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FLOODS IN POLAND FROM 1946 TO 2001 — ORIGIN, TERRITORIAL EXTENT AND FREQUENCY

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Abstract. Based on the data concerning floods on the territory of Poland during the period 1946–2001, the reasons generating floods, the number of regional floods in the rivers catchment systems, and sites of local floods occurrence, were defined. Both types of floods: caused by riverbank overflows, and land flooding by rain or snow-melt water, were considered.
In the most cases, the floods were caused by rainfall. They were connected with changes in the rainfall structure within Poland. In each season of the year floods of various origin were observed. When the flood initiating factors appeared simultaneously, the flood grew into a catastrophic size.
In present analysis, for the first time in Poland, a large group of local floods has been distinguished. A special attention has been paid to floods caused by sudden flooding of the land (flash flood), including floods in the urban areas — more and more frequent during the recent years. The results of the analyses have provided important data for the assessment of the flood hazard in Poland, and for the creation of a complex flood control strategy for the whole country and/or for selected regions.

Key words: flood, classification of floods, floods territorial extent, frequency of floods occurrence, torrential and rapid rainfall, threat of life, material losses.

Abstrakt. Na podstawie zbioru danych z lat 1946–2001 określono przyczyny występowania powodzi w Polsce, liczbę powodzi regionalnych w układzie zlewni rzecznych oraz miejsca wystąpień powodzi lokalnych. Pod uwagę wzięto zarówno powodzie spowodowane wylewem wód po przekroczeniu stanu brzegowego, jak i zalania terenu wodami opadowymi, bądź roztopowymi.
Stwierdzono, że większość stanowiły powodzie opadowe, zarówno w przypadku powodzi o zasięgu regionalnym, jak i lokalnym. Jest to spowodowane m.in. przez zmiany zachodzące w strukturze opadów w Polsce. Powodzie o różnej genezie występowały na terenie całego kraju, o każdej porze roku. W przypadkach jednoczesnego wystąpienia kilku czynników generujących powódź, przybierała ona rozmiary katastrofalne.
W analizie po raz pierwszy w Polsce wyodrębniono liczną grupę powodzi lokalnych. Szczególną uwagę zwrócono na powodzie spowodowane nagłym zalaniem terenu (*flash flood*), w tym na powodzie na terenach zurbanizowanych — coraz liczniejsze w ostatnich latach. Wyniki analiz dostarczają istotnych danych do oceny zagrożenia powodziowego w Polsce i opracowania kompleksowej strategii ochrony przeciwpowodziowej — ogólnokrajowej i w skali regionalnej.

Słowa kluczowe: powódź, klasyfikacja powodzi, zasięg terytorialny powodzi, częstość występowania powodzi, opady ulewne i nawalne, zagrożenie życia, szkody materialne.

INTRODUCTION

According to The Polish Water Act from July 2001, a flood definition assumes that water in streams, natural water reservoirs, channels or seas rises to such a level that it is flooding river valleys or depressed areas and is causing threats to people and their properties.

The basis of the floods analysis were the archival data from different levels of the Flood Main Committee, from the actual Crisis Management Structures, and from the Institute of Meteorology and Water Management (IMWM). It was also based on the results of the IMWM alarm water gauges net measurement.

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There were also added floods, which did not meet the legal criterion of the water "exceeded river bank level" but when areas not carrying streams or not having enough drainage ability of the ground were flooded by rainfall or melts, causing harms and threats as by regular floods (Iwiński *et al*., 2003).

CLASSIFICATION AND FREQUENCY OF FLOODS IN DIFFERENT SEASONS OF A YEAR

The main reasons of high water in rivers and lakes were:

— increased water inflow in consequence of intensive rainfalls or melting of snow (these phenomena often appeared together);

— more difficult outflow of water, e.g. in consequence of ice-jam in river, sedimentation of river bed load, of overgrowing river bed and valleys with vegetation, concentration of lifted water in the main river etc.;

— rise of the water-level of the Baltic Sea, and bays and lakes hydraulically connected with the Baltic Sea.

CLASSIFICATION OF FLOODS WITH REGARD TO THEIR GENESIS

The classification of floods with regard to their genesis (Iwiński *et al*., 2003) was shown in the Table 1.

Rainfall floods appear in all rivers of the country. They reach the most dangerous sizes in the mountainous and piedmont rivers (Nysa Kłodzka, Dunajec and Kamienna) and in rivers flowing out from mountains, like Wisła and Odra rivers. In the case of large lowlands rivers (Narew, Bug and Noteć) and landlakes rivers (Pisa, Omulew and Drawa), the intensive rainfalls do not cause big flood hazards, but in the small and average size lowlands rivers (Pilica, Bzura and Wkra) they cause great threats as melt floods.

Melt floods are caused by melting snow-cover. Very often, this kind of floods appears in the Mała Wisła, Soła, Skawa, Raba and Dunajec rivers and in the upper Odra River, but they do not cause greater harms. The different situation is in the right tributaries of Wisła River, such as Wisłok and San rivers; here the danger caused by this kind of floods is much greater.

Rainfall-melt floods appear when snow melting and rainfalls occur simultaneously. These two types have the largest size in the large lowland rivers (Narew, Bug, Warta and Noteć). They are dangerous in the middle and lower Wisła River and in the lower Odra River. In the medium size lowland rivers (Pilica, Bzura and Wkra), they cause threats similar to rainfall floods. In the mountainous and mountain-foot rivers (Nysa Kłodzka, Dunajec and Kamienna), rainfall-melt floods do not cause greater risks, even when it is the thickest snow cover in the mountains.

Jam floods. They appear in rivers in two situations: (1) during the river freezing period when the slush ice appears in the running water, and stops on shallows and other obstacles creating jams; (2) during the ice melting period when the ice drift creates jams like in the case of slush-ice jams. The most risky jam floods appear during the melt floods in the large lowlands

Table 1

Classification of floods of different origin and territorial extent

Type of flood	Location	Hydrological winter						Hydrological summer					
Months		XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
Regional floods	the cost of the Baltic Sea	storm floods									storm		
			jam-storm										
	catchments and river basins					rainfall floods							
				melt									
				rainfall-melt									
			jam floods										
		damage											
Months		XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
Local floods	small river catchments					rainfall floods							
				rainfall-melt									
			jam floods										
		damage											
	small catchments in towns							rainfall					

rivers (upper and lower Wisła, lower Odra, Narew, Warta and Noteć).

Storms surges. Storm winds cause rise of water level in the Baltic Sea, and in lakes and bays hydraulically connected with the Baltic Sea. Sea-water sometimes floods cities and settlements. Wind rising the Baltic water makes also more difficult outflow of water and ice from rivers, causing floods on their outlets (river mouths). If simultaneously appear melt, rainfall and jam flood in the river catchment, the extent of the storm surges increases, and it can touch the whole area and be very dangerous, becoming even of a catastrophic size.

Floods resulting from damages of dams or not proper management of outflow from storage reservoirs. The examples:

— damage of the dam in Górowo Iławieckie (caused death of people);

— flood on Dunajec below the Rożnów reservoir, in 1960 (improper exploitation).

CLASSIFICATION OF FLOODS WITH REGARD TO THE TERRITORIAL EXTENT

When considerable areas of the country are flooded, they can be named **regional floods**, for example:

— rainfall flood (July 1997) in the upper and the middle Odra and the upper Wisła river basins;

— melt flood (1979) in the Narew and the lower Wisła river basins;

— rainfall flood (1980) on the whole country area.

When areas from several to several hundred km^2 are flooded, they are named **local floods**. They occurr very often because the drainage of sewer systems is not effective enough. Local floods in the small catchments (watersheds) are caused mainly by events commonly called “cloud-bursts”, for example:

— rainfall flood in Gdańsk and other large towns in Poland (June 2001);

— the upper Nidzica catchment flood (September 1995) caused by rainfalls, landslides of loess slopes and riverbed vegetation.

Disastrous (catastrophic) floods appear (Fig. 1) when flood causes death of people and high property losses or environmental damages. It can have regional character (melt flood — in 1979, in the Narew and the lower Wisła river basins, rainfall flood — in 1980 on the whole country area) or local character (torrential rainfall in the Biała Głuchołazka catchment in 1998, when some people have got drowned).

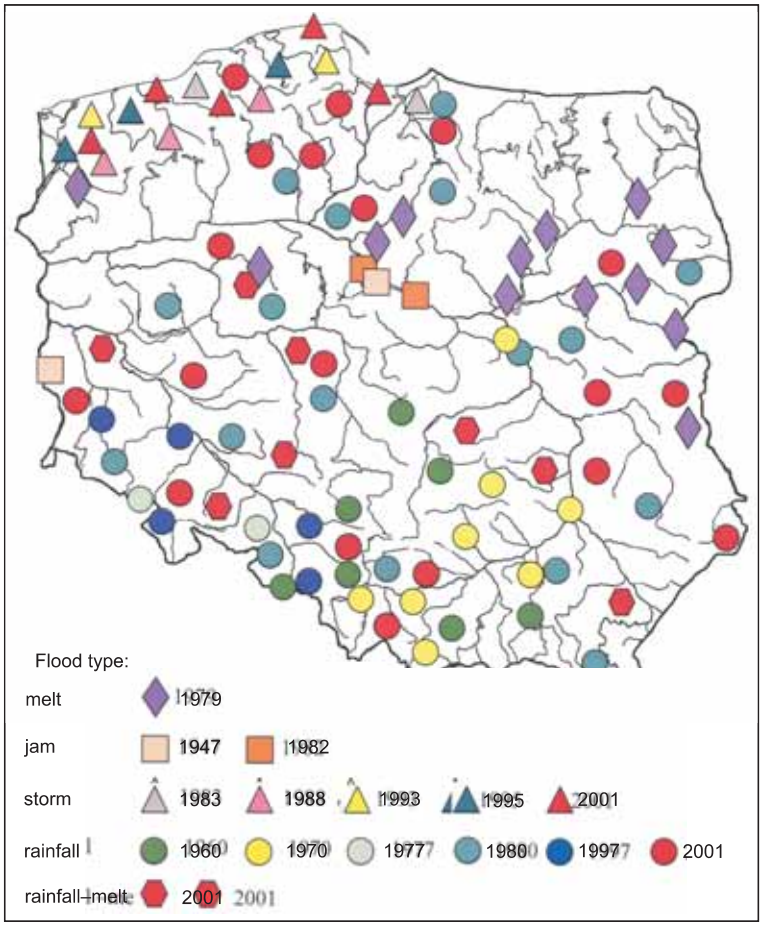

Fig. 1. Disaster floods of regional extent in Poland from 1946 to 2001

THE TEMPORAL SCHEDULE

The analyses showed that regional and local floods appeared in the same periods of a year (Table 1) (Iwiński *et al.*, 2003).

Rainfall floods. In the most cases, they occurred in the warm period of a year, from March to October (local floods in towns: from May to September), especially in June and July. There was absence of floods in December, one case in January, and single floods appeared during February–April and October–November periods.

Melt floods. Most often they occurred in March. Some floods appeared also in January and February.

Rainfall-melt floods. They appear from January to April, with culmination in March.

Jam floods. The jam floods of a regional extent appeared only twice: in January and in February. The remaining were of a local character. Local events were caused mostly by accumulation of lifting ice in flowing water both in the first and in the final phases of ice phenomena, i.e. from December to April.

Storm surges (mainly regional floods). In the most cases they appeared in autumn–winter, from November to February. Only several cases in March, even in April, two in August (connected with rainfall).

Floods resulted from the dams' damage (mainly local floods). There were 25 events identified mostly as of local character (6% of the all local floods). They were mostly of mixed genetic character when the damage occurred during the flood of other genesis.

SPATIAL DISTRIBUTION AND FREQUENCY OF FLOODS IN POLAND, FROM 1946 TO 2001

REGIONAL FLOODS

The analyses of spatial distribution of floods on the country area have been carried out separately for floods of different origin. To see the tendency of floods occurrence changes with time, for periods: 1946–1960, 1961–1970, 1971–1980, 1981–1990 and 1991–2001, the maps were constructed (Fig. 2).

Rainfall floods. From 1946 to 2001, there were identified 67 cases of rainfall regional floods. It was noted that:

1. In the 10-years periods, one can distinguish two periods with small number of regional floods: 1946–1960 (15 years) — 6 cases, and 1981–1990 — 7 cases.

2. In the decades 1961–1970, 1971–1980 and 1991–2001, there were registered 12, 16 and 28 cases of regional rainfall floods, respectively. It means that during these three decades (1961–2001) regional rainfall floods were absent during five years, only.

Melt and rainfall-melt floods. From 1946 to 2001, there were identified 46 cases of regional melt and melt-rainfall floods. It was noted, that:

1. The number of regional melt and melt-rainfall floods was similar to the number of rainfall floods. Only two of these floods were classified as the catastrophic events (1979, 2001). The flood in 1979 was the second in size of the flooded area (about 1 million ha) during the post-war period.

2. One should pay attention to melt floods which often appear in the Mała Wisła, Soła, Skawa, Raba and Dunajec rivers (1962, 1966, 1967, 1974, 1987, 1979, 1998 and 2000) and in the upper Odra river basin, not causing any greater threats. However, to the east of the Dunajec River, on the right tributaries of the Wisła River (the Wisłoka and the San with Wisłok catchments), one could observe much higher probability of

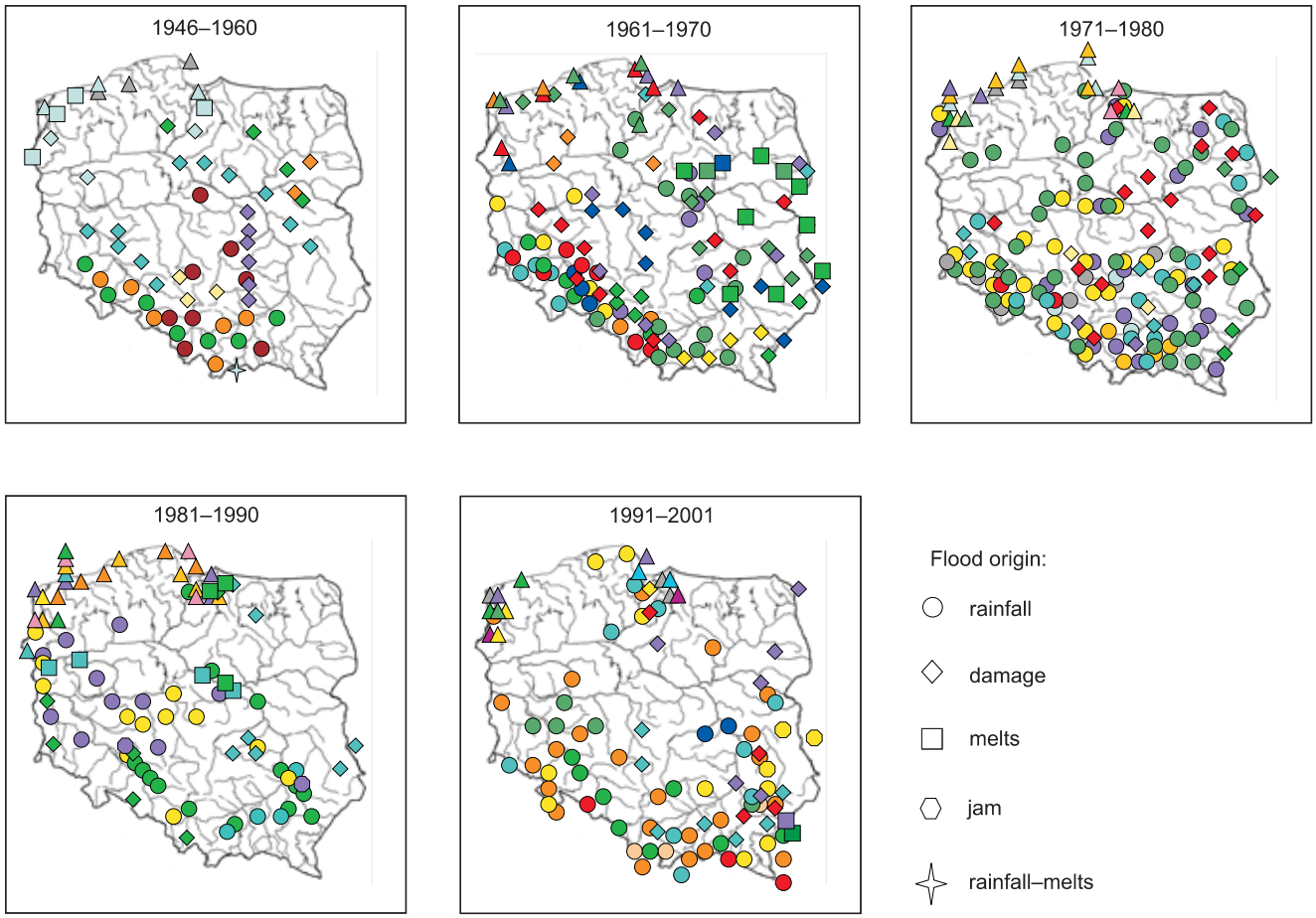

Fig. 2. The spatial distribution of regional floods in Poland from 1946 to 2001

Colours differentiate years

melt and rainfall-melt floods occurrence. This was in relation to floods in the Mała Wisła, Soła, Skawa, Raba, Dunajec and upper Odra watersheds.

3. In 2001, after the very frosty and snowy-winter, a catastrophic rainfall-melt flood had occurred on the large part of Poland territory.

Storm surges. Storm floods (surges) occurred every 1.5 year in average, without any tendency of changes of their number in particular decade. These floods begun most often with local water lifting in the outlet parts of the Przymorze rivers (41 cases).

Jam floods. There were identified only 6 cases of jam regional floods. It was noted, that:

1. Regional jam floods occurred in the Wisłok, San, the middle and lower Wisła, Bzura, Bug and Warta rivers. This type of floods appeared often but usually of local character.

2. Only two jam floods were classified as catastrophic events: in 1947 and 1982 (the last one in the area of the backwater of the Włocławek Dam).

The frequency of floods occurrence (number of flood events during a multiyear period) was presented in catchment and river courses system closed by water gauges of the IMWM. The map presents number of regional floods (separately for each genetic type in each catchment) in four classes: 1–5, 6–10, 11–15 and above 15 events. For some catchments, there is no data on flood events or the existing data are not satisfying (for transit rivers, when the flood was mainly in valleys, not affecting catchments of tributaries; the floods number is marked by a colour belt shown along rivers and seacoast).

The most important conclusions from the map (Fig. 3) are as following:

— catchments and transit (main) rivers (Wisła, Odra, Warta and Bug), with the greatest number of regional floods (above 15), are grouped mainly in the southern part of the country (south of Warsaw parallel 52°15'), and on the area of Szczecin Bay and Dąbie Lake.

— within the same southern part of the country and in the lower Wisła river, catchments with 11 to 15 regional floods events are grouped.

— North of the Warsaw parallel (52°15'), there is an area with the smallest number of events: from 1 to 5 cases; the exceptions are: the Szczecin Bay and Dąbie Lake (above 15),

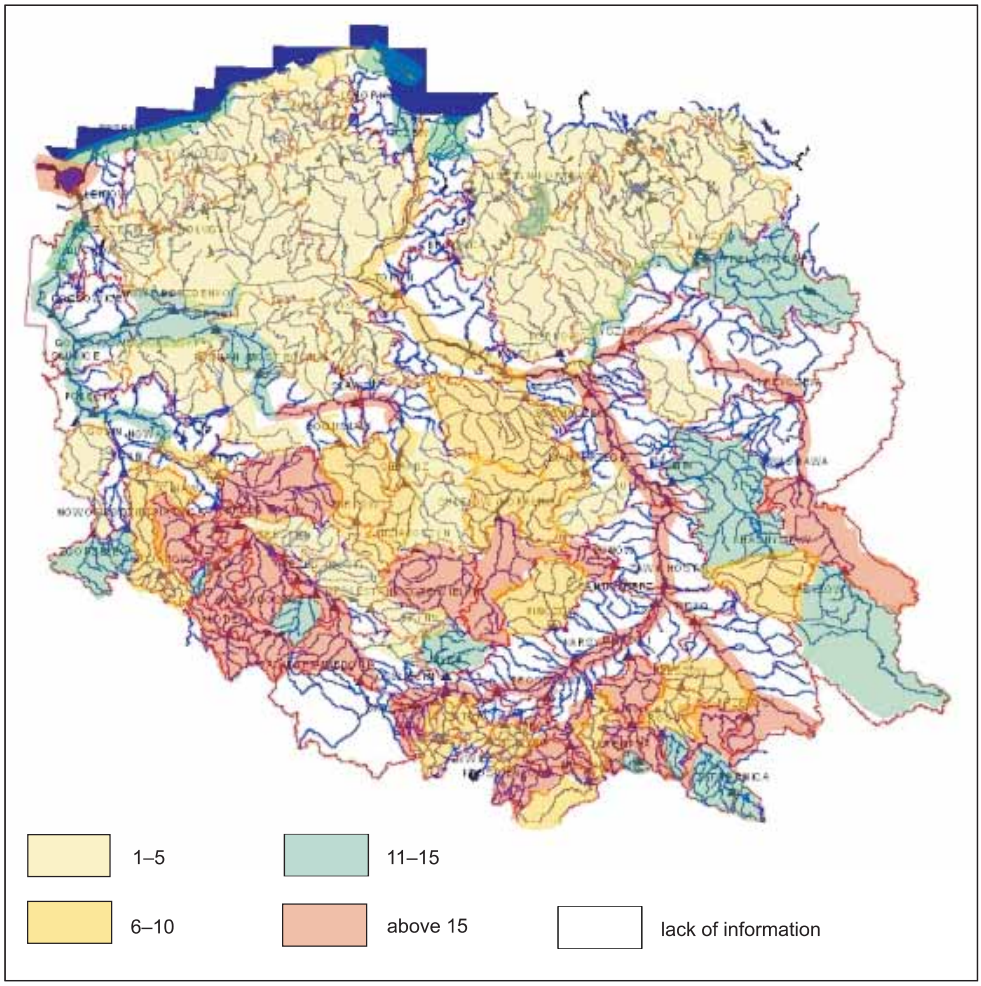

Fig. 3. Number of floods in catchments system in Poland from 1946 to 2001

Lines around rivers mean the floods only in river valleys not in catchments areas

the lower Wisła (11–15), outlet parts of the Przymorze rivers, the Narew River and upper part of its watershed, the middle and lower Odra, the lower Warta River and its valley.

LOCAL FLOODS

Local floods in the small catchments occurred every year in many regions of Poland. There were identified 404 cases of this kind of floods.

The impetuous increases of water levels and of flows in streams with small drainage catchments, in majority of cases are caused by torrential rainfalls of large efficiencies (Lorenc, 1998). When water surpasses riverbanks, it floods the ground causing the threat for people health and life as well as economic and environmental harms and losses.

Local floods are dangerous and difficult for prediction (for ability to warn people) because the phenomena develop usually rapidly, what causes immediate threat. Therefore, we called them "flash floods".

Apart from the above mentioned rainfall local floods, there were also distinguished (Fig. 4):

— melt local floods caused by impetuous snow-covers melting (winter and spring);

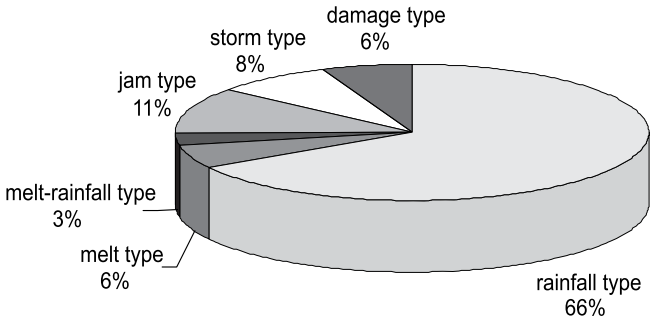

Fig. 4. Percentage of different genetic types of local floods

— rainfall-melt local floods caused by impetuous snow-covers melting, intensified by often heavy rainfalls (winter and spring);

— storm surges;

— jam local floods, caused mostly by accumulated ice flowing with watercourse;

— damage type local floods, caused by damages or destruction of dams, and flooding embankments, mainly during high water.

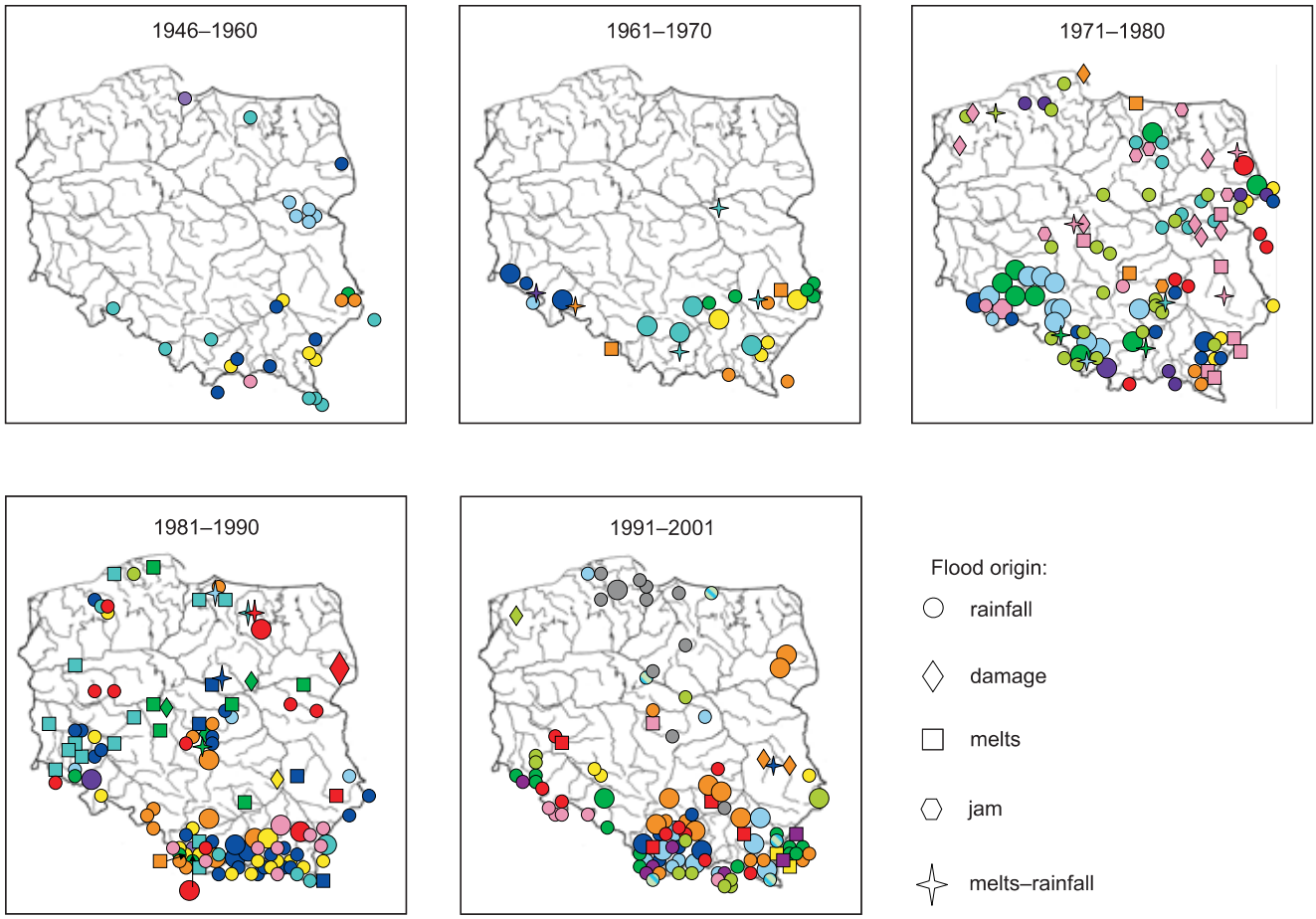

Fig. 5. The spatial distribution of local floods in Poland from 1946 to 2001

Colours differentiate years

Another criterion of local floods classification is urbanisation of the eventful areas. From this point of view, one can distinguish:

— local floods on the open areas,

— local floods in towns,

— local floods on the depressed areas (including areas of post mining subsidence).

Local floods in towns can be caused not only by water from rivers, channels or seas. They may be caused directly by intensive falls, when there is lack or too small capacity of the sewers systems or when the outflow is made difficult because of high water in the tributary (Ostrowski, 1999).

The spatial analysis (Fig. 5) showed that most of the local floods appeared on the areas of the following provinces: Małopolska, Fore-Carpathian, Silesian, Holy Cross Mts., Lower Silesian and Pomeranian (Żuławy and Kaszuby).

This is an important statement because above-mentioned part of the country (approximately below the 51° parallel), where considerable number of local floods have occurred, is also an area with tempestuous rainfalls of a large efficiencies (above 50 mm).

Smaller number of flood events or their absence was noted in basins of the Noteć, Pilica, lower Odra and lower Wisła rivers, and in the Suwałki region (right-sided tributaries of the Biebrza River).

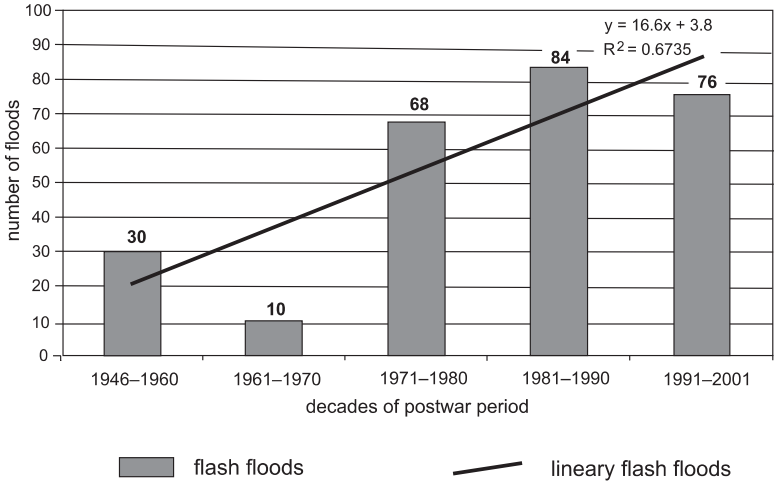

Fig. 6. Number of flash floods in Poland in decades of 1946–2001 period

The analyses showed the increasing frequency of events from the beginning of 1970s. The greatest increase of the floods number was observed in flash flood events (Fig. 6).

CONCLUSIONS

1. In Poland after the World War II occurred floods of different origin and various territorial extent. Nearly 590 of flood cases were identified. Rainfalls were the most frequent cause of flood origin (about 60%).

2. During the analysed multiyear period (from 1946 to 2001), 15 times occurred in Poland regional floods classified as catastrophic events because of their socio-economical damages. There were noted also cases of local floods which were classified as catastrophic ones because of people death and size of damages.

Since the beginning of 1996, rainfall regional floods occurred every year; twice they were catastrophic. During the last period, the flooded areas have expanded. The increase of the number of regional rainfall floods in the Pomeranian region was observed.

Local floods occurred every year; in some parts of the country — even several times. Harms and losses caused by them may be compared with damages caused by more rare regional floods appearing simultaneously on greater areas.

3. The analyses showed also that the most hazardous situations were generated when several reasons causing floods appeared at the same time. The greatest probability of coincidence of reasons causing catastrophic floods could be found in the following cases:

— the convergence of the high water wave from the tributary and the main river. Especially dangerous places were: the outlet of the Nysa Kłodzka River to the Odra River, the outlet of the Warta River to the Odra River, outlets of the Dunajec, San and Narew rivers to the Wisła River;

— intensive rainfalls during snow melting (on the lowlands);

— intensive rainfalls in cities on rivers, during the high water wave;

— damage of dam during flood (a great danger for grounds below the building).

4. The most threatened areas were city-industrial agglomerations protected by embankments located in river valleys where were the greatest amplitudes of water level changes.

5. The greatest potential threat was in the Żuławy Gdańskie area because of the simultaneous occurrence of high water on the Wisła river and ice-jam in its outlet part. In the described situation, it was very probable that the damage on the left embankment of the Wisła river, below Tczew, with danger of the catastrophic destruction in the Żuławy Gdańskie and the city of Gdańsk, would occur.

6. Very often happened that the most endangered potentially flooded areas were created by men's activity. The most frequent reason was the insufficient capacity of stream-beds

because of built-up valleys and the urbanisation of catchments without necessary reconstruction of the drainage system.

7. During the last 12 years (1991–2002), comparing with all the 32 years (1971–2002), the frequency of the occurrence of the torrential and rapid rainfalls has considerably increased (>30 and >50 mm/day). To the most threatened areas belong the Żuławy and the Gdańsk Gulf regions, and generally area of the country south of the 51° parallel: the Carpathians, southern part of the Sudetes, and the central part of the Bug river basin.

8. During the last 10 years, an increased number of local floods there is observed within the urbanised grounds (Łódź, Gdańsk — 2001, Warsaw — 2002) and on the grounds influenced by mining.

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