JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.150274
2024, No. 61 (IV–VI): 202–212

Atmospheric precipitation in the West Pomeranian Voivodeship in Poland (1991–2020) – Annual and seasonal variability

Jadwiga Nidzgorska-Lencewicz*, Agnieszka Mąkosza, Małgorzata Czarnecka

West Pomeranian University of Technology in Szczecin, Faculty of Environmental Management and Agriculture, Department of Environmental Management, Juliusza Słowackiego St, 17, 71-434 Szczecin, Poland

* Corresponding author

RECEIVED 07.08.2023 ACCEPTED 11.03.2024 AVAILABLE ONLINE 24.06.2024

Abstract: The paper presents a detailed analysis of precipitation conditions in the West Pomeranian Voivodeship in Poland, covering data from 21 poviats[1]. The basic data consisted of monthly sums of atmospheric precipitation from 49 stations of the Institute of Meteorology and Water Management National Research Institute (Pol.: Instytut Meteorologii i Gospodarki Wodnej Państwowy Instytut Badawczy – IMGW-PIB) in 1991–2020. Variability of precipitation conditions was demonstrated through annual and seasonal totals, the share of seasonal precipitation in annual totals, and the ratios of summer to winter precipitation and autumn and spring precipitation. It was found that area averaged annual totals ranged from below 600 mm in the poviats located in the west of the Voivodeship to more than 800 mm in the poviats located in the north-east. On average, the lowest annual totals were recorded in the area of the Police (550 mm) and Gryfino (565 mm) poviats, and the average highest in the Koszalin (842 mm) poviat. In most poviats, there was a slight, statistically insignificant tendency of increasing annual totals. The contribution of precipitation in spring, summer, autumn, and winter to the annual total in the voivodeship was 21, 33, 24, and 22%, respectively. The greatest year-to-year variability was found for summer (*Vs* = 28–39%) and winter precipitation totals (*Vs* = 29–35%). The most statistically significant result of the analysed features was identified for the calendar spring. The most prominent statistically significant changes in precipitation conditions were observed in the Goleniów, Kamień, and Sławno poviats.

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

INTRODUCTION

The evidence for global climate system warming is clear, supported by observations of rising air temperatures across various spatial scales: local, national, regional, continental, hemispheric, and global. This surface warming trend has been observed consistently worldwide (IPCC, 2023). The changes in global temperatures are not isolated; they coincide with alterations in other climatic variables, such as precipitation. Hynčica and Huth (2019) found a significant decline in the ratio of solid (e.g. snow) to total precipitation across large portions of Europe. The strongest negative trend is identified in a belt that extends from the northern Scandinavian coast through central and eastern Europe to southern and south-eastern Europe. Prognoses indicate an increase in not only the intensity but also in the frequency of precipitation. Such changes are currently being observed in various regions worldwide (IPCC, 2023). Consequently, the literature on the subject pays particular attention to the assessment of trends with respect to maximum precipitation (Łupikasza *et al.*, 2011; Aalbers *et al.*, 2018; Twardosz, Cebulska and Guzik, 2023), identification of relationships with causative factors (Lenggenhager and Martius, 2019; Silva da and Haerter, 2023; Twardosz, Cebulska and Guzik, 2023; Ustrnul *et al.*, 2023; Palarz *et al.*, 2024) or projections (Thompson *et al.*, 2017; McKenna and Maycock, 2022).

The precipitation regime in Poland is changing. However, with respect to annual precipitation totals, no clear significant

[1] In the Polish administrative division terminology "voivodeship" corresponds to "province" and "poviat" to "county".

trends have been identified (Degirmendžić, Kożuchowski and Żmudzka, 2004; Wibig, 2009; Czarnecka and Nidzgorska-Lencewicz, 2012; Degirmendžić and Kożuchowski, 2017; Pińskwar *et al.*, 2019; Szwed, 2019; Grzywna *et al.*, 2020). Emphasis is put on the increasing inter-annual variability of annual rainfall totals, which results in an increase in the frequency of both drought and floods (Ziernicka-Wojtaszek and Kopcińska, 2020). Regardless of the multiannual period under analysis, the identified changes are generally statistically insignificant, and the observed tendencies are often multidirectional, depending on the amount of precipitation at the beginning and end of the analysed precipitation series. Therefore, according to some authors, for the purpose of analysing the temporal variability of unstable climate elements, such as precipitation, Fourier analysis would be more favourable than the linear trend. Using Fourier analysis, cyclical variability in both annual as well as seasonal totals was identified (Czarnecka and Nidzgorska-Lencewicz, 2016; Walanus *et al.*, 2022). In 1951–2020, the cyclic changes in seasonal precipitation in Pomerania significantly varied from approx. 6 to 30 years. Nevertheless, main and predominant cyclic components can be identified, notably quasi 7-years, 10-years and 15-years (Czarnecka and Nidzgorska-Lencewicz, 2016). However, according to Miętus (1996), the temporal structure of precipitation conditions along the Polish coast of the Baltic Sea is primarily determined by short pseudo-cycles ranging from 2–13 years, particularly in summer and autumn.

Changes in the pluvial regime in Poland are predominantly manifested in the seasonal and monthly precipitation totals. The most visible increases were observed during the cold half-year, especially in March (Żmudzka, 2002; Degirmendžić, Kożuchowski and Żmudzka, 2004; Czarnecka and Nidzgorska-Lencewicz, 2012; Pińskwar *et al.*, 2019; Szwed, 2019; Szymanowski *et al.*, 2019; Kalbarczyk and Kalbarczyk, 2021). Forecast based on climatic models shows that annual precipitation totals in Poland are expected to increase further, especially in the northern part of the country (from 200 to over 400 mm). Precipitation in warmer season is expected to decrease further, whereas in colder season it is expected to increase (Szwed, 2019).

Polish literature on the subject most frequently characterises the pluvial conditions based on multiannual measurement series and covers the whole country (Degirmendžić *et al.*, 2004; Czarnecka and Nidzgorska-Lencewicz, 2012; Szwed, 2019; Grzywna *et al.*, 2020; Ziernicka-Wojtaszek and Kopcińska, 2020; Kalbarczyk and Kalbarczyk, 2021). It also focuses on selected regions (Świątek, 2011; Skowera, Kopcińska and Bokwa, 2016; Szyga-Pluta, 2018; Wypych, Ustrnul and Schmatz, 2018; Szymanowski *et al.*, 2019) or individual stations (Majewski, Przewoźniczuk and Kleniewska, 2010; Szyga-Pluta and Grześkowiak, 2016).

There are two studies strictly dedicated to precipitation conditions in the West Pomeranian Voivodeship, i.e. Koźmiński, Trzeciak and Czarnecka (1977) and Koźmiński, Czarnecka and Górka (1982). These studies provide a detailed characterisation of numerous features of precipitation and related phenomena, including aspects targeted to address the needs of agricultural production. The analysis was based on data obtained from more than 100 precipitation stations during the periods 1956–1975 (Szczecin Voivodeship – 54 stations) and 1956–1980 (Koszalin Voivodeship – 56 stations). The results were presented as precipitation regions of particular voivodeships. Precipitation values recorded in the said regions also constitute an integral part of the monograph by Koźmiński, Michalska and Czarnecka (2012). The assessment of the precipitation variability presented therein was based on results from 67 precipitation posts referred to in the two aforementioned studies covering the former voivodeships, i.e. Szczecin and Koszalin, as well as on the results from 9 meteorological stations in the period 1961–2000. A wider perspective on precipitation conditions, particularly those concerning Pomerania in the period 1961–2000, is illustrated in four charts by Czarnecka and Koźmiński (2004).

Considering the already observed changes in precipitation conditions and forecasts (IPCC, 2023), an in-depth analysis of precipitation conditions was conducted to facilitate more effective and integrated management of water resources in the region. The analysis was presented in administrative terms for 21 individual poviats of the West Pomeranian Voivodeship for the period from 1991 to 2020, including the latest applicable climatic norms.

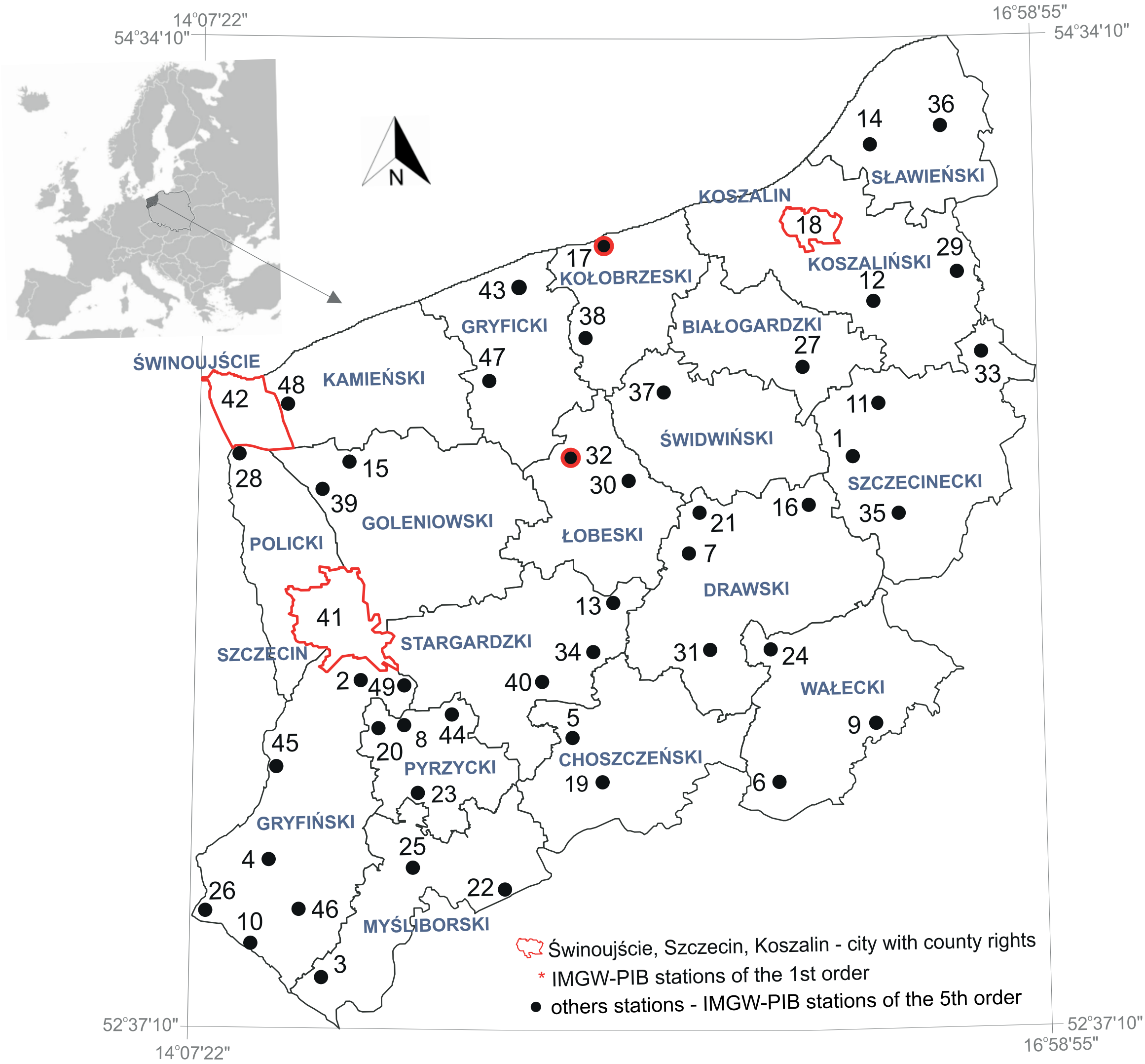
MATERIALS AND METHODS

The West Pomeranian Voivodeship encompasses an area of 22,892.48 km^2 and consists of 18 poviats and 3 cities with the poviat status (Fig. 1). Among the 18 poviats, the Police poviat is the smallest, covering an area of 665 km^2, and the Gryfino poviat is the largest, spanning 1,869 km^2. The three cities with the poviat status are Koszalin, Szczecin, and Świnoujście, with areas of 98, 301, and 201 km^2, respectively.

In Kondracki's (2023) physical-geographical regionalisation, the West Pomeranian Voivodeship is located in the South Baltic Coasts, especially Szczecin and Koszalin regions, in its north-western part, and in the Pomeranian Lake District, part of the South Baltic Lakes, its south-eastern part. The terrain elevations in the Voivodeship range from minor depressions to 247.5 m a.s.l. at the highest point (Góra Krajoznawców in the Bytów Lake District in the western part of the Voivodeship). Notably, thermal winter is no longer reported in the north-western part of the Voivodeship, and the number of days with snow cover is the lowest in Poland – fewer than 30 days. The Voivodeship has a long growing season of 230–240 days. An area with more than 240 days is only found in the mid Odra valley (Tomczyk and Bednorz, 2022).

The basic data for this study comprised monthly measurements of atmospheric precipitation at all 49 stations operating within the IMGW-PIB measurement-observation network between 1991 and 2020. The locations of the stations are indicated in Figure 1. The 18 poviats of the West Pomeranian Voivodeship were represented by 46 precipitation stations of the 5th order. The number of stations in each poviat varied from one to seven, with individual stations operating in the poviats of Białogard, Kamień, Police, and Świdwin. The most abundant basic data, obtained from seven stations, were for the largest poviat, i.e. Gryfino. Data for the three cities with the poviat status were collected from three meteorological stations of the 1st order located in the respective cities. The stations from which the basic data was collected represent highly diverse physiographic conditions of the Voivodeship and are located at altitudes above sea level across a wide range, i.e. from 1 m in Szczecin to 165 m in Sępolno Wielkie (szczecinecki county).

With respect to the administrative units with precipitation data from at least two stations, the presented precipitation



Station name	Longitude	Latitude	Height above sea level	Station name	Longitude	Latitude	Height above sea level
1. Barwice	16°21´29˝E	53°44´53˝N	120	26. Osinów Dolny	14°08´12˝E	52°50´55˝N	4
2. Binowo	14°39´01˝E	53°18´29˝N	55	27. Osówko	16°04´16˝E	53°54´34˝N	55
3. Boleszkowice	14°34´00˝E	52°43´37˝N	49	28. Podgrodzie	14°19´54˝E	53°43´57˝N	2
4. Chojna	14°26´14˝E	52°57´52˝N	25	29. Polanów	16°40´59˝E	54°07´07˝N	80
5. Choszczno	15°24´23˝E	53°10´09˝N	55	30. Poradz	15°36´21˝E	53°42´06˝N	91
6. Człopa	16°06´57˝E	53°05´05˝N	85	31. Poźrzadło Wielkie	15°55´27˝E	53°23´08˝N	136
7. Drawsko Pomorskie	15°49´28˝E	53°31´59˝N	112	32. Resko*	15°23´36˝E	53°45´49˝N	52
8. Giżyn	15°01´00˝E	52°56´15˝N	67	33. Sępolno Wielkie	16°46´24˝E	53°56´51˝N	165
9. Gostomia	16°25´37˝E	53°11´19˝N	152	34. Sierakowo	16°30´59˝E	54°12´59˝N	50
10. Gozdowice	14°19´20˝E	52°46´01˝N	38	35. Silnowo	16°29´53˝E	53°38´00˝N	157
11. Grzmiąca	16°26´21˝E	53°50´09˝N	100	36. Sławno	16°40´13˝E	54°21´06˝N	25
12. Grzybnica	16°26´45˝E	54°02´42˝N	90	37. Sławoborze	15°42´07˝E	53°53´07˝N	52
13. Ińsko	15°32´28˝E	53°26´06˝N	127	38. Starnin	15°27´24˝E	53°57´54˝N	34
14. Jeżyczki	16°23´26˝E	54°20´05˝N	10	39. Stepnica	14°37´14˝E	53°38´53˝N	2
15. Kartlewo	14°47´33˝E	53°47´28˝N	21	40. Suchań	15°19´33˝E	53°16´43˝N	53
16. Kluczewo	16°11´13˝E	53°38´57˝N	146	41. Szczecin*	14°37´22˝E	53°23´43˝N	1
17. Kołobrzeg*	15°23´20˝E	54°09´31˝N	4	42. Świnoujście*	14°14´32˝E	53°55´24˝N	4
18. Koszalin*	16°09´19˝E	54°12´16˝N	33	43. Trzebiatów	15°15´53˝E	54°03´59˝N	10
19. Krzęcin	15°29´03˝E	53°04´55˝N	71	44. Warnice	14°40´15˝E	52°51´06˝N	62
20. Linie	14°45´23˝E	53°11´11˝N	35	45. Widuchowa	14°23´28˝E	53°07´08˝N	15
21. Łabędzie	15°48´33˝E	53°39´02˝N	100	46. Wierzchlas	14°30´08˝E	52°50´17˝N	60
22. Łubianka	15°11´30˝E	52°53´03˝N	68	47. Witno	15°03´47˝E	53°56´40˝N	20
23. Mielęcin	14°53´56˝E	53°04´41˝N	67	48. Wolin	14°36´57˝E	53°50´15˝N	2
24. Mirosławiec	16°05´19˝E	53°20´23˝N	110	49. Żelewo	14°51´59˝E	53°17´30˝N	20
25. Myślibórz	14°51´23˝E	52°54´45˝N	62				

Fig. 1. Location of meteorological stations of Institute of Meteorology and Water Management National Research Institute (IMGW-PIB) considered in the study source: own elaboration

characteristics are area averaged values. With respect to the four aforementioned counties and cities with county rights, the characteristics are, perforce, data from particular stations.

In general, most stations provided a complete data set. There were one-year long series missing for the stations in Łabędzie (2015), Silnowo (2017) and Osówko (1991), and a four-year long series for the station in Resko (2015–2018). Lack of data from one month was identified for the stations in: Chojna (2019), Łubianka (2020), Podgrodzie (2017) and Warnice (2010). In such cases, the characteristics from the years indicated in brackets next to the name of the station were calculated on the basis of 11 months.

Distribution of precipitation was developed primarily using the seasonal and annual totals as well as precipitation quotients: summer (June, July, August) and winter (December, January, February), autumn (September, October, November) and spring (March, April, May). As for the calendar winter, precipitation values from December of the previous year were taken into account, therefore the first winter season includes the data from December of 1990, January and February of 1991. The integral part of the characteristics of precipitation conditions was the assessment of the temporal variability of all the presented features of precipitation in the 30-year long period under analysis, conducted with the use of the coefficient of variation (*Vs*, in %) as the quotient of the standard deviation to the mean value, as well as the statistical evaluation of the linear trend. 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 factors such as the coastal location, coastline the course of the hills and river valleys of the Pomeranian Lake District as well as large forest cover, the presence of several thousand lakes in the conditions of prevalent rain-bearing air masses from the western sector, are the reasons why the highest precipitation totals in the West Pomeranian Voivodeship are recorded in north-western and western slopes of the terminal moraine hills, particularly with forest cover. Elevation above sea level of the hills as well as the relative difference in altitude favour the formation of precipitation (Kirschenstein, 2002; Świątek, 2011; Koźmiński, Michalska and Czarnecka, 2012). According to Degirmendžić, Kożuchowski and Żmudzka (2004), the circulation factor explains up to 44% of precipitation variance.

The analysis of the time period 1991–2020 showed that in six administrative units located in the western part of the West Pomeranian Voivodeship, that mean annual precipitation totals did not exceed 600 mm and in two poviats located in the north-east of the voivodeship, annual precipitation totals exceeded 800 mm (Fig. 2, Tab. 1). The variability of area-averaged annual precipitation in 1991–2020 generally aligns with the distribution shown by isohyets, identified in previously analysed multiannual periods of 1956–1975 and 1961–2000 (Koźmiński, Trzeciak and Czarnecka, 1977; Koźmiński, Czarnecka and Górka, 1982; Czarnecka, and Koźmiński, 2004; Koźmiński, Michalska, and Czarnecka, 2012). In the characterised 30-year period, the area with, the highest average annual precipitation totals was found to

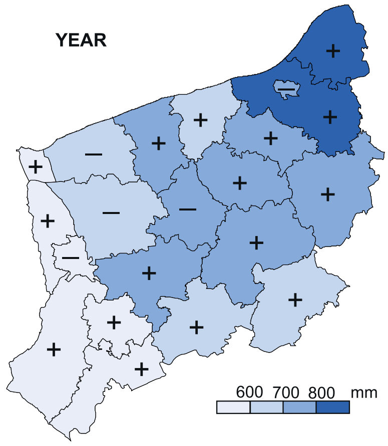


Fig. 2. Spatial distribution of annual precipitation totals (1991–2020); +/– positive/negative tendency, source: own study

Table 1. Basic statistic of atmospheric precipitation by poviats in West Pomeranian Voivodeship (years 1991–2020)

Poviat	Statistics	Precipitation (mm) in averaging period				
		I–XII	III–V	VI–VIII	IX–XI	XII–II
Białogardzki	$\bar{x}$	756	151	248	184	174
	min.	536	85	72	84	66
	max.	1111	229	478	305	294
	Vs	19	25	39	32	34
Choszczeński	$\bar{x}$	622	135	213	137	136
	min.	455	66	109	64	78
	max.	924	204	411	209	213
	Vs	17	29	37	26	31
Drawski	$\bar{x}$	702	148	222	160	171
	min.	531	85	77	88	78
	max.	1086	219	435	286	296
	Vs	16	25	33	31	33
Goleniowski	$\bar{x}$	641	134	213	156	137
	min.	468	78	94	83	47
	max.	876	212	339	235	212
	Vs	16	28	31	23	30
Gryficki	$\bar{x}$	717	141	234	183	158
	min.	526	84	105	100	65
	max.	991	241	381	285	237
	Vs	15	25	28	26	31
Gryfiński	$\bar{x}$	565	124	196	127	119
	min.	413	65	117	57	46
	max.	768	177	354	202	186
	Vs	16	26	32	30	29
Kamieński	$\bar{x}$	640	127	217	160	135
	min.	437	73	89	85	55
	max.	972	200	398	292	232
	Vs	20	27	38	29	34
Kołobrzeski	$\bar{x}$	694	133	233	182	146
	min.	493	66	93	104	50
	max.	968	185	363	291	247
	Vs	16	23	30	28	34
Koszalin	$\bar{x}$	738	134	255	197	152
	min.	507	64	110	100	62

cont. Tab. 1

Poviat	Statis-tics	Precipitation (mm) in averaging period				
		I–XII	III–V	VI–VIII	IX–XI	XII–II
Koszalin	max.	1013	203	398	292	250
	Vs	16	26	33	28	33
Koszaliński	$\bar{x}$	843	161	263	214	204
	min.	687	78	108	111	79
	max.	1321	224	533	371	323
	Vs	16	21	33	30	35
Łobeski	$\bar{x}$	728	150	233	166	179
	min.	588	87	67	86	68
	max.	1088	212	429	289	293
	Vs	17	24	32	30	34
Myśliborski	$\bar{x}$	582	129	194	132	129
	min.	411	65	103	57	53
	max.	809	203	338	212	204
	Vs	18	28	35	32	29
Policki	$\bar{x}$	550	114	190	133	112
	min.	364	66	72	54	40
	max.	705	172	329	204	174
	Vs	16	25	31	28	32
Pyrzycki	$\bar{x}$	572	126	193	131	123
	min.	395	66	106	52	58
	max.	836	191	371	213	194
	Vs	18	29	37	33	29
Sławieński	$\bar{x}$	830	146	265	233	185
	min.	659	80	121	123	92
	max.	1182	231	445	383	307
	Vs	16	23	33	30	32
Stargardzki	$\bar{x}$	727	144	233	175	175
	min.	572	87	97	96	75
	max.	1091	210	428	295	280
	Vs	16	22	31	29	33
Szczecinecki	$\bar{x}$	729	150	232	175	172
	min.	579	85	102	96	71
	max.	1088	208	428	301	268
	Vs	17	22	30	32	34
Szczecin	$\bar{x}$	567	125	196	130	116
	min.	382	57	90	48	37
	max.	840	203	369	206	179
	Vs	19	28	36	29	30
Świdwiński	$\bar{x}$	779	153	250	187	189
	min.	607	89	76	85	83
	max.	1132	242	419	321	320
	Vs	17	24	30	35	33
Świnoujście	$\bar{x}$	585	121	194	149	121
	min.	388	50	84	71	45
	max.	783	185	409	218	183
	Vs	16	29	36	24	31
Wałecki	$\bar{x}$	684	146	222	151	166
	min.	474	77	101	86	74
	max.	1042	212	417	268	268
	Vs	18	29	35	30	32

Explanations: $\bar{x}$ = mean; min. = minimum; max. = maximum; *Vs* = coefficient of variation (%).
Source: own study.

be slightly larger. The increase is due to the inclusion of two poviats, i.e. Koszalin and Sławno, which are represented by four precipitation stations.

The variability of the annual precipitation totals in 1991–2020 in selected administrative units is presented in Figure 3. The lowest precipitation totals were identified in 2003 and 2018. In 2003, the lowest annual precipitation totals were recorded mainly in the poviats located in the western and southern part of the voivodeship, namely: Goleniów, Police, Gryfino, Myślibórz, Pyrzyce, Choszczno, Wałcz, as well as in Świnoujście and Szczecin. In these poviats, the annual totals did not exceed 500 mm, with the lowest values identified in the Myślibórz and Gryfino poviats: 411 and 413 mm, respectively. By far, the lowest annual total, merely 382 mm, was recorded in Szczecin. In 2018, the lowest annual precipitation totals were identified in poviats located in the northern parts of the West Pomeranian Voivodeship. The variability of annual precipitation between neighbouring poviats was much greater in 2018 than in 2003. In the Koszalin Poviat, the annual precipitation amounted to 734 mm, whereas in Koszalin it was only 507 mm, and in the Szczecinek Poviat, it was 635 mm. The year 2018 was atypical as the preceding year, 2017, was marked by the highest area-averaged annual totals across almost the entire voivodeship. In 2017, in most of the poviats located in the western part of the voivodeship, annual totals amounted to approx. 900 mm. The highest totals, over 1,100 mm, were identified in the Świdwin, Białogard, Koszalin and Sławno poviats. During the 30-year period under analysis, the contrasting annual precipitation totals, reaching a maximum in 2017 and a minimum in 2018, were recorded in the northern part of the voivodeship, namely in Świnoujście and Goleniów, Gryfice, Świdwin, and Kołobrzeg poviats.

In 1991–2020, the variability of the area-averaged annual precipitation totals did not show much difference between poviats (Fig. 3). In most poviats, the values of the coefficient of variation *Vs* ranged from 16 to 19%. Contrasting values of *Vs* were found for annual precipitation in the neighbouring poviats of Gryfice and Kamień, where *Vs* was 15 and 20%, respectively. Similar to what is presented in the existing national, regional, and local studies on pluviometric conditions, annual precipitation totals in the 30-year period of 1991–2020 did not show a statistically significant linear trend. In most administrative units of the West Pomeranian Voivodeship, there was a slight tendency for an increase in annual totals. However, in four poviats in the north-western part of the voivodeship and in Koszalin, a slight decrease was recorded. An insignificant increase in annual precipitation, more pronounced in the north of Poland, was found in the periods 1891–2000 (Zawora and Ziernicka, 2003), 1961–1990 and 1991–2017 (Pińskwar *et al.*, 2019), and in 1951–2013 (Szwed, 2019).

A marked increase in precipitation from the west and southwest to the north-east is also evident in the calendar seasons (Fig. 4, Tab. 1). In all seasons, the Police and Gryfino poviats record the lowest precipitation, with the area-averaged totals not exceeding 125 mm in spring and winter, 200 mm in summer, and 135 mm in autumn. In spring, the lowest precipitation values were also recorded in Świnoujście. In summer, the area of the lowest precipitation values encompasses Szczecin and the Pyrzyce and Myślibórz poviats. In autumn and winter, the average lowest precipitation is recorded in almost the same poviats as in summer, with the exception of Świnoujście in autumn and Myślibórz poviat in winter.

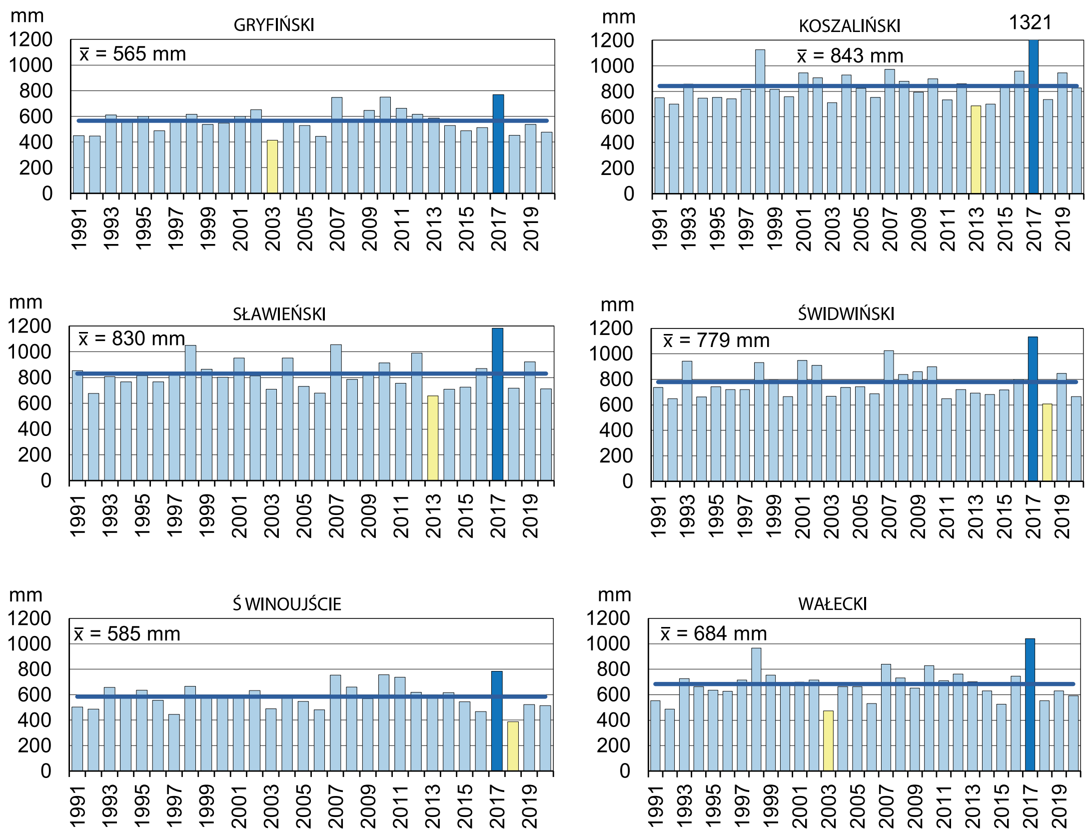


Fig. 3. The course of annual precipitation totals (mm) in selected poviats in the years 1991–2020; $\bar{x}$ = average value; source: own study

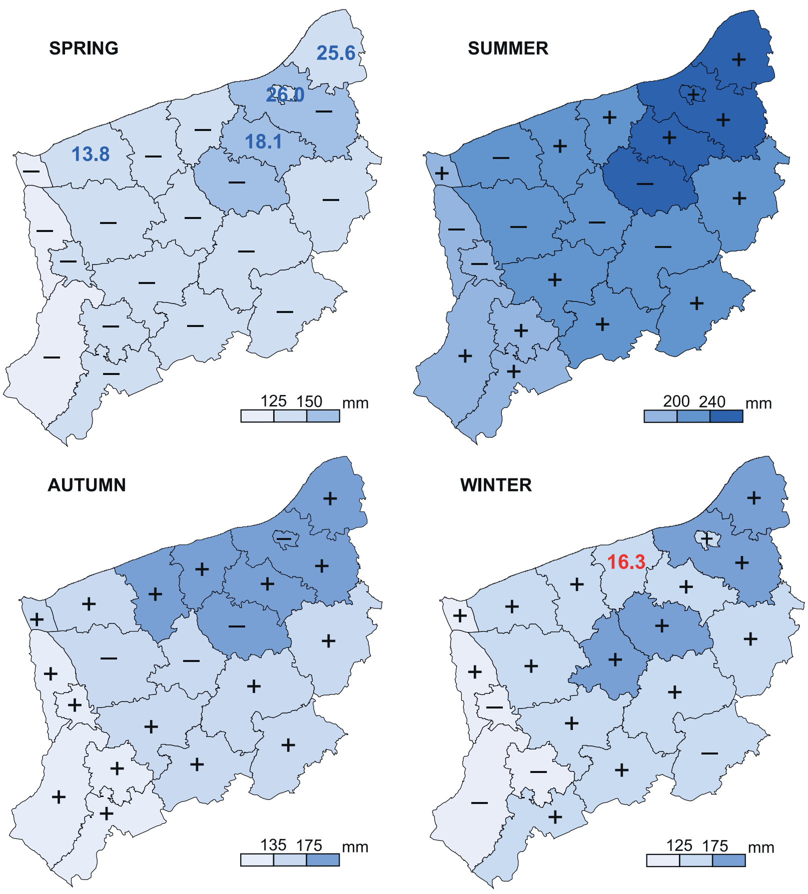


Fig. 4. Spatial distribution of seasonal precipitation totals (mm) in the years 1991–2020; **16.3** = coefficient of determination (R^2 in %) significant at least $\alpha \leq 0.05$; colour values of R^2 indicates direction of trend (positive/negative); +/– positive/negative tendency; source: own study

In the West Pomeranian Voivodeship, the Koszalin Poviat is the only one consistently privileged in terms of precipitation in all seasons, with mean area-averaged precipitation totals exceeding 150 mm in spring and 240 mm in summer, and reaching 175 mm in autumn and winter. In the calendar spring, the region with the highest average precipitation values includes the Białogard and Świdwin poviats, while in summer, it encompasses Koszalin and the Sławno Poviat. In autumn, mean area-averaged precipitation values exceeding 175 mm were recorded in the compact area of the north-eastern part of the voivodeship, covering seven administrative units. In winter, the range of precipitation with values greater than 175 mm was slightly smaller, encompassing only four poviats. It is worth noting that annual totals recorded at the synoptic station in Koszalin are lower than the totals in the whole Koszalin Poviat. This discrepancy is likely due to the location of the station in Koszalin, situated in the north-eastern outskirts of the second most populated city in the West Pomeranian Voivodeship, as well as its significantly lower altitude (33 m a.s.l.) compared to the two precipitation stations representing the Koszalin Poviat. The precipitation stations in this poviat, Polanów and Grzybnica, are located at two- and three-times higher altitudes of 75 and 90 m a.s.l., respectively.

The coefficients of variation for seasonal precipitation in particular administrative units range from 21 to 39% (Tab. 1). Almost throughout the voivodeship, the lowest variability in precipitation is identified in calendar spring. Only the Choszczno and Goleniów poviats, and Świnoujście have lower year-to-year variability recorded in autumn. The highest inter-annual variability, depending on the poviat, is found in the two seasons contrasting in terms of precipitation amount: summer or winter. Higher variability in summer is generally characteristic of the western part of the voivodeship, whereas in winter, it is found in most poviats in the north-western part. By comparison, based on average results for the whole country in 2001–2018, Ziernicka-Wojtaszek and Kopcińska (2020) state that, in terms of precipitation, the most unstable season was autumn (Vs = 37%) and the most stable was winter (Vs = 27%).

The analysis of the linear trend revealed a downward trend in calendar spring precipitation in all administrative units of the voivodeship. However, a statistically significant negative trend was identified only in the Białogard, Kamień, Sławno poviats and in Koszalin (Fig. 4). Coefficients of determination of linear regression equations explaining the decrease in summer precipitation in the Sławno poviat and in Koszalin amounted to approx. 26% and were statistically significant even at α = 0.01. Precipitation values in the calendar winter, summer, and autumn show a general upward tendency, though not uniformly across the entire voivodeship. In summer, a downward tendency was observed in seven administrative units in the north-western and central parts of the voivodeship (Drawno, Świdwin, Łobez, Goleniów, Kamień, Police poviats, and Szczecin). In autumn, a negative trend was observed in the Kamień, Łobez, and Świdwin poviats and in Koszalin, whereas in winter, it was observed in the poviats of the southern part of the voivodeship, i.e. Gryfino, Pyrzyce, Wałcz poviats, and Szczecin. Apart from spring, the only case of a statistically significant linear trend was recorded for precipitation in the calendar winter in the Kołobrzeg Poviat; the remaining instances were statistically insignificant.

The results discussed demonstrate significant conformity with data presented in the literature on the subject. However, their assessment with respect to the latest research results is difficult due to the scale of the studies and the size of the basic data set. Szwed (2019) indicates that the increase in winter precipitation in 1951–2013 in the north-west and west, recorded at some stations, was statistically significant at the 0.05 level. Higher precipitation in the calendar winter in 1991–2017, compared to 1961–1990, recorded in the north of Poland, was also demonstrated by Pińskwar *et al.* (2019). An increase in winter precipitation in south-western Poland in the years 1981–2010 compared to the period 1891–1930, in conjunction with a higher frequency of zonal circulation, is also indicated by Szymanowski *et al.* (2019). At the country scale, there is a decrease in summer precipitation, with an increase observed only in the western part of the Poland. Moreover, the identified increase in spring precipitation recorded almost all over the country was not found in the period 1991–2020 in the area of the West Pomeranian Voivodeship.

The continental features of the pluvial conditions in Poland are manifested by a predominance of calendar summer precipitation in the annual precipitation total, although this is less pronounced in the north-western part of the country. It is also worth noting the results by Mikolaskova (2009), which identify five main regions within Europe according to their annual course of precipitation: North-Western Europe, Central Europe, Eastern Europe, Mediterranean region, and Western Asia. The analysis presented in the study demonstrated that the maximum continentality, from the perspective of precipitation, is recorded in the centre of Europe, especially in northeast of the Czech Republic and south of Poland.

In the West Pomeranian Voivodeship, the average summer precipitation total in the 30-year period 1991–2020 constituted approx. one-third of the annual total, showing slight differences (approx. 3%) between poviats (Fig. 5). Polish studies published so far indicate that the average lowest contribution to the annual total was found for calendar winter. In the period 1951–2010, area-averaged precipitation in Poland (38 stations) in summer, autumn, winter, and spring constituted 37%, 24%, 17%, and 22% of the annual total, respectively (Czarnecka and Nidzgorska-Lencewicz, 2012). On the scale of the whole country, a markedly lower share of winter precipitation compared to summer precipitation in the period 2001–2018 is also presented by Ziernicka-Wojtaszek and Kopcińska (2020). However, the contribution of seasonal precipitation to the annual total shows significant regional differences. Kożuchowski and Wibig (1988) distinguished three basic types of seasonal precipitation distribution: the type characteristic for southern Poland, the Pomeranian type, and the central zone type. The classification was based on the magnitude of seasonal precipitation in descending order. Precipitation totals in the southern Poland type are ordered as summer, spring, autumn, and winter; in the Pomeranian type: summer, autumn, winter, and spring; in the central zone type: summer, autumn, spring, and winter. Kirschenstein (2005) conducted an analysis of the variability of pluvial conditions based on 136-year measurement series (1961–1996) for six stations located in north-western Poland, including two stations located in the West Pomeranian Voivodeship. The analysis identified all three classification types by Kożuchowski and Wibig (1988), with a clear predominance of the central zone type and the lowest frequency of the northern type (approx. 5%), as well as other types not included in the aforementioned classification.

The aforementioned classification was also adopted in the present paper. It was demonstrated that the averaged values for the entire voivodeship fall within the Pomeranian type, which is characterised by the predominant share of summer precipitation (33%), followed in descending order followed by autumn precipitation (24%) and winter precipitation (22%), with the lowest percentage share of spring precipitation (21%). Nevertheless, the assessment of individual administrative units shows that although the Pomeranian type is observed in most administrative units, it is not present in all of them. The Pomeranian type (summer, autumn, winter and spring) was found mainly in the Baltic neighbouring poviats as well as the Goleniów, Szczecinek, and Białogard poviats. The predominance of the percentage share of winter precipitation over spring precipitation was not high, ranging from 0.5% to 4.7%. In Świnoujście, as well as Stargard and Myślibórz poviats, the share of winter and spring precipitation in annual total was found to be the same. An increase in the share of winter precipitation in the annual totals was confirmed only in the Goleniów and Kołobrzeg poviats (Fig. 5). However a slight upward tendency was manifested throughout the entire voivodeship. The results by Szwed (2019) also indicate the increasing contribution of winter precipitation in the annual total throughout Poland. This confirms the estimation by Kożuchowski (2004) on the increasing contribution of precipitation in increasingly frequent warm winter seasons.

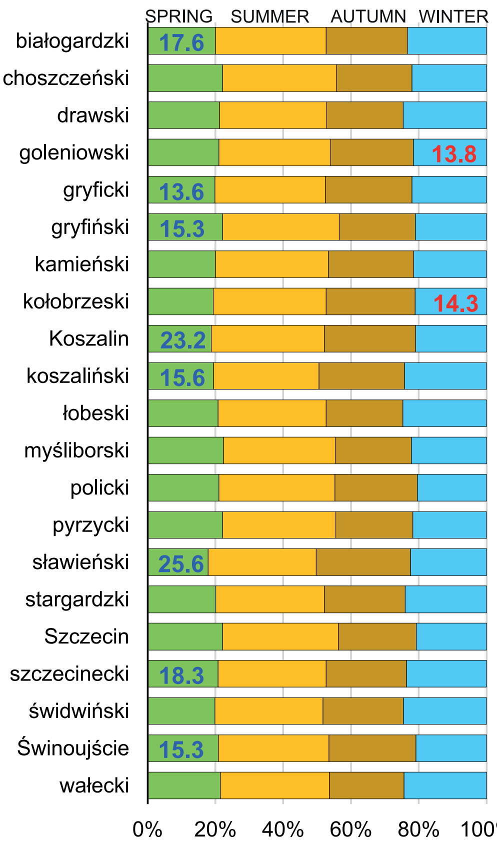


Fig. 5. Percentage share of seasonal precipitation in the annual total (years 1991–2020); **17.6** = coefficient of determination (R^2 in %) significant at least $\alpha \leq 0.05$; colour values of R^2 indicates direction of trend (positive/negative); source: own study

The most pronounced multiannual variability was identified with respect to percentage share of spring precipitation. With an explicitly negative tendency in all administrative units of the voivodeship, a statistically significant decrease was identified in eight poviats, i.e. Białogard, Gryfice, Gryfino, Koszalin, Sławno, Szczecinek, as well as in Koszalin, Świnoujście, and throughout the entire voivodeship. In the Sławno Poviat and in Koszalin, the coefficients of determination explaining the trend exceeded 20% (Fig. 5).

The transitional character of the climatic conditions of Poland is also manifested in the annual course of precipitation. In the national literature, the quotient of seasonal precipitation totals are used to characterise the oceanic and continental features of the pluvial regime. A widely adopted measure of the oceanic features is the autumn/spring quotient. High values of the quotient indicate the oceanic character, while low values indicate a continental course of annual precipitation totals. Another indicator of pluvial oceanism, used by numerous authors (Kożuchowski and Wibig, 1988; Tamulewicz, 1996; Kirschenstein, 2005; Szyga-Pluta, 2018), is high value of the winter/summer quotient. Some authors use the inverse of the quotient, i.e. summer/winter, to express the predominance of summer precipitation over winter precipitation, which is characteristic for the continental regime (Czarnecka and Nidzgorska-Lencewicz, 2012; Szwed, 2019; Ziernicka-Wojtaszek and Kopcińska, 2020).

The West Pomeranian Voivodeship is the area of Poland showing the weakest features of pluvial continentalism. In 1951–2010, the north-western area of the voivodeship and the narrow coastal strip were marked with by far the lowest quotient (<1.5) of summer and winter precipitation (Czarnecka and Koźmiński, 2004). it is a universally recognised feature that the predominance of summer precipitation over winter precipitation increases from the north-west to the south and south-east. Therefore, in terms of spatial distribution, the results of the analysed 30-year period are surprising (Fig. 6). In the poviats located to the west, and also in Koszalin, the quotient of summer to winter precipitation was the highest and exceeded 1.6. In contrast, the lowest predominance of summer precipitation over winter precipitation (quotient below 1.4) was identified in the poviats located in the central and south-western parts of the voivodeship, which are characterised by the most varied topography and altitude above sea level. Such distribution patterns may be due to multidirectional, though statistically insignificant, stronger or weaker tendencies of precipitation in both seasons. Additionally, it may be a manifestation of ongoing changes in the pluvial regime, particularly given the fact that in all poviats, the predominance of summer precipitation over winter precipitation is decreasing, although the changes are statistically insignificant. The negative trend in the quotient of summer to winter precipitation was found only in the Goleniów Poviat. According to Szwed (2019), on a national scale, the smallest changes in the ratio of summer precipitation to winter precipitation are recorded in the north-west of Poland.

The oceanic features of pluvial conditions, described with the quotient of autumn to spring precipitation, were pronounced mainly in the northern poviats, particularly in Koszalin and the Sławno Poviat, where the quotient values exceeded 1.4. In the administrative units of the central and southern part of the voivodeship (with the exception of Stargard Poviat), the quotients were below 1.2 (Fig. 6). The predominance of autumn precipitation over summer precipitation in the analysed 30-year period was slightly higher, yet the spatial distribution was generally

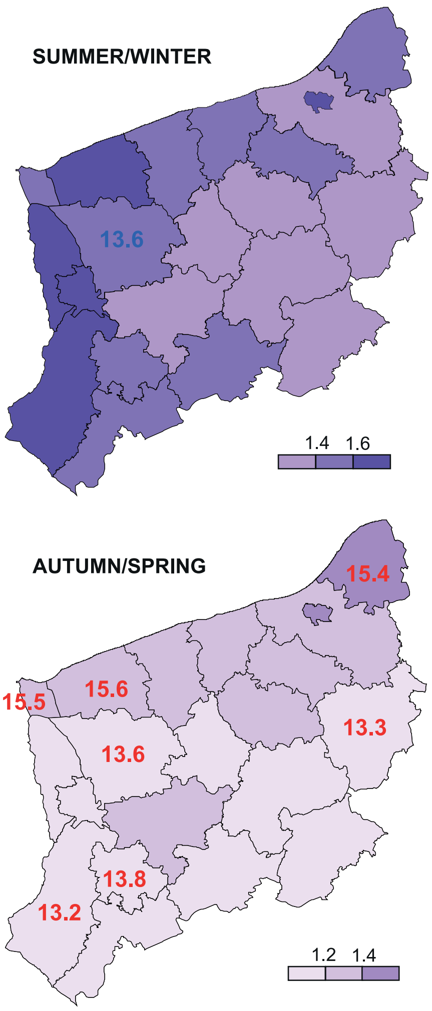


Fig. 6. Quotients of precipitation totals: summer/winter, autumn/spring (years 1991–2020); explanations as in Fig. 4; source: own study

similar to that for 1951–2010 (Czarnecka and Nidzgorska-Lencewicz, 2012). Unlike quotients of summer to winter precipitation, the quotients of precipitation in autumn and spring show a positive tendency. However, a statistically significant increase (R^2 from approx. 13% to almost 16%) was tested only in seven poviats (Gryfino, Pyrzyce, Goleniów, Kamień, Świnoujście, and also in Sławno and Szczecinek), predominantly in the western area of the voivodeship (Fig. 6). The direction of changes is in line with the results by Ziernicka-Wojtaszek and Kopcińska (2020). A clear increase in the quotient of autumn to spring precipitation in Poland in the period 2001–2018 was demonstrated by the results from 39 out of 47 stations, with the increase being statistically significant in 11 instances.

CONCLUSIONS

In the period 1991–2020, area-averaged annual totals recorded in six poviats in the western part of the West Pomeranian Voivodeship did not exceed 600 mm and were found to increase over 800 mm in two poviats located to the north-east. At three synoptic stations representing cities with the poviat status, i.e. Świnoujście, Koszalin, and Szczecin, mean annual totals and calendar winter totals were higher in the period 1991–2020, whereas the totals of calendar summer were found to be lower than those recorded in the period 1951–2010. However, the inter-annual changes, similar to the changes in area-averaged annual totals recorded in all poviats, did not reveal a statistically significant linear trend.

In most poviats of the northern parts of the West Pomeranian Voivodeship, contrasting values of annual totals were recorded in two subsequent years – 2017 and 2018. In the West Pomeranian Voivodeship, the lowest precipitation values in all seasons are recorded in the Police and Gryfino poviats, where mean area totals in spring and winter do not exceed 125 mm, in summer – 200 mm, and in autumn – 135 mm. Only the koszaliński poviat is rich in precipitation, where mean area totals in spring and summer are higher than 150 mm and 240 mm, respectively, in autumn and winter – 175 mm.

In the period 1991–2020, the changes in the basic features of the pluvial regime in the West Pomeranian Voivodeship were generally statistically insignificant. In most poviats, a markedly lower inter-annual variability as well as most prominent multi-annual changes were identified with respect to calendar spring. A statistically significant negative linear trend was found in the following poviats: Białogard, Kamień, Sławno, and Koszalin. A negative trend in the percentage share of spring precipitation in the annual total was observed in a larger area encompassing the poviats of Białogard, Gryfice, Gryfino, Koszalin, Sławno, Szczecinek, and in two cities with the poviat status – Świnoujście and Koszalin.

The oceanic features of precipitation, expressed with the quotient of autumn to spring totals, were reinforced not only in the poviats characterised by a downward trend of the share of spring precipitation in the annual total, i.e. Gryfino, Sławno, Szczecinek poviats, and in Świnoujście, but also in the poviats of Goleniów, Kamień, and Pyrzyce.

In the West Pomeranian Voivodeship, the most prominent statistically significant changes in precipitation conditions in 1991–2020 were identified in the Goleniów, Kamień, and Sławno poviats. In each of these poviats, there was an increase in the value of autumn to spring precipitation quotient. Moreover, in the Goleniów Poviat, there was an increase in the share of winter precipitation in the annual total and a decrease in the quotient of summer to winter precipitation. In the Kamień and Sławno poviats, a decrease in calendar spring precipitation was observed, and in the case of the Sławno Poviat, there was also a decrease in the percentage share of spring precipitation in the annual totals. The Goleniów Poviat is the only one with a decrease in the quotient of summer to winter precipitation due to a statistically significant increase in the share of winter precipitation in the annual total.

CONFLICT OF INTERESTS

All authors declare that they have no conflicts of interests.

REFERENCES

Aalbers, E.E. *et al.* (2018) "Local-scale changes in mean and heavy precipitation in Western Europe, climate change or internal variability?," *Climate Dynamics*, 50, pp. 4745–4766. Available at: https://doi.org/10.1007/s00382-017-3901-9.

Czarnecka, M. and Koźmiński, C. (2004) "Opady atmosferyczne. Zmienność opadów. Liczba dni z opadem I. Liczba dni z opadem II. [Precipitation. Precipitation variability. Number of days with precipitation – I. Number of days with precipitation – II]," in C. Koźmiński and B. Michalska (eds.) *Atlas zasobów i zagrożeń klimatycznych Pomorza [Atlas of climatic resources and hazards in Pomerania]*. Szczecin: Wyd. AR, US Szczecin, pp. 40–43.

Czarnecka, M. and Nidzgorska-Lencewicz, J. (2012) "Wieloletnia zmienność sezonowych opadów w Polsce [Multiannual variability of seasonal precipitation in Poland]," *Woda-Środowisko-Obszary Wiejskie*, 12(2), pp. 45–60.

Czarnecka, M. and Nidzgorska-Lencewicz, J. (2016) "The cyclical nature of seasonal precipitation in Pomerania in the period 1951–2010," *Russian Meteorology and Hydrology*, 41, pp. 247–254, Available at: https://doi.org/10.3103/S1068373916040038.

Degirmendžić, J. and Kożuchowski, K. (2017) "Mediterranean cyclones, the atmospheric moisture content and precipitation in Poland," *Geographia Polonica*, 90(1), pp. 5–20. Available at: https://doi.org/10.7163/GPol.0075.

Degirmendžić, J., Kożuchowski, K. and Żmudzka, E. (2004) "Changes of air temperature and precipitation in Poland in the period 1951–2000 and their relationship to atmospheric circulation," *International Journal of Climatology*, 24(3), pp. 291–310. Available at: https://doi.org/10.1002/joc.1010.

Grzywna, A. *et al.* (2020) "The analysis of spatial variability of precipitation in Poland in the multiyears 1981–2010," *Journal of Water and Land Development*, 46, pp. 105–111. Available at: https://doi.org/10.24425/jwld.2020.134202.

Hynčica, M. and Huth, R. (2019) "Long-term changes in precipitation phase in Europe in cold half year," *Atmospheric Research*, 227, pp. 79–88. Available at: https://doi.org/10.1016/j.atmosres.2019.04.032.

IPCC (2023) "Summary for policymakers," in *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. Geneva, Switzerland, pp. 1–34. Available at: https://doi.org/10.59327/IPCC/AR6-9789291691647.001.

Kalbarczyk, R. and Kalbarczyk, E. (2021) "Precipitation variability, trends and regions in Poland: Temporal and spatial distribution in the years 1951–2018," *Acta Geographica Slovenica*, 61(2), pp. 41–71. Available at: https://doi.org/10.3986/AGS.8846.

Kirschenstein, M. (2002) "Cyrkulacyjne uwarunkowania opadów w północno-zachodniej Polsce [The differentiation of precipitation in the north-west Poland depending on the type of atmospheric circulation]," *Przegląd Geofizyczny*, 1–2, pp. 45–59.

Kirschenstein, M. (2005) "Wieloletnie zmiany sum opadów atmosferycznych na wybranych stacjach północno-zachodniej Polski [Long-term changes in precipitation sums at selected stations in north-western Poland]," *Słupskie Prace Geograficzne*, 2, pp. 199–214.

Kondracki, J. (2023) *Geografia regionalna Polski [Regional geography of Poland]*. 3rd edn. Warszawa: Wydaw. Nauk. PWN.

Koźmiński, C., Czarnecka, M. and Górka, W. (1982) *Opady atmosferyczne na terenie województwa koszalińskiego [Precipitation in the Koszalin Voivodeship]*. Szczecin: Wyd. Zakładu Upowszechniania Postępu AR w Szczecinie.

Koźmiński, C., Michalska, B. and Czarnecka, M. (2012) *Klimat województwa zachodniopomorskiego [The climate of the West Pomeranian Voivodeship]*. Szczecin: AR w Szczecinie, Uniwersytet Szczeciński.

Koźmiński, C., Trzeciak, S. and Czarnecka, M. (1977) *Opady atmosferyczne na terenie województwa szczecińskiego [Precipitation in the Szczecin Voivodeship]*. Szczecin: Wyd. Zakładu Upowszechniania Postępu AR w Szczecinie.

Kożuchowski, K. (2004) "Zmienność opadów atmosferycznych w Polsce w XX i XXI wieku [Variability of atmospheric precipitation in Poland in the 20th and 21th century]," in K. Kożuchowski (ed.) *Skala, uwarunkowania i perspektywy współczesnych zmian klimatycznych w Polsce [Scale, conditions and perspectives of the contemporary climatic changes in Poland]*. Łódź: Wydaw. Biblioteka, pp. 47–58.

Kożuchowski, K. and Wibig, J. (1988) "Kontynentalizm pluwialny w Polsce, zróżnicowanie geograficzne i zmiany wieloletnie [Pluvial continentality in Poland: geographic variations and long-term variability]," *Acta Geographica Lodziensia*, 55.

Lenggenhager, S. and Martius, O. (2019) "Atmospheric blocks modulate the odds of heavy precipitation events in Europe," *Climate Dynamics*, 53, pp. 4155–4171. Available at: https://doi.org/10.1007/s00382-019-04779-0.

Łupikasza, E.B., Hänsel, S. and Matschullat, J. (2011) "Regional and seasonal variability of extreme precipitation trends in southern Poland and central-eastern Germany 1951–2006," *International Journal of Climatology*, 31(15), pp. 2249–2271. Available at: https://doi.org/10.1002/joc.2229.

Majewski, G., Przewoźniczuk, W. and Kleniewska, M. (2010) "Warunki opadowe na stacji meteorologicznej Ursynów SGGW w latach 1960–2009 [Precipitation at the meteorological station in Ursynów WULS – SGGW in 1960–2009]," *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska*, 19(2), pp. 3–22.

McKenna, C.M. and Maycock, A.C. (2022) "The role of the North Atlantic Oscillation for projections of winter mean precipitation in Europe," *Geophysical Research Letters*, 49, e2022GL099083. Available at: https://doi.org/10.1029/2022GL099083.

Miętus, M. (1996) "Zmienność temperatury i opadów w rejonie polskiego wybrzeża Morza Bałtyckiego i jej spodziewany przebieg do roku 2030 [Long-term variation of temperature and precipitation on the Polish Coast and expected changes]," *Materiały Badawcze IMGW. Seria Meteorologia*, 26.

Mikolaskova, K. (2009) "Continental and oceanic precipitation régime in Europe," *Central European Journal of Geosciences*, 1, pp. 176–182. Available at: https://doi.org/10.2478/v10085-009-0013-8.

Palarz, A. *et al.* (2024) "Radar-based heavy precipitation events in Germany and associated circulation patterns," *International Journal of Climatology*, 44(1), pp. 196–216. Available at: https://doi.org/10.1002/joc.8323.

Pińskwar, I. *et al.* (2019) "Observed changes in precipitation totals in Poland," *Geografie*, 124(3), pp. 237–264. Available at: https://doi.org/10.37040/geografie2019124030237.

Skowera, B., Kopcińska, J. and Bokwa, A. (2016) "Changes in the structure of days with precipitation in Southern Poland in 1971–2010," *Időjárás*, 120(4), pp. 365–381.

Silva da, N.A. and Haerter, J.O. (2023) "The precipitation characteristics of mesoscale convective systems over Europe," *Journal of Geophysical Research: Atmospheres*, 128, e2023JD039045. Available at: https://doi.org/10.1029/2023JD039045.

Świątek, M. (2011) "Precipitation changes on the Polish coast of the Baltic Sea (1954–2003) due to changes in intensity of westerlies over Europe," *Climate Research*, 48(23–29), pp. 23–29. Available at: https://doi.org/10.3354/cr00904.

Szwed, M. (2019) "Variability of precipitation in Poland under climate change," *Theoretical and Applied Climatolology*, 135, pp. 1003–1015. Available at: https://doi.org/10.1007/s00704-018-2408-6.

Szyga-Pluta, K. (2018) "Zmienność czasowa i przestrzenna opadów atmosferycznych w Wielkopolsce w latach 1981–2014 [Temporal and spatial variability of atmospheric precipitation in Wielkopolska in the 1981–2014 period],” *Przegląd Geograficzny*, 90(3), pp. 495–516. Available at: https://przegladgeograficzny.igipz.pan.pl/artykul/item/12127.html (Accessed: July 10, 2023).

Szyga-Pluta, K. and Grześkowiak, K. (2016) “Warunki pluwialne w Poznaniu w latach 1981–2015 [Pluvial conditions in Poznań in the 1981–2015 period],” *Badania Fizjograficzne, Seria A, Geografia Fizyczna*, 67 pp. 239–256. Available at: https://doi.org/10.14746/bfg.2016.7.18.

Szymanowski, M. *et al.* (2019) “Spatio-temporal changes in atmospheric precipitation over south-western Poland between the periods 1891–1930 and 1981–2010,” *Theoretical and Applied Climatology*, 135, pp. 505–518. Available at: https://doi.org/10.1007/s00704-018-2376-x.

Tamulewicz, J. (1996) “Poznańska seria opadów atmosferycznych w świetle wskaźników kontynentalizmu pluwialnego [The Poznań precipitation series in the light of pluvial continentality indices]. *Badania Fizjograficzne nad Polską Zachodnią, Seria A, Geografia Fizyczna*, 47, pp. 115–126.

Thompson, V. *et al.* (2017) “High risk of unprecedented UK rainfall in the current climate,” *Nature Communications*, 8, 107. Available at: https://doi.org/10.1038/s41467-017-00275-3.

Tomczyk, A.M. and Bednorz, E. (ed.) (2022) *Atlas klimatu Polski (1991–2020) [Polish climate atlas (1991–2020]*. Poznań: Bogucki Wydaw. Nauk.

Twardosz, R., Cebulska, M. and Guzik, I. (2023) “The variability of maximum daily precipitation and the underlying circulation conditions in Kraków, Southern Poland,” *Water*, 15, 3772. Available at: https://doi.org/10.3390/w15213772.

Ustrnul, Z. *et al.* (2023) “The influence of circulation conditions on extreme precipitation totals over the territory of the Western Carpathians in the warm season,” *Contributions to Geophysics and Geodesy*, 53(4), pp. 399–411. Available at: https://doi.org/10.31577/congeo.2023.53.4.5.

Walanus, A. *et al.* (2022) “In search of periodicity in the annual precipitation in Europe (1881–2020),” *Water*, 14(13), 2026. Available at: https://doi.org/10.3390/w14132026.

Wibig, J. (2009) “The variability of daily precipitation totals in Poland (1951–2000),” *Geographia Polonica*, 82(1), pp. 21–32. Available at: https://rcin.org.pl/dlibra/publication/74808/edition/55498/content (Accessed July 10, 2023).

Wypych, A., Ustrnul, Z. and Schmatz, D.R. (2018) “Long-term variability of air temperature and precipitation conditions in the Polish Carpathians,” *Journal of Mountain Science*, 15(2), pp. 237–253. Available at: https://doi.org/10.1007/s11629-017-4374-3.

Ziernicka-Wojtaszek, A. and Kopcińska, J. (2020) “Variation in atmospheric precipitation in Poland in the years 2001–2018,” *Atmosphere*, 11(8), 794. Available at: https://doi.org/10.3390/atmos11080794.

Zawora, T. and Ziernicka, A. (2003) “Precipitation variability in time in Poland in the light of multi-annual mean values (1891–2000),” *Studia Geograficzne*, 75, pp. 123–128.

Żmudzka, E. (2002) “O zmienności opadów atmosferycznych na obszarze Polski nizinnej w drugiej połowie XX wieku [About the variability of precipitation in lowland Poland in the second mid-twentieth century],” *Wiadomości Instytutu Meteorologii i Gospodarki Wodnej*, 25(4), pp. 23–38.