Janusz KOZAK[1*] and Ewa JACHNIAK[1]

THE VARIABILITY OF THE ATMOSPHERIC PRECIPITATION IN THE REGION OF WIELKA LAKA DAM RESERVOIR

ZMIENNOŚĆ OPADÓW ATMOSFERYCZNYCH W REGIONIE ZBIORNIKA ZAPOROWEGO WIELKA ŁĄKA

Abstract: The aim of this research was the analysis of the precipitation variability in the last decade in the region of Wielka Laka reservoir. The daily sums of the precipitation (from 2005 to 2018) were the research material. They were obtained from the Aqua S.A. in Bielsko-Biala. The measurements were carried out according to the standard method using the Hellman pluviometer. In research the precipitation indicators were used, which are commonly applied. They were used to description of the precipitation characteristics. The frequency of days with precipitation at the certain height was determined according to the Olechnowicz-Bobrowska classification. The classification of individual years and months in respect of the excess or lack precipitation was conducted based on the Kaczorowska method. In the analysed multi-year period (2005–2018) the dry years prevailed, however the significant regularity wasn't noticed. In the analysed multi-year period the highest rainfall was recorded in 2010 year, when in May the total precipitation was summarised at the 171 mm level. The recorded precipitation accompanied the inflow of air masses in the directions from the east (E) to the northwest (NW).

Keywords: the atmospheric precipitation, the synoptic situation

Introduction

The atmospheric precipitation is one of the most variable weather elements, both in respect of their height, length of their duration and dates (probabilities) of their occurrence. This variability intensifies particularly in mountain areas. The most climate elaborations connected with atmospheric precipitation don't show a permanent downward or upward trend in annual rainfall sums [1–3].

Many researchers show the increasing rainfall anomalies and increase the frequency of the months with extremely high and extremely low rainfall [4–6]. One of the reasons may be growth the greenhouse gases concentrations, i.a. the increasing of the CO_2 concentration in atmosphere [7].

[1] Institute of Environmental Protection and Engineering, University of Bielsko-Biała, Willowa 2, 43-300 Bielsko-Biała, Poland.

* Corresponding author: jkozak@ath.bielsko.pl

The seasonal hydrological threats caused by heavy rainfall are not uncommon. The example is the flood that occurred in southern Poland in May and June in 2010 year, especially in the area of the Silesian Foothills, the Zywiec Beskids and the Silesian Beskids [8,9]. In the Polish Carpathians, in the whole multi-year period (1881–2010) the anomalously high rainfall occurred in 1931, 2007 and 2010 year. In turn 25 years were defined as anomalously wet [10]. The nowadays the general decrease of the rainfall is observed, it will intensify the phenomenon of the hydrological and soil drought. Average number of days without precipitation in the Silesian Beskids (Wisla Malinka) reached 43 % in years 1984–2013 [11]. During the growing season of the recent years the rainfall deficit, particularly in June and August, is observed [12, 13]. Recently the similar drought periods are also observed in Central Europe, i.a. in Germany and Czech Republic [14].

The increasing demand of water necessary for society and industry makes the necessity to conduct the appropriate water management. The dam reservoirs ensure the proper water management (i.a. the Wielka Laka reservoir in Bielsko-Biala).

The measurements of the atmospheric precipitation in the region of Wielka Laka reservoir allowed to conduct the analysis of the precipitation variability in the last decade.

The aim of this research was the analysis of the precipitation variability in the last decade in the region of Wielka Laka reservoir.

Research methodology

The daily sums of the precipitation (from 2005 to 2018) were the research material. They were obtained from the Aqua S.A. in Bielsko-Biala. The rainfall post is located near the dam crown of the Wielka Laka reservoir in Wapienica at an altitude of 478 m a.s.l. (Fig. 1).

Fig. 1. The location of Aqua S.A. rainfall station in Wapienica (Bielsko-Biała district) (the own study based on www.google.com/maps)

The measurements were carried out according to the standard method using the Hellman pluviometer, due to uncertain results from automatically heated pluviometer. The solid precipitation during the winter season have been converted for liquid precipitation according to the IMGW methodology.

In research the precipitation indicators were used, which are commonly applied. They were used to description of the precipitation characteristics.

The frequency of days with precipitation at the certain height was determined according to the Olechnowicz-Bobrowska classification [15]. This classification includes the 5 classes, which are connected to daily rainfall sums:

0.1–1.0 mm – the day with very low rainfall,
1.1–5.0 mm – day with low rainfall
5.1–10 mm – day with moderately strong rainfall,
10.1–20 mm – day with strong rainfall,
above 20 mm – day with very strong rainfall.

The classification of individual years and months in respect of the excess or lack precipitation was conducted based on the Kaczorowska method [16].

This method takes into account the rainfall sum percentage at the certain time (year, month) in ratio to the average rainfall sum from the analysed multi-year period, which is considered as the norm.

The results

The analysed multi-year period had the average value of the annual precipitation sums at the 1281 mm level. The highest rainfall (1775.8 mm) was recorded in 2010 year, while the lowest rainfall (1002.5 mm) occurred in 2015 year and they constituted 78 % of the average precipitation from the multi-year period (Fig. 2).

In the mountain catchment the important problems are the extreme rainfall, because they shape the hydrological situation. The daily extreme rainfall [mm] for analysed multi-year period in individual months was presented in Table 1.The extreme rainfall

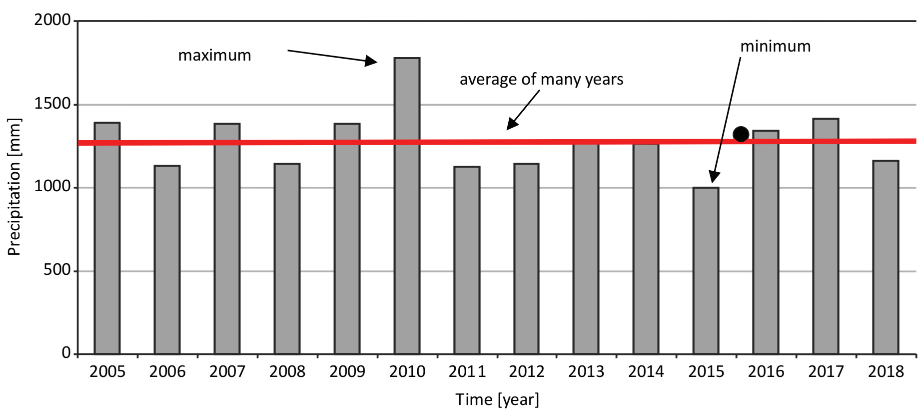

Fig. 2. Annual rainfall sums in the years 2005–2018

Table 1

The maximum daily rainfall [mm] in individual months in years 2005–2018

Month	Year													
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
January	27.0	18.5	14.0	11.5	15.0	15.0	12.0	14.5	11.0	14.0	23.0	9.0	8.5	8.0
February	15.0	10.0	13.0	9.8	27.5	12.5	20.5	24.0	11.5	16.5	19.0	47.0	11.0	14.0
March	14.3	30.5	15.8	14.0	37.0	12.5	37.0	16.5	36.0	26.5	25.0	15.5	18.5	10.0
April	28.2	25.0	6.8	15.1	0.8	32.0	31.5	19.0	13.5	10.5	40.0	24.0	32.0	8.0
May	36.0	27.0	20.3	21.5	21.5	**171.0**	29.5	17.5	32.0	75.0	33.0	26.5	18.5	38.5
June	34.0	53.0	38.5	35.5	50.0	60.0	37.0	39.0	62.0	62.5	20.0	11.5	23.0	29.0
July	23.5	18.5	29.0	55.0	28.0	26.9	55.0	12.5	39.5	25.0	26.5	39.0	24.0	83.5
August	36.0	30.5	58.0	27.5	77.5	**105.0**	41.0	20.0	22.0	23.5	10.5	27.0	20.5	25.5
September	54.5	13.5	75.5	30.0	14.5	28.5	16.0	35.0	29.5	25.0	18.5	36.0	68.0	43.5
October	8.0	39.5	19.0	21.0	29.0	22.0	13.5	29.5	19.5	35.0	11.0	58.5	26.0	21.0
November	13.5	39.0	27.5	19.5	71.0	14.5	1.0	34.0	18.5	16.0	25.0	28.5	17.5	5.5
December	27.5	9.7	9.5	26.5	7.5	26.0	11.0	13.0	22.0	11.5	11.0	33.0	12.5	34.5
Max. year	**54.5**	**53.0**	**75.5**	**55.0**	**77.5**	**171.0**	**55.0**	**39.0**	**62.0**	**75.0**	**40.0**	**58.5**	**68.0**	**83.5**

Explanation: max. year – the maximum daily rainfall [mm] in individual year; red colour – the days with highest rainfall.

Table 2

The number of days with rainfall [mm] in individual months of the year in years 2005–2018

Month	Year													
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
January	21	11	24	15	17	15	16	25	22	11	18	17	9	14
February	18	20	16	13	19	11	9	15	16	3	9	17	16	12
March	16	20	13	17	21	13	7	13	13	8	13	16	13	9
April	13	17	8	12	2	13	13	12	11	15	12	13	20	7
May	20	20	16	15	15	**29**	13	9	16	18	15	15	17	13
June	18	13	12	9	19	14	18	15	17	11	9	13	9	17
July	16	5	13	19	13	14	21	14	8	16	13	16	16	16
August	19	17	8	11	8	15	13	12	7	16	6	12	11	8
October	7	9	12	14	8	16	7	11	17	14	15	7	16	13
October	5	7	14	12	20	7	11	14	5	10	10	19	15	11
November	13	16	18	12	10	13	1	11	17	8	15	13	18	6
December	23	14	10	16	18	18	15	13	8	12	8	12	15	21

Explanation: red colour – the days with highest rainfall.

(as a daily sum) slightly exceeded 50 mm and only in 2010 was recorded the daily rainfall at the 171 mm level. In the same year (with the highest annual rainfall sum) (Fig. 2) the extreme rainfall above 100 mm was recorded in May and August (Table 1).

After analysing the years in respect of the number of days with precipitation, the 65% days of the year with precipitation were recorded in the analysed period. The number of days with precipitation oscillated from 142 in 2014 year to 189 in 2005 year in individual years (Fig. 3).

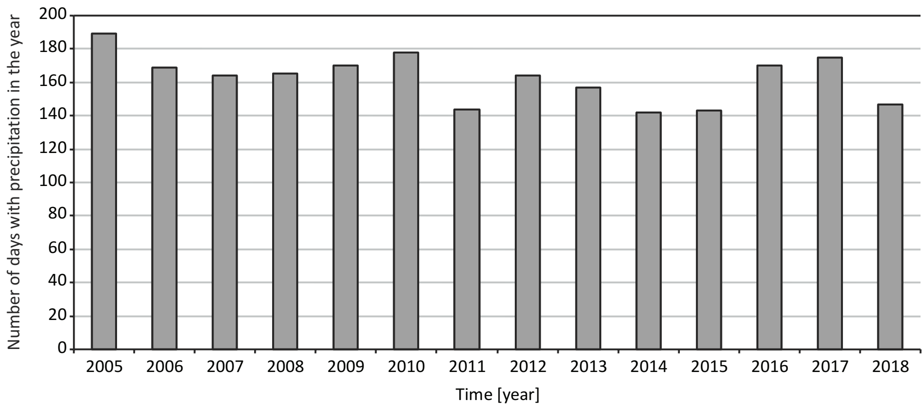

Fig. 3. The number of days with precipitation in the years 2005–2018

The variation in the number of days with precipitation in individual months was very large (Table 2). It oscillated from 1 day, 2–3 days (in November 2011, April 2009 and February 2014 respectively) with precipitation to 25 days (in January 2012) and 29 days (in May 2010) with precipitation. Then the rainfall was recorded almost every day.

The classification of the rainfall, which includes the ranges of the daily precipitation height in the whole research period (Table 3) showed that the most days were recorded with low rainfall (39 %) and moderate strong (22 %). In turn the days with very low and very strong rainfall were recorded at 15 % and days with strong rainfall only occurred at 9 % per year.

Table 3

The percentage share of rainfall in individual classes in whole multi-year period

Rainfall 2005–2018	
[mm]	[%]
0.1–1.0	16
1.1–5.0	39
5.1–10.1	22
10.1–20.0	14
20	9

Table 4

The number of days with precipitation in individual rainfall classes in whole multi-year period (2005–2018)

Rainfall [mm]	Year													
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0.1–1.0	33	39	20	25	24	25	37	33	24	13	18	21	33	28
1.1–5.0	69	66	58	74	71	55	53	63	66	51	67	72	57	54
5.1–10.0	41	31	49	31	33	50	20	31	29	39	28	38	37	33
10.1–20.0	28	22	22	21	23	36	16	23	21	27	20	20	30	19
> 20.0	16	11	15	14	18	12	18	13	17	12	10	17	17	13

The detailed share of the precipitation in individual rainfall classes was presented in Table 4.

The classification of the individual years in relation to multi-year period (according to Kaczorowska method) gives the information about the potential possibility the occurrence of the deficiency or excess atmospheric precipitation (Fig. 4). In the whole multi-year period average (7) and dry (5) years prevailed and only 2010 year was classified as extremely humid and 2017 year was classified as very humid.

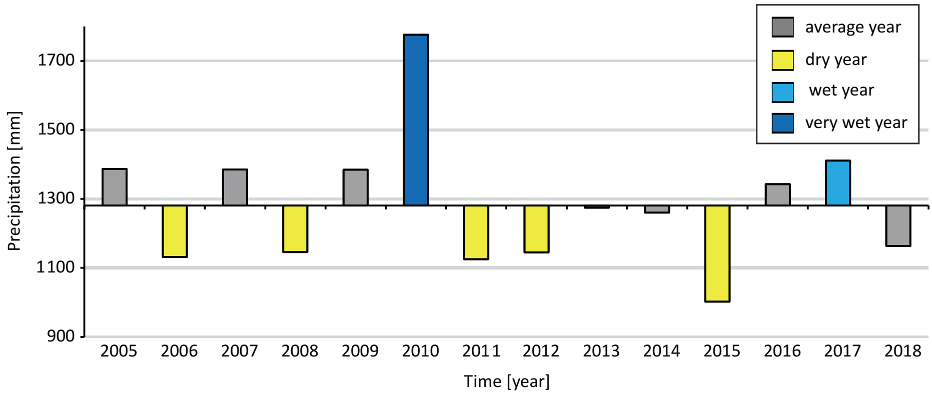

Fig. 4. The classification of precipitation conditions in years 2005–2018

The Table 5 shows the classification of precipitation conditions in individual months in years 2005–2018.

The above analysis of the multi-year period (2005–2018) (Table 5) indicated that the largest percentage share had the average months (35 %) and dry months (21 %). The percentage share of very dry and very humid months was similar and constituted 12 % of all analysed months from the multi-year period. In turn, the wet months (10 %) and extremely dry and extremely wet (5 %) had the minimal percentage share.

According to the daily calendar of the circulation types [17] annual rainfall sums including the low-pressure baric system (cyclonic system) and the high-pressure baric system (anti-cyclonic system) were analysed. The cyclonic system favors the probability of the precipitation occur, while the anti-cyclonic system does not favor the convection and the cloud formation and rainfall formation (Tables 6–9). In the analysed multi-year period almost the three times more days with precipitation in the anti-cyclonic situation were recorded. This also translates on the similar ratio of the annual rainfall sums.

The air masses shaping the weather in the upper Vistula basin [11] have been daily set together with rainfall sums and number of days with rainfall (Table 10 and 11).

The air masses moving over Europe shaping the climate and have the influence on the individual meteorological elements, i.a. precipitation of varying amounts. The percentage share of the precipitation heights in the whole multi-year period (2005–2018) on the directional rose of air mass inflow was presented on the following

Table 5

The classification of precipitation conditions in individual months in years 2005–2018

Month	Year													
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
January	w	p	p	s	s	bs	s	bw	p	bs	p	s	bs	bs
February	p	p	p	s	p	bs	bs	p	s	bs	p	w	s	s
March	s	p	s	p	bw	bd	s	p	p	s	p	s	p	bs
April	s	w	ss	s	ss	s	p	p	bs	p	p	p	bw	ss
May	w	p	p	p	p	sw	bw	bs	bw	sw	bw	p	p	p
June	p	bw	p	p	sw	w	p	sw	sw	p	p	s	p	bw
July	bw	bs	w	sw	p	p	sw	s	p	bw	w	bw	p	sw
August	w	bw	p	p	p	bw	p	s	bs	w	bs	p	p	p
October	p	bs	sw	bw	bs	p	s	w	bw	p	p	s	sw	w
October	ss	s	s	p	w	ss	s	w	bs	p	s	bw	w	p
November	s	bw	bw	s	p	s	ss	s	p	s	w	s	p	ss
December	w	s	bs	p	bs	p	s	s	bs	s	bw	p	s	bw

Explanation:

s	dry	bs	very dry	ss	extremely dry	p	average
w	wet	bw	very wet	sw	extremely wet		

Table 6

The number of days with precipitation in the anti-cyclonic situation (2005–2018)

Month	Year														
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2005–2018
January	10	6	4	11	11	5	4	8	5	3	5	6	4	3	85
February	5	6	3	10	5	0	6	6	4	0	2	3	6	6	62
March	3	6	3	1	2	5	3	8	1	0	3	6	3	0	44
April	2	0	4	0	0	3	1	0	2	3	5	1	6	1	28
May	7	7	2	5	4	4	6	3	3	4	5	9	5	3	67
June	9	6	2	3	1	1	10	1	4	1	5	3	0	9	55
July	3	2	0	2	3	2	2	4	2	3	5	7	6	4	45
August	3	1	0	2	0	4	4	4	5	2	2	3	5	2	37
September	3	5	3	2	3	4	1	2	3	2	8	1	0	7	44
October	4	3	8	5	5	1	6	2	2	1	5	6	3	4	55
November	6	8	3	5	2	1	1	5	6	3	5	6	8	1	60
December	7	11	3	6	4	2	3	5	3	2	7	5	7	0	65
Sum	62	61	35	52	40	32	47	48	40	24	57	56	53	40	647

Table 7

The number of days with precipitation in the cyclonic situation (2005–2018)

Month	Year														
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2005–2018
January	11	5	20	4	6	10	11	16	17	8	13	11	5	10	147
February	13	14	13	3	12	11	3	9	12	3	6	13	10	5	127
March	12	14	10	16	17	8	4	5	11	8	9	10	10	9	143
April	10	16	4	12	2	10	12	12	8	11	7	10	13	6	133
May	12	13	13	10	10	25	6	6	13	14	9	6	11	10	158
June	8	6	10	5	18	13	8	14	13	10	4	10	9	8	136
July	13	3	13	17	10	11	18	10	6	12	7	9	10	12	151
August	15	16	8	9	8	11	9	8	2	14	4	8	6	5	123
September	4	4	9	12	5	11	6	9	14	12	6	6	16	6	120
October	1	4	6	7	13	4	5	12	3	9	5	12	12	7	100
November	7	8	15	7	8	11	0	6	11	5	9	6	10	0	103
December	16	3	7	10	13	14	12	8	5	9	1	7	8	0	113
Sum	122	106	128	112	122	139	94	115	115	115	80	108	120	78	1554

Table 8

The sum of the monthly rainfall [mm] in the anti-cyclonic situation (2005–2018)

Month	Year														
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2005–2018
January	36.8	8.0	33.1	38.5	32.0	12.5	8.5	21.3	19.0	4.0	15.0	25.0	14.0	9.0	276.7
February	18.2	21.9	13.2	35.6	13.5	0.0	10.5	6.5	6.1	0.0	16.0	13.5	20.5	12.5	188.0
March	3.1	12.7	9.0	1.5	13.0	9.0	11.5	27.5	3.0	0.0	12.5	44.5	5.5	0.0	152.8
April	7.5	0.0	9.4	0.0	0.0	15.0	2.5	0.0	5.0	8.5	15.0	3.5	18.0	1.0	85.4
May	37.6	25.0	23.8	12.7	22.5	34.0	46.0	4.5	16.0	25.5	35.0	17.5	23.5	21.0	344.6
June	46.1	83.4	3.0	46.4	5.5	1.5	37.0	3.5	26.0	3.5	29.0	23.0	0.0	90.0	397.9
July	35.2	14.5	0.0	7.5	7.5	8.0	19.0	20.0	44.0	17.5	21.5	73.5	17.5	12.0	297.7
August	9.1	9.0	0.0	12.7	0.0	15.0	15.0	15.5	12.0	9.5	11.5	8.5	21.0	9.5	148.3
September	56.4	21.8	22.0	16.5	5.5	35.0	3.5	5.5	16.5	15.0	49.5	12.5	0.0	88.5	348.2
October	4.5	6.0	27.1	29.0	16.0	0.5	20.5	2.5	5.0	3.0	13.5	7.0	3.0	29.5	167.1
November	22.8	34.1	13.3	13.0	2.5	0.5	1.0	8.0	15.0	11.0	30.0	15.0	21.5	3.0	190.7
December	26.1	41.9	14.9	18.5	5.0	21.5	2.0	13.5	6.0	7.5	36.0	22.5	18.5	0.0	233.9
Sum	303.4	278.2	168.8	231.9	123.0	152.5	177.0	128.3	173.6	105.0	284.5	266.0	163.0	276.0	

Table 9

The sum of the monthly rainfall [mm] in the cyclonic situation (2005–2018)

Month	Year														
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2005–2018
January	109.5	64.0	89.2	19.5	30.7	59.5	48.5	123.0	86.5	36.5	79.0	44.5	18.0	22.0	830.4
February	73.4	48.8	78.2	18.5	119.5	61.5	22.5	69.0	65.5	29.0	53.5	138.0	46.5	39.5	863.4
March	63.8	98.1	72.0	95.8	175.5	47.6	44.0	45.5	88.5	72.5	55.5	32.5	74.5	36.0	1001.8
April	67.8	119.5	14.4	55.7	1.3	71.5	102.5	98.5	26.5	52.0	80.5	107.0	161.0	22.0	980.2
May	123.5	88.9	69.9	71.6	101.0	502.0	94.5	41.0	165.5	277.0	115.5	70.5	62.0	106.0	1888.9
June	88.8	75.9	118.3	28.5	233.5	201.5	78.0	199.0	232.5	123.0	43.0	48.0	87.5	86.0	1643.5
July	157.5	25.5	159.4	238.7	117.5	139.8	312.0	46.5	68.5	152.5	79.5	137.5	67.5	212.0	1914.4
August	153.7	143.5	87.2	80.0	134.5	210.4	89.5	54.0	40.0	125.0	23.5	76.5	69.0	53.0	1339.8
September	59.0	15.0	257.0	137.8	34.5	106.0	52.5	117.0	177.5	105.5	26.0	68.0	393.5	58.0	1607.3
October	8.0	46.0	56.3	54.5	130.0	14.0	36.5	122.0	27.5	85.5	30.5	205.0	129.5	61.0	1006.3
November	36.5	111.5	174.5	46.1	116.0	80.0	0.0	51.2	86.5	45.0	89.0	60.0	84.0	0.0	980.3
December	131.6	15.0	30.6	66.0	46.5	100.0	48.0	44.0	29.0	47.0	2.5	68.0	39.0	0.0	667.2
Sum	1073.1	851.7	1207.0	912.7	1240.5	1593.8	928.5	1010.7	1094.0	1150.5	678.0	1055.5	1232.0	695.5	

Table 10

The sum of the annual rainfall [mm] for individual air masses (2005–2018)

Air masses	Year														
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2005–2018
PA	114.2	64.0	175.2	102.8	95.2	108.0	67.5	79.0	54.0	47.0	37.0	130.5	87.0	9.5	1170.9
PPk	9.1	34.2	88.3	43.8	43.1	19.0	55.5	13.5	22.0	37.5	16.0	84.0	8.5	165.5	640.0
PPm	260.9	372.4	385.3	237.3	230.5	225.1	353.0	220.4	355.0	246.5	257.5	185.0	382.5	231.5	3942.9
PPmc	44.1	48.1	101.6	51.1	75.0	109.0	76.5	29.0	76.5	244.5	137.5	123.5	138.5	83.5	1338.4
PPms	719.0	425.8	483.7	477.0	516.7	999.1	343.5	367.1	506.6	501.5	281.0	471.5	381.0	369.5	6842.9
PZ	35.9	5.4	28.8	56.0	29.0	57.2	56.5	42.5	8.0	21.5	38.0	55.5	64.5	25.0	523.8
rmp	203.7	181.7	122.9	178.1	395.0	258.4	172.5	393.5	252.5	162.0	235.5	293.0	349.0	104.0	3301.8

Explanation of symbols: PA – artic air; PPk – polar continental air; PPm – polar sea air; PPmc – polar sea air warm; PPms – polar sea air old; PZ – tropical air; rmp – different.

Table 11

The number of days with rainfall for individual air masses (2005–2018)

Air masses	Year														
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2005–2018
PA	25	10	20	16	14	16	15	14	13	6	10	9	13	5	186
PPk	6	18	16	11	15	8	13	7	9	14	6	17	7	19	166
PPm	36	41	44	36	24	30	35	37	40	28	34	31	45	23	484
PPmc	5	12	10	12	14	17	11	9	14	27	19	11	16	11	188
PPms	98	64	52	59	66	73	39	47	57	45	46	74	50	39	809
PZ	5	3	4	4	3	7	6	8	2	2	5	4	9	3	65
rmp	14	21	18	27	34	27	25	42	22	20	23	24	35	22	354

Explanation of symbols: PA – artic air; PPk – polar continental air; PPm – polar sea air; PPmc – polar sea air warm; PPms – polar sea air old ; PZ – tropical air; rmp – different.

graph (Fig. 5). The significant share of precipitation from multi-year period (2005–2018) in directions from the east (E) to northwest (NW) is visible.

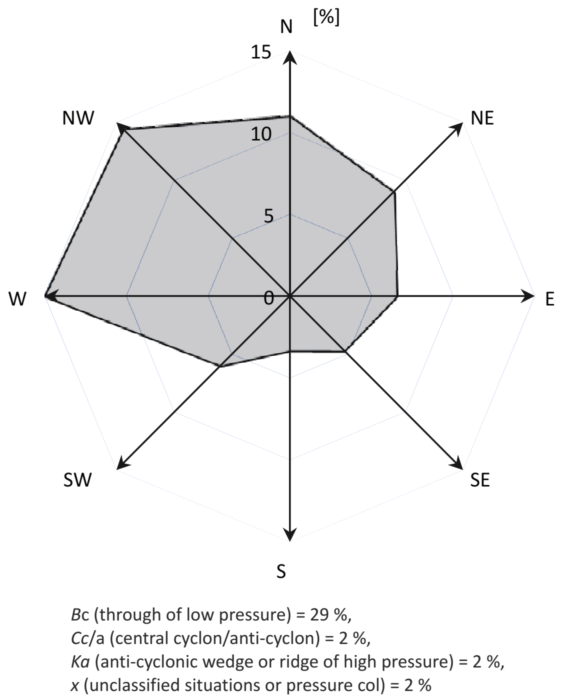

Fig. 5. The percentage share of the rainfall at different directions of air masses inflow in the multi-year period (2005–2018)

Conclusion

1. In the analysed multi-year period (2005–2018) the dry years prevailed, however the significant regularity wasn't noticed.

2. In the analysed multi-year period the highest rainfall was recorded in 2010 year, when in May the total precipitation was summarised at the 171 mm level.

3. The most days with precipitation were characterized as low rainfall and they constituted 39 % of all recorded precipitation days.

4. No significant variability in the number of days with precipitation was observed in individual months in the whole multi-year period.

5. The recorded precipitation accompanied the inflow of air masses in the directions from the east (E) to the northwest (NW).

6. In the whole multi-year period 65 % of days with precipitation were recorded, in which the days with low rainfall dominated.

References

[1] Zawora T, Ziernicka A. Precipitation variability in time in Poland in the light of multi-annual mean values (1891-2000). Stud Geograf Acta Univers Wratislav. 2003;75(2542):125. Available from: www.researchgate.net/publication/296003585_Precipitation_Variability_in_Time_in_Poland_in_the_Light_of_Multi-Annual_Mean_Values_1891-2000.

[2] Zmudzka E. The contemporary climate changes in Poland, Acta Agrophys. 2009;13(2):555-68.

[3] Cebulak E, Limanówka D, Pyrc R, Gębica L, Starkel L. Influence of Selected Mountain Barrier for the Distribution of Precipitation in the Polish Carpathians, Prz Geof. 2018;1-2:123-34. Available from: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-3587888f-cf18-4a77-89d5-b028a359b445?q=bwmeta1.element.baztech-65f312a4-3368-4988-abef-c21d2b7e7283;6&qt=CHILDREN-STATELESS.

[4] Benestad RE. Can we expect more extreme precipitation on the monthly time scale? J Climate. 2006;19:630-7. DOI: 10.1175/JCLI3656.1.

[5] Schönwiese CD, Grieser J, Trömel S. Secular change of extreme monthly precipitation in Europe. Theor Appl Climatol. 2003;75:245-50. DOI: 10.1007/s00704-003-0728-6.

[6] Müller M, Kašpar M, Matschullat J. Heavy rains and extreme rainfall-runoff events in Central Europe from 1951 to 2002. Natural Hazards Earth Syst Sci. 2009;9:441-50. DOI: 10.5194/nhess-9-441-2009.

[7] Räisänen J. Impact of increasing CO_2 on monthly-to-annual precipitation extremes: analysis of the CMIP2 experiments. Climate Dynamics. 2005;24(2):309-23. DOI: 10.1007/s00382-004-0510-1.

[8] Maciejewski M, Ostrowski M, Walczykiewicz T. Dorzecze Wisły: monografia powodzi maj czerwiec 2010 (Vistula river basin: flood monograph May June 2010). Warszawa: Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy Warszawa; 2011. ISBN: 9788361102595.

[9] Wozniak A. Opady w 2010 roku w Karpatach Polskich na tle wielolecia 1881-2010 (The rainfall in 2010 in the Polish Carpathians against the background of the multi-year period 1881-2010). Pr Geograf. 2013;133:35-48. DOI: 10.4467/20833113PG.13.009.1099.

[10] Cebulska M, Twardosz R. Anomalously wet seasons and years in the Polish Carpathian Mountains and in their foreland (1881-2010). Przegl Geof. 2014;3-4:111-26. Available from: www.researchgate.net/publication/286275721_Anomalously_wet_seasons_and_years_in_the_Polish_Carpathian_Mountains_and_in_their_foreland_1881-2010.

[11] Cebulska M. Periods without precipitation and with low precipitation in the Polish Carpathians in the years of 1984-2013. Pol J Agron. 2018;34:52-61. DOI: 10.26114/pja.iung.355.2018.34.06.

[12] Durlo G. Climatic water balance of wegetation periods at the Wyrchczadeczka forest nursery in the Silesian Beskids. SYLWAN. 2007;6:53-61. DOI: 10.26202/sylwan.2006047.

[13] Durlo G. Klimatyczny bilans wodny na obszarze Parku Krajobrazowego Góry Opawskie (Climatic water balance in the Gory Opawskie Landscape Park). SYLWAN. 2019;163(10):802-10. DOI: 10.26202/sylwan.2019050.

[14] Hänsel S, Ustrnul Z, Łupikasza E, Skalake P. Assessing seasonal drought variations and trends over Central Europe. Adv Water Resour. 2019;127:53-75. DOI: 10.1016/j.advwatres.2019.03.005.

[15] Olechnowicz-Bobrowska B. The frequency of days with precipitation in Poland. Przegl Geograf. 1970;86:13.

[16] Kaczorowska Z. The rainfall in Poland over a long-term cross-section. Przegl Geograf. 1962;33:72.

[17] Niedzwiedz T. Calendar of the atmosphere circulation types for southern Poland – computer collection. Sosnowiec: University of Silesia in Katowice. Department of Climatology; 2017.