Bulletin of Geography. Physical Geography Series, No. 13 (2017): 29–37
http://dx.doi.org/10.1515/bgeo-2017-0011

ISSN 2080-7686

Climatic changes on Szczecin Seashore and their impact on river flows

Małgorzata Świątek

Szczecin University, Poland

* Correspondence: Faculty of Geosciences, Szczecin University, Poland. E-mail: malgorzata.swiatek@usz.edu.pl

Abstract. An analysis has been made of the variability of temperature and precipitation at stations at Szczecin, Świnoujście, Resko and Kołobrzeg, as well as a study of river flows in the Ina and Rega Rivers in Goleniów, Resko and Trzebiatów, for the years 1955–2014. Data was provided by IMGW-PIB. Correlation and regression methods have been used in this work. Studies have shown that the average annual, spring and summer air temperature on Szczecin Seashore is rising. Precipitation totals remain basically unchanged. They grow a little in July in Świnoujście and in March in Szczecin. No significant changes in river flows occurred in the course of the examined sixty-year period. Flows in the Ina River rose slightly in February and they diminished in the Rega River in October in Resko and in May in Trzebiatów. Long-term variability of river flows is more strongly affected by the variability of precipitation totals than by the variability of air temperature. The variability of flows correlates most strongly with the variability of precipitation totals in March, April and November, while the influence of the preceding month's precipitation on river flows is evident in all the year.

Key words:
temperature,
precipitation totals and river flow variability,
northern Poland

Introduction

Estimated simulations of climate changes provide for temperature rises in Poland by 2°C in the summer and by 6°C in the winter. Annual precipitation totals will most likely grow up to 20% (Kędziora 2010). Over the years 1951–2006 the greatest thermal changes concerned minimum daily temperature. In north-western Poland these amounted to 0.28°C/10 years, constituting the most substantial change in all of Poland (Kejna et al. 2009). Since the mid-20th century a decreasing trend has been observed in the summer-to-winter precipitation ratio in Poland, while an intensification in liquid precipitation (caused by a drop in the number of days with negative air temperature, particularly in north-western Poland) contributes to only a slight growth in underground water resources, including soil storage (retention). This has resulted from more intensive evaporation, as well as warmer winters and greater direct (surface) runoff (Kędziora 2010). The changes pose a risk of diminishing water resources and resultant threats to agriculture, forestry and municipal economies, and subsequently also to industry. On the other hand, scientists also propagate the view that although climatic changes will exert a negative influence in southern Europe, they will simultaneously have a positive effect in northern, and particularly north-western Europe (Olesen and Bindi 2002). Therefore, it is crucial that a relationship be established between the climate changes and changes in river basin water resources, which in this paper were estimated on the grounds of river flow volumes.

Similarly to the entire northern hemisphere, climate warming occurred on Szczecin Seashore, manifesting itself through a shortened period of negative air temperatures and an increase in monthly average temperatures (February–May, July and August) and annual air temperatures. At the same time the sum of annual precipitation totals in Szczecin rose, which was due to a significant increase in precipitation totals in March (Kirschenstein 2013; Świątek 2013). Significant air temperature spikes in Poland are not generally accompanied by an increment in seasonal and annual precipitation totals (Przybylak 2011), and this could cause water deficits in ecosystems.

Recently, a study into the impact of climate change (precipitation and temperature patterns) on flows in Poland was conducted by Piniewski et al. (2016, 2017a-c) Osuch et al. (2016, 2017), Meresa et al. (2016) and Romanowicz et al. (2016). Most of these studies mainly focused on the prediction of frequency and severity of droughts and floods.

Of course, in addition to climate change, land use changes and water management works have a great influence on river flows in the research area. These factors mainly affect the rate of outflow and, indirectly, the total volume of drainage. This is especially true for short periods of time. Some studies have tried to distinguish human-induced changes from those caused by natural forcing (Romanowicz and Osuch 2011; Piniewski et al. 2016) and their studies have shown that making such a distinction is difficult.

The objective of the paper is to analyse the changes the climate elements which have a crucial impact on the runoff volume from the selected river basins of Szczecin Seashore. Those elements include air temperature (which determines evaporation from the surface of the researched area) and precipitation totals. Analysis of the concomitance of long-term changes in climatic and hydrological elements is a major factors in determining natural environmental conditions and improving agricultural efficiency.

Materials and methods

The data used in the paper relates to the period between the years of 1955 and 2014 and were provided by the Institute of Meteorology and Water Management – National Research Institute (Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy IMGW-PIB). The paper features air temperatures and precipitation totals measured at the following stations: Szczecin, Świnoujście, Resko and Kołobrzeg (Fig. 1). The analysis of water resource variability on Szczecin Seashore was conducted on the basis of river flows in the Ina and Rega Rivers in Goleniów, Resko and Trzebiatów. Goleniów is located in the lower course of the Ina, while Resko lies in the middle course of the Rega and Trzebiatów (Fig. 1) near its mouth, but sufficiently far from Mrzeżyno (where the Rega flows into the sea) for any river backwater to occur only sporadically.

When preparing the source materials for analysis, average daily air temperature values and precipitation totals characterising Szczecin Seashore were determined on the basis of the data from individual stations. Following that, average monthly and annual air temperatures, monthly and annual precipitation totals, and average monthly and annual river flows were determined. Linear regression was used to determine temporal trends of average monthly air temperatures, monthly precipitation totals in individual months and in a year, and monthly and annual trends of river flow values. Multiannual changes have been presented per 10 years. Then Pearson correlation coefficients were calculated for a given month's precipitation and temperature on the one hand, and river flows in the subsequent month on the other (e.g. temperature and precipitation in March and streamflows in April). Moreover, the statistical significance of the determined correlations was defined at the level of $p \leq 0.05$ using the Fisher–Snedecor test.

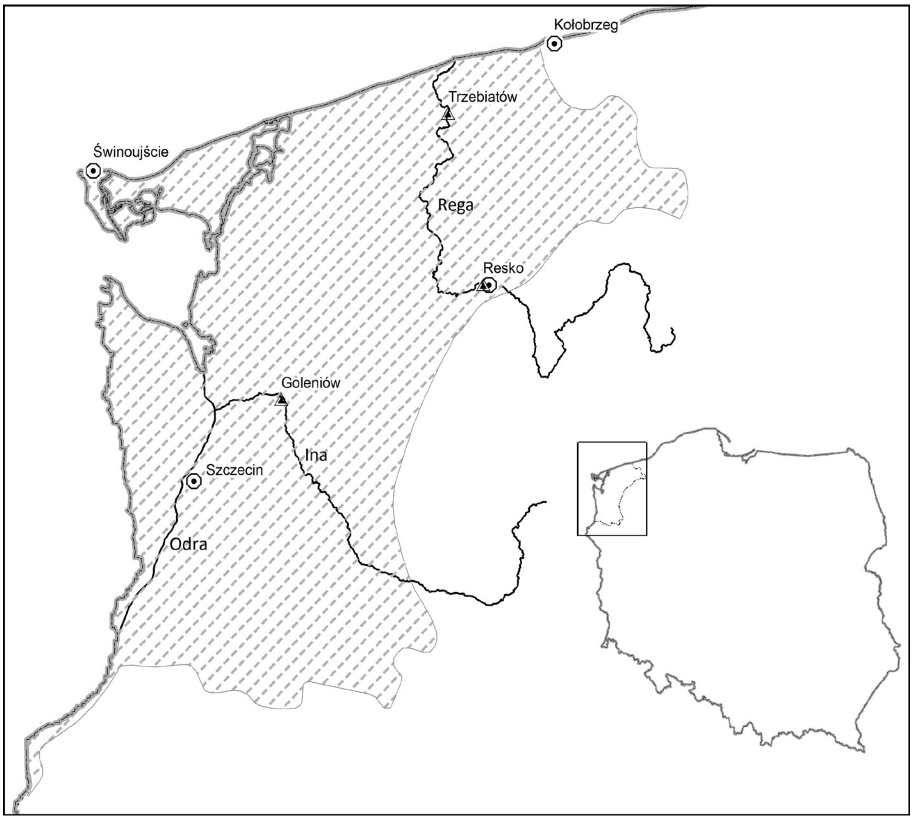

Fig. 1. Location of stations from which data was taken. Meteorological stations are marked with circles and hydrological stations with triangles. The Szczecin Seashore is marked with hatchings. Author: Szymon Walczakiewicz.

Climatological and hydrological description of the analysed river basins

In both analysed river basins, average annual precipitation totals exceed average Polish precipitation sums. In the upper part of the Rega River basin average annual precipitation totals 668 mm (Łabędzie station, 1961–2000, Kaniecki et al. 2004) and 681 mm in the estuarial part (Trzebiatów station, 1961–2000, Kaniecki et al. 2007). The highest annual precipitation totals in the Rega River basin were observed in the region of Łobez, at 712 mm (Wiewecko station, 1961–2000, Graf and Puk 2006). In the Ina River basin precipitation is lower, ranging from 543 mm in Przelewice (1971– 2000, Kostecki 2003) on the flatland to 681 mm in the hilly terrain of the Ińsko Lake District, where the river has its source (Ińsko station, 1961–2000, Graf 2004). Both of these river basins typically have low seasonal variability. Precipitation totals for the warm half of the year exceed the precipitation sums of the cool half of the year by a mere dozen-or-so per cent (Kostecki 2003; Graf 2004; Kaniecki et al. 2007). Both of the river basins have significant water-retaining capacities, which results from their large numbers of lakes and forests. Furthermore, within the Rega River basin there are numerous wetlands – the upper and middle course of the river runs through a water surplus zone (Kaniecki et al. 2004), while in the middle and upper part of the Ina River basin the majority of wetlands have been ameliorated. Significant water retentiveness, along with low precipitation variability, means that both of the rivers have a low flow irregularity indicator. There is typically a substantial proportion of groundwater runoff in relation to total runoff. The groundwater runoff is similar to the direct runoff volume (Graf 2003a; Kaniecki et al. 2004) or exceeds it; in the lower and middle part of the Rega River basin it amounts to 60–70% of the total runoff volume (Kaniecki et al. 2004). High precipitation totals relative to the low-lying part of Poland translate into large values of specific discharge from a basin. In the Rega River basin the value is 8.03 $dm^3s^{-1}km^{-2}$ (Trzebiatów station, 1961–2000, Kostecki 2007), and

6.3 $dm^3s^{-1}km^{-2}$ in the Ina River basin (Goleniów station, 1961–2000, Ziętkowiak and Sobkowiak 2006), while the average for Poland is 5.5 $dm^3s^{-1}km^{-2}$. Relatively high precipitation in the cool half of the year results in runoff being approximately twice that of the warm half of the year (Kaniecki et al. 2006) and in the Krąpiel River basin, a tributary of the Ina, it is nearly three times as high (Ziętkowiak 2004).

Results

The conducted analysis demonstrated a statistically significant increase (at a level of significance of $p \leq 0.05$) of average annual air temperature values in all the researched locations (Table 1). The changes observed were relatively substantial – time trend coefficients (linear regression) ranged from 0.24°C/10 years in Świnoujście to 0.29°C/10 years in Szczecin and Kołobrzeg. The changes in yearly precipitation totals were not as significant. Long-term changes in precipitation totals and air temperature in particular months are shown in Table 1.

No significant changes in river flows occurred in the course of the examined sixty-year period. Flows in the Ina River (at Goleniów station) rose slightly in February and they slightly diminished in the Rega River in Resko station in October and in Trzebiatów station in May (Table 2). The increase in Ina River flow in February may be associated with increased snow cover instability and thaw in winter, which is caused by an increase in winter air temperature (Koźmiński et al. 2012).

In Goleniów there was a fairly distinct growing trend of average annual flow volumes in the Ina River in the years 1955–2002. During the period from 2002 to 2006 they fell successively, following which (in the years 2007–2014) the flow volume was at the level recorded during the period of 1995–1970 (Fig. 2a). This phenomenon was not observed in Rega (Fig. 2b), which may be indicative of local (primarily anthropogenic) conditions influencing the flow variability in Ina.

The next stage of analysis involved a comparison of changes in river flow volumes in relation to averaged climatic changes using the Pearson correlation coefficient (on the basis of the data obtained from the Szczecin, Świnoujście, Resko and Kołobrzeg stations) for Szczecin Seashore. The correlation coefficients of average monthly and annual temperature values – as well as monthly and annual precipitation totals – to river flow volumes are presented in Table 3.

The relations between the flows and average annual air temperatures were found to be statistically insignificant, while the correlation coefficients of flows with average annual precipitation totals were proven to be significant (at the level of $p \leq 0.05$). The correlation coefficient of flows in the Ina River in Goleniów with averaged precipitation sums on Szczecin Seashore was 0.488. For the Rega River the correlations were stronger – in the case of flows in Trzebiatów (lower course of the river) the coefficient amounted to 0.633, and 0.615 in Resko (middle course of the river).

The co-occurrence of changes in precipitation totals and river flows throughout the year (including in winter) as expressed by the relatively high and seasonally stable correlation coefficients, is associated with the thickness and instability of the snow cover in the described area being extremely low in comparison with the rest of Poland.

Correlation analysis was also employed in order to analyse the impact of the precipitation totals and temperatures of a preceding month on river flow volumes. The results are presented in Table 4. These results were similar to those obtained for the data of the same months (i.e. those without a one-month shift).

Discussion

The greater influence of changes in atmospheric precipitations than of warming is manifested both in observations and model projections in many areas, among others in Central and Eastern Europe (Piniewski et al. 2017c). It is believed that the growing trends of precipitation sums in many parts of Europe are influenced by the increase of the number of short episodes of extremely intensive precipitation with a simultaneous rise in the frequency of precipitation-free periods (Karl et al. 1999; Kjellström 2004).

Research conducted for six selected catchments in Poland (Osuch et al. 2017) projected a decrease in frequency and intensity of low-flow events and

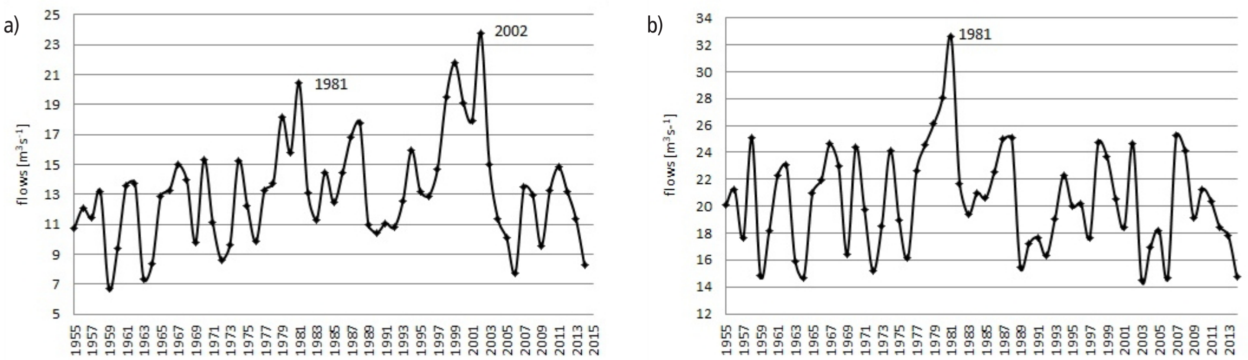

Fig. 2. Long-term variability of average annual river flows in the Ina River in Goleniów (a), and in the Rega River in Trzebiatów (b)

Table 1. Long-term changes (linear trend) in monthly and annual precipitation totals (prec.) and air temperature (temp.) at selected stations of Szczecin Seashore, and the average for Szczecin Seashore (1955–2014)

month	Świnoujście		Szczecin		Resko		Kołobrzeg		Szczecin Seashore	
	prec.	temp.	prec.	temp.	prec.	temp.	prec.	temp.	prec.	temp.
	mm/10 years	°C/10 years	mm/10 years	°C/10 years	mm/10 years	°C/10 years	mm/10 years	°C/10 years	mm/10 years	°C/10 years
Jan	1.6	0.26	2.3	0.34	3.4	0.26	2.6	0.28	2.5	0.29
Feb	0.6	0.41	1.6	**0.53**	2.8	0.44	1.8	0.42	1.7	0.45
Mar	1.1	**0.34**	**2.5**	**0.38**	3.6	**0.33**	2.1	**0.37**	2.3	**0.35**
Apr	-3.3	**0.48**	-1.5	**0.54**	-2.1	**0.52**	-1.8	**0.53**	-0.2	**0.52**
May	1.5	**0.34**	0.2	**0.33**	0.0	**0.36**	1.3	**0.46**	0.8	**0.37**
Jun	1.7	0.12	1.7	0.04	2.1	0.11	3.6	**0.28**	2.3	0.14
Jul	**6.8**	**0.30**	1.3	**0.31**	-1.1	**0.39**	-1.3	**0.37**	1.3	**0.34**
Aug	1.8	**0.30**	1.7	**0.33**	2.0	**0.36**	1.9	**0.35**	1.9	**0.34**
Sep	1.4	0.12	0.4	0.17	-1.9	0.11	0.6	0.08	0.1	0.12
Oct	0.2	0.04	0.1	0.10	-1.4	0.02	2.4	0.03	0.5	0.05
Nov	0.5	0.11	0.4	0.17	1.9	0.14	0.7	0.17	0.9	0.15
Dec	0.0	0.12	0.9	0.21	2.9	0.16	2.0	0.18	1.4	0.17
Year	1.3	**0.24**	1.2	**0.29**	1.2	**0.27**	1.6	**0.29**	1.1	**0.27**

Statistically significant ($p \leq 0.05$) trends are marked in bold

Table 2. Long-term changes (linear trend) in average monthly and annual river flows in the Ina River in Goleniów (1955–2014), in the Reda River in Resko (1957–2014) and in Trzebiatów (1955–2014)

month	change in river flow [m^3s^{-1}per 10 years]		
	Ina (Goleniów)	Rega (Resko)	Rega (Trzebiatów)
Jan	0.82	0.07	0.00
Feb	**1.30**[a]	0.25	0.81
Mar	0.94	0.22	0.50
Apr	0.32	-0.03	-0.26
May	-0.11	-0.29	**-0.79**
Jun	0.29	-0.12	-0.17
Jul	0.29	-0.14	-0.09
Aug	0.29	-0.26	-0.04
Sep	0.05	-0.25	-0.24
Oct	0.39	**-0.37**	-0.62
Nov	0.42	-0.23	-0.29
Dec	0.07	-0.28	-0.73
Year	0.45	-0.10	-0.19

Statistically significant ($p \leq 0.05$) trends are marked in bold, [a] p=0.0502

Table 3. Correlation coefficients of average monthly and annual river flows in the Ina River in Goleniów (1955–2014) the Rega River in Resko (1957–2014) and the Rega River in Trzebiatów (1955–2014) with average monthly and annual temperature values as well as monthly and annual precipitation totals on Szczecin Seashore.

month	Ina (Goleniów)	Rega (Resko)	Rega (Trzebiatów)
	correlation with precipitation totals		
Jan	**0.467**	**0.588**	**0.565**
Feb	**0.487**	**0.513**	**0.482**
Mar	**0.558**	**0.707**	**0.710**
Apr	**0.640**	**0.675**	**0.723**
May	0.210	**0.260**	**0.290**
Jun	**0.332**	**0.460**	**0.552**
Jul	**0.314**	**0.482**	**0.476**
Aug	0.038	0.238	**0.282**
Sep	**0.433**	**0.514**	**0.543**
Oct	0.232	**0.426**	**0.410**
Nov	**0.472**	**0.622**	**0.605**
Dec	**0.550**	**0.532**	**0.557**
Year	**0.488**	**0.615**	**0.633**
	correlation with air temperature		
Jan	**0.477**	**0.413**	**0.474**
Feb	**0.485**	**0.309**	**0.422**
Mar	0.255	**0.284**	**0.280**
Apr	-0.130	-0.182	**-0.268**
May	-0.177	-0.246	-0.253
Jun	-0.191	**-0.361**	**-0.333**
Jul	**-0.422**	**-0.539**	**-0.501**
Aug	-0.091	**-0.352**	**-0.341**
Sep	**-0.343**	**-0.418**	**-0.399**
Oct	-0.022	-0.062	-0,060
Nov	-0.024	0.076	0.084
Dec	0.099	0.080	0.148
Year	0.070	-0.174	-0,170

Statistically significant (p≤0.05) coefficients are marked in bold

Table 4. Correlation coefficients of average monthly river flows in the Ina River in Goleniów (1955–2014), in the Rega River in Resko (1957–2014) and in the Rega River in Trzebiatów (1955–2014) with average monthly temperature values as well as monthly precipitation totals on Szczecin Seashore in preceding months. Statistically significant (p≤0.05) coefficients are marked in bold

month	Ina (Goleniów)	Rega (Resko)	Rega (Trzebiatów)
	correlation with precipitation totals in previous month		
Jan[a]	0.144	0.058	0.109
Feb	**0.411**	**0.548**	**0.543**
Mar	**0.452**	**0.463**	**0.409**
Apr	**0.538**	**0.572**	**0.710**
May	**0.553**	**0.550**	**0.583**
Jun	0.193	0.220	0.227
Jul	**0.517**	**0.547**	**0.648**
Aug	**0.437**	**0.463**	**0.458**
Sep	**0.278**	**0.340**	**0.389**
Oct	**0.515**	**0.430**	**0.543**
Nov	**0.461**	**0.507**	**0.503**
Dec	**0.303**	**0.307**	**0.288**
	correlation with air temperature		
Jan[a]	0.084	0.071	0.035
Feb	0.234	0.197	0.239
Mar	0.111	0.176	0.095
Apr	-0.165	-0.136	-0.243
May	-0.173	**-0.307**	**-0.365**
Jun	-0.091	-0.203	-0.223
Jul	-0.172	-0.208	-0.189
Aug	**-0.342**	**-0.494**	**-0.457**
Sep	-0.077	**-0.429**	**-0.359**
Oct	**-0.291**	-0.260	**-0.400**
Nov	-0.213	-0.241	-0.217
Dec	**-0.306**	-0.232	**-0.276**

[a] 1956–2014
Statistically significant (p≤0.05) coefficients are marked in bold

increases in flood indices (Osuch et al. 2016). Projections of changes in extreme inflows in the Vistula and the Odra (Piniewski et al. 2016) show that streamflow droughts are expected to be less severe and high river flows and floods are predicted be on the rise. Additionally, greater higher changes are anticipated to be typical for lowland catchments than mountainous ones (Meresa et al. 2016).

Kożuchowski and Degirmendžić (2005) or Wibig (2012), inter alia, have determined no significant changes in the constituents of water balance in Poland, apart from a change in evaporation values. This does not, however, mean that the situation may not be different in the future. Wibig (2012) points to certain statistically insignificant tendencies towards growing humidity deficits in the summer in Poland. In turn, Vincente-Serrano et al. (2010) demonstrate strong relationships between current global climate changes and a decrease in the value of the Standardized Precipitation Evaporation Index (SPEI). At the same time, there is a risk that the direct runoff proportion will grow in the total runoff volume in Poland, causing, inter alia, intensification of soil erosion, as forecasted by Ryszkowski et al. (1991), among others.

The changes in flow volumes caused by climate changes are compounded by the acceleration of water circulation in river basins, which is an effect of anthropogenic activities. In the analysed terrain those changes were significant during the researched period, particularly in the Ina River basin. An increasing density of drainage ditches on wetland terrains and within the expansive, flat valley of the Ina River (Graf 2003, 2004) caused direct runoff to intensify at the expense of groundwater runoff. The use of drainage ditches to include small lakes and wetland terrains into the drainage system of both the Ina (Graf 2004), and the Rega (Kaniecki et al. 2004; Zię̨tkowiak 2007) has accelerated direct runoff, while simultaneously decreasing both water infiltration into the substrate (due to diminished volume of groundwater runoff) and evaporation from the terrains that used to be without drainage. River bed regulation and the construction of embankments in the lower section of the Ina River and its tributary, the Ina Mała (Small Ina) contributed to the acceleration of water runoff. These embankments were built under the Programme of Rural Areas Development for 2007–2013 (http://zzmiuw.pl/realizacja-inwestycji), that is, at the end of the period researched in the paper. In turn, in the Rega River basin runoff was accelerated by dredging and straightening of small water courses both in the upper (Kaniecki et al. 2004) and lower (Kaniecki et al. 2007) part of the basin, practically transforming those water courses into drainage ditches. Furthermore, there are now fewer forested areas in the upper part of the river basin (Kaniecki et al. 2004), which, similarly to drainage of wetlands, has contributed to diminished water retentiveness in the river basin and consequently accelerated direct runoff. Less surface retention and faster runoff reduce evaporation from the basin and thus increase the value of runoff volume, thus reducing the effect of increases in air temperature.

Changes in the drainage basin management, such as water melioration and urbanisation are contributing to the reduction of the effects of climate warming on river flows (Viger et al. 2011). So it is likely that, without the anthropogenic transformation of the river basin, streamflows in the surveyed catchments would have been slightly reduced due to evaporation. At the same time it should be noted that an overall tendency of increase in mean seasonal and even annual flows were conducted in several Polish catchments, both in medium-small ones (Piniewski et al. 2017a) and in the greatest ones – the Odra and Vistula river basins (Piniewski et al. 2017b). A reduction in flow decreases also results in lower evapotranspiration of plants under certain climatic conditions, due to the more efficient management of water by plants in conditions of higher atmospheric carbon dioxide concentrations (Kundzewicz and Kowalczak 2008).

In studying the flow regime in the Upper Narew River before and after construction of a storage reservoir Siemianówka Romanowicz and Osuch (2011) found that a single approach to analysing changes caused by water management and land use under climatic variability is not sufficient for all the changes taking place in the catchment. Instead, a range of different approaches should be used.

Conclusions

The conducted research demonstrated that the average annual air temperature on Szczecin Seashore is rising. So too is the temperature in spring and summer. Precipitation totals remain basically unchanged. They have grown a little in July in Świnoujście and in March in Szczecin. River flow volume basically stays the same. In the Ina River it slightly intensifies in February, while in the Rega River it diminishes in October (in Resko) and in May (in Trzebiatów).

The long-term variability (from year to year) of river flows is more strongly affected by the variability of precipitation totals than by the variability of air temperature. In the winter, the increase in air temperature (due to less frequent negative temperatures and frequent mid-winter thaws) has resulted in the intensification of river flows. This arises from increasingly scarcer and only short-lasting snow cover on Szczecin Seashore, i.e. from the decreased nival storage and poorer ground frost penetration, which both enable river alimentation in winter. The variability of flows correlates most strongly with the variability of precipitation totals in March, April and November, while the influence of the preceding month's precipitation on river flows is evident during the whole year at a relatively steady level. The fact that trends of long-term changes in river flows (and thus in water resources) are more strongly affected by changes in precipitation totals than by changes in air temperatures in the studied river basins on Szczecin Seashore is a positive finding from the point of view of the agricultural economy (and other economies) and the natural environment. Therefore, as the climate on the Seashore is evidently getting warmer, the strong impact of these changes on river flow changes could thus result in the diminishing of water resources in individual river basins. If the rise in evaporation had not been not compensated with sufficiently intensive precipitation, a serious problem would have occurred. Fortunately, precipitation totals on the Seashore are slightly rising, although they are not statistically significant increases.

References

GRAF R., 2003, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-104-A Recz. Główny Urząd Geodezji i Kartografii, Rzeszów.

GRAF R., 2004, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-92-C Ińsko. Główny Urząd Geodezji i Kartografii, Rzeszów.

GRAF R., PUK K., 2006, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-92-A Łobez. Główny Urząd Geodezji i Kartografii, Rzeszów. http://zzmiuw.pl/realizacja-inwestycji (accessed: 19.07.2017) - Zachodniopomorski Zarząd Melioracji i Urządzeń Wodnych w Szczecinie.

KANIECKI A., BACZYŃSKA A., GOGOŁEK A., 2004, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-80-D Świdwin. Główny Urząd Geodezji i Kartografii, Rzeszów.

KANIECKI A., BACZYŃSKA A., GOGOŁEK A., 2006, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-80-C Starogard. Główny Urząd Geodezji i Kartografii, Rzeszów.

KANIECKI A., BACZYŃSKA A., GOGOŁEK A., 2007, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-67-D Trzebiatów. Główny Urząd Geodezji i Kartografii, Rzeszów.

KARL T., NICHOLLS N., GHAZI A., 1999, CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes. Workshop summary. Climatic Change, 42: 3–7.

KEJNA M., ARAŹNY A., MASZEWSKI R., PRZYBYLAK R., USCKA-KOWALKOWSKA J., VIZI Z., 2009, Daily minimum and maximum temperature in Poland in years 1951-2005, Bulletin of Geography. Physical Geography Series, 2: 35–58.

KĘDZIORA A., 2010, Zmiany klimatyczne i ich wpływ na warunki wodne krajobrazu rolniczego. [in:] Koźmiński Cz., Michalska B. and Leśny J. (eds), Klimatyczne zagrożenia rolnictwa w Polsce, Uniwersytet Szczeciński, Szczecin: 103–138.

KIRSCHENSTEIN M., 2013, Zmienność temperatury powietrza i opadów atmosferycznych w północno-zachodniej Polsce. Akademia Pomorska, Słupsk.

KJELLSTRÖM E., 2004, Recent and future signatures of climate change in Europe. Ambio, 33, 4: 193–198.

KOSTECKI M., 2003, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-103-A Stargard Szczeciński. Główny Urząd Geodezji i Kartografii, Rzeszów.

KOSTECKI M., 2007, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-79-B Brojce. Główny Urząd Geodezji i Kartografii, Rzeszów.

KOŹMIŃSKI CZ., MICHALSKA B., CZARNECKA M., 2012, Klimat województwa zachodniopomorskiego. ZUT i US, Szczecin.

KOŻUCHOWSKI K., DEGIRMENDŽIĆ J., 2005, Contemporary changes of climate in Poland: trends and variation in thermal and solar conditions related to plant vegetation. Polish Journal of Ecology, 53, 3: 283–297.

KUNDZEWICZ Z., KOWALCZAK P., 2008, Zmiany klimatu i ich skutki. Kurpisz, Poznań.

MERESA H., OSUCH M., ROMANOWICZ R., 2016, Hydro-Meteorological Projections into 21-st Century for Selected Polish Catchments. Water, 8, 5, 206. DOI:10.3390/w8050206.

OLESEN J. E., BINDI M., 2002, Review. Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy, 16: 239–262.

OSUCH M., LAWRENCE D., MERESA H., NAPIÓRKOWSKI J., ROMANOWICZ R., 2016, Projected changes in flood indices in elected catchments in Poland in the 21st century. Stochastic Environmental Rescue Risk Assessment. DOI:10.1007/s00477-016-1296-5.

OSUCH M., ROMANOWICZ R., WONG W., 2017, Analysis of low flow indices under varying climatic conditions in Poland. Hydrology Research. DOI: 10.2166/nh.2017.021.

PINIEWSKI M., SZCZEŚNIAK M., KUNDZEWICZ Z., MEZGHANI A., HOV O., 2016, Changes in low and high flows in the Vistula and the Odra basin: Model projections in the European-scale context. Hydrological Processes, 31: 2210–2225.

PINIEWSKI M., MERESA H., ROMANOWICZ R., OSUCH M., SZCZEŚNIAK M., KARDEL I., OKRUSZKO T., MEZGHANI A., KUNDZEWICZ Z., 2017a, What can we learn from the projections of changes of flow patterns? Results from Polish case studies. Acta Geophysica, 65: 809–827.

PINIEWSKI M., SZCZEŚNIAK M., HUANG S., KUNDZEWICZ Z., 2017b, Projections of runoff in the Vistula and the Odra river basin with the help of SWAT model. Hydrology Research. DOI:10.2166/nh.2017.280.

PINIEWSKI M., SZCZEŚNIAK M., KARDEL I., 2017c, CHASE-PL – Future Hydrology Data Set: Projections of Water Balance and Streamflow for the Vistula and Odra Basins, Poland. Data, 2 (2), 14. http://www.mdpi.com.

PRZYBYLAK R., 2011, Changes in Poland's climate over the last millennium. Czasopismo Geograficzne, 82, 1-2: 23–48.

ROMANOWICZ R., OSUCH M., 2011, Assessment of land use and water management induced changes in flow regime of the Upper Narew. Physics and Chemistry of the Earth, 36: 662–672.

ROMANOWICZ R., BOGDANOWICZ E., DEBELE S., DOROSZKIEWICZ J., HISDAL H., LAWRENCE D., MERESA H., NAPIÓRKOWSKI J., OSUCH M., STRUPCZEWSKI W., WILSON D., WONG W. K., 2016, Climate change impact on hydrological extremes: preliminary results from the Polish-Norwegian Project. Acta Geophysica, 64, 2; 477–509.

RYSZKOWSKI L., KĘDZIORA A., OLEJNIK J., 1991, Potential effects of climate and land use changes on the water balance structure in Poland. [in:] Brouwer F., Thomas A., Chadwick M. (eds), Land use changes in Europe. Processes of changes, environmental transformations and future patterns. The GeoJournal Library, 18: 461.

ŚWIĄTEK M., 2013, Zmiany temperatury powietrza i sum opadów na obszarze Pobrzeży Południowobałtyckich i ich wpływ na klimatyczny bilans wodny, na tle zmian globalnych. [in:] Borówka R., Cedro A. and Kavetskyy I. (eds), Współczesne problemy badań geograficznych, Uniwersytet Szczeciński i PAN, Szczecin: 35–45.

VIGER R., HAY L., MARKSTROM L., 2011, Hydrologic effects of urbanization and climate change on the Flint River basin, Georgia, Earth Interactions, 15, 20: 1–25.

VINCENTE-SERRANO S., BEGUERÍA S., LÓPEZ-MORENO J., 2010, A Multiscalar Drought Sensitive to Global Warming: The Standardized Precipitation Evaporation Index. Journal of Climate, 23: 1696–1718.

WIBIG J., 2012, Warunki wilgotnościowe w Polsce w świetle wskaźnika standaryzowanego klimatycznego bilansu wodnego. Woda – Środowisko – Obszary Wiejskie, 12, 2 (38): 329–340.

ZIĘTKOWIAK Z., SOBKOWIAK L., 2006, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-90-B Goleniów. Główny Urząd Geodezji i Kartografii, Rzeszów.

ZIĘTKOWIAK Z., 2004, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-91-D Chociwel. Główny Urząd Geodezji i Kartografii, Rzeszów.

ZIĘTKOWIAK Z., 2007, Komentarz do mapy hydrograficznej w skali 1:50000 arkusz N-33-79-A Gryfice. Główny Urząd Geodezji i Kartografii, Rzeszów.

Received 28 September 2017
Accepted 18 October 2017