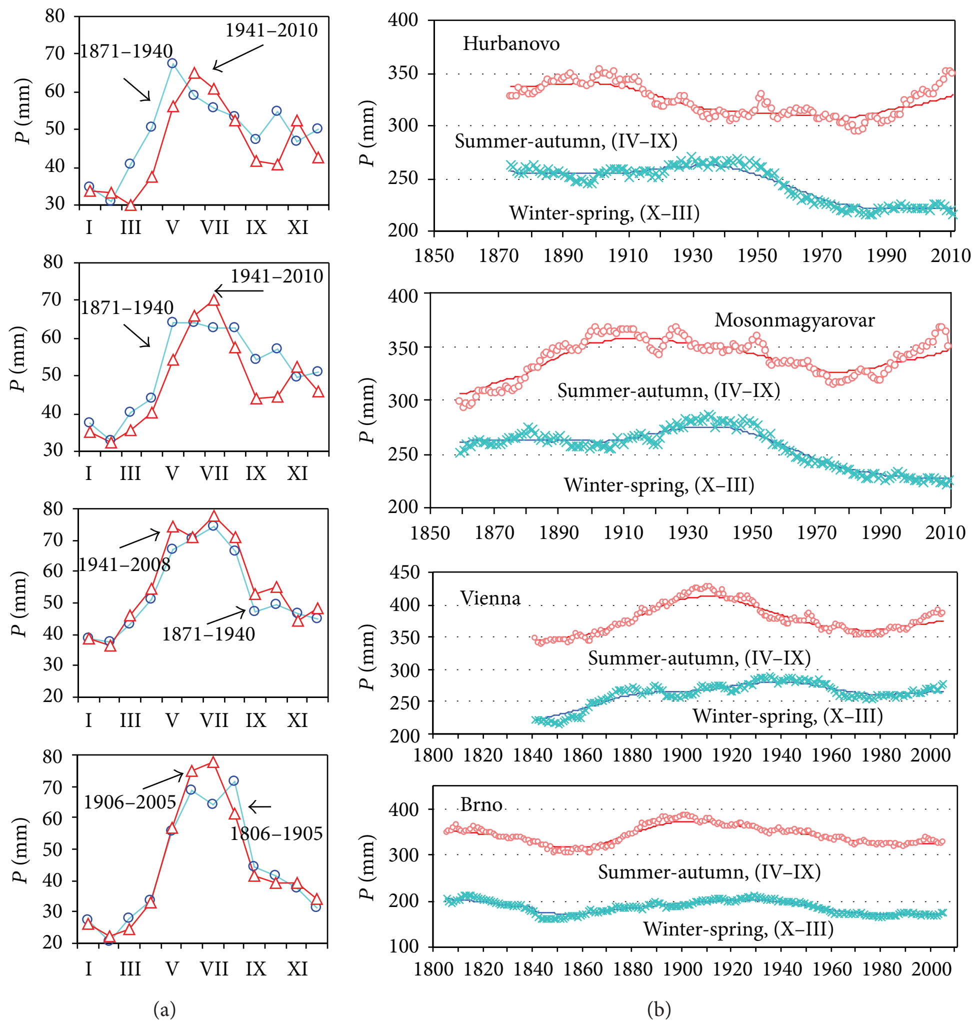

Figure 6: (a) Annual precipitation cycle for two time periods. (b) Course of 30-year moving averages precipitation for warm half-year (April to September) and cold half-year (October to March) at Hurbanovo, Mosonmagyarovar, Vienna, and Brno precipitation stations.

Table 2: Total number of days with precipitation depths in the individual classes over two different periods: 1872–1941 and 1942–2011.

Frequency	1872–1941	1942–2011
<0.1	17112	17196
0.1–<0.2	507	584
0.2–<0.4	663	799
0.4–<0.8	1022	1029
0.8–<1.6	1257	1192
1.6–<3.2	1429	1436
3.2–<6.4	1566	1485
6.4–<12.8	1266	1196
12.6–<25.6	659	564
25.6–<51.2	130	131
51.2–<102	9	8

Finally we tested the null hypothesis that the daily precipitation in the periods 1892–1911 and 1992–2011 (for warm half-year and cold half-year) results from the same distribution. We tested the changes in the mean value and in the standard deviation. We cannot reject the zero hypothesis on the 0.05 significance level that both periods have the same mean value for any of the seasons.

In Slovakia, several authors dealt with areal, regional, and temporal analysis of precipitation patterns in Slovakia during the period 1901–2000 [44–46]. The theory of increased daily precipitation extremality has not been clearly proved by analyses of observed data for the Hurbanovo station, yet. Brunovsky et al. [2] have studied several methodologies of defining extreme events. Yearly averages of daily precipitation totals appear to be stationary; number of rainy days was lower and rainfalls were heavier at the beginning and at the end of the last century, and distribution of heavy rainfalls in the period from 1901 to 2006 is quite uniform. Our results show

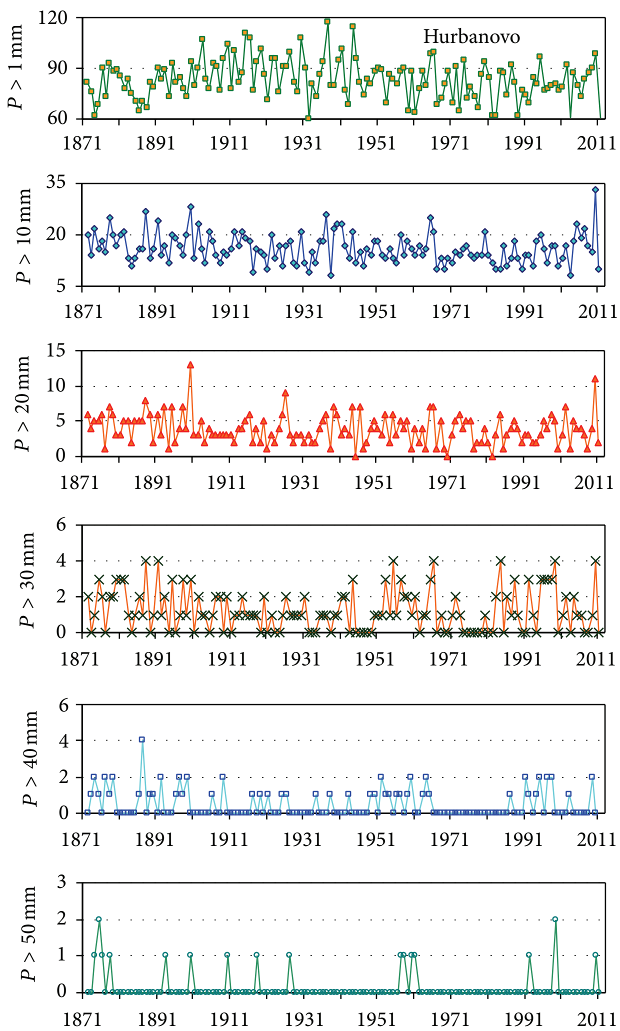

FIGURE 7: Number of days with precipitations above 1, 10, 20, 30, 40, and 50 mm. Hurbanovo 1872–2011.

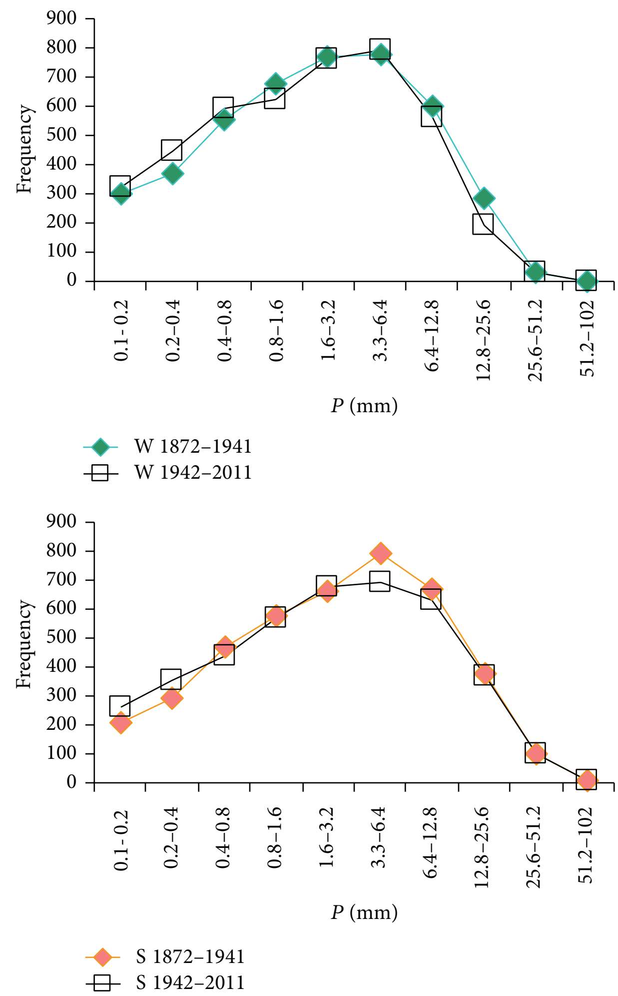

FIGURE 8: Comparison of frequency curves of daily precipitation for Hurbanovo in cold half-year (W) and warm half-year (S) for two time periods: 1872–1941 and 1942–2011.

that after the dry period lasting for two decades (1972–1991) we can consider the period 1992–2011 as a very extreme one. Our analysis of the precipitation series for the Hurbanovo station shows that the same precipitation conditions we experience today were observed in the past at Hurbanovo (1892–1911) and possibly in the broader region, as well.

4.2.2. Maximum Annual 24-Hour Precipitation Series. Considering the lengths of daily precipitation data for the Hurbanovo station (1872–2011), we compared the maximum annual 24-hour precipitation during the whole period and separately for the cold half-year and warm half-year, (Figure 9). The trends indicate a moderate decrease in the maximum annual 24-hour precipitation series.

In the Figure 10 the changes in theoretical distribution curves (log-Pearson type III) of maximum daily precipitation in Hurbanovo station of two 70-year periods are graphically presented. During the first period (1872–1941) 100-year precipitation (P_{100}) was 99 mm and 1000-year precipitation (P_{1000}) was 62 mm. P_{100} in the second period (1942–2011) was 89 mm and P_{1000} was 142 mm.

4.2.3. The Assessment of Periods without Precipitation Longer Than 29 Days. The last goal of the study was the assessment of periods without precipitation longer than 29 days. The Slovak meteorologists consider this period as a certain threshold of the drought, at the Central Danube region. In the evaluation of extreme dry periods we resumed the analysis done by Petrovic [26]. We calculated the periods of days without precipitation longer than 29 days in the series of daily precipitation for the period 1872–2011. The dates of occurrence of periods without precipitation longer than 29 days and number of days without precipitation for the Hurbanovo station are listed in Table 4. Number of periods without precipitation longer than 29 days in individual decades for Hurbanovo is presented in Figure 11. The longest period of days without precipitation was 83 days in 1947. The periods without precipitation longer than 29 days had occurred

Table 3: Statistical characteristics of the selected twenty-year periods of the daily precipitation of the whole year and warm and cold half-years.

	1872–1891	1892–1911	1912–1931	1932–1951	1952–1971	1972–1991	1992–2011
Whole year							
Average	5.79	**4.49**	3.99	3.99	4.12	3.95	**4.38**
Standard deviation	7.50	**6.23**	5.78	5.73	6.22	5.55	**6.52**
Variance	56.25	**38.81**	33.39	32.82	38.74	30.84	**42.48**
Maximum	82.50	**75.50**	88.80	46.20	77.70	43.60	**81.80**
Skewness	3.20	**3.23**	3.68	2.65	3.57	2.71	**3.53**
Kurtosis	16.47	**16.87**	25.82	8.98	20.09	9.54	**19.98**
Count	2022	**2645**	2957	2899	2671	2580	**2574**
Warm half-year							
Average	6.29	**5.16**	4.72	4.75	4.90	4.64	**5.51**
Standard deviation	8.44	**7.08**	6.84	6.72	7.22	6.39	**7.92**
Variance	71.23	**50.15**	46.83	45.18	52.11	40.81	**62.80**
Maximum	82.50	**75.50**	88.80	46.20	77.70	43.60	**81.80**
Skewness	3.24	**3.20**	3.68	2.45	3.35	2.52	**3.17**
Kurtosis	15.76	**16.27**	24.18	7.14	17.31	7.75	**15.29**
Count	1065	**1312**	1398	1291	1277	1281	**1234**
Cold half-year							
Average	5.23	**3.83**	3.33	3.38	3.41	3.27	**3.33**
Standard deviation	6.25	**5.18**	4.52	4.70	5.05	4.48	**4.64**
Variance	39.05	**26.80**	20.46	22.07	25.46	20.11	**21.54**
Maximum	60.50	**41.10**	36.70	41.70	47.00	36.10	**44.30**
Skewness	2.60	**2.79**	2.58	2.49	3.44	2.59	**2.98**
Kurtosis	11.13	**10.46**	8.95	7.95	17.76	8.80	**13.17**
Count	957	**1333**	1559	1608	1394	1299	**1340**

usually 5-6 times in each decade. Dry periods longer than 50 days occurred 7 times during the 130 years of observation.

5. Conclusions

Precipitation is a principal component of the water cycle, so that understanding its regime may be of profound social and economic significance. The detection of oscillations in precipitation time series yields important information for understanding the climate. From the analysis of precipitation series at Central Danubian lowland region, it can be concluded that

(i) in the Danubian lowland region, the driest decade was between 1981 and 1990, and the wettest decade was between 1891 and 1900;

(ii) prior to 1870, the climate in the Danubian lowland region was probably even drier than between 1981 and 1990;

(iii) from the long-term point of view (above 180 years), there is no consistent trend in the annual precipitation and the trend is increasing or decreasing according to the time period which is being evaluated and only a multiannual variability has been detected in the analyzed time series;

(iv) the precipitation time series contain 3.5, 5, 7, 10, 13, 22, and 30-year cycles;

(v) the seasonal precipitation fluctuates in multiannual cycles, too;

(vi) the frequency analysis did not confirm changes in the statistical characteristics of daily precipitation at the Hurbanovo station;

(vii) neither high daily precipitation (over 51.2 mm per day) nor long dry periods (more than 50 days without precipitation) occur more frequently nowadays;

(viii) the decrease in annual precipitation over the period 1942–2011 (compared to 1872–1941) is caused by the less frequent occurrence of daily precipitation between 0.4 and 25.6 mm.

According to Slovak climatologists [23, 29] the climate in the Danubian lowland transformed from warm and dry to warm and very dry in the 20th century. Recently climate in this region began to show some features typical for the Mediterranean region. A more detailed investigation of the precipitation series, possibly air temperatures as well, has to be done in order to correctly assess the water runoff in the future. The analysis of precipitation is useful, but it is not a substitute for the analysis of stream flow or groundwater levels. We need to be careful that we do not assume that observed or projected changes in precipitation will translate

Table 4: Date of occurrence of periods without precipitation (above 0.9 mm) longer than 29 days and number of days without precipitation at Hurbanovo station (first column: 1872–1941; second column: 1942–2011).

Date of occurrence 1872–1941	Duration [day]	Date of occurrence 1942–2011	Duration [day]
20.XII.1873	46	26.VII.1947	83**
22.XII.1881	58*	10.II.1949	33
8.I.1887	42	2.III.1950	32
2.XII.1888	39	6.IV.1952	30
8.II.1889	41	5.III.1953	35
28.I.1890	33	7.XI.1953	50*
27.X.1892	36	10.I.1959	42
18.I.1896	37	13.IX.1961	35
1.XII.1897	38	30.IX.1965	35
4.II.1913	34	7.IX.1966	36
22.X.1920	30	21.I.1968	35
8.III.1921	38	29.VIII.1969	57*
19.IX.1921	34	28.VII.1973	30
5.XII.1924	56*	25.III.1975	41
24.VIII.1926	34	9.III.1976	44
28.II.1929	31	23.X.1978	35
10.VI.1932	30	6.V.1979	32
3.VIII.1932	50*	27.III.1981	31
17.VII.1933	31	18.X.1983	39
		10.IX.1985	34
		8.X.1988	36
		9.I.1989	40
		1.I.1991	36
		13.II.1991	34
		14.VII.1992	49
		5.I.1997	38
		23.I.1998	41
		5.II.2003	59*
		14.X.2005	34
		20.IX.2006	34
		17.XII.2006	43
		25.III.2007	40
		25.X.2011	38

simply or directly to changes in stream flow [47]. According to [48] the reconstruction efforts in climate sciences provide a template for an effort in hydrologic reconstruction, which might be anticipated to provide the same benefits to hydrologists analyzing changing systems: (i) the generation of baseline data against which to evaluate contemporary changes; (ii) analysis of natural variability and long-term cycles affecting hydrological systems; (iii) investigation of hydrological influence on human societies in historical contexts; (iv) evaluation of the nature and magnitude of changes that have been imposed on basins over prehistorical and historical timescales, and assessment of the sensitivity and response of hydrological systems to these changes; and (v) generation of data sets against which to evaluate and improve models of hydrological systems over timescales that exceed the length of the instrumented record. Even thorough knowledge of the past can help us in estimating the impact of climate change on water resources capacity in the future.

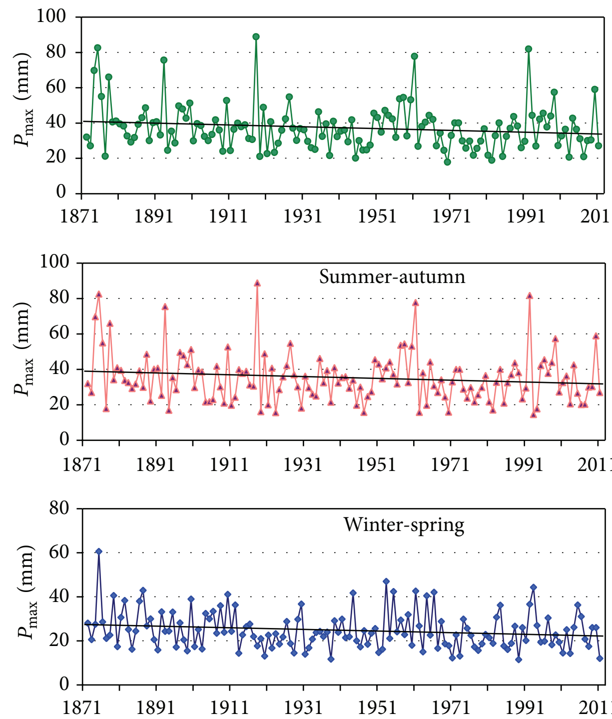

Figure 9: Maximum annual 24-hour precipitation (P_{max}) at the Hurbanovo station during the period 1872–2011, whole year, warm half-year, and cold half-year. The black line is the linear trend of the maximum annual 24-hour precipitation.

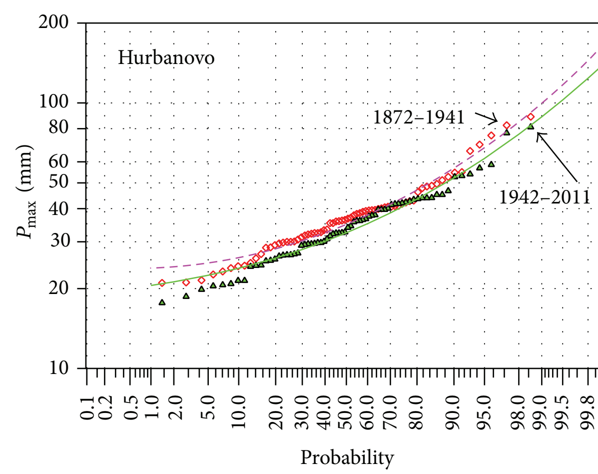

Figure 10: Empirical and theoretical (log Pearson type III) distribution curves of maximum annual 24-hour precipitation; comparison of two periods 1872–1941 and 1942–2011.

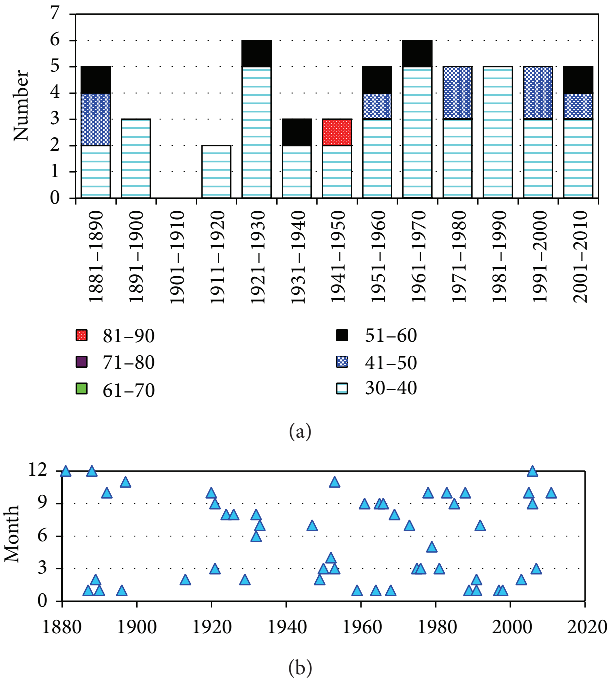

Figure 11: Number of periods without precipitation longer than 30, 40, 50, 60, 70, and 80 days during individual decades at the Hurbanovo station (a), month of drought occurrence (b).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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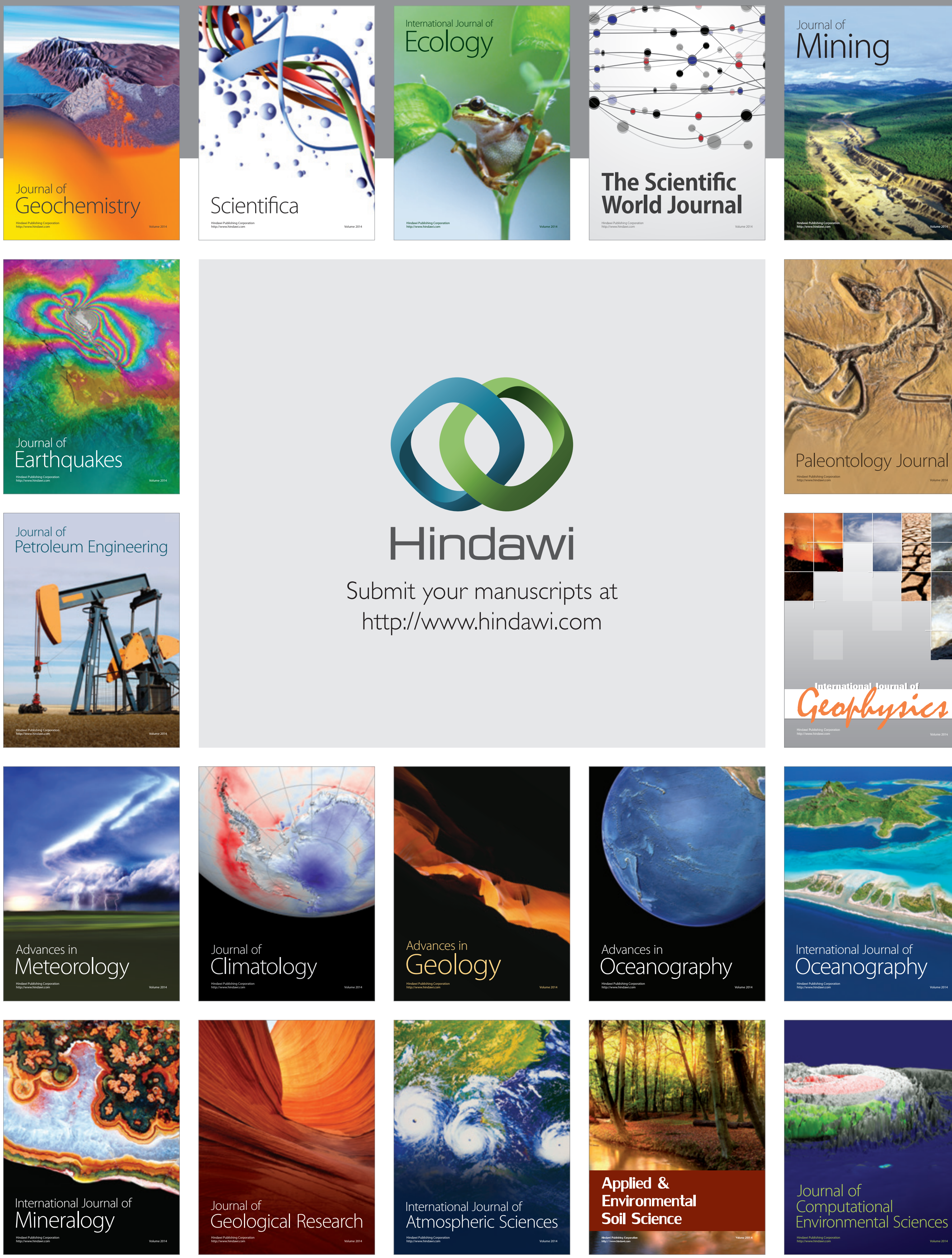

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