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Characteristics of long-term variability of precipitation in the territory of Poland based on GPCC data for the years 1901–2010

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Abstract : *The study contains an analysis of precipitation, covering multiple profiles and based on the GPCC database that provides monthly mean values for the territory of Poland. The analysis includes data for the period 1901–2010 with a spatial resolution of 0.5°x°0.5° of geographic longitude and latitude. The initial section of the analysis contains an assessment of GPCC data accuracy for the territory of Poland and the period 1961–1990. The following sections include a data analysis in monthly profiles and hydrological cycle profiles, taking into account hydrological summer and hydrological winter. A cluster analysis is also included, with drought and flood periods indicated. The periodical nature of precipitation is assessed and the trends in climate changes calculated.*
Keywords : *GPCC data, monthly precipitation, frequency analysis, climate trend in precipitation, taxonomic analysis of precipitation, wet years, dry years*

I. Introduction

The demand for temporal and spatial characteristics of atmospheric precipitation, despite numerous studies published and analyses completed [Kożuchowski 1984, 1996; 2004; Obrębska-Starklowa 1991; Dynowska, Maciejewski 1991; Niedźwiedź and Czekierda 1997; Niedźwiedź and Twardosz 2004, Degirmendžić et alt. 2004; Kirschenstein, Baranowski 2005; Mager et alt. 2009; Zawora, Ziernicka 2003; Ziernicka-Wojtaszek 2006; Żmudzka 2002; 2009, Twardosz and Walanus 2009, Cebulska et alt. 2013], has grown in recent decades due to the documented hypotheses proposing effects of human activities on regional climate factors. New computational capacities and comprehensive analyses covering long measurement series also attract the interest of researchers who test out their hypotheses proposing escalation and polarization of extreme phenomena. The renewed interest in climate factors, including atmospheric precipitation, also results from accumulation of flood damages and periods of hydrological drought.

The available studies of variations in atmospheric precipitation [Niedźwiedź 1991, 1998, 2009, 2011, Twardosz 2004, 2011, 2013; Zawora, Ziernicka 2003; Żmudzka 2002, 2009; Mager et alt. 2009] demonstrate changes in statistical trends, depending on the period observed, and provide a basis for an assessment of the nature and directions of those changes. The results of assessments of the pluvial nature of precipitation, demonstrating a reduction in the proportion of total summer precipitation, also indicate a reduced continental influence [Degirmendžića et alt. 2004], [Cebulska and Twardosz 2007]. The trend analyses [Kożuchowski 1996; Twardosz 1997, Ziernicka-Wojtaszek 2006] demonstrate an increased variability of precipitation.

Precipitation plays an important role in the global circulation of energy and water. The detailed knowledge of precipitation volumes reaching the Earth land surface is particularly important for an assessment of the quantity of fresh water available as well as for water management, necessary to meet the demand for water. This knowledge is also used to mitigate the risks of floods and droughts.There is a growing body of scientific evidence confirming the hypothesis proposing climate changes caused by human activities. The intensity of those changes depends on the region and varies in time and space. The analyses of climate changes at a regional level demonstrate a strong correlation with anthropogenic impacts. The climate changes observed are characterised by shortened period of high-intensity precipitation and more frequent periods of long-lasting precipitation that cause great floods. Also the periods characterised by high temperatures and reduced precipitation have become longer. The polarization of extreme phenomena is an established fact, associated with the variations in and intensity of human activities.

The Polish National Water Management Strategy for 2030 emphasises that water retention is insufficient already at present. An effective plan for flood control capacity is necessary to balance the consequences of an increase in the volumes of flowing bodies of water. On the other hand, retention of usable and manageable water resources is required to overcome the consequences of droughts.The total volume of flowing water in Poland amounts to 61.9 billion m^3/year on average, including 88% of domestic resources. The total natural capacity of Polish lakes amounts to about 18.2 billion m^3, plus additional 3.5 billion m^3 or more in retention reservoirs. The relatively small total capacity of Polish retention reservoirs, estimated to be about 4 billion m^3 and representing less than 6% of the long-term mean annual outflow, is insufficient to ensure the full protection against floods and droughts, a safe level of water supplies to the consumer population and to the industrial and agricultural sectors. The present conditions entail an actual hazard posed by the effects of droughts and floods. The geomorphological conditions in Poland provide an opportunity to retain up to 15% of the mean annual outflow. The sole reasonable solution is to adopt measures designed to use the natural retention capacity.

The scientific studies published focus mainly on the global aspects while ignoring (as reasonably emphasised in the Strategy) “regional analyses showing confirmed correlations between the causes and reasons of floods and their types and intensity, analyses of and interrelations between the structure and volumes of precipitation and its consequences in local catchment areas, separate small hydrographic systems, or local drainage areas”. This study aims at supplementing necessary information about the characteristics of long-lasting precipitation series, precipitation total and mean values in areas particularly exposed to extreme events: the upper Vistula River basin and the upper and middle Oder River basin. The need to provide such information is also emphasised in the documents developed within the United Nations Framework Convention on Climate Change. The requirement to adapt policies to the observed climate changes, characterised by an increase in temperatures by at least 1°C and changed precipitation patterns, entails the need to develop regional and local analyses of climate changes and thus to provide a basis for scenarios aimed at balancing the effects of climate changes.

Table 1. A statement of annual balances of water resources in the upper Vistula and the upper and middle Oder for the period 1901 – 2010

Region of water resources assessment	Area [km^2]	Total of precipitation p.a. mean values for the long-term period[mm], GPCC data	Volume V[billion m^3/year]	Trend [mm/year]	Trend [million m^3/year]
Poland	312679	619.1	193.58	0.002	0.625
upper Vistula	43109	742.3	32.00	0.294	12.674
upper and middle Oder	53467	671.8	35.92	-0.236	-12.618

II. The role of GPCC Precipitation Climatology Centre in collecting and providing precipitation data

The intense interest in analyses of long-lasting precipitation series results from the need to assess climate changes and their effects on all spatial scales. This demand has led to numerous research and monitoring programmes initiated, supported and carried out by international organizations. In this context, the Global Precipitation Climatology Centre(GPCC) was established in 1989 by the World Meteorological Organization (WMO). The Centre is supported and operated by the DeutscherWetterdienst (DWD, the German Meteorological Office) as a German contribution to the World Climate Research Programme (WCRP).

The main objective of the GPCC is a global analysis of monthly precipitation on Earth land surface based on data provided by “in-situ” precipitation stations. In 1994, GPCC was requested by the WMO to support climate monitoring activities carried out by the Global Climate Observing System (GCOS). The GPCC has joined the GCOS network (GSNMC) in 1999, focusing on atmospheric precipitation while temperature monitoring is conducted by the Japan Meteorological Agency (JMA).

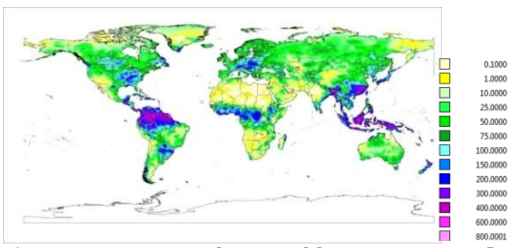

Figure 1. An example, monthly precipitation [mm]: May 2010, GPCC data

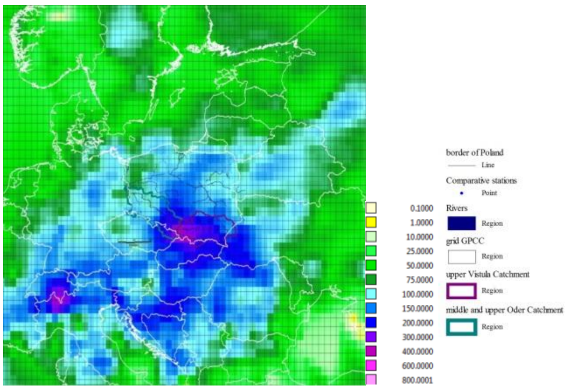

Figure 2. A raster based on GPCC monthly precipitation data [mm]: May 2010, GPCC data

The objective of the GPCC is to meet the users' demand for accurate analyses, current and readily available datasets. For example: The WCRP, as part of the Global Energy and Water Cycle Exchanges Project (GEWEX), requires high spatial resolution and accuracy of data for the last two decades while the priorities of the GCOS and IPCC focus on long-term uniformity of time series showing climate changes.

All GPCC products represent gridded near and non-real-time datasets of precipitation on the Earth land surface. Only monthly data is made available in spatial resolutions 0.5°x 0.5° to 2.5°x 2.5° of geographic longitude and latitude. The datasets are made available on the Internet (http://gpcc.dwd.de).
The products are developed based on complete sets of information from the world precipitation database originating from more than 97000 stations that provide protected and classified raw records.

III. Characteristics of data for 1901-2010

The GPCC data representing total precipitation volumes in individual months in the period 1901–2010, with a spatial resolution of 0.5°x 0.5° of geographic longitude and latitude, converted to the analysed area of Polish catchment basin. Thus a sequence of monthly precipitation values was obtained that is analysed in this study. The GIS mechanisms are used in the spatial analysis of data.
The calculated sequence values were subject to a simple statistical analysis in order to determine the basic statistics: the minimum and maximum values, the mean value, standard deviation of the sample and the value of the coefficient of variation.
The data is analysed using profiles modelled for individual calendar years and for hydrological years divided into hydrological summers and hydrological winters. The analyses of monthly precipitation cover the years 1901–2010, and the analyses of cumulative monthly total values of precipitation cover the hydrological years 1902–2010.

IV. An assessment of accuracy of the GPCC data for the period 1961–1990

An analysis of error of mean monthly values of total precipitation for 43 locations was completed to verify the data. The verification covered the period of 30 years from 1961 to 1990 (comparable data was available for that period [9]). The results of the analysis are shown in tabular and graphic formats. The results of data verification demonstrate errors amounting to a few percent for 38 locations. For 5 locations: Jelenia Góra, Kętrzyn, Kłodzko, Legnica, Przemyśl, the error values exceed 10%. The locations are situated in 0.5°x 0.5° grid meshes partly situated abroad. The values of errors may be affected by measurements made available by neighbouring stations located in the cross-border belt. The data does not contain random errors. The nature of the errors is systematic, as confirmed by the GPCC values of mean monthly precipitation that are greater than the measured ones.

Table 2. A statement of mean monthly values of total precipitation [mm] for the locations deviating from the analysed dataset for the period 1901– 2010 based on GPCC data

Locationname	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Jelenia Góra	72.4	65.6	65.7	66.9	85.5	99.1	109.1	103.3	69.0	67.2	76.9	77.3
Kętrzyn	36.6	26.4	31.8	38.5	52.1	75.3	86.1	81.8	57.3	53.4	53.6	43.7
Kłodzko	52.4	46.4	50.9	53.1	83.9	96.4	105.3	102.2	64.8	55.8	59.7	58.4
Legnica	33.2	29.7	34.2	43.8	64.5	71.5	84.1	81.7	46.9	45.1	40.9	36.5
Przemyśl	38.2	35.3	40.6	53.8	77.3	100.5	106.0	86.4	67.6	55.4	47.1	41.7

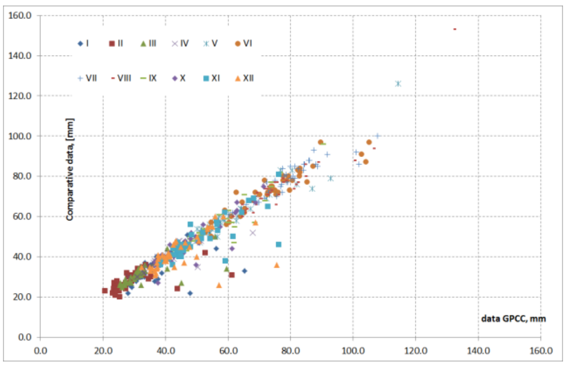

Figure 3. An assessment of data accuracy, a comparison of monthly precipitation with the GPCC data [mm], the years 1961–1990

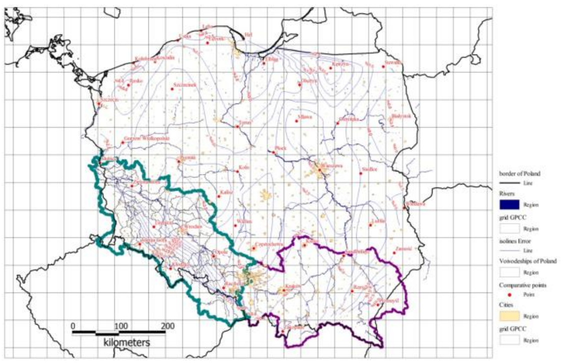

Figure 4. Relative error, a comparison of mean monthly precipitation with the GPCC data [mm], the years 1961–1990

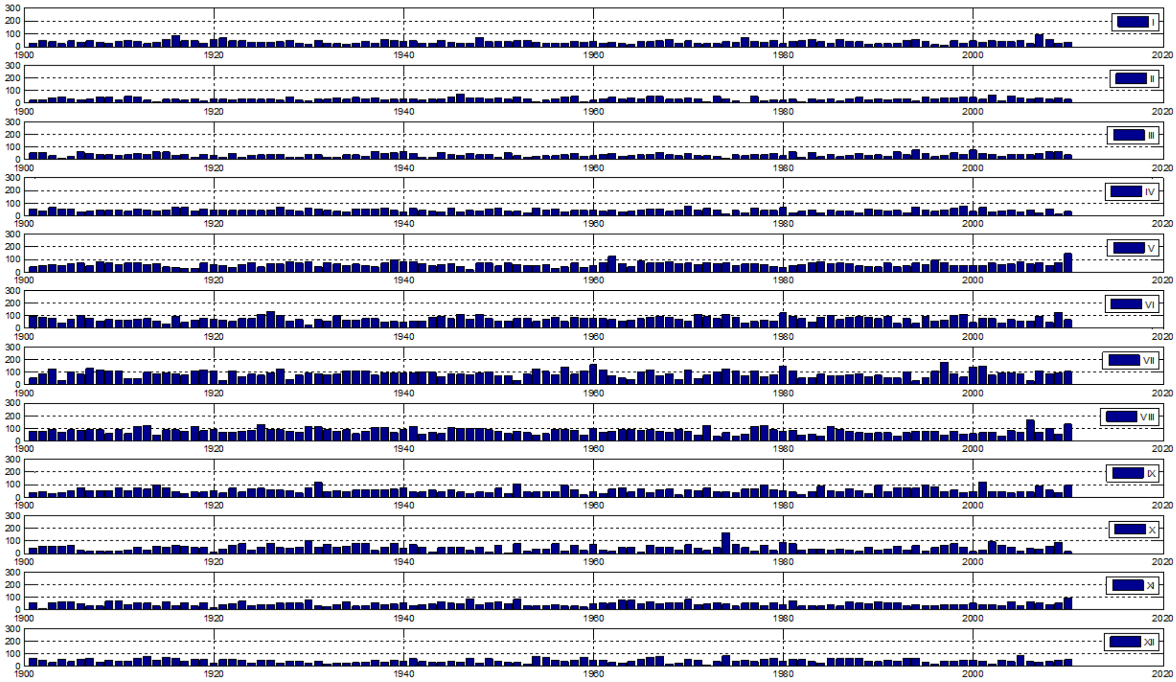

Figure 5. Totals of precipitation in individual months [mm] in the analysed period 1901–2010 in the Polish catchment basin

Table 3. A comparative statement of mean monthly values of precipitation and an error assessment for the period 1961– 1990 for selected towns

				Comparative data, monthly precipitation [mm]												
		WMO code	Elevation [m above sea level]	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
1	Białystok	12295	*148*	35	26	31	36	56	74	80	70	52	46	46	40	592
2	Częstochowa	12550	*295*	33	30	31	39	69	80	86	76	49	40	41	38	612
3	Elbląg	12160	*40*	37	27	29	35	52	78	85	77	71	52	58	47	648
4	Gorzów Wlk	12300	*65*	36	29	32	41	53	71	62	57	46	39	45	45	554
5	Hel	12135	*1*	37	28	27	30	43	56	70	72	61	48	56	46	574
7	Kalisz	12435	*140*	26	23	25	32	52	60	67	66	45	36	42	34	509
9	Kętrzyn	12185	*108*	28	20	26	35	53	78	80	66	57	47	50	37	576
10	Kielce	12570	*268*	40	34	35	42	60	73	86	79	50	39	47	48	633
12	Koło	12345	*115*	26	26	26	30	48	64	72	69	45	39	41	35	519
13	Kołobrzeg	12100	*3*	47	31	39	39	47	62	88	69	68	55	62	55	663
14	Koszalin	12105	*33*	43	30	35	39	55	72	88	74	82	62	69	55	704
15	Kraków	12566	*237*	34	32	34	48	83	97	85	87	54	46	45	41	686
16	Legnica	12415	*122*	25	24	27	41	64	71	72	74	43	38	36	31	545
17	Lębork	12125	*17*	45	33	36	38	54	57	85	75	75	63	68	55	684
18	Lublin	12495	*171*	32	30	30	42	57	72	76	72	50	39	44	39	583
19	Łeba	12120	*2*	41	30	33	36	48	50	79	71	77	67	68	54	653
20	Mława	12270	*147*	30	25	30	36	50	77	75	71	50	41	49	41	573
21	Olsztyn	12272	*133*	36	26	33	37	54	84	79	77	59	50	56	47	639
22	Opole	12530	*176*	36	32	32	39	71	78	84	86	51	44	44	41	638
23	Ostrołęka	12285	*95*	30	26	29	38	58	73	67	72	45	42	49	40	570
24	Płock	12360	*106*	28	24	32	32	57	72	73	64	44	36	46	37	545
25	Poznań	12330	*86*	30	24	27	36	53	60	69	57	43	39	39	38	515
26	Przemyśl	12695	*279*	29	29	34	48	76	97	100	77	55	42	40	40	667
27	Racibórz	12540	*190*	32	30	35	46	83	82	93	80	51	40	45	35	651
28	Resko	12210	*55*	51	35	44	48	54	67	78	66	63	56	62	60	683
29	Rzeszów	12580	*200*	30	28	30	45	71	85	91	77	50	41	39	40	626
30	Sandomierz	12585	*217*	29	27	27	38	61	80	86	69	43	37	37	34	568
31	Siedlce	12385	*146*	26	22	26	35	59	75	66	62	48	38	41	35	534
32	Słubice	12310	*21*	37	31	33	40	60	63	58	60	46	37	43	45	553
33	Suwałki	12195	*184*	32	24	32	35	57	75	77	68	54	49	52	39	594
34	Szczecin	12205	*1*	36	27	32	38	52	57	61	55	44	38	46	41	527
35	Szczecinek	12215	*137*	42	31	37	37	53	72	79	63	57	47	53	50	621
37	Toruń	12250	*69*	27	23	26	30	56	78	77	60	45	39	40	35	536
38	Ustka	12115	*9*	51	36	40	39	44	52	83	74	81	75	81	60	715
39	Warszawa	12375	*106*	22	21	26	33	58	71	69	62	43	27	41	32	515
40	Wieluń	12455	*195*	35	31	33	39	64	73	77	73	49	40	51	42	607
41	Włodawa	12497	*175*	29	25	28	36	52	68	81	60	47	39	39	33	536
42	Wrocław	12424	*120*	28	26	26	39	64	80	84	78	48	40	43	34	590
43	Zakopane	12625	*857*	44	42	50	77	126	177	167	153	96	67	65	57	1122
44	Zamość	12595	*212*	25	23	28	40	62	83	79	68	48	38	36	33	563
45	Zielona Góra	12400	*192*	36	31	32	42	60	62	67	71	45	43	45	48	582

		GPCC data, monthly precipitation [mm]												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
1	Białystok	33	24	30	35	57	74	78	69	51	45	46	38	578
2	Częstochowa	36	31	32	43	72	83	88	82	48	40	44	40	639
3	Elbląg	33	24	27	33	51	72	80	75	65	48	57	43	608
4	Gorzów Wlk	36	29	31	40	53	70	62	56	46	39	44	45	552
5	Hel	36	25	26	31	44	59	76	69	57	46	48	43	559
7	Kalisz	27	25	26	33	54	64	70	69	46	37	44	36	531
9	Kętrzyn	37	25	32	36	53	79	81	75	60	51	62	46	637
10	Kielce	37	31	32	41	61	75	84	77	48	38	44	43	613
12	Koło	27	26	27	31	50	65	73	68	45	38	42	35	526
13	Kołobrzeg	46	30	38	40	51	65	86	70	72	58	65	55	675
14	Koszalin	43	29	36	39	54	63	86	71	77	62	68	54	682
15	Kraków	31	28	31	45	77	90	89	89	53	41	43	38	653
16	Legnica	29	27	29	44	67	75	77	81	47	42	42	37	599
17	Lębork	43	31	34	37	50	55	81	73	74	63	67	54	660
18	Lublin	30	28	29	41	58	73	77	69	49	39	42	38	572
19	Łeba	43	31	34	37	50	55	81	73	74	63	67	54	660
20	Mława	32	24	31	37	57	85	77	76	51	45	54	42	611
21	Olsztyn	35	25	33	36	55	83	80	78	60	50	57	46	637
22	Opole	34	30	30	41	73	81	83	84	51	43	45	39	635
23	Ostrołęka	32	25	30	37	63	80	70	73	47	41	51	40	589
24	Płock	29	24	31	33	57	76	74	66	45	38	47	37	558
25	Poznań	32	25	27	36	52	61	72	59	43	39	41	40	528
26	Przemyśl	38	35	41	51	82	105	108	82	62	46	45	50	745
27	Racibórz	39	35	35	48	81	83	87	85	51	43	47	43	677
28	Resko	48	33	41	44	51	65	75	64	60	52	59	56	648
29	Rzeszów	33	29	31	44	70	87	92	75	48	39	39	41	629
30	Sandomierz	30	27	28	39	61	79	85	70	45	38	38	36	576
31	Siedlce	29	23	27	36	59	74	66	65	48	40	43	37	547
32	Słubice	38	33	33	37	57	59	57	61	44	37	44	48	548
33	Suwałki	34	23	31	35	55	74	79	71	56	48	52	40	598
34	Szczecin	36	28	32	38	52	60	60	54	45	37	44	41	526
35	Szczecinek	42	29	36	37	54	69	80	65	61	50	57	50	630
37	Toruń	27	21	25	28	54	78	72	58	44	39	44	32	524
38	Ustka	47	34	38	38	46	53	84	72	77	71	76	59	695
39	Warszawa	28	24	27	33	59	73	68	68	43	38	45	37	541
40	Wieluń	34	31	32	38	64	74	79	74	48	40	48	41	603
41	Włodawa	31	27	27	37	54	68	79	64	47	38	41	37	552
42	Wrocław	31	26	27	38	64	78	78	78	49	40	46	37	591
43	Zakopane	56	53	56	72	114	148	136	132	91	69	73	69	1069
44	Zamość	27	24	29	41	64	82	81	67	49	39	38	35	576
45	Zielona Góra	38	32	33	44	63	65	68	72	46	44	48	51	605

		Relative error [%]												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Error of total
1	Białystok	-6.2	-8.6	-2.6	-2.6	1.2	-0.5	-2.5	-1.9	-2.3	-3.1	-0.8	-5.2	-2.4
2	Częstochowa	7.6	3.7	3.7	9.5	4.8	3.6	2.5	7.2	-2.1	0.9	6.3	5.9	4.3
3	Elbląg	-9.5	-12.0	-6.1	-6.0	-1.1	-8.1	-6.1	-3.2	-8.0	-7.2	-2.6	-8.6	-6.2
4	Gorzów Wlk	-1.1	0.1	-2.4	-2.4	0.6	-1.0	-0.8	-0.9	-1.0	1.1	-1.1	-0.3	-0.4
5	Hel	-1.8	-12.4	-5.2	4.0	1.3	6.2	7.9	-4.3	-6.2	-3.6	-14.2	-7.5	-2.6
7	Kalisz	5.8	9.7	4.6	3.7	3.8	6.9	4.1	4.1	2.1	2.9	3.9	4.9	4.3
9	Kętrzyn	30.8	27.3	24.0	3.9	0.2	1.1	1.0	13.8	5.5	8.1	23.2	24.1	10.6
10	Kielce	-7.5	-8.1	-8.4	-3.0	2.3	2.8	-2.0	-2.1	-3.9	-1.9	-6.5	-9.5	-3.2
12	Koło	2.8	-1.9	2.0	2.5	3.6	2.2	1.3	-1.7	0.0	-1.4	1.9	0.2	1.3
13	Kołobrzeg	-2.7	-2.0	-3.2	2.2	8.7	4.4	-2.4	1.5	5.9	4.6	4.1	0.1	1.8
14	Koszalin	1.0	-3.6	1.7	-0.7	-2.7	-12.9	-2.1	-3.5	-6.4	0.4	-1.1	-1.3	-3.1
15	Kraków	-7.6	-13.7	-8.0	-7.3	-7.5	-7.5	4.2	1.9	-2.8	-9.8	-4.9	-8.4	-4.8
16	Legnica	17.0	13.7	7.5	8.3	5.2	6.3	7.3	9.2	8.9	10.1	17.7	18.5	9.8
17	Lębork	-4.2	-5.4	-6.9	-2.9	-7.2	-3.9	-4.3	-3.2	-1.4	-0.3	-2.0	-2.7	-3.4
18	Lublin	-5.1	-6.7	-3.9	-2.2	1.0	1.2	1.5	-4.2	-2.5	-0.3	-3.6	-3.7	-1.8
19	Łeba	5.1	4.1	1.6	2.4	4.4	9.5	3.0	2.3	-4.0	-6.3	-2.0	-0.9	1.1
20	Mława	7.3	-3.4	3.0	3.6	13.2	10.9	2.5	6.9	1.5	9.2	10.7	1.3	6.6
21	Olsztyn	-2.1	-3.0	-0.9	-2.0	1.3	-1.0	1.5	0.8	0.9	-0.7	1.2	-1.5	-0.3
22	Opole	-6.7	-5.0	-4.9	4.6	3.3	3.3	-1.7	-1.8	0.9	-1.9	2.8	-4.9	-0.5
23	Ostrołęka	8.3	-3.6	3.9	-3.6	8.1	9.3	3.8	1.6	4.2	-1.5	5.0	-0.9	3.3
24	Płock	3.5	-1.5	-2.7	3.0	0.5	5.8	0.9	2.8	3.3	6.1	2.9	0.9	2.4
25	Poznań	5.2	4.3	1.4	1.1	-1.0	1.8	3.7	4.2	0.9	1.0	4.5	4.3	2.5
26	Przemyśl	29.5	19.8	19.5	6.9	7.9	8.5	7.8	6.8	12.9	9.1	12.8	24.9	11.6
27	Racibórz	21.2	18.0	1.1	3.3	-3.0	1.2	-6.1	5.9	0.7	6.9	4.7	22.5	4.0
28	Resko	-6.3	-6.6	-7.8	-7.8	-4.7	-3.6	-3.7	-2.5	-4.3	-7.1	-4.6	-6.8	-5.1
29	Rzeszów	11.0	4.7	3.8	-2.8	-1.8	2.6	0.9	-2.0	-3.4	-5.1	0.3	3.0	0.5
30	Sandomierz	2.6	1.4	2.5	2.9	-0.4	-0.7	-1.7	1.9	4.8	2.1	3.9	5.7	1.4
31	Siedlce	9.9	5.0	3.1	1.9	-0.7	-1.0	-0.1	5.2	1.0	5.2	5.1	7.0	2.4
32	Słubice	2.0	6.1	0.2	-6.3	-4.7	-6.2	-2.3	2.1	-3.7	-0.5	2.9	6.0	-0.8
33	Suwałki	4.8	-2.2	-3.2	0.1	-3.3	-1.5	2.2	4.4	3.6	-1.8	0.1	3.0	0.7
34	Szczecin	-0.8	3.9	-1.0	-0.5	-0.8	5.9	-1.2	-2.3	1.4	-3.2	-3.7	-0.6	-0.3
35	Szczecinek	0.0	-5.8	-1.6	0.1	1.0	-4.6	1.4	3.1	7.4	7.3	7.0	0.4	1.5
37	Toruń	0.3	-9.8	-2.1	-6.2	-3.2	-0.5	-6.0	-3.0	-2.1	0.5	11.0	-7.4	-2.3
38	Ustka	-7.8	-6.3	-4.2	-2.0	3.5	1.4	1.4	-2.5	-5.6	-4.8	-5.8	-2.5	-2.9
39	Warszawa	27.7	14.4	3.7	-1.0	1.4	2.3	-1.1	9.4	-0.1	39.3	9.3	15.1	5.1
40	Wieluń	-1.7	-1.4	-4.3	-1.9	0.4	1.8	2.7	1.0	-1.3	-1.2	-5.2	-2.7	-0.6
41	Włodawa	6.8	8.4	-2.7	4.1	4.6	0.3	-3.1	7.2	0.9	-1.4	5.4	10.8	2.9
42	Wrocław	9.3	-0.3	4.1	-2.9	0.0	-3.0	-7.7	0.6	1.7	1.1	6.6	9.8	0.2
43	Zakopane	27.9	25.7	11.7	-6.9	-9.1	-16.3	-18.4	-13.6	-5.7	2.6	11.9	20.8	-4.8
44	Zamość	8.0	5.6	2.3	1.3	4.0	-0.7	2.4	-0.9	1.3	1.4	6.8	6.5	2.4
45	Zielona Góra	6.8	2.9	2.1	5.6	4.9	5.5	1.8	1.7	2.3	2.8	6.6	5.7	4.0

Table 4. A statement of monthly precipitation values and selected statistics for the period 1901– 2010 in the Polish catchment basin

Months of the calendar year , Statistics														
	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'	Min	Max
Min [mm]	7.15	4.95	8.05	6.16	16.48	24.54	25.09	32.86	15.57	3.77	11.18	7.53	3.77	65.05
Max [mm]	89.65	67.94	72.48	74.09	142.84	128.23	175.25	159.98	112.92	162.51	90.12	79.78	43.51	175.25
Mean [mm]	36.23	30.74	34.12	40.93	59.06	72.01	84.98	76.95	52.92	44.66	45.47	40.97	19.15	102.01
Standard deviation of the sample [mm]	14.20	11.81	13.69	12.83	17.91	20.63	28.55	22.94	20.13	24.33	15.58	15.68	7.44	21.04
Coefficient of variation[]	0.39	0.38	0.40	0.31	0.30	0.29	0.34	0.30	0.38	0.54	0.34	0.38	0.39	0.21

Table 5. A statement of mean monthly values of total precipitation, cumulative in a hydrological year and in the summer and winter seasons with selected statistics for the period 1901–2010 in the territory of Poland

Year	Months of the hydrological year												Hydrologicalseasons	
	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	WINTER (XI-IV)	SUMMER (V-X)
Statistics														
Min [mm]	11.2	35.8	54.9	91.6	109.6	144.2	202.3	251.5	324.3	382.0	420.9	465.2	144.2	263.0
Max [mm]	84.4	148.1	213.3	251.6	283.3	330.3	393.1	491.2	582.6	678.1	743.8	762.5	330.3	571.1
Mean [mm]	45.1	85.9	122.3	153.1	187.1	227.9	287.2	359.0	444.3	521.3	574.4	619.1	227.9	391.2
Standard deviation of the sample [mm]	15.0	21.3	27.8	29.4	35.0	37.5	41.1	45.6	53.3	59.6	65.2	69.7	37.5	57.6
Coefficient of variation []	0.332	0.248	0.227	0.192	0.187	0.164	0.143	0.127	0.120	0.114	0.114	0.113	0.164	0.147

V. A taxonomicanalysis

A taxonomic analysis of calendar year profiles was completed using the calculated statistics for monthly precipitation: the mean value, the standard deviation of the sample and the coefficient of variation. The objective of the calculations was to determine year clusters and to identify drought and flood periods.The algorithm is graphically depicted as a dendrogram with its nodes representing clusters and its leaves representing objects. The leaves are located on the zero level, and the nodes at a height corresponding to the measure of dissimilarity between clusters represented by the descendant nodes.

One of the most popular cluster analyses in the hydrology, developed by Ward (1963), is used in this study. The measure is determined based on an analysis of variance.The Ward's method belongs to the family of agglomerative clustering methods. It is recognised as the most effective method in generating uniform clusters.

The results of clustering monthly precipitation in the years 1901–2010 described by mean values, standard deviations and coefficients of variation using the Ward's method are represented as a cluster tree. The analysis focuses on a detailed representation of two extreme clusters identified as drought and flood periods in the territory of Poland.

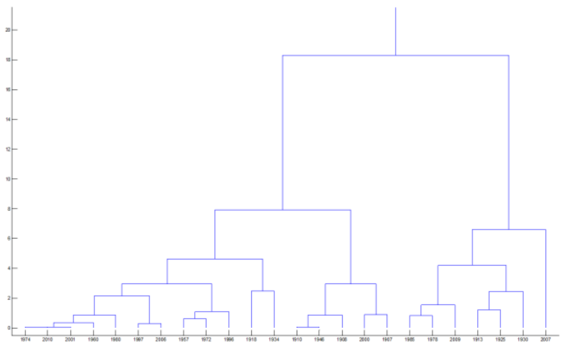

Figure 6. The cluster of "flood years" classified according to mean monthly precipitation in the territory of Poland

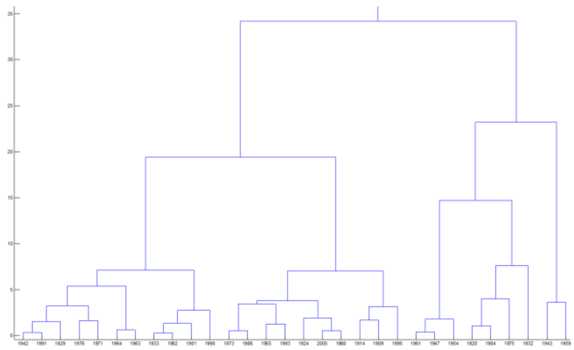

Figure 7. The cluster of "drought years" classified according to mean monthly precipitation in the Polish catchment basin

The cluster of "flood years" represents the levels of mean monthly precipitation in the Polish catchment basin ranging from 49.05 to 67.34 [mm], standard deviations ranging from 28.0 to 45.99 [mm] and the coefficient of variation from 0.49 to 0.76. The following calendar years are included in the cluster according to their ranks: 1974, 2010, 2001, 1960, 1980, 1997, 2006, 1957, 1972, 1996, 1918, 1934, 1910, 1946, 1908, 2000, 1907, 1985, 1978, 2009, 1913, 1925, 1930, 2007.The cluster includes 24 years in total, i.e. about 22 % of the analysed period.

In contrast, the cluster of drought years includes the years when the values of mean monthly precipitation in the Polish catchment basin ranged from 41.06 to 50.71 [mm], standard deviations from 20.61 to 29.94 [mm] and the coefficient of variation ranged from 0.44 to 0.73. The following calendar years are included in the cluster: 1942, 1991, 1929, 1976, 1971, 1964, 1963, 1933, 1902, 1901, 1990, 1973, 1986, 1955, 1993, 1924, 2005, 1988, 1914, 1909, 1995, 1961, 1947, 1954, 1920, 1984, 1975, 1932, 1943, 1959. The cluster includes 30 years in total, i.e. about 27% of the analysed period.

VI. Periodicity of precipitation

The periodicity of precipitation in the Polish catchment basin was assessed using signal processing theory with a harmonic analysis applied. The procedures necessary to calculate the values of predominating frequencies were developed in Matlab. The inverses of those values represent the predominating period of repeatability of an event. The analysis was completed for various profiles of the analysed dataset. The periodicity of monthly precipitation considered using monthly profiles of calendar years in the analysed period 1901–2010 may be described as follows: February is characterised by a long predominating period of repeatability: 55 years while predominating periods of repeatability for the remaining months amount to 2.3 to 36 years. Period of repeatability of minimum values: 11 years, maximum values: 3 years, medium values: 10 years.

Table 6. A statement of periodicity values (inverses of predominating frequencies) for mean monthly precipitation sequences in the period 1901–2010 by months in the territory of Poland

Analysedsequence profile	Months of the calendar year												Statistics				
	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'	Minimum values	Maximum values	Meanvalues	Standard deviationvalues	Values of the coefficient of variation
	[years]																
Predominating period in years	4.54	54.50	7.79	2.32	36.33	9.08	3.89	4.04	7.79	5.74	3.30	6.41	10.90	3.21	9.91	5.45	5.45

The periodicity of total monthly precipitation considered using hydrological year profiles in the analysed period 1902–2010 is characterised by several predominating periods: 2, 3, 5 and 10 years. In an analysis of predominating frequencies, the 3-year periods for the months December–February, June and October are clearly identifiable.

Table 7. A statement of periodicity values (inverses of predominating frequencies) for sequences of cumulative total of mean monthly precipitation in the period 1901–2010 by hydrological years in the territory of Poland

Analysedsequence profile	Months of the hydrological year											
	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'
	[years]											
Predominating period in years	21.60	3.00	3.00	3.00	5.40	27.00	5.40	2.63	9.82	9.82	9.82	2.45

The periodicity of total monthly precipitation considered using hydrological summer and hydrological winter profiles in the analysed period 1902–2010 equals 27 years for the winter season and 36 years for the summer season.

Table 8. A statement of periodicity values (inverses of predominating frequencies) for sequences of total mean monthly precipitation in the hydrological winter and hydrological summer in the period 1901– 2010 in the Polish catchment basin

Analysedsequence profile	Seasons of the hydrological year	
	WINTER (XI-IV)	WINTER (XI-IV)
	years	
Predominating period in years	27	36

VII. Premises for an analysis of climate changes observed in precipitation

The trend in climate changes considered using total monthly precipitation profiles for the hydrological summer is described by linear equations with indicated boundary values of coefficients determined at a 5% significance level. The linear trend form is characterised mainly by a slope *a* [mm/year]. For the analysed period of 1902–2010, the slope value is negative and varies between -0.036 [mm/year] for January of the hydrological year and 0.12 [mm/year] for June of the hydrological year. The total of precipitation in the analysed period of 109 years is characterised by a positive trend -0.002 [mm/year].

Table 9. Values of parameters of the linear trend in total monthly precipitation in a hydrological year in the analysed period in the territory of Poland

		Months of the hydrological year											
	Units	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'
Slopevalue *a*	[mm/year]	-0.010	-0.010	-0.036	-0.021	0.035	-0.019	0.065	0.120	0.093	-0.036	0.011	0.002
Lower limit at a 95% confidence level		-0.101	-0.140	-0.206	-0.200	-0.179	-0.247	-0.186	-0.157	-0.232	-0.399	-0.386	-0.422
Upper limit at a 95% confidence level		0.081	0.119	0.133	0.158	0.248	0.210	0.315	0.397	0.417	0.326	0.409	0.427

Coefficientvalue *b*	[mm]	64.8	106.0	193.4	194.7	119.4	264.2	161.0	124.5	263.3	592.6	551.9	614.4
Lower limit at a 95% confidence level		-113.567	-147.438	-137.595	-155.877	-297.551	-182.229	-328.268	-417.459	-370.858	-116.901	-225.478	-215.750
Upper limit at a 95% confidence level		243.2	359.4	524.4	545.3	536.4	710.6	650.2	666.5	897.5	1302.1	1329.4	1444.6

The trend in climate changes considered using monthly precipitation profiles for the calendar summer is described by linear equations with indicated boundary values of coefficients determined at a 5% significance level. The slope values are both negative and positive for the analysed period 1901–2010. The months of January, April, June, August, October and November are characterised by a decreasing trend in precipitation while the remaining months by a positive trend. The values vary between -0.125 in August and +0.046 [mm/year] in March.

Table 10. Values of parameters of the linear trend in monthly precipitation in a calendar year in the analysed period in the territory of Poland

		Months of the calendar year											
	Units	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'
Slopevalue *a*	[mm/year]	-0.020	0.020	0.046	-0.056	0.091	0.043	-0.009	-0.125	0.058	-0.005	0.012	0.005
Lower limit at a 95% confidence level		-0.105	-0.050	-0.035	-0.132	-0.015	-0.080	-0.179	-0.260	-0.062	-0.150	-0.081	-0.089
Upper limit at a 95% confidence level		0.065	0.091	0.128	0.020	0.196	0.166	0.162	0.010	0.178	0.141	0.105	0.098
Coefficientvalue *b*	[mm]	75.09	-8.76	-56.41	151.07	-118.32	-12.00	101.89	321.17	-59.96	53.74	21.61	31.99
Lower limit at a 95% confidence level		-90.74	-146.70	-215.51	2.52	-325.04	-252.71	-231.92	56.97	-294.37	-230.78	-160.57	-151.37
Upper limit at a 95% confidence level		240.93	129.17	102.70	299.62	88.40	228.71	435.71	585.37	174.45	338.27	203.78	215.35

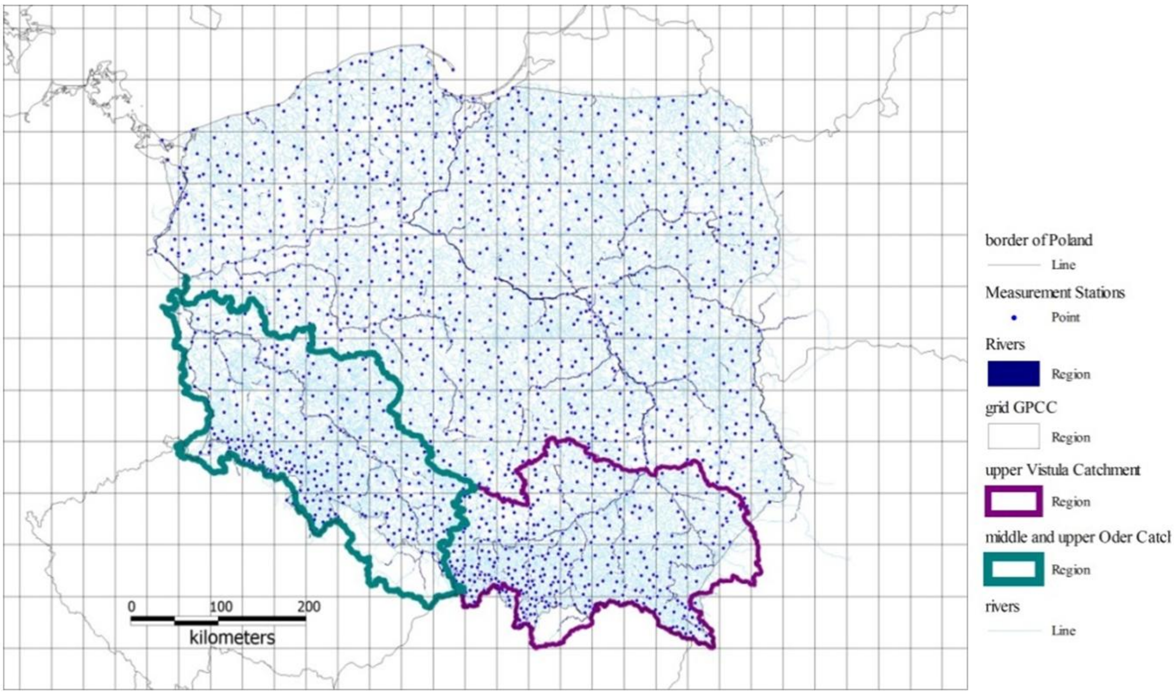

Figure 8. The upper Vistula and upper and middle Oder river basins on the GPCC data grid

VIII. The upper Vistula and the upper and middle Oder

The values of monthly precipitation for the upper Vistula and upper and middle Oder river basins are calculated using GIS mechanisms. The GPCC data representing total precipitation volumes in individual months in the period 1901–2010, with a spatial resolution of 0.5°x 0.5° of geographic longitude and latitude, converted to the analysed area of the upper and middle Oder river basin. A sequence of monthly precipitation values was obtained and is analysed below, like in the analysis covering the territory of Poland.The calculated sequence values were subject to a simple statistical analysis in order to determine the basic statistics: the minimum and maximum values, the mean value, standard deviation of the sample and the value of the coefficient of variation. The data is analysed using profiles modelled for individual calendar years and for hydrological years divided into hydrological summers and hydrological winters. The analyses of monthly precipitation cover the years 1901–2010, and the analyses of cumulative monthly total values of precipitation cover the hydrological years 1902–2010.

Table 11. A statement of selected statistics for monthly precipitation in the period 1901–2010 in the upper and middle Oder river basin

Statistics		
	Minimum values	Maximum values
Min [mm]	3.54	67.31
Max [mm]	41.11	260.93
Mean [mm]	19.00	117.42
Standard deviation of the sample [mm]	8.09	30.55
Coefficient of variation []	0.43	0.26

Table 12. A statement of selected statistics for monthly precipitation in the period 1901–2010 in the upper Vistula river basin

Statistics		
	Minimum values	Maximum values
Min [mm]	2.8	72.4
Max [mm]	41.2	233.0
Mean [mm]	18.2	131.3
Standard deviation of the sample [mm]	8.53	33.60
Coefficient of variation []	0.47	0.26

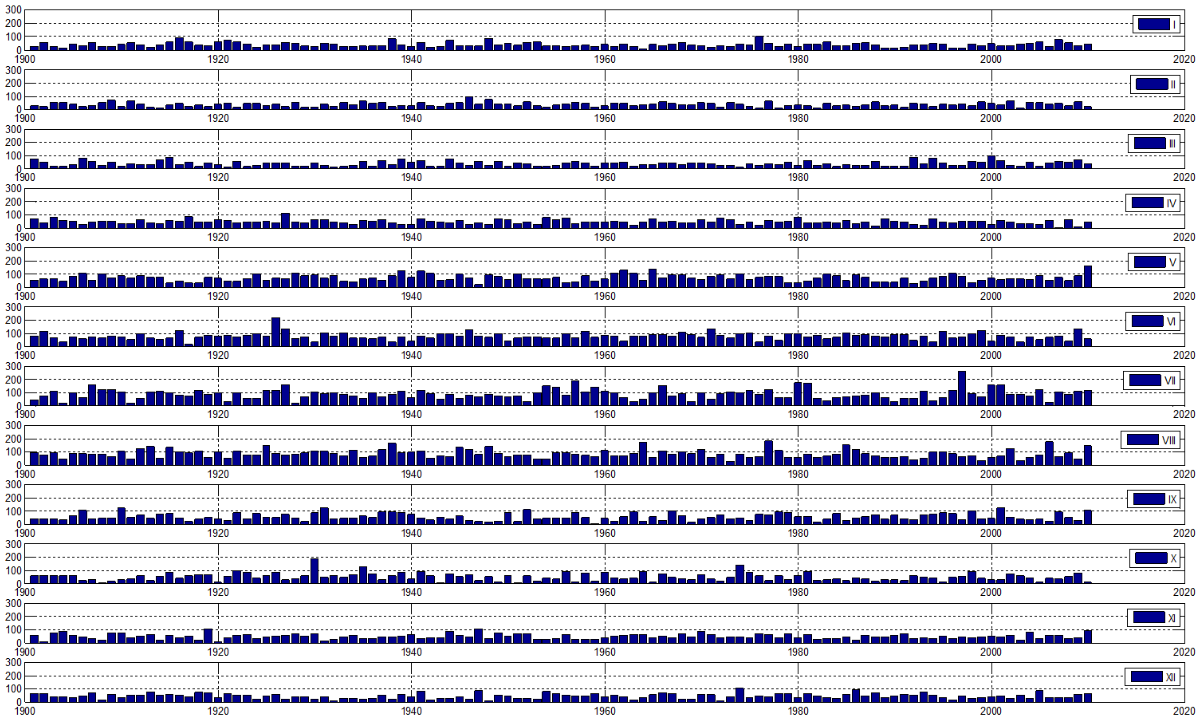

Figure 9. Totals of precipitation in individual months [mm] in the analysed period 1901–2010 in the upper and middle Oder river basin

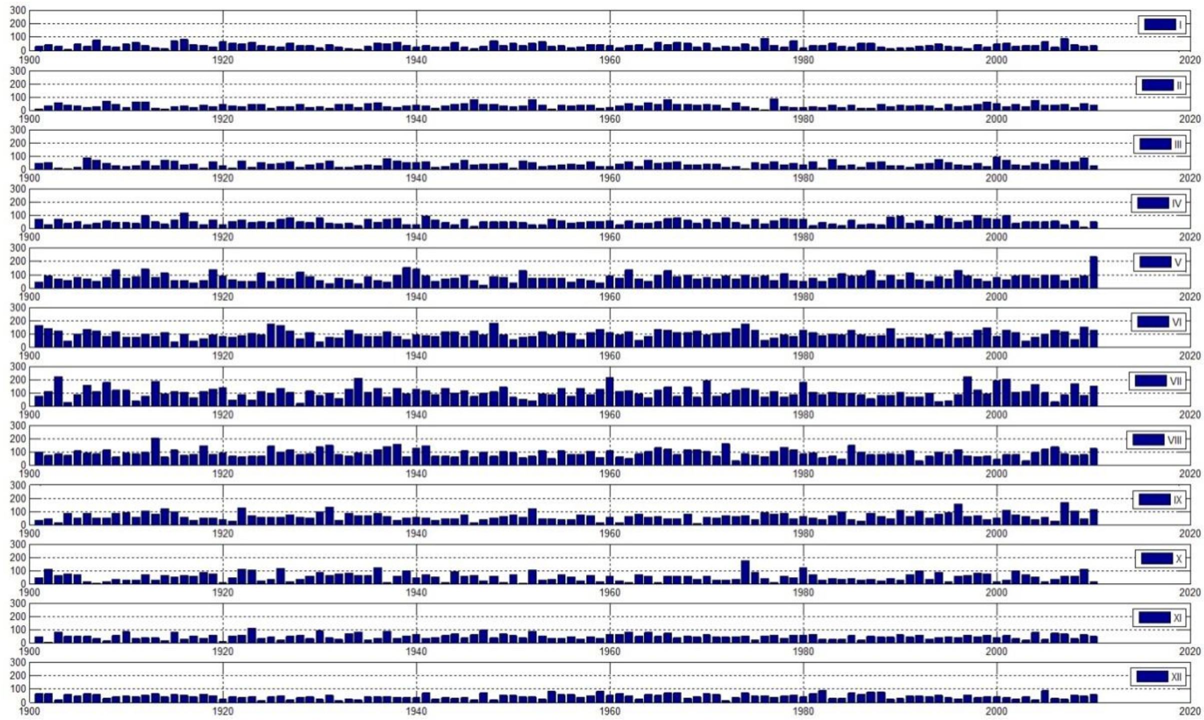

Figure 10. Totals of precipitation in individual months [mm] in the analysed period 1901–2010 in the upper Vistula river basin

Table 13. A statement of statistics for total monthly precipitation, cumulative for a hydrological year and in the summer and winter seasons in the period 1901–2010 in the upper and middle Oder river basin

	Hydrologicalseasons	
	WINTER (XI-IV)	SUMMER (V-X)
Min [mm]	161.1	230.6
Max [mm]	399.5	619.5
Mean [mm]	251.8	420.0
Standard deviation of the sample [mm]	42.5	77.7
Coefficient of variation []	0.169	0.185

8.1 A taxonomic analysis

The results of clustering monthly precipitation in the years 1901–2010 described by mean values, standard deviations and coefficients of variation using the Ward's method are represented as a cluster tree. The analysis focuses on a detailed representation of two extreme clusters identified as drought and flood periods in the area of upper and middle Oder river basin. The cluster of "flood years" represents the levels of mean monthly precipitation in the upper and middle Oder river basin ranging from 52.48 to 75.80 [mm], standard deviations ranging from 28.41 to 64.58 [mm] and the coefficient of variation from 0.37 to 1.01. The following calendar years are included in the cluster: 1997, 1926, 2010, 1930, 1927, 1977, 1941, 1915, 1939, 1966, 1981, 1974, 2001, 1938, 1946, 1910, 2009, 1931, 1925, 1965, 1907, 1948, 2000, 1913, 1985, 1954, 2006. The cluster includes 27 years in total, i.e. about 25 % of the analysed period.

In contrast, the cluster of drought years includes the years when the values of mean monthly precipitation in the upper and middle Oder river basin ranged from 40.63 to 52.17 [mm], standard deviations ranged from 13.87 to 25.63 [mm] and the coefficient of variation from 0.31 to 0.63. The following calendar years are included in the cluster: 1953, 1943, 1982, 2003, 1904, 1989, 1992, 1911, 1983, 1921, 1990, 1991, 1973, 1928, 1940, 1936, 2008, 2004, 1950. The cluster includes 19 years in total, i.e. about 17% of the analysed period.

The cluster of "flood years" represents the levels of mean monthly precipitation in the upper Vistula river basin ranging from 61.46 to 86.44 [mm], standard deviations ranging from 43.37 to 64.63 [mm] and the coefficient of variation from 0.65 to 0.85. The following calendar years are included in the cluster: 2010, 1974, 2001, 1960, 1913, 1903, 1997, 1934, 1925, 1908, 1972, 1996, 2000, 1948. The cluster includes 15 years in total, i.e. about 14% of the analysed period.

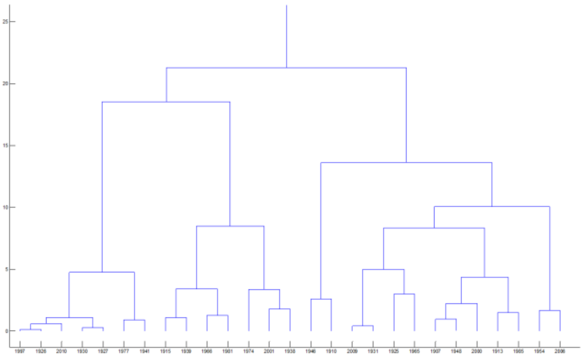

Figure 11. The cluster of "flood years" classified according to mean monthly precipitation in the upper and middle Oder river basin

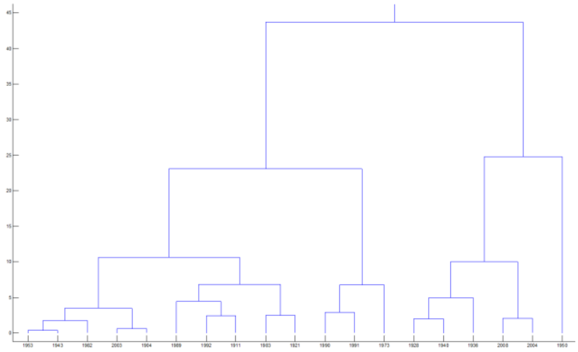

Figure 12. The cluster of "drought years" classified according to mean monthly precipitation in the upper and middle Oder river basin

In contrast, the cluster of drought years includes the years when the values of mean monthly precipitation in the upper Vistula river basin ranged from 45.33 to 68.69 [mm], standard deviations ranged from 15.61 to 36.79 [mm] and the coefficient of variation from 0.30 to 0.68. The following calendar years are included in the cluster: 1973, 1969, 1984, 1957, 1986, 1946, 1961, 1951, 2003, 1954, 1928, 1993, 1982, 1904, 1932, 1942, 1921, 1917, 1911, 1956, 1971, 1950, 1988, 1963, 1976, 1983, 1992, 1964, 1979, 1935, 1905, 1990, 1929, 1947, 1991, 1995, 1924, 1953, 1907, 1910, 2002, 1999, 1998, 1922, 1945, 1915, 1952, 1916, 1923, 1987, 1977, 1981, 1944, 1994, 1958, 1967. The cluster includes 56 years in total, i.e. about 50% of the analysed period.

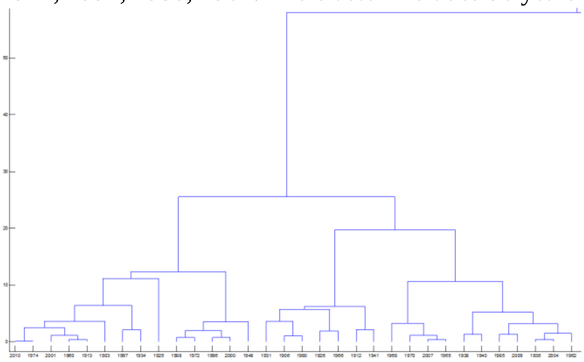

Figure 13. The cluster of "flood years" classified according to mean monthly precipitation in the upper Vistula river basin

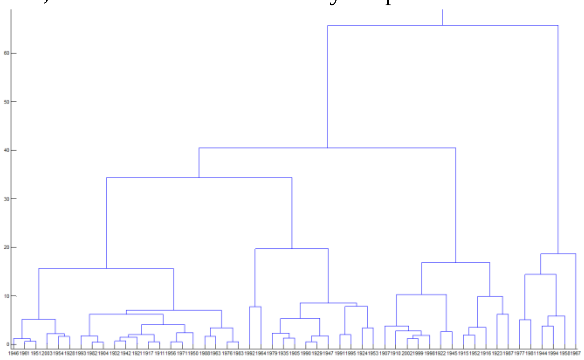

Figure 14. The cluster of "drought years" classified according to mean monthly precipitation in the upper Vistula river basin

8.2 Periodicity of precipitationin the upper and middle Oder river

The periodicity of precipitation in the upper and maiddle Oder river basin was assessed using signal processing theory with a harmonic analysis applied. The procedures necessary to calculate the values of predominating frequencies were developed in Matlab. The inverses of those values represent the predominating period of repeatability of an event. The analysis was completed for various profiles of the analyseddataset.The periodicity of monthly precipitation considered using monthly profiles of calendar years in the analysed period 1901–2010 may be described as follows: October is characterised by a long predominating period of repeatability: 36 years while predominating periods of repeatability for the remaining months amount to 2.1 to 7.79 years. Period of repeatability of minimum values: 2.1 years, maximum values: 3.89 years, medium values: 3.21 years.

Table 14. A statement of periodicity values (inverses of predominating frequencies) for mean monthly precipitation sequences in the period 1901–2010 by months in the upper and middle Oder river basin

Analysedsequence profile	Months of the calendar year												Statistics				
	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'	Min	Max	Mean	Standard deviation of the sample	Coefficient of variation
	[years]																
Predominating period in years	5.45	2.42	2.10	2.37	3.21	2.66	3.89	7.79	2.37	36.33	2.10	6.41	2.10	3.89	3.21	9.91	4.19

The periodicity of total monthly precipitation considered using hydrological year profiles in the analysed period 1902–2010 is characterised by several predominating periods: 2, 3, 5 and 10 years. In an analysis of predominating frequencies, the 3-year periods for the months November–February are clearly identifiable.

Table 15. A statement of periodicity values (inverses of predominating frequencies) for sequences of cumulative total of mean monthly precipitation in the period 1901–2010 by hydrological years in the upper and middle Oder river basin

Analysedsequence profile	Months of the hydrological year											
	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'
	[years]											
Predominating period in years	3.00	3.00	3.00	3.00	2.16	2.08	3.48	4.91	4.91	9.82	9.82	4.91

The periodicity of total monthly precipitation considered using hydrological summer and hydrological winter profiles in the analysed period 1902–2010 equals 2.08 years for the winter season and 2.35 years for the summer season.

Table 16. A statement of periodicity values (inverses of predominating frequencies) for sequences of total mean monthly precipitation in the hydrological winter and hydrological summer in the period 1901– 2010 in the upper and middle Oder river basin

Analysedsequence profile	Seasons of the hydrological year	
	WINTER (XI-IV)	SUMMER (V-X)
	[mm]	
Predominating period in years	2.08	2.35

8.3 Periodicity of precipitation by months in the upper Vistula area

The periodicity of monthly precipitation by months of a calendar year in the analysed period 1901–2010 may be characterised as follows: September is characterised by the absence of periodicity while the predominating period of repeatability for the remaining months ranges from 2.1 to 12.11 years. Period of repeatability of minimum values: 3.6 years, maximum values: 36.3 years, medium values: 3.5 years.

Table 17. A statement of periodicity values (inverses of predominating frequencies) for mean monthly precipitation sequences in the period 1901–2010 by months in the upper Vistula river basin

Analysedsequence profile	Months of the calendar year												Statistics				
	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'	Minimum values	Maximum values	Meanvalues	Standard deviationvalues	Values of the coefficient of variation
	[years]																
Predominating period in years	4.19	4.04	7.79	2.32	2.66	12.11	3.89	2.10	109.00	5.74	3.03	2.87	3.63	36.33	3.52	12.11	5.45

The periodicity of total monthly precipitation considered using hydrological year profiles in the analysed period 1902–2010 is characterised by two periods of 3 and 13 years. An analysis demonstrates a distinct repeatability period for October: 36 years.

Table 18. A statement of periodicity values (inverses of predominating frequencies) for sequences of the cumulative total of mean monthly precipitation in the period 1901–2010 by hydrological years in the upper Vistula river basin

Analysedsequence profile	Months of the hydrological year											
	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'
	[years]											
Predominating period in years	3.00	3.00	3.00	3.00	13.50	13.50	13.50	3.60	3.48	2.08	3.48	36.00

The periodicity of total monthly precipitation considered using hydrological summer and hydrological winter profiles in the analysed period 1902–2010 amounts to 13.5 years for the winter season and 36 years for the summer season.

Table 19. A statement of periodicity values (inverses of predominating frequencies) for sequences of total mean monthly precipitation in the hydrological winter and hydrological summer in the period 1901– 2010 in the upper Vistula river basin

Analysedsequence profile	Seasons of the hydrological year	
	WINTER (XI-IV)	SUMMER (V-X)
	[years]	
Predominating period in years	13.50	36.00

8.4 Premises for an analysis of climate changes observed in precipitation

8.4.1 An analysis by hydrological years, 1902–2010 – the upper and middle Oder

The trend in climate changes considered using total monthly precipitation profiles for the hydrological summer is described by linear equations with indicated boundary values of coefficients determined at a 5% significance level. The linear trend form is characterised mainly by a slope *a* [mm/year]. For the analysed period of 1902–2010, the slope value is negative and varies between -0.236 [mm/year] for November of the hydrological year and -0.006 [mm/year] for July of the hydrological year. The total of precipitation in the analysed period of 109 years is characterised by a negative trend -0.236 [mm/year].

Table 20. Values of parameters of the linear trend in total monthly precipitation in a hydrological year in the analysed period in the upper and middle Oder area

		Months of the hydrological year											
	Jednostki	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'
Slopevalue *a*	[mm/rok]	-0.037	-0.031	-0.071	-0.070	-0.015	-0.109	-0.096	-0.095	-0.006	-0.109	-0.106	-0.236
Lower limit at a 95% confidence level		-0.146	-0.190	-0.273	-0.290	-0.269	-0.367	-0.395	-0.433	-0.421	-0.582	-0.630	-0.795
Upper limit at a 95% confidence level		0.073	0.128	0.131	0.150	0.240	0.149	0.204	0.243	0.409	0.363	0.417	0.323
Coefficientvalue *b*	[mm]	119.7	152.3	270.2	304.6	234.5	465.2	507.8	584.4	497.7	783.7	831.7	1132.8
Lower limit at a 95% confidence level		-94.434	-159.038	-125.263	-125.618	-263.722	-39.031	-77.511	-77.027	-313.989	-140.601	-191.831	39.482
Upper limit at a 95% confidence level		333.8	463.7	665.6	734.9	732.7	969.5	1093.0	1245.9	1309.3	1707.9	1855.3	2226.1

8.4.2 An analysis by months of a calendar year, 1901–2010 – the upper and middle Oder

The trend in climate changes considered using monthly precipitation profiles for the calendar summer is described by linear equations with indicated boundary values of coefficients determined at a 5% significance level. The slope values are both negative and positive for the analysed period 1901–2010. The months of January, April, June, August, October and November are characterised by a decreasing trend in precipitation while the remaining months by a positive trend. The values vary between -0.129 in October and +0.108 [mm/year] in July.

Table 21. Values of parameters of the linear trend in monthly precipitation in a calendar year in the analysed period in the upper and middle Oder area

		Months of the calendar year											
	Units	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'
Slopevalue *a*	[mm/year]	-0.032	0.006	0.037	-0.101	0.024	-0.001	0.108	-0.106	0.010	-0.129	-0.015	0.013
Lower limit at a 95% confidence level		-0.131	-0.087	-0.073	-0.197	-0.127	-0.163	-0.120	-0.291	-0.146	-0.305	-0.125	-0.100
Upper limit at a 95% confidence level		0.067	0.099	0.147	-0.005	0.174	0.161	0.336	0.080	0.166	0.047	0.095	0.126
Coefficientvalue *b*	[mm]	102.98	24.19	-33.08	244.37	22.33	79.17	-122.94	290.42	33.41	300.98	77.30	18.48
Lower limit at a 95% confidence level		-90.86	-158.46	-248.51	56.61	-271.49	-238.31	-569.19	-72.58	-271.65	-43.33	-138.40	-202.95
Upper limit at a 95% confidence level		296.83	206.83	182.35	432.13	316.15	396.65	323.31	653.42	338.48	645.30	292.99	239.90

8.4.3 An analysis by hydrological years, 1902–2010 – the upper Vistula area

The trend in climate changes considered using total monthly precipitation profiles for the hydrological summer is described by linear equations with indicated boundary values of coefficients determined at a 5% significance level. The linear trend form is characterised mainly by a slope *a* [mm/year]. For the analysed period of 1902–2010, the slope value is positive and varies between 0.002 [mm/year] for November of the hydrological year and 0.339 [mm/year]. Looking at the last month of the hydrological year (October), the total of precipitation in the analysed period of 109 years is characterised by a positive trend of 0.294 [mm/year].

Table 22. Values of parameters of the linear trend in total monthly precipitation in a hydrological year in the analysed period in the upper Vistula area

		Months of the hydrological year											
	Units	'XI'	'XII'	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'
Slopevalue *a*	[mm/Year]	0.002	0.031	0.022	0.051	0.124	0.162	0.288	0.364	0.369	0.256	0.339	0.294
Lower limit at a 95% confidence level		-0.117	-0.121	-0.182	-0.172	-0.141	-0.138	-0.070	-0.051	-0.144	-0.313	-0.253	-0.314

Upper limit at a 95% confidence level		0.121	0.183	0.225	0.274	0.390	0.462	0.645	0.778	0.882	0.825	0.932	0.903
Coefficientvalue *b*	[mm]	43.739	29.465	86.530	65.075	-38.851	-61.899	-228.156	-280.820	-184.688	126.087	27.158	166.422
Lower limit at a 95% confidence level		-189.471	-268.456	-311.421	-371.509	-558.694	-649.023	-927.748	-1091.743	-1188.078	-986.385	-1132.474	-1023.654
Upper limit at a 95% confidence level		276.948	327.387	484.481	501.660	480.992	525.226	471.436	530.104	818.701	1238.559	1186.791	1356.497

8.4.4 An analysis by months of a calendar year, 1901–2010 in the upper Vistula area

The trend in climate changes considered using monthly precipitation profiles for the calendar summer is described by linear equations with indicated boundary values of coefficients determined at a 5% significance level. The slope values are both negative and positive for the analysed period 1901–2010. The months of January, August and October are characterised by a decreasing trend in precipitation while the remaining months by a positive trend. The values vary between -0.113 in August and +0.139 [mm/year] in May.

Table 23. Values of parameters of the linear trend in monthly precipitation in a calendar year in the analysed period in the upper Vistula area

		Months of the calendar year											
	Units	'I'	'II'	'III'	'IV'	'V'	'VI'	'VII'	'VIII'	'IX'	'X'	'XI'	'XII'
Slopevalue *a*	[mm/Year]	-0.005	0.040	0.069	0.027	0.139	0.043	0.020	-0.113	0.096	-0.040	0.005	0.034
Lower limit at a 95% confidence level		-0.107	-0.056	-0.045	-0.094	-0.037	-0.139	-0.234	-0.291	-0.074	-0.226	-0.113	-0.069
Upper limit at a 95% confidence level		0.098	0.137	0.183	0.148	0.316	0.224	0.273	0.065	0.267	0.146	0.122	0.137
Coefficientvalue *b*	[mm]	48.40	-43.57	-95.41	-1.98	-193.48	13.65	66.63	311.97	-124.90	129.07	39.19	-23.95
Lower limit at a 95% confidence level		-151.58	-232.78	-317.51	-238.06	-538.91	-341.22	-429.72	-36.10	-458.20	-234.64	-189.75	-225.81
Upper limit at a 95% confidence level		248.39	145.64	126.69	234.11	151.94	368.53	562.99	660.05	208.39	492.78	268.14	177.91

IX. Conclusion

The study contains an analysis of precipitation, covering multiple profiles and based on the GPCC database that provides monthly mean values for the territory of Poland, for the upper Vistula and upper and middle Oder river basins. The analysis includes data for the period 1901–2010 with a spatial resolution of 0.5°x°0.5° of geographic longitude and latitude. The data is analysed using profiles modelled for individual months of the calendar year and for hydrological years divided into hydrological summers and hydrological winters. Two clusters are distinguished in the taxonomic analysis: the cluster of drought years and the cluster of flood years. The periodical nature of precipitation is assessed and the trends in climate changes calculated. The characteristics of trend in climate changes are described by linear equations with indicated boundary values of coefficients determined at a 5% significance level.The study contains the results of data verification for 43 locations. An analysis of error of mean monthly total values was completed, based on a 30-year verification period from 1961 to 1990. The results of data verification demonstrate errors amounting to a few percent for 38 locations. For 5 locations: Jelenia Góra, Kętrzyn, Kłodzko, Legnica, Przemyśl, the error values exceed 10%. The nature of errors is systematic which indicates the need to introduce data verification procedures.In the analysis of monthly precipitation in the territory of Poland, the following calendar years are included in the "flood years" cluster: 1974, 2010, 2001, 1960, 1980, 1997, 2006, 1957, 1972, 1996, 1918, 1934, 1910, 1946, 1908, 2000, 1907, 1985, 1978, 2009, 1913, 1925, 1930, 2007. The cluster includes 24 years in total, i.e. about 22 % of the analysed period.The opposite cluster (drought years) includes the calendar years: 1942, 1991, 1929, 1976, 1971, 1964, 1963, 1933, 1902, 1901, 1990, 1973, 1986, 1955, 1993, 1924, 2005, 1988, 1914, 1909, 1995, 1961, 1947, 1954, 1920, 1984, 1975, 1932, 1943, 1959. The cluster includes 30 years in total, i.e. about 27% of the analysedperiod.In the upper and middle Oder area, the "flood years" cluster includes: 1997, 1926, 2010, 1930, 1927, 1977, 1941, 1915, 1939, 1966, 1981, 1974, 2001, 1938, 1946, 1910, 2009, 1931, 1925, 1965, 1907, 1948, 2000, 1913, 1985, 1954, 2006. The cluster includes 27 years in total, i.e. about 25 % of the analysed period. The opposite cluster (drought years) includes the calendar years: 1953, 1943, 1982, 2003, 1904, 1989, 1992, 1911, 1983, 1921, 1990, 1991, 1973, 1928, 1940, 1936, 2008, 2004, 1950. The cluster includes 19 years in total, i.e. about 17% of the analysedperiod.In the upper Vistula area, the cluster of "flood years" includes the calendar years: 2010, 1974, 2001, 1960, 1913, 1903, 1997, 1934, 1925, 1908, 1972, 1996, 2000, 1948. The cluster includes 15 years in total, i.e. about 14% of the analysed period. The following years are classified in the opposite cluster (drought years): 1973, 1969, 1984, 1957, 1986, 1946, 1961, 1951, 2003, 1954, 1928, 1993, 1982, 1904, 1932, 1942, 1921, 1917, 1911, 1956, 1971, 1950, 1988, 1963, 1976, 1983, 1992, 1964, 1979, 1935, 1905, 1990, 1929, 1947, 1991, 1995, 1924, 1953, 1907, 1910, 2002, 1999, 1998, 1922, 1945, 1915, 1952, 1916, 1923, 1987, 1977, 1981, 1944, 1994, 1958, 1967. The cluster includes 56 years in total, i.e. more than 50% of the analysed period.The predominating periodicity values of mean monthly precipitation in the territory of Poland range from 2 to 36 years. Period of repeatability of minimum values: 11 years, maximum values: 3 years, medium values: 10 years. The periodicity of monthly precipitation by months of a calendar year in the upper and middle Oder area in the analysed period 1901–2010 may be characterised as follows: the predominating period of repeatability by months ranges from 2 to 36 years. Period of repeatability of minimum values: 2.1 years, maximum values: 3.89 years, medium values: 3.21 years.The upper Vistula area is characterised by the absence of periodicity in September while the predominating period of repeatability for the remaining months ranges from 2.1 to 12.11 years. Period of repeatability of minimum values: 3.6 years, maximum values: 36.3 years, medium values: 3.5 years. The climatic trends in the territory of Poland by hydrological months as assessed for the analysed period 1902–2010 vary from -0.036 [mm/year] for January of the hydrological year to 0.12 [mm/year] for June of the hydrological year. The total of precipitation in the analysed period of 109 years is characterised by a positive trend -0.002 [mm/year].

The upper and middle Oder area is characterised by a negative value of the coefficient ranging from -0.236 [mm/year] for November of the hydrological year to -0.006 [mm/year] for July of the hydrological year. The total of precipitation in the analysed period of 109 years is characterised by a negative trend -0.236 [mm/year]. The trend for the upper Vistula area varies between 0.002 [mm/year] for November of the hydrological year to 0.339 [mm/year]. Looking at the last month of the hydrological year (October), the total of precipitation in the analysed period of 109 years is characterised by a positive trend of 0.294 [mm/year].The described analyses confirm the hypotheses proposing climate changes resulting from human activities. The analyses emphasise the regional nature of those changes. The differences in their consequences, as disclosed in the analyses by months of the calendar year and hydrological months, indicate temporal and spatial variability and a regional nature of the changes. This study aims at supplementing necessary information about the characteristics of long-lasting precipitation series, precipitation total and mean values in areas particularly exposed to extreme events: the upper Vistula River basin and the upper and middle Oder River basin. The study demonstrates the need to adapt policies to the ongoing climate changes affecting precipitation and to adopt regional and local plans and strategies as required to develop scenarios designed to balance the climate change effects.

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