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Evaluation of Technical Measures Implemented in the Field of Flood Protection and Water Retention in Poland During the Period of 2003-2018

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Abstract: Flood prevention has become one of the most important priorities of public safety and risk mitigation in Poland. The study presents an evaluation of the actions implemented in 16 voivodships of Poland in the field of flood prevention and water retention. Voivodships correspond to individual regions of the country. The analysis covering the period of 2003-2018 was carried out on the basis of data obtained mainly from Local Data Bank. A set of indicators, divided into infrastructural and economic ones were applied. The assessment of technical measures covered two basic types of hydro engineering facilities: flood embankments and retention reservoirs. The economic indicators illustrate the expenditures incurred on the implementation of technical means of flood prevention. The obtained results provide means to categorise the voivodships into subsets. Units similar in terms of the carried out water management were assigned to 4 types. Voividships similar in terms of the expenditures designated to the implementation of water management tasks were divided into 4 groups. Taking into account the dynamics of the investments and financial outlays on water management measures related to the existing flood risk assessment, the situation is satisfactory in 4 voivodships, but insufficient or unsatisfactory in 7 of them. The obtained results show that in order to achieve the flood prevention levels required in the studied regions additional actions are necessary, including but not limited to technical measures.

Keywords: water management, flood protection, retention, regional differentiation, multi-indicator analysis

1. Introduction

Flooding is listed as one of the most frequent weather-related disasters (EC 2015). Changes in the pattern of this phenomenon are difficult to observe. Even though no robust and widespread increase in the amplitude and frequency of high river flows throughout Europe could be detected, there have been an increasing trend in the number of floods with large magnitude and severity (Kundzewicz et al. 2018). The magnitude and frequency of floods varies inter alia with human pressure and climate change, including global warming (Blöschl et al. 2019). Increasing temperatures and changes in precipitation significantly affect hydrological systems, water resources and properties that are essential for water management such as mean and extreme values of river flows, river and lake water levels and groundwater levels, i.e. (Staśko et al. 2017, Piniewski et al. 2020). Observing the current rate of global warming, the target of limiting it within 2 degrees by the end of the century seems more and more unrealistic. At 4 C global warming and climate change could increase the flood risk in Europe by 220% by 2080 (Alfieri at al. 2015). This threat has an important social and economic dimension. There is no doubt that costs of flood-related damages have been rising, partly due to the increasing exposure of people and assets (Kundzewicz et al. 2014, Alfieri et al. 2015).

The occurrence of floods in Europe and Poland is diversified in temporal and spatial terms. Short-term floods lasting less than 24 h (56%) prevail, of which 39% are river floods, 4% are coastal floods and the remaining 1.5% are compound events, i.e., floods caused by a co-occurrence of storm surge and high river flows (Paprotny et al. 2018). In southern Europe there are mostly flash floods that occur between September and November, in western and central Europe there are mostly river foods that take place between June and Augusts. Snowmelt floods dominate in northern European countries, while coastal floods are typical in areas of the North and the Baltic seas.

Poland is located in a temperate-transitional climate zone, therefore it is exposed to the clash of oceanic and continental air masses. These factors, together with much varied topography create the high risk of various natural hazards. Floods are considered to be one of the most important of them. In Poland, in case of natural phenomena there are four basic types of floods: flash floods, snowmelt floods, ice-jam floods and coastal floods. The areas of flash floods risk are located:

- in the Oder basin – the upper and middle Oder basin with the basins of the mountain tributaries (the Olza, Osobłoga, Mała Panew, Nysa Kłodzka, Ślęza, Bystrzyca, Kaczawa, Bóbr, Nysa Łużycka);

- in the Vistula's basin – the basin of the upper and middle Vistula (to the estuary of the Wieprz River) including the basins of the mountain and foothill tributaries (Przemsza, Soła, Skawa, Raba, Dunajec).

Administratively, they belong to the southern voivodships, i.e.: Małopolskie, Podkarpackie, Śląskie, Opolskie, Świętokrzyskie and Dolnośląskie. The threat of snowmelt floods occurs mainly in the central lowland part of the country, i.e. the areas of the middle and lower Odra and Vistula rivers, in the lowland tributaries of the Odra (Barycz, Warta, Noteć), in the lowland tributaries of the Vistula (Bug, Narew, Bzura, Drwęca) and rivers which run directly into the Baltic Sea. This kind of threats occur mainly in the voivodships: Wielkopolskie, Zachodniopomorskie, Mazowieckie, Warmińsko-Mazurskie and Podlaskie. Ice-jam floods occur in larger lowland rivers, mainly in the middle and lower Vistula and Oder rivers and in their larger tributaries. It concerns mainly the voivodships: Mazowieckie, Zachodniopomorskie and Pomorskie. Coastal flooding take place in the north of the country, including areas of Żóławy, the Vistula Lagoon, the Szczecin Lagoon and the lower sections of rivers running directly into the Baltic sea. It concerns mainly the Pomorskie and Zachodnio-Pomorskie Voivodships (Bednarczyk et al. 2006, Kowalewski 2006, KPZK 2020).

According to the assessment of flood risk for voivodships developed by Gołąb (2018):

- high risk exists in eight voivodships: Dolnoślaskie, Lubuskie, Małopolskie, Opolskie, Podkarpackie, Śląskie, Pomorskie, Zachodnopomorskie;
- medium risk exists in five voivodships: Kujawsko-pomorskie, Łódzkie, Mazowieckie, Podlaskie, Wamińsko-mazurske, Wielkopolskie;
- low risk covers two voivodships: Lubelskie, Świętokszyskie.

Until the end of 2020, The Concept of the National Spatial Planning 2030 (KPZK 2011) was the main document concerning spatial development and spatial planning of national importance. According to this concept, flood and drought counteractions were indicated as one of the most important strategic objectives. Two so-called functional areas (FA)were designates: FA exposed to flood hazard at the level of river basins, FA of water resources conservation and management. Objectives established for functional areas should be taken into account in planning activities carried out by administrative units. The complexity of the issue and the considerable spatial distribution of existing threats require an integrated territorial approach to development. Integrated management for functional areas related to water management requires cooperation within basin districts and water regions as well as administrative units of various levels. Protection against flooding and drought is a matter of State Water Holding Polish Waters as well as central, regional and local administration bodies. These

authorities develop and implement policy concerning technical and non-technical measures to minimize risks at regional level, i.e. functional areas, voivodships as well as local (municipal) levels. The authorities are also involved in decision making process regarding water, building, settlement and infrastructure investments allocated in flood risk areas. The activities are based on water management planning documents, including: flood hazard maps, flood risk maps, flood risk management plans. According to the National Flood Hazard Management Plan (KPZK 2020) the areas at risk of flooding were determined for 981 river sections having total length of 29 301.7 km. Moreover, a significant flood risk was determined for rivers sections having total length of 1 394.4 km.

According to the provisions of Art. 165.1. of the Water Law Act (Dz. U. 2017, item 1566, as amended), flood protection shall be implemented by:

- spatial management of river valleys and floodplains areas,
- rational water retention, rational use of flood-control structures, water flow control,
- ensuring the proper functioning of early warning and response system for hazards in the atmosphere and hydrosphere and forecasting floods,
- preservation, creation and restoration of water retention systems,
- construction, reconstruction and maintenance of flood control structures,
- carrying out ice-breaking activities,
- conducting information policy in the field of flood prevention, protection and mitigation.

Due to the existing legal, natural and socio-economic conditions most of the existing spatial development plans for voivodships required designation of functional areas related to flood risk and then the revision and adjustments of planned activities in their respective areas.

The literature regarding cross-sectional or comparative assessment of actions undertaken by administrative units for flood protection and the state of flood protection is limited. An example of a study using various indicators (mainly socio-economic) covering the whole country is the one conducted by Dumieniecki, Pasiecznik-Dominiak and Tiukało (2015) for municipalities. The authors indicated the quantitative and spatial differentiation of the municipalities depending on the exposure of the inhabitants to the flood risk with probability of Q1% and differentiation of municipalities due to the potential losses caused by flooding. The survey shows that that flooding with medium probability (Q1%) covers more than 50% of municipalities (1301 units). The largest number of them is located in the southern voivodships, i.e.: Lubuskie, Dolnośląskie, Opolskie and Podkarpackie. Similar conclusions apply to potential flood losses. In this case, apart from municipalities located in mountain regions in the south of the country, significant threat was indicated in several

units of Mazowieckie Voivodship. Dubiel (2015) conducted questionnaire and empirical surveys on flood prevention, protection and mitigation in the Śląskie Voivodship. The Oder and Vistula (Poland's two largest rivers) and their numerous tributaries in the voivodship are mostly unregulated, embanked only at small sections. The preparation of flood protection facilities in 17% of the surveyed municipalities has been considered to be good. However, similar number of municipalities indicated poor preparation, poor technical condition and insufficient number of hydrotechnical structures, flood banks, polders and retention reservoirs. An assessment of flood protection measures implemented between 2007 and 2016 was prepared by Gołąb (2018). The evaluation was based on flood protection programmes for individual river basins and the incurred costs of their implementation. The basic scope of investment activities of such programmes included, among others: construction, reconstruction and modernisation of flood protection embankments, protection of banks and stream bottoms, reconstruction of watercourse channels, construction of flood control reservoirs. The results were related to the current degree of flood risk in the voivodeships. The research shows that none of the flood programmes have delivered the expected results. There were significant delays in implementation, some of the programmes were even cancelled before the deadline. In the author's opinion, considerable financial outlays have not been translated into improved flood safety.

The main objective of the presented study was to evaluate the actions implemented in the years 2003-2018 in voivodships in the field of flood protection and water retention. The assessment was carried out using a set of infrastructural and economic indicators. The obtained results show diversification of the voivodships in terms of the amount of investments carried out and financial expenses incurred for water management

2. Methods

The assessment of the existing flood risk indicates the need to monitor the situation with respect to river basins as well as administrative units. In this study, the analysis concerns technical flood protection measures, i.e. those related to the construction of flood control structures and water retention facilities in 16 voivodships. A set of indicators, divided into infrastructural (4 indicators) and economic ones (3 indicators) were applied.

2.1. Infrastructural indicators

The assessment of technical measures covered two basic types of hydroengineering facilities: flood embankments and retention reservoirs. In the first case, a flood banks density index W1 was calculated according to Equation:

$$W_1 = \left[\frac{X_1}{X_{11}}\right] x1000 \text{ [-]}, \quad (1)$$

where:
X_1 – the total length of flood banks constructed in the years 2003-2018 [km],
X_{11} – the length of rivers [km].

One of the flood protection measures and drought prevention is surface water retention. The proposed indicator refers water retention in surface water reservoirs to urban areas. The surface water storage capacity index W2 was calculated by means of the following Equation:

$$W_2 = \left[\frac{X_2}{X_5}\right] x100 \text{ [m}^3\text{/10 ha]}, \quad (2)$$

where:
X_2 – the capacity of surface water reservoirs built in the years 2003-2018 [m^3],
X_5 – the mean area of urbanized and built-up land in the years 2003-2018 [ha].

Apart from the capacity of water reservoirs, the number of reservoirs was taken into account. It is implicated by the fact that a higher number of smaller capacity reservoirs can be more spatially and functionally favorable than one very large reservoir. Therefore, the surface density index of constructed artificial reservoirs W3 was determined by the following Equation:

$$W_3 = \left[\frac{X_3}{X_5}\right] \text{ [pcs./km}^2\text{]}, \quad (3)$$

where:
X_3 – number of water reservoirs built in the years 2003-2018 [pcs],
X_5 – the mean area of urbanized and built-up land in the years 2003-2018 [km^2].

In addition to technical means for flood protection, drought-related measures were analyzed. The irrigation surface density index was calculated from Equation:

$$W_4 = \left[\frac{X_8}{X_6}\right] \text{ [-]}, \quad (4)$$

where:
X_8 – the area of irrigated land in the years 2013-2018 [km^2],
X_6 – the area of the voivodship in 2018 [km^2].

2.2. Economic indicators

Apart from the indicators that allow to assess technical flood prevention measures of voivodships in terms of quantity, two indicators related to economic issues were proposed. The first indicator illustrates the expenditures incurred on the implementation of flood-banks in relation to 1 km of the river network. It was calculated according to Equation:

$$W_5 = \left[\frac{X_4}{X_{11}} \right] \text{[PLN/km]}, \tag{5}$$

where:
X_4 – expenditures on flood-banks in the years 2013-2018 [PLN],
X_{11} – the length of river network [km].

The indicator that describes the expenditure incurred on the implementation of small water retention facilities in relation to the impermeable surfaces, is calculated by the following Equation:

$$W_6 = \left[\frac{X_9}{X_5} \right] \text{[PLN/km}^2\text{]}, \tag{6}$$

where:
X_9 – financial expenditure on the implementation of small water retention facilities in the years 2013-2018 [PLN],
X_5 – the mean area of urbanized and built-up land in 2003-2018 [km^2].

The indicator regarding expenditure incurred on water management in general, related to the number of inhabitants, was calculated by means of the following Equation:

$$W_7 = \left[\frac{X_{10}}{X_7} \right] \text{[PLN/person]}, \tag{7}$$

where:
X_{10} – water management expenditures in the years 2013-2018 [PLN],
X_7 – average population in the province in the years 2003-2018 [person].

2.3. Standardized indictors and similarity intervals

In order to transform previously calculated indicators into comparable form, the values obtained for each voivodships were normalized according to Equation:

$$Z_{1.....7} = \frac{W_{1....7}}{W_{1...7\,\max}} \text{ [-]}, \tag{8}$$

Aggregate assessment for water management in individual voivodships was conducted by means of the synthetic Perkel index [Runge 2007] according to Eqution:

$$W_{IT(E)} = \frac{1}{n}\sum_{1}^{n} Z_{ij} \quad [-], \tag{9}$$

where:
$W_{IT(E)}$ – infrastructural (IT) or economic (E) synthetic indicator of water management in a voivodship,
j – 1,2, ..., n,
Zij – normalized value of indicators Wij,
n – the number of attributes.

The synthetic indicator was calculated separately for infrastructural and economic indicators. The higher value of the infrastructural synthetic indicator means the higher investment activity of the voivodship related to the implementation of tasks in the field of water management. The higher values of the economic synthetic indicator the higher financial expenses designated for this purpose in the years 2003-2018.The next step was to develop classes of the voivodships with similar characteristics. The number of classes was determined using basic formulas for the frequency distribution of grouped data (Tarka & Olszewska 2018), taking into account that the analysis concerns 16 voivodships:

- $k = \sqrt{N} = \sqrt{10} = 3{,}16$
- $k \leq 1 + 3{,}222\ logN \leq 4{,}222$
- $k \leq 5\ logN \leq 5$

The number of classes was set at 4 (k = 4), and the range of intervals was established by the mean of Equation:

$$h = \frac{Z_{1-7(\max)} - Z_{1-7(\min)}}{k} \tag{10}$$

where:
N – number of the voivodeships,
h – the range of intervals.

Input data for the variables X_1-X_{10} were taken from the Local Data Bank (LDB). The variable X_{11} was calculated on the basis of the Map of Hydrographic Division of Poland (2013) in shp. format. The obtained values of the indicators X_1-X_{11} are presented in Tables 1-2. Spatial analyses were performed and the individual maps prepared by means of the ArcMap application being part of the ArcGIS software.

Table 1. The variables X_1-X_6 concerning water management in the analyzed voivodeships for the years 2003-2018 (Own study based on LDB)

No.	Voivodship	X_1 [km]	X_2 [m^3]	X_3 [pcs.]	X_4 [kPLN]	X_5 [ha]	X_6 [km^2]
1.	Dolnośląskie	158.1	27 783 691	7	823 952.1	135254.8	19 947
2.	Kujawsko-Pomorskie	82.2	26 000	1	164 795.3	84166.94	17 971
3.	Lubelskie	87.0	1 090 400	15	267 289.8	91586.38	25 123
4.	Lubuskie	95.6	3 380 321	4	227 287.6	62261.75	13 988
5.	Łódzkie	37.3	21 052 288	10	34 165.9	95183.44	18 219
6.	Małopolskie	556.0	759 250	2	522 056.9	86065.31	15 183
7.	Mazowieckie	154.4	3 493 676	14	268 012.2	185104.9	35 559
8.	Opolskie	73.5	5 679 700	3	180 134.5	55545.44	9 412
9.	Podkarpackie	208.1	625 214	12	468 087.3	78307.94	17 846
10.	Podlaskie	2.1	773 170	14	9 152.1	74762.75	20 187
11.	Pomorskie	265.3	289 519	12	476 904.2	91191.63	18 323
12.	Śląskie	102.7	51 721 963	10	147 934.5	140967.6	12 333
13.	Świętokrzyskie	109.6	38 273 794	13	301 707.0	51829.63	11 710
14.	Warmińsko- Mazurskie	174.5	15 759	6	77 811.4	88168.69	24 173
15.	Wielkopolskie	255.2	9 781 538	11	128 933.4	151594.4	29 826
16.	Zachodniopomorskie	173.2	694 028	10	278 557.5	97922.44	22 905

Table 2. The variables X_7-X_{11} concerning water management in the analyzed voivodeships for the years 2003-2018 (Own study based on LDB)

No.	Voivodship	X_7 [person]	X_8 [km^2]	X_9 [kPLN]	X_{10} [kPLN]	X_{11} [km]
1.	Dolnośląskie	2 898 271	10170.16	96 044.1	5 632 854.6	12378.790511
2.	Kujawsko-Pomorskie	2 080 066	84.836	28 649.3	1 873 086.9	6061.399851
3.	Lubelskie	2 159 436	167.346	73 081.7	1 487 635.8	9884.609199
4.	Lubuskie	1 015 091	73.946	27 587.0	1 194 308.8	5084.137697
5.	Łódzkie	2 532 163	1512.158	56 642.1	1 430 567.1	7073.719764
6.	Małopolskie	3 326 769	932.16	25 617.6	5 309 226.0	9354.699512
7.	Mazowieckie	5 264 696	0.912	140 253.8	5 305 643.5	15414.414958
8.	Opolskie	1 019 379	1786.858	36 590.0	1 573 938.6	5220.06819
9.	Podkarpackie	2 115 509	30.92	34 547.2	1 968 417.0	10208.140796
10.	Podlaskie	1 194 294	9.64	70 897.8	940 532.6	7660.01446
11.	Pomorskie	2 260 886	131.162	11 159.6	2 235 003.4	6463.231316
12.	Śląskie	4 624 091	57.456	34 494.7	4 625 456.9	6583.006154
13.	Świętokrzyskie	1 270 564	3.015	58 670.1	1 172 792.5	4814.042811
14.	Warmińsko- Mazurskie	1 436 272	18.3	30 196.1	1 237 677.0	10197.969557
15.	Wielkopolskie	3 432 066	624.004	274 753.6	2 733 735.4	10478.150434
16.	Zachodniopomorskie	1 705 236	3316.43	45 404.1	1 867 432.3	8407.824052

3. Characteristics of voivodships in terms of investment measures in water management

The results of the individual indicators for the voivodships according to annual reporting periods from 2003 to 2018 are presented in Figures 1-2 and Tables 3-4.

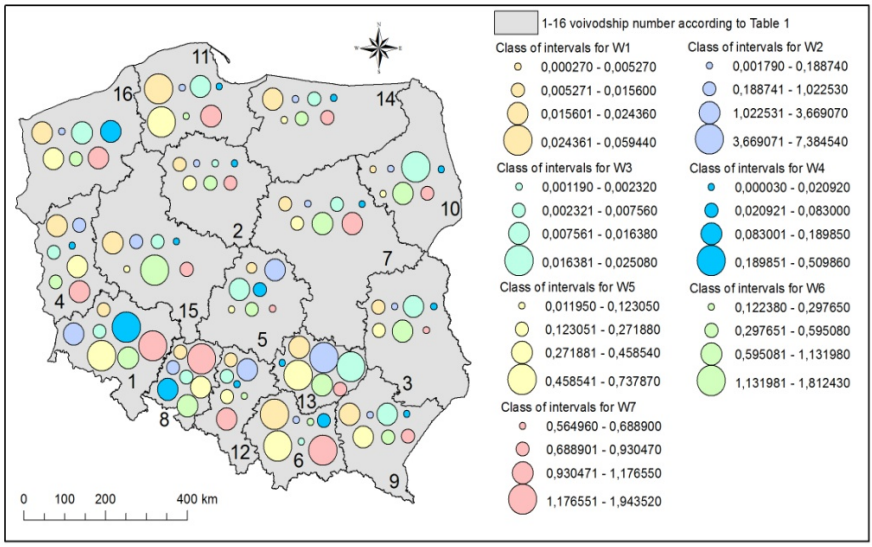

Fig. 1. Diversity of voivodships according to infrastructural and economic indicators W1-W7 (Own study)

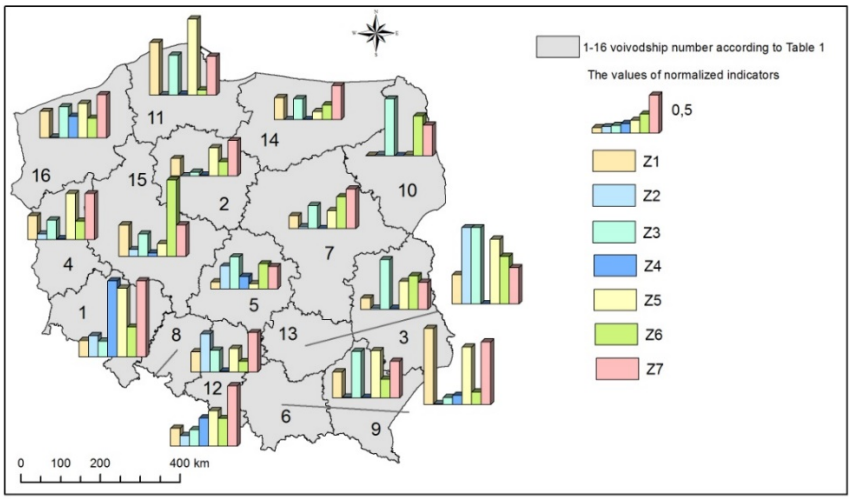

Fig. 2. Diversity of voivodships according to the normalized indicators Z1-Z7 (Own study)

Table 3. Values of the infrastructural and economic indicators for the voivodeships in the years 2003-2018 (Own study)

No.	Voivodship	W_1 [-]	W_2 [m^3 /10ha]	W_3 [pcs. /km^2]	W_4 [-]	W_5 [kPLN /m]	W_6 [kPLN /ha]	W_7 [kPLN /person]
1.	Dolnośląskie	0.01277	2.05417	0.00518	0.50986	0.66562	0.71010	1.94352
2.	Kujawsko-Pomorskie	0.01356	0.00309	0.00119	0.00472	0.27188	0.34039	0.90049
3.	Lubelskie	0.00880	0.11906	0.01638	0.00666	0.27041	0.79795	0.68890
4.	Lubuskie	0.01880	0.54292	0.00642	0.00529	0.44705	0.44308	1.17655
5.	Łódzkie	0.00527	2.21176	0.01051	0.08300	0.04830	0.59508	0.56496
6.	Małopolskie	0.05944	0.08822	0.00232	0.06139	0.55807	0.29765	1.59591
7.	Mazowieckie	0.01002	0.18874	0.00756	0.00003	0.17387	0.75770	1.00778
8.	Opolskie	0.01408	1.02253	0.00540	0.18985	0.34508	0.65874	1.54402
9.	Podkarpackie	0.02039	0.07984	0.01532	0.00173	0.45854	0.44117	0.93047
10.	Podlaskie	0.00027	0.10342	0.01873	0.00048	0.01195	0.94830	0.78752
11.	Pomorskie	0.04105	0.03175	0.01316	0.00716	0.73787	0.12238	0.98855
12.	Śląskie	0.01560	3.66907	0.00709	0.00466	0.22472	0.24470	1.00030
13.	Świętokrzyskie	0.02277	7.38454	0.02508	0.00026	0.62672	1.13198	0.92305
14.	Warmińsko-Mazurskie	0.01711	0.00179	0.00681	0.00076	0.07630	0.34248	0.86173
15.	Wielkopolskie	0.02436	0.64524	0.00726	0.02092	0.12305	1.81243	0.79653
16.	Zachodniopomorskie	0.02060	0.07088	0.01021	0.14479	0.33131	0.46367	1.09512

Table 4. Values of the normalised indicators for the voivodeships in the years 2003-2018 (Own study)

No.	Voivodship	Z1	Z2	Z3	Z4	W_{IT}	Z5	Z6	Z7	W_E
1.	Dolnośląskie	0.21489	0.27817	0.20634	1.00000	**0.42485**	0.90207	0.39179	1.00000	**0.76462**
2.	Kujawsko-Pomorskie	0.22817	0.00042	0.04737	0.00926	**0.07131**	0.36846	0.18781	0.46333	**0.33987**
3.	Lubelskie	0.14809	0.01612	0.65297	0.01306	**0.20756**	0.36647	0.44027	0.35446	**0.38707**
4.	Lubuskie	0.31637	0.07352	0.25614	0.01037	**0.16410**	0.60587	0.24447	0.60537	**0.48524**
5.	Łódzkie	0.08872	0.29951	0.41886	0.16279	**0.24247**	0.06546	0.32834	0.29069	**0.22816**
6.	Małopolskie	1.00000	0.01195	0.09265	0.12042	**0.30626**	0.75632	0.16423	0.82114	**0.58056**
7.	Mazowieckie	0.16853	0.02556	0.30154	0.00005	**0.12392**	0.23564	0.41806	0.51853	**0.39074**
8.	Opolskie	0.23690	0.13847	0.21533	0.37236	**0.24077**	0.46767	0.36346	0.79444	**0.54186**
9.	Podkarpackie	0.34299	0.01081	0.61096	0.00340	**0.24204**	0.62144	0.24341	0.47875	**0.44787**
10.	Podlaskie	0.00461	0.01400	0.74658	0.00094	**0.19153**	0.01619	0.52322	0.40520	**0.31487**
11.	Pomorskie	0.69063	0.00430	0.52464	0.01404	**0.30840**	1.00000	0.06752	0.50864	**0.52539**
12.	Śląskie	0.26248	0.49686	0.28282	0.00914	**0.26283**	0.30455	0.13501	0.51468	**0.31808**
13.	Świętokrzyskie	0.38305	1.00000	1.00000	0.00050	**0.59589**	0.84936	0.62457	0.47494	**0.64962**
14.	Warmińsko-Mazurskie	0.28790	0.00024	0.27131	0.00148	**0.14023**	0.10341	0.18896	0.44339	**0.24525**
15.	Wielkopolskie	0.40978	0.08738	0.28930	0.04103	**0.20687**	0.16676	1.00000	0.40984	**0.52553**
16.	Zachodniopomorskie	0.34659	0.00960	0.40715	0.28398	**0.26183**	0.44900	0.25583	0.56347	**0.42277**

4. Discussion

In accordance with the methodological assumptions the voivodships were divided into 4 types in terms of water management activities that were carried out and 4 groups in terms of the expenditures devoted to the implementation of water management tasks (Fig. 3, Table 5).

Types of the voivodships are the following:

- type A – voivodships at very high level of water management investments,
- type B – voivodships at high level of water management investments,
- type C – voivodships at medium level of water management investments,
- type D –voivodships at low level of water management investments.

Groups of the voivodships are the following:

- group 1 – the voivodships with very high expenditure,
- group 2 – the voivodships with high expenditure,
- group 3 – the voivodships with medium expenditure,
- group 4 – the voivodships with low expenditure.

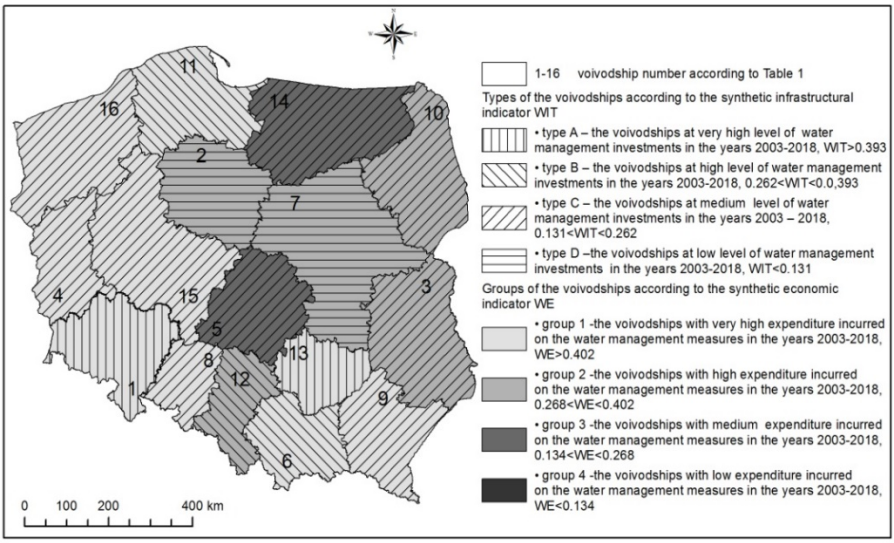

Fig. 3. Types and groups of the voivodships according to the implementation level and expenditures incurred on water management in the years 2003-2018 (Own study)

Table 5. Typology of voivodships according to implementation level and expenditures incurred on water management in the years 2003-2018 (Own study)

	Type A		Type B		Type C		Type D	
Group 1	Dolnośląskie Świętokrzyskie	2*	Małopolskie Pomorskie	2	Lubuskie, Opolskie, Podkarpackie, Wielkopolskie, Zachodniopomorskie	5		0
Group 2		0	Śląskie	1	Lubelskie. Podlaskie	2	Kujawsko-Pomorskie Mazowieckie	2
Group 3		0		0	Łódzkie. Warmińsko-Mazurskie	2		0
Group 4		0		0		0		0

* no. of the voivodships

According to the results presented above, there is a diversification of the voivodships with regard to technical flood protection measures undertaken in the analysed period. The obtained picture of the situation was compared with the results of the study made by Gołąb (2018) that concerns the issue of flood protection of Poland in 2007-2016. The abovementioned work contains the flood risk assessment of the voivodeships that was developed using the RCB method (2010, pp. 14-18) and flood risk maps (ISOK 2018). The results of the assessment are presented in Fig. 4.

The analysis of relation between the existing flood risk in the voivodships with the infrastructural and economic activities undertaken by the authorities in the analyzed period to prevent, reduce and counteract floods shows that in the group of the voivodships with a high flood risk, the best results were achieved in the Dolnośląskie Voivodship. Lower but still satisfactory effects were noted in the Pomorskie and Małopolskie Voivodships. In the remaining voivodeships of this group (Lubuskie, Opolskie, Podkarpackie, Zachodniopomorskie) the level of implementation of technical measures to minimize risks is medium, in spite of the very high financial expenditure. The Śląskie Voivodship is the only region with a high flood risk, slightly lower expenditure incurred on water management and high level of implemented technical investments.

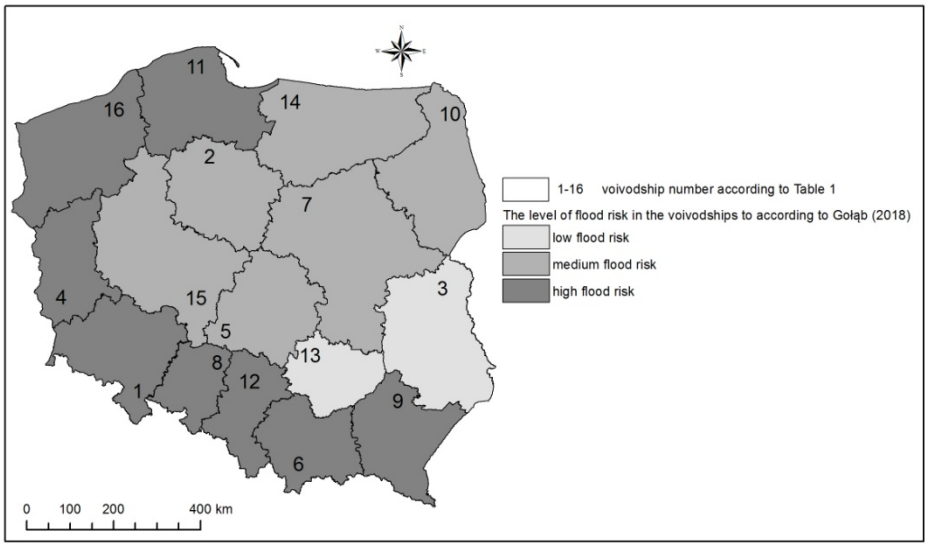

Fig. 4. The flood risk assessment in voivodships using RCB method (Own study based on Gołąb, 2018)

Quite large variation was observed in the case of regions assigned to a group of low flood risk. In Świętokrzyskie Voivodship the tasks were implemented at a high level and with very high expenditure. Whereas, in the Lubelskie Voivodship the achievements are medium despite high expenditure. The unfavorable situation occurs in the voivodeships of medium flood risk. This is particularly evident in case of the Kujawsko-Pomorskie and Mazowieckie Voivodeships, where significant financial expenditures were not reflected in investment activities in water management, especially compared to other voivodeships. The situation is slightly better in the Wielkopolskie Voivodship. Łódzkie, Warmińsko-Mazurskie and Podlaskie Voivodships were assessed at the medium level.

5. Summary

Flood protection has become one of the most important priorities of public safety and risk prevention in Poland. In accordance with the overall objective of the European Directive (Directive 2000) there is a strong need to limit flood losses which involves appropriate land-use management of flood risk areas. Taking into account the progressing climate change, and consequently the increasing number of extreme weather events, it is fair to assume that the endangered areas will grow larger.

Spatial development plans for each of the 16 voivodships place a strong emphasis on enhancement of security in the flood risk areas as well as on drought mitigation. These tasks are implemented mainly using technical methods, including e.g. the establishment and modernisation of flood prevention embankments or construction of retention reservoirs. Taking into account the dynamics of the investments and financial outlays on water management measures, the situation is satisfactory in 4 voivodships i.e. Dolnośląskie, Świętokrzyskie, Małopolskie and Pomorskie. The study also indicated voivodships where implementation of flood protection measures appears to be insufficient (Kujawsko-Pomorskie and Mazowieckie voivodships) or unsatisfactory (Lubelskie, Opolskie, Podkarpackie, Wielkopolskie, Zachodniopomorskie). Development plans for voivodships define three main measures applicable in flood loss mitigation: restriction of settlement development in high flood risk areas, enhancement of water retention and implementation of the broadly defined green-and-blue infrastructure. These goals are directly linked to the coordination of activities undertaken by various entities responsible for water management, flood prevention and spatial planning. These are State Water Holding Polish Waters as well as regional, sub regional and local administration authorities. Apart from flood risk mitigation implemented at the regional level, local spatial planning also plays a very important role, especially in terms of rational conversion of arable land into urbanized and built-up land (Mrozik & Przybyła 2013, Pawłat-Zawrzykraj & Podawca 2019, Podawca & Pawłat-Zawrzykraj 2019). Unfortunately, adverse situation associated with uncontrolled urbanisation, especially due to administrative decisions that allow to place new investments (particularly new settlements) in flood-risk areas and rising urban pressure on river valleys, do not correspond to the flood prevention objectives listed above. These particular problems were highlighted in the report of the Supreme Audit Office (Kowalewski 2018). The report pointed them out as symptoms of defective spatial planning system and inadequate spatial management. In Poland, the demand for residential areas is overestimated. In the country populated by 38.162 million people, the capacity of areas designated for settlements is about 60 million. Some of these areas are also designated in flood-risk areas (Kowalewski 2018). All of these factors demonstrate the need for stronger coordination of activities undertaken at various administrative levels, starting from national, through regional to local ones.

References

Alfieri, L., Feyen, L., Dottori, F. & Bianchi, A. (2015). Ensemble flood risk assessment in Europe under high end climate scenarios. *Global Environmental Change, 35*, 199-212. Retrieved from: https://doi.org/10.1016/j.gloenvcha.2015.09.004. (12.02.2021)

Bednarczyk, S., Jarzębińska, T., Mackiewicz, S. & Wołoszyn, E. (2006). *The vademecum of flood protection*. KZGW, Gdańsk. Retrieved from: https://docplayer.pl/4135934-Vademecum-ochrony-przeciwpowodziowej.html.(10.02.2021) (in Polish).

Blöschl, G., Hall, J., Viglione, A., Perdigão, R.A., Parajka, J., Merz, B. & Boháč, M. (2019). Changing climate both increases and decreases European river floods. *Nature, 573*(7772), 108-111.

Dubiel, B. (2015). Prevention and compensation the results of flood risk in the silesian municipalities. *Studia Ekonomiczne. Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach, 232*, 23-38 (in Polish).

Dumieński, G., Pasiecznik-Dominiak, A. & Tiukało, A. (2015). Social-economical assessment of polish communities to flood threat w: Kotowski, A., Piekarska K., Kaźmierczak B. (red). *Interdyscyplinarne Zagadnienia w Inżynierii i Ochronie Środowiska*. 100-125. Wrocław. Oficyna Wydawnicza Politechniki Wrocławskiej, Tom 6 (in Polish).

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy Retrieved from: https://eur-lex.europa.eu/eli/dir/2000/60/oj. (08.02.2021)

Dz. U. 2017. item 1566 as amended; The Act of 20 July 2017 - Water Law.

EC – European Commission 2015. Communication from the Commission to the European Parliament and the Council - The Water Framework Directive and the Floods Directive: Actions towards the 'good status' of EU water and to reduce flood risks, COM(2015) 120 final, European Commission, Brussels.

Gołąb, N., (2018). Flood Protection of Poland in the Years 2007-2016. Bezpieczeństwo i zagrożenia kryzysowe. Źródła i rodzaje zagrożeń bezpieczeństwa publicznego. *Przedsiębiorczość i Zarządzanie, 19,8*(2), 87-100 (in Polish).

ISOK, (2018). Flood hazard maps and flood risk maps. Retrieved from: https://wody.isok.gov.pl/imap_kzgw/ (01.02.2021).

Kowalewski, Z., (2006). Floods in Poland – types, occurence and flood control system. *Water-Environment-Rural Areas, 6,1*(16), Instytut Melioracji i Użytków Zielonych w Falentach, 207-220 (in Polish).

Kowalewski, A., Markowski, T. & Śleszyński, P. (2018). Studies on spatial chaos. *Studia KPZK PAN, 182*, Warszawa. Retrieved from: https://journals.pan.pl/skpzk/125267 (01.02.2021) (in Polish).

KPZK, (2011). *The National Spatial Development Concept 2030*. Retrieved from: http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wmp20120000252(08.02.2021)

KPZK, (2020). *The national crisis management plan*. Retrieved from: https://rcb.gov.pl/krajowy-plan-zarzadzania-kryzysowego (08.02.2021).

Kundzewicz, Z.W., Kanae, S., Seneviratne, S.I., Handmer, J., Nicholls, N., Peduzzi, P., Mechler, R., Bouwer, L.M., Arnell, N., Mach, K., Muir-Wood, R., Brakenridge, G. R., Kron, W., Benito, G., Honda, Y., Takahashi, K. & Sherstyukov, B. (2014). Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal, 59*(1), 1-28.

Kundzewicz, Z.W., Pińskwar, I. & Brakenridge, G.R. (2018). Changes in river flood hazard in Europe: a review. *Hydrology Research 49*(2), 294-302. DOI: https://doi.org/10.2166/nh.2017.016. (12.02.2021)

LDB. Local Data Bank of Statistics in Poland. [online] https://bdl.stat.gov.pl/BDL/start (01.02.2021).

Map of Hydrographic Division of Poland (2013) prepared by the Department of Hydrography and Morphology of River Channels of the Institute of Meteorology and Water Management commissioned by the Minister of Environment and financed by the National Fund for Environmental Protection and Water Management – shp.

Mrozik, K., Przybyła, Cz. (2013). *Mała retencja w planowaniu przestrzennym*. Poznań: PRODRUK, 1-216.

Pawłat-Zawrzykraj, A., Podawca, K. (2019). Voivodeship classification in accordance with the directions of agricultural and forest lands repurposement, *Journal of Ecological Engineering. 20*(11), 100-108.

Piniewski, M., Okruszko, T. & Kundzewicz, Z.W. (2020). Impact of the climate change on the water resources of Poland. *Gospodarka Wodna. 3*, 19-25 (in Polish).

Podawca, K, Pawłat-Zawrzykraj, A. (2019). The agriculture and forestry lands level of changes in planning process as a sustainable development measure of municipalities located within national parks impact areas. *Journal of Ecological Engineering, 20*(8),153-164.

RCB (2010). Procedure of elaboration of sub-reports for the Report on the National Security. Retrieved from: http://rcb.gov.pl/wp-content/uploads/procedura.pdf (01.02.2021).

Staśko, S., Tarka, R. & Buczyński, S. (2017). Extreme weather events and their effect on the groundwater level (Examples from Lower Silesia). *Przegląd Geologiczny. 65,* 11(2), 1244-1248 (in Polish).

Suttie, D., Hussein, K. (2015). *Territorial approaches to Regional Development*. IFAD. p.5. Retrieved from: https://aer.eu/territorial-approaches/(10.02.2021).

Tarka, D., Olszewska, A.M. (2018). *Elements of Statics. Statistical description*. Białystok: Publishing House of the Białystok University of Technology, 1-213 (in Polish).