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Trends, Variability, and Seasonality of Maximum Annual Daily Precipitation in the Upper Vistula Basin, Poland

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Received: 29 June 2018; Accepted: 9 August 2018; Published: 10 August 2018

Abstract: The aim of this study was to detect trends in maximum annual daily precipitation in the Upper Vistula Basin. We analyzed data from 51 weather stations between 1971 and 2014. Then we used the Mann–Kendall test to detect monotonical trends of the precipitation for three significance levels: 1, 5, and 10%. Our analysis of weather conditions helped us describe the mechanism behind the formation of maximum annual daily precipitation. To analyze precipitation seasonality, we also used Colwell indices. Our study identified a significant trend of the highest daily precipitation for the assumed significance levels (0.01, 0.05, 0.1) for 22% of the investigated weather stations at different elevations. The significant trends found were positive and an increase in precipitation is expected. From 1971 to 2014, the maximum daily total precipitation most often occurred in the summer half-year, i.e., from May until September. These months included a total of 88% of days with the highest daily precipitation. The predictability index for the highest total precipitation within the area was high and exceeded 5%. It was markedly affected by the coefficient of constancy (C) and to a lesser degree by the seasonality index (M). Our analysis demonstrated a convergence of the Colwell indices and frequency of cyclonic situation and, therefore, confirmed their usability in the analysis of precipitation seasonality.

Keywords: linear trend; atmospheric circulation; precipitation seasonality

1. Introduction

In recent years, there has been an increased frequency of extreme or anomalous atmospheric events of variable reach and duration such as intense rainfalls [1,2] or prolonged rainless periods [3]. The main goal of the presented studies was analysis of atmospheric precipitation with different time scales. The trends of precipitation were observed but not always statistically significant. Additionally, the studies did not confirm clear increase trends in flows together with an increase of precipitations. The rainfalls lead to sudden floods in the rivers and streams and flooding of urban areas as the sewerage networks lose their hydraulic capacity [4] while the rain-free periods result in droughts. Both phenomena bring about substantial damage and material loss to technical infrastructure and agriculture. Researchers try to find the reasons for the occurrence and intensification of the extreme weather events. The number of studies about their quantitative assessment and probabilistic variability in the context of their prediction has been growing rapidly [5–9].

Being able to predict changes in precipitation characteristics is crucial for assessing water resources in selected areas. Recent years brought about many studies focused on trends in extreme rainfalls in various regions of the world [10–16]. The results of these analyses reviewed by Rana and Moradkhani [17] clearly indicated a significant increase in the depth of extreme precipitation in North America. Jakob and Walland [18] demonstrated a relatively constant level of the highest daily precipitation in Australia. A study by Soro et al. [19] showed a significant drop in the highest daily precipitation in the West Africa. Contrary to that, Agilan and Umamahesh [20] confirmed a hypothesis assuming an increase in extreme precipitation of variable duration in Southern Asia. Trends in the highest daily precipitation in Europe were analyzed by Madsen et al. [21] who established a general growth in the extreme precipitation but without any clear trends in enlarging maximum flows.

Extreme precipitation is characterized by high temporal and spatial variability. Recent years have witnessed a considerable growth in the number of studies on precipitation seasonality triggered by ongoing climate changes. These trends were studied both on a global and regional scale [22–26]. Seasonal analysis of precipitation in Central Europe showed its slight increase in the spring and autumn and a decline in the summer and winter. A positive trend in total precipitation was only noticed in March. Skowera et al. [27] observed a significant growth in the trends of total precipitation for selected weather stations in Opole region, Poland for the summer half of the year. Despite the lack of significant trends in the remaining months, seasonal variability of rainfall is definitely on the increase. The precipitation variability occurring in Central Europe depends mostly on atmospheric circulation that determines predominance of continental or oceanic weather trends and shapes the global or regional climate [28].

Considering the remarks presented above, the aim of this study was to evaluate frequency and trends of changes in the highest total precipitation in the Upper Vistula Basin, southern Poland. We also identified the main types of atmospheric circulation and suggested a novel research approach consisting of linking the type of the atmospheric circulation that determines the occurrence of the annual maximum daily precipitation with seasonality indicators of the precipitation.

2. Data and Methods

The study area comprised the Upper Vistula Basin. It accounts for about 25% of the entire Vistula Basin and about 15% of Poland's area and occupies the southeastern region of the country. It covers part of the Carpathians, the Subcarpathian valleys, and Małopolska Uplands. The study area shows large variations in elevation. This determined the depth of precipitation and its extreme values [29]. Input data included total daily precipitation recorded in the years between 1971 to 2014 at 51 weather stations located in the Upper Vistula Basin for which data continuity was maintained. The data were obtained from the Research Institute of Meteorology and Water Management in Warsaw. The Upper Vistula Basin and weather stations are depicted in Figure 1.

The study included the following steps: significant verification of the monotonic trend for the annual maximum daily precipitation, analysis of the weather conditions' impact on the occurrence of the highest daily precipitation, and seasonality analysis of the annual maximum daily precipitation.

2.1. Significance Verification of the Trend for the Highest Daily Total Precipitation

Assessment of the trends observed for the quality indicators was carried out on a monthly scale using the nonparametric Mann–Kendall test [30–33]. The test is commonly employed to detect monotonic trends in a series of environmental, climate, or hydrological data. The null hypothesis, H_0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_A, is that the data follow a monotonic trend. The Mann–Kendall test statistic is calculated according to the equation

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{1}$$

where n is the number of data records.

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 \text{ for } (x_j - x_i) > 0 \\ 0 \text{ for } (x_j - x_i) = 0 \\ -1 \text{ for } (x_j - x_i) < 0 \end{cases} \tag{2}$$

The standardized MK test statistic (Z) can be estimated by the equation

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{V}(S)}} \text{ if } S > 0 \\ 0 \quad\quad\; \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{V}(S)}} \text{ if } S < 0 \end{cases} \tag{3}$$

where $\mathrm{V}(S)$ is the the variance of S.

$$\mathrm{V}(S) = \frac{[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]}{18} \tag{4}$$

where t denotes the number of ties up to sample i.

The statistic S is closely related to the Kendall's one, which is given by the formula

$$\tau = \frac{S}{D} \tag{5}$$

$$D = \left[0.5n(n-1) - 0.5\sum_{j=1}^{p} t_j(t_j - 1)\right]^{1/2} \cdot [0.5n(n-1)]^{1/2} \tag{6}$$

where p is the number of the tied groups in the data set and t_j is the number of data points in the j-th tied group. A positive value of S indicates an 'upward trend' and a negative value indicates a 'downward trend'. S = 0 indicates no trend. If the autocorrelation and/or partial autocorrelation plots of the time series of indicators revealed the presence of significant temporal dependence in the data across years, the Mann–Kendall test in conjunction with the block bootstrap method should be used. In analyzed observation series, no cases with autocorrelation were found.

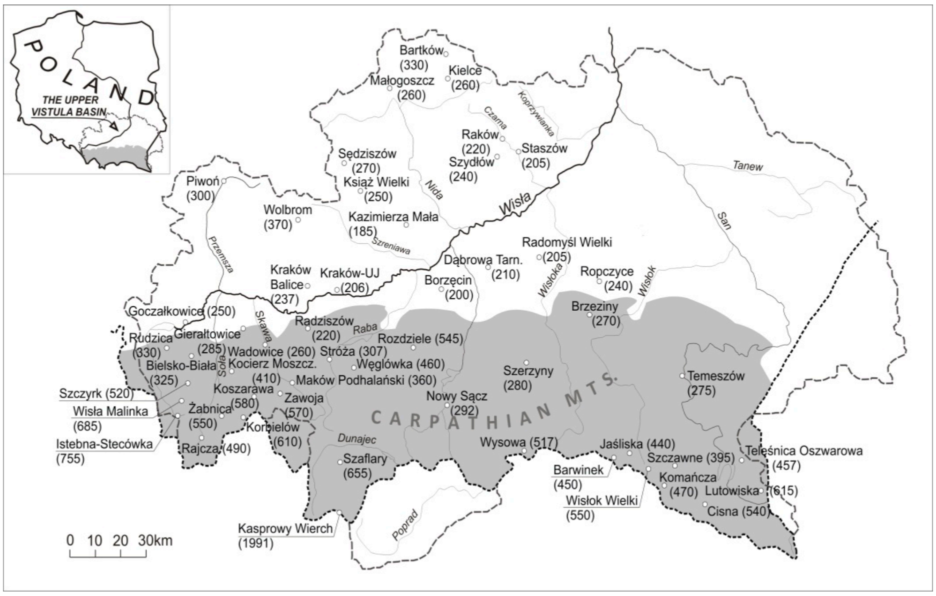

Figure 1. Location of the Upper Vistula Basin and weather stations (number indicates the elevation of station in meters above sea level).

2.2. Analysis of Weather Conditions' Impact on the Occurrence of the Highest Daily Precipitation

We analyzed the annual maximum daily precipitation for individual months. Effects of the circulation forms on the occurrence of the highest daily precipitation were assessed based on a calendar of synoptic circulations developed by Niedźwiedź [34,35] for Southern Poland. The calendar was drawn up using MSL weather maps of Europe for 00 and 12 UTC. It also accounted for the pressure maps at 700 hPa. The classification prepared by Niedźwiedź [34,35] contains a list of 21 types of atmospheric circulation, weather fronts, and types of air masses. The calendar of circulation types includes 16 types of weather situations marked with letters denoting the advection vector and with an index 'a' for anticyclonic and 'c' for cyclonic systems. The other four types (Ca, Ka, Cc, Bc) are non-directional circulation types with variable advection vectors [36]. The last type in this classification (21), which was marked X, comprises situations that cannot be classified into other types and saddle points (cols).

2.3. Seasonality Analysis of the Occurrence of the Annual Maximum Daily Precipitation

Seasonal variability of the annual maximum daily precipitation was analyzed based on Colwell indices of predictability P and its components, i.e., constancy C and seasonality M. These indices are commonly used in hydrology to evaluate the variability of flows, precipitation, and seasonality of their occurrence [37,38]. Moreover, it should be emphasized that the literature has not provided a lot of results so far since Colwell indices were used to analyze the seasonality of annual maximum daily precipitation (only other types of precipitation were analyzed). The determination of Colwell indices requires dividing the observational series into categories to obtain a matrix describing the analyzed process. The matrix columns reflect fixed time steps and the rows describe the state of individual events. If N_{ij} is the number of events when a variable reaches state i in a time step j, X_i summarizes the number of columns for each state i, Y_i summarizes the number of rows for individual time steps j, and Z denotes the total number of analyzed observations. Then seasonality M is defined by the equation [39]

$$M = \frac{H(x) + H(y) - H(xy)}{\log s} \tag{7}$$

where

$H(x)$—uncertainty with respect to time,

$H(y)$—uncertainty with respect to state,

$H(xy)$—uncertainty with respect to the interaction of time and state,

s—number of matrix rows.

Uncertainty with respect to time $H(x)$ is calculated using the formula

$$H(x) = -\sum_{j=1}^{t} \frac{X_j}{Z} \log \frac{X_j}{Z} \tag{8}$$

where t is the number of matrix columns.

Uncertainty with respect to state $H(y)$ is calculated by using the equation

$$H(y) = -\sum_{i=1}^{s} \frac{Y_i}{Z} \log \frac{Y_i}{Z} \tag{9}$$

Lastly, uncertainty with respect to the interaction of time and state $H(xy)$ is calculated by using the formula

$$H(xy) = -\sum_i \sum_j \frac{N_{ij}}{Z} \log \frac{N_{ij}}{Z} \tag{10}$$

Constancy (C) and predictability (P) are defined by the equations

$$C = 1 - \frac{H(y)}{\log s} \tag{11}$$

$$P = 1 - \frac{H(xy) - H(x)}{\log s} \tag{12}$$

$$P = C + M \tag{13}$$

Constancy C represents a tendency of the variable to remain unchanged throughout the year and assumes maximum values of C = 1 when the variable maintains the same value for each analyzed period. The seasonality index M shows the maximum value (M = 1) when the variable changes over individual time steps, but the occurrence of certain values can be predicted. Predictability index P is a measure of variability in the subsequent analyzed time steps and its maximum value is 1. In practical terms, the predictability is essentially a measurement of the variation among successive periods in the pattern of a periodic phenomenon. When the variation is low, predictability is high [40]. In the article, the predictability was indicated regarding months where the maximum precipitations appeared.

3. Results and Discussion

3.1. Significant Verification of the Trend for the Annual Maximum Daily Precipitation

Our study investigated the long-term records of the annual maximum daily precipitation at individual weather stations for possible monotone trends. We used the Mann–Kendall test to assess significance at the levels of 1, 5, and 10%. Table 1 and Figure 2 summarize the significant data.

Table 1. Statistical parameters of the annual maximum daily precipitation and trend values (1971–2014).

Weather Station	Annual Maximum Daily Precipitation (mm)	Coefficient of Variation (%)	Mann–Kendall Statistics	Trend (mm/10 Years)
Wolbrom	82.3	36	1.901	4(***)
Rajcza	124.8	42	2.137	5.8(**)
Kocierz Moszczanicki	180.4	62	2.473	9.5 (**)
Kraków Balice	87.4	36	1.852	2(***)
Książ Wielki	86.4	36	2.823	4.3(*)
Wisłok Wielki	89.7	31	3.216	4.7(*)
Nowy Sącz	82.6	33	1.730	2.7(***)
Radomyśl Wielki	93.9	39	1.966	3.7(**)
Wysowa	84.5	32	1.721	3(***)
Cisna	102.0	28	2.205	3.5(**)
Komańcza	93.5	31	1.703	2.6(***)

Symbols: trend significant at the level of 1% *, 5% **, 10% ***.

A significant trend indicating that the highest daily precipitation value is increasing at all assumed levels within the entire study area manifested itself only for Książ Wielki and Wisłok Wielki. Additionally, a significant trend at 5% occurred at Rajcza, Kocierz Moszczanicki, Radomyśl Wielki, and Cisna (Table 1, Figure 2). For a few weather stations, we also observed a linear trend significant at the level of 0.1. This happened in Wolbrom, Kraków-Balice, Nowy Sącz, Wysowa, and Komańcza. In general, a growing significant trend in the annual maximum daily precipitation at 0.01 was visible for almost 4% of the weather stations, at 0.05 for 12% of the stations, and at 0.10 for 22% of the stations. We found no significant trends in the annual maximum daily precipitation for the remaining weather stations. On the contrary, the highest total monthly precipitation was similar to that in Polish Western Carpathians, i.e., had a form of irregular fluctuations instead of a trend [41]. Niedźwiedź et al. [42] published similar results for Southern Poland, which indicated growing but insignificant trends in daily precipitation. Insignificant trends in monthly precipitation were also described by Hermida et al. for Pyrenees [43]. Zeleňáková et al. [44] who investigated changes in monthly precipitation trends in

Slovakia confirmed dynamically growing precipitation trends in the summer months especially in July and declining trends, especially in December in the northern part of the country. Growing trends in extreme precipitation occurred for all seasons in central-eastern Germany while, in southern Poland, the trends for the same seasons were reversed [45]. Insignificant trends observed for the majority of weather stations in our study reflected the course of high water in the catchments of the Upper Vistula Basin. Research conducted by Kundzewicz et al. [46], Wałęga et al. [47], and Młyński et al. [48] showed a stable runoff of high water in the catchments of the Upper Vistula Basin in recent decades. Flood size in this region depends on multiple factors such as geology, soils, geomorphological evolution, landscape structure, or land use. These factors turn precipitation transformation into runoff. This is why we confirmed the relationship between the trends in the highest daily precipitation and maximum flows [49].

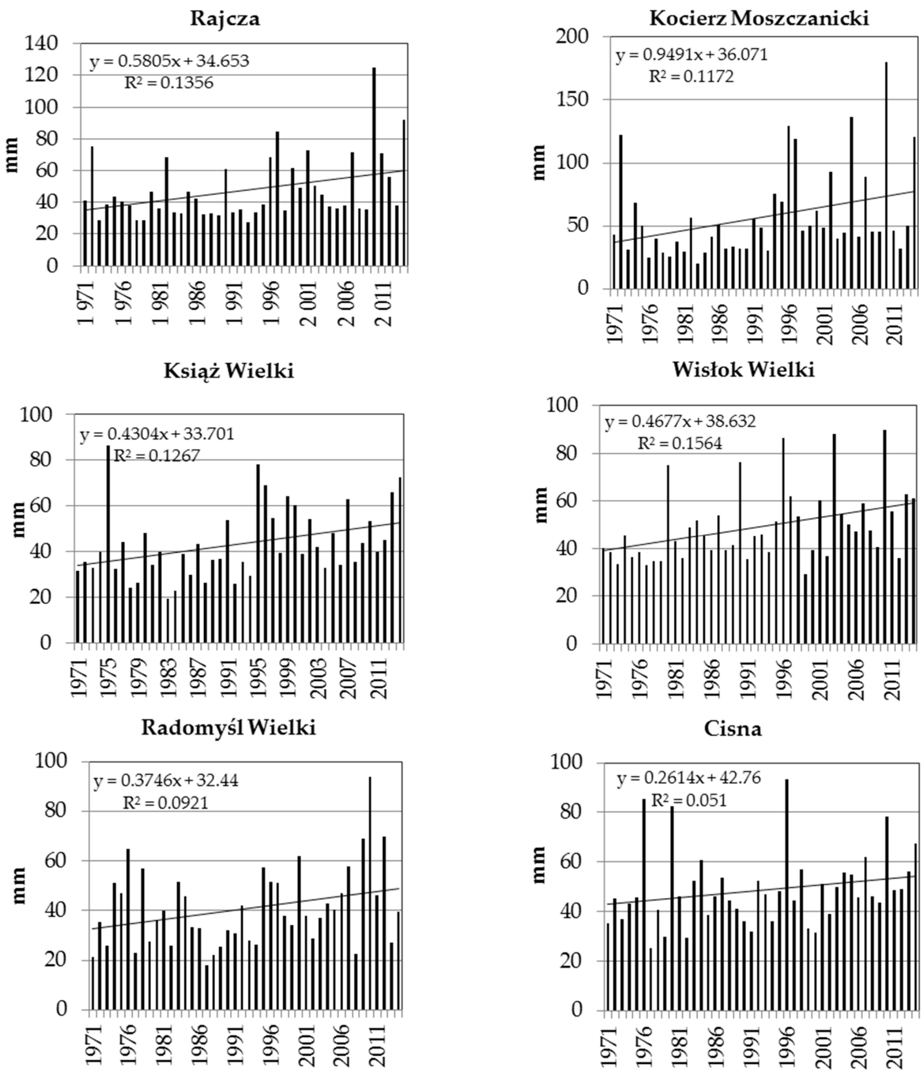

Figure 2. The annual maximum daily precipitation and significant trend at 0.05 (1971–2014).

3.2. Analysis of Weather Conditions Impact on the Occurrence of the Highest Daily Precipitation

The annual maximum daily precipitation, which is similar to the highest total monthly precipitation in the Polish Carpathians [41,50], shows year-to-year variation not only at the measurement points but also within the study area characterized by variable relief. As far as the annual course was concerned, the earliest highest daily precipitation occurred on 3 January 2006 in Sędziszów and the latest on 29 December 1986 at Kasprowy Wierch and Zawoja. The annual maximum daily precipitation may occur in any month but most frequently between May and September. In our study, these months accounted for 88% of all events of the annual maximum daily precipitation including 46% in June and July (Figure 3). The annual maximum daily precipitation events were the least frequent in the cold half of the year, i.e., from October until April. In the winter, in which includes the months of December, January, and February, the number of the annual maximum daily precipitation events was below 1% (Figure 3). In the right-bank part of the Upper Vistula Basin, the annual maximum daily precipitation occurred most often in May (30%) and, in the left-bank part, the annual maximum daily precipitation occurred most often in July (50%). The variability range of the annual maximum daily precipitation, which is the difference between the highest and lowest precipitation, was 195.6 mm for Kasprowy Wierch and 176.7 mm for Szczyrk. The smallest variability range of only 50.1 mm was recorded in Kaźmierza Mała.

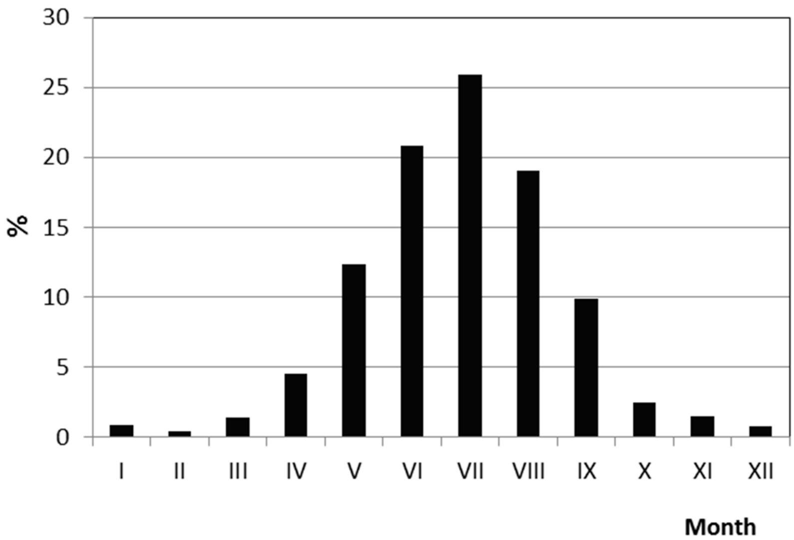

Figure 3. Frequency (%) of the annual maximum daily precipitation over the year (1971–2014).

From 1971 to 2014, the highest daily precipitation exceeded 200 mm at only two weather stations during the period studied, which were both located in the Carpathian area. In both cases, this represented slightly over 50% of the total for the month in which the precipitation occurred (Figure 4a). This happened in Szczyrk on 31 August 2010 and at Kasprowy Wierch on 30 June 1973. For two years of the study (May, July, and August 2010 and July 2001), the highest daily precipitation exceeded 150 mm for seven weather stations. On 31 August 2010, in Wisła Malinka located in the Mała Wisła catchment and in Kocierz Moszcznicki and Żabnica, this occurred in two stations located in the Soła basin. These events accounted for 51% to 57% of the total monthly precipitation for the month they occurred in while, at the other weather stations, the highest daily precipitation accounted for 22% to 29% of the monthly precipitation. During the flood in 2010, in the whole area of the Upper Vistula Basin, the highest daily sum of precipitation was recorded only on 20 out of 51 precipitation gauge stations. The Upper Vistula Basin has been under low pressure air mass since the beginning of May 2010. On 16 May 2010, the center of the low-pressure air mass moved from Hungary to Western Ukraine and the warm front covering the eastern part of Poland was associated with the low pressure air mass. Precipitation occurred in the zone in front of the warm front and it encompassed southern and southeastern Poland.

In July 2001, the annual maximum daily precipitation occurred between 23 and 27 July. Record total daily rainfall was recorded in Wolbrom, Maków Podhalański, Gierałtowice, Kielce, and Raków where it accounted for up to 53% of the total rainfall for that month. The annual maximum daily precipitation occurred on 16 May 2010 at 16 weather stations in the Upper Vistula Basin. Total precipitation on this day exceeded 50 cm with some places reaching 200 mm [51]. The rainfalls were caused by a low-pressure area lingering over the studied basin. In July 2001 and May 2010, the Upper Vistula Basin experienced floods triggered by intense rainfalls particularly in the Western part of Polish Carpathians.

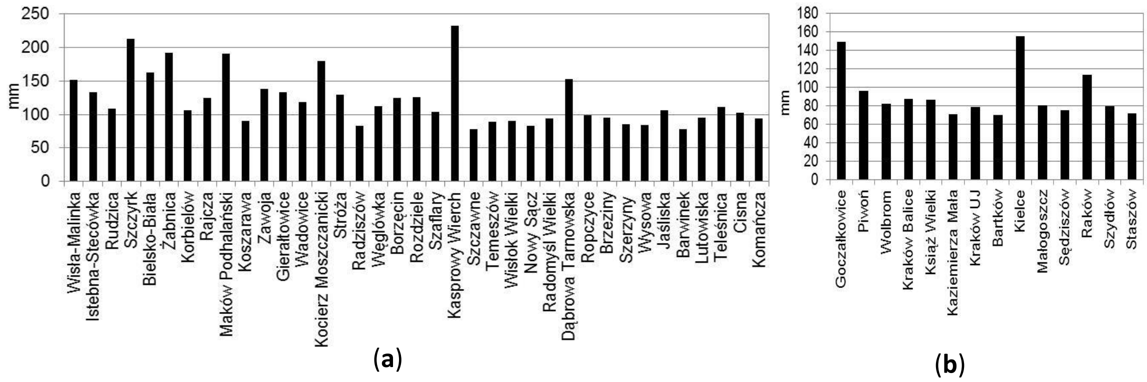

Figure 4. The annual maximum daily precipitation from 1971 to 2014 for the right-bank (**a**) and left-bank (**b**); Upper Vistula Basin.

However, the annual maximum daily precipitation recorded for at least 50% of the weather stations occurred in May 2014 (Figure 5a), July 1997, 2004, August 1972, and 1985, and September 1996 (Figure 5b). The rainfalls were brought by polar maritime air masses incoming from the north (Nc) and the northeast (NEc) (Table 2) [52]. In the summer of 2014, Southern Europe experienced intense rainfall. Total precipitation that July was 84% higher (over three standard deviations) than normal with respect to July from 1982 to 2013 [53]. That year, the annual maximum daily precipitation was recorded for 15 weather stations in the Upper Vistula Basin. This happened on 9, 11, 23, and 31 July.

Table 2. Percentage of weather stations with the annual maximum daily precipitation and circulation types (1971 to 2014)

Date	% of Stations with the Annual Maximum Daily Precipitation *	Circulation Type
15 May 2014	61	NEc
5 July 1997		Bc
6 July 1997		Nc
7 July 1997	65	NEc
8 July 1997		Nc
9 July 1997		Nc
27 July 2004		Nc
28 July 2004	63	NEc
29 July 2004		NEc
7 August 1985		Nc
8 August 1985	51	Nc
20 August 1972		NEc
21 August 1972	75	Nc
22 August 1972		Nc
6 September 1996		Nc
7 September 1996	57	Nc

* >50% of the weather stations. Symbols according to Niedźwiedź (1981): NEc—cyclonic (low pressure) circulation with air advection from the northeast; Nc—cyclonic (low pressure) circulation with air advection from the north, Bc—trough, a low-pressure area, or an axis of a low pressure trough with various advection vectors.

The annual maximum daily precipitation most often correlated with three types of cyclonic circulation: northern (Nc), northeastern (NEc), and trough (Bc). These types of circulation accounted for 66% (Figure 6) of the annual maximum daily precipitation in the entire Upper Vistula Basin. Only 7% of the annual maximum daily precipitation correlated with anticyclonic circulation particularly northeastern (NEa) (2%) and anticyclonic wedge (Ka) (2%). In the years between 1971 to 2014, the highest daily precipitation between March and November most often occurred in the trough (35%). In the summer and the warmer half of the year, the highest precipitation causing river and stream floods is associated with air advection from the north and the northeast [52].

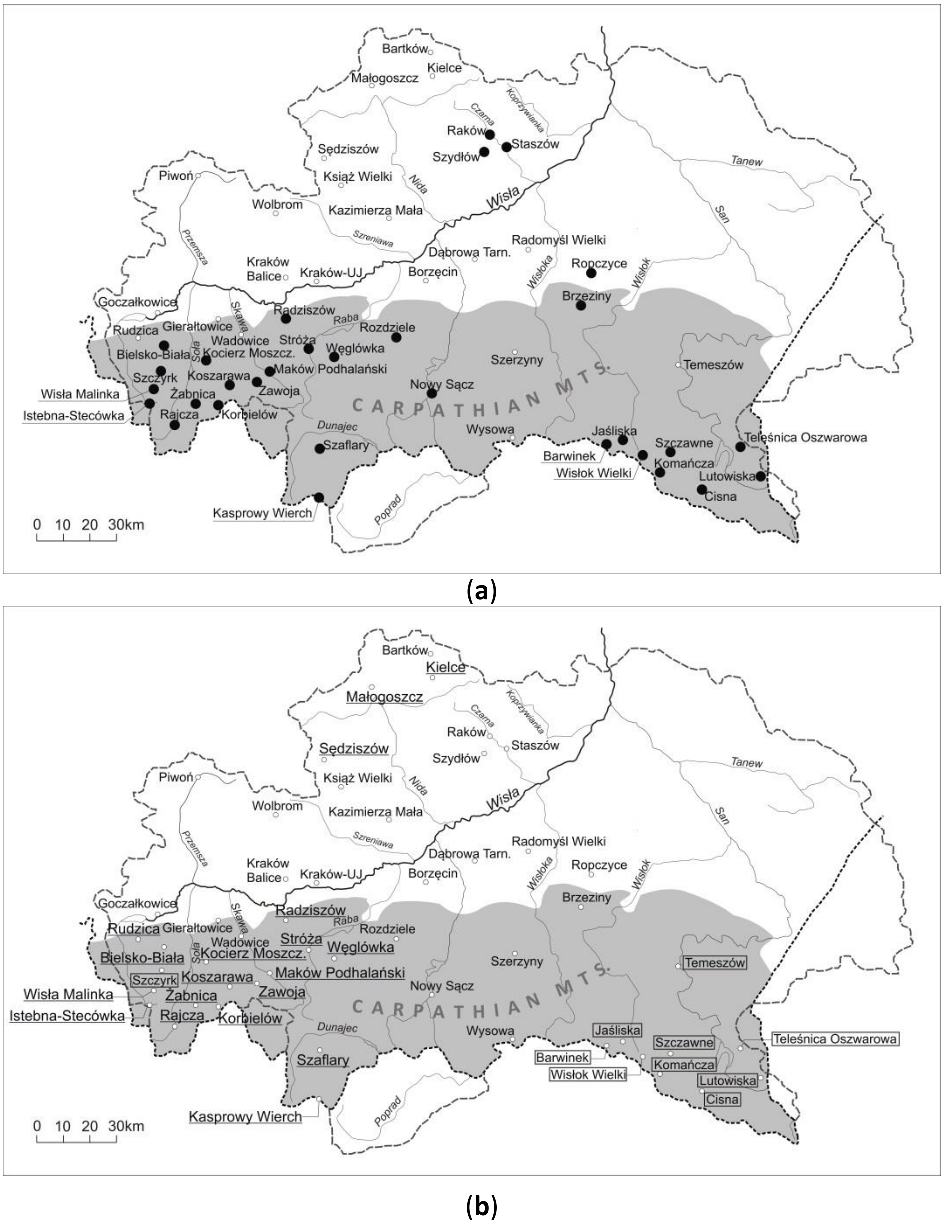

Figure 5. Location of the weather stations with the annual maximum daily precipitation on 15 May 2014 (**a**); and 6 and 7 September 1996 (**b**).

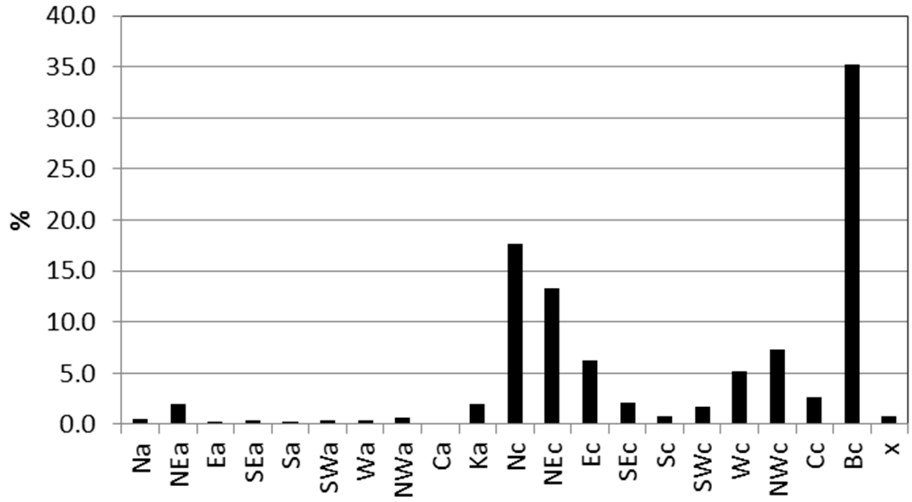

Figure 6. The annual maximum daily precipitation for different circulation types (1971–2014): 21 types of synoptic situations (circulation types, a—anticyclonic, c—cyclonic): Na, Nc—North, NEa, NEc—North–East; Ea, Ec—East, SEa, SEc—South–East, Sa, Sc—South, SWa, SWc—South–West, Wa, Wc—West, NWa, NWc—North–West, Ca—central anticyclone situation, Ka—anticyclonic wedge or ridge of high pressure, Cc—central cyclonic, center of low, Bc—through of low pressure (different directions of air flow and frontal system in the axis of through), x—unclassified situations or pressure col.

3.3. Seasonality Analysis of the Occurrence of the Annual Maximum Daily Precipitation

Seasonal variability of the annual maximum daily precipitation at the investigated weather stations located in the Upper Vistula Basin was based on Colwell indices, which included predictability P, constancy C, and seasonality M. M/P and C/P ratios were also determined. The calculation results are shown in Figure 7.

Our analysis showed a stable course of the highest daily precipitation recorded at the weather stations located in the Upper Vistula Basin. This is confirmed by high values of the constancy index C, which exceeded 0.35 for all weather stations. The most stable course of the annual maximum daily precipitation was observed at Barwinek where this parameter reached 0.60. The lowest C (0.36) was calculated for the station in Kociesz Moszczanicki. The highest daily precipitation for the investigated weather stations showed relatively high values of the seasonality index M, which ranged from 0.07 (Szczawne) to 0.22 (Kasprowy Wierch). The analyzed weather stations are located above 185 m a.s.l. where the stability of weather conditions shaping the rainfall characteristics may be disturbed. This is why we noticed high values of the seasonality index M. Figure 3 confirmed the seasonal course of precipitation frequency over the year and confirmed that the warm months (May to September) are the most abundant with regard to the annual maximum daily precipitation. This indicates a significant repeatability of the precipitation pattern and the mechanisms generating the maximum total precipitation. The values of the predictability index P ranged from 0.50 (Borzęcin) to 0.80 (Jaśliska). Such high values mean that it is easy to predict the highest daily precipitation characterized by variable values over the investigated multi-year period. Since the predictability index P is the sum of constancy C and seasonality M, it is possible to determine C and M by showing their share in the total value of P (C/P and M/P) (Figure 7b). The precipitation we analyzed showed a strong effect of the constancy index C on the value of predictability index P. The C/P ratio always exceeded 65%, which demonstrated a low impact of the seasonality index M on the predictability of the annual maximum daily precipitation. The predictability index P usually did not exceed 0.60 for the weather stations characterized by a significant trend of total precipitation. Moreover, the stations showing the significant trend demonstrated relatively low seasonality (M/P was lower than 0.20 except for Kocierz Moszczanicki where it exceeded 0.30).

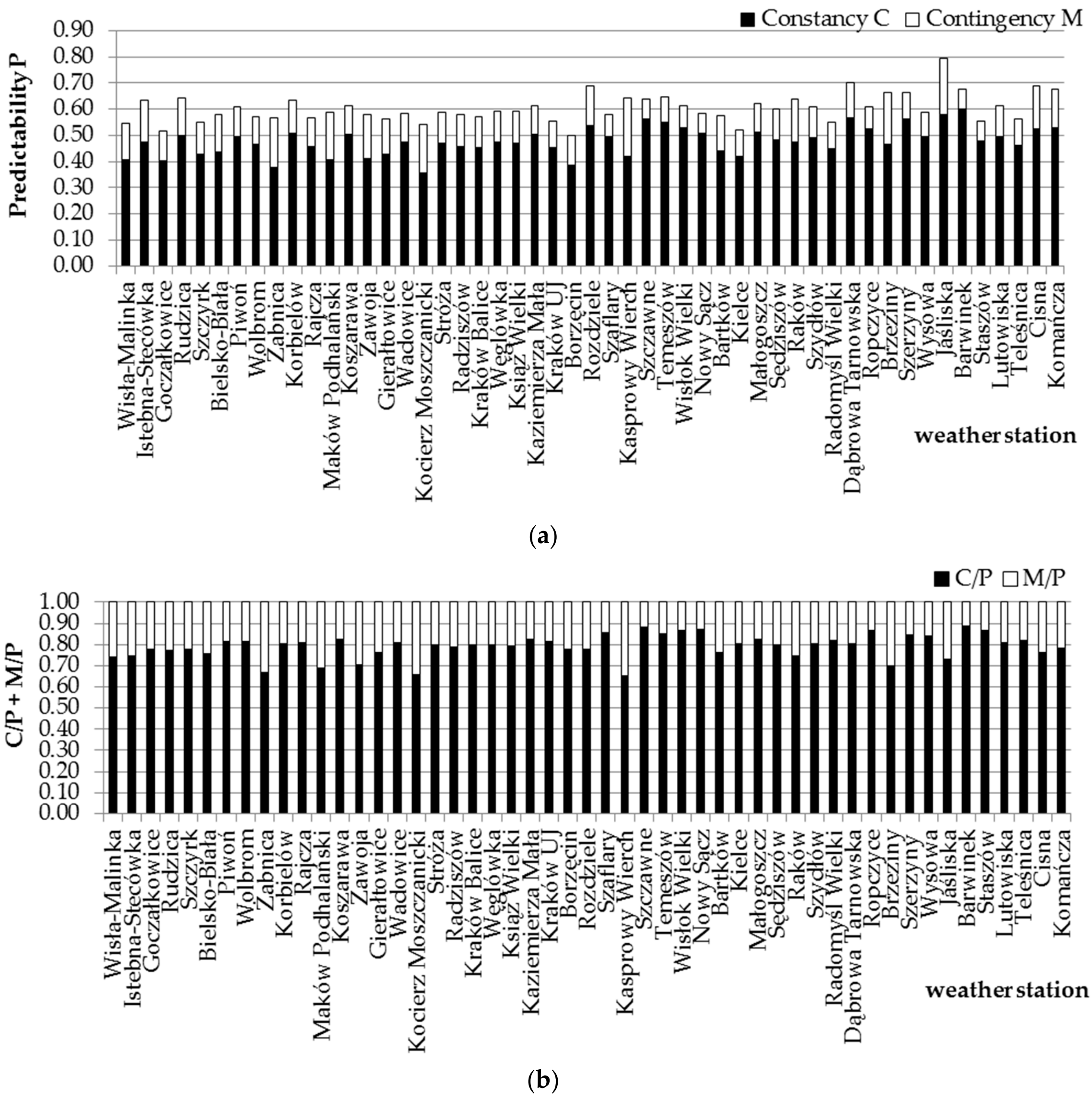

Figure 7. Colwell indices values: (**a**) C, M, and P parameters; and (**b**) M/P and C/P ratios.

4. Conclusions

A small number of weather stations (22%) located at range elevations from 185 to 1991 (a.s.l.) showed a significant trend of the annual maximum daily precipitation for the assumed significance levels (0.01, 0.05, 0.1). The significant trends found were positive and an increase in precipitation is expected. Only short-term fluctuations without significant precipitation trends were observed for the remaining stations. The annual maximum daily precipitation in the Upper Vistula Basin may be caused by continuous precipitation occurring over a large area or by heavy rains of local reach. The precipitation may take place throughout the year, but between 1971 to 2014, the rainfall most often occurred in the warmer parts of the year, i.e., from May until September. These months included a total of 88% of days with the highest daily precipitation. Between October to April, the highest daily total precipitation occurred sporadically and their frequency in particular months did not exceed 5%. Additionally, we demonstrated that Colwell indices are a relatively simple solution of seasonality of the annual maximum daily precipitation. We noticed high values of the predictability index (>0.50) of the annual maximum daily precipitation at the examined weather stations. It was, to a high degree, affected by the value of constancy index C and, to a small degree, affected by the seasonality index M. The values of the latter were below 0.22 and for a few stations they were even lower than 0.10. This indicates a small effect of seasonality on the predictability of the annual maximum daily precipitation. However, considering the annual maximum daily precipitation for the entire research period at all weather stations and the values of Colwell indices determined for each station, we noticed that, for all weather stations, these characteristics are usually associated with three types of cyclonic circulations featuring the annual maximum daily precipitation. As far as the predictability index was concerned, the majority of the annual maximum daily precipitation events (45%) in the research area occurred in the northeastern (NEc) cyclonic circulation. These events were slightly less common for the north cyclonic circulation and the trough, which accounted for a total of 43%. There were also a few cases of east (Ec) and northwestern (NWc) cyclonic circulation with 12% recorded for this index. The maximum frequency of the annual maximum daily precipitation occurred within the trough (35%) and for the north and northeastern cyclonic circulation (a total of 31%) (Figure 6). Our analysis demonstrated the convergence of the Colwell indices values with the frequency of the cyclonic circulation, which confirms the possibility of using these indices to analyze precipitation seasonality.

Author Contributions: Study design, D.M. and A.W. Data collection, D.M. and A.W. Statistical analysis, D.M., M.C., and A.W. Data interpretation, D.M. and M.C. Manuscript preparation, D.M. Literature search, D.M., M.C., and A.W.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank the Head of the Department of Sanitary Engineering and Water Management, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Krakow, for financial support. We thank anonymous reviewers for their constructive comments, which helped substantially improve the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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