Analysis of the exposure of Polish lakes to flood risk

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Abstract: Flooding constitutes one of the main natural hazards in Poland, which causes enormous social, economic and environmental losses. The main causes of the occurrence of floods include intensive rainfall, rapid melting of snow and ice cover, as well as strong gusts of wind from the sea. Based on the *resilience* theory (resistance, elasticity), which constitutes an efficient tool for the description of the social-ecological system capability or components thereof to mitigate the effects of dangerous events, as well as the capability of reconstructing and adapting the system to new conditions, the authors have analysed the exposure of Polish lakes to flood risks with a probability of occurrence Q0.2%, Q1% and Q10%. In order to determine the level of exposure of lakes to the risk of flooding by flood waters, studies were conducted using the flood hazard and flood risk maps which were developed under the Project entitled "IT System of the Country's Protection against Extreme Hazards". The result of the efforts of the group of authors is the determination of the number of lakes, which are located in the flood risk area Q0.2%, Q1% and Q10%, including division into risk level groups (low, moderate and high). The results presented in the paper may constitute a contribution to further, more detailed studies concerning assessment of the vulnerability of Polish lakes located in the flood prone area.

Key words: social-ecological system, flood risk, flood hazard, exposure, sensitivity, vulnerability

Introduction

Flooding is one of the most frequent natural disasters in Poland (RCB 2010). It may be caused by intensive rainfall, rapid melting of snow and ice cover on rivers, strong gusts of wind from the sea or the failure of pooling water structures, as well as of flood preventive structures. Along with the development of urbanisation and the increasing violence of extreme weather events, floods in recent years have had an increasingly adverse impact on the sense of safety amongst the society, and generate increasingly severe losses in the economy and the natural environment (Strzelecka 2014; Zwoździak 2015).

In spite of many activities, it is not possible to completely eliminate the risk of floods (so-called residual risk). Implementation of a combination of measures, both technical and non-technical, may only reduce the risk of the occurrence of adverse effects of flooding. To ensure efficiency of these actions it is necessary to inform and raise public awareness of the flood threat and risk (Gromek 2014; Strzelecka 2014).

One of the methods to prevent floods and reduce their adverse effects is rational spatial policy and avoidance of development of areas in which floods may cause great losses (both social as well as economic and environmental). Therefore it is so important to identify all areas at risk of flood waters in Poland, and to evaluate the elements of social-ecological systems of great importance which are potentially located within the boundaries of a probable occurrence of this phenomenon.

According to the definition (UNISDR 2007) exposure defines those elements of the system (people, buildings etc.) which are located in the flood risk area and may cause or be a source of potential losses. The social-ecological system (SES) (Holling 1973) is considered as a system of closely related and interplaying components of geographic space, its natural resources, on one side, and human capital on the other side (Holling 1973). Both components are conditioned by cultural and historic factors, as well as political and economic ones (Tiukało and Dumieński 2013).

In consequence, lakes presented in the further part of the article constitute components of social-ecological systems. SES may be considered as an administrative district (Tiukało and Dumieński 2013) or commune (Dumieński, Michalik et al. 2015; Dumieński, Pasiecznik-Dominiak et al. 2015). The authors have thus identified the elements (of exposure) – Polish lakes – for all three scenarios of flood occurrence. This is the continuation of research works conducted by the Institute of Meteorology and Water Management – PIB Branch in Wrocław, which concern an assessment of Polish social-ecological systems exposed to adverse effects of flood waters (Dumieński, Pasiecznik-Dominiak et al. 2015).

In order to improve the safety of the citizens, a Project entitled “IT System of the Country’s Protection against Extreme Hazards” (Polish: “Informatyczny System Ochrony Kraju przed Nadzwyczajnymi Zagrożeniami” – abbr. ISOK) was set up, which supports Poland’s obligations associated with the implementation of the so-called Flood Directive (*Directive 2007/60/WE*), which constitutes an efficient tool for identification and management of flood risk.

An initial flood risk assessment (Polish: *wstępna ocena ryzyka powodziowego* – abbr. WORP) was conducted under the ISOK Project, which defines the most important areas at risk of flooding in Poland, characterised by the greatest probability of the occurrence of flooding, causing a threat to people’s life and health, as well as considerable economic and environmental losses. The aim of WORP was to identify rivers or river sections and embankments for which precise spatial data had been prepared, i.e. digital models of terrain and cross-sections of river beds, as well as hydrological data necessary to conduct hydraulic modelling, which lays the basis for the preparation of flood hazard maps (Polish: *mapy zagrożenia powodziowego* – abbr. MZP). For the areas identified by WORP – also under the ISOK Project – flood hazard maps and flood risk maps (Polish: *mapy ryzyka powodziowego* – abbr. MRP) were developed. Documents supplementing the above works will be Flood Risk Management Plans (Polish: *Plany Zarządzania Ryzykiem Powodziowym* – abbr. PZRP) for river basin areas and water regions, considering PZRP on the side of the sea, including internal marine waters (Tiukało and Sadowska 2015).

The flooding range areas presented in MZP are a basis for spatial planning at various levels. Borderlines of areas under threat of flooding are considered, amongst others, in the country’s spatial development

conceptions, provincial spatial development plans, local spatial development plans, and in decisions concerning the determination of the location of public purpose investments or in planning permission decisions. An example of a flood hazard map, developed within the framework of the ISOK Project, is presented in Figure 1. Flood hazard maps are available to the public at the ISOK Project website (<http://mapy.isok.gov.pl/imap/>).

Methods

The source of information on the exposure of Polish lakes to the threat of flooding occurrences is flood hazard maps. Flood hazard maps present areas at risk of flooding with a particular probability of occurrence (*Directive 2007/60/WE*): (i) areas in which the probability of flooding occurrence is low and equals 0.2% (i.e. once per 500 years; a so-called 500-year flood); (ii) areas in which the probability of flooding occurrence is moderate and equals 1% (i.e. once per 100 years; a so-called 100-year flood); (iii) areas in which the probability of flooding occurrence is low and equals 10% (i.e. once per 10 years; a so-called 10-year flood).

Lakes, due to their great importance for local communities, have become an object of many studies conducted by limnologists (Bogdanowicz et al. 2012). This enables assessment of the impact of climate changes on lake ecosystems and determination of threats, which may become obstacles for the use of lakes in the future.

Studies have contributed to the assessment of the status of lakes, which allows us to expand our knowledge on the weaknesses of the environment and the future threats associated with this. Based on the studies and analyses conducted on the impact of climate changes on lakes, common risk assessment and lake vulnerability methods have been developed. The main criteria used by limnologists while assessing vulnerability of lakes include the following: changes in water resources, water temperature, water quality, damage to the shoreline, damage to reed rushes, presence of invasive species, impact on agriculture, fishery, human health and tourism. All problems are inter-related and totally inter-dependent; maintenance of a constant water balance has a positive influence on the development of tourism, which in turn results in urbanisation of the lakes’ shoreline and destruction of natural reed rushes, which act as a natural filter for

Fig. 1. Example of the flood hazard map with the depth of water indicated for areas in which probability of flood occurrence is low – once per 500 years ($Q_{0.2\%}$): Sheet Bobrowice M-33-7-A-a-4 (access: <http://mapy.isok.gov.pl>).

purification of water. Taking into account the high rate of development of tourism, limnologists consider the social-economic consequences of the deterioration of the ecological condition of the lake, effects of which, they believe, might be serious (Bogdanowicz et al. 2012).

The authors of the paper focus mainly on the issues concerning identification of these lakes, which participate in the flow of flood waters. Additionally, they consider sensitivity to that hazard assigning the lake a flood hazard class, which depends on the water level elevation over the lake table.

The analysis of exposure of lakes to flood risk was possible using vector data for flood hazard areas, obtained as a result of mathematical modelling and using data of surface waters included in the Topographic Objects Database (*Polish: Baza Danych Obiektów Topograficznych – abbr. BDOT*), and also registered on flood hazard maps. The remaining aspects are typical of limnological studies and require detailed data, which are not available in the MZP database.

Based on the vector data of surface waters included in MZP, it was not possible to clearly select the lakes, due to lack of discrimination between the water body types (lakes, ponds). Therefore, the data have been supplemented with information about physiographic objects stored in the database of the National Register of Geographic Names (*Polish: Państwowy Rejestr Nazw Geograficznych – abbr. PRNG*), from which only lakes were selected (Fig. 2).

Fig. 2. Map of locations of Polish lakes entered in the National Register of Geographic Names (PRNG)

Fig. 3. Map of locations of Polish lakes subjected to potential losses in their ecosystems caused by flood events. Lakes were selected on the basis of Flood Hazard Maps (MZP)

Having the point layer of lakes from PRNG and the polygonal layer of still waters from BDOT, based on selection conducted according to location, all objects classified as lakes were selected from BDOT (Fig. 3). After having obtained the proper polygonal layer of lakes it was possible to select those objects which

are located in the flood hazard zones for the three scenarios of probability of flood occurrence: Q0.2% (Fig. 4), Q1% (Fig. 5), and Q10% (Fig. 6).

To illustrate the number of lakes at risk, depending on various flood scenarios, and their spatial distribution, a summarised map has been prepared (Fig. 7).

Fig. 4. Distribution map of lakes in Poland exposed to flooding with the probability of occurrence Q0.2% (once per 500 years)

Fig. 5. Distribution map of lakes in Poland exposed to flooding with the probability of occurrence Q1% (once per 100 years)

Fig. 6. Distribution map of lakes in Poland exposed to flooding with the probability of occurrence Q10% (once per 10 years)

Fig. 7. Summarised map of Polish lakes exposed to flooding with various probabilities of occurrence (Q0.2%, Q1%, and Q10%)

Results

As a result of the analysis, 181 lakes have been registered, which are at risk of flood waters. Concerning the probability of flooding there are 181 Q0.2% lakes, 177 Q1% and 160 Q10% lakes. The list of all registered objects (lakes) at risk of flooding is presented in tabular form (Table 1). Flood hazard maps, apart from the borderlines of areas under threat, also include information concerning the water depth as well as the water speed and direction, which have a direct impact on the threat for people and on the extent of property losses.

Three levels of threat have been applied to assess the level of threat, depending on the increased elevation of flood waters above the elevation of the water level in the lake (Dumieński, Michalik et al. 2015). For the areas (zones) created this way, relevant indices of a risk have been applied: HIGH, MODERATE, and LOW. Zone I corresponds with the HIGH index, zone II, MODERATE and zone III, LOW. A lake is considered to be under a high threat within the flood hazard area when the increased elevation of flood waters is greater than 2 metres; a moderate threat is within the range of 0.5-2 metres; and a low threat is 0-0.5 metres. The rule used for the division of lakes located in the flood hazard area is presented in Figure 8.

Table 1. Tabular presentation of Polish lakes at risk during flooding.

No.	PRNG	LAKE NAME	OPTIONAL NAME	Q0.2%	Q1%	Q10%
1	1580	Bachotek		+	+	+
2	2035	Bajkał		+	+	+
3	3801	Berdyczewo		+	+	+
4	4615	Białe Lake		+	+	+
5	5596	Białcz	Bielisz/Bielicz/Bielcz	+	+	+
6	5645	Bielkowskie Lake		+	+	+
7	5965	Biezdruhowo		+	+	+
8	6097	Binowo		+	+	+
9	6179	Lake Biskupie		+	+	+
10	6279	Lake Bledzewskie	Lipawki	+	+	
11	6535	Zbąszyńskie	Lake Zbąszyńskie/Błędno	+	+	
12	8285	Borek		+	+	+
13	9811	Grajwy	Brajmura/Zalew	+	+	+
14	13884	Bużyska		+	+	+
15	13890	Bużysko		+	+	+
16	15701	Lake Chobienickie		+	+	+
17	16779	Rokitno		+	+	+
18	19906	Lake Czekanowskie	Głębocek	+		
19	21012	Lake Czyste		+	+	+
20	21075	Czyżno	Czyżon	+	+	
21	21649	Dąbie		+	+	+
22	23475	Dębno Małe	Dąbie Małe, Małe Dąbie /Dębno Małe	+	+	+
23	24131	Długie Lake	Długie	+	+	+
24	24905	Dobrzeńsko		+	+	+
25	25540	Lake Pańskie	Dołusze	+	+	+
26	26159	Lake Koronowskie		+	+	+
27	26506	Drużno	Drużno	+	+	+
28	26536	Drwęckie Lake	Lake Drwęckie	+	+	+
29	26720	Dubie	Dubie Południowe, Adamowo	+	+	+
30	27173	Duża Łacha		+	+	+
31	27192	Duża Reptówka		+	+	+
32	27305	Lake Duże		+	+	+
33	27414	Żurskie Lake	Żur	+	+	+
34	28819	Dzierzgoń	Lake Malborskie	+	+	+
35	28967	Kotowickie Jeziora	Lake Dziewicze	+	+	+
36	29779	Lake Farskie		+		
37	31708	Gardno		+	+	+

No.	PRNG	LAKE NAME	OPTIONAL NAME	Q0.2%	Q1%	Q10%
38	32460	Lake Gródkowskie		+	+	+
39	33857	Lake Głuche		+	+	+
40	35115	Gorzelec		+	+	+
41	37608	Lake Grabowskie		+	+	+
42	39420	Lake Grójeckie		+	+	+
43	46755	Lake		+		
44	47785	Lake Juskowskie		+	+	+
45	53170	Lake Kierzkowskie	Lake Wójcińskie	+	+	+
46	53804	Kleśno	Lipawki	+	+	
47	54633	Lake Kłosowskie		+	+	+
48	55515	Kocioł		+	+	+
49	57104	Konin		+	+	+
50	57643	Lake Kopanickie		+	+	+
51	57961	Koperung	Kopaniny	+	+	+
52	58635	Mochel		+	+	+
53	59145	Kostrzyńskie	Lake Kostrzyńskie	+	+	+
54	59447	Księżno	Lake Kościelne	+	+	
55	59725	Kotło		+	+	+
56	60132	Lake Kowalskie	Zalew Kowalski	+	+	+
57	60922	Koźlanka		+	+	+
58	61603	Krąg		+	+	+
59	63338	Nisko	Lake Krzesińskie	+	+	+
60	63502	Krzemień	Krzemień	+	+	+
61	63606	Krzywa Jama		+	+	+
62	63612	Krzywa Noga		+	+	+
63	63637	Lake Krzywianieckie		+	+	+
64	63755	Lake Krzywe		+	+	+
65	64704	Kuchnia		+	+	+
66	67387	Leszcze		+	+	+
67	67715	Lake Leśniańskie	Lake Sucha	+	+	+
68	68132	Lake Lidzbarskie		+	+	+
69	68567	Lipiec		+		
70	68791	Lipkusz		+	+	+
71	69655	Kodno	Lake Zaporowe/Lake Lisowskie	+	+	+
72	69834	Liwieniec		+	+	+
73	70148	Lubie	Lake Lubieszewskie, Lubieszewo, Lake Lube	+	+	+
74	70736	Lake Ludziskie	Ludzisko	+	+	+
75	70835	Lutol		+	+	+
76	70853	Lake Lutomskie		+	+	+
77	71050	Łacha		+	+	+
78	71367	Lake Łapińskie Nowe		+	+	+
79	72361	Łąki		+	+	
80	72498	Łębsko		+	+	+
81	72786	Łęgowo	Lake Łęgowskie	+	+	+
82	76240	Maleszewo	Maliszewo	+	+	
83	76272	Lake Maltańskie	Malta	+	+	+
84	76444	Mała Reptówka		+	+	+
85	76676	Lake Kierzkowskie Małe	Lake Małe Kierzkowskie	+	+	+
86	77192	Mała Szczekowa	Mały Szekeń	+	+	
87	78699	Lake Mączne		+	+	+
88	79844	Mielno	Dubielno	+	+	+
89	79854	Mielno	Lake Koziejowskie	+	+	+
90	81937	Młyński Staw		+	+	+
91	81971	Młyńskie	Lake Młyńskie	+	+	+
92	81990	Lake Młyńskie		+	+	

No.	PRNG	LAKE NAME	OPTIONAL NAME	Q0.2%	Q1%	Q10%
93	82085	Mniszek		+	+	+
94	83309	Morliny	Ornowo	+	+	+
95	86416	Nieciecz		+	+	+
96	86540	Niedziółka		+	+	
97	87189	Niklerz		+	+	+
98	87744	Nogat		+	+	+
99	89023	Nowe Orle	Lake Orle	+	+	+
100	89276	Lake Nowe		+	+	+
101	89795	Lake Nowowiejskie		+	+	+
102	90927	Lake Obrzańskie		+	+	+
103	91109	Zaręba		+	+	
104	91380	Lake Ogonowskie		+	+	+
105	91731	Okno		+	+	+
106	95293	Ostrów		+	+	+
107	99213	Piaseczno		+	+	+
108	99726	Lake Piaskowe		+	+	
109	101389	Lake Piotrkowskie	Lake Piotrkowickie, Lake Piotrkowieckie	+	+	+
110	101493	Piotrowskie Lake		+	+	+
111	102347	Plawniowice		+	+	+
112	102385	Plaźno	Plężno, Pląsno, Dźwierzchno	+	+	+
113	102690	Okrajek	Lake Płytkie	+	+	+
114	107011	Lake Pokrzywnickie		+	+	+
115	107907	Pomocnia		+	+	
116	110025	Prądzik		+	+	+
117	110138	Lake Proboszczowskie		+	+	+
118	110252	Prostynia	Lake Koziejowskie, Prostyń	+	+	+
119	113476	Pauzeńskie Lake	Lake Pauzeńskie/Puzy	+	+	+
120	113857	Radgoszcz	Lake Radgoskie	+	+	+
121	114166	Lake Raduszeckie		+	+	+
122	115347	Reskowskie Lake	Reskowo	+	+	+
123	118170	Wielkie Rudno	Grażyna/Rudno/Dubie	+	+	+
124	118244	Lake Ruduskie	Lake Wojnowskie	+	+	+
125	119015	Rybojadło	Rybojadło, Lake Rybojadło	+	+	+
126	120209	Lake Sadłogoskie	Sadłogoszcz	+	+	+
127	121649	Sianowskie Lake		+	+	+
128	122155	Lake Sieluńskie		+	+	+
129	123504	Lake Święte	Małe, Mielno, Skępskie	+	+	+
130	123505	Lake Wielkie	Lake Skępskie Wielkie	+	+	+
131	124530	Lake Słodkie	Cisek, Lake Czyżkowskie	+	+	
132	124637	Lake Słone		+	+	+
133	125488	Smordy	Lake Jakuba	+	+	+
134	126521	Lake Sołeckie		+	+	+
135	129251	Stare Orle	Lake Orle	+	+	+
136	131226	Stoczek		+	+	+
137	131719	Lake Straszyńskie	Lake Goszyńskie	+	+	+
138	132126	Strunowo	Stronno	+	+	+
139	132460	Strzelno		+	+	+
140	133905	Lake Swarzędzkie		+	+	+
141	134440	Lake Szarlejskie	Szarlej, Gopło, Lake Łojewskie	+	+	+
142	135005	Szczypa		+	+	+
143	136939	Lake Ślepe	Lake Laskowe	+	+	+
144	138210	Lake Święte	Mień	+	+	+
145	140696	Lake Tryszczuńskie		+	+	+
146	141842	Turzynek		+	+	+
147	142050	Lake Tylickie Małe	Lake Środkowe, Małe	+	+	

No.	PRNG	LAKE NAME	OPTIONAL NAME	Q0.2%	Q1%	Q10%
148	142051	Lake Tylickie	Lake Fabryczne	+	+	+
149	146070	Wielka Łacha		+	+	+
150	146339	Lake Wielkie		+	+	+
151	146390	Rybaki		+	+	+
152	146391	Wielkie Dębno	Dąbie Wielkie	+	+	+
153	146406	Wielkie Lake		+	+	+
154	146407	Wielkie Lake	Rybno	+	+	+
155	146616	Lake Wielowiejskie	Lake Wielkowiejskie	+	+	+
156	147037	Lake Wierzchnie	Lake Wierzchnie	+	+	+
157	147221	Wierzysko		+	+	+
158	148487	Wiry	Lake Mostowe	+	+	+
159	150535	Lake Wolickie	Ptur, Ptur, Lake Pturskie	+	+	+
160	152024	Wstążki		+	+	
161	155195	Zacharz		+	+	+
162	155839	Zagnanie		+	+	+
163	162014	Lake Złotnickie		+	+	+
164	162130	Zły Łęg		+	+	+
165	164030	Żółwino	Żółwin, Lake Żółwińskie	+	+	+
166	164653	Kamienny Dół		+	+	+
167	201446	Lake Ośniańskie		+	+	+
168	201447	Kiszki		+	+	+
169	201754	Lake Rybackie		+	+	+
170	201833	Domastryjewo		+	+	+
171	202785	Czarna Łacha		+	+	+
172	202956	Sołeczno		+	+	+
173	203552	Lake Kapeloniaste		+	+	+
174	204058	Małe Rudno		+	+	+
175	204433	Gęsie		+	+	+
176	205544	Ruda Łacha		+	+	+
177	205620	Lake Jonica		+	+	+
178	205836	Kotowicko		+	+	+
179	205837	Lake Panieńskie		+	+	+
180	206319	Teselak		+	+	+
181	206320	Wornińskie Lake		+	+

Fig. 8. Delimitation of the areas (zones) for three different levels of flood threat (high, moderate, and low) for lakes

Because the methodology of generation of flood hazard areas used by MZP makes it impossible to directly determine the increased elevation of flood waters over the elevation of the lake water surface, in order to define this value and the threat for lakes associated with this, an additional buffer zone of 100 metres around the lakes' shoreline has been used for the layer of lakes at risk. The lake water surface elevations within a buffer zone defined thus have been estimated, as well as the increased elevations of flood waters over the lake water surface.

As a result maps showing lakes subjected to potential risk, taking into consideration the threat level of the flooding phenomenon, have been created (Figs 9-11). The threat level is expressed by an increased elevation of flood waters above the elevation of the lake water table for the three scenarios of flooding occurrence probability (Q0.2%, Q1%, Q10%). For the flooding occurrence probability Q0.2% scenario, a percentage diagram, showing the share of lakes with different levels of flood threat, has been additionally prepared (Fig. 12).

Discussion and Conclusion

The result of efforts of the team of authors is the determination of the number of lakes, which – based on analyses of flood hazard maps – are located within the zone of the flood risk. The identified lakes are listed in tabular form (Table 1). The maps (Figs 9-11) show the lakes with a division into individual groups, taking into account the level of the flood threat for a lake. This level is expressed by an increased elevation of flood waters above the elevation of the lake water surface. In all scenarios of the probability of flooding

Fig. 9. Distribution map of lakes in Poland exposed to flooding with the probability of occurrence Q0.2% arranged according to flood threat levels; data from BDOT

Fig. 10. Distribution map of lakes in Poland exposed to flooding with the probability of occurrence Q1% arranged according to flood threat levels; data from BDOT

Fig. 11. Distribution map of lakes in Poland exposed to flooding with the probability of occurrence Q10% arranged according to flood threat levels; data from BDOT

Fig. 12. Differentiation of flood threat level within a group of 181 lakes located within the flood range with the probability of occurrence once per 500 years

occurrence for which flood hazard maps were elaborated, three groups (levels) of division of the flood threat for lakes have been proposed, i.e. low, moderate and high.

Based on the conducted analysis of lakes' exposure it is evident that 181 lakes are at risk of flooding at probability Q0.2%, 177 at probability Q1%, and 160 at probability Q10%. While analysing the lakes under the threat of Q0.2% (500-year flood), it should be stressed that over 50% of these lakes are located within the range of a high threat (over 2 metres). On the scale of the entire country, the greatest number of lakes at risk are found in the Kuyavian-Pomeranian Province.

The area presented in the flood hazard maps, endangered by flood risk, allows us to determine the level of flood risk for this area, through application of the defined loss coefficients for different forms of land development (Dz.U. 2013 poz. 104). In contrast, flood risk in the area under study is characterised by the amount of losses of property caused by flooding with flood waters. However, under the Polish law (Dz.U. 2013 poz. 104), while calculating the amount of losses for the area at risk of flooding, losses originating from the impact of flood waters on surface waters (including lakes), have not been taken into consideration. There are also no loss coefficients assigned for the usage class "waters", or indexation of rates defining potential losses from the moment of publication of the ordinance. This results, on the one hand, in the lack of a full image of flood losses in Poland; on the other hand, it transfers the burden to evaluate the losses in the ecosystem into intermediate costs.

The material presented may contribute to further, more detailed analyses and assessments of vulnerability and *resilience* of lakes within the area at risk of a flood hazard. Through identification of the lakes (exposure) as well as by assigning flood hazard levels to these objects, the authors initiated the process of determination of their sensitivity, assuming that this constitutes those features and circumstances of the system or its elements which make the system at risk of adverse effects (losses), and their extent depends on the features of the system's elements (UNISDR 2007). Based on the approach adopted in the flood hazard analysis of Polish social-ecological systems, we may receive a comprehensive image of vulnerability, as a resultant exposure (system elements), sensitivity (features of these elements) and adaptation measures (undertaking technical and non-technical actions).

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