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VARIABILITY OF SPRING RIVERFLOW OF SELECTED LOWLAND RIVERS

Abstract: This paper aims at identification of changes in the spring discharge of six lowland rivers in Poland in 1966-2006. The contribution of the spring flow (February, March, April) in the annual flow was analysed as well as the 0.95 quantile time series of the daily flow. To investigate how the date of the occurrence of the spring riverflow changes, for each hydrological year the day up to which 50% of the annual flow had been reached was determined (CMD, the center of mass data). A test based on linear regression was applied, which determined the direction and rate of the changes. In five rivers, a statistically insignificant tendency to increase the contribution of the spring flow in the annual flow has been observed. A decreasing tendency in the spring discharge of all rivers has been shown; in two cases the changes are statistically significant. The tendencies in the CMD time series are not consistent.

Key words: spring flow, discharge, lowland rivers in Poland.

INTRODUCTION

The annual flow variability of the lowland rivers in Poland is distinctly marked and depends on the catchment inflow, which is shaped by precipitation and air temperature. Due to different kinds of inflow occurring in various seasons, the river discharge is formed differently. In the winter half-year, precipitation reaching the ground can be in solid or liquid form, depending on air temperature. In favourable atmospheric conditions ($t_p \leq 0^\circ\text{C}$), snow cover forms on the ground and remains for a few weeks or even months. River inflow originating from snowmelt takes place much later after the catchment had received the snow cover, and can contribute significantly to the total annual river inflow. The magnitude and rate of snowmelt runoff is influenced by the retention of the water accumulated in the snow cover and the intensity of snowmelt, which depend on the changes of air temperature. The processes described are characteristic for the lowland part of Poland.

The hydrological regime of Polish rivers is well known, but the long-term runoff tendency is still being investigated, both as regards its mean and extreme values (Kasina et al., 2007; Piętka, 2009). Because of the global climate warming one can expect a tendency of spring peak flow to decrease, which follows from the decrease of both snow cover and solid precipitation (Sui, Koehler, 2001). The changes in the course of snowmelt peak flow have been investigated by Dettinger and Cayan (1995) and McCabe and Clark (2005). The air temperature of the Earth exhibits an increasing tendency. In individual months, the magnitude of the changes as well as their direction vary (Kozuchowski, Żmudzka, 2001; Marsz, 2005). The most obvious is the warming of January, February, and March, while in November and December, a decreasing tendency is observed.

Changes in the sum of solid precipitation are also noticeable. An analysis of multi-annual data from 1958-2000, originated from climate re-analyses of Princeton University (USA) and the European Centre for Medium-Range Weather Forecasts (UK), indicates that the annual sum of snow precipitation and its share in total precipitation decreases by as much as 20% in the Bzura river catchment (Piętka, 2008). Moreover, the snow cover appeared in the Bzura and Liwiec river catchments earlier, and it disappeared also earlier. This results from the cooling at the beginning of winter and also from the earlier beginning of spring.

Many-directional changes in air temperature undoubtedly influence the rate of hydrological processes. The questions arise: Can an earlier winter and an earlier spring influence the date of occurrence of the peak flow, and: How can air temperature and the sum of snow precipitation impact the rate of inflow and formation of a river discharge?

In this paper temporal and quantitative changes of the spring flow in six lowland rivers have been estimated. The choice of objects studied was related to the regions with the largest snow inflow with simultaneous snow melt in almost the entire catchment area. Dynowska (1994) counts the rivers selected among those with the hydrological snow regime, strong and moderate, which is presented in fig. 1.

METHODS OF RESEARCH

Spring flow in six rivers in Polish lowlands has been studied. The largest catchment is that of the Bzura river up to the Sochaczew profile (6258 km²), while the smallest, that of the Świder river up to the Wólka Mładzka profile (845 km²). The data come from the years 1966-2006; only the series of daily discharges of the Bzura river is somewhat shorter, since it ends with the year 2002.

The objects of analysis have been the sums of the share of the spring discharge in the annual discharge and the values of the 0.95-quantile calculated from the daily values of the spring discharge in the given

Explanations: A - weak snow regime, B - strange snow regime, C - moderate snow regime, D - snow-rain regime, E - rain-snow regime

Fig. 1. Location of investigated catchments together with the type of river regime according to Dynowska (1994)
Numbers correspond to table 1 and 2

hydrological year. The period of spring discharge was defined as February, March, and April. To study the temporal variability of the spring discharge, the day when the discharge reached 50% of the annual value was determined. This hydrological characteristic is called CMD (Center of Mass Data), accepted by McCabe and Clark (2005).

To determine the direction and rate of changes a parametric test was used, based on linear regression, whose statistic is the Pearson correlation coefficient. It can be used with the assumption of independence of series whose distribution is close to normal. The test statistic, significance level, and the estimate of independence of the data series have been calculated by

means of the software package *Hydrospect 2.0* (Radziejewski, Kundzewicz, 2004). In each case, the critical significance level p_{kr} achieved, at which the hypothesis of no changes should be rejected, has been indicated. It was assumed that the greater the significance level, the stronger the changes are and they had been detected with better certainty. The assumption about the independence of elements of the data series has been investigated by means of the Kendall test. The assumption of the normal distributions has been investigated by means of the Shapiro-Wilk test.

THE RESULTS OF THE STUDY

Table 1 shows the equations of the linear function, correlation coefficients R and significance levels p_{kr} obtained for the time series of the contribution of the spring flow to the total flow. All series are independent and satisfy the assumption of the distribution consistent with the normal. The sum of discharge in February, March, and April in the period 1966-2006 constituted, on the average, from 35% of the annual discharge (in the Noteć river catchment) to 41% (in the Liwiec river catchment). The share of the spring discharge in the total discharge has not changed essentially. In most rivers, except for the Noteć river, a small increasing tendency has been observed. There are no significant changes at the level of $\alpha = 0.10$.

The 0.95-quantile of the spring flow and the linear functions illustrating the direction of the changes are shown in fig. 2. The Kendall test indicates that the elements of the series are significantly related in the case of the Noteć river. In no case was a distribution consistent with the normal observed. The 0.95-quantiles of the spring flow of all the rivers show a decreasing tendency, which means that the flows are getting lower. A maximum value of the 0.95-quantile of the spring flow was observed until 1980. One should stress that the rate of negative change in various rivers is varied. The changes vary from ca. $1 \text{ m}^3/\text{s}/10 \text{ years}$ (the Skrwa river) to $> 13.00 \text{ m}^3/\text{s}/10 \text{ years}$ (the Bzura river). Large changes are observed in the discharge of the Liwiec river catchment ($> 8 \text{ m}^3/\text{s}/10 \text{ years}$) and the Narew river catchment ($\sim 8 \text{ m}^3/\text{s}/10 \text{ years}$). The decreasing tendencies of the 0.95-percentile of the spring flow of these two rivers are statistically significant at the significance level $\alpha = 0.05$. In the case of other rivers, the significance levels achieved are high, with the exception of the Skrwa river ($p_{kr} = 0.326$).

The temporal variability of the spring flow was studied by means of the CMD characteristic, which can indicate changes of the date of the spring flood occurrence. One can venture a hypothesis that its earlier date, controlled by the occurrence of 50% of the flow, is an evidence of the impact of winter warming. In over 75% of cases, maximum river discharges in the period studied (1966-2006) occurred between February and April. In each hydrological year the CMD values formed time series which were analysed. The independence of all CMD series has been verified by means of the Kendall

Fig. 2. Values of 0.95-quantile of the spring flow in years 1966-2006 of investigated catchments: 1. Bzura river up to the Sochaczew profile, 2. Liwiec river up to the Łochów profile, 3. Narew river up to the Suraz profile, 4. Noteć river up to the Pakość profile, 5. Skrwa river up to the Parzeń profile, 6. Świder river up to the Wólka Mładzka profile (numbers correspond to table 1 and 2)

test. A distribution consistent with the normal of four time series (the Bzura, Narew, Skrwa, and Świder rivers) is verified by the Shapiro-Wilk test. The earliest occurrence of 50% of the annual discharge occurs in the Skrwa river catchment. On the average, in the period studied, 50% of annual discharge occurred on the 142nd day of the hydrological year (22 March). The latest CMD, which occurred on the 158th day of the hydrological year (7 April), was in the Bzura river catchment. An analysis of CMD time series of six rivers shows that the changes are not significant, and the linear tendencies discovered are not consistent (Table 1). In three rivers (Liwiec, Narew, Świder) a decreasing tendency was observed, in three others (Bzura, Noteć, Skrwa), an increasing one, the spring flow with a delay of 1.5 to 3 days in the period of 10 years.

Table 1. Results of statistical tests and the level of significance for contribution of the spring flow to the total flow (%) in years 1966-2006

No.	River - gauge	Linear regression		
		Equation	Correlation coefficient R	Significance level p_{kr}
1.	Bzura – Sochaczew ⁽¹⁾	$y = 0,0515x + 37,78$	0,058	0,267
2.	Liwiec - Łochów	$y = 0,027x + 40,548$	0,027	0,139
3.	Narew - Suraz	$y = 0,0914x + 38,459$	0,110	0,508
4.	Noteć – Pakość	$y = -0,0334x + 35,315$	-0,044	0,217
5.	Skrwa - Parzeń	$y = 0,0652x + 37,788$	0,207	0,805
6.	Świder – Wólka Mładzka	$y = 0,178x + 38,154$	0,079	0,038

(1) - 1966-2002

Table 2. Results of statistical tests and the level of significance for *CMD* time series in years 1966-2006

No.	River - gauge	Linear regression		
		Equation	Correlation coefficient R	Significance level p_{kr}
1.	Bzura – Sochaczew ⁽¹⁾	$y = 0,3468x - 543,77$	0,136	0,577
2.	Liwiec - Łochów	$y = -0,0939x + 333,37$	-0,036	0,177
3.	Narew - Suraz	$y = -0,5756x + 1301$	-0,211	0,815
4.	Noteć – Pakość	$y = 0,2608x - 359,93$	0,096	0,457
5.	Skrwa - Parzeń	$y = 0,153x - 161,83$	0,058	0,283
6.	Świder – Wólka Mładzka	$y = -0,0031x + 149,62$	-0,001	0,64

(1) - 1966-2002

SUMMARY

Lowland rivers exhibit the most obvious changes of spring flow according to the value of the 0.95-quantile. In the last four decades there is a distinct or less marked decreasing tendency of the spring flow which can – indirectly – indicate that the impact of the spring runoff is decreasing and the

share of the snow alimentionation in its formation becomes smaller. The date of the spring flow does not exhibit inambiguous and distinct changes. Three rivers show symptoms of earlier occurrence of the spring peak flow. Hydrological variables undergo smaller variations than do meteorological parameters. The thesis regarding the changes of the magnitude of spring runoff could be confirmed also in other catchments, including upland and mountain ones. A comparison of the results with the progress of meteorological factors, which influence the rate of snowmelt and which have a decisive role in the formation of spring peak flow, is also recommended.

REFERENCES

- Dettinger M.D., Cayan D.E., 1995, Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California, *Journal of Climate*, vol. 8, 606– 623.
- Dynowska I., 1994, Odpływ rzeczny [Riverflow], [in:] *Atlas of the Republic of Poland*, Główny Geodeta Kraju, PPWK im. E. Romera S.A., Warszawa.
- Kasina M., Pociask-Karteczka J., Nieckarz Z., 2007, Tendencje występowania wysokich przepływów w dorzeczu Dunajca w II połowie XX wieku [Trends in high river flows in the Dunajec River drainage basin in the second half of the 20th century], *Folia Geographica, Series Geographica-Physica*, vol. 35-36, 5-33.
- Kożuchowski K., Żmudzka E., 2001, Ocieplenie w Polsce: skala i rozkład sezonowy zmian temperatury powietrza w drugiej połowie XX wieku [The warming in Poland: the range and seasonality of the changes in air temperature in the second half of 20th century, in Polish], *Przegląd Geofizyczny*, vol. 46, 1-2, 81-90.
- Marsz A.A., 2005, O przyczynach „wcześniejszego następowania zimy” na obszarze Europy nadbałtyckiej w ostatnim 30-leciu XX wieku [The causes of the „earlier occurrence of winter” in Baltic Europe during the last thirty years of the 20th century], *Przegląd Geograficzny*, vol. 77, 3, 289-310.
- McCabe G.J., Clark M.P., 2005, Trends and Variability in Snowmelt Runoff in the Western United States, *Journal of Hydrometeorology*, vol. 6, 476-482.
- Piętka I., 2008, *Rola zasilania śnieżnego w odpływie rzek nizinnych* [Importance of snowmelt alimentionation of lowland rivers], master's thesis, Faculty of Geography and Regional Studies, University of Warsaw.
- Piętka I., 2009, Wieloletnia zmienność wiosennego odpływu rzek polskich [Long-term variations of spring runoff of Polish rivers], *Prace i Studia Geograficzne*, vol. 43, 81-95.
- Radziejewski M., Kundzewicz Z.W., 2004, *Hydrospect Version 2.0, User's Manual*.
- Sui J., Koehler G., 2001, Rain-on-snow induced flood events in Souther Germany, *Journal of Hydrology*, vol. 252, 205-220.

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