Polish Geological Institute Special Papers, 15 (2004): 77–84
Proceedings of the Conference "Risks caused by the geodynamic phenomena in Europe"

FLOOD HAZARD — REGIONS OF FREQUENT HIGH WATER

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Abstract. In order to fix areas of direct flood impact we must take into account not only historical floods but also analyse hydrological conditions of high water occurrence. As it is known in case of conjunction of unfavourable events, in particular the embankment damage, high water is a flood. We define high water as the exceeding of so-called an alarm water level. In our researches all high water events in Poland in period 1946–2001 were analysed, that means caused by rainfall, snow melt, ice jams and storm winds in estuaries. As a result, we defined frequency and areas where high water of different types was noticed. These results are basis for further researches concerned with danger floods in Poland.

Key words: high water, flood hazard.

Abstrakt. Niezbędnym elementem przy określaniu obszarów występowania powodzi jest analiza warunków kształtowania się wezbrań. Wiadomo, że przy niekorzystnej koniunkcji zjawisk, w szczególności awarii wałów, wezbranie staje się powodzią. W artykule zdefiniowano wezbranie jako wzrost poziomu wody ponad tzw. stan alarmowy. Przeanalizowano wszystkie tego rodzaju zdarzenia w Polsce w okresie od 1946 do 2001 roku, precyzując genezę ich wystąpień. Wynikiem analizy jest ocena częstości występowania wezbrań różnych typów w poszczególnych regionach Polski. Badania są podstawą prac związanych z oceną zagrożenia powodziowego w Polsce.

Słowa kluczowe: stan alarmowy, zagrożenie powodziowe.

CLIMATIC CONDITIONS IN POLAND

Poland is located in the geographic latitudes where the weather conditions are mainly affected by the humid masses of air from the Atlantic Ocean (westerly circulation) or dry, continental air from eastern Europe and Asia (easterly circulation). In result the weather in Poland is highly variable. Marine air brings cloud cover and precipitation, while continental air usually brings dry and sunny weather. Therefore, the climate in Poland is often described as transitional between marine and continental. There are among other frequent, rapid changes of air temperature, intensive rainfall, storms and showers.

Atmospherical precipitation is characterised by exceptionally high variability. It is mainly related to the movement of atmospheric fronts, and its layout is largely determined by the topography of the area. The amount of rainfall increases with the elevation above sea level, while the location of a given area and the existence of cover (forested or not forested) have clearly more impact on summer than on winter rainfall. Most of the territory has total annual precipitation of 500 to 700 mm, and the highest recorded precipitation is in the Carpathians and the Sudetes mountains (Fig. 1).

Summer precipitation (May to October) is twice that of winter precipitation (November to April). Most precipitation falls between June and August, and the least between January and March (Fig. 2 — example for Warsaw).

Another characteristic of the Polish climate is snowfall in winter, most often in December and January. The snow cover may appear as early as October and it may disappear as late as the end of April. The snow cover is thickest in the eastern half of Poland and, of course, in the mountains. Outside the mountains, the average number of days with snow cover varies from about 40 days in the north-west to almost 100 days in the north-eastern part of Poland.

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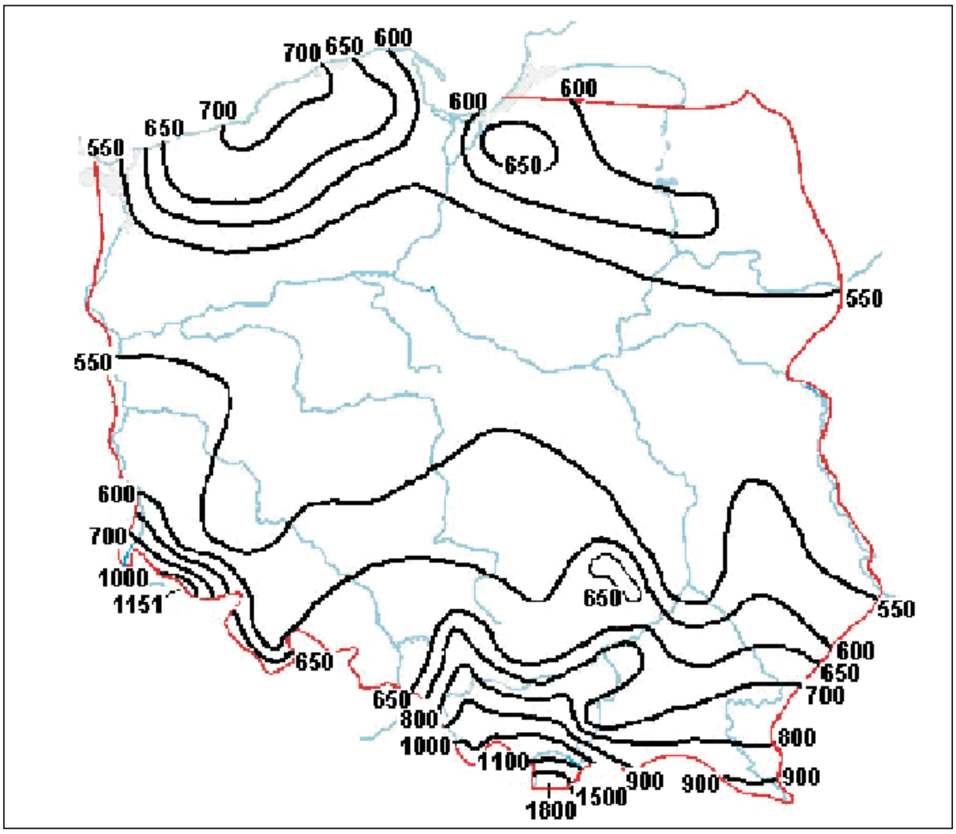

Fig. 1. Average annual total rainfall [mm] (1951–2000)

HYDROLOGICAL CONDITIONS IN POLAND

Almost 90% of the area is covered by the basins of the two biggest rivers: the Vistula River (56% of the area of the country) and the Odra River (34% of the area). Water from over 97% of Polish territory flows to the Baltic Sea (Fig. 3). The Vistula and the Odra rivers flow from the south to the north, fed with the waters of tributaries from the mountains and uplands, and then from lowlands and lake districts. River run-off is most strongly related to precipitation — its amount, annual pattern and form (rain or snow). The rivers of northeastern Poland (e.g. the Bug and the Narew) and most of the lowland rivers are mainly supplied by melting snow — the springtime run-off is 1.5–2 times higher than average annual run-off. Mountain rivers have a high level of flow both in spring (melting snow) and in the summer (rainfall), and usually the summer run-off is higher than average. On most rivers the highest average monthly run-offs can be observed in March, April and May. The driest months are September and October (in the mountains also the period from November to February, Fig. 4).

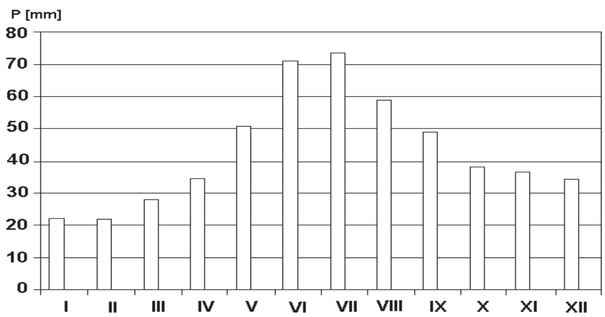

Fig. 2. Normal monthly rainfall, P[mm], in Warsaw (1951–2000)

In winter, when air temperature drops significantly, ice formation occurs on rivers: initially slush ice and riverbank ice, and then permanent ice cover. The time when rivers freeze and the length of the period over which ice is present depend on the geographic location of the river basin and the severity of a particular winter. On average, the rivers in the north-east and east freeze earliest (already in November and December), and

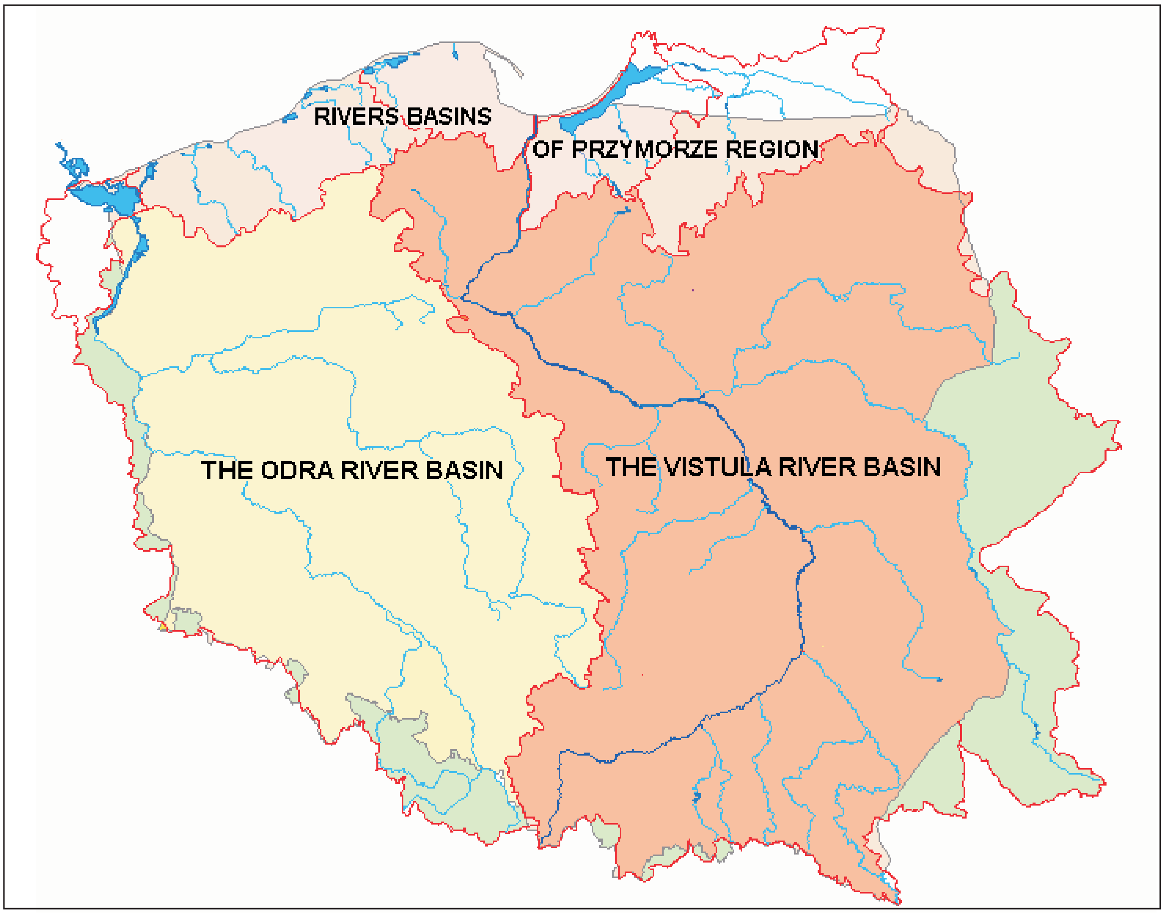

Fig. 3. Drainage basins in Poland

the ice is observed for about 90 days. On the upper Vistula, ice exists for about 60 days, and in the west of Poland 10 days a year on average. The ice usually disappears in March, although in the west the process begins a few weeks earlier, while in the north-east it can last until April.

Polish rivers can be affected by:

— high water – increases of water level caused by increased supply or hampered outflow;

— floods – high water which endanger human lives or cause social, economic and environmental damage.

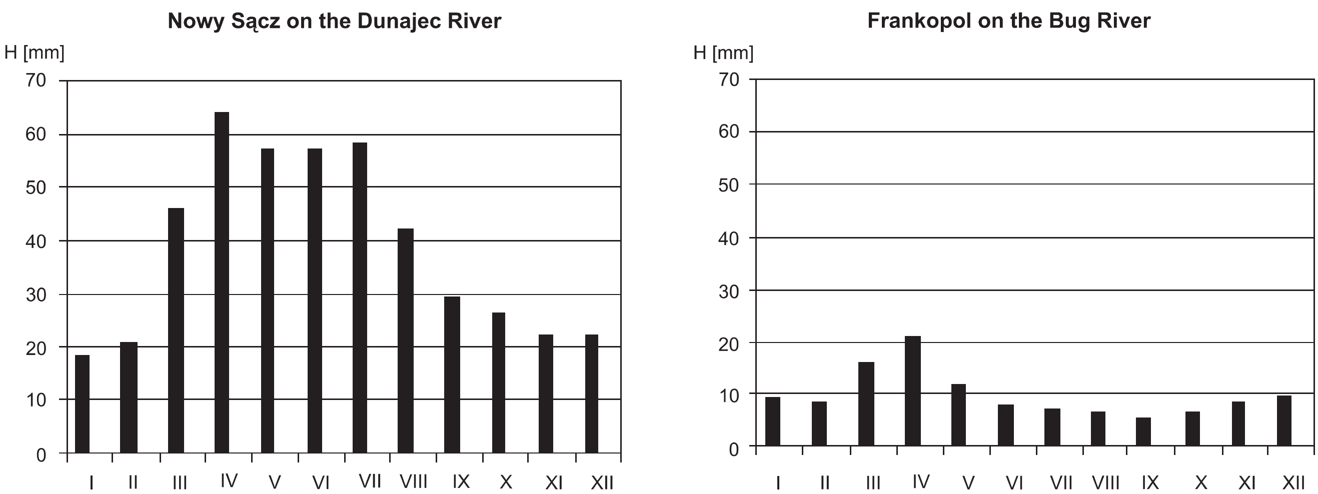

Fig. 4. Average monthly runoff, H [mm], in period 1951–2000

Table 1

Time (months) when high water occurs

Type of high water	Months											
	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
O	●●●● (blue)					●●●● (blue)	●●●● (blue)	●●●● (red)	●●●● (red)	●●●● (red)	●●●● (red)	●●●● (blue)
R	●●●● (blue)	●●●● (blue)	●●●● (blue)	●●●● (blue/red)	●●●● (red)	●● (red)						
S	●●●● (blue)	●●●● (red)	●●●● (red)	●●●● (red)	●●●● (blue)				●●●● (blue)	●●●● (blue)		●●●● (blue)
Z		●●●● (red)	●●●● (red)	●●●● (blue/red)	●●●● (blue)							

●●●● (red) time when high water occures most frequently
●●●● (blue) time when high water occures

Types of high water

O raintall-related R snow melt-related S storm-related Z ice jam-related

The primary cause of all high water is usually some meteorological phenomenon: heavy rainfall, storms, increase or decrease of temperature in winter. This phenomenon is caused by atmospheric processes which occur over a territory many times larger than the area of Poland, usually initiated many thousands of kilometres from Polish borders.

In terms of origin, high water may be divided into those related to precipitation, snow-melting, storm and ice jams (Fig. 5, Table 1). In addition floods are divided into natural or human made.

Precipitation-related high water are mainly caused by heavy rain which begins suddenly (e.g. following a cloudburst) or they may be caused by less intensive rain over long duration. They occur on every river in the country and are most dangerous on rivers in the mountains and mountain foothills (mainly in the upper Vistula River basin, in rivers that flow out of the Świętokrzyskie Mountains and in the upper and middle Odra River basin). Related precipitation usually occurs between May and September, but mainly in July and August.

The condition for **snow melt-related high water** for a given area is snow cover with large water content. The time of melting is related to the meteorological conditions (increase in temperature to above zero levels, rainfall). Most commonly, these types of high water occur in February and March in the Odra River basin and in March and April in the Vistula River basin. Usually they affect large areas. Snow melt-related high water occur both in lowlands and in the mountains, and the strongest are observed on the lowland rivers (the Narew, the Bug, the Warta and the Noteć) and on the middle and lower Vistula River and the lower Odra River.

On the coast, on the Vistula Lagoon and the Szczecin Lagoon and on the lower sections of rivers, which flow directly into the Baltic Sea, **storm-related high water** is observed. Apart from the geographical factors, the main role is played by selected meteorological factors, like specific pressure patterns and strong winds from the north. Storm-related high water is most common between November and January, but it may also occur at other times.

Ice jam-related high water may occur practically anywhere in Poland. It is caused by total or partial blockage of the riverbeds by ice. In the beginning of winter, in the presence of certain atmospheric pressure conditions, cloudless sky and rapid decrease of temperature to –10°C (most often in December and January), tiny water borne particles of ice gather in the areas where the flow rate is low. The most dangerous ice jam-related high water occurs during snow-melting periods on large lowland rivers - ice-float gathers in narrow or shallow sections of the riverbeds (particularly dangerous on the middle and lower Vistula River, the lower reach of the Odra, the Narew, the Bug, the Warta and the Noteć rivers). Especially dangerous are ice-jams in estuaries of rivers, which flow into the Baltic Sea. Sea ice blocks river outflow, water moves back upstream and water level increases. Ice jam-related high water and floods occur most commonly from December to February.

Poland's geographic location and the predominant south-north direction of flow of precipitation and melt water in the rivers have such an effect that large waves formed in the south move along rivers and threaten areas in central and north Poland. The maximum flow rate of the spring high water on the Vistula River usually increases along the river, as it is systematically supplied with melted waters from central and then eastern and northeastern Poland (Fig. 6). In contrast, the maximum flow rate of summer high water on the Vistula River, formed in the south, usually decreases as it flows down the river (Fig. 7, rainfall never covers the entire 200,000 km^2 of the Vistula River drainage basin at the same time). On the Odra River the pattern of high water is slightly different. The difference in the maximum flow rate along the river during springtime and summertime high water is not so clear. One has to remember that the snow cover in the Odra River basin is usually significantly smaller than in the Vistula River basin.

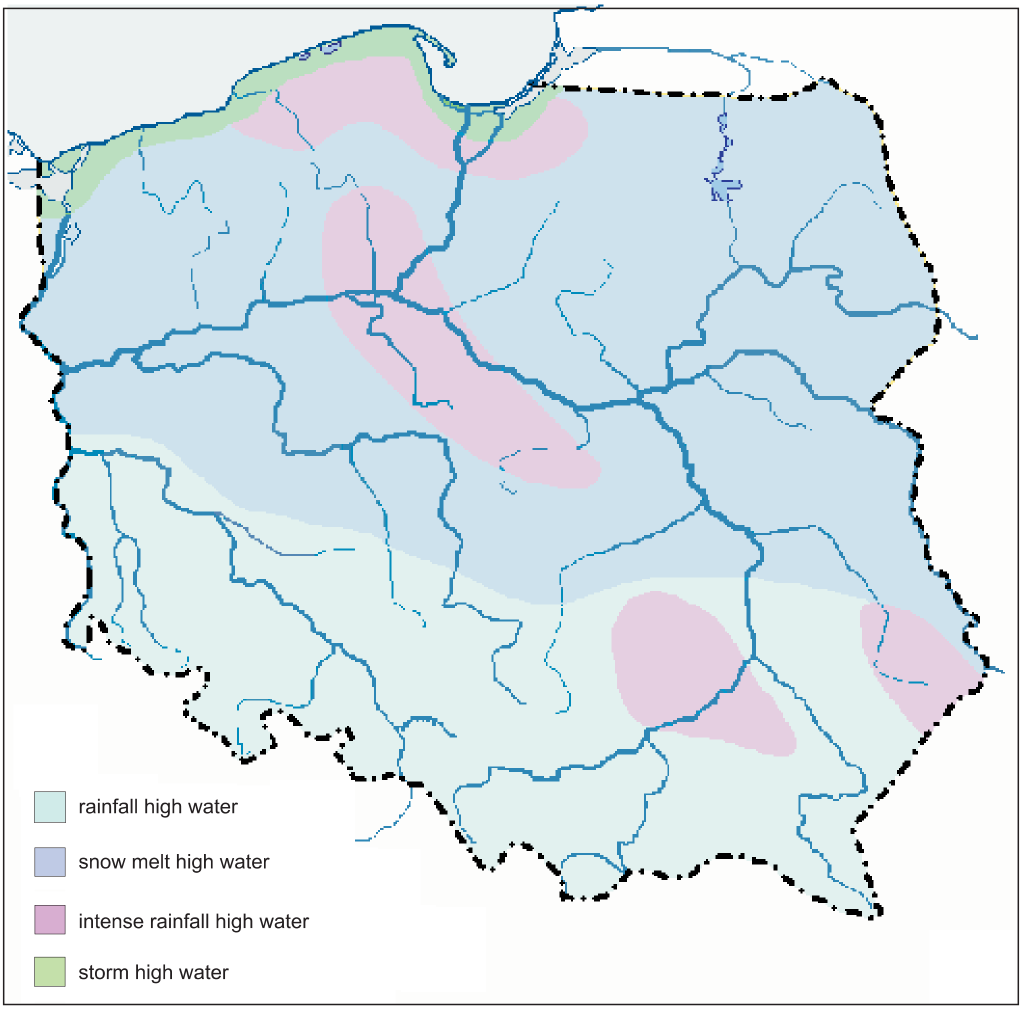

Fig. 5. Types of high water by geographical area

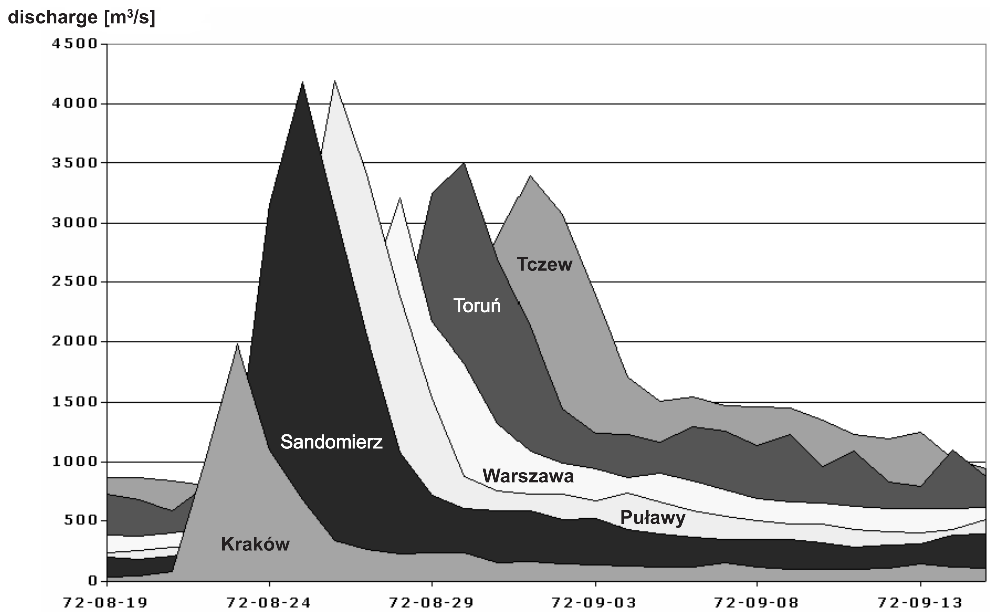

Fig. 6. Transformation of the rainfall-related wave along the Vistula River in 1972

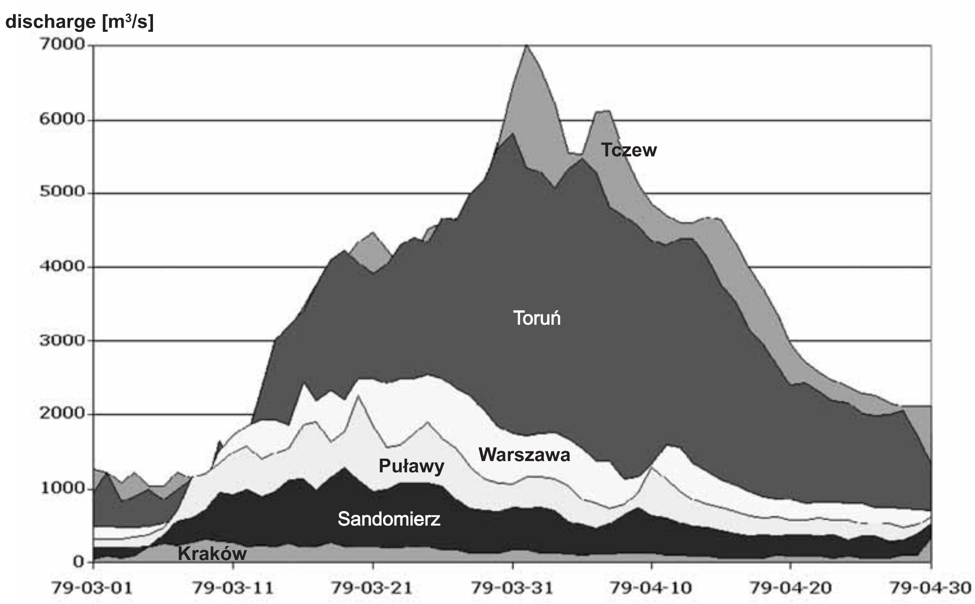

Fig. 7. Transformation of the melting-related wave along the Vistula River in 1979

FREQUENCY OF HIGH WATER IN POLAND

In our research hydrological and meteorological yearbooks and archival materials of the Central Office of Hydrological Forecasting were a source of basic data. We have analysed decades in the period 1946–2001. High water is defined as exceeding of a so-called alarm stage. The set of schematic maps present results of the analysis.

DISCUSSION

1. All types of freshets may occur in various regions, except for storm-related which only pose danger for the relatively narrow coast of the Baltic Sea.

2. Small number of high water is observed in the northeastern part of Poland — about 5 events (both rainfall- and snow melt-related) in each decade and only 5 rainfall-related high water in all period 1946–2001.

3. Rainfall-related high water is more frequent in the upper and middle Odra River (30 events per 55 years) and in particular in catchments of the Bóbr and Kwisa rivers (70–80 events in period 1946–2001, Fig. 8).

4. In the upper Vistula River basin rainfall-related high water are observed in the part from the river spring to the right tributary — the Wisłoka River and also in the Kamienna River that among other drains the region of the Świętokrzyskie Mts. (20–30 events).

5. Small numbers of rainfall-related freshets occur in the northern part of Poland (less than 5 events).

6. Snow melt high water are observed in the middle and lower Odra and Vistula River basins, in particular in the Bóbr and Kwisa rivers distinguishing themselves with 50–55 events per 55 years and also in the Bug, Narew and Wkra rivers, where 30–45 events were found in analysed period (Fig. 9).

7. Ice jam-related high water is observed especially in central Poland — in the Vistula River, upstream to the Włocławek water reservoir, in the middle and lower Bug River and in the Pilica River (Fig. 9).

8. Storm-related high water occurs in the coast of the Baltic Sea and on the Vistula River and the Szczecin lagoons but more frequent in the western part of the coast — about 20 events in fifty-year period in comparison with less than 10 events in the east part (Fig. 10).

Decade 1981–1990 was dry: on 80% of the total area of Poland only 5 rainfall-related high water were noticed.

9. In period of 1946–2001, the largest exceeding of the mean high water level (that can be identified with the alarm stage) were noticed first of all in southern Poland – in mountainous tributaries of the upper Vistula River and the upper and middle Odra River. Differences between the highest stage and the mean high level exceeded 400–500 cm. The smallest exceeding (less than 100 cm) were observed in northeastern Poland (Fig. 11).

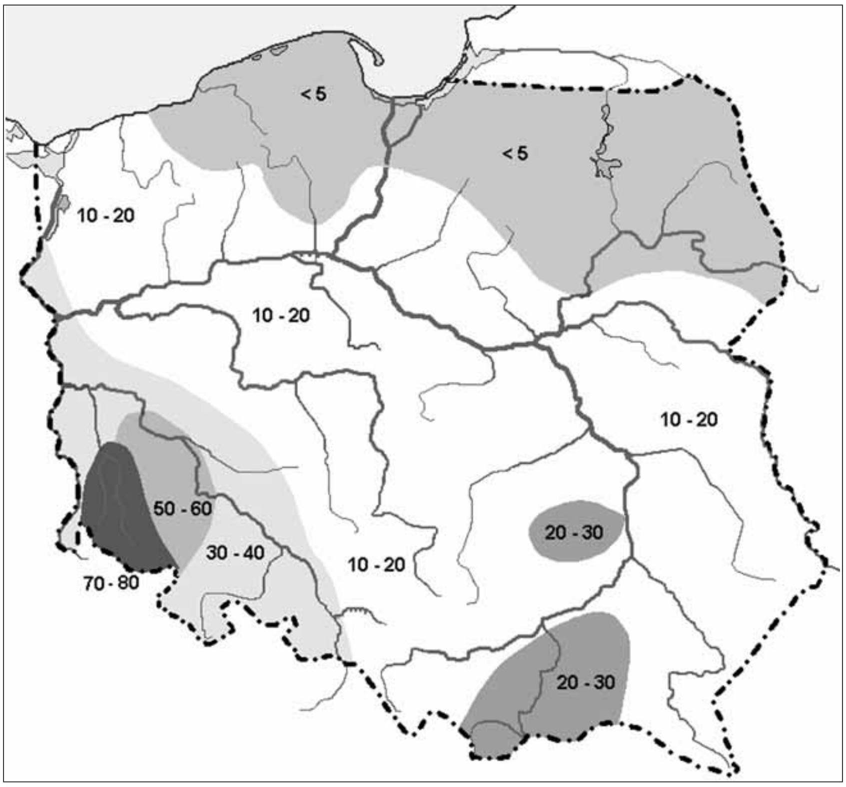

Fig. 8. Number of rainfall-related high water in period 1946–2001

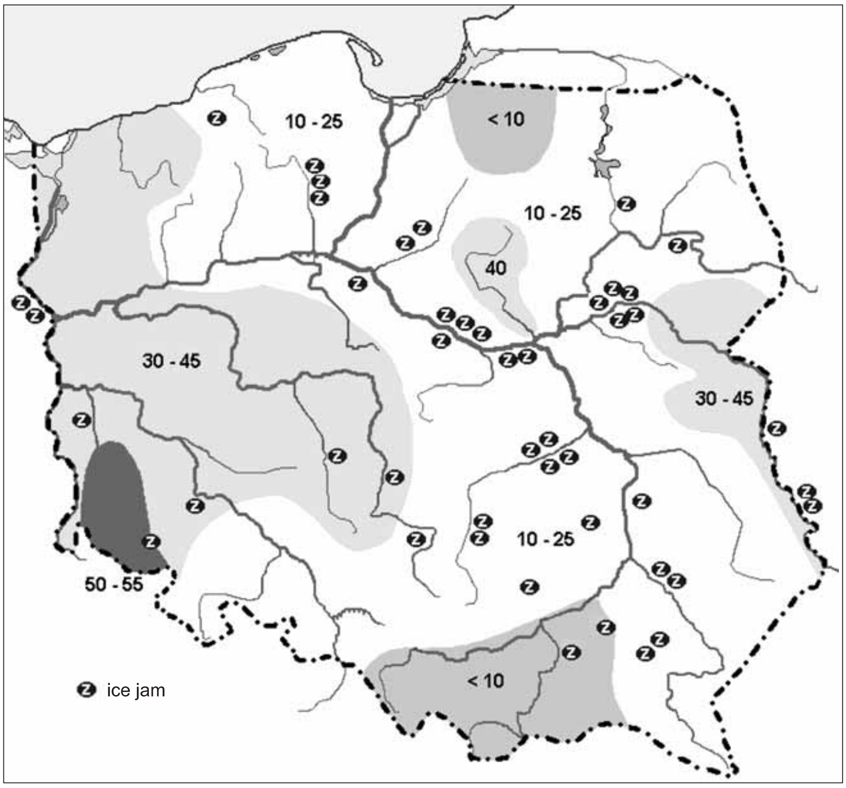

Fig. 9. Number of snow melt-related high water in period 1946–2001 and places of observed ice jams

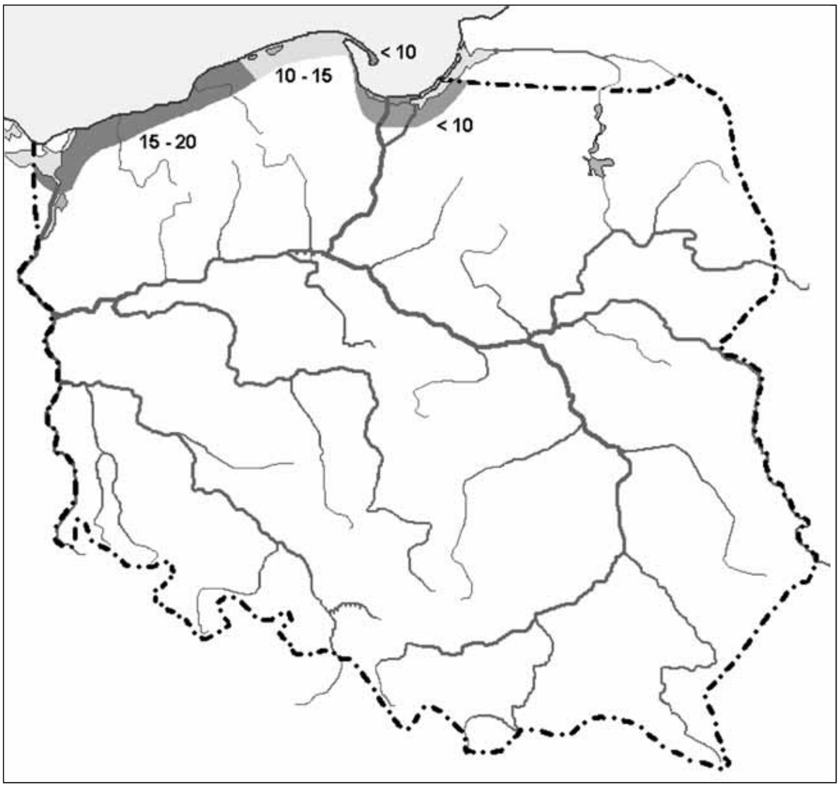

Fig. 10. Number of storm-related high water in period 1946–2001

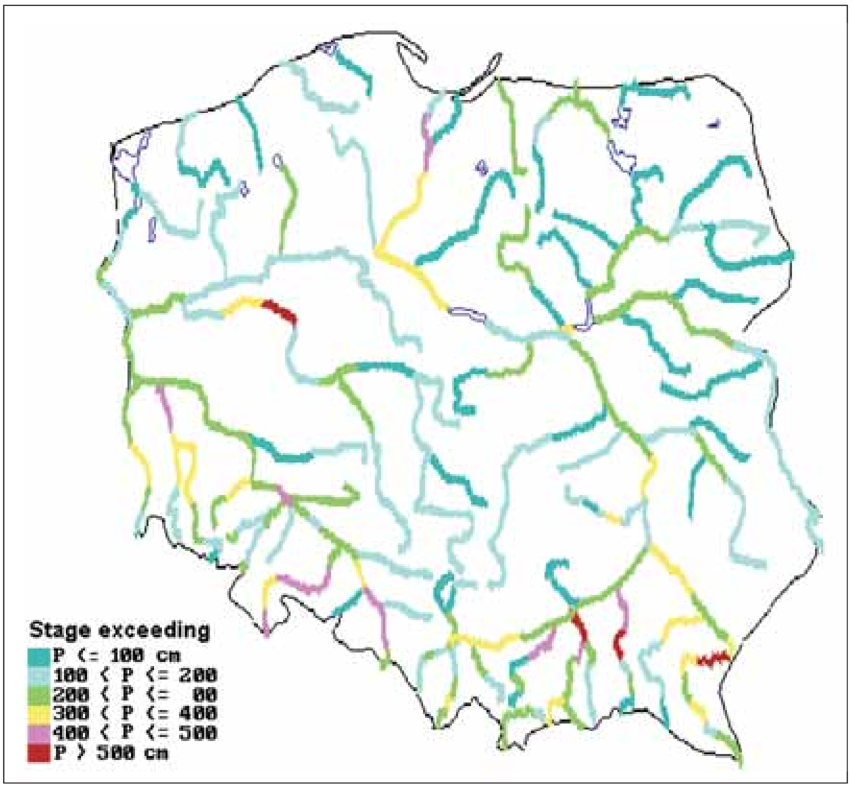

Fig. 11. The largest exceeding [cm] of the mean high water level in period 1946–2001