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River runoff response to climate changes in Poland (East-Central Europe)

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Abstract Climate change in Poland is expressed primarily by a decrease in rainfall and an increase in winter air temperatures. The response of river runoff to climate change in Poland is uncertain. The mean annual flows of two major rivers crossing the country (the Vistula and the Oder) observed in the years 1901–2008 reveal the occurrence of periods of wet and dry years. No statistically significant trends were observed. The periodicity of runoff caused by different types of the atmospheric circulation is the only observed effect. Maximum discharges for 462 water gauges were analysed in the period 1951–2006. During the last 20 to 30 years neither the number, nor the relative magnitude of maximum river discharges for 462 water gauges in Poland have increased (1961–2006). They are even slightly smaller than in 1951–1980. However, a number of absolute maxima occurred in 1997 and 1979. There is a relationship between NAO and river flow – especially during snowmelt season in Carpathian Mountains catchments.

Key words floods; atmospheric circulation; NAO; trends; Vistula River; Oder River; Carpathian Mountains

INTRODUCTION

Climate change, and in particular "global warming", are universally known facts and are obvious to any scientist as well as to ordinary citizens of the world. Research done on their impact on other elements of the environmental system, especially on water, has not provided unequivocal results. Studies related to trends in river flows during the 20th century at scales ranging from catchment size to global size have detected significant trends in some indicators of river flow, and some have demonstrated statistically significant links with trends in temperature or precipitation; but no globally homogeneous trend has been reported. There is evidence of a coherent pattern of change in annual runoff, with some regions experiencing an increase at higher latitudes and a decrease in parts of West Africa, southern Europe and southern Latin America (IPCC, 2007). Changes in annual riverflow usually relate to changes in total precipitation, but this does not directly translate into changes in flood flows; however, there exists a number of studies stating that high flows have become more frequent. In many cases, more frequently disastrous floods or droughts are more "CNN-effect" than realistic scientific proved events (Kundzewicz, 2003).

Relatively little research has been done on rivers in Poland, and there are no clear statements regarding hydrological changes related to climate conditions (Miler, 1999; Kaczmarek, 2003; Kasina *et al.*, 2006, 2007; Pociask-Karteczka & Nieckarz, 2010; Wrzesiński, 2010). The purpose of the paper is to present an overview of the current research results on river runoff response to climate changes in Poland, with particular interest in the mean annual and extreme river flows.

STUDY AREA

Poland is located in East-Central Europe, in the Baltic Sea basin (Fig. 1). Poland's temperate climate is oceanic-type in the north and west, and becomes gradually warmer and continental-type towards the south and east of the country. Summers are warm, with average temperatures between 17°C and 20°C. Winters are cold, with average temperatures around 3°C in the northwest and −6°C in the northeast. Over most of Poland, total annual precipitation is between 500 and 625 mm. Much of the winter precipitation is snow. Precipitation increases considerably in the southern mountains and slightly at the Baltic Sea shore.

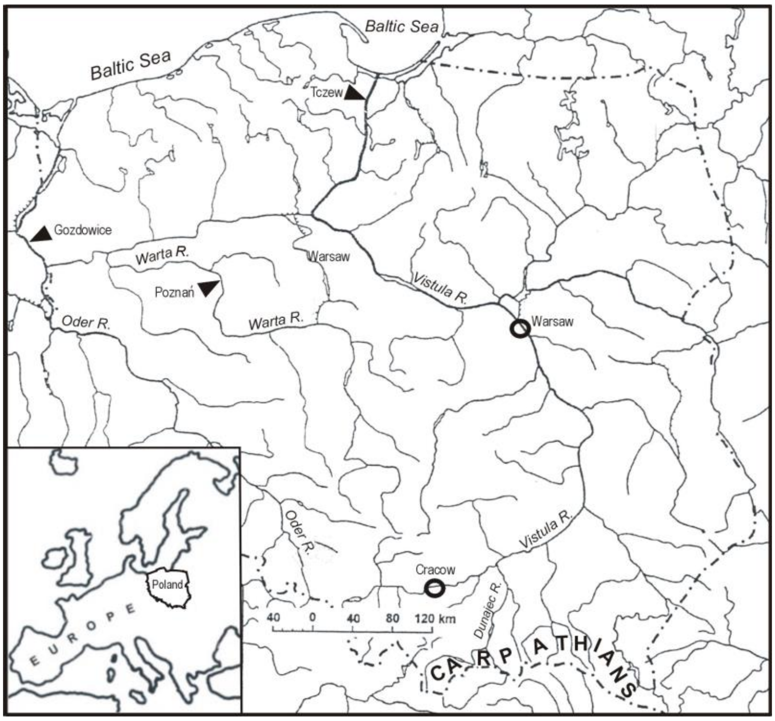

Fig. 1 River network and location of selected water level gauges in Poland.

RESULTS

Trends in river discharge

Mean annual discharge data for the principal rivers crossing the country (the Vistula at Tczew and Oder at Gozdowice, Fig. 1) were examined by Stachý (2010) for the period 1901–2008 (Fig. 2). The analysis of time series of runoff revealed the occurrence of periods of "wet years" ($Q_i > Q_{Me}$; where Q_i is mean annual discharge, Q_{Me} is median discharge) and "dry years" ($Q_i < Q_{Me}$) (Fig. 2). The longest dry period occurred in 1943–1964, when the mean discharge was equal 937 $m^3 s^{-1}$ in the Vistula River and 459 $m^3 s^{-1}$ in the Oder River. The longest wet period occurred in 1965–1982, when mean discharges were 1240 $m^3 s^{-1}$ in the Vistula River and 611 $m^3 s^{-1}$ in the Oder River. The occurrence of the wet and dry periods was caused by different types of atmospheric circulation. Statistically significant autocorrelation coefficients indicate that the mean annual discharge was dependent in consecutive years on the retention ability of the catchments. No statistically

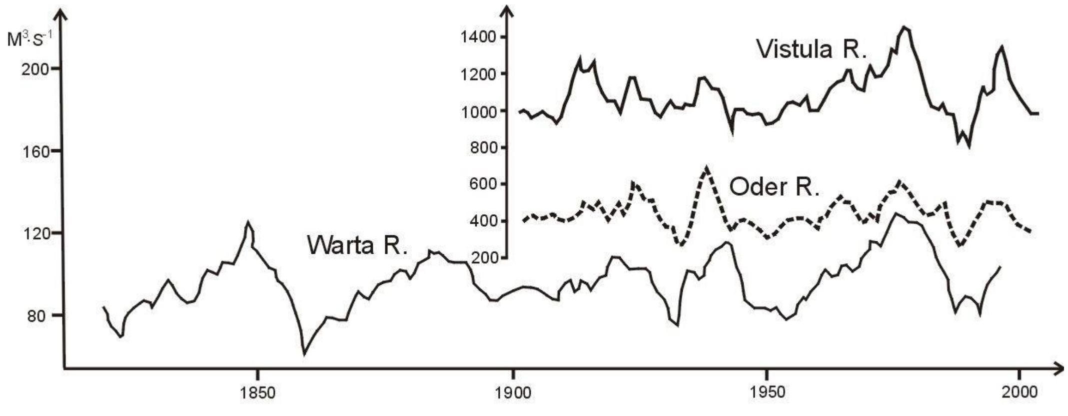

Fig. 2 Time series of the 5-years moving values of the Vistula and Oder rivers (1901–2008) and 11-year moving values of the Warta River (1882–1997) (after Stachý, 2010, and Miler, 1999).

significant trends in mean annual flows of the Vistula and the Oder were observed (Stachý, 2010). The longest existing Polish flow records, since 1822, referring to the Warta River (at Poznań), were analysed. The mean annual flow positive flow trend of the Warta River was statistically insignificant in 1882–1997 ($\alpha = 0.05$) (Miler, 1999). However, the annual maximum flow of the Warta River shows a statistically significant decrease and the origin of this decrease is not likely to be attributed to climate (Fig. 2) (Graczyk *et al*., 2002).

The study covered virtually all of Poland and was done by Jokiel & Bartnik (2010); maximum discharge for 462 water gauges was analysed (1951–2006). The Francou-Rodier flood index coefficient, *K*, and the number of maximum flows were also analysed. The Francou-Rodier flood index coefficients *K* is calculated according to the following formula: $K = 10\ [1 - (\log WWQ - 6)/\log A - 8]$, where *WWQ* is maximal discharge ($m^3 \cdot s^{-1}$) and *A* is catchment area (km^2) (Françou & Rodier, 1969).

One may state that during the last 20–30 years neither the number, nor the relative magnitude of maximum river discharges in Poland has increased. The number of maximum flows was even slightly smaller than in 1951–1980. However, numerous absolute maxima were observed in 1979 and 1997. “Flood years” in Poland did not necessarily match “flood years” in Europe as a whole – for instance 1968 and 1995. But 1970 was a “flood year” in both Poland and in Europe. It is worth mentioning that the 1980s decade was an extremely uneventful period.

Mean, maximum and minimum annual, as well as winter and summer discharges for 17 Carpathians river catchments were studied by Soja (2002) for the years 1951–1995. The Carpathian Mountains are the second largest chain of mountains in Central Europe after the Alps; they spread across the southern part of Poland forming a barrier to oceanic Atlantic air masses arriving from the west and polar-continental air masses arriving from the east and northeast. Precipitation and mean specific runoff are the highest in Poland and reach approximately 1600 mm and 50 $dm^3 \cdot s^{-1} \cdot km^{-2}$ respectively. Among hundreds of calculated linear trends, only some were found to be statistically significant. Negative tendencies were characteristic of maximum winter and summer discharges (17, 13, respectively) and positive tendencies were dominant in minimum annual, winter and summer discharge (13, 13, 13, respectively) (Table 1).

Table 1 Amount of tendencies of the Carpathians river discharges in 1951–1995 (after Soja, 2002, with changes).

Discharge	Time period	Negative tendency	Positive tendency
Maximum	Winter	17	0
	Summer	13	4
	Year	6	1
Mean	Winter	10	7
	Summer	8	9
	Year	9	8
Minimum	Winter	4	13
	Summer	4	13
	Year	4	13

The Dunajec River is one of the longest (247 km) rivers and tributaries of the Vistula River in the Carpathians. Its basin area (6798 km^2) includes the Tatra Mts – the highest part of the Carpathian mountain chain with Mt Gerlach (2655 m a.s.l.). Changes of high river discharge were studied by Kasina *et al.* (2006–2007) in 20 rivers in the Dunajec River basin. The analysis was based on the normalized daily discharge data from 20 sub-catchments with areas ranging from 58.4 to 5316 km^2. The high river discharge (HRD) taken into consideration was defined as discharge greater than the fifth percentile of daily river discharges in a year or in half-year seasons in particular years (winter half-year from November to April and summer half-year from June to October). Three methods were used to determine if the HRD trends were statistically significant and either decreasing or increasing: (1) parametric linear regression, (2) non-parametric Mann-Kendall, and (3) Spearman’s rank correlation tests. Three time series were examined:

1971–1990, 1984–2003, 1951–2003. For the majority of the studied time series, trends were positive, but not statistically significant.

Changes of the stability of flow regime

A river flow regime describes the average seasonal behaviour of a river, as determined by its genetic sources and by its ambient climate. As a result of variability in climatic conditions, a given flow series can demonstrate different flow regimes from year to year.

Wrzesiński (2010) analysed daily discharge time series for the Warta River and calculated the frequencies of characteristic rates of discharge for successive 20-year periods from 1822 to 2005. This simple qualitative analysis shows that regime types expressed by frequencies of characteristic rates of discharge were unstable for 20-year periods in the years 1822–2005 (Fig. 3).

Flow regimes in the second part of the 20th century are characterized by an increasing share of discharge rates (x) in the mean and high discharge ranges ($AvQ_{Max} > x > ULQ_M$, $ULQ_M > x > Q_M$; for explanation see Fig. 3). In turn, the contribution of low discharge ($< AvQ_{Min}$) is less than several (Fig. 3). Periods deviating the most from some regularities were observed in the 1850s and were characterized by dominating low discharges.

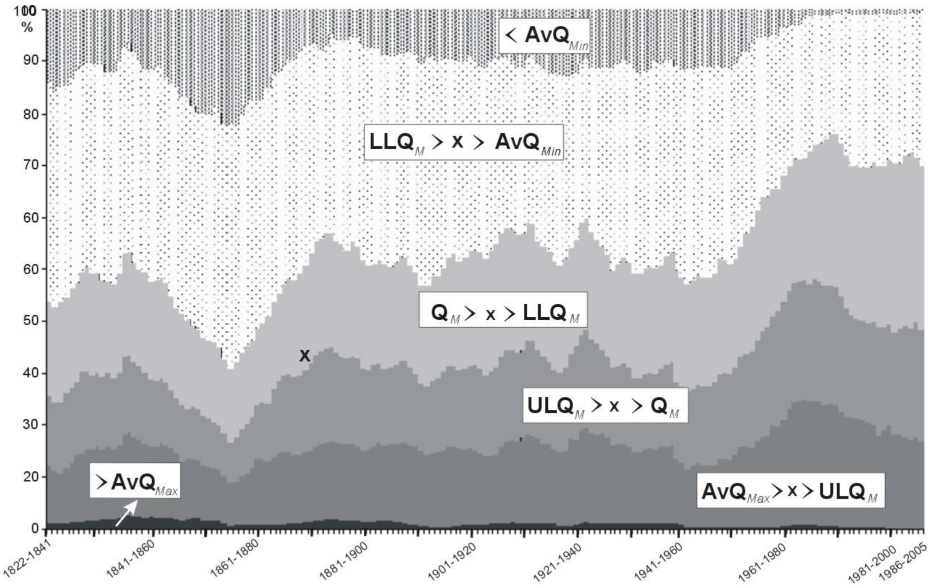

Fig. 3 Frequencies of characteristics discharges in the 20-year periods in 1822–2005 (after Wrzesiński 2010, with changes). Characteristics discharges: Q_M – average discharge, ULQ_M – upper limit of mean discharge range, LLQ_M – lower limit of mean discharge range, AvQ_{Max} – average high discharge, AvQ_{Min} – average low discharge.

River flow in Poland and the North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is one of the major regional system controlling atmospheric circulation and the weather conditions over eastern Central Europe, especially in the winter season (Wibig, 2000). The NAO is characterized by considerable variability, but there has been a more positive regime since the late 1970s. Based on periodicity and a strong correlation between temperature conditions and NAO_{DJFM}, four air-circulation periods have been identified for Poland: E0 (1864–1899), EI (1900–1929), EII (1930–1970) and EIII (1971–1995) (Marsz, 1999). Each period differs in terms of weather conditions for cloudiness (Fig. 4). The robust warming effect marked by the rise in air temperature during the winter in period EIII (especially in northwestern Poland) is linked to an increase in the frequency of the influx of polar marine air masses from the North Atlantic (Marsz, 1999).

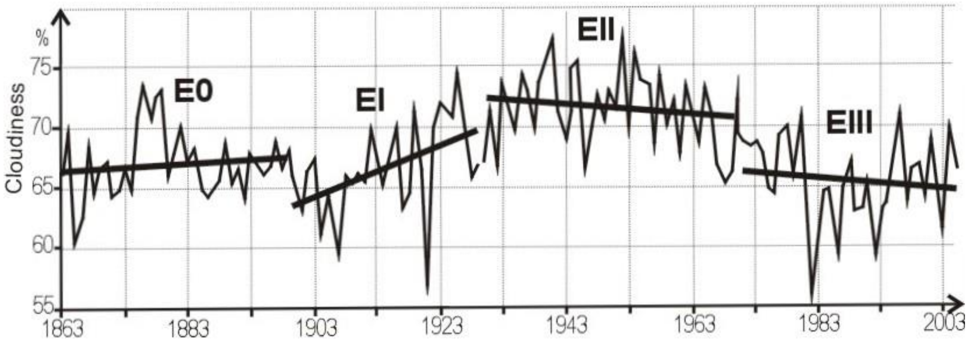

Fig. 4 Time series of mean annual cloudiness (%) in Cracow in NAO circulation periods (E), EI, EII, EIII) (after Matuszko 2007, with changes).

The effect of the NAO on annual river flow is seen primarily in terms of spring meltwater runoff. Considerable flooding prompted by the Vistula and Oder rivers occurs following winters characterized by extremely low NAO indices (Kaczmarek, 2002). There is a link between the NAO and Warta River runoff in April, August, and September (Styszyńska, 2002). In some cases there is also an interdependence between the NAO winter index and the runoff of some Carpathian rivers. If there is a strong positive NAO phase in December and January, river runoff of some rivers at the end of summer and the beginning of autumn is less than usual. The correlation between the winter NAO index and mean monthly discharge in the winter is also significant in the case of the Dunajec River; the same is true in August and September (Limanówka *et al.*, 2002; Pociask-Karteczka, 2006; Pociask-Karteczka *et al.*, 2002–2003, 2003a,b).

Hydrological maxima events and 10-day discharge averages for Carpathian rivers with respect to the North Atlantic Oscillation were studied by Pociask-Karteczka & Nieckarz (2010). Statistically significant relationships between Hurrell's winter index, the NAO-December index, and hydrological maxima events were identified in the research. Higher than usual discharge during 10-day periods in the spring and summer, as well as lower than usual discharge during 10-day periods in September and August, are associated with a positive NAO phase during the preceding winter. River discharge during the third 10-day period of July is also associated with a positive NAO phase during the preceding winter.

CONCLUSIONS

Research has shown that climate changes expressed in Poland, particularly warming (0.55°C 100 years^{-1}; Lorenc, 2001) and decreasing precipitation (Kożuchowski & Żmudzka, 2003) do not lead to unequivocal trends in river discharges. Minor exceptions do apply. Periodicity caused by different types of atmospheric circulation is the only certain appearance in river flow (Stachý, 2010). Similar conclusions were stated by Jokiel (1997). One may state that statistically significant increase or decrease in river discharge in Poland as a response to climate changes in Poland has not been observed. But, changes in the hydrological regime, as expressed by the increasing contribution of mean and high rates of discharge and a decreasing contribution of low rates of discharge, have been observed, particularly in the second part of the 20th century.

A relationship between river flow and the North Atlantic Oscillation does exist. Negative NAO_{DJFM} episodes in the winter are associated with higher than usual river flows during the snowmelt season; positive NAO_{DJFM} episodes are associated with higher than usual river flows at the end of the summer and at the beginning of autumn.

The results described herein reveal the need for research focused on changes in air circulation patterns. This type of research would be helpful in the identification of the key sources of increasing variability in meteorological phenomena affecting hydrological processes.

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