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2. MAXIMUM DISCHARGES AND MAXIMUM RUNOFFS IN POLAND

2.1. Introduction

The total river runoff from the territory of Poland averages about 61.5 $km^3 \cdot year^{-1}$. It corresponds to the mean specific discharge accounting for 5.5 $dm^3 \cdot s^{-1} \cdot km^{-2}$ and the river runoff depth reaching the value of 175 mm. Because of these values Poland is among the last countries in Europe. At the same time, the totals of the annual river discharges characterise with great long-term variability. During the wettest years Polish rivers may discharge even 89.9 km^3 of water (year 1981), while in the exceptionally dry less than 37.6 km^3 (year 1954). Relation of these values is close to 2.4 and belongs to the highest in Europe (Fal 1993).

Characteristic feature of the river runoff in Poland is not only its great temporal variability, but also similarly significant spatial variability, in spite of relatively small area of the country (Figure 2.1).

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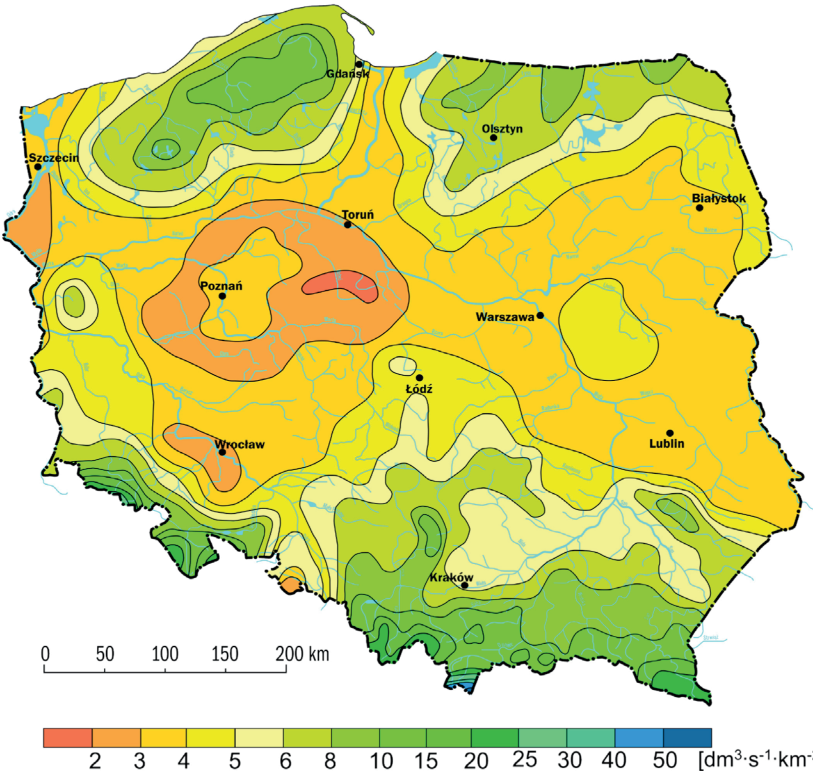

Figure 2.1. The mean specific discharge in Poland

Source: elaboration based on IMGW 1996

The mean specific discharge in the Oder River basin (4.99 $dm^3 \cdot s^{-1} \cdot km^{-2}$) is much smaller than in the Vistula River basin (5.54 $dm^3 \cdot s^{-1} \cdot km^{-2}$) (Fal 1997). The greatest mean specific discharges observed in the Tatra rivers basins (50 $dm^3 \cdot s^{-1} \cdot km^{-2}$) are more than 50 times bigger than the smallest values recorded for the lowland parts of the country (locally below 1 $dm^3 \cdot s^{-1} \cdot km^{-2}$). Their extreme values are even more differentiated. The maximum, usually episodic specific runoffs in the Sudetes often exceed 500 $dm^3 \cdot s^{-1} \cdot km^{-2}$, while in the Carpathians are greater than 1000 $dm^3 \cdot s^{-1} \cdot km^{-2}$ and reach even 3000 $dm^3 \cdot s^{-1} \cdot km^{-2}$ (Dobrowolski et al. 2007, Byczkowski 1996, Bryndal 2009). In lowlands, the minimum specific discharges are smaller than 0.1 $dm^3 \cdot s^{-1} \cdot km^{-2}$, while in uplands and mountainous territories of the country they reach 2–3 $dm^3 \cdot s^{-1} \cdot km^{-2}$. In the North of Poland they are about 5 $dm^3 \cdot s^{-1} \cdot km^{-2}$. In Polish rivers flooding levels and low water levels may appear in the same year. The spatial distribution of the river runoff depends mainly on the diversification of the geophysical conditions and the country location within the transitional climate zone. The differences are visible both in the local and in the regional scale.

Despite the fact that extreme meteorological and hydrological phenomena in Poland are not of such a great dimension as in the other parts of the world, torrential rainstorms and river flash floods seriously threaten economy and even people's lives. The richer infrastructure and higher development level, the bigger losses caused by flood waters are. Hence, it is easy to show that the losses being the results of floods increase with the economic growth and civilisation development. In spite of many efforts and undoubted achievements in flood controlling, sensitivity of our environment to flood disasters is great and is still growing.

In Polish conditions, river surges and accompanying floods appear all over the year. Due to their time of appearance and their causative factors, a few types of surges, and as a consequence a few types of floods can be distinguished. The most important is the division considering causative agents. Genetic types of surges that can be differentiated are as follows: rainfall, snow-melt, winter and storm surge. Some of them can be divided into sub-types, e.g. among winter surges there are frazil-ice surges, ice surges and ice jam surges (Byczkowski 1996, Bartnik and Jokiel 2012). All surge types mentioned here can be divided into two basic groups: surges caused by an increased inflow and surges being results of water affluxes in river beds and hindered runoffs. Usually, the favourable conditions for river flash floods are as follows: disadvantageous atmospheric conditions, small retention efficiency of the river drainage basin and river valley, improper hydro-technical structures, deforestation or urbanisation of the catchment's area, building catastrophes and many other local factors.

Basing on many years observations particular types of surge areas in Poland can be distinguished today. On lowlands and Lubelska Upland the most frequently occurring are snow-melt surges. In Małopolska, in the south of Mazowsze, in Silesia and in Bieszczady Mountains rainfall and snow-melt surges predominate. While in Sudety and Carpathian Mountains rainfall surges are very often. Seasons of the biggest frequency of the particular surges, as well as the average number of surges in specific region within the year, can be also determined (Mikulski 1963, Byczkowski 1996, Dobrowolski et al. 2007, Bryndal 2009, Bartnik and Jokiel 2012).

River surges may be investigated in many different ways, beginning with a more or less formal description of the shape and the parameters of the flood wave (e.g. its volume, depth, time of propagation and going down), the estimation of its frequency and the analysis of the influence of the causative factors (e.g. climatic changes, river basin character and its hydrological cycle), to the process of building of a surge model. The last one helps not only to foresee a flood's shape, a peak size or a volume, but also to estimate the risk of its appearance and to forecast possible results.

One of the most important and most interesting aspects of studies on global warming consequences is predicting changes, which can appear at the extremes of a hydrological cycle, including instantaneous discharges and runoffs, as well as surges types and frequencies. The conclusions are, so far, rather unambiguous and, in principle, independent on the forecasting procedures (empirical or theoretical). They usually lead to conclusions that in small and medium river basins, global warming causes an increase in depth and frequency of river floods, not only in the aspect of the absolute extremes, but also in seasonal characteristics.

2.2. Materials and methods

In the chapter, an attempt to systematise and to investigate maximum floods (WWQ described in $m^3 \cdot s^{-1}$) and corresponding specific discharges (WWq described in $dm^3 \cdot s^{-1} \cdot km^{-2}$) observed in 1951–2006 for

462 Polish gauging sections was made. The considered river basins are diversified and ranged from 4.1 to 194 376 km^2. The investigated cross-sections are located in different regions of Poland (Figure 2.2).

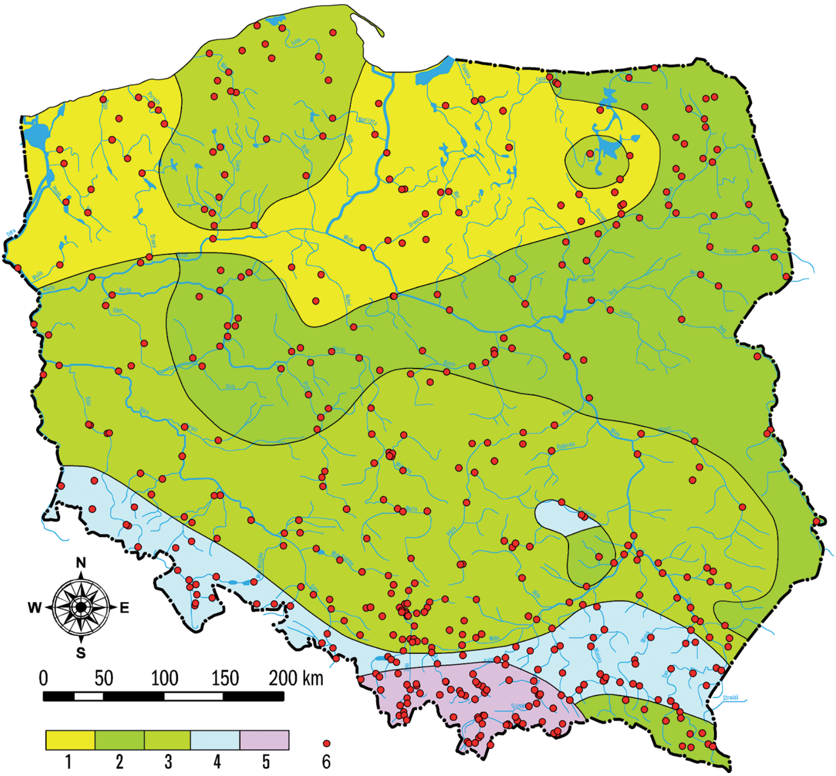

Figure 2.2. Observed gauges and the hydrological river regimes in Poland
1 – nival underdeveloped, 2 – nival well-developed, 3 – nival medium-developed, 4 – nival-pluvial, 5 – pluvial-nival, 6 – observed cross-sections

Source: elaboration based on I. Dynowska (1971), A. Bartnik and P. Jokiel (2012)

Treated as a group they represent the spectrum of all conditions influencing formation of maximum runoffs in our country. It is worth noticing that the authors had at their disposal significantly greater number of registered maxima (data came from 885 cross-sections). However, the only data that was taken into consideration were from at least 20-year-long series. Time encompassed by the series was insignificant (Figure 2.3). We acknowledged that the WWQ values from the shorter series should not be used in such statistical analyses.

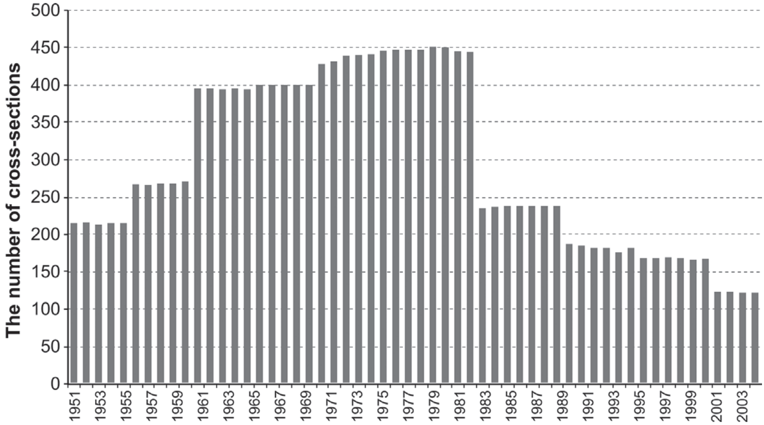

Figure 2.3. The number of cross-sections observed in particular years

Source: own elaboration

All attempts were made to answer the following questions: if and in what way the frequency and the depth of maximum discharges and runoffs were changing in the perennial scale? If there are any proofs that in our country the number and depth of maximum instantaneous discharge peaks and the number of river floods is increasing? The analyses were conducted basing on the high water indexes previously defined by the authors (Bartnik and Jokiel 2007, 2008) and relying on Françou-Rodier index (K). A couple of comments on a seasonal differentiation of WWQ in long-term period and the attempts to outline the spatial variability of WWQ and WWq in Poland were also presented.

In the consecutive analysis from the previously mentioned set of gauging stations the 388 observation points with known annual river discharge were chosen (Figure 2.4). Most of them were located in the Vistula River catchment (221), the remaining stations were placed in the Oder catchment and in the North of Poland (117).

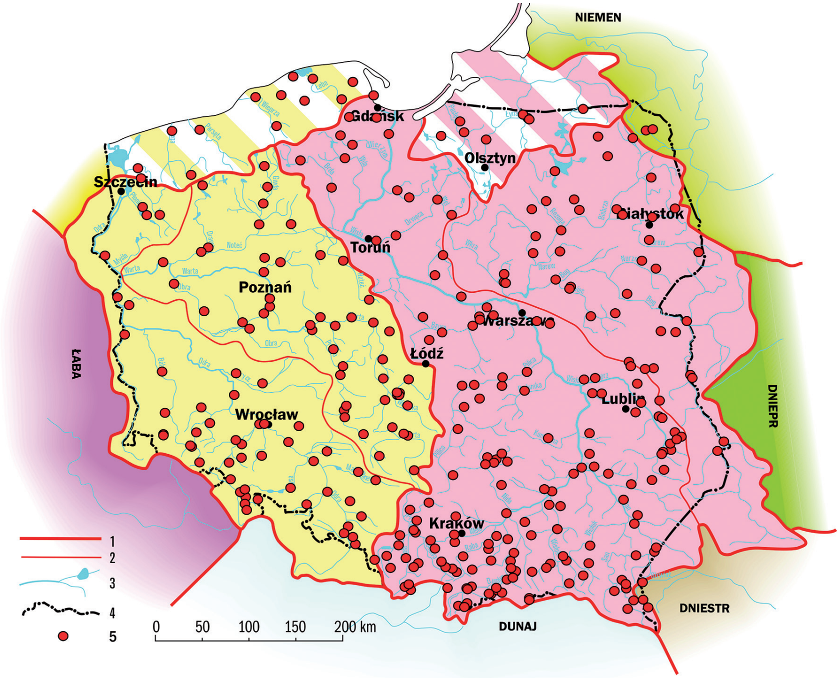

Figure 2.4. Spatial distribution of the gauging stations completed with information of annual discharges in 1951–2010 period

1 – main drainage divides, 2 – secondary drainage divides, 3 – rivers and lakes, 4 – county borders, 5 – gauging stations

Source: own elaboration

The chosen water gauges were at the outlets of basins, which were placed in the different regions of Poland. These basins characterised with different water regimes and diversified magnitudes of mean annual river discharge and mean groundwater discharge (Figures 2.1, 2.2, 2.4 and 2.5). Therefore, the studied set of stations represents the full spectrum of geographical and hydrological conditions appearing in the territory of Poland. Moreover, the considered stations were relatively evenly distributed in space.

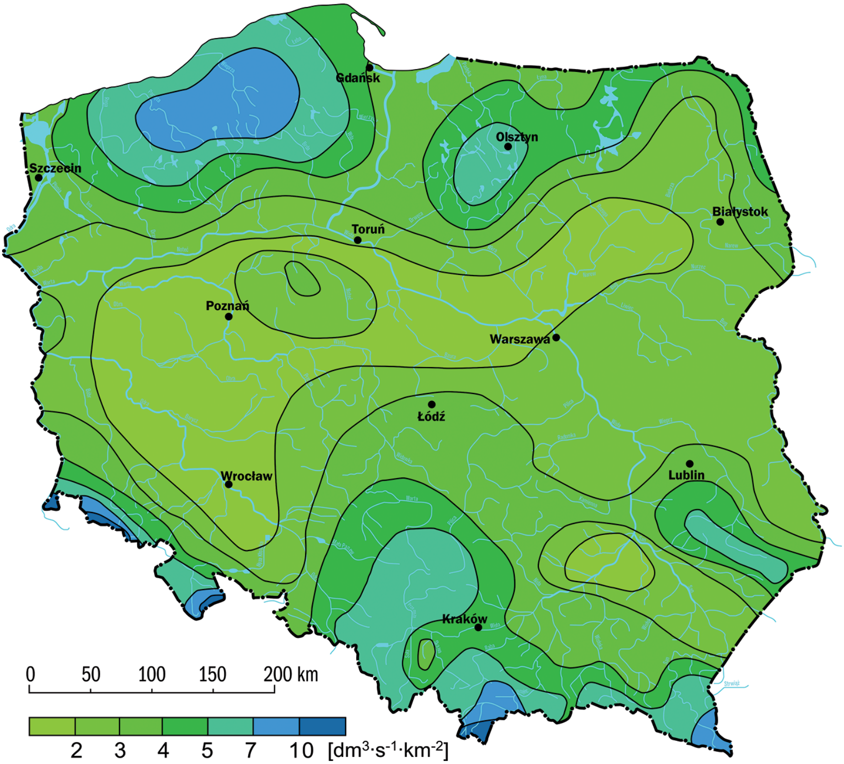

Figure 2.5. The mean specific groundwater runoff in Poland

Source: elaboration based on P. Jokiel (1994)

In the Vistula River catchment, the studied basins areas ranged between about 4 km^2 (the Strążyski Torrent to Zakopane) and 194 376 km^2 (the Vistula River to Tczew). Within the Oder River catchment, the range was narrower: from 35 km^2 (the Wilczka River to Wilkanow) to 109 729 km^2 (the Oder to Gozdowice). The average area of the studied basins was almost equal to 5300 km^2, while one out of four basins had the area larger than 2300 km^2.

The hydrometric records, which have been taken into consideration in this analysis had been obtained between 1951 and 2010. The annual sum of river runoff (V_R) was calculated for each year of the investigated period and for each studied basin. The received data series were of different lengths and involved different time intervals. Therefore, only series of the minimum length of 10 years were taken for the analysis. Hence, not the time intervals but the series lengths were important in the particular gauging cross sections. The series lengths within the set of river basins were fairly differentiated. The greatest number of the sequences recorded was of the length between 21 and 30 years. For only 11 cross sections the recorded sequences included the whole period of measurements. The length of 25% of series was greater than 41 years. As a result the number of data in different terms was diverse. For example, between 1971–2006 the data was gathered for 200 water gauging stations, while the number of considered basins records from the 1950s and from the end of the last decade slightly exceeded 50 (Figure 2.6).

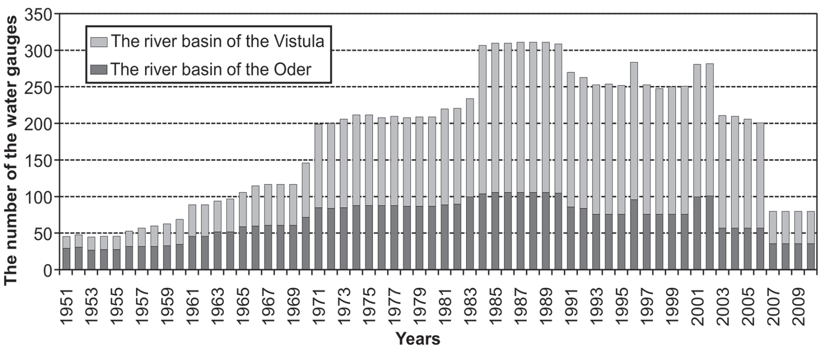

Figure 2.6. The number of gauging stations and the information of annual runoff in the particular years of the studied period

Source: own elaboration

The year during which the annual river runoff was the greatest was identified for each investigated basin (R_{Vmaks}). It should be pointed that the relative and absolute values of runoff records, as well as their spatial distribution and dynamics were not the issues of this analysis. Of great importance was their position on the time axis and relative frequency in the particular years of the long-term period. In the following analysis, for each year and for both big Polish river catchment areas (the Vistula and the Oder) the frequencies of occurring of the biggest annual runoff records in two sets of basins were calculated. Particular years (sometimes years sequences) during which the appearance of the biggest annual river runoff records for both river catchment areas had very small or very big frequency were identified (Jokiel and Stanisławczyk 2013). An attempt was made to answer the question whether years of the biggest annual river runoff had appeared synchronically in both river catchment areas. An important aspect of this analysis was to evaluate the differences and similarities between two catchment areas, in relation to the two sets of river basins. The calculated greatest mean specific discharges (q_{Rmaks}) let to define for both river catchment areas (the Vistula and the Oder) the formulas of the envelope curves, which show in scale of two extensive catchment areas and in function of basins area the specific limits of maximum annual runoff values.

2.3. Maximum discharges and runoff floods

During a flooding event a great amount of water flows downstream a river. Its volume depends on the size and the character of the catchment's area and the river. Maximum discharge floods of Polish rivers, regarding climatic and hydrographical conditions of our country, are not equal in magnitude to the observed world's maxima. The Amazon River, when flooding transfers to the Atlantic volume of water of about 200 thousands $m^3 \cdot s^{-1}$, the Yenisey – 100 thousands $m^3 \cdot s^{-1}$, while the Mississippi – 70 thousands $m^3 \cdot s^{-1}$. In comparison with these discharge floods, the Vistula and the Oder maximum discharges are not so impressive: the Vistula near river mouth – about 8 thousands $m^3 \cdot s^{-1}$; the Oder – 3.3 thousands $m^3 \cdot s^{-1}$. The maximum specific runoff floods calculated for the peaks of the maximum observed discharge floods in the rivers of our country are much lower than maximum specific runoff floods registered in the world (Shaw 1994, Herschy 1998, Smith and Ward 1998, Arnell 2002, Ozga-Zielińska et al. 2003, O'Connor and Costa 2004, Jokiel and Tomalski 2004, Bartnik and Jokiel 2012 – Figure 2.7), although the differences between them are not so significant.

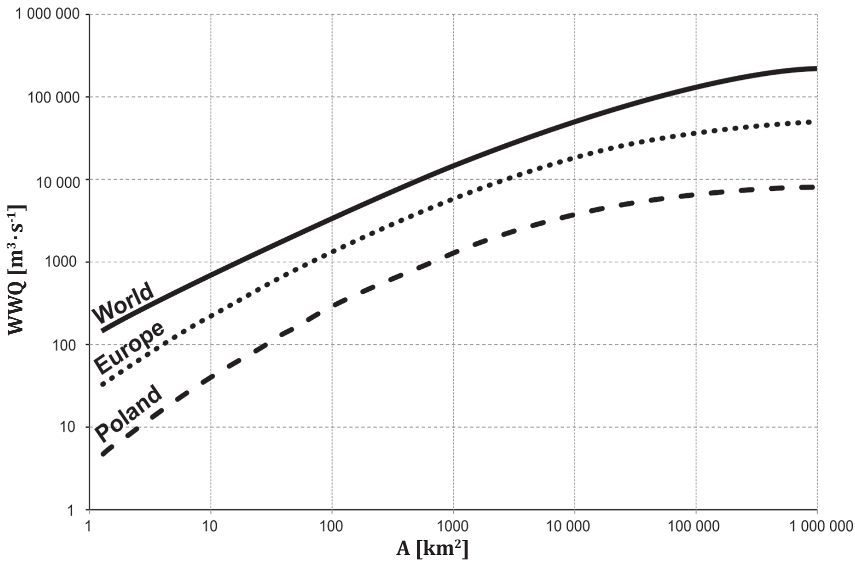

Figure 2.7. Envelope curves for maximum river discharge floods (WWQ) and river basins areas (A) ratios for the obtained data

Source: own elaboration

Theoretical investigations and observations conducted on experimental plots and small river basins indicate that, in extremely disadvantageous conditions the maximum specific runoff floods in mountains and uplands may even reach the value of 35 thousands $dm^3 \cdot s^{-1} \cdot km^{-2}$, while in the lowlands until 12 thousands $dm^3 \cdot s^{-1} \cdot km^{-2}$ (Smith and Ward 1998). The theoretical boundary for specific maximum runoff in Poland is assumed to be close to 30 thousand $dm^3 \cdot s^{-1} \cdot km^{-2}$ (Byczkowski 1996, Stachý et al. 1996). This value is not only confirmed by the measurements and forecasts of the maximum runoff floods for the small basins affected by violent thaws presented by Ciepielowski (1970), Twaróg (2004), Dobrowolski et al. (2004), Bryndal (2009) and authors (2012), but also by theoretical estimations obtained by using different empirical formulas and hydrological models (Byczkowski 1996, Soczyńska 1997, Ozga-Zielińska et al. 2003, Ostrowski and Zaniewska 2007).

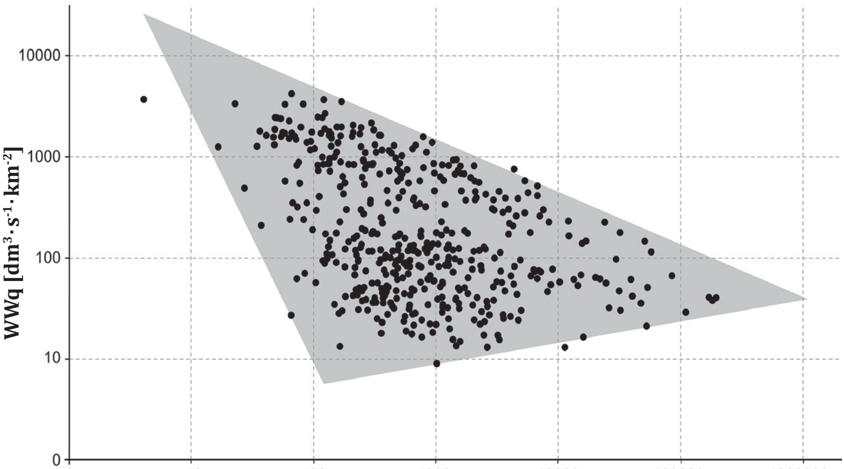

Figure 2.8. The variability area of the maximum specific runoff (WWq) and drainage area (A)

Source: own elaboration

The maximum discharge floods of Polish rivers are significantly smaller than the maximum discharges registered for the greatest rivers of the world. Within the investigated group of basins maximum discharges ranged from 1.78 to 7840 $m^3 \cdot s^{-1}$. The envelope curves plotting maximum observed floods (WWQ) against their drainage areas (A) obtained by the authors for northern hemisphere (eq. 2.2), Europe (eq. 2.3) (Bartnik and Jokiel 2007, 2008), and for the analysed data from Poland (eq. 2.4) are shown in Figure 2.7. The envelope curve calculated for all the rivers in the world calculated by Rodier and Roche (1984) (eq. 2.1) is also presented here. The functions of these curves may be estimated from:

$$WWQ_{SW} = 500 \cdot A^{0.43} \tag{2.1}$$

$$\log WWQ_{PP} = -0.053 \cdot (\log A)^2 + 0.858 \cdot \log A + 1.914 \tag{2.2}$$

$$\log WWQ_{EU} = -0.0899 \cdot (\log A)^2 + 1.083 \cdot \log A + 1.13 \tag{2.3}$$

$$\log WWQ_{PL} = -0.097 \cdot (\log A)^2 + 1.14 \cdot \log A + 0.546 \tag{2.4}$$

where:

WWQ_X – maximum discharge [$m^3 \cdot s^{-1}$],
$_{SW}$ – world,
$_{PP}$ – northern hemisphere,
$_{EU}$ – Europe,
$_{PL}$ – Poland,
A – drainage area [km^2].

During discharge peaks, in basins of given drainage areas, the functions presented here can be treated as peculiar discharge size boundaries. It is easy to observe that the envelope curve calculated for the studied Polish rivers peak discharges is estimated by the same function as the function for the northern hemisphere and Europe (parabola 2º). However, this function is located much "lower" than the three other functions. For the given drainage area discharge peaks observed in Poland are several times smaller than the culminations registered in Europe. This ratio, however decreases with increasing A.

Table 2.1. Maximum discharges and maximum specific runoffs in the categories of the basins drainage areas

River	Gauge station	Drainage area [km^2]	WWQ [$m^3 \cdot s^{-1}$]	WWq [$dm^3 \cdot s^{-1} \cdot km^{-2}$]
1	2	3	4	5
Drainage area > 100 000 km^2				
Wisła	Płock	169 494	6 900	40.7
Wisła	Tczew	194 376	7 840	40.3
Wisła	Toruń	181 033	6 890	38.1
Wisła	Włocławek	172 389	6 080	35.3
Wisła	Kępa Polska	168 956	5 820	34.4
Odra	Gozdowice	109 729	3 180	29.0
Odra	Widuchowa	110 524	1 670	15.1
10 000 km^2 < Drainage area < 100 000 km^2				
Wisła	Popędzynka	10 704	2 650	247.6
Wisła	Jagodniki	12 058	2 800	232.2
Wisła	Szczucin	23 901	5 410	226.4
Wisła	Sandomierz	31 846	5 690	178.7
San	Rzuchów	12 180	2 020	165.8
Wisła	Karsy	19 857	3 130	157.6
Wisła	Annopol	51 518	7 960	154.5
San	Radomyśl	16 824	2 480	147.4
Wisła	Zawichost	50 732	7 450	146.9
San	Nisko	15 595	2 180	139.8
1000 km^2 < Drainage area < 10 000 km^2				
Raba	Proszówki	1 470	1 390	945.6
Soła	Oświęcim	1 386	1 300	938.0
Dunajec	Czorsztyn	1 124	941	837.2
Dunajec	Sromowce Wyżne	1 269	1 050	827.4
Dunajec	Gołkowice	2 047	1 680	820.7
Dunajec	Krościenko	1 579	1 290	816.8

1	2	3	4	5
Dunajec	Nowy Sącz	4 341	3 300	760.2
Poprad	Muszyna	1 513	1 120	740.0
San	Lesko	1 613	1 110	688.1
Poprad	Muszyna – Milik	1 695	1 160	684.4
100 km^2 < Drainage area < 1 000 km^2				
Sękówka	Gorlice	121.2	450	3 712.9
Hoczewka	Hoczew	169.0	601	3 556.2
Wielki Rogoźnik	Ludźmierz	124.0	336	2 709.7
Wisła	Ustroń – Obłaziec	108.2	270	2 495.4
Biała	Czechowice – Bestwina	118.0	291	2 466.1
Wisła	Skoczów	296.7	648	2 184.0
Biały Dunajec (Cicha Woda)	Szaflary	210.0	435	2 071.4
Wiar	Rybotycze	169.0	336	1 988.2
Łososina	Piekiełko	155.0	308	1 987.1
Skawa	Osielec	244.0	478	1 959.0
Drainage area < 100 km^2				
Złotna	Miszkowice	21.9	208.0	9 497.7
Bystra	Zakopane – Kuźnice	16.2	76.0	4 691.4
Kamionka	Jamnica	62.5	271.0	4 336.0
Kamienica Nawojowska	Łabowa	66.1	281.0	4 251.1
Wapiennica	Podkępie	52.9	199.0	3 761.8
Strążyski Potok (Młyniska)	Zakopane – Dolina Strążyska	4.1	15.3	3 731.7
Kamienna	Jakuszyce Dolne	5.8	20.9	3 603.4
Żabniczanka	Żabnica	22.8	77.2	3 386.0
Brennica	Górki Wielkie	82.2	276.0	3 357.7
Biały Dunajec (Cicha Woda)	Zakopane – Harenda	58.4	195.0	3 339.0

Source: elaboration based on A. Bartnik and P. Jokiel (2012).

The maximum specific runoff floods from the studied Polish basins are within a wide range: from 9 to 9498 $dm^3 \cdot s^{-1} \cdot km^{-2}$ (Table 2.1). This range is almost the same as the range received thanks to flood simulations for small basins (rainfall 1%) using MOREMAZ-2 model – within Small Basins Programme (Ostrowski and Zaniewska 2007). The scope of WWq variability, which is determined by diversified basins areas, is shown in Figure 2.8. Only 70 control cross-sections were characterised by runoff floods exceeding 1000 $dm^3 \cdot s^{-1} \cdot km^{-2}$, while in 2/3 cross-sections maxima were smaller than 500 $dm^3 \cdot s^{-1} \cdot km^{-2}$. It is worth mentioning that the discharges. which were bigger than 1000 $dm^3 \cdot s^{-1} \cdot km^{-2}$, were observed only in basins of drainage areas smaller than $1.0 \cdot 10^3$ km^2.

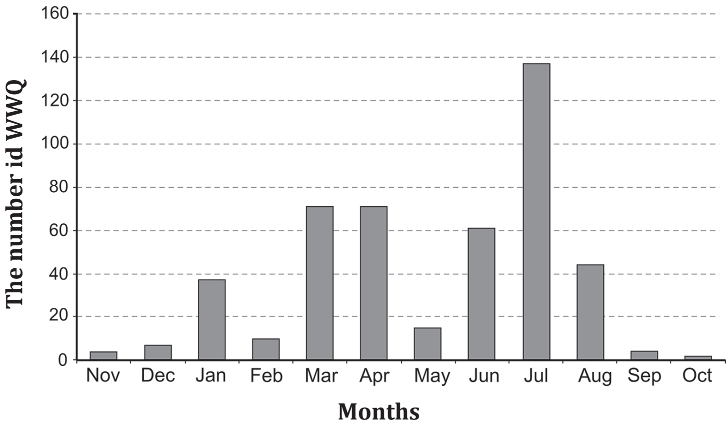

Figure 2.9. The number of WWQ's in particular months

Source: own elaboration

Interesting conclusions can be drawn from the analysis of WWQ frequency in particular months of the year. As it can be clearly seen in Figure 2.9 among 462 events, 137 were registered in July, while 142 were observed in March and April (71 events each month). It should be emphasized that WWQ appears in Polish rivers in each month, even in autumn from September to November). During the cold half-year the number of registered maxima was smaller than in the warmer half-year (44% in contrast to 56% of all WWQ).

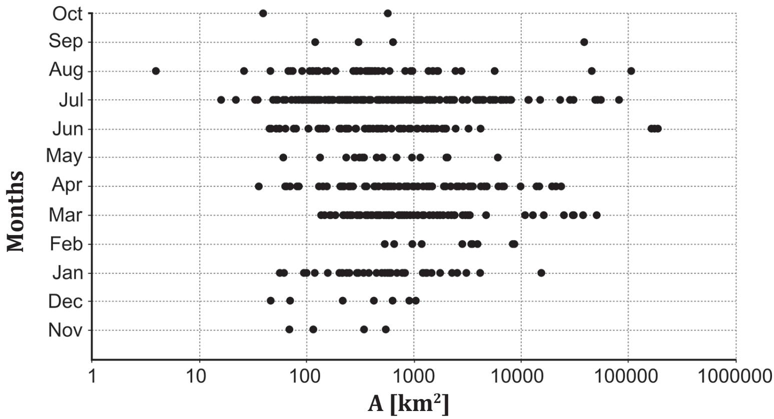

Figure 2.10. WWQ terms in function of drainage areas

Source: own elaboration

It is worth seeing the time of the appearance of WWQ from the angle of drainage areas (Figure 2.10). We will notice then that the autumnal peaks (IX–XII) appeared only in small and medium basins (50–1000 km^2), while in large ones (>10^4 km^2) the WWQ were observed almost only in March and April and from June to July. The greatest specific discharges were recorded while summer floods (VI–VII), but at the same time a few autumnal and May floods were characterised by greater specific discharges than spring flood peaks (III–IV).

2.4. K indexes

The relative parameter which enables to valorise maximum runoffs is *Françou-Rodier index* or *K index* (eq. 2.5) (Françou and Rodier 1969, Rodier 1987, Smith and Ward 1998, Jokiel and Tomalski

2004, Twaróg 2004, Bartnik and Jokiel 2007, 2008). It is based on a simple transformation of the envelope curve equation of maximum flows (Françou and Rodier 1969). The K index is given by:

$$K = 10 \cdot (1 - \frac{\log WWQ - 6}{\log A - 8}) \tag{2.5}$$

notations as above.

K index is a non nominal value, it allows to compare sizes of flood peaks in river basins of different areas. In the opinions of the authors cited above, the higher the index is the greater river basin susceptibility to flood occurrence becomes. It is, therefore, a measurement of river "floodness". In some conditions it can be treated as a peak estimator of the *reliable maximum of the flood* (cf. Ozga-Zielińska et al. 2003).

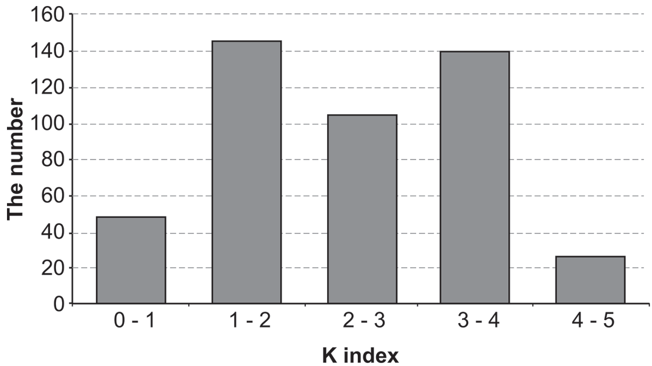

Figure 2.11. Françou-Rodier indexes of Polish rivers in 1951–2006

Source: own elaboration

K indexes for different rivers of the Earth were presented in the issue by Smith and Ward (1998). The Amazon River is characterised by the greatest K index – 6.76. Slightly lower values were registered for Japanese Shingu Oga River – 6.29, the Indian Narmada River

– 6.21 and the North American West – Nueces River – 6.16. Russian Kolyma River is also characterised by the index exceeding 6.0 (6.39). Extremely high K index was calculated for "jökulhlaup" flood for Island river Skeidara – 7.34 (Bartnik and Jokiel 2007, 2012). Taking K into account, the biggest susceptibility to floods have Asian rivers, the smallest characterises the European rivers. According to the studies on the three continents of the northern hemisphere (Northern America, Asia and Europe) 80% of the K indexes range from 2.1 to 5.1 with median value close to 3.8 (Bartnik and Jokiel 2008).

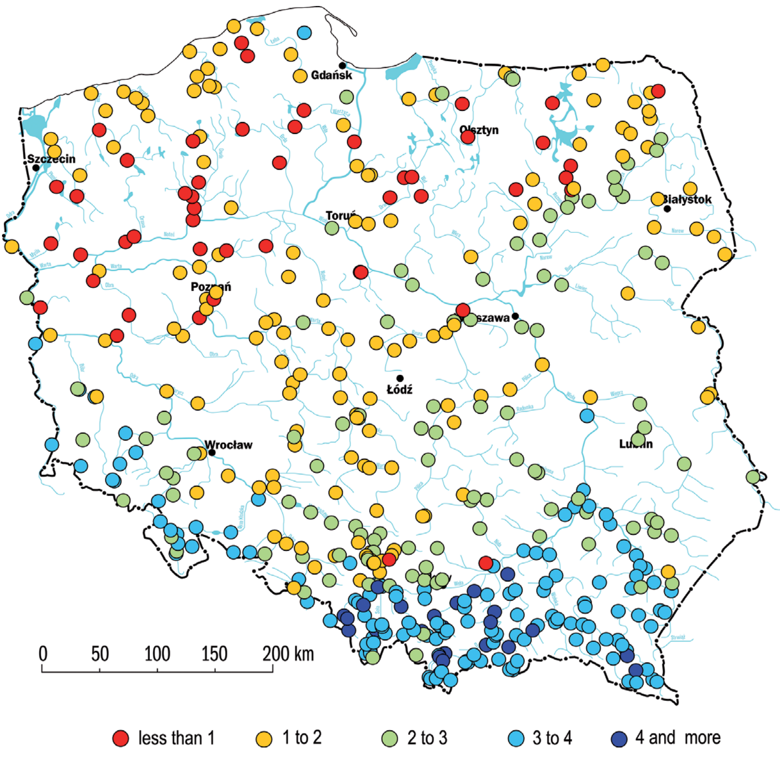

Figure 2.12. Diversification of the K indexes in Poland

Source: elaboration based on A. Bartnik and P. Jokiel (2012)

K indexes of the European rivers may be also high: the French Tech in Pas du Loup River – 5.61, the British Divie River – 5.01, the Italian Orba River – 5.46, while the Spanish Almanzore River – 5.24 (Bartnik and Jokiel 2007). From the previously mentioned calculations made by the authors it can be concluded that 90% of K values obtained for the European rivers is within the range between 1.77 and 4.87. At the same time, theoretical probability of exceeding K = 4.87 for the rivers on our continent is equal to 5%.

So far calculated K indexes for Polish rivers have not exceeded 5.0; the Lopuszanka River (Piaski) – 4.64; the Kamienica River (Labowa) – 4.26; the Miechowka River (Miechow) – 4.42; the Dunajec River (Nowy Sacz) – 4.31 (Twaróg 2004, Jokiel and Tomalski 2004, Bartnik and Jokiel 2012). Only in less than 10% cases K indexes were higher than 3.5. Even during the memorable flood in Oder catchment area in 1997 K indexes for flood waves culminations were smaller than 4.0.

In the studied group of cross-sections K indexes are within the range: from slightly above 0 to 4.42 (average – 2.37; Cv – 46%). Indexes greater than 4.0 were rather rare (Figure 2.11) and concerned mainly Carpathian rivers – Figure 2.12 (see in Twaróg 2004, Jokiel and Tomalski 2004, Bartnik and Jokiel 2012). The bimodal character of the frequency distribution also draws our attention. Similarly frequent (140 cases each) were the indexes from the ranges: below the average (1–2) and above the average (3–4). The former concerns mainly lowland rivers, the latter – mountain rivers.

From the analysis of Figure 2.13 some conclusions arise from the half of the 1980s to the end of the studied period the number of WWQ clearly decreased in comparison with the previous multiyear period. At the same time, the peaks registered for last 20 years long period were usually relatively high (average K > 3.0) and two floods were characterised by K values higher than 4.0. It seems that, WWQ are recorded rarely in cold half-year months, but if they appear their K indexes are quite high. Particularly numerous floods with great K indexes were noted down in July 1997 (WWQ were observed for

31 rivers and their average K were greater than 3.0). Similar was the year 1970 – 15 floods with average K > 3.0. Even more WWQ were registered in March and April 1979 (38 and 31). However, the average K indexes of these floods were smaller than 2.0. Similar number of WWQ was recorded in June 1980, but this time, the average K was much higher than 2.0 (Figure 2.13).

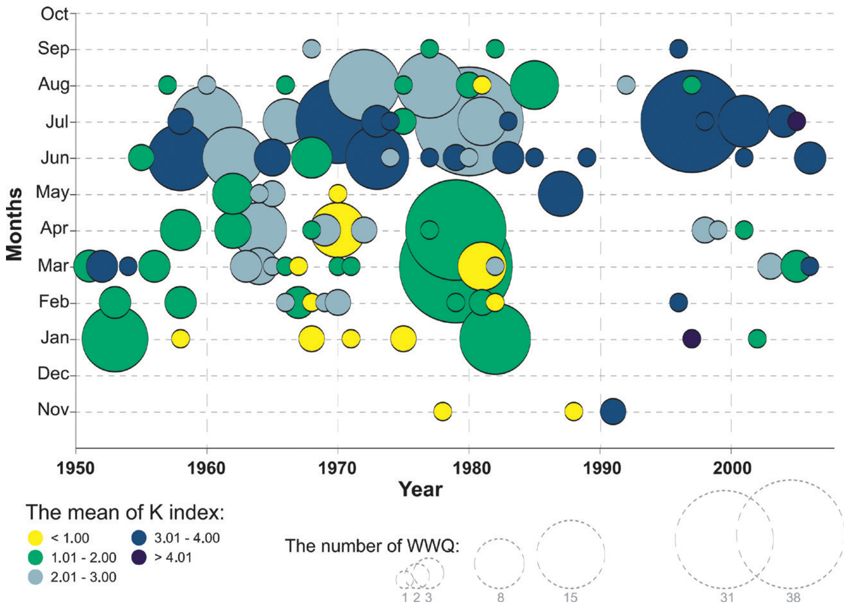

Figure 2.13. The number of WWQ and average coefficients in particular months of multiyear period

Source: own elaboration

The image of multiyear and seasonal variability of terms and absolute scales of the flow peaks, depicted above, should be examined in the temporal and numeral context of the studied series as well as in the context of the fact that one of the series is always represented by one WWQ value.

2.5. High water level indexes

According to the previously presented idea of the high water level index – IWW (Bartnik and Jokiel 2007) for each year of the period of investigations (1951–2006), we calculated the total number of maxima (WWQ) registered for Polish rivers. The obtained data was presented as percent values, with reference to the number of observed rivers in particular year – WW (Figure 2.14A). This indicator shows in how many percent of the studied Polish rivers we registered WWQ (the greatest streamflow of a given river during observation period).

Each absolute maximum of a river flow (WWQ) is described by a comparable and non-nominal K index, which characterises the scale of the event. Hence, a product of WW and the sum of K indexes calculated for each year allows to estimate not only the relative numerical strength of the maxima in our country, but also to compare their scale in relation to the particular years of the multi year period. As a consequence it enables a temporal analysis of the probable changes of so called "Polish floodness":

$$IWW_i = WW_i \cdot \sum_{j=1}^{N} K_i \qquad (2.6)$$

where: IWW_i – high water level index for an i year, WW_i – high water level indicator for an i year, K_i – K index for an i year, N – the number of rivers for which WWQ were registered in an i year.

In relation to the number of cross-sections, which had at least 20 years long series, the greatest percentage of the maxima were recorded in 1997 (about 19%), in 1979–1980 (16% and 8%) as well as in 1958 and 1970. At the same time in the years: 1959, 1961, 1976, 1984, 1986, 2000 and almost during the whole time period between 1990–1995, WWQ were observed for none of Polish rivers – Figure 2.14A. Taking into account the relative number of WWQ, in particular years and their scale measured by K indexes – IWW_P, it can be seen even more clearly the domination of the 1997 and previously mentioned years of high water levels (Figure 2.14B).

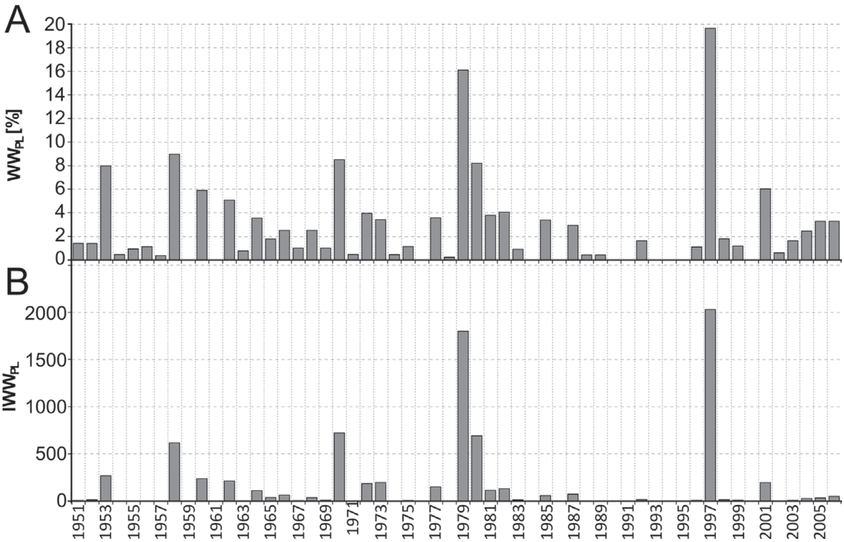

Figure 2.14. High water level indicators (A) and high water level indexes (B) in multiyear period

Source: own elaboration

It is worth mentioning that during last 20 or 30 years, neither the number nor the relative size of maximum river runoffs in Poland increased, but were even slightly smaller than in 1951–1980. Therefore, it seems that the problems of the size and the direction of the influence of the contemporary observed climatic changes on the increase of frequency and scale of extreme hydrological phenomena in Poland (e.g. runoff peaks) is still arguable. Conclusions are, therefore, not simple relationships between causes and effects.

Perennial changeability of Polish rivers susceptibility to floods, measured by IWW, can be seen from the angle of northern hemisphere and the European rivers susceptibility (Figure 2.15).

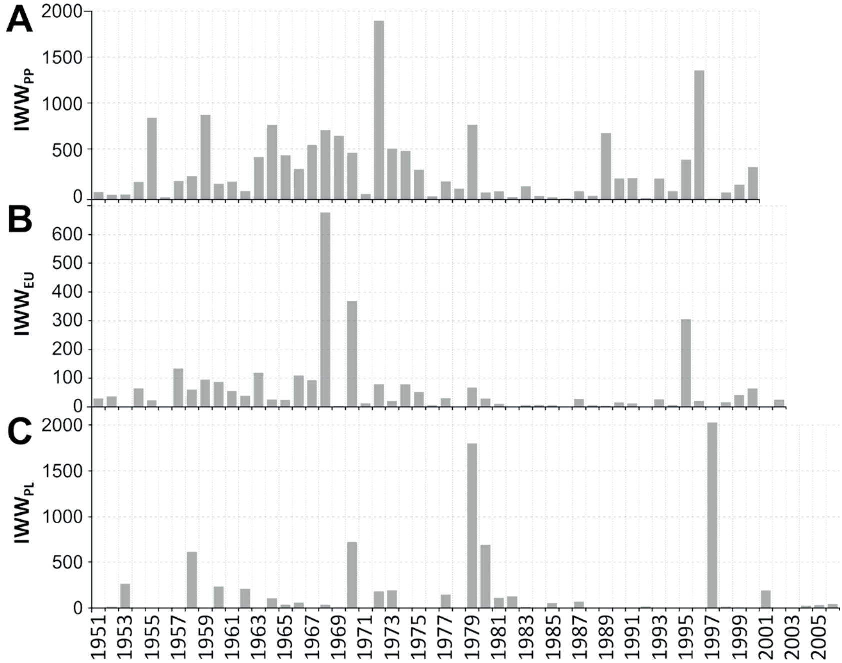

Figure 2.15. High water indexes for the northern hemisphere (A), Europe (B) and Poland (C) in multiyear period

Source: own elaboration

The years, during which many absolute maxima were recorded, such as 1997 and 1979 were completely insignificant in scale of the northern hemisphere and Europe. At the same time the European flood years – 1968 and 1995, as well as 1972 and 1996 – flood years for the whole northern part of the earth were not registered in Poland as the years with numerous WWQ. Only 1970 was noticeable in both the European and Polish scale. It is worth noticing that the decade of the 1980s was recorded as an extremely peaceful period. The rivers of the northern hemisphere, as well as the European and the Polish ones were characterised with a very small number of absolute maxima. Numerical expression of the lack of significant co-variability of IWW in scale of particular regions are low correlation coefficients calculated for 1951–2000: IWW (PP and EU) – 0.27, IWW (PP and P) – 0.03, IWW (EU and P) – 0.03.

2.6. Years and envelope curves of the biggest annual river runoff

The biggest frequencies of occurrence of maximum annual river runoff in the Oder River catchment area were recorded in 1977, 1981 and 1997 (Figure 2.16A). The dominant is the 1977, during which every four river basin within the catchment area was characterised with the biggest annual river runoff record noted for the whole investigation period. Taking into account the scale of contemporary floods and the earlier analyses all previously mentioned years can be considered as the major flood years within the Oder catchment, during the whole last century (Stachý et al. 1996, Dubicki et al. 1999, Jokiel and Stanisławczyk 2013). In the 22 years of the long-term period, within the Oder catchment area at least one maximum river annual runoff was recorded (the runoff from at least one river basin was extremely high). In the remaining years of the long-term period (38 years) for any of the considered river basins the maximum runoff values were recorded.

In the basins within the Vistula catchment area relatively the biggest number of maximum annual river runoff records appeared in: 2000, 2010 and 1980 (Figure 2.16B). High river runoff values were registered in these years for about 10% of the basins placed within this catchment area – it was in total about 30% of the considered basins. In contrary to the Oder River catchment area, in the Vistula River catchment area none of the years can be distinguished with exceptionally great frequency of occurrence of annual maximum values. It is worth mentioning that in the Vistula catchment area the number of years during which none of the river basins characterised with maximum annual runoff (27) is similar to the number of years during which in at least one river basin occurred long-term maximum of the annual river runoff. In the Oder River catchment area these values were significantly different (22 and 38 years respectively).

During long-term period the terms characterised with the increased frequency of the maximum annual runoff records can be shown in the scale of the whole country (Figure 2.16C). They include the following years: 1967–1982, 1988–1989, 1994–2005 and the year 2010. The greatest number of the maximum annual river runoff in the investigated set of river basins was registered in the 1970s. This decade is quite often considered as the wettest in Poland in the whole last century (Fal 1993). Particular attention deserves long-term period between 1951 and 1966, during which in sparse river basins the maximum annual river runoff records were registered. It should be pointed that the 1950s and the first half of the 1960s in Poland are very often mentioned in the bibliography as the extremely dry period of the significant deficit annual river runoff (Stachý et al. 1979, Fal 1993, 1997, Stachý 2011). The number of years during which none of the 338 considered river basins characterised with the maximum annual river runoff record is 25. In the 9 years the number of such events was recorded for more than 5% of the observed basins.

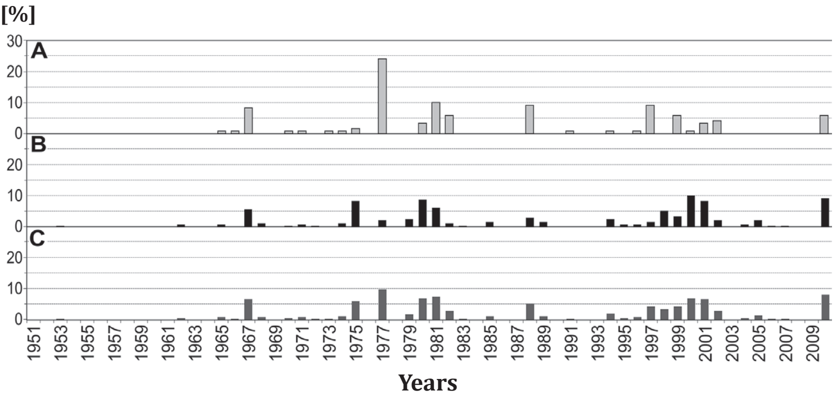

Figure 2.16. The frequency of the maximum annual runoffs in the Oder (A) and the Vistula River basins (B) and in Poland (C) in the period 1951–2010

Source: own elaboration

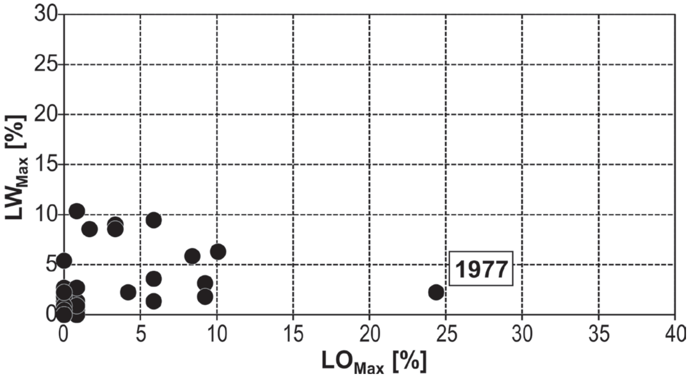

Figure 2.17. The comparison of the maximum annual runoffs frequency in the Oder (LO_{max}) and the Vistula (LW_{max}) catchment areas in 1951–2010 (LO_{max} and LW_{max} – the relative number of the maximum annual runoffs in the Oder and the Vistula River catchment areas)

Source: own elaboration

The years of the greatest relative number of the maximum runoff records were not observed simultaneously in both vast river catchment areas (Figure 2.17). Particularly big disproportions have been recorded in 1977. In the Oder catchment area the frequency of occurring of the maximum river runoff values was in above mentioned year many times larger than in the Vistula catchment area. Such inequalities appeared in a few remaining years as well, although they were not so evident (e.g. in 2000). Basing on the analysis of the presented graph it could be concluded that in most of the investigated years there is a big convergence between the frequencies of the maximum annual runoff records which were registered in both set of basins. It is worth emphasizing that the frequencies calculated for two river catchment areas range between 0–10%.

To estimate the envelope curve for the maximum specific annual discharges only basins of the areas exceeding 10 km^2 were taken into consideration. From the authors point of view, it is a reasonable condition due to the limited amount of hydrometric data obtained

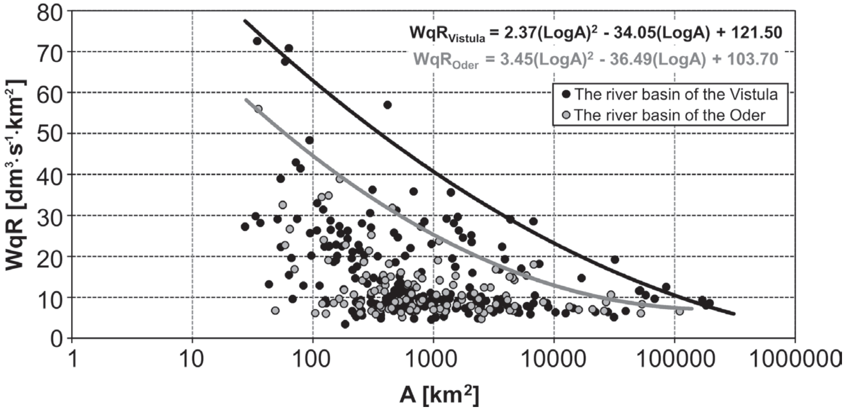

Figure 2.18. Maximum specific annual runoffs (WqR) in the Oder and the Vistula River basins in 1951–2010. Envelope curves and their equations were shown above

Source: own elaboration

for vary small basins. From the envelope curves outlined it can be clearly stated that the maximum specific annual discharges (WqR). In respect to the almost all ranges of the basins surfaces are much bigger in the basins within the Vistula catchment area than in the basins within the Oder catchment area (Figure 2.18). With increasing surface area this difference decreases. In very vast river basins of the two catchment areas (above 100 000 km^2) the maximum specific annual discharges reach very similar values.

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