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Variability of sums of precipitation in vegetation period in north-eastern Poland during the years 1951–2000

Zmienność sum opadów atmosferycznych w okresie wegetacyjnym
w północno-wschodniej Polsce w latach 1951–2000

Summary. The research was conducted on variability of precipitation in selected stations of the Institute of Meteorology and Water Management (IMGW) in north-eastern Poland during the years 1951–2000. Individual months of the vegetation period were characterized using a 30-year moving sample. Evaluation of the values precipitation norms and the analysis of tendencies for all months as well as probability of anomaly calculated by means of gamma distribution were described. It was established that probability of occurrence of precipitations below the lower limit of the norm at all the stations displayed a significant increasing trend in August and precipitation exceeding the upper limit of the norm – showed a significantly decreasing trend. A growing, mostly significant trend of probability of occurrence of high precipitation was found in all examined localities in June and September.

Key words: atmospheric precipitation, north-eastern Poland

INTRODUCTION

This study is a continuation of research concerning precipitation conditions of north-eastern Poland in 1951–2000 [Banaszkiewicz and Grabowska 2009, 2010a, b, 2011]. The research covered, among others, determination the precipitation norms' values and the analysis tendencies for all months of the vegetation period, presentation the spatial distribution the negative precipitation anomaly occurrence of probability and the selected precipitation sums from the upper limit of the norm in case of a positive anomaly in the multi-year period 1991–2020. The issues discussed here may be useful in analyses concerning meeting water requirements of crop plants in the examined area, since precipitation changes for Poland predicted on the basis of climatic scenarios are unreliable, particularly for the summer period [Kędziora 2010, Serba *et al.* 2009, Szwejkowski *et al.* 2008].

MATERIALS AND METHOD

Characteristics of precipitation conditions of north-eastern Poland have been prepared on the basis of sums of precipitation in 1951–2000, with reference to individual months of the vegetation period (from April to September). The data originated from 12 weather stations and 6 posts of the Institute of Meteorology and Water Management (IMGW) (Fig. 1). Precipitation variability was analysed using a 30-year moving sample for monthly sums of precipitation, i.e. the data from 1951–2000 were used for creating 21 strings of variables, concerning subsequent 30-year periods. It was assumed that gamma distribution of those variables is characterised by parameters α and β, which were estimated using the method of maximum likelihood, according to formulas provided by Johnson and Kotz [Otop and Kuchar 2004 after Johnson and Kotz 1970]. For each distribution of total precipitation obtained, critical values (X_o) were calculated according to the following formula: $P(X > X_o) = p_o$, where X is a monthly (or seasonal) sum for various values of probability (p_o = 0.99, 0.95, 0.90, 0.10, 0.05 and 0.01).

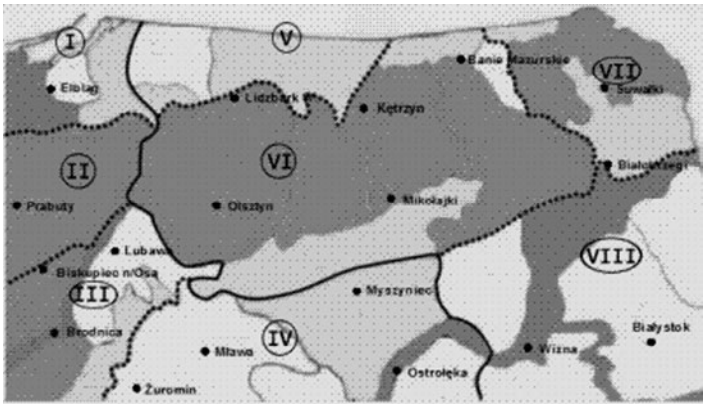


Fig. 1. North-eastern Poland: physical and geographical regions according to Kondracki [2009]: I – Gdańsk Seashore, II – Iława Lakeland, III – Chełmińsko-Dobrzyńskie Lakeland, IV – North Mazovian Lowland, V – Old Prussian Lowland, VI –Mazurian Lakeland, VII – Lithuanian Lakeland, VIII – North Podlasie Lowlands
Legend: province limits, subprovince limits (own study)

Rys. 1. Polska północno-wschodnia: regiony fizyczno-geograficzne wg Kondrackiego [2009]: I – Pobrzeże Gdańskie, II – Pojezierze Iławskie, III – Pojezierze Chełmińsko-Dobrzyńskie, IV – Nizina Północnomazowiecka, V – Nizina Staropruska, VI – Pojezierze Mazurskie, VII – Pojezierze Litewskie, VIII – Nizina Północnopodlaska
Legenda: granice prowincji, granice podprowincji (opracowanie własne)

The spatial variation of values of precipitation norms was calculated and presented according to Mrugała [1997, 2001], determining their upper and lower limits, respectively, as mean values of deviations (positive and negative) from the mean 50-year sum of precipitation. Trends of sums of precipitation and values of probability of a positive and negative anomaly were described by linear trends. For each element under analysis, the significance of regression coefficient for the obtained trend was calculated at the

significance level of $\alpha = 0.05$, 0.01 and 0.001. Determined regression models, taking into account confidence limits and prediction at the level of $\alpha = 0.05$, were used as a basis to calculate the probability of a negative precipitation anomaly and selected sums of precipitation from the upper limit of the norm in case of a positive anomaly in a 30-year period of 1991–2020. Those values are presented in figures.

Calculations and figures were prepared based on Excel 2003 and the statistical software STATISTICA[1]. The SURFER[2] application was used to analyse and graphically present materials. Geostatic methods applied in climatologic studies of precipitation – ordinary kriging and simple point kriging were used for spatial interpolation [Łupiksza 2007, Ustrnul 2004].

RESULTS AND DISCUSSION

Precipitation norms

Due to the low variety of mean monthly values of the lower limit of the norm, their spatial distribution was presented with isolines drawn every 2.5 mm, and for the upper limit of the norm – every 5.0 mm (Fig. 2 and 3).

Lower limit of the norm

Values of this norm in April ranged on average between 22.5 and 25.0 mm in the majority of the examined area. In the highest points of the Lubawa and Szeski Humps, they exceeded 25.0 mm; the lowest values (below 22.5 mm) were recorded in the North Podlasie and Old Prussian Lowlands, Mława Hills and the area of Myszyniec. For most of the region, the lower limit of the norm in May ranged from 32.5 to 35.0 mm. Values below 32.5 mm were observed in Mława Hills and the Suwałki Lakeland; slightly higher (above 35.0 mm) occurred near Mikołajki and the Lubawa Hump and reached 37.5 mm in the Białystok Upland. In June, this norm amounted to 45.0 mm in the western and south-western part of the region, while values below 42.5 mm occurred in the zone between the Olsztyn Lake District and the Mława Hills, increasing to 50.0–52.5 mm in the Land of Great Mazurian Lakes and decreasing to 47.5–50,0 mm in the eastern part of the region. In July, values of the lower limit of the norm were generally the highest (50.0–52.5 mm) in the western part of the region (the Lubawa Hump, the Iława Lakeland and the Olsztyn Lakeland). In most areas of the Mazurian and Kurpie Plains, the Kolno Upland and the Lower Narew Valley, the values amounted to below 45.0 mm and about 47.5 mm in the eastern part of the region. In August, they ranged generally from 45.0 to 50.0 mm in the Mazurian Lakeland and the Gdańsk Seashore, and they were lower in mesoregions situated in the east and south of the area (from 37.5 mm to above 45.0 mm). In September the values of isolines representing the lower limit of the norm decreased quite regularly from the north west (the Elbląg Hills) towards south and south-east, from above 47.5 mm to 32.5–35.0 mm.

The mean monthly values of their lower limits of precipitation norm for all month of vegetation period were lower from 13–21 mm in April and May to 25–41 mm in July from comparable mean multiyear sums [Banaszkiewicz and Grabowska 2010a].

[1] StatSoft, Inc. (2007). STATISTICA (data analysis software system), version 8.0. www.statsoft.com.
[2] Surfer Version 8.05 – May 11 2004 Surface Mapping System 1993–2004 Golden Software, Inc. Serial Number WS –075888-1983

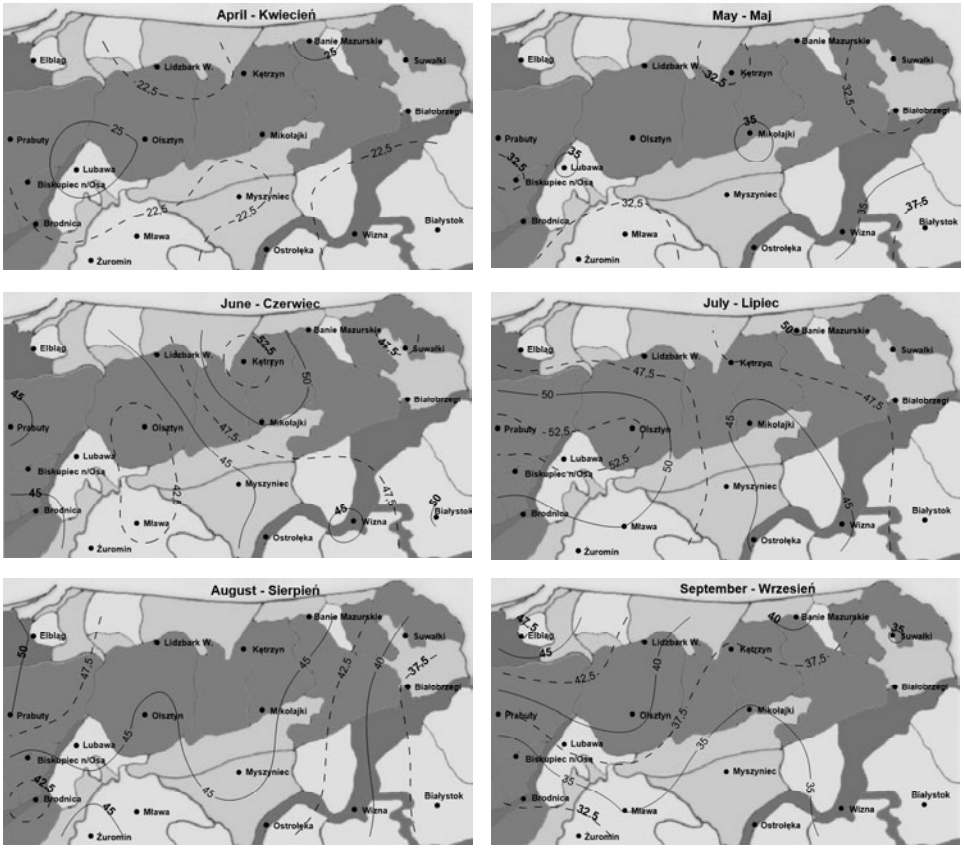


Fig. 2. Mean values (in mm) of lower limit of precipitation norm in the month from April to September in north-eastern Poland (1951–2000)
Rys. 2. Wartości dolnej granicy normy opadowej (w mm) w miesiącach od kwietnia do września w północno-wschodniej Polsce (1951–2000)

Upper limit of the norm

The mean values of the upper limit of the norm in April exceeded 60 mm in the zone of the Lubawa Hump and the central part of the area. They ranged from 55 mm to 60 mm for most of the region, with the lowest values (up to 55 mm) recorded in its southern and eastern areas. In May, recorded values generally amounted to 70–75 mm, while in the area of the Lubawa Hump, the Iława Lakeland, the Kurpie Plain and the Białystok Upland, they reached 75–80 mm. The distribution of isolines representing the upper limit of the norm in June demonstrates that they were generally the highest in the area of the lake district: from above 105 mm in the Iława Lakeland and the Lubawa Hump, to 110–115 mm in the Land of Great Mazurian Lakes, and the lowest values (below 100 mm) were recorded in the southern part of the Biebrza Valley, the Mława Hills and the Augustów Plain. In July, the western part of the region was characterised by the occurrence

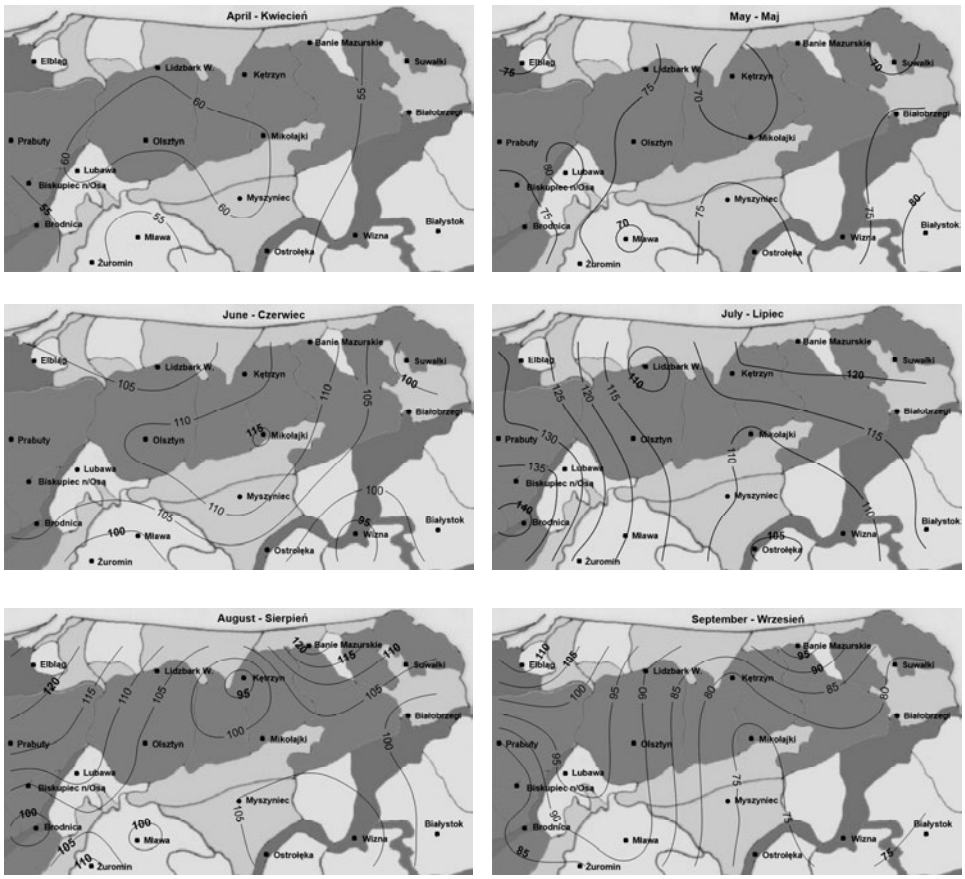


Fig. 3. Mean values (in mm) of upper limit of precipitation norm in the month from April to September in north-eastern Poland (1951–2000)
Rys. 3. Wartości górnej granicy normy opadowej (w mm) w miesiącach od kwietnia do września w północno-wschodniej Polsce (1951–2000)

of the highest values of this norm (from above 115 to 140 mm); values exceeding 120 mm were also observed in the area of the Szeski Hump and the Suwałki Lakeland. In the zone between the Old Prussian Lowlands in the south to the Lower Narew Valley in the south, the values of the upper limit of the norm amounted to about 105–115 mm. Isolines representing the upper limit of the norm in August are characterised by values decreasing from the north-west (the Elbląg and Górowo Hills) and the north (the Szeski Hump) to the south-east and south (from above 120 mm to 105 mm), with the lowest values (below 100 mm) recorded in the Land of Great Mazurian Lakes, Chełmińsko-Dobrzyńskie Lakeland, the Mława Hills, the Augustów Plain and the Białystok Upland. In September (as in August), the norms decreased quite regularly from the north-west to the south-east, from 110 mm in the Elbląg Hills to about 90 mm in the Mława Hills, and 75 mm in the Mazurian Plain, the Kurpie Plain and the Lower Narew Valley.

Tab. 1

Table 1. Monthly linear trend regression coefficients of precipitation probability below lower and above upper limit of norm in north-eastern Poland in successive 30-year sequences of moving sample from 1951–2000 (1 – probability of precipitation below lower limit of norm, 2 – probability of precipitation above upper limit of norm)

Tabela 1. Miesięczne wartości współczynników regresji trendu liniowego prawdopodobieństwa wystąpienia opadów powyżej i poniżej granicy normy w północno-wschodniej Polsce w ruchomych ciągach 30-letnich w wieloleciu 1951–2000 (1 – prawdopodobieństwo wystąpienia opadów poniżej dolnej granicy normy, 2 – prawdopodobieństwo wystąpienia opadów powyżej górnej granicy normy)

Station Stacja	April/Kwiecień		May/Maj		June/Czerwiec		July/Lipiec		August/Sierpień		September/Wrzesień	
	1	2	1	2	1	2	1	2	1	2	1	2
Banie Maz.	0.005***	0.001	-0.003**	-0.003*	-0.006***	0.006***	0.000	-0.003**	0.003**	-0.006***	0.002*	0.002
Białobrzegi	0.002	0.004**	-0.007***	0.002	-0.003**	0.006***	0.004***	0.000	0.005***	-0.004***	-0.001	0.006***
Białystok	0.003***	-0.000	-0.004***	0.000	-0.002**	0.003**	-0.001	0.002***	0.005***	-0.005***	-0.005***	0.005***
Biskupiec n. Osą	0.003**	-0.002***	0.000	-0.005***	-0.007***	0.004***	0.005***	-0.001*	0.008***	-0.001	-0.004***	0.006***
Brodnica	0.003**	0.002***	-0.000	-0.002	-0.006***	0.006***	0.000	-0.002***	0.005***	-0.006***	-0.003***	0.008***
Elbląg	0.006***	0.000	-0.004**	-0.004***	-0.003**	0.003***	0.006***	-0.006***	0.001	-0.004***	0.002***	0.003***
Kętrzyn	0.004***	0.002**	-0.010***	-0.004***	-0.005***	0.006***	0.004***	-0.006***	0.004***	-0.008***	-0.001	0.001
Lidzbark Warm.	0.005***	0.001	-0.004***	-0.003***	0.001	0.005***	0.003***	-0.007***	0.003**	-0.008***	0.001	0.004***
Lubawa	-0.000	0.001**	-0.001	-0.005***	-0.000***	0.007***	0.009***	-0.006***	0.003**	-0.004***	-0.000	0.003***
Mikołajki	0.006***	0.002***	-0.008***	-0.001	-0.001	0.003***	0.004***	-0.004***	0.001	-0.002**	-0.000	0.006***
Mława	0.002***	0.002***	-0.003***	-0.001	-0.002*	0.003***	0.006***	-0.005***	0.010***	-0.005***	-0.000	0.006***
Myszyniec	0.008***	-0.001**	-0.005***	-0.002**	-0.002***	0.004***	0.004***	-0.002*	0.008***	-0.008***	-0.002*	0.008***
Olsztyn	0.003***	0.003***	-0.006***	-0.002***	-0.001	0.002*	0.008***	-0.007***	0.004**	-0.007***	0.002*	0.004***
Ostrołęka	0.005***	0.001	-0.003*	-0.002	-0.002*	0.005***	0.003**	-0.004***	0.004***	-0.003***	-0.005***	0.010***
Prabuty	0.005***	0.002**	-0.003***	-0.003***	-0.003*	0.007***	0.007***	-0.005***	0.003***	-0.003***	-0.000	0.005***
Suwałki	0.004***	0.002**	-0.003*	-0.003*	0.000	0.002***	-0.002*	-0.001	0.004***	-0.005***	-0.000	0.002**
Wizna	0.002**	0.005***	0.001	0.001	0.003***	0.001*	0.005***	-0.002**	0.005***	-0.003***	-0.006***	0.008***
Żuromin	0.006***	0.000	-0.001	-0.004***	-0.005***	0.005***	-0.000	-0.004***	0.004***	-0.003***	-0.002***	0.005***

Values significant at the level: * 0.05; ** 0.01; *** 0.001
Wartości istotne na poziomie: * 0,05; ** 0,01; *** 0,001

For all months under investigation, the mean multi-year sums of precipitation recorded in the examined weather stations in 1951–2000 were lower than the mean monthly values of their upper limits of the precipitation norm. Deviations ranged from 14÷24 mm in April to 30÷55 mm in July [Banaszkiewicz *et al*. 2011]. The presented values of monthly precipitation norms are similar to the values of norms for north-eastern Poland recorded in 1951–1990, provided by Mrugała [2001].

Precipitation anomaly trends

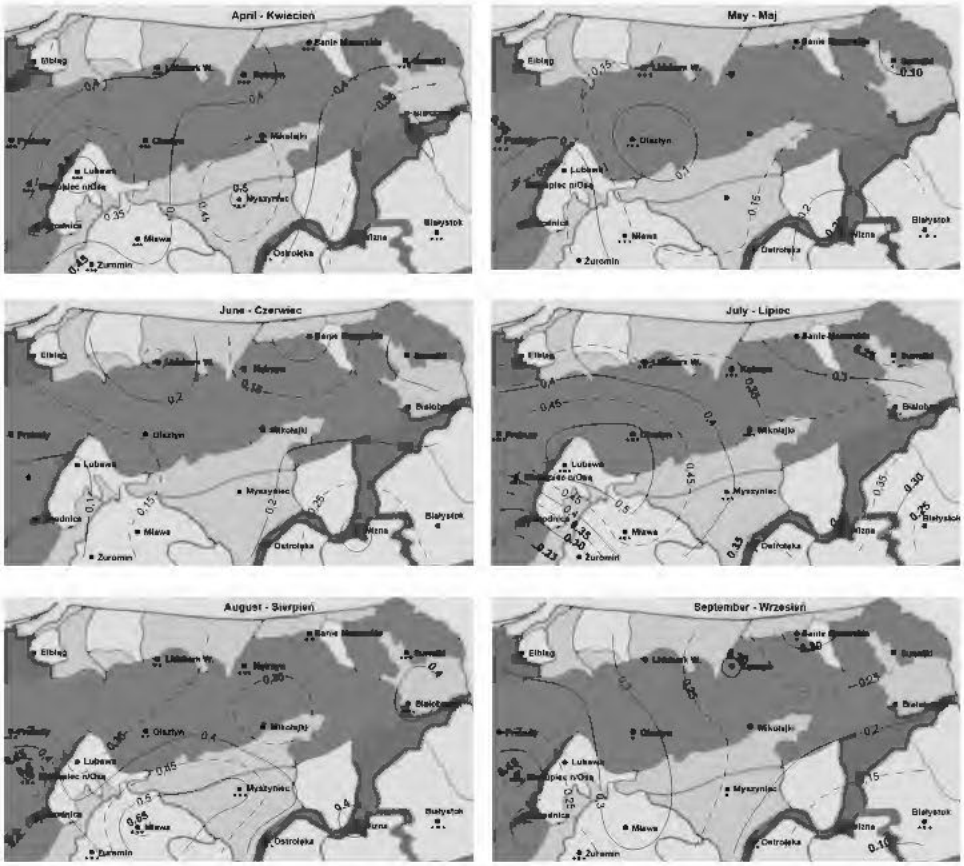
The probability of occurrence of precipitation below the lower limit of the norm in a 30–year series of the moving sample in August generally demonstrated a significant upward trend in all stations under analysis (Tab. 1). Upward trends, mostly significant, were also observed in April in the majority of the examined localities (except from Lubawa) and in July (except for Białystok, Suwałki and Żuromin). Upward negative anomaly trends also indicate an increasing probability of rainfall shortage in those months and in the examined localities. A decreasing, mostly significantly negative, anomaly trend was found in most of the examined localities in May (except for Biskupiec on the Osa River and Wizna), in June (except for Lidzbark Warmiński, Suwałki and Wizna) and in September (except for Banie Mazurskie, Elbląg, Lidzbark Warmiński and Olsztyn). The trends observed indicate a decreasing probability of a precipitation shortage in those months and localities.

The probability of precipitation exceeding the upper limit of the norm demonstrated mostly significant decreasing trends in August (in all stations) and in most localities in May and July. On the other hand, a growing, mostly significant trend of probability of occurrence of high precipitation was found in all examined localities in June and September. Slight increasing trends were also recorded in most of the examined localities in April, except for Białystok, Biskupiec on the Osa River and Myszyniec.

In summer months, the probability of occurrence of precipitation below the lower and above the upper limit of the norm revealed trends similar to the changes in the sums of precipitation in the region in 1951–2000 examined by Banaszkiewicz *et al.* [2011].

The probability of occurrence of a negative precipitation anomaly in the 30-year period of 1991–2020

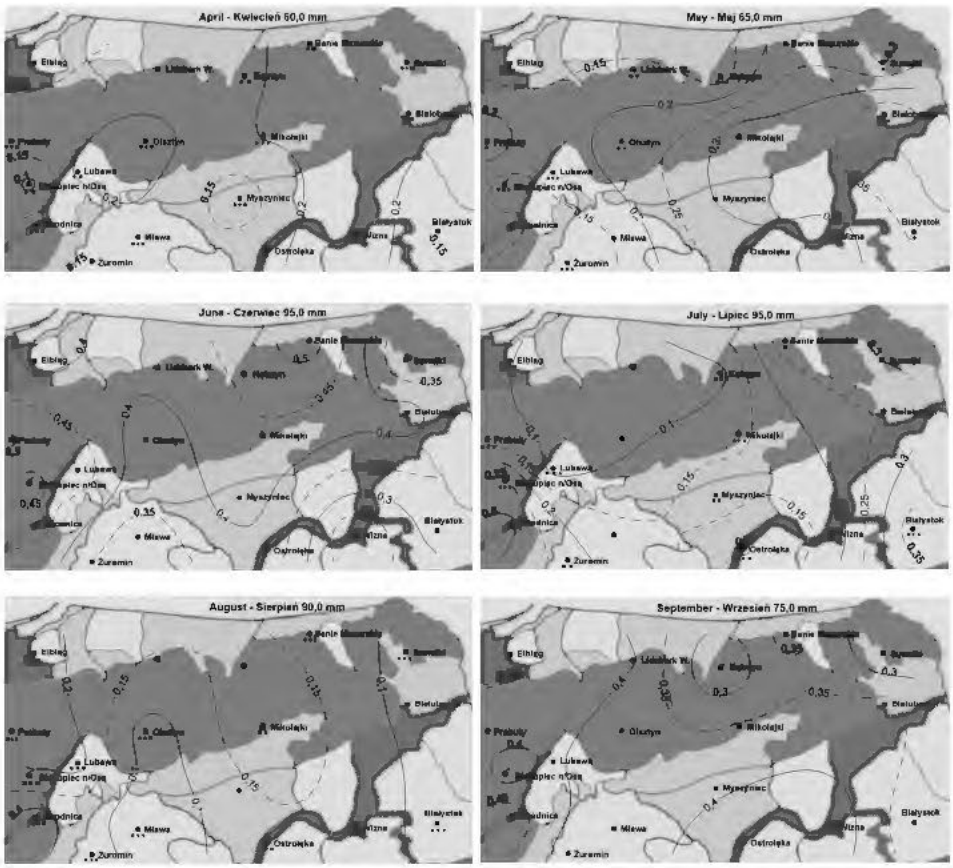
Verified linear regression equations were applied to predict the probability of occurrence of a precipitation anomaly. After performing an analysis and eliminating equations which did not meet prediction conditions, a reduced number of weather stations were used to study spatial variation of a negative anomaly – 14 in May and 16 in June. The probability of occurrence of precipitation below the lower limit of the norm in April (Fig. 4) ranges generally from 0.40 to 0.45, while in the area of the Lubawa Hump and the North Podlasie Lowlands it is slightly lower (0.30–0.35). In May it amounts to 0.10–0.20 for the most part of the Mazurian Lakeland, while in the area of the Chełmińsko-Dobrzyńskie Lakeland and the North Podlasie Lowland it varies from 0.15 to 0.25. In June, it ranges from 0.10–0.20 in the lake district (from the Chełmińsko-Dobrzyńskie Lakeland to the Land of Great Mazurian Lakes), to 0.20–0.30 in the Kolno and Białystok



Values significant at the level: * 0.05; ** 0.01;*** 0.001. Stations without names designated • were not used in spatial analysis/Wartości istotne na poziomie * 0,05; ** 0,01;*** 0,001. Stacje bez podanej nazwy oznaczone • nie były wykorzystane w analizie

Fig. 4. Probability of occurrence of precipitation below the lower limit of norm in the month from April to September in the years 1991–2020
Rys. 4. Prawdopodobieństwo wystąpienia opadów poniżej dolnej granicy normy w miesiącach od kwietnia do września w latach 1991–2020

Uplands and in the Biebrza Valley. Spatial interpretation of the results of equations for July revealed that in the entire area under examination, the probability of a negative anomaly in this month is high, ranging from 0.40–0.50 in the western part of the region to 0.25–0.35 in other parts (except for the vicinity of Wizna). For August, those values are about 0.35–0.40 for the most part the area, with values above 0.45 covering the south-western zone of the region. In September, they ranges from about 0.15–0.20 in the Chełmińsko-Dobrzyńskie Lakeland and the North Podlasie Lowland, to 0.20–0.30 on the Elbląg, Górowo and Mława Hills, the Szeski Hump and the Olsztyn Lakeland.



Values significant at the level: * 0.05; ** 0.01; *** 0.001. Stations without names designated • were not used in spatial analysis/Wartości istotne na poziomie * 0,05; ** 0,01; *** 0,001. Stacje bez podanej nazwy oznaczone • nie były wykorzystane w analizie

Fig. 5. Probability of occurrence selected values of precipitation from upper limit of norm in the month from April to September in the years 1991–2020
Rys. 5. Prawdopodobieństwo wystąpienia wybranych sum opadów powyżej górnej granicy normy w miesiącach od kwietnia do września w latach 1991–2020

The probability of occurrence of selected sums of precipitation from the upper limit of the norm in the 30-year period of 1991–2020

Since 15 weather stations were used for analysing the spatial differentiation of the above-mentioned parameters for May, July and August, the isoline distribution presented for those months is less precise. In April, the probability range of sums of precipitation of 60 mm (Fig. 5) for most of the region amounts to 0.15–0.20. In May, in the case of 65 mm precipitation, it differs from 0.15–0.20 in the western part to 0.25–0.35 in the eastern part

of the examined area. In June, with a sum of precipitation of 95 mm, it was lower (0.25–0.35) in the south of the region than in the north (0.40–0.50). In July, for precipitation of 95 mm, its probability ranges for the most part of the area from 0.1 to 0.15; higher amounts (0.20–0.30) were recorded in the Chełmińsko-Dobrzyńskie Lakeland, the Lithuanian Lakeland and the Białystok Upland (0.3–0.35). In August, for the sum of precipitation of 90 mm, its probability ranges from 0.10–0.15 for most of the region to 0.20 in the Gdańsk Seashore and the Iława Lakeland. In September, for precipitation of 75 mm, it is the highest (0.40–0.45) in the western part of the region (the Gdańsk Seashore, the Iława Lakeland, the Chełmińsko-Dobrzyńskie Lakeland, and the Górowo Hills), amounting to 0.30–0.40 in other parts of the area.

CONCLUSIONS

Determined characteristics describing sums of precipitations for individual months of the vegetation period (from April to September) in north-eastern Poland of 1951–2000 led to the following conclusions:

1. For all months under examination, the multi-year mean sums of precipitation recorded in the examined stations in 1951–2000 were higher than the mean values of their lower limit of the precipitation norm and they were lower than the value of their upper limit of the norm.

2. The probability of occurrence of precipitation below the lower limit of the norm in 30-year series of the moving sample revealed, in the majority of the examined stations, generally significant growing trends – in August, April and July – and decreasing trends in May, June and September. On the other hand, the probability of precipitation exceeding the upper limit of the norm showed significantly increasing trends in most localities (in June, September and in April) and decreasing trends in August, May and July.

3. The probability of occurrence of a negative anomaly was the highest in April (0.40–0.45) in the majority of the examined area, and in July (0.40–0.50) in its western part. In August, it amounted, generally, to about 0.35–0.40 and values above 0.45 covered the south-west of the region.

4. The probabilities of occurrence of selected sums of precipitation from the upper limit of the norm in the 30-year period of 1991–2020 (of 60 mm in April and 90 mm in August) are similar – they amounted to 0.15–0.20 for most of the area. In the case of 95 mm precipitation in July, it was even lower (0.10–0.15). In June, for the sum amounting to 95 mm, it was the highest in the north (0.40–0.50) and in September, for the value of 75 mm, it reached 0.40–0.45 in its western part.

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Streszczenie. Badano zmienność opadów atmosferycznych Polski północno-wschodniej w wybranych stacjach IMGW w latach 1951–2000. Scharakteryzowano sumy opadów poszczególnych miesięcy okresu wegetacyjnego z zastosowaniem 30-letniej próby kroczącej. Opracowano wartości norm opadowych, tendencje sum opadów oraz prawdopodobieństwa wystąpienia anomalii wyliczone z rozkładu gamma. Stwierdzono, że prawdopodobieństwo wystąpienia opadów poniżej dolnej granicy normy wykazywało w sierpniu we wszystkich badanych stacjach przeważnie istotny trend rosnący, a opadów przekraczających górną granicę – przeważnie istotne tendencje malejące. Wzrastającą, przeważnie istotną, tendencję pojawiania się dużych opadów notowano we wszystkich badanych miejscowościach w czerwcu i wrześniu.

Słowa kluczowe: opady atmosferyczne, północno-wschodnia Polska