Kubiak-Wójcicka, K. (2018), Flow characteristics of the Vistula River at the Tczew gauging station in 1951–2010 based on Flashiness Index, pp. 119-129. In Gastescu, P., Bretcan, P. (edit, 2018), *Water resources and wetlands*, 4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania), p.312

4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania)

# FLOW CHARACTERISTICS OF THE VISTULA RIVER AT THE TCZEW GAUGING STATION IN 1951–2010 BASED ON FLASHINESS INDEX

**Katarzyna KUBIAK-WÓJCICKA**
Department of Hydrology and Water Management, Faculty of Earth Sciences, Nicolaus Copernicus University, Toruń, Poland, *e-mail: kubiak@umk.pl*

## Abstract

The aim of the paper is to analyze seasonal and multi-year variability of Vistula River discharge in its estuary part. The study was conducted on the basis of daily discharge values of the Vistula recorded on the gauging station Tczew in hydrological years 1951 through 2010. The data come from the Institute of Meteorology and Water Management – National Research Institute. The Tczew gauging station closes the whole Vistula's basin which area is 193,806.46 square kilometers. Based on the Richards-Baker flashiness index (R-BI), which is an index of absolute discharge fluctuations throughout a year related to the runoff, there has been determined the frequency and dynamics of short-term runoff changes. The results indicate that average daily fluctuations of the discharge vary from 0.01 (November 1960) to 0.156 (February 1953). The higher the index value, the greater is the fluctuation of discharge. The most even discharges in the analysed period took place in April and the greatest fluctuations – in August and February. The analysis of the trends of average monthly values of the R-BI index in the period of 1951-2010 revealed statistically significant growing trend, while in case of average monthly discharge – statistically insignificant slight growing trend.

**Keywords**: discharge, flashiness index Richards-Baker Index, Vistula, Poland

## 1 INTRODUCTION

Knowing the discharge of a river, and especially its spatial and temporal variability, is extremely important for the sustainable management of water resources and for establishing strategic plans for water management within a catchment. The main causes of variability in river discharge are climatic variability, especially with regard to global warming (Arnell 1999), and human activity (Zillgens et al. 2007; Stonevičius et al. 2014). Analysis of long-term observations can be used to study climate variability and to develop new predictive models of river discharge for particularly sensitive areas (Klavinš et al. 2008; Hanel et al. 2012; Hall et al. 2014; Štefunková et al. 2013; Sarauskiene et al. 2014). The uneven distribution of discharge over the year has been discussed using various hydrological indices and variability metrics (Pfeiffer and Ionita 2017). Many characteristics include the time and frequency of extreme phenomena such as floods and droughts on daily, seasonal and annual scales (Oueslati et al. 2010). These indices have statistical bases, to help select from the large number of different hydrological indices those that will represent the main aspects of the flow regime (Olden and Poff 2003; Assani et al. 2006). One simple hydrological index used to assess changes in the flow regime (the frequencies and speeds of short-term changes in flows) and to determine trends of changes is the flashiness index proposed by Baker (2004). This index has been used in studies by other authors, among others to identify: changes in small urban catchments (ten Veldhuis and Schleiss 2017); the impact of changes in land use on catchment flow conditions (Dow 2007; Kotei et al. 2013; Královec et al. 2016); the regionalisation of flow regime in watercourses in the Mediterranean Sea basin (Oueslati et al. 2010); and changes in discharge trends (Holko et al. 2011). Contrasts in conditions in Polish rivers are observed to be increasing: after a wet year there is an exceptionally dry year. Seasonal discharge variability is increasing: during the same year more and more periods of extreme low waters and high surges occur (Jokiel 2016; Bąk and Kubiak-Wójcicka 2017). It is therefore important to know the annual and long-term discharge regime both for small catchments, and for large river basins such as the Vistula. The Vistula basin is extremely important to the economy, as it accounts for a significant share of Poland's water resources, which are among the lowest in Europe (Kubiak-Wójcicka and Piątkowski 2017).

## 2 STUDY AREA AND METHODS

The study covered the Vistula River, the largest river in Poland, with the second-largest river basin area in the Baltic Sea catchment. It is 1,022 km in length. The water gauge at Tczew covers the entire Vistula basin, at 194,376 km$^2$ (Atlas podziału hydrograficznego Polski, 2005). The water gauge station at Tczew is located at kilometre 908.6 of the Vistula River. The most important right-bank tributaries of the Vistula are: the Dunajec, Wisłoka, San, Wieprz, Bug and Narew, Drwęca; the main left-bank tributaries are: the Pilica, Bzura and Brda (Fig. 1). The Vistula runs meridionally, from south to north. The Vistula has its sources on the slopes of Barania Góra, at 1,106 m a.s.l., and flows to the Baltic Sea, creating a delta in the Vistula Marshlands (Pol. *Żuławy Wiślane*). In the lower section of the Vistula, there is a dam at Włocławek, which since 1968 has created a water reservoir. The distance between the Włocławek dam and the station in Tczew is 233.7 km. The average retention time of water in the reservoir is 5.2 days (Gierszewski 2006).

The area of the Vistula basin represents 87.1% of the country's total catchment area. In terms of land use in Poland, the largest share in the Vistula basin belongs to agricultural land (61%), of which, arable land accounts for 42% of the river basin. Forests and wooded areas cover 53,100 km$^2$, i.e. 31.5% of the catchment area. Built-up areas cover 8,151 km$^2$, i.e. 4.8%, and anthropogenic areas cover 1,553 km$^2$ (0.9%). River and lake beds, wetlands and bogs occupy 1.7% (own calculations based on Corine 2012).

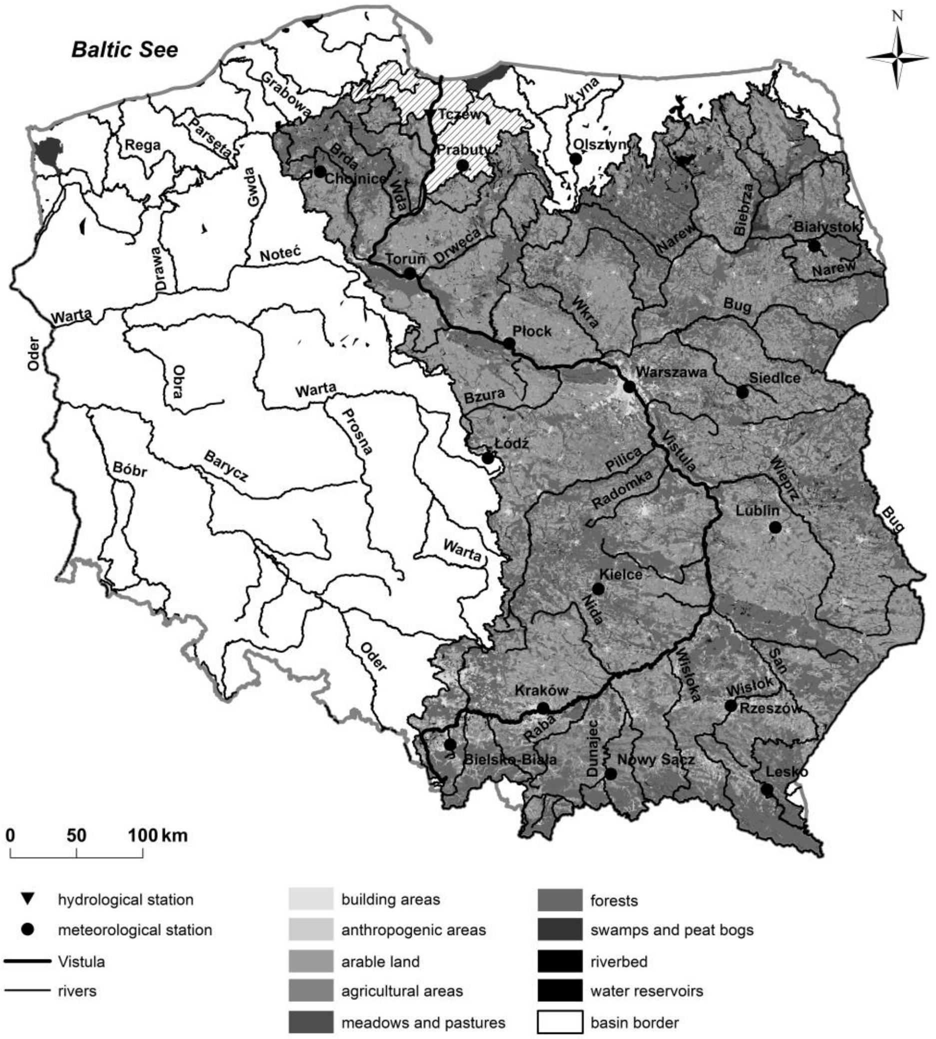


**Figure 1.** Land use of the Vistula basin according to Corine 2012

The study uses the daily values of Vistula flows at the Tczew station in the hydrological years 1951–2010. Meteorological conditions were established using daily sums of precipitation for 16 meteorlogical stations in the Vistula basin. The locations of the meteorological stations are shown in Fig. 1. For 14 of the meteorological stations, the data come from the hydrological years 1952–2010, while for 2 stations (Nowy Sącz and Lesko) data are from 1955–2010. The mean monthly and annual sums of precipitation for Poland were calculated as the average sums of precipitation from all meteorological stations. The hydrological and meteorological data come from the Institute of Meteorology and Water Management of the National Research Institute (IMGW-PIB).

Analysis of the long-term variability of river discharge is presented using the average monthly and annual flow for the years 1951–2010. Due to the strong upward trend in air temperatures in the Carpathian region after 1980 (Spinoni et al. 2015), comparative analyses of data from 1951–1980 and 1981–2010 were carried out.

In order to determine the variability of flows, several hydrological indices were used, including coefficient of variation (Cv) and the long-term trend of annual discharges, which is commonly used for the hydrological characterisation of rivers (Déry et al. 2016; Kliment and Matoušková 2008). The discharge variability (Cv) was calculated as the standard deviation of all daily discharge values divided by the average annual discharge.

An important part of the study is to determine the rate of change in short-term flows. Because floods occur rapidly and over a short time, the index defined in the literature as the “flashiness index” was used; it was proposed by Baker et al. (2004) and is referred to as the RB Index (RBI) after the authors’ surnames (Richards–Baker).

$$RB\ index = \frac{\sum_{i=n}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

Where: $q$ – average daily discharge, $i$ – day, $n$=365 (366)

RBI is a dimensionless index that ranges from 0 to 2 (Holko et al. 2011; Berhanu et al. 2015; Královec et al. 2016). The index expresses how flow varies between two time units (days). Zero represents a steady flow, while a higher index value indicates an increased frequency of flows. Watercourses that quickly rise and fall are considered to be “faster” than those that maintain a more steady flow (Fongers et al. 2008).

The aim of this study was to analyze long-term changes in flows and precipitation in 1951–2010 and compare them between the periods 1951–1980 and 1981–2010. These comparative periods allowed upward or downward trends to be identified in the analysed long-term period. The degree of seasonal variability of Vistula flows at the Tczew station was based on the Cv variation index and the flashiness index (RBI), which characterises the short-term nature of a phenomenon.

## 3 RESULTS AND DISCUSSION

### 3.1 Atmospheric precipitation in the years 1952–2010

In the area of the Vistula basin, there is a temperate climate that is transitional between a land and sea climate, which results from humid air masses from over the Atlantic meeting dry air from deep in the Eurasian continent.

The annual amount of precipitation in the Vistula basin varied, ranging from about 500 to 1,000 mm in the hydrological years 1952–2010. The highest sums of precipitation were recorded in mountainous areas in the south of the basin, where they amounted to 998.8 mm (Bielsko-Biała precipitation station). In the Carpathian areas sums of precipitation clearly decline from west to east. At the Nowy Sącz station precipitation was 738.1 mm. In the Bieszczady mountains another increase in precipitation was recorded; at the Lesko station it totalled 815.6 mm. In the Carpathian Foothills the rainfall was lower, ranging from 675.9 mm in Kraków to 634.3 mm in Rzeszów.

In the central part of the basin the annual sums of precipitation were lower, ranging from 600 to 650 mm in upland areas (Kielce 635 mm; Lublin 588.6 mm). The lowest sums of precipitation slightly exceeded 500 mm in the central part of the basin (Warsaw 522 mm; Toruń 533.4 mm; Siedlce 534.8 mm; Płock 537.9 mm; Łódź 564.6 mm; Białystok 587.7 mm). In the lower part of the basin, annual precipitation was slightly higher, amounting to about 600 mm (Chojnice 578.5 mm; Olsztyn 629.6 mm; Prabuty 624.5 mm).

The average annual sum of precipitation in the Vistula basin in the years 1952–2010 was 636.1 mm. In decadal terms, the largest sum of precipitation was recorded in 2001–2010 (680.3 mm), while the lowest was in the years 1952–1960 (569.6 mm). The average sum of precipitation in the years 1952–1980 was 638.1 mm, which was only 5.6 mm below the average values for 1981–2010. It should therefore be assumed that the average precipitation in the 30-year periods was close to the average values in long-term period of 1952–2010 (Fig. 2).

The highest annual sums of precipitation at individual meteorological stations were recorded in 2010 (at 5 meteorological stations) and in 2001 (at 3 meteorological stations). For the lowest sums of precipitation, the variation was decidedly higher. The lowest annual sums of precipitation were recorded in 1954 (at 2 meteorological stations), 1959 (2 meteorological stations), 1969 (2 meteorological stations) and 1982 (2 meteorological stations).

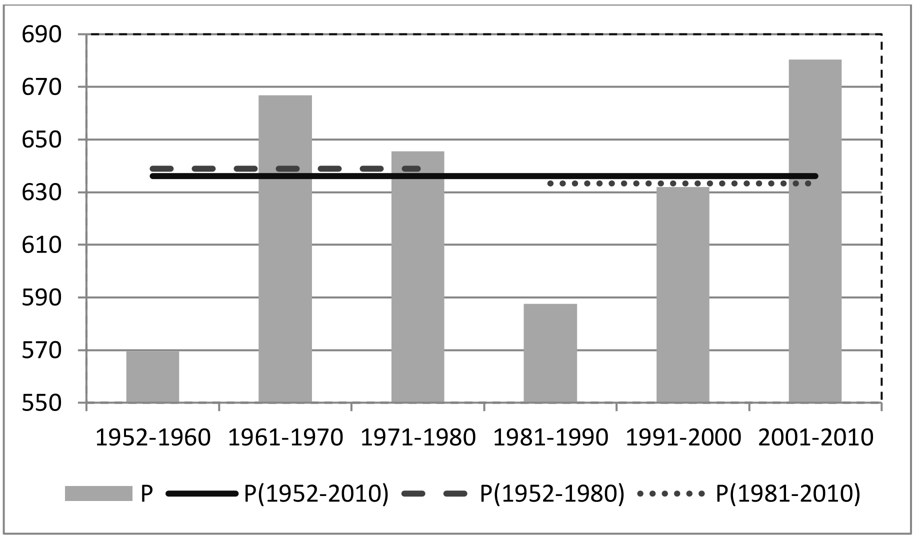


**Figure 2.** Annual sums of precipitation (mm) at 16 meteorological stations in the Vistula basin by decade, compared against 1952–2010, 1952–1980 and 1981–2010

## 3.2 Vistula flow variability

### 3.2.1 Annual flows of the Vistula in 1951–2010

In the long-term study period of 1951–2010, the variation in annual flow of the Vistula at the Tczew station was itself variable. The largest variations were in maximum flows, which fluctuated from 6,430 m$^3$/s (1962) to 1,600 m$^3$/s (1984). Average flows ranged from 1,663 m$^3$/s (2010) to 646 m$^3$/s (1954). The lowest amplitudes were within low flows, which fluctuated from 754 m$^{3/}$s (1981) to 264 m$^3$/s (1960) (Fig. 3).

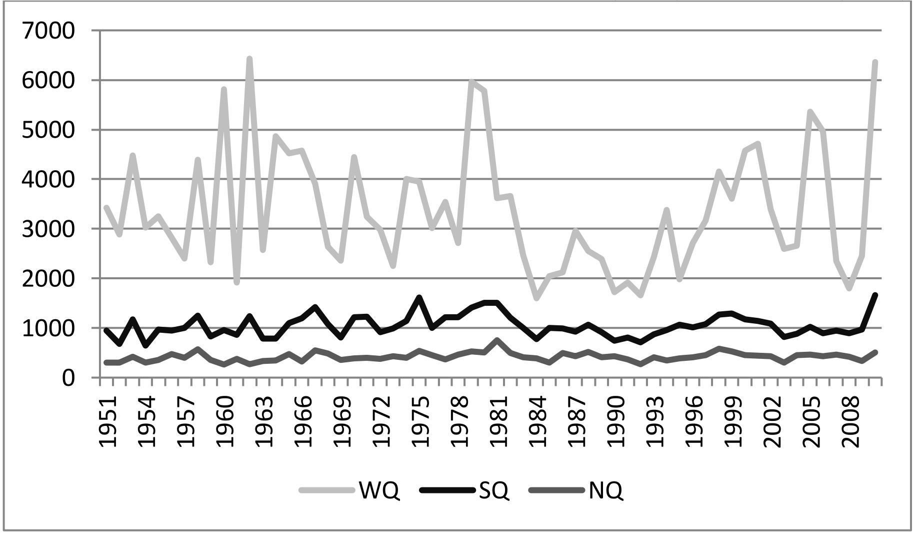


**Figure 3.** Maximum (WQ), minimum (NQ) and average (SQ) annual flows in m$^3$/s of the Vistula at Tczew in 1951–2010

Analysing the average flows of the two time periods shows that the average flow was about 5% higher in 1951–1980 than in 1981–2010 (Fig. 4). The largest decadal values were for 1971–1980, while the most stable decadal flow values were in the last 30 years – with the difference in average flow rates being only 2% between individual decades. The average annual flows in the years 1981–2010 (SSQ=1,020 m$^3$/s) are about

3% below the values for 1951–2010 (SSQ=1,048 m$^3$/s), while in the years 1951–1980 these values were about 3% higher (SSQ=1,072 m$^3$/s).

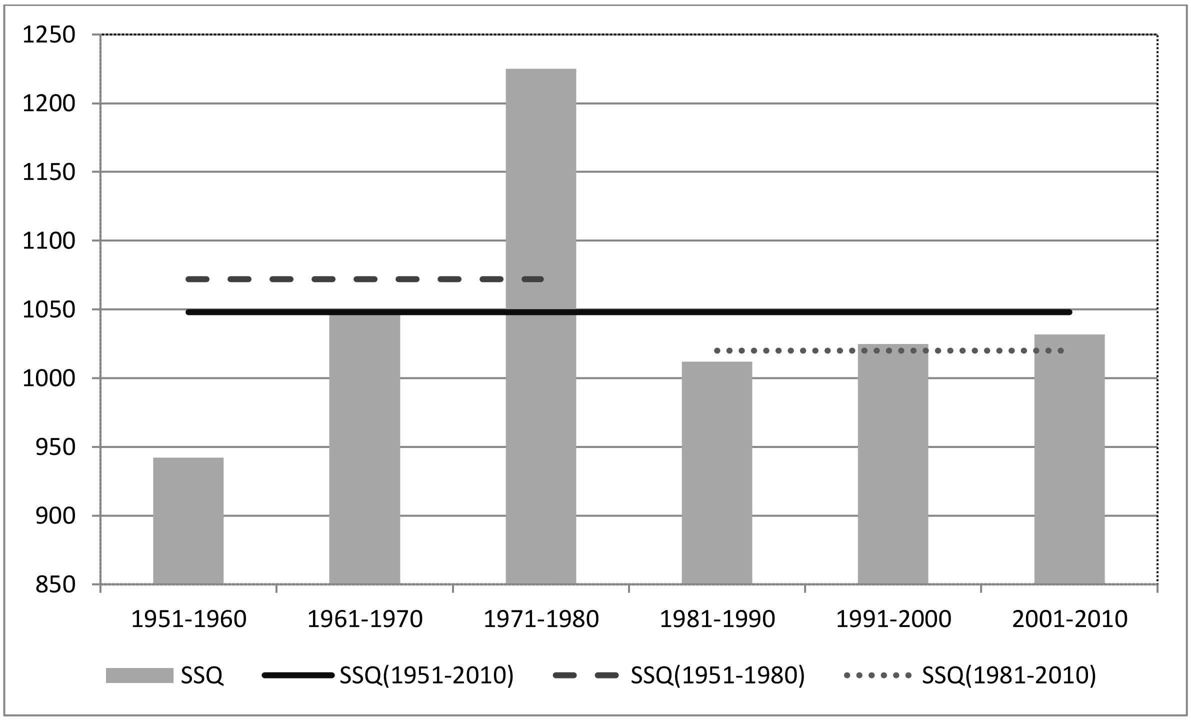


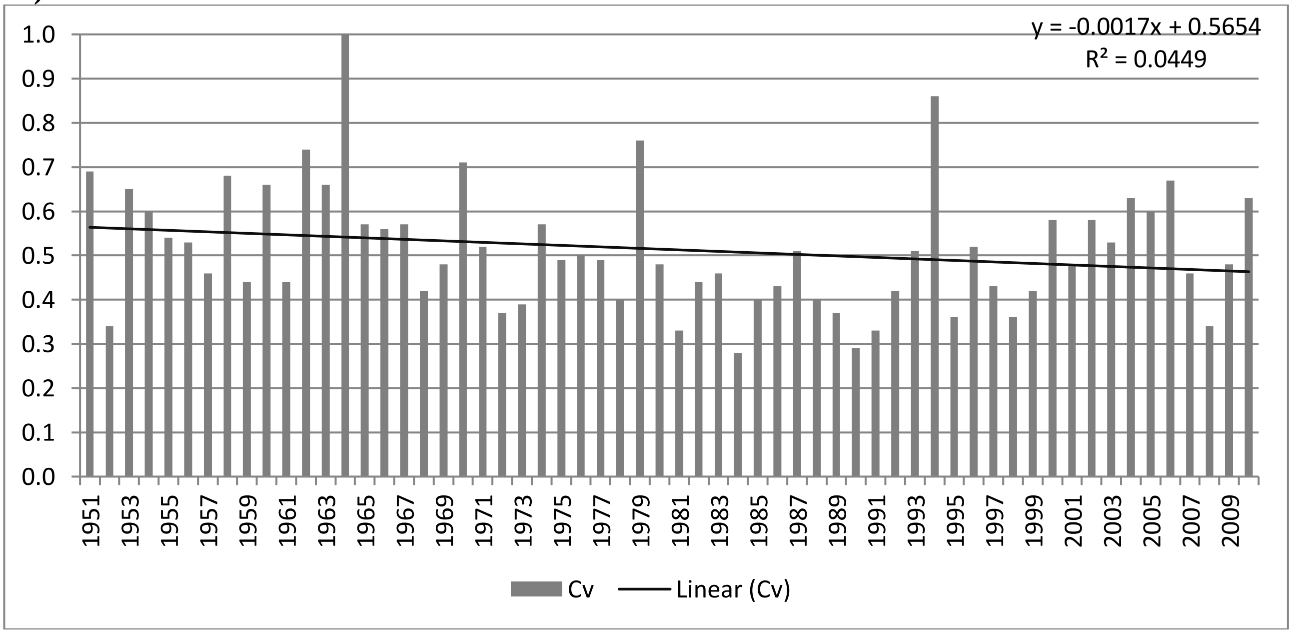
**Figure 4.** Average annual long-term flow (SSQ) in m$^3$/s of the Vistula at Tczew by decade compared against 1951–2010, 1951–1980 and 1981–2010

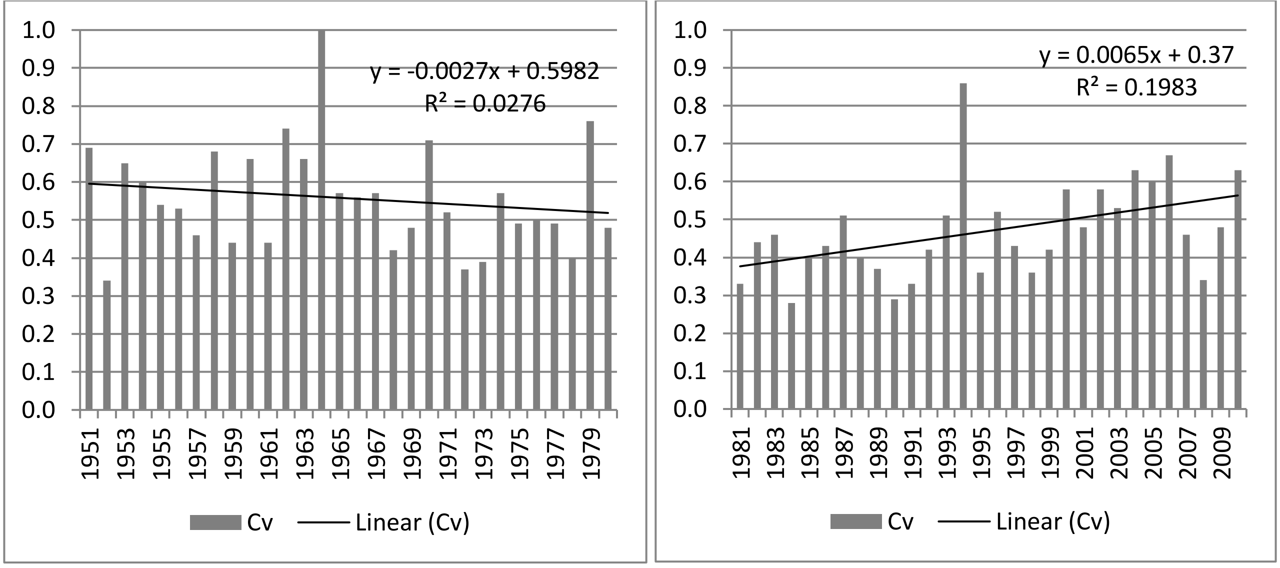
### 3.2.2 Coefficient of variation of annual discharges

Two hydrological indices were used to determine the variability of annual discharges. The first of these is the coefficient of variability of annual flows of Cv. The second is the flashiness index (RBI), which indicates the dynamics of short-term changes in flow.

The coefficient of variation of average annual discharges of the Vistula in 1951–2010 has a slight downward trend (Fig. 5). The last 30 years (1981–2010) have seen an upward trend in the coefficient of variation of flows. The highest flow variability was in 1964 (Cv=1.0) and 1994 (Cv=0.86), while the lowest was in 1984 (Cv=0.28) and 1990 (Cv=0.29).

**5a)**





**5b)** **5c)**

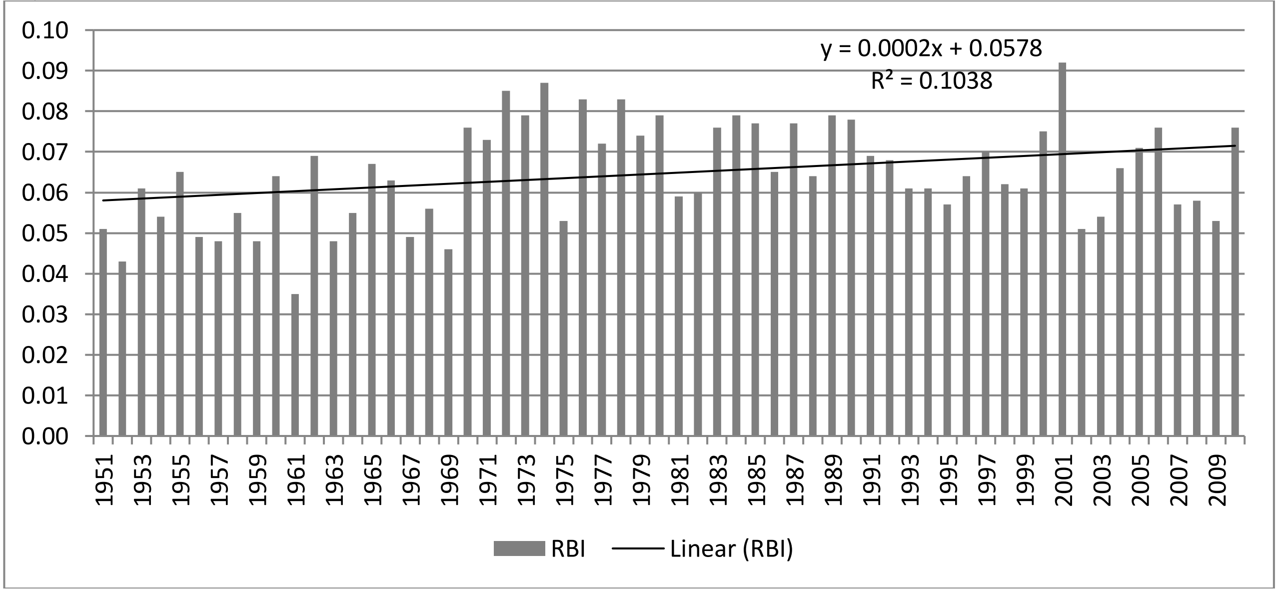
**Figure 5.** Coefficient of variation of average annual discharges of the Vistula at Tczew: a) 1951–2010, b) 1951–1980, c) 1981–2010

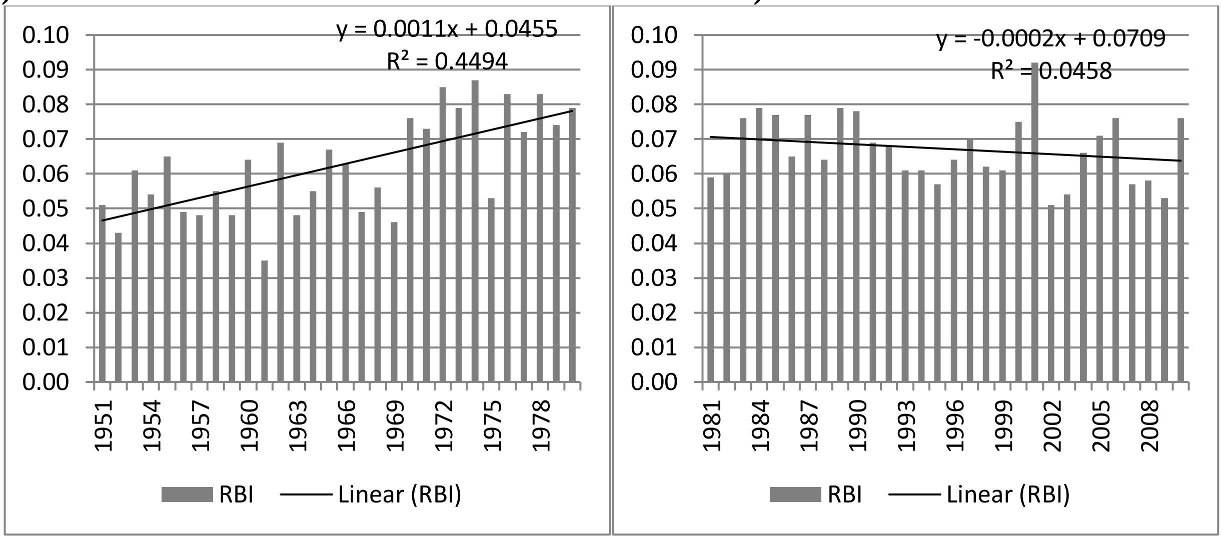
The annual RBI index values show little variability compared to other rivers, i.e. from 0.035 (1961) to 0.092 (2001). Figure 6 shows the values of the RBI index in particular years, along with trend lines for the long-term study period. Compared to other watercourses, the RBI rates are not large, which indicates a reasonably balanced flow regime over the long-term study period. This is related to the large area of the basin that is covered by the station at Tczew. The diversity of land use and time of water supply from the whole basin help to moderate the maximum flows. For example, the RBI range for rivers in the central United States averaged from 0.006 to 0.3 over the year (Fongers et al. 2008). In contrast, RBI indices for the rivers of Ethiopia are much higher and range from 0.011 to 1.113 (Bernhanu et al. 2015). The RBI index for the rivers of Slovakia and Austria ranges between 0.06 and 0.43 (Holko et al. 2011).

Over the entire period of 1951–2010, there is a noticeable upward trend in the RBI index, even though the index decreased over the last 30 years.

Fluctuations over time are visible in RBI index values. Some year-on-year fluctuations in the RBI index are visible, e.g. in 1994 had the highest RBI index (0.092), while 1995 had one of the lowest (0.51).

**6a)**




6b)

6c)

**Figure 6.** RBI index for average annual discharges of the Vistula at Tczew: a) 1951–2010, b) 1951–1980, c) 1981–2010

### 3.2.3 Seasonal discharge variability

The Vistula flow rate varies seasonally over the hydrological year. The flow regime has one clear maximum flow rate in the year, resulting from the runoff of meltwater in April (Figs 7, 8). The maxima resulting from summer rainfall (mainly in July and August) do not play a major role. The minimum flow occurs in September. The discharge in the winter half-year (Nov–Apr) constitutes 56% of the annual discharge, while the discharge in the summer half-year (May–Oct) is 44%.

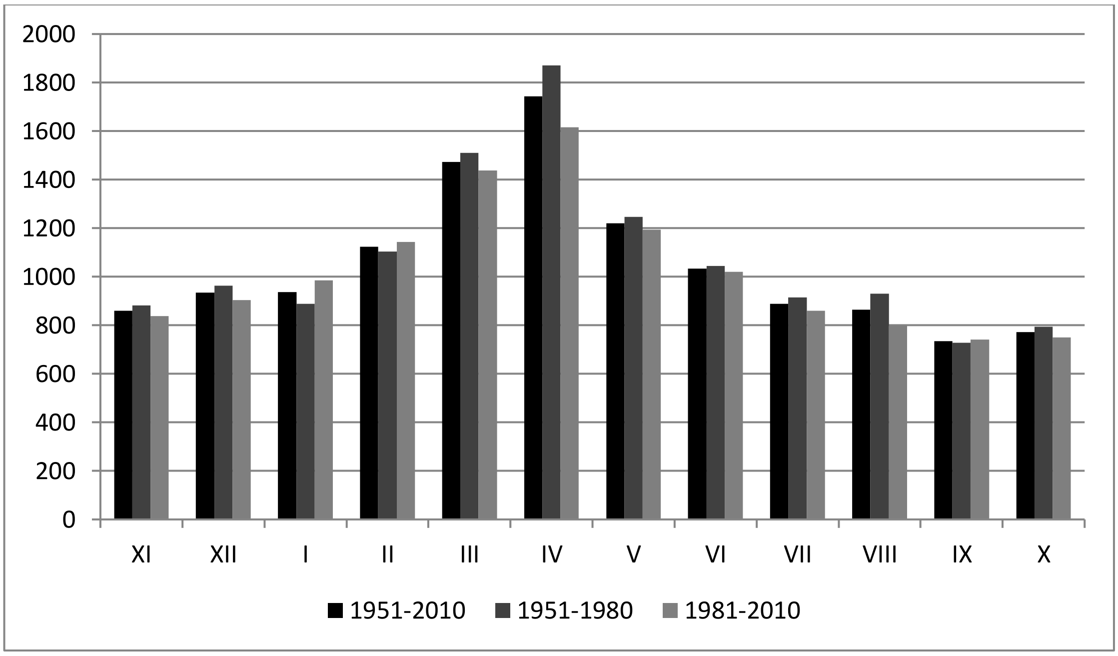


**Figure 7.** Annual course of average monthly flows (in $m^3/s$) of the Vistula at Tczew in 1951–2010

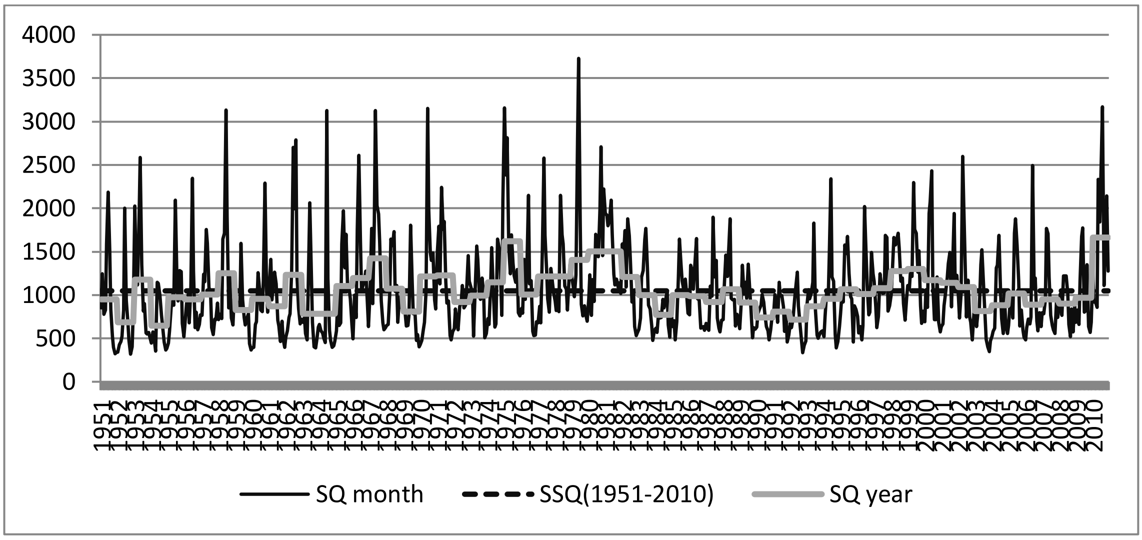


**Figure 8.** Average monthly flow (in m³/s) of the Vistula at Tczew compared against average annual and long-term average flow

## Cv and RBI indices

The highest Cv coefficients of variation were 0.82 in March (1965), and 0.76 July (1970). High Cv values most often resulted from the river being supplied by meltwaters in March and April, and rainfall in July and August. The lowest Cv values were 0.02 and occurred in September (1990), October (1961) and November (2007), which is related to low supply to the river.

Analysing average monthly RBI values revealed that in the period from 1951 to 1968, RBI ranged between 0 and 0.05, indicating only small short-term variations in flow. RBI values between 0.05 and 0.10 occurred mainly from December to April and from July to August. The maximum RBI index occurred in February 1953 (0.156) and was associated with the beginning of a meltwater surge, which lasted until April (Fig. 9). From 1970 to 2001, there is a clear increase in the RBI index throughout the year. For most months of the year, the RBI ranged from 0.05 to 0.10, while RBI values between 0.10 and 0.15 occurred mainly in June, July and August. The increase in RBI in this period is due to the fact that in these months the hydroelectric plant at the Włocławek dam switches twice daily from peak operation, to regeneration, to run-of-river mode in order to meet morning and evening peak demands. The maximum RBI value occurred in August 2004 (RBI=0.153). The high RBI value was due to large sums of precipitation (over 100 mm) in June, July and August in the south of the country. The sums of precipitation in these months were around 200 mm at some stations. High rainfall was also recorded at precipitation stations in the north of the Vistula basin, where monthly sums of precipitation exceeded 100 mm in August and were also preceded by significant July sums of precipitation. From 2002 to 2010 there was an increase in the number of months with an RBI index ranging from 0.0 to 0.05, as compared to the previous period of 1970–2001. This is most likely a result of the hydroelectric plant changing from peak operation mode to run-of-river mode. Despite this, months with RBI ranging from 0.05 to 0.1 still predominate, which may be the result of interventional water discharges from the dam to improve shipping conditions between June and October.

## 4 CONCLUSION

In the years 1981–2010 there was a drop in average annual flows of the Vistula (SSQ=1,020 m³/s) relative to the years 1951–1980 (SSQ=1,072 m³/s) and 1951–2010 (SSQ=1,048 m³/s), despite the average annual sums of precipitation in the basin in both 30-year periods being comparable to the long-term period 1952–2010.

The coefficient of variation of average annual discharges of the Vistula in the long-term period 1951–2010 has a slight downward trend. The last 30 years (1981–2010) saw an upward trend in the coefficient of variation of flows. The highest flow variabilities were in 1964 (Cv=1.0) and 1994 (Cv=0.86), while the lowest were in 1984 (Cv=0.28) and 1990 (Cv=0.29).

The annual RBI index values show little variability compared to other rivers, i.e. from 0.035 (1961) to 0.092 (2001). Over the entire long-term period of 1951–2010, there is an upward trend in this index, even though there was a downward trend in the index over the last 30 years.

Seasonal variability of flows was analysed using the monthly Cv coefficient of variation and the RBI index. The highest Cv values in the year occur in March (Cv=0.82) and July (Cv=0.76), and result from supply by meltwaters and rainfall. The lowest variability of flows is caused by a lack of rainfall and uniform supply by ground waters, and was recorded in January (Cv=0.30).

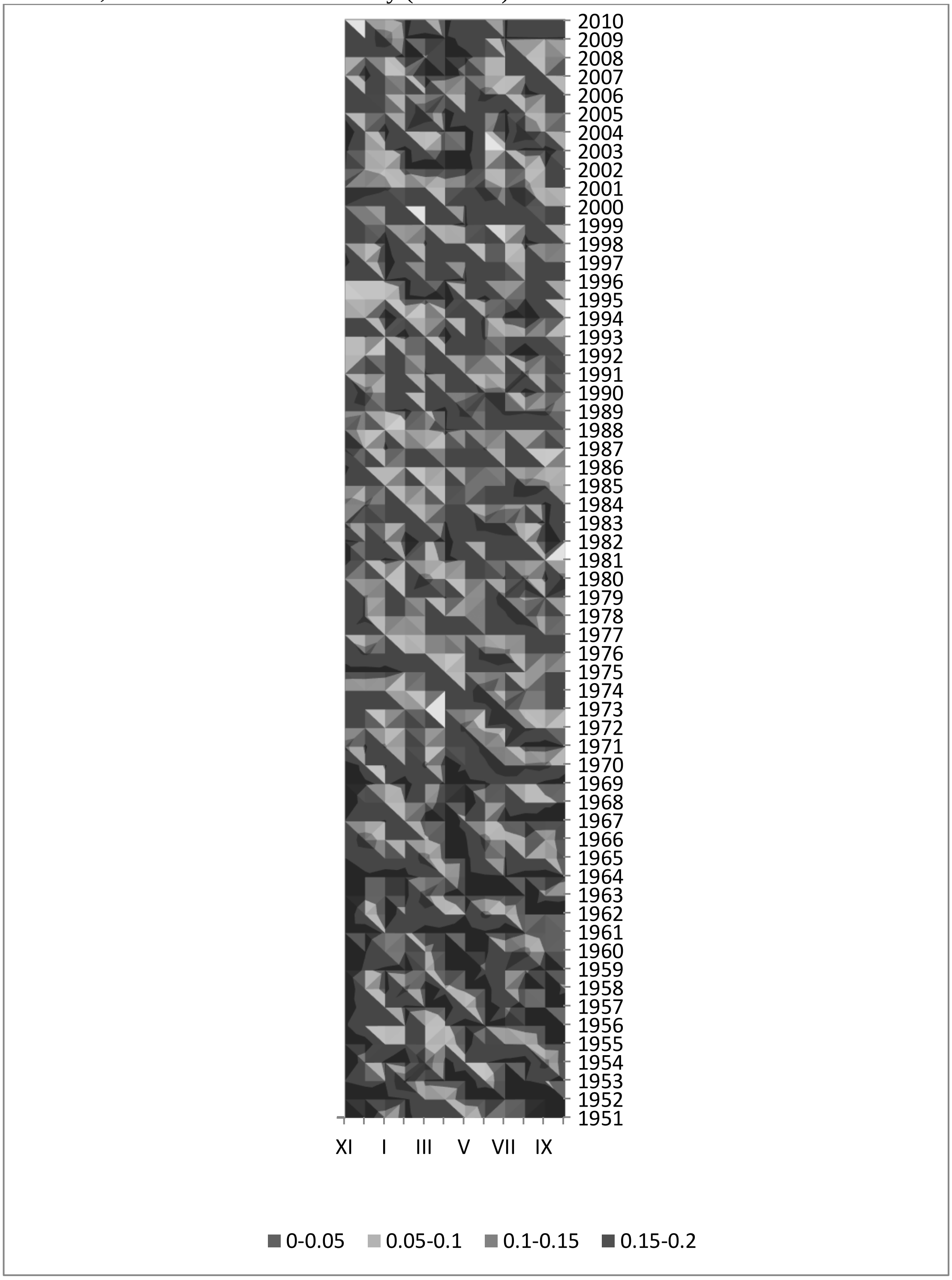


**Figure 9.** Average monthly RBI index for the Vistula in Tczew in 1951–2010

The short-term variability of flows in the Vistula was analysed using the RBI flashiness index. In the period from 1951 to 2010, monthly RBI values were higher than annual values, and ranged from 0.02 to 0.156.

In the years 1951–1969, average monthly RBI values mainly ranged between 0 and 0.05, indicating only small short-term variations in flow. From 1970 to 2001, there is a clear increase in this index throughout the year, with values from 0.05 to 0.10 dominating. High values from 0.10 to 0.15 occurred mainly in June, July and August. The increase in RBI in this period is due to the peak operation of the hydroelectric plant at the Włocławek dam. From 2002 to 2010, months with RBI in the range from 0.05 to 0.1 still predominated, despite the fact that after 2002 the power plant at Włocławek operated in run-of-river mode. The high RBI in this period may be the result of interventional water discharges from the dam to improve sailing conditions during low waters.

The RBI indicator has the advantage of showing flow dynamics in shorter time intervals than other hydrological indices. The RBI index is useful for detecting the gradual changes in flow regime that may be related to the operation of a hydropower plant or changes in water management in the basin.

## REFERENCES

Arnell, N.W. (1999). The effect of climate change on hydrological regimes in Europe: a continental perspective, *Global Environmental Change*, **9**, 5–23.

Assani, A.A., Tardif, S. and Lajoie, F. (2006). Statistical analysis of factors affecting the spatial variability of annual minimum flow characteristics in a cold temperate continental regime (southern Québec, Canada), *Journal of Hydrology*, **328**,753–763.

Atlas podziału hydrograficznego Polski. (2005). IMGW, Warszawa

Baker, D.B., Richards, R.P., Loftus, T.T. and Kramer, J.W. (2004). A new flashiness index: characteristics and applications midwesterns rivers and streams. *Journal of the American Water Resources Association*, 503–522.

Bąk, B. and Kubiak-Wójcicka, K. (2017). Impact of meteorological drought on hydrological drought in Toruń (central Poland) in the period of 1971–2015, *Journal of Water and Land Development*, **32**, 3–12, DOI: 10.1515/jwld-2017-0001

Berhanu, B., Seleshi, Y., Demisse, S.S., Assefa, M. and Melesse, A.M. (2015). Flow regime classification and hydrological characterization: a case study of Ethiopian Rivers, *Water*, **7**, 3149-3165, doi:10.3390/w7063149

Déry, S.J., Stadnyk, T.A., MacDonald, M.K. and Gauli-Sharma, B. (2016). Recent trends and variability in river discharge across northern Canada, *Hydrol. Earth Syst. Sci.*, **20**, 4801–4818, doi:10.5194/hess-20-4801-2016

Dow, L. Ch. (2007). Assessing regional land-use/cover influences on New Jersey Pinelands streamflow through hydrograph analysis, *Hydrological Processes*, **21**, 185–197, DOI: 10.1002/hyp.6232

Fongers, D. (2008). Thornapple River Watershed Flashiness Report, http://www.barrycd.org/TRWP/Appendix%202%20Flashiness%20Report.pdf

Gierszewski, P. (2006). Intensywność wymiany wody w Zbiorniku Włocławskim, *Dok. Geogr.*, **32**, 64–69.

Hall, J., Arheimer, B., Borga, M., Brázdil, R., Claps, P., Kiss, A., Kjeldsen, T.R., … Blöschl, G. (2014). Understanding flood regime changes in Europe: a state-of-the-art assessment, *Hydrol. Earth Syst. Sci.*, **18**, 2735–2772. doi:10.5194/hess-18-2735-2014

Hanel, M., Vizina, A., Máca, P. and Pavlásek, J. (2012). A multi-model assessment of climate change impact on hydrological regime in the Czech Republic, *J. Hydrol. Hydromech.*, **60**, 3, 152–161, DOI: 10.2478/v10098-012-0013-4

Holko, L., Parajka, J., Kostka, Z., Škoda, P. and Blöschl, G. (2011). Flashiness of mountain streams in Slovakia and Austria, *Journal of Hydrology*, **405**, 392–401.

Jokiel, P. 2004. Zasoby wodne środkowej Polski na progu XXI wieku. Wydawnictwo Uniwersytetu Łódzkiego, Łódź, 114 p. [in Polish]

Klavinš, M., Rodinov, V., Timukhin, A. and Kokorite, I. (2008). Patterns of river discharge: long-term changes in Latvia and the Baltic region, *Baltica*, **21** (1–2), 41–49. Vilnius. ISSN 0067-3064.

Kliment, Z. and Matoušková, M. (2008). Long-term trends of rainfall and runoff regime in Upper Otava River basin, *Soil and Water Res.*, **3**, 155–167.

Kotei, R., Kyei-Baffour, N., Ofori, E. and Agyare, W.A. (2013). Changes in the Sumampa streamflow flashiness in the forest–savannah transitional zone, Mampong-Ashant, Ghana 1985–2009, *ARPN Journal of Engineering and Applied Sciences*, **8** (9), 770–778.

Královec, V., Kliment, Z. and Matoušková, M. (2016). Evaluation of runoff response on the basis of a comparative paired research in mountain catchments with the different land use. Case study of the Blanice River, Czechia, *Geografie*, **121**, 2, 209–234.

Kubiak-Wójcicka, K. and Piątkowski, K. (2017). Evaluation of water and wastewater infrastructure in communes of kujawsko-pomorskie voivodeship. *Infrastructure and Ecology of Rural Areas*, **III/1**, 907–922, DOI: http://dx.medra.org/10.14597/infraeco.2017.3.1.070

Olden, J.D., Poff, N.L. (2003). Redundancy and the choice of hydrologic indices for characterizing streamflow regimes, *River Res. Applic.*, **19**, 101–121.

Oueslati, O., De Girolano, A.M., Abouabdillah, A. and La Porto, A. (2010). Attempts to flow regime classification and characterisation in Mediterranean stream using multivariate analysis, *International Workshop* Advances in Statistical Hydrology. May 23–25, 2010 Taormina, Italy

Pfeiffer, M. and Ionita, M. (2017). Assessment of Hydrologic Alterations in Elbe and Rhine Rivers, Germany, *Water*, **9**, 684, doi:10.3390/w9090684

Sarauskiene, D., Kriauciuniene, J., Reihan, A. and Klavins, M. (2014). Flood pattern changes in the rivers of the Baltic countries, *Journal of Environmental Engineering and Landscape Management*, DOI:10.3846/16486897.2014.937438

Spinoni, J., Szalai, S., Szentimrey, T., Lakatos, M., Bihari, Z., Nagy, A., Nemeth, A., … and Vogt, J. (2015). Climate of the Carpathian Region in the period 1961–2010: climatologies and trends of 10 variables. *International of Climatology*. **35**, 1322–1341, DOI: 10.1002/joc.4059

Štefunková, Z., Hlavčová, K. and Lapin M. (2013). Runoff change scenarios based on regional climate change projections in mountainous basins in Slovakia, *Contributions to Geophysics and Geodesy*, **43/4**, 327–350, doi: 10.2478/congeo-2013-0019

Stonevičius, E., Valiuškevičius, G., Rimkus, E. and Kažys, J. (2014). Climate induced changes of Lithuanian Rivers runoff in 1960–2009, *Water Resources*, **41**(5), 592–603, DOI: 10.1134/S0097807814050133

Ten Veldhuis, M.-C. and Schleiss, M. (2017). Statistical analysis of hydrological response in urbanising catchments based on adaptive sampling using inter-amount times. *Hydrol. Earth Syst. Sci.*, **21**, 1991–2013, doi:10.5194/hess-21-1991-2017

Zillgens, B., Merz, B., Kirnbauer, R., and Tilch, N. (2007). Analysis of the runoff response of an alpine catchment at different scales, *Hydrol. Earth Syst. Sci*., **11**, 1441–1454.