

## Precipitation in the West Pomeranian Voivodeship in Poland (1991–2020) – monthly variability

Jadwiga Nidzgorska-Lencewicz\* , Agnieszka Mąkosza , Małgorzata Czarnecka 

West Pomeranian University of Technology in Szczecin, Department of Environmental Management,  
Słowackiego 17, 71-434, Szczecin, Poland

\* Corresponding author

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**Abstract:** The article presents the spatio-temporal variability of the pluvial conditions in the West Pomeranian province in Poland as per 21 poviats<sup>1</sup>. The basic data for the study were monthly precipitation totals and maximum 24-hour period total for each month, obtained from 49 stations of the Institute of Meteorology and Water Management National Research Institute in 1991–2020. It was found that area averaged highest values of precipitation, on average, ranging from 71 to 100 mm, were recorded in July (with the exception of the Kołobrzeg and Sławno poviats), and the lowest, ranging from 29–38 mm, were recorded in April. Precipitation in the warm half-year (April–September), depending on a given powiat, ranged from 317 to 444 mm, which constitutes 52–58% of the annual total. Even higher variability was found with respect to the cold half-year (October–March) characterised by precipitation totals within the range of 234–404 mm. In the analysed multi-year period, statistically significant monthly precipitation totals were found only on several occasions: a positive trend was observed in January in the Kołobrzeg powiat, in July in Koszalin and Szczecinek poviats and in October in Myślibórz and Kołobrzeg poviats. The only instance of a marked decrease in monthly precipitation was identified for June in the Kamień Pomorski powiat. In all poviats of the voivodeship, there were nonsignificant tendency of an increase in precipitation in the cold half-year and reduction of the predominance of precipitation in the warm half-year over cold half-year.

**Keywords:** extreme, Poland, poviats, precipitation, regional climate change, spatial variability, tendency, trend

### INTRODUCTION

The review of the literature on the pluvial variability in Poland suggests that annual totals of precipitation have not changed significantly since the second half of the 20<sup>th</sup> century and throughout the two decades of the 21<sup>st</sup> century. Regardless of the multi-year period under analysis, the identified changes were usually statistically insignificant and the observed tendency were often inconsistent between different studies (Zawora and Ziernicka, 2003; Czarnecka and Nidzgorska-Lencewicz, 2012; Degirmendzić and Kożuchowski, 2017; Pińskwar *et al.*, 2019b; Szwed, 2019; Grzywna *et al.*, 2020; Ziernicka-Wojtaszek and

Kopcińska, 2020). More pronounced, higher and worrisome tendencies are observed in the distribution of seasonal and monthly precipitation totals – generally, precipitation shifts from the warmer to colder half-year (Czarnecka and Nidzgorska-Lencewicz, 2012; Pińskwar *et al.*, 2019b; Szymanowski *et al.*, 2019). Numerous authors demonstrated a statistically significant increase in precipitation in March, particularly in the northern and central part of Poland (Degirmendzić, Kożuchowski and Żmudzka, 2004; Świątek, 2011; Szwed, 2019; Łupikasza and Małarzewski, 2021). Additionally, the studies indicate an increase in the number of days with precipitation (Wibig, 2009; Świątek, 2011). This increase, however, does not translate into an increased annual totals as the intensity of precipitation decreases (Kożuchowski, 2004). For example, in the south of Poland, there are statistically significant downward trends in the number of

<sup>1</sup> In the Polish administrative division terminology “voivodeship” corresponds to “province” and “powiat” to “county”.

days with 20.1–30.0 mm of precipitation as well as upward trends recorded for the number of days with daily precipitation totals of up to 5 mm, particularly in the cold half-year (Skowera, Kopcińska and Bokwa, 2016). The study by Ziernicka-Wojtaszek and Kopcińska (2020) points to the increasing variability of precipitation from one year to another which results in the observed more frequent occurrence of droughts and floods. Hänsel (2020) based on data from 220 stations from 1851 to 2015 showed that in Europe since the 1980s there has been an increase in the frequency of very dry and wet years. However, the analyses of long-term observational series of extreme precipitation in Poland so far have not demonstrated the unambiguous and significant direction of change (Łupikasza, 2010; Łupikasza, Hänsel and Matschullat, 2011; Pińskwar *et al.*, 2019a; Twardosz and Cebulska, 2020). This contradicts some forecasts for the future which predict that the intensity of precipitation and flood risk will increase (Kundzewicz, 2011; IPCC, 2023). The results by Tabari (2020) suggest that changes in the intensity of floods and extreme precipitation due to global warming are significant and pronounced when totalled up in different climatic regions. Regionalisation of changes reduces the overload of extreme phenomena on a local scale and provides more reliable results. In Europe, changes in extreme precipitation show differences depending on a region, employed data sets and calculated parameters (Łupikasza, Hänsel and Matschullat, 2011; Kholiavchuk and Cebulska, 2019; Pińskwar *et al.*, 2019a).

This article presents the results which are a continuation of research on variability of precipitation in the West Pomeranian Voivodeship (Nidzgorska-Lencewicz, Mąkosza and Czarnecka, 2024). The aim of the present paper was a demonstration of the multiannual (period 1991–2020) spatial and temporal variability in the pluvial conditions considered predominantly in monthly terms. It is assumed that the presented results will contribute to a more effective, integrated management of water resources in the region.

## MATERIALS AND METHODS

The administrative structure of the West Pomeranian Voivodeship is comprised by 18 poviats and three cities with poviat rights: Szczecin, Świnoujście and Koszalin. Among the poviats, the Police poviat has the smallest surface area – 665 km<sup>2</sup>, and Gryfino the largest 1869 km<sup>2</sup>.

The basis for the research were the results of precipitation measurements from all 49 stations operating within the measurement-observation network of the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB) in the period 1991–2020 – their location is presented in Figure S1. This included 44 precipitation stations of the 5<sup>th</sup> order (precipitation stations) and 5 meteorological stations of the 1<sup>st</sup> order (synoptic stations), namely: Kołobrzeg-Dźwirzyno, Koszalin, Resko, Szczecin and Świnoujście. The stations are located at an altitude from 1 to 165 m a.s.l.

The assessment of precipitation conditions in the West Pomeranian Voivodeship was conducted using the monthly totals as well as 24-hour period values.

The characteristics of precipitation presented herein are area averaged values obtained from the stations located within the poviats, with the exception of 7 administrative units (Świnoujście, Szczecin, Koszalin and the poviats: Police, Kamień Pomorski,

Świdwin and Białogard) which were represented by individual stations.

The only exception to the aforementioned principle are the results demonstrating the absolute minimum and maximum monthly values and maximum 24-hour period precipitation totals recorded in the thirty-year-long period under analysis, measured at particular stations located in particular administrative units of the West Pomeranian Voivodeship.

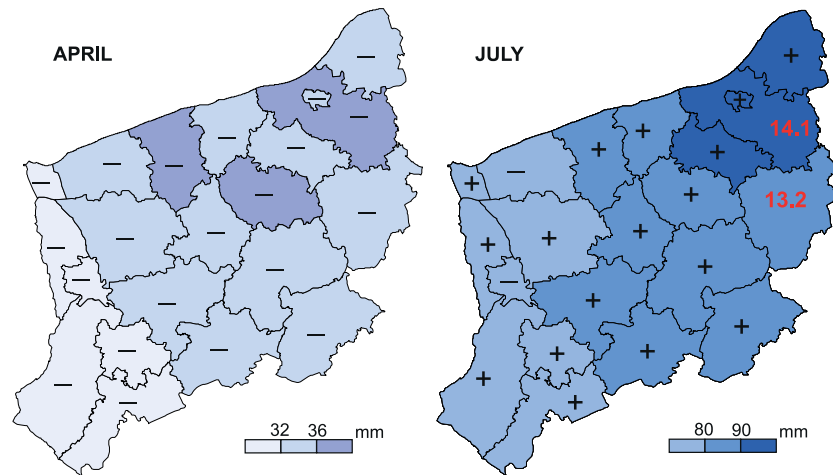
As has been indicated in the Introduction, the present paper is a continuation of the research on the pluvial conditions in the West Pomeranian Voivodeship. Detailed information on the amount of basic materials is presented in part I (Nidzgorska-Lencewicz, Mąkosza and Czarnecka, 2024).

In the assessment of the variability of precipitation conditions in particular poviats of the voivodeship in the analysed thirty-year-long period, the present paper makes use of a coefficient of variation  $V_s$  (%) i.e. a quotient of standard deviation and the mean value, as well as the statistical evaluation of the linear trend equation. Trend of changes were assessed using simple linear regression and coefficient of determination ( $R^2$  in %), and the statistical significance of trends was verified with a Student  $t$ -test ( $p < 0.05$  and  $p < 0.01$ ). The term ‘tendency’ used herein refers to statistically insignificant changes at  $p < 0.05$ .

## RESULTS AND DISCUSSION

The temporal structure of precipitation throughout the year is presented in Table S1. The analysis of the results given therein shows that in the period 1991–2020, the month characterised by the highest area averaged precipitation (with the exception of the Ślawno poviat) is still July (Czarnecka and Koźmiński, 2004). In the western poviats, the area averaged monthly totals do not exceed 80 mm, whereas in the central and eastern part – most frequently, the totals ranged from 80 to 90 mm (Fig. 1). By far the highest monthly precipitation total in July (100 mm) was recorded in the Koszalin poviat. Previously conducted research (Koźmiński, Trzeciak and Czarnecka, 1977; Koźmiński, Czarnecka and Górka, 1982; Czarnecka and Koźmiński, 2004; Kirschenstein, 2005; Koźmiński, Michalska and Czarnecka, 2012) show that the average lowest precipitation values in the West Pomeranian Voivodeship were recorded in February or March. For example, in the years 1961–1996 in Koszalin and Szczecin, the lowest values of precipitation in February were 36.4 and 29.1 mm, respectively (Kirschenstein, 2005). However, in the thirty-year-long period under analysis, the period with markedly lowest precipitation was April. Area averaged precipitation in April did not show great spatial variability; the lowest values (28.5 mm) were observed in the Police poviat, and the highest (38.2 mm) in the Koszalin poviat (Tab. S1). In most administrative units, precipitation in April ranged from 32 to 35 mm and was by 2.5 times lower than that recorded in July (Fig. 1). Precipitation values below 32 mm were identified in the poviats of western part of the voivodeship, whereas the values exceeding 36 mm in the Gryfice, Świdwin and Koszalin poviats.

The course of precipitation in the period 1991–2020, in two characteristic months in a year, i.e. April and July, is presented in diagrams for selected administrative units (Fig. 2). In the most poviats, the lowest area averaged precipitation in April did not



**Fig. 1.** Spatial distribution of April and July precipitation totals in the years 1991–2020; **14.1** = coefficient of determination ( $R^2$  in %) significant at least  $\alpha \leq 0.05$ ; colour values of  $R^2$  indicates direction of trend (positive/negative); +/- positive/negative tendency; source: own study

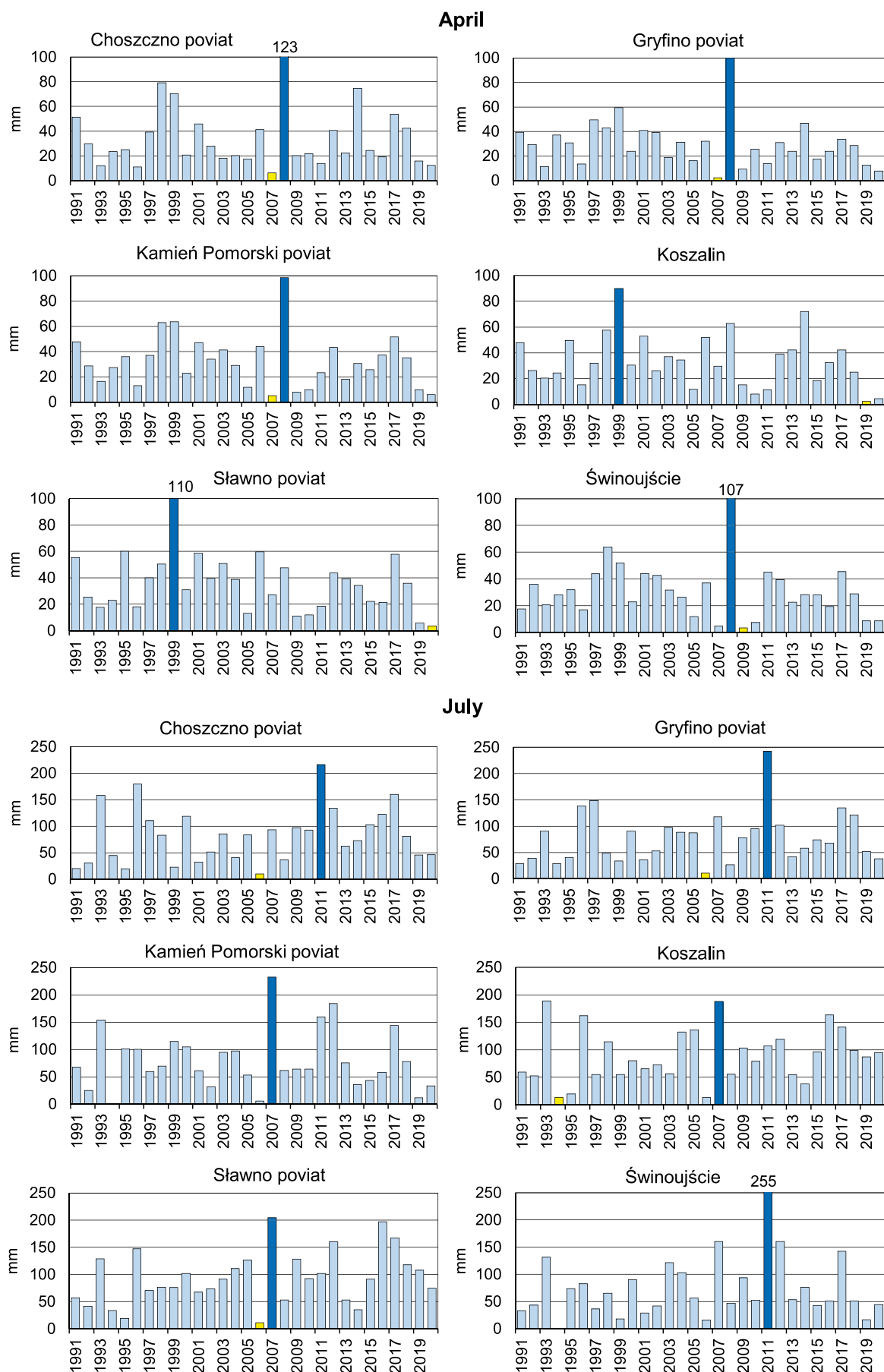
exceed 5 mm, and in the majority of the area of the West Pomeranian Voivodeship, the scarcest precipitation in April was recorded in the last two years of the period under analysis i.e., 2019 and 2020 – for example, in the Choszczno and Sławno poviats. Lower precipitation totals for April were recorded only in the western poviats in 2007 (e.g. the Gryfino poviat) or in 2009 (e.g. in Świnoujście). The highest precipitation values in April were recorded in the majority of the area of the voivodeship in 2008. Only in the four eastern poviats (Sławno, Koszalin, Szczecinek and Koszalin town), the average highest precipitation in April was recorded in 1999, and in the Białogard poviat in 2017.

By far the lowest area averaged precipitation in July was recorded, predominantly, in 1994 (Fig. 2). However, in eight poviats, located mostly in the north-west of the voivodeship, the lowest totals in July were recorded in 2006. In the Szczecin Lowland, July of 2006 was classified both as extremely warm as well as extremely dry (Michalska and Kalbarczyk, 2007). The lowest precipitation values in July in the dry year of 2006 were also recorded in the Łobez, Kołobrzeg and Sławno poviats. In turn, the highest precipitation in July was recorded with similar frequency in the years 2007 and 2011, and in some poviats higher totals were also determined for the years: 1993, 1996, 2016 and 2017. Record high precipitation in July 2007 occurred in the Goleniów, Kamień Pomorski, Gryfice, Łobez, Świdwin and Sławno poviats. In 2011, the highest precipitation values in July were recorded in the poviats located in the north and west of the voivodeship, e.g. Choszczno or Gryfino (Fig. 2). In many poviats, area averaged precipitation totals in July exceeded 200 mm, which is at least two times higher, and in the Gryfino poviat three times, than the norm for this month. By the far highest total in July (255 mm) was determined in Świnoujście in 2011.

April was found to be the month with not only average lowest precipitation values, but was also characterised by the highest inter-annual variability. Only in the Kamień Pomorski poviat, Szczecin and Świnoujście, was there a markedly higher variability in precipitation in July. As is presented in Table S1, the values of the coefficient of variation ( $V_s$  in %) of April precipitation generally exceeded 60%, and in the Choszczno and Goleniów poviats amounted to approx. 75%. In July, such great variability was

determined only for Świnoujście due to record low (on the voivodeship scale) precipitation in 2011. Throughout a year, apart from April and July, great inter-annual variability showing great spatial variability was also identified in October –  $V_s$  from 43 to 65% (Tab. S1). In the thirty-year-long period under analysis, the lowest variability was determined for precipitation in May and December –  $V_s$  values in the vast majority of cases were below 50%. Contrasting variability in precipitation in two consecutive months – great in April and slight in May, was found for the period 1971–2000 (Czarnecka and Koźmiński, 2004). Nevertheless, the assessment of precipitation variability on a country scale by (Szwed, 2019) shows that in the period 1951–2013, the most variable precipitation is identified with respect to July and June, whereas the highest stability is recorded from January to March. In turn, in the period 2001–2018, the highest variability was characteristic for September and October, and the lowest for March (Ziernicka-Wojtaszek and Kopcińska, 2020).

Almost all results of the assessment of the temporal trends of area averaged monthly precipitation totals in the period 1991–2020 in 21 administrative units of the West Pomeranian Voivodeship proved insignificant. A statistically significant trend (at  $\alpha = 0.05$ ) was identified only in six cases and in different months in a year. In the Koszalin and Szczecinek poviats, there was an increase in precipitation in July (Fig. 1). A positive trend was also determined with respect to precipitation in October in the poviats: Myślibórz ( $R^2 = 13.9\%$ ) and Pyrzyce ( $R^2 = 13.4\%$ ), and in January in the Kołobrzeg poviat ( $R^2 = 18.8\%$ ). A statistically significant decrease in precipitation was identified only in June in the Kamień Pomorski poviat ( $R^2 = 14.7\%$ ). The results for the thirty-year-long period under analysis did not confirm the positive trend in precipitation in March found for this area in the fifty-year-long period 1951–2000 (Koźmiński, Michalska and Czarnecka, 2012). However, the analysis of slope coefficients allows to distinguish some tendency in changes of the monthly precipitation totals. The same direction of changes in precipitation values in all administrative units, without exceptions, is observed in January, March and in April. In January, there is a pronounced upward tendency, whereas in March in April the opposite – a downward tendency. The identical tendency,



**Fig. 2.** The course of April and July precipitation totals in selected poviats in the years 1991–2020; yellow bar = lowest values, navy blue bar = highest values; source: own study

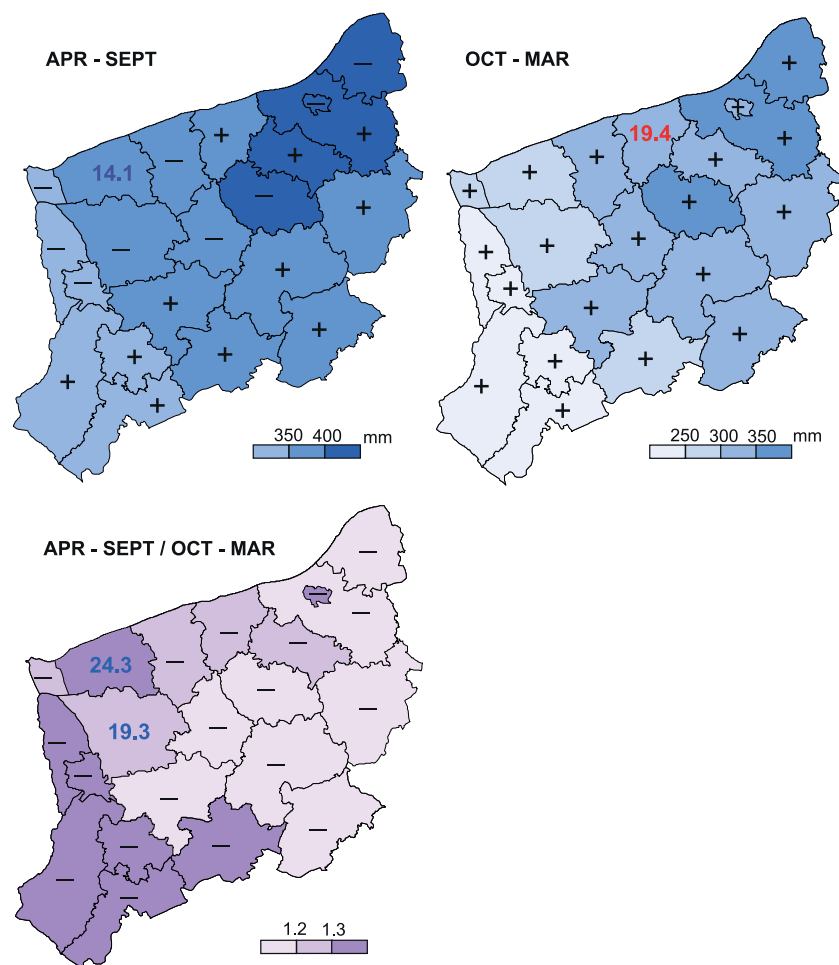
in almost all poviats (with the exception of two or three poviats) was found with respect to a positive in precipitation in July and October and negative in June and August. The aforementioned directions of changes in the West Pomeranian Voivodeship are, with respect to many months, in line with the results presented by Pińskwar *et al.* (2019b) on a country scale as the effect of comparison of the pluvial conditions in two time intervals: 1961–1990 and 1991–2017. Only the changes in precipitation in March in the period 1991–2020 recorded in all administrative units of the voivodeship were of opposite direction, which is surprising given the positive statistically significant trend, even at  $\alpha = 0.01$ , found for the period 1951–2000 in Koszalin, Szczecinek and Resko (Kozłmiński, Michalska and Czarnecka, 2012). It is worth mentioning the suggestion put forward by Brien *et al.* (2013) concerning the necessary caution when drawing conclusions regarding tendency of atmospheric precipitation as they show high sensitivity/variation depending on the given time period.

Area averaged lowest and highest monthly precipitation totals vary within a wide range, from 0 to 255 mm (Tab. S1). The lowest totals, which in many poviats and months were below 5 mm, generally occurred in the first half of a year, most often in January. Nonetheless, such low precipitation was also recorded in the summer months such as in July in the Kamień Pomorski poviat or in June in the Koszalin poviat and Koszalin. The

maximum precipitation totals were recorded only in the months of the calendar summer, by far most frequently in July. In many poviats, the values exceeded 200 mm even in the poviats characterised by the average lowest precipitation e.g. the Gryfino or Police poviat or in Świnoujście.

From the agricultural perspective, particular importance in the assessment of the temporal structure of precipitation conditions is given to the cycle of precipitation characterised not only by totals of the calendar seasons but also by half-year precipitation: the warm half-year (April–September) and the cold half-year (October–March). As is presented in Figure 3, area averaged precipitation in the warm half-year (April–September), similarly to precipitation in the calendar summer (Nidzgorska-Lencewicz, Mąkosza and Czarnecka, 2024), show a regular increase from the west to the north-east. In six poviats located to the west of the voivodeship, the totals are below 350 mm. The poviats: Białogard, Koszalin, Sławno, Świdwin and Koszalin were favoured in terms of precipitation values. Among those, the highest totals (443 mm) were recorded in the Sławno poviat followed by slightly lower values (439 mm) in the Koszalin poviat (Tab. S1).

Spatial distribution of precipitation in the cold half-year (October–March) is slightly less regular, yet the changes demonstrate a similar direction to that of the warm half-year though they show higher variability. The lowest totals, below



**Fig. 3.** Spatial distribution of warm half-year and cold half-year precipitation totals (mm) and quotient of them in the years 1991–2020; explanations as in Fig. 1; source: own study

250 mm, were characteristics for the same poviats as in the warm half-year, with the exception of Świnoujście. The highest totals, over 350 mm, were determined for the poviats: Sławno, Koszalin and Świdwin. Only in the Koszalin powiat, the totals of the period October–March exceed 400 mm. In most administrative units of the West Pomeranian Voivodeship, precipitation in the warm half-year was by at least 70 mm higher than in the cold half-year. By far the lowest difference, of only 35 mm, was found for the Koszalin powiat. The highest predominance of precipitation in the warm half-year, approx. 90 mm, was observed with respect to the poviats: Choszczno, Gryfino, Kołobrzeg as well as Koszalin and Szczecin.

In the thirty-year-long period under analysis, mean precipitation in the warm half-year recorded in the West Pomeranian Voivodeship amounted to 376 mm, and in the cold half-year 303 mm, which represents 55.3 and 44.7%, respectively, of the annual total and clearly diverges from the values, in the corresponding periods, 63 and 37%, provided by (Grzywna *et al.*, 2020) on the country scale (53 stations) in the period 1981–2010.

The values of the quotient of precipitation in both half-year periods fall within a similar range from 1.1 to 1.4 and are lower than the values recorded for the period 1961–1996 (Kirschenstein, 2005) or 1951–2010 (Czarnecka and Nidzgorska-Lencewicz, 2012).

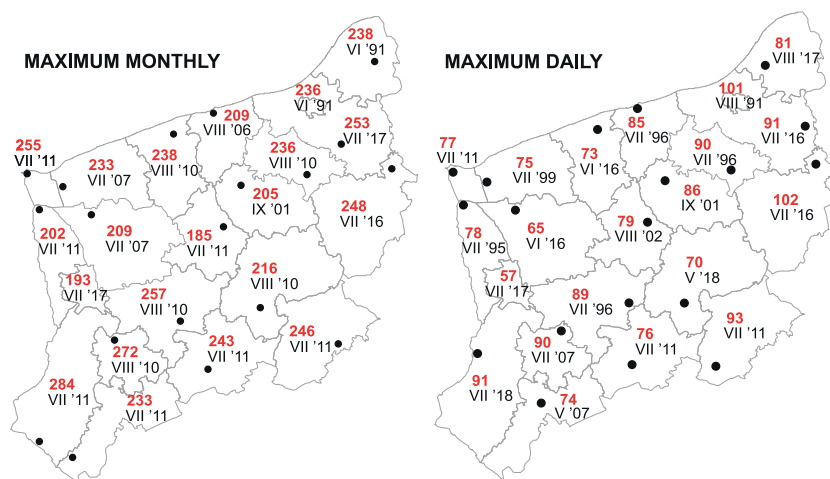
Although all studies concern the multiannual changes in precipitation in the warm and cold half-year as insignificant, the authors point to a clearly negative phenomenon of decreasing predominance of precipitation in the warm half year over precipitation in the cold half-year (e.g. Czarnecka and Nidzgorska-Lencewicz (2012), Pińskwar *et al.* (2019b), Szwed (2019)). The statistical analysis of changes in precipitation in both half year periods and their mutual relationship in the thirty-year-long period (1991–2020) in West Pomeranian Voivodeship also showed that almost all results were insignificant. As is presented in Figure 3, a negative trend is observed only with respect to the total precipitation in the warm half year in the Kamień Pomorski powiat, and a positive – in the warm half-year in the Kołobrzeg powiat. However, throughout the whole voivodeship, there is a marked tendency of increasing precipitation in the cold half year. In the warm half-year, there is both a tendency of a slight increase (11 poviats) as well as decrease (10 poviats) in

precipitation. Consequently, the quotients of precipitation in both half year periods show a decreasing tendency in all administrative units of the voivodeship.

The results obtained by Pińskwar *et al.* (2019a) indicate that in Poland, the signal for 24-hour precipitation total is not so clear as there was a decreasing trend recorded in winter in the cold-half year as well as a weak increasing trend for the warm half-year. However, importantly, the number of days with intense precipitation is found to increase particularly in the north-west of Poland. Wibig and Piotrowski (2018) have shown that the directions of air masses advection contributing to the phenomenon of intense precipitation did not change – from the western and southern sector in the cold season in a year and from the southern and eastern sectors in the warm seasons in a year. In turn, Świątek (2011) demonstrated that in the zone of the Polish coast of the Baltic Sea, the more intense western advection causes more frequent precipitation and the direction air masses advection shows a stronger effect on the number of days with precipitation than on the precipitation total.

Given the aforementioned results, the characteristics based on area averaged values were supplemented with the absolute monthly maxima and 24-hour maxima (Fig. 4). Unlike the previous results, based on averaged values for particular administrative units, the data presented herein were obtained from particular stations located in a given administrative units. In the period 1991–2020 the absolute monthly maxima of precipitation totals were recorded in the month of the calendar summer as has been shown in the analysis of data presented in Table S1. In almost all poviats, represented by at least two precipitation stations, the absolute maxima of the monthly totals exceeded 200 mm, i.e. they were approx. three times higher than the norm for a given month. The record monthly total of 284 mm was identified in Gozdowice in the Gryfino powiat in July 2011. In almost the entire area of the voivodeship, the absolute maximum monthly totals were determined to have occurred in this century, mainly in the last decade of the 30-year-long period under analysis. Only in the Białogard and Sławno powiat and in Koszalin the highest monthly total was identified in the year 1991.

In Szczecin, the highest values of 24-hour period precipitation amounted to 57 mm, and in Koszalin and the Szczecinek



**Fig. 4.** Absolute monthly and daily maximum of precipitation totals (mm) in the years 1991–2020; source: own study

poviat (Sępólno Wielkie) the maximum 24-hour totals were almost twice as high as amounted to 101 and 102 mm, respectively. In most powiats, the maximum 24-period totals did not exceed 70 mm and, generally, did not deviate from the monthly norm (Tab. S1) and, in many administrative units, were found to markedly exceed the monthly norm. The absolute 24-hour precipitation totals, similarly to the monthly maxima, were recorded most frequently in July though in different years of the multiannual period under analysis.

## CONCLUSIONS

In the West Pomeranian Voivodeship, in the period 1991–2020, the highest area averaged values of precipitation were characteristic for July. Only in the Kołobrzeg and Sławno powiats, equally high, or even slightly higher, totals were recorded in August. In turn, in almost all powiats, the lowest values were recorded in April.

April proved to be the month characterised by not only the lowest values of precipitation but also, in the scale of almost the entire area of the voivodeship, showed highest variability in precipitation from one year to another. In the Choszczno and Goleniów powiats, the coefficients of variation amounted to approx. 75%. Only in Szczecin, Świnoujście and in the Kamień Pomorski powiat, a clearly higher variation was found with respect to precipitation in July. In most powiats, mainly in the western part of the voivodeship, the least variable was precipitation in December, whereas in many administrative units of the central and eastern part of the voivodeship – precipitation in May.

In the period 1991–2020, precipitation in the warm half-year (April–September) constituted from 52 to 58% of the annual total and the predominance over precipitation in the cold half-year (October–March) was approx. from 35 to 100 mm. Both the lowest as well the highest differences between precipitation values in both half year periods concerned administrative units located in various parts of the West Pomeranian Voivodeship.

The statistical assessment of the variability of the monthly precipitation totals in the thirty-year-long period under analysis, i.e. 1991–2020, produced statistically significant results only in a few cases with respect to different powiats. A statistically significant positive trend, at the level  $\alpha = 0.05$ , was identified with respect to January in the Kołobrzeg powiat, July in the Koszalin and Szczecinek powiats, and October in the Myślibórz and Pyrzyce powiat. The only instance of a statistically proven decrease in monthly precipitation was found for June in the Kamień Pomorski powiat.

Area averaged precipitation totals in the warm half-year demonstrated a significant decrease in the Kamień Pomorski powiat, and in the cold half-year there was a statistically significant increase in Kołobrzeg powiat. In all administrative units of the voivodeship there was a tendency of decreasing prevalence of precipitation in the warm half-year over precipitation in the cold half-year.

## SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at [https://www.jwld.pl/files/Supplementary\\_material\\_Nidzgorska.pdf](https://www.jwld.pl/files/Supplementary_material_Nidzgorska.pdf).

## CONFLICT OF INTERESTS

All authors declare that they have no conflicts of interests.

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