Original Research

Variability of Water Resources Flowing Away from Small Agricultural Catchment

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Abstract

Monthly, seasonal and annual values for outflow and outflow coefficient measured over ten years for a small agricultural catchment are presented. The catchment is situated at 723-822 m a.s.l and covers 40.57 ha. Mean annual precipitation total during the investigated period was 850 mm and mean annual air temperature was 5.9ºC. Average annual overall outflow from the catchment was 446 mm, i.e. 52% of total precipitation. The outflow varied considerably in relation to rainfall/snowfall/snowmelt conditions. The highest monthly outflow was in March and the lowest in November (20.6% and 3.8% of the annual outflow, respectively). Considerable variability of the outflow from the catchment is caused mainly by frequent torrential rains in summer and infiltration of water into groundwater reserves during spring snowmelt.

Keywords: outflow, precipitation, water resources, outflow coefficient, small catchment

Introduction

Water resources consist of determined water quantity whose quality makes possible its utilization in an individual area over an established timespan [1]. These are natural watercourses or water channelled through a series of artificial collection and delivery channels to meet the requirements. Poland, like many other European countries, is facing water shortages for economic purposes [2]. Water resources in Poland are scarce in comparison with other European countries. According to the Institute of Meteorology and Water Management (IMGW) [3], renewable surface water resources in Poland are 1580 m^3 per inhabitant, whereas for the rest of Europe the figure is 4,560 m^3. This shortage of available surface water requires Poland to develop improved water collection, storage and distribution system to improve water balance of the country [4, 5].

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Another problem with water resources is their random occurrence that determines availability [6, 7]. Rational management of water resources requires a proper understanding of the dynamics of water cycle in a catchment. The conceptual models of precipitation-outflow relationships regard a catchment as a system with concentrated parameters, which are determined using observation of precipitation and water regime in a closed cross section [8-10]. Variability of river outflow depends mainly on the cyclicity and seasonality of climatic conditions, on geological structure, surface features and land use [7, 11-13].

In Poland, considerable time and space variability of water resources are observed. The greatest flows in watercourses occur in spring and are smaller during the summer-autumn season [6, 7, 14]. The greatest shortage of precipitation and the lowest outflows are registered in central Poland, while in the south the situation is far better in this respect.

Water resources flowing away from the catchment area could be accumulated in so-called small retention reservoirs and used to solve some economic and ecological problems [5, 6, 15-17].

The present work aims to determine time variability of water resources flowing away from a small agricultural catchment situated in the Spisz Polski region and presents the results of ten-year hydrological research. Statistical analysis of monthly, seasonal and annual precipitation, and outflow coefficients was conducted with respect to precipitation.

Material and Methods

The investigations were conducted in the hydrological years 1992-2001 in a small agricultural catchment in Trybsz village, Łapsze Niżne commune in the Małopolskie region (49º23'40" N, 20º09'32" E). The catchment, situated above 700 m a.s.l, is part of mountain areas forming the Spisko-Gubałowskie Foothills mezoregion. It covers 0.406 km^2 and is closed by a hydrometric cross-section on watercourse order 6, which is a left-bank tributary to the Trybszanka River inflowing at km 0+670. Height difference of the catchment area is 99 m at mean elevation 766 m a.s.l. and weighted average slope 11.8%. The areas with land slope between 10 and 18% make up about 53% of total area. Brown soil with granulometric composition of medium and heavy loams and usually silty clays occur in the catchment area. These are very acidic soils (pH in KCl was below 4.5 in the top layers), characterized by small porosity and low coefficient of permeability. This is particularly apparent for the subsoil, which is compact or compressed. Arable lands prevail in the catchment area with grasslands constituting 60.11% and ploughlands 18.17%. The remaining area is covered by trees or bushes, or is wasteland [18].

The catchment has a cool and wet mountain climate. The precipitation data were supplied by the IMGW precipitation station in Białka Tatrzańska, whereas the temperature measurements came from the IMGW meteorological station in Bukowina Tatrzańska.

Water outflow from the watercourse was determined on the basis of constant registration of the water state by means of limnograph with weekly recording placed at the calibrated flow closing the catchment. Moreover, the water state was checked on a staff gauge. On the basis of flow rate curve and water state, mean daily outflows were determined in $dm^3 \cdot s^{-1}$ and converted into outflow in mm. These were used to establish monthly, seasonal and yearly outflows. The outflow coefficient was computed as a ratio of outflow total to precipitation total during the analyzed period.

Results

Individual years revealed considerable variability of air temperatures and precipitation, which allows regard for the investigated period as representative for different pluviothermal conditions.

Mean annual air temperature ranged from 4ºC in 1996 to 6.7ºC in 1994 and 2001, which gave an average of 5.9ºC for the whole period of investigations. The coolest months were December and January with temperatures respectively -2.7ºC and -3ºC, and the warmest were July and August 15.6 and 15.7ºC (Fig. 1).

Annual precipitation totals fluctuated from 723 mm in 1993 to 1,002 mm in 2001. Mean annual precipitation total

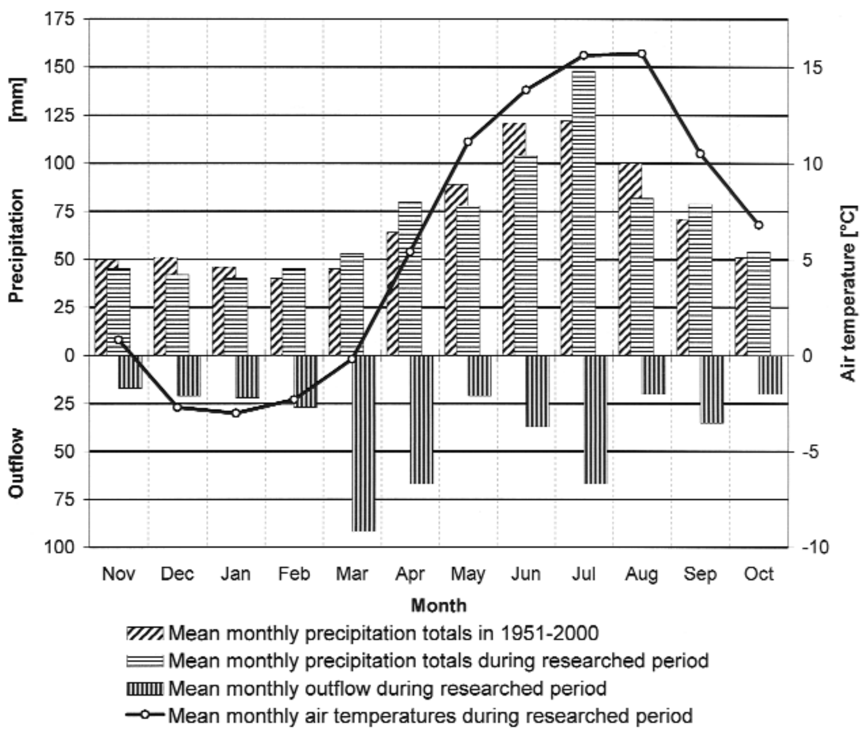

Fig. 1. Mean monthly precipitation totals during the multi-annual hydrological period 1951-2000, and during the period of research registered by the precipitation station in Białka Tatrzańska and mean air temperatures in hydrological years 1992-2001 from the meteorological station in Bukowina Tatrzańska.

Table 1. Mean precipitation in multi-annual period (*P*), and in study period (P) and outflows (H) in mm and outflow coefficients (C) in %.

Years	Parameter	Month and period														
		XI Nov	XII Dec	I Jan	II Feb	III Mar	IV Apr	V May	VI Jun	VII Jul	VIII Aug	IX Sep	X Oct	XI-IV Nov-Apr	V-X May-Oct	XI-X Nov-Oct
1951-2000	*P*	50	51	46	40	45	64	89	121	122	100	71	51	296	554	850
1992	P	21	76	54	63	45	53	72	55	60	71	105	78	312	441	753
	H	11	28	23	13	90	53	19	19	15	22	41	17	218	133	351
	C	52	37	43	21	200	100	26	35	25	31	39	22	70	30	47
1993	P	62	47	37	45	53	51	50	107	99	96	50	26	295	428	723
	H	38	25	55	4	86	79	5	9	15	18	18	6	287	71	358
	C	61	53	149	9	162	155	10	8	15	19	36	23	97	17	50
1994	P	37	31	56	14	71	114	89	95	49	61	49	95	323	438	761
	H	14	19	21	10	135	97	15	36	3	8	6	23	296	91	387
	C	38	61	38	71	190	85	17	38	6	13	12	24	92	21	51
1995	P	42	51	43	42	66	96	70	139	47	132	80	9	340	477	817
	H	21	23	27	44	53	88	36	61	9	26	42	7	256	181	437
	C	50	45	63	105	80	92	51	44	19	20	53	78	75	38	53
1996	P	68	41	20	13	46	49	126	87	169	134	196	44	237	756	993
	H	14	32	12	1	10	39	71	21	52	36	200	23	108	403	511
	C	21	78	60	8	22	80	56	24	31	27	102	52	46	53	51
1997	P	21	32	7	22	39	99	109	77	301	87	40	70	220	684	904
	H	13	10	2	25	86	57	28	10	184	51	5	24	193	302	495
	C	62	31	29	114	221	58	26	13	61	59	13	34	88	44	55
1998	P	51	51	59	69	43	104	94	115	121	36	77	75	377	518	895
	H	21	43	40	114	20	63	15	20	51	7	14	34	301	141	442
	C	41	84	68	165	47	61	16	17	42	19	18	45	80	27	49
1999	P	68	21	21	64	18	61	37	147	115	80	55	111	253	545	798
	H	30	9	10	9	120	36	7	106	32	12	5	56	212	218	432
	C	44	43	48	14	667	59	19	72	28	15	9	50	85	40	54
2000	P	45	44	50	75	101	73	81	81	208	31	58	12	388	471	859
	H	6	20	20	30	180	69	8	6	80	7	7	3	325	111	436
	C	13	45	40	40	178	95	10	7	38	23	12	25	84	24	51
2001	P	32	25	50	43	53	105	50	141	313	91	75	24	308	694	1002
	H	5	4	6	22	138	92	9	80	231	11	15	3	267	349	616
	C	16	16	12	51	260	88	18	57	74	12	20	13	87	50	61
Mean 1992-2001	P	45	42	40	45	53	80	78	104	148	82	79	54	305	545	850
	H	17	21	22	27	92	67	21	37	67	20	35	20	246	200	446
	C	38	50	55	60	174	84	27	36	45	24	44	37	81	37	52

Precipitation station recorded at the Białka Tatrzańska.

Table 2. Statistical parameters describing values of: monthly precipitation (P), outflow (H) and outflow coefficient (C) in half-years and hydrological year during investigated period.

Parameter	Winter half-year (XI-IV)			Summer half-year (V-X)			Hydrological year (XI-X)		
	P [mm]	H [mm]	C [%]	P [mm]	H [mm]	C [%]	P [mm]	H [mm]	C [%]
Average	51	41	82	91	33	30	71	37	56
Median	50	25	59	80	18	24	60	21	40
Lower quartile	37	13	39	53	8	16	43	10	19
Upper quartile	64	56	90	110	36	41	90	48	61
Minimum	7	1	8	9	3	6	7	1	6
Maximum	114	180	667	313	231	102	313	231	667
Range	107	179	659	304	228	96	306	230	661
Standard deviation	24.2	39.6	95	57.6	45.6	20.3	48.3	42.7	73.2
Coefficient of variation	0.47	0.97	1.16	0.63	1.37	0.68	0.68	1.15	1.31

during the period of research was 850 mm and identical to the multi-annual average for 1951-2000. Mean precipitation total in the summer half-year was 545 mm, i.e. 240 mm higher than in the winter half-year. The lowest monthly precipitation total (42 mm) was noted in December and January (40 mm) and the highest in June (109 mm) and July (148 mm) (Fig. 1). The lowest monthly precipitation (7 mm registered in January 1997) was almost 7-fold lower than the average for this month measured over the 1951-2000 hydrological multi-annual period. In July 2001 the highest monthly rainfall of 313 mm was registered, which constituted 257% of the average for this month (Table 1). Precipitation was characterized using a seven-class classification system according to Kaczorowska [19], which revealed that the measurement period was standard. There were three dry years (1992, 1993 and 1994), five normal years (1995, 1997, 1998, 1999 and 2001) and two wet years (1996 and 2001).

Mean annual total outflow from the catchment during the period of research was 446 mm, but differed in individual hydrological years fluctuating from 351 to 616 mm (Table 1).

Considering the half-years, winter outflow in 1992, 1993, 1994, 1995, 1998 and 2000 was much higher (218-325 mm) than summer outflow (71-181 mm). The years of 1996, 1997 and 2001 were characterized by much greater outflows in the summer period, respectively 403, 302 and 349 mm, whereas in the winter period the values were 108, 193 and 267 mm. Only in 1999 was the outflow both in the winter and summer period similar, respectively 212 and 218 mm at simultaneous big difference of the outflow coefficient: 85% in the winter and only 40% in the summer period.

The highest monthly outflows were noted in March (20.6% of the annual outflow) and in April and July (15%), the lowest in November – only 3.8% of the annual outflow. Monthly outflows ranged between 1 and 231 mm, but 50% of results fell within the 10-48 mm range. Average monthly outflow during the measurement period was 37 mm and median 21 mm, which evidences a right side asymmetry (Table 2, Fig. 2).

Considerable outflow variability has been evidenced by a high variation coefficient which is almost twice higher than for precipitation. The summer half-year is characterized by a greater outflow dynamic (higher values of range, standard deviation and variation coefficient), with three extreme values (184 mm in July 1997, 200 mm in September 1996 and 231 mm in July 2001).

The annual outflow coefficient for the research period was 52% fluctuating in individual years from 47 to 61%. Outflow coefficients in the winter were much higher than in the summer half-year. The exception was the wet year (1996), when summer rainfall was over thrice higher than in the winter half-year (Table 1).

The highest average monthly outflow coefficients during the measurement period were registered in March and April, respectively 174 and 84% of the precipitation, the lowest were noted in August (24%) and May (27%). The highest monthly outflow coefficient (C) was determined in March 1999, when it constituted 667% of the precipitation.

Monthly variability of the outflow coefficient (C) was higher (higher values of range, standard deviation and variation coefficient) than the outflow (H). In the winter half-year, variation coefficient for (C) was almost twice higher than in summer, i.e. unlike as for the outflow. In the summer half-year precipitation variation coefficients and outflow coefficient values were similar, which suggests that the outflow in this half-year depended primarily on the precipitation layer.

Discussion

Research conducted under different topographic and climatic conditions focused on catchments of similar areas. Measurements conducted for six years by Kowalik [14] in Rzyki village situated in the eastern part of the Mały Beskid

Mts. in catchments B (0.274 km^2) and G (0.475 km^2), situated 425 m a.s.l. in the upper part of the Wieprzówka River basin. They revealed average annual outflow of 870 mm from catchment B at precipitation of 468 mm, i.e. by 22 mm bigger than in the studied catchment on the Spisko-Gubałowskie Foothills. Mean annual outflow from catchment G, was 363 mm at precipitation of 820 mm, i.e. lower by 83 mm. The outflows from catchments B and G constituted on average 54 and 44% of precipitation.

Much smaller outflows from catchments were registered in the research of Rajda et al. [17]. The annual outflows from agricultural catchments A (0.364 km^2) and D (0.546 km^2) situated on the Wielickie Foothills, on about 300 m a.s.l., were 173 (A) and 277 mm (D), constituting respectively 26 and 34% of the precipitation. These outflows and outflow coefficients were about twice lower than registered in the catchment on the Spisko-Gubałowskie Foothills.

In the three-year research conducted by Ostrowski and Bogdał [16] on the Wadowickie Foothills in catchments Górka (0.87 km^2), Barnczak (1.21 km^2) and Wronowiec (1.60 km^2) with forest cover, respectively, 1.49, 1.13 and 9.79%, mean annual outflows of 371, 450 and 524 mm were noted, which constituted 41, 49 and 54% of precipitation. Therefore, the outflow coefficients under these conditions were, respectively, 66 mm lower and 13 and 87 mm higher than those registered in a smaller catchment. Howevere, the outflow coefficients for Barnczak and Wronowiec catchments were comparable.

Besides the precipitation layer and the air temperature, physiographic and habitat conditions also affect the amount and time diversification of the outflow from a catchment. Research conducted in other regions of Poland have revealed that river outflow from the catchments is much lower than in the mountain or sub-mountain regions. According to studies conducted by Kosturkiewicz et al. [20] on Wieruszowska Uppland in three basic catchments of the Pomianka Stream: G (3.27 km^2), G-8 (0.32 km^2) and D (2.22 km^2) with forest cover of respectively 65, 100 and 55%, annual outflows at 738 mm precipitation were 261, 108 and 93 mm, i.e. between 1.5 and almost 5 times lower than in the analyzed catchment.

Research conducted by Pierzgalski et al. [21] in the Łutownia River catchment (121 km^2) on the Bielska Plain revealed the annual outflow of 114 mm at precipitation 619 mm, which constituted 18% of annual precipitation.

Similar values were registered in the Sępólna River catchment (183.8 km^2) in the Krajeńskie Lake District, where the annual outflow constituted 22% of the 656 mm precipitation layer. The outflow coefficient in these catchments is 2-3 times lower than from the Western Carpathians catchments [6].

Research conducted in 1981-90 by IMGW as part of Small Catchment Programme registered a 40% mean outflow coefficient from 44 catchments. The identical outflow coefficient was noted in the Bystrzanka catchment (13 km^2) in the Beskid Niski Mts. and in the presented catchment at almost the same precipitation. Higher outflow coefficient

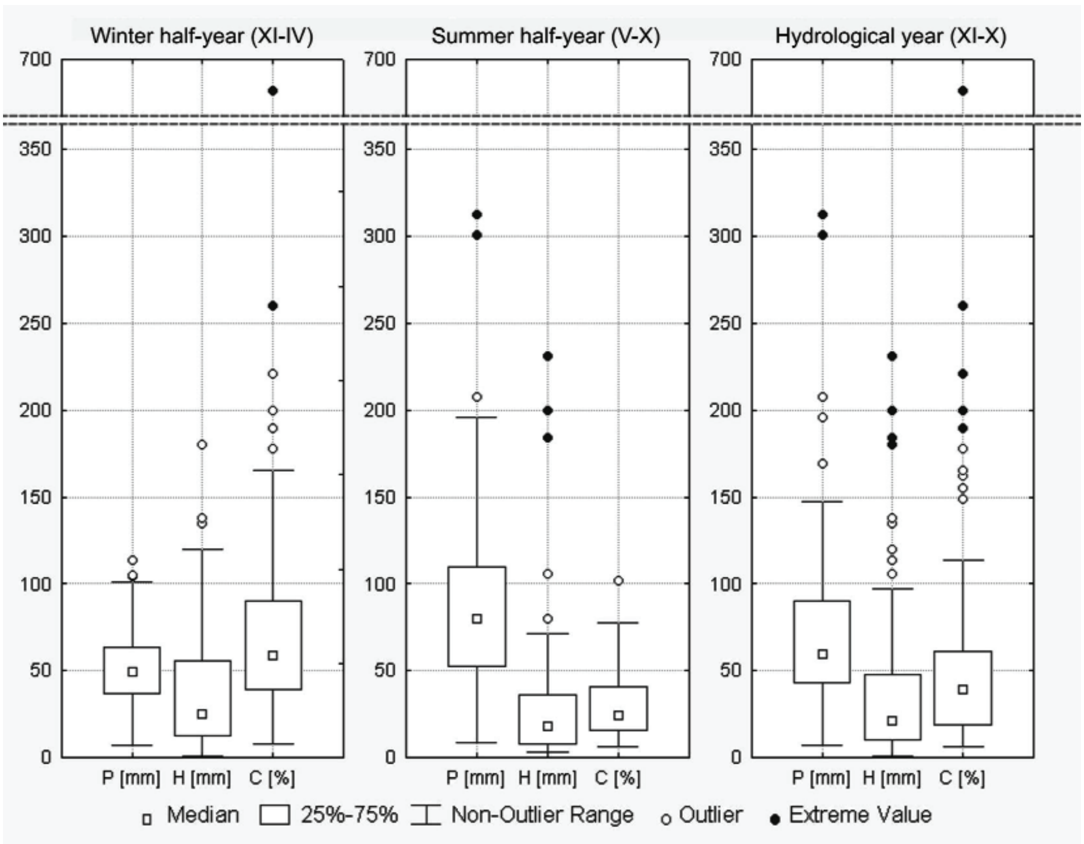

Fig. 2. Box-and-Whiskers diagram showing changeability of monthly precipitations [mm], outflows [mm] and outflow coefficients [%] in the half-years and hydrological year.

was noted in the Parsęta River catchment (54%) in the Drawskie Lake District and in Brennica (59%) in the Beskid Śląski Mts. [6].

Investigations conducted by Latron and Gallart [10] in Can, the Vila agricultural catchment covering 0.56 km^2 localized 130 km north-east of Barcelona (Spain) on about 1,115 m a.s.l., showed outflows fluctuating from 255 to 386 mm (1995-2002), which constituted about 43% of the precipitation. They were several dozen millimetres lower than the outflows registered on the Spisko-Gubałowskie Foothills (351-616 mm).

The Authors' own and other authors' research demonstrated that the water resources flowing away from the catchment area are influenced by numerous factors, including, among others, precipitation and its distribution, the air temperature and physiographic parameters of the catchment such as area hypsometry, land slope, soil permeability, land use (particularly forest cover), river network, lake cover and the occurrence of water-heads.

Conclusions

1. Hydrological activity of the catchment was best demonstrated by the outflow, which fluctuated in the individual years from 351 mm to 616 mm. On average 446 mm of water flowed away annually from the catchment during the measurement period, which constituted 52% of precipitation. The highest mean monthly outflows (H), respectively 92 mm and 67 mm, were registered in March and April. They constituted 174 and 84% of the precipitation and resulted from the thermal conditions at that time.
2. In the annual cycle the outflow varied considerably in relation to rainfall/snowfall/snowmelt conditions. 55% of the annual precipitation flowed away from the catchment in the winter half-year and 45% in the summer half-year.
3. The mean outflow coefficient (C) was about twice higher in the winter than in the summer half-year, whereas the values of half-year outflows differed only slightly. It is an effect of about twice lower precipitation in the winter half-year.
4. Annual total outflow from the catchment depended on precipitation. In dry years it did not exceed 400 mm, in average years it ranged from 400 to 500 mm and in the wet years exceeded 500 mm.
5. Considerable variability of the outflow was caused mainly by frequent torrential rains in summer and by great water amounts infiltrating into groundwater due to snowmelt. Therefore, the outflow coefficient properly characterizes the outflow only in the summer half-year, when the outflow is primarily determined by the precipitation layer, whereas it seems useless in the winter period.
6. The research demonstrated that considerable amounts of water, which might have been used to meet local economic needs or serve for landscape or ecological purposes, flow away from the area of the agricultural catchment on the Spisko-Gubałowskie Foothills.

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