

**MAXIMUM 1-, 2-, 3-, 4-DAILY PRECIPITATION TOTALS
AT THE KIELCE UPLAND (POLAND)**

Keywords: maximum daily precipitation, trends, Central Poland

Introduction. The question concerning maximum daily precipitation analysis have been undertaken in numerous research papers across the World. In Poland a particularly valuable, comprehensive and broad study on the spatial structure and temporal variability of rainfall in the entire country have been present by Stach (2007). In this study data from more than 2000 rain gauges in the 1956-1980 period and geostatistical methods were used in the rainfall analysis.

The maximum daily precipitation analysis for the entire Poland were performed, among others, by Fal and Plenzler (1981), Fal (1987), Bogdanowicz and Stachý (1998), Ustrnul and Czekierda (2000, 2001, 2009). The summaries of those research, in general, took the form of maps showing spatial or regional variability of the analysed rainfall characteristics. In the regional perspective, the problem of extremely high daily precipitation totals have been reflected in the works of Cebulak (1991, 1992), Kłysik and Fortuniak (1993), Cebulak et al. (2000), Kaszewski and Siwek (2000, 2005), Kirschenstein (2001), Otop (2004), Cebulak and Pyrca (2006), Głowicki et al. (2006), Siwek (2010) and Suligowski (2013).

In the present paper the characteristics of maximum daily precipitation totals on the Kielce Upland in Poland in 1961-2006 period have been shown.

The Kielce Upland is a physiographic macroregion which is a part of the much larger Małopolska Upland. The area of the Kielce Upland is 6800 km². In the west it borders with the Przedborz Upland – a macroregion that is also a part of the Małopolska Upland. In the south it borders with the Niecka Nidzińska macro-region (Małopolska Upland) and in the north it borders with the South Mazowsze Hills. Its eastern boundary is formed by the Vistula Valley, the Lublin Upland, and a section of the Vistula Plain (the Sandomierz Upland) (Fig. 1).

The region of interest possesses a variety of landforms such as low and midsize rounded hills, flattened foothills in some places, as well as the Świętokrzyskie Mountains (Holy Cross Mts) right in the central part of the Upland, rising to 611 m above the sea level. The

region is drained by a network of rivers with a characteristic central “point” of origin. Most of the smaller streams serve as tributaries to the following rivers: the Kamienna, the Czarna Nida, the Opatówka, the Koprzywnianka, the Czarna Staszowska, and the Czarna Maleniecka. The northern part of the region is drained by the upstream sections of the Radomka and the Iłżanka rivers (Fig. 1).

The spatial distribution of annual atmospheric precipitation totals across the analyzed region is the result of westerly and north-westerly rain-bearing air flows that dominate the area. A distinct hypsometric rainfall gradient can be observed at gauging stations located in the western part of the research area. The average annual precipitation total (based on data from 1961–2000) is 620–680 mm in this region. In the Świętokrzyskie Mts., the mean annual rainfall average exceeds over 800 mm (Town of Święty Krzyż – 826 mm). Lower precipitation totals are observed on the SE side of this mountain range (Staszów – 543 mm, Klimontów – 572 mm, Sandomierz – 568 mm). This is true regardless of the elevation of the given gauging station which allows one to conclude that this is a case of a rain shadow where the leeward side of a mountain range receives less rain than the windward side. Likewise, low mean annual precipitation totals are recorded in the Iłża Foothills area (Osówka – 528 mm, Kurzacze – 575 mm). Work done by Kłysik (1985), Żarnowiecki (1991), Olszewski (1992) and other researchers has confirmed the climatic individualism of the Świętokrzyskie Mountains, including the existing precipitation relationships.

Precipitation during the summer season (May–October) constitutes a major portion of annual precipitation. Summer rainfall constitutes 60-62% of the annual total in the western part of the Upland while in the central and eastern parts, it reaches 66%. July is the month of maximum precipitation. Finally, a tentative autumn and spring precipitation quotient boundary runs across the region (Kozuchowski and Wibig 1988, Suligowski 1998).

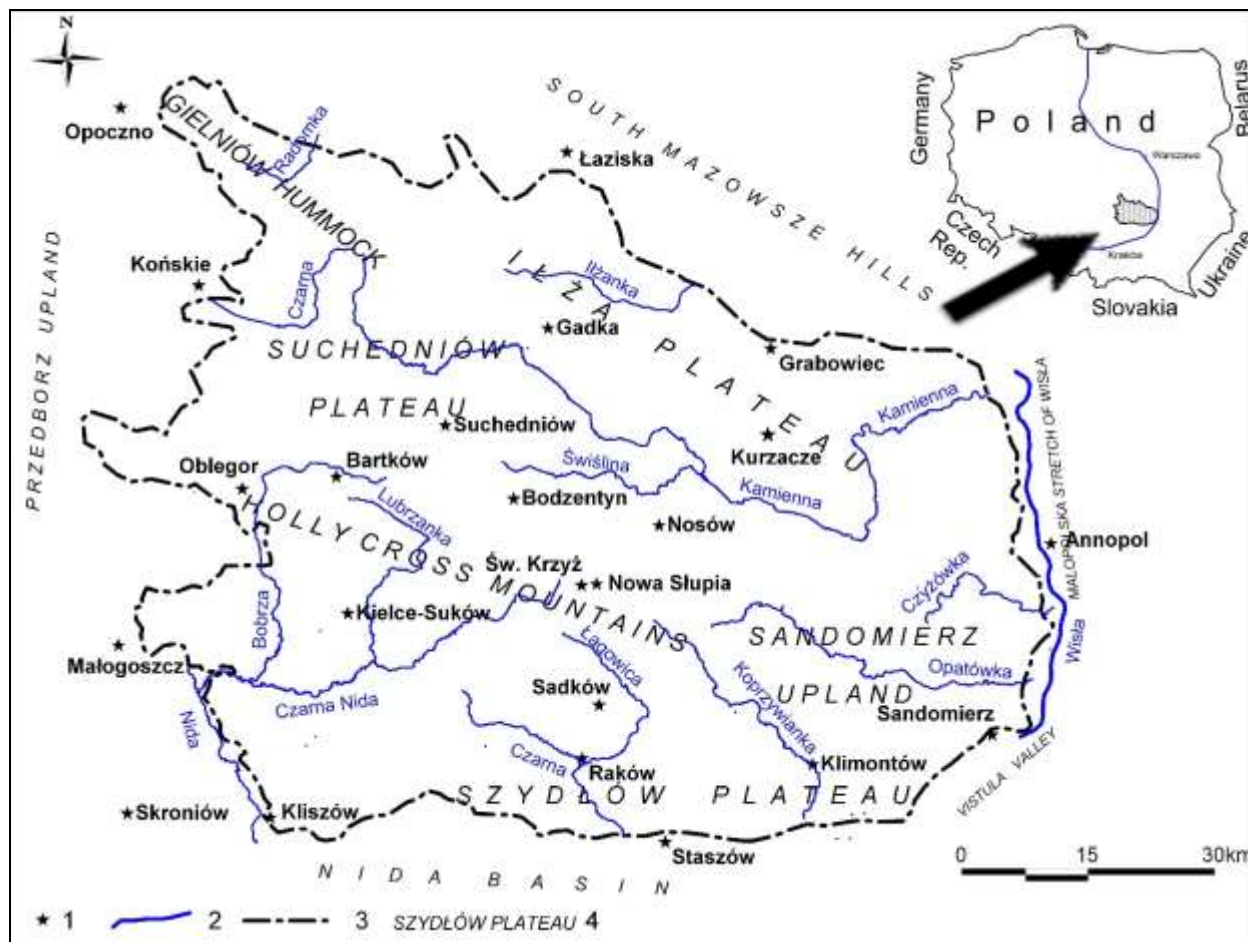


Fig. 1 – The study area with rain gauges location

(1 – rain gauge, 2- river, 3- Kielce Upland boundaries, 4- mesoregion name)

The study is based on daily precipitation totals recorded during the summer season (May–October) at 23 rain gauges in the Kielce Upland and its immediate vicinity (Fig. 1).

Changes in the Institute of Meteorology and Water Management (Polish acronym – IMGW) gauging network throughout the 20th century as well as gaps in archival materials made it possible to analyze only the 1961–2006 time period. Data were obtained from the IMGW database and, in part, from annals of precipitation (Precipitation 1961–1981).

One-day as well as consecutive 2-day, 3-day, and 4-day maximum annual precipitation totals were compiled for each gauging point. The observation data series were analyzed for homogeneity before proceeding to the main analysis. An analysis of archival IMGW materials indicates that, over the years, data homogeneity have not been affected by circumstances. The maximum precipitation series were also analyzed for heterogeneity. The independence of particular elements was analyzed using the Wald-Wolfowitz test. The numbers in each series were found to be within the test's critical area at a level of significance of 0.05. In light of this, there was no reason to reject the null hypothesis

concerning the randomness of the elements of any particular series. Precipitation series stationarity analysis was performed using two nonparametric tests: the Kruskal-Wallis test based on analysis of variance by ranks (also the Mann-Whitney test) and the Spearman rank correlation coefficient test. The herein calculated test values, chi-square, and t-Student's, are lower than the critical values of the above mentioned statistics at the assumed level of significance of 0.05.

The analysis results suggest that there is no reason to reject the homogeneity hypothesis for the series analyzed. It can, therefore, be asserted with a high degree of certainty that all of the analyzed series (within the 1-day, 2-day, 3-day, and 4-day precipitation groups) are homogeneous – they originate from the same statistical population.

Results. The course of maximum 1-, 2-, 3-, 4-daily precipitation totals in the 1961–2006 period indicates the irregular fluctuation and high year by year variety in all measuring points. Extreme high values of daily precipitation totals occurred only in a few periods. They took place in the second half of the 60's, at the beginning of the 70's and at the turn of the 20th and 21st century. Therefore

in specific way they document wet years (1966, 1968, 1970, 1997) that have occurred in the analyzed region. Maximum rainfall totals correlates with the maximum activity of cyclonic types of atmospheric circulation over the southern Poland in this period.

On the basis of the performed *t*-Student test analysis, statistically significant trend of

the maximum annual daily precipitation totals were not documented on the most of rain gauges in the region in 1961–2006. The results from Bodzentyn and Gadka are exceptions, where those changes were proven at the $\alpha = 0,05$ significance level, in addition to all daily intervals (fig. 2).

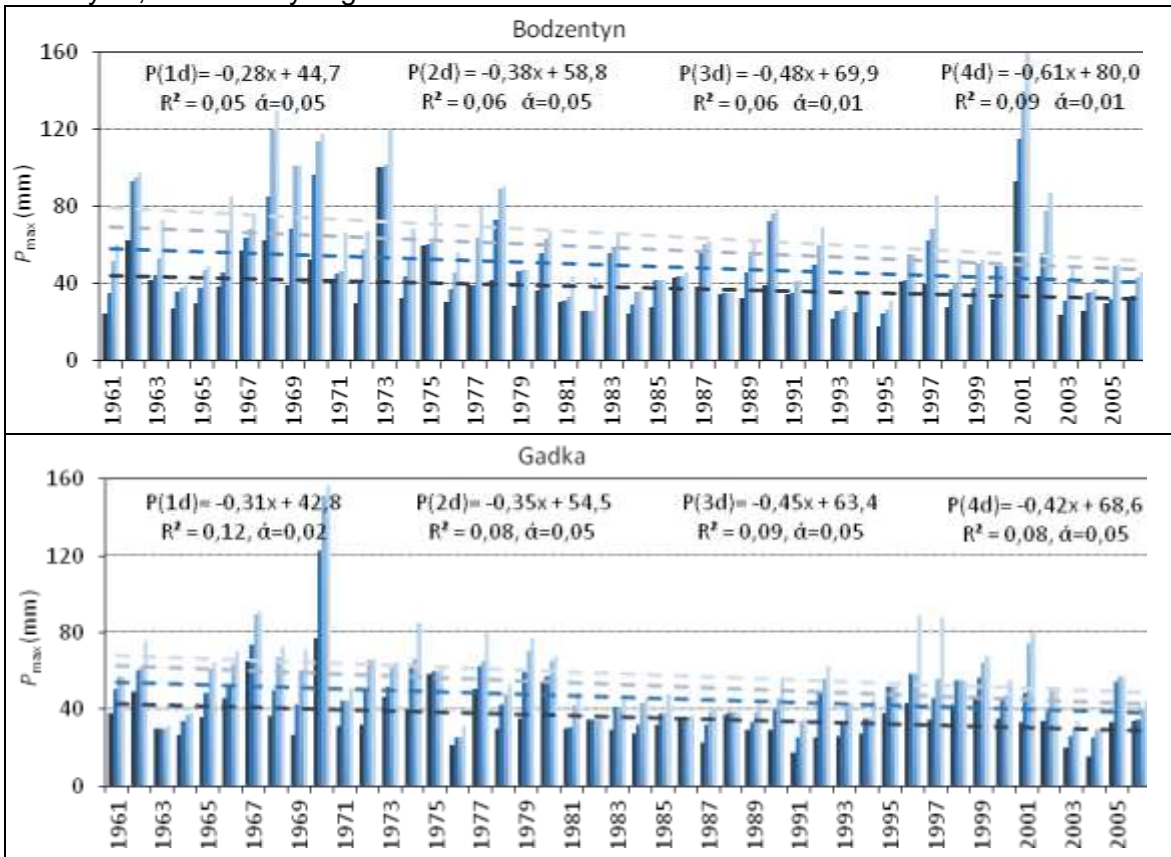


Fig. 2 – Multi-annual course of maximum 1-, 2-, 3-, 4-daily precipitation totals P_{max} (mm) at selected precipitation stations of Kielce Upland (1961–2006) along with linear trends and appropriate equations at a significance level α . R^2 – coefficient of determination

In the analyzed period on a number of gauging stations there is an upward tendency of maximum precipitation totals, particularly visible in SW part of the research area.

The highest increase in 1-day maximum precipitation totals have been found in Kielce – Suków station ($+3,4 \text{ mm} \cdot 10 \text{ yr}^{-1}$). However, starting from 2-day period the opposite direction of changes emerges for the rain gauges in the Kielce Upland – the decrease of maximum precipitation totals. This downward trend is visible in the central part of the Świętokrzyskie Mountains, mostly in Bodzentyn, where it reaches $-4,8 \text{ mm} \cdot 10 \text{ yr}^{-1}$ (1-day total, $\alpha = 0,05$), $-4,7 \text{ mm} \cdot 10 \text{ yr}^{-1}$ (2-day total, $\alpha = 0,05$), $-7,9 \text{ mm} \cdot 10 \text{ yr}^{-1}$ (3-day total, $\alpha = 0,01$) i $-9,9 \text{ mm} \cdot 10 \text{ yr}^{-1}$ (4-day total, $\alpha = 0,01$).

The downward trend is also visible in gauging stations located on the Przedgórze Iłżeckie and on the areas bordering the Kielce

Upland from the east and north. Obtained results do not deviate from the general regularities, which characterize the run of annual precipitation totals in Poland in the second half of 20th century (Kożuchowski 2004). The rainfall totals do not show any significant trend of changes and depending on the assumed calculation period, annual rainfall totals have upward or downward trends (Żmudzka 2002, 2009, Kożuchowski and Żmudzka 2003, Zawora and Ziernicka 2003, Kożuchowski 2004, Niedźwiedz and Twardosz 2004, Olszewski et al. 2007, Cebulska and Twardosz 2012). A small downward trend of extreme annual daily precipitation totals in Łódź in 1904-2000 have been shown in the analysis performed by Podstawczyńska (2008).

The annual daily precipitations totals were found in the wide range – from 13,0 mm (Małogoszcz in 2004) to 155,2 mm (Kielce–

Suków in 2001) (fig. 3a). The highest value at the Kielce Upland is second only to the precipitation total registered on Kasprowy Wierch in 30.06.1973 (232,0 mm), although the official record of maximum daily precipitation totals in Poland (in 1951–2006 period) is 300,00 mm (Hala Gąsienicowa) (Ustrnul and Czekerda, 2009).

The rainfalls exceeding 100 mm/day were registered in a few rain gauges, most of them located in the Holy Cross Mts. It should be mentioned that there have also existed extremely high rainfalls connected with the movements of thunderstorm cells, that resulted in high rainfalls away from the analysed rain gauges. On 17 July 1967 in Mroczków (the western part of the Kielce Upland) there was a thunderstorm with the precipitation total of 121.3 mm registered in 1 hour and 45 minutes (the daily sum - 133.9 mm) (Precipitations, 1968). Low maximum daily precipitation totals in analysed time (no higher than 70 mm), were registered in Grabowiec, Kurzacze (Iłża Plateau) and in Łaziska.

The highest sums of precipitation in the region from 2 consecutive days have been registered in 1970. The maximum value have been registered in Końskie gauging station. During two days (17 and 18 July) the precipitation total reached $P_{max} = 200.9$ mm (fig. 3b).

It is certainly lower value than those recorded in 2 consecutive rainfall days in other regions of Poland. For example on Hala Gąsienicowa – 372,8 mm (29–30.06.1973), on Międzygórze – 364,6 mm (5–6.07.1997) or in the rain gauge of the Wrocław University on the Śnieżnik Mountain – 428 mm (Piasecki et al. 1997). The lowest maximum two day precipitation totals recorded on remaining rain gauges located in Kielce Upland in 1961–2006 period have not exceeded 20 mm (Staszów – 18,5 mm in 1982).

The maximum 3- and 4-day precipitation totals in the analyzed region have not reached high values, ranging from 21 mm (3-day) and 21,9 mm (4-day) to 220,9 mm (3-day) and 223,0 (4-day) – both in 1970 (fig. 3c,d). Much higher 3-day precipitation totals have been recorded on rain gauges located in Sudety Mountains in July 1970: Kamienica Łądecka – 456,00 mm, Międzygórze – 431,2 mm, Sanka (in Czech Republic) – 536,7 mm (Dubicki and Malinowska-Małek 1999), also in rain gauges located in the Polish Carpathian Mountains: in Wapiennica Dam – 396,6 mm (Precipitations, 1972), Hala Gąsienicowa – 384,5 mm (Precipitations, 1973), Ustroń Równica Willage – 348,5 mm (Cebulak et al. 2011).

In the frequency distribution of the maximum annual 1-, 2-, 3, and 4-daily precipitation totals on gauging stations located in the Kielce Upland a large dispersion have been observed (fig. 3). The biggest differences have been found in the absolute maximum group. For example, the biggest 1-day precipitation total in Annopol (62 mm) was about 2,5 times smaller than the value registered in Kielce-Suków (155,2 mm), and similarly, 2-day precipitation total in Kurzacze (80,4 mm) was 2,5 times smaller than the value in Końskie (200,9). Differences between 3- and 4-day precipitation totals in relation to those mentioned above were smaller. Significantly smaller variations have been recorded among other parameters – central measures and dispersions measures. The average deviation in the group of the lowest values was from 1,7 mm (1-day) to 2,6 mm (4-day).

The medians fluctuated between 31,1–41,0 mm (1-day), 41,1–51,9 mm (2-day), 45,7–63,2 mm (3-day), 48,9–70,3 mm (4-day). Because of the clear right-sided asymmetry of the values distribution, the mean values recorded on all gauging points were higher from the median values ranging from 35,1±1,5 mm to 45,1±2,8 mm (1-day), 46,0±2,0 mm to 59,1±3,3 mm (2-day), 51,5±3,2 mm to 69,2±4,0 mm (3-day) and from 56,5±3,6 mm to 74,6±4,2 mm (4-day).

The interquartile range was generally getting higher in the following days: for 1-day from 10,6 mm (Gadka) to 21,0 mm (Nowa Słupia), 2-day – 15,8 mm (Nosów) and 28,5 mm (Nowa Słupia), 3-day – 18,0 mm (Opoczno) and 36,2 mm (Końskie), 4-day – 28,0 mm (Opoczno) and 35,6 mm (Kielce-Suków).

The spatial distribution of the maximum 1-, 2-, 3- and 4-daily precipitation totals within the borders of the Kielce Upland have been present on figure 4. The highest daily precipitation totals ranged between 62–155 mm. The zone of highest rainfalls (over 120 mm/day) spreads in the south-west part of the Upland, embracing the highest ridges of the Holy Cross Mts. and Kielce agglomeration (fig. 4). The lowest values from among maximum sums create the border surrounding of the mentioned area. Especially low values accompany the eastern, north-eastern and northern part of the area – Sandomierz Upland and Iłża Plateau (less than 80 mm/day).

The distribution of multidiurnal rainfalls is similar, but it is accompanied by a distinct centre with the highest precipitation total (3-, 4- days) in the west of Kielce Upland (fig. 4).

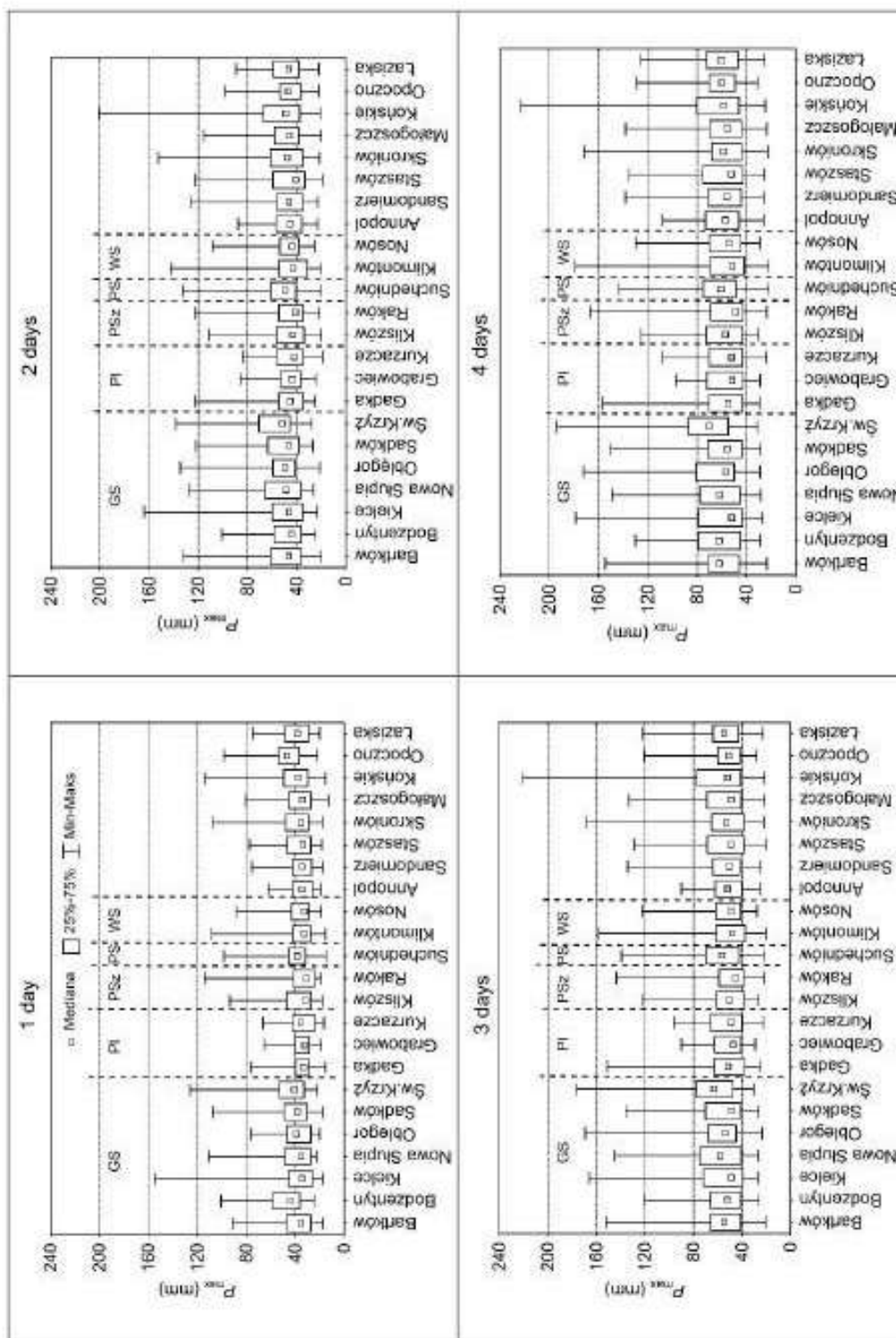


Fig. 3 – Statistical parameters for series of the 1-, 2-, 3-, 4-daily maximum precipitation totals P_{max} (mm) (1961–2006) at precipitation stations of different mesoregions located within the Kielce Upland.

Mesoregions: GS – Holy Cross Mts., PI – Iłża Plateau, PSz – Szydłów Plateau, PS – Suchedniów Plateau, WS – Sandomierz Upland

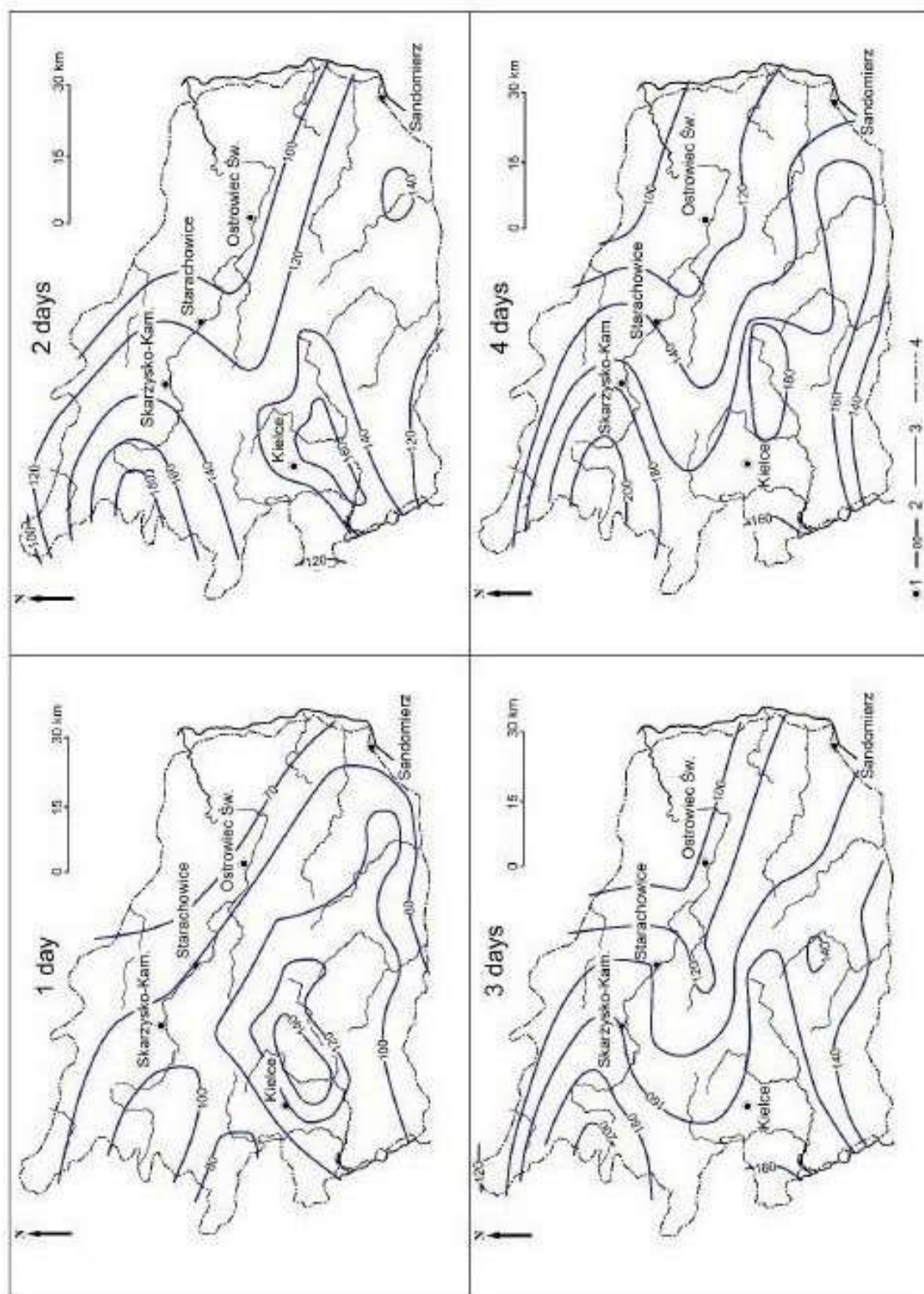


Fig. 4 – Spatial distribution of the highest 1-, 2-, 3-, 4-daily precipitation totals P_{max} (mm) recorded at the Kielce Upland (1961–2006).
 1 – major cities, 2 – isohyets, 3 – rivers, 4 – Kielce Upland boundaries

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Суліґовські Р. Максимальні 1-, 2-, 3-, 4-добові суми опадів на височині Кельце (Польща). Описано статистичні характеристики максимальних річних сум опадів за добу на височині Кельце у фізико-географічному макрорегіоні Центральна Польща. Дослідження було засноване на щоденних сумах опадів, зафіксованих під час літнього сезону (травень-жовтень) 1961-2006 рр. у 23 гідрометричних пунктах. На більшості пунктів статистично значущих тенденцій максимальних добових сум опадів виявлено не було. Максимальна добова сума опадів на височині Кельце досягала 155,2 мм (Кельце-Сукув - 21.07.2001). Цей показник нижче, ніж загальний по Польщі, зареєстрований на Гала Гасьєніцова в Татрах (300,0 мм). Дощі, що перевищують 100 мм/день, були зареєстровані в декількох пунктах, розташованих в основному на високих ділянках височини Кельце (Свентокшинський хребет) Найвищі суми опадів в регіоні понад 2 дні поспіль було зареєстровано в 1970 році на станції Коньске: протягом двох днів (17 і 18 липня) в 1970 році опадів було $P_{\max} = 200,9$ мм. 3- і 4-добові суми опадів, проаналізовані в регіоні, не перевищує значення, починаючи від 21,0 і 21,9 мм – до 220,9 мм і 223,0 і (як в 1970).

Ключові слова: максимальна добова опади, тенденції, Центральна Польща.

Suligowski R. Maximum 1-, 2-, 3-, 4-daily precipitation totals at the Kielce Upland (Poland). The present paper describes statistical characteristics of the maximum annual daily precipitation totals in Kielce Upland - a physiographic macroregion of central Poland. The study was based on daily precipitation totals recorded during the summer season (May–October) 1961–2006 at 23 rain gauging points. On the majority of the gauging points statistically significant tendencies of maximum daily precipitation totals were not identified. The maximum daily precipitation in the Kielce Upland reached 155.2 mm (Kielce-Suków – 21.07.2001). In Poland it was only lower than the daily precipitation total registered on Hala Gąsienicowa in Tatra Mountains (300,0 mm). The rainfalls exceeding 100 mm/day were registered in a few rain gauges located mostly on the highest areas of the Kielce Upland (Holy Cross Mts.) The highest sums of rainfall in the region from 2 consecutive days were registered in 1970. The maximum value was registered in Końskie rain gauge. During two days (17 and 18 July) in 1970 the rainfall was $P_{\max} = 200.9$ mm. The 3- and 4-daily precipitation totals analysed in the region did not exceed high values, ranging from 21,0 and 21,9 mm to 220,9 and 223,0 mm (both in 1970).

Keywords: maximum daily precipitation, trends, central Poland.

Суліґовски Р. Максимальные 1-, 2-, 3-, 4-суточные суммы осадков на возвышенности Кельце (Польша). Описаны статистические характеристики максимальных годовых сумм осадков за сутки на возвышенности Кельце в физико-географическом макрорегионе Центральная Польша. Исследование было основано на ежедневных суммах осадков, зафиксированных во время летнего сезона (май-октябрь) 1961-2006 гг. в 23 гидрометрических пунктах. На большинстве пунктов статистически значимых тенденций максимальных суточных сумм осадков выявлено не было. Максимальная суточная сумма осадков на возвышенности Кельце достигала 155,2 мм (Кельце-Сукув - 21.07.2001). Этот показатель ниже, чем общий по Польше, зарегистрированный на Гала Гасьєніцова в Татрах (300,0 мм). Дожди свыше 100 мм/день, были зарегистрированы в нескольких пунктах, расположенных в основном на высоких участках возвышенности Кельце (Свентокшинський хребет). Высокие суммы осадков в регионе более 2-х дней подряд были зарегистрированы в 1970 году на станции Коньске: в течение двух дней (17 и 18 июля) в 1970 году осадков выпало 200,9 мм. 3- и 4-суточные суммы осадков, проанализированы в регионе, не превышает значения, начиная от 21,0 и 21,9 мм - до 220,9 мм и 223,0 и (как в 1970).

Ключевые слова: максимальная суточная осадки, тенденции, Центральная Польша.

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