THE RESULT OF TESTS
KAMIENNA PILOT CATCHMENT

DT1.3.1 reports from pilot action - testing the prototype of the FroGIS tool in the river basins	Version 2 1 2019

Content

1. Purpose and scope of testing

The purpose of testing was:

- to apply FroGIS in the Polish pilot catchment called Kamienna.
- to develop valorisation maps for existing flood, drought and water quality issues in the pilot catchment.
- to test the sensitivity of the analysis to subjective choices, in order to provide suggestions for the future application of the valorisation tool. The investigated subjective choices were: the choice of SPUs used in the analysis, the choice of indicator classification methods, the choice of weights used for the final aggregation.
- to validate the obtained map with expert opinions.

2. Characteristics of the catchment

Kamienna catchment was chosen as a pilot catchment because it has a bad ecological status and all of its problems (i.e. flooding, drought, water quality) occur within its area. It is located in the area of the Polish Upland (according to Konracki, physico-geographical division) in the water region of Central Vistula. Kamienna River is a left-bank tributary of the Vistula, it is 156 km long and flows from west to east. The catchment is covered mostly by arable land (54%), forests (30%) and has a large share of urban areas, located close to the main river channel. There is a large number of small, artificial reservoirs in its area and two large ones: Wióry and Brody Iłżeckie. Due to its location (lowland / piedmont) and land use, it is characterized by high flow dynamics which creates large needs and possibilities of water retention. Details are shown on the map in Fig. 1 and table Tab. 1.

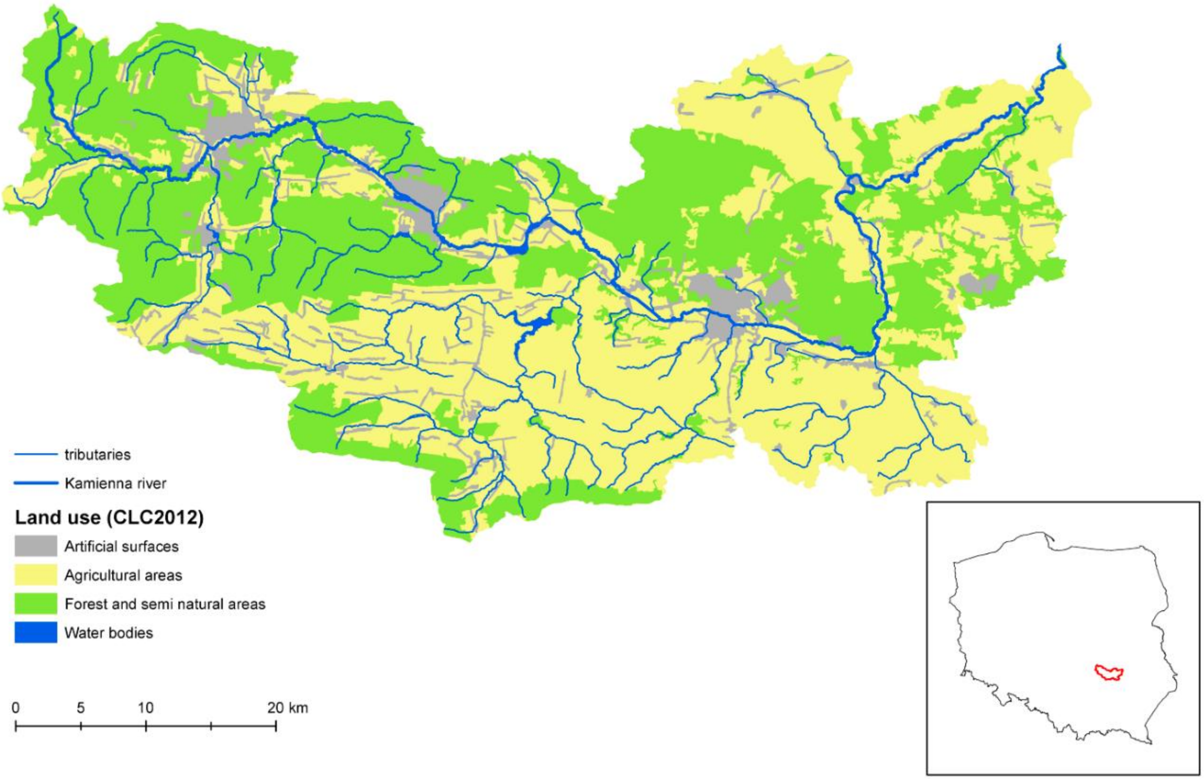


Fig. 1 Map of landuse in the Kamienna catchment

Tab. 1 Characteristic of Kamienna catchment

Characteristic	Unit	Value
Character of catchment		Lowland/piedmont
Catchment size:	km2	2020
Average flow low/avg/high*	m3/s	2.9/8.3/40
Extreme flow low/high*	m3/s	0.07/113
Annual precipitation low/avg/high*	mm	420/640/920
Annual air temperature min/avg/max*	°C	03.06.2012
Agriculture area	%	54.2
Urban area	%	15.6
Forest area	%	29.6
Open Water area	%	0.6
Flooded area (1/100 years)	km2	55.6
Artificial drainage area	km2	59.2
Ecological status no good/bad	water body	2/11
Major problems to achieve good ecological status		Phitoplancton, Phytobenthos, Macrophytes, BOD5,PO4, Norganic

3. Issues identified in the catchment

Recognition of problems present in the catchment was the first stage of data preparation for the development of a valorisation map. It allows the FroGIS application user to determine the main goal of the analysis, how many valorisation maps should be developed and then decide what planning units can be chosen. Additionally, this recognition will allow to gather data necessary for the process of selecting weights and interpreting the results of analysis. The process of problem identification can be carried out on a review of publicly available documents and discussions with the main stakeholders.

3.1. Review of existing assessments of floods/drought/water quality

The flood risk analysis was based on flood risk maps developed in the ISOK project in 2013 and available on the http://mapy.isok.gov.pl/imap portal. The flooding extend is presented therefor the probability of occurrence once every 10, 100 and 500 years. As shown in Fig. 2, floods occur practically along the entire length of the Kamienna River, omitting its source section. The greatest threat concerns agricultural lands located in the lower part of the basin, especially at its outlet to the Vistula river. The urban areas Starżyszko Kamienna, Starachowice and Ostrowiec Świętokrzyski are slightly threatened. Problems with poor water quality were diagnosed according to reports of the Voivodship Inspectorate for Environmental Protection in Kielce conducted in 2010-2017. That assessment identifies the mouth section of the Kamienna river and its upper tributary Kamionka as reaches with bad water status. The main cause of its poor condition are biological indicators such as phytobenthos and phytoplankton, and a problem with macrophytes only in the lower river reach. Problems concerning priority substances (i.e. Benzo (a) pyrene, Benzo (b) fluoranthene, Bezo (g, h, i) perylene) occur in the central part of the Kaminna catchment below the town of Starachowice and in the mouth section of Świśliny. Exceeded physico-chemical indicators (i.e. BOD5) were found only Brody Iłżyckie reservoir and in the lower section of Kamienna River below Ostrowiec Świętokrzyski, in which a problem with general alkalinity was noted.

The status assessment does not include 14 Water Bodies, which consist about 30% of the Kamienna catchment area. In particular, there is no assessment of the Ścięgno, Wolnak or Przepść rivers, catchments which areas are used in 90% for agriculture and do not include nature protection areas. Therefore, in July 2018, one-time monitoring was carried out, which showed elevated nutrient concentrations in a number of tributaries. However, during this period there was a climatic, agricultural and hydrological drought which can make the samples unrepresentative. Despite the fact that in the current assessment of water status, the maximum values and samples collected during extreme phenomena are rejected, it can be noticed after statistical analysis of all measurements (Fig. 3), that acceptable limit of good status for PO4, Organic Nitrogen is often exceeded and slightly less for Total P and BOD5. In order to determine the duration of exceedances occurrence monthly statistics of selected agricultural catchments are presented in Fig. 4 (Kamionka, Szewnianka, Pokrzywianka and Świślina). It shows that the exceedance occurs in the summer months and this applies to compounds (PO4, Total P and Organic N), which get into the waters as a result of surface runoff. Exceedances of good status are caused by point discharges from large towns along the Kamienna river section below Skarżysko Kamienna and Starachowice, which have a very negative impact on the Brody Iłżyckie Reservoir below, where sediments accumulate and algae with cyanobacteria blooms occur.

Problems connected to droughts were analysed on the basis of the Drought Impact Mitigation Plan (DIMP), which contains an assessment (Fig. 5) of four types of drought (climatic, agricultural, hydrological, hydrogeological). It concludes that the greatest problems are caused by agricultural drought in the north-eastern part of the Wolanka catchment, then in the lower and middle sections of the Kamienna river and all sub-catchments with an agricultural land use. The climatic drought extent is equally large and its concentrated in the middle of the catchment. A very small threat is visible in case of hydrological and hydrogeological drought. In order to confirm the results of that valorisation, a map was drawn up (Fig. 6) with the number of farmers crop damage compensation applications in 2018. The comparison of these maps shows that the acute problem of agricultural drought was confirmed in the south-eastern part of the basin.

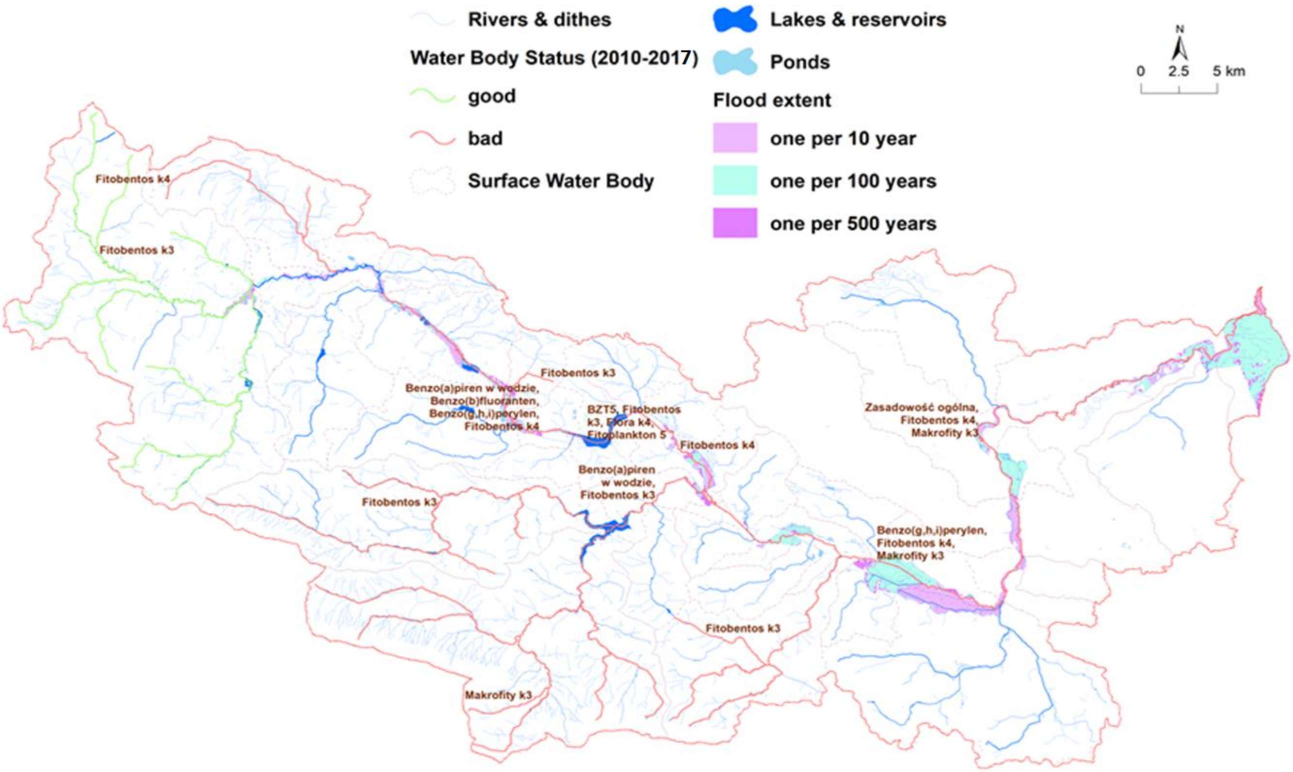


Fig. 2 Water body status and flooding extent

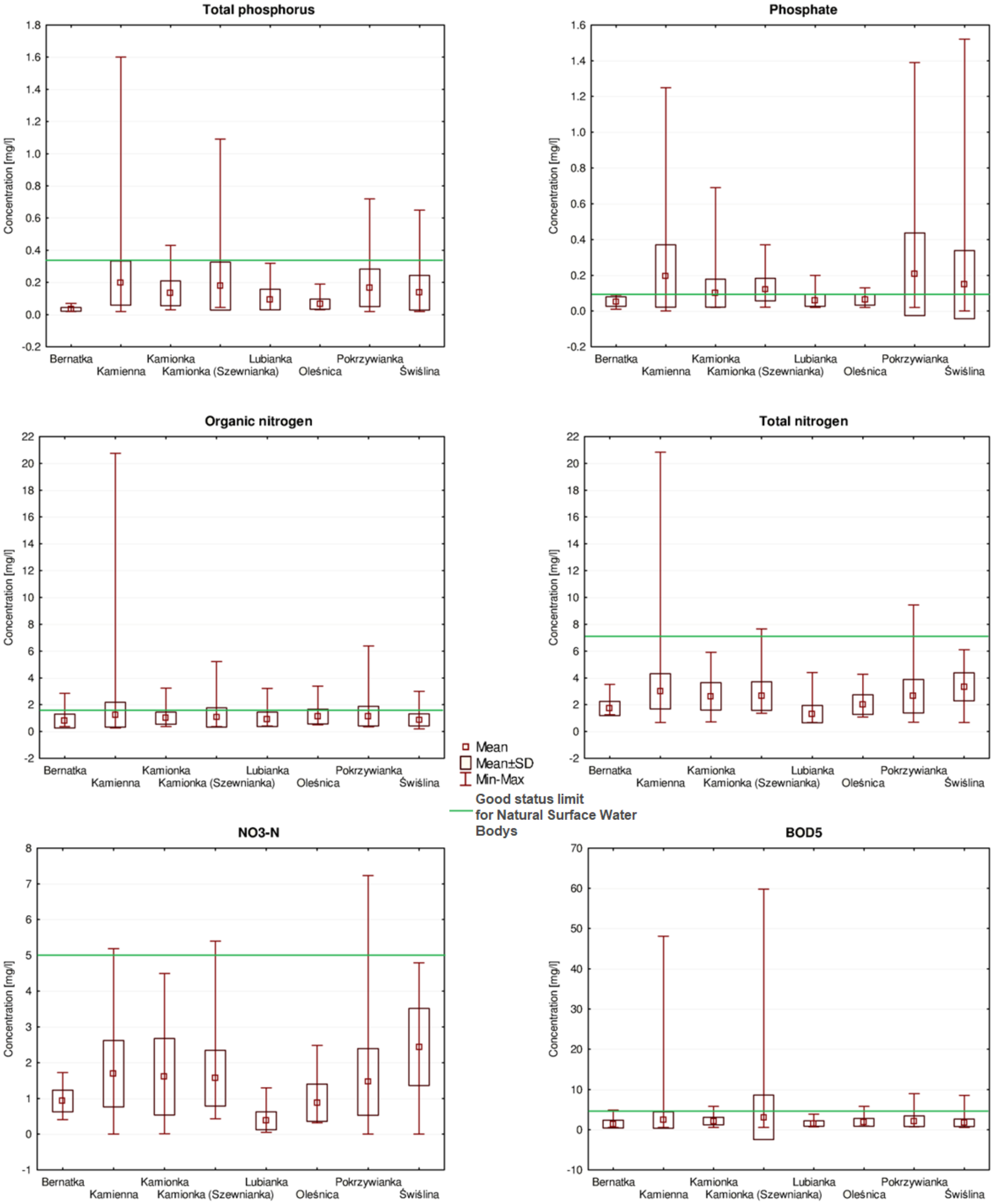


Fig. 3 Statistics of nutrients concentration in selected rivers (minimum number of measurements 21 (Bernatka), max 1047 (Kamienna) in the period 2000-2017

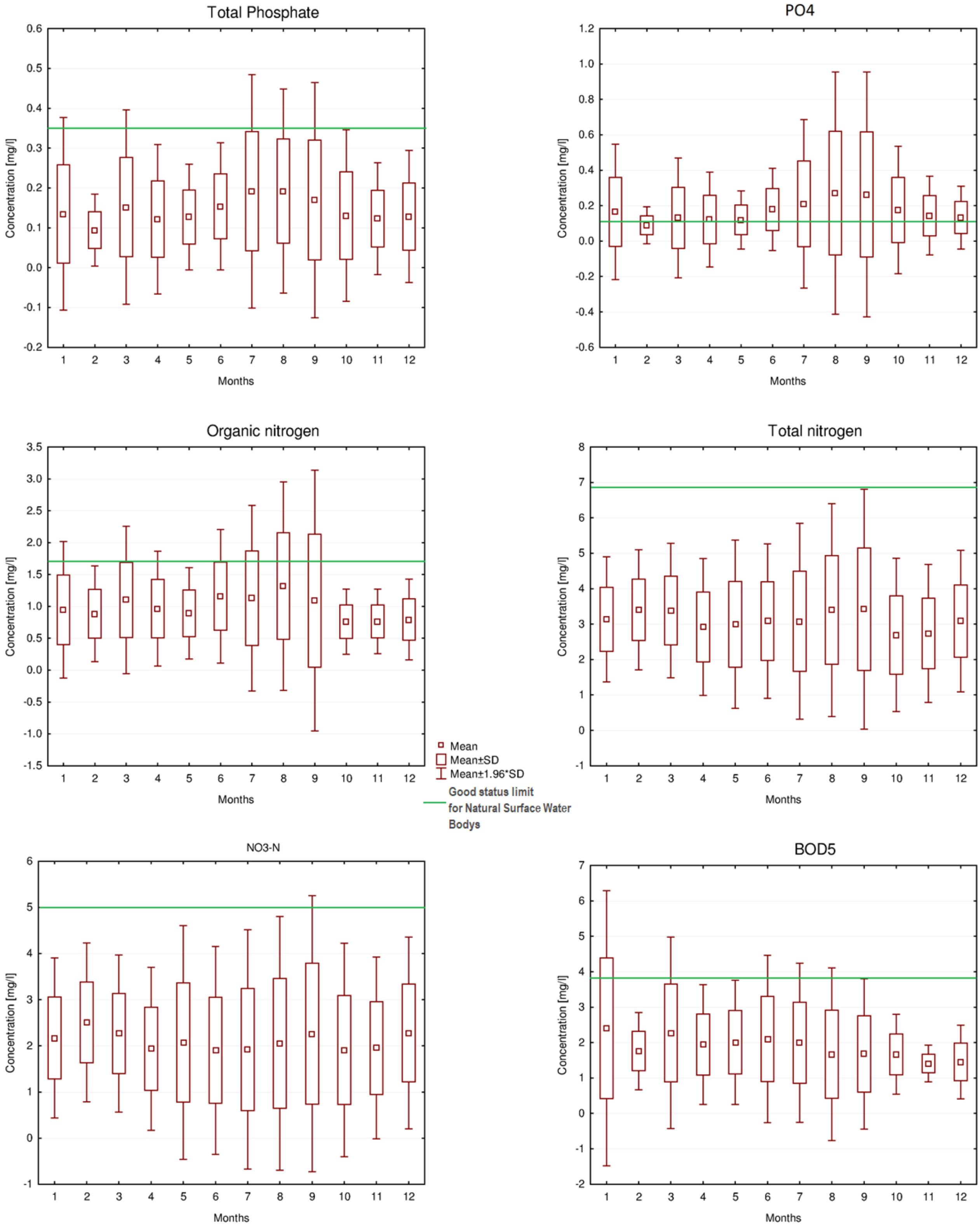


Fig. 4 Monthly statistics of nutrient concentrations in selected agricultural catchments (Kamionka, Szewnianka, Pokrzywianka and Świślina) in the period 2000-2017

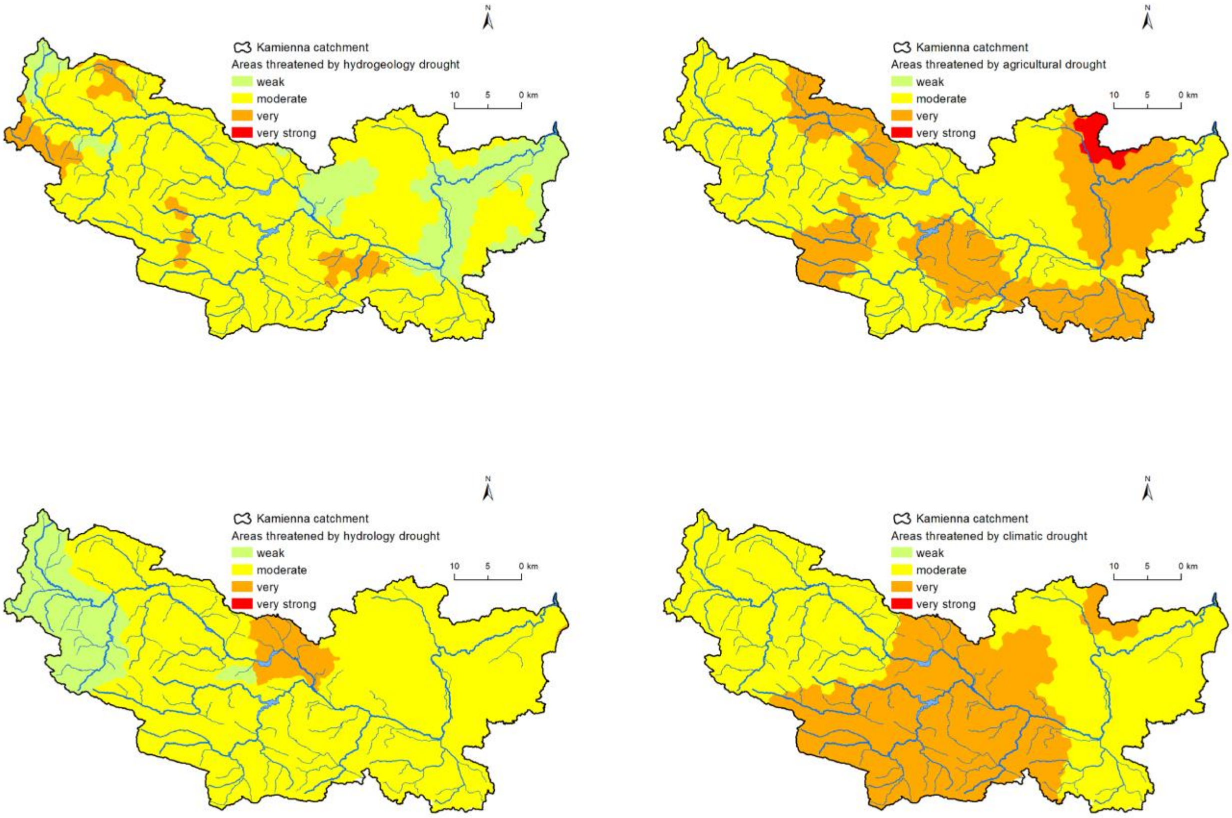


Fig. 5 Map of areas threatened by different types of drought included in the Drought Management Plan approved in 2016

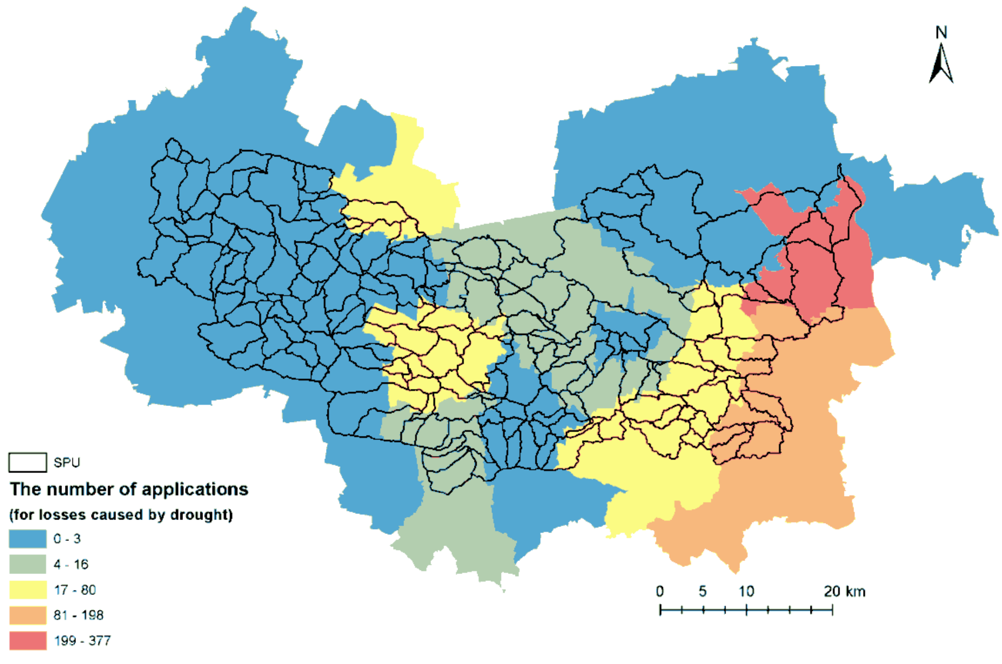


Fig. 6 Number of farmers crop damage compensation applications in 2018 (source: Świętokrzyska Agricultural Chamber http://www.sir-kielce.pl access date 1.08.2018)

3.2. Review of existing and planned measures

The task of the next analysis is to determine the existing and planned stakeholder activity in the scope of N(S)WRM. This will allow identifying areas with high water retention potential, which will be used to identify weighting factors for indicators. The existing activities were identified using Geomelio and Polish Waters databases as well as materials summarized in Tab. 2. Among them, about 400 ponds were identified, eight medium-sized water retention reservoirs, including two fish ponds, seven weirs and several damming systems on ditches.

Planned activities were identified on the basis of the materials listed in Tab. 2. Map in Fig. 7 includes only 12 water retention reservoirs proposed for construction or modernization and 3 dry retention reservoirs. Other activities concerning, for example, on drought didn't have a precise location, but only the conditions under which they should be applied.

Tab. 2 Action plans used for identification of existing and planned N(S)WRM

Goals	Action plans Name
Water quality	Water and environmental program of the country, 2016
Flood	Flood Risk Management Plan (FRMP) for the central Vistula,2016
Drought	Drought Impact Mitigation Plan (DIMP) for the central Vistula, 2016
General	River Basin Management Plan for Vistula (RBMP), 2016 River Maintenance Plan for area of Regional Water Management Authority in Warsaw, 2016 Small retention program, 2006 Action plans separately for lowlands and mountains - Increasing retention possibilities and counteracting drought and floods in forest ecosystems, 2007-2015 Rural Development Program, 2014-2020 Operational Program Infrastructure and Environment, 2014-2020;

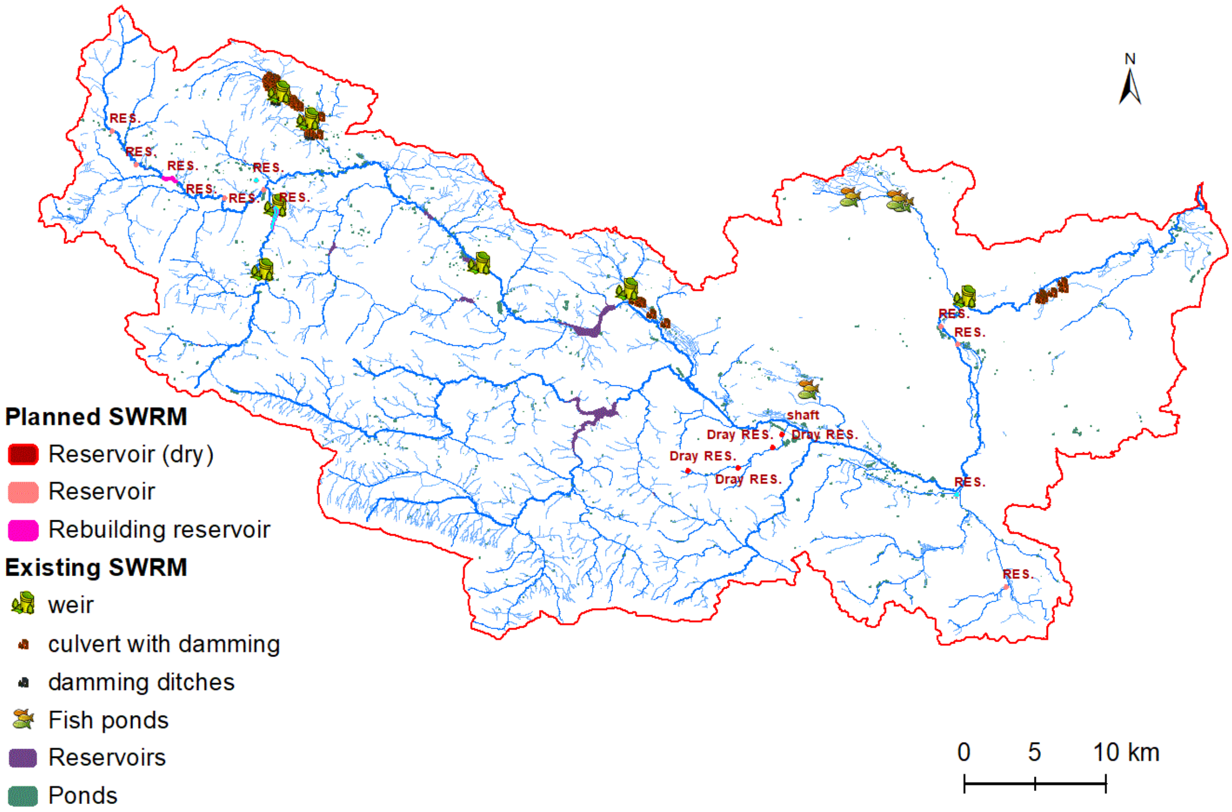


Fig. 7 Existing and planned SWRM for flood mitigation (RES means reservoir)

3.3. Results of consultations and terrain recognition

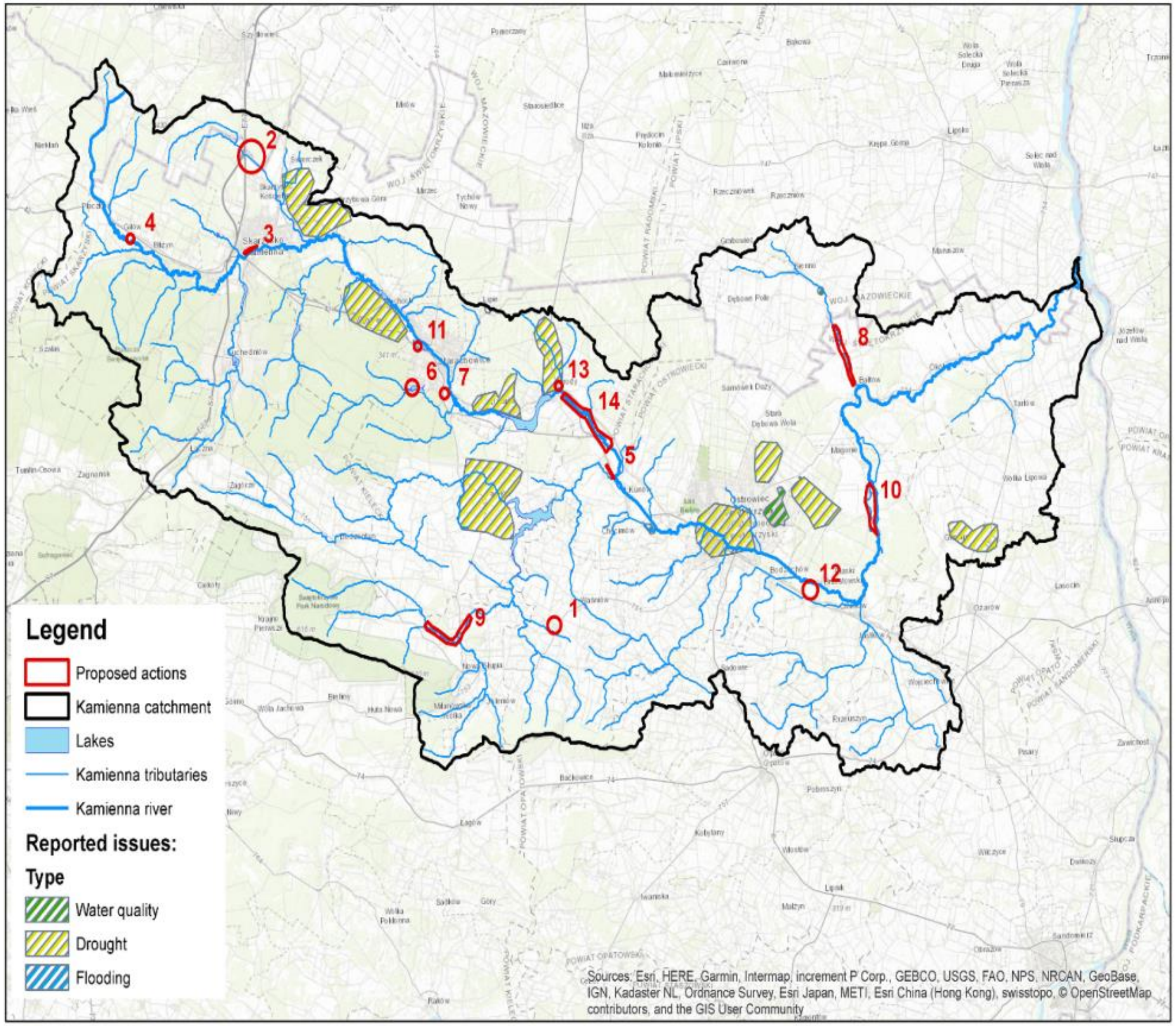
The meeting took place on July 10, 2018 from 11am until 3pm at the "Przystań Wodna Brody" hotel on the waterfront of the Brody Iłżeckie reservoir. The 25 participants included 9 WULS-SGGW representatives and the remaining number consisted representatives of the Regional Water Management Authority in Warsaw (RWMA) as well as local Town Councils, Forest District Administration, Chamber of Agriculture, Catchment Management and Water Supervision Bodies.

The aim of the meeting was to present the method and results of spatial valorisation of the needs and possibilities of water retention in the Kamienna basin and discussion of its results. In addition, there were workshops on planning activities in the field of small retention.

Conclusions:

- According to the majority of participants, the initial valorisation of the region is needed
- From the perspective of the region (southern and central Europe) there should be a coherent message to managers of structural programs regarding matters related to water management.
- At present, the voice of experts is missing.
- Secondly, discussions between specialists from various fields are important.

The terrain recognition was carried out on the 9 and 11 July 2018 by project employees and invited experts. Work was conducted by four groups and included preparation of a photo documentation, water quality and streamflow measurements, water sampling, interviewing and polling selected sewage treatment plants. Results of those consultations and field recognition are available in Fig. 8.



Legend for the proposed actions:

1. Regulated outflow from drainage systems
2. Regulated outflow from drainage systems
3. Dike removal
4. Construction of a new reservoir
5. Reconstruction of historical factory system driven by water (Staszic channel and reservoir)
6. Reconstruction of Lublianka reservoir
7. Reconstruction of Piachy reservoir
8. Using the natural process of river bed infiltration (Wolanka)
9. Increasing in-channel flood retention
10. Increasing water retention in oxbow lakes (Floodplain restoration and management)
11. Reconstruction of the Pastewnic bank-side reservoir
12. Construction of new reservoir in Ćmielów
13. Construction of a dry reservoir on Lublianka river
14. Conversion of arable land to meadows and pastures

Fig. 8 Results of consultations and terrain recognition

3.4. Summary

On the basis of maps from chapter 3.1.-3.3 and expert knowledge, maps showing needs and possibilities of water retention (in SPU units) for separate catchment problems, were developed. These maps will show several SPUs having high needs and possibilities of water retention recognized by the expert (also in the field). These maps will be used to verify the valorisation method in chapter 6.

Methodology for determining areas with high water retention potential for the flood mitigation goal

The development of data identifying the weights of flood risk mitigation indicators was based on a map of existing and planned retention measures available in Fig. 7, field recognition and consultations outputs shown in Fig. 8 and analysis of layers with land cover, soils and river network distribution. Data were grouped according to retention needs and possibilities. The group of possibilities includes the presence of watercourses, medium and poor soil permeability as well as agricultural or urban land use, while the group of needs includes the number of existing or planned activities, water facilities in the catchment area.

Chosen areas were split into four categories:

- 1 - SPUs with existing water facilities;
- 2 - SPUs with 1 planned water facility;
- 3 - SPUs with 2 planned water facilities;
- 4 - SPUs with 3 or more planned water facilities.

Additionally, for the SPUs with larger cities, the second category of flood hazard was assigned due to the sealing (low permeability) of urban surfaces causing the increase of surface runoff. On the basis of the categorized SPU, a map was prepared to identify the weights of flood indicators.

In the central part of the catchment, in the vicinity of Ostrowiec Świętokrzyski around 4 dry reservoirs are planned ,two weirs with a small dam and a floodgate are present , therefore this area has been recognized as the one with the highest demand for water retention. High retention needs and possibilities were also recognized in the south-western part of the catchment, as well as in the upper part of the Kamienna River, where there are larger urban areas, numerous existing small water retention facilities and planned construction, reconstruction or modernization of reservoirs.

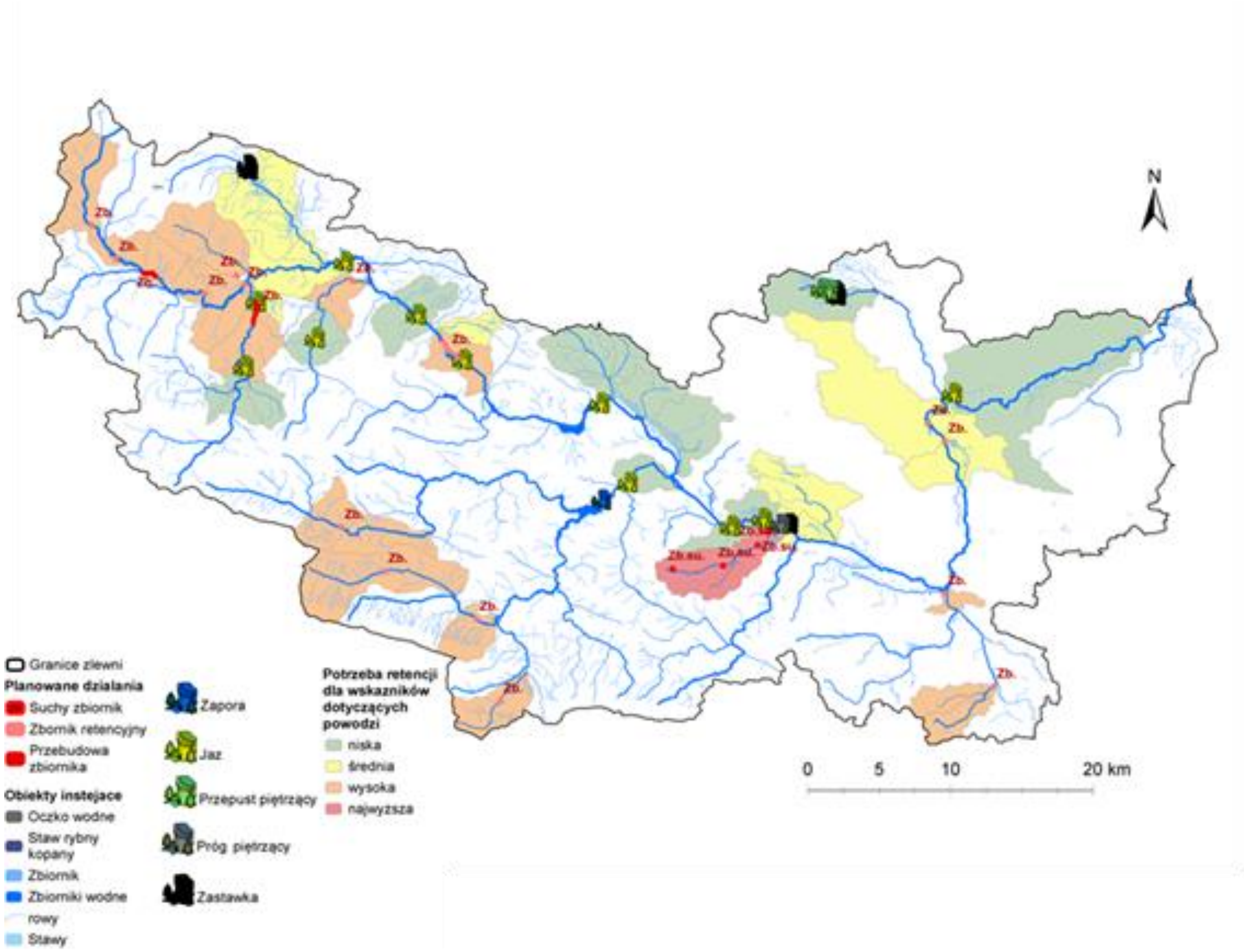


Fig. 9 Map for identifying flood indicators weights

Methodology for determining areas with high water retention potential for the drought mitigation goal

The development of data identifying the weights of drought mitigation indicators was based on data obtained from Świętokrzyska Agricultural Chamber on the number of farmers crop damage compensation applications in 2018 (Fig. 6) and DIMP for the central Vistula water region (Fig. 5). The number of applications has been assigned to the given municipalities. Then the data was divided into two groups. The group of retention possibilities includes the presence of watercourses, medium and poor soil permeability as well as agricultural or urban land use, while the group of needs includes the number of farmers crop damage compensation applications from 01.05.18 until 01.08.18.

In the DIMP for the water region of central Vistula, homogeneous surface water bodies (JCWP) have been indicated, where investments in small water retention facilities aiming at limiting the effects of drought are planned for implementation. During the analysis of the developed map of existing and planned activities, it was assumed that the small retention facilities were included in the JCWP according to DIMP which target to limit the effects of drought, therefore these areas were also classified as vulnerable to drought.

Selected areas have been divided into three categories of drought risk:

> 1 - low risk of drought - average number of farmers crop damage compensation applications or one planned small water retention facility;
> 2 - medium drought risk - high number of farmers crop damage compensation applications or two planned small water retention facilities;
> 3 - high risk of drought - the largest number of farmers crop damage compensation applications and planned small retention facilities.

A verification map for drought indicators was prepared on the basis of the categorized SPUs.

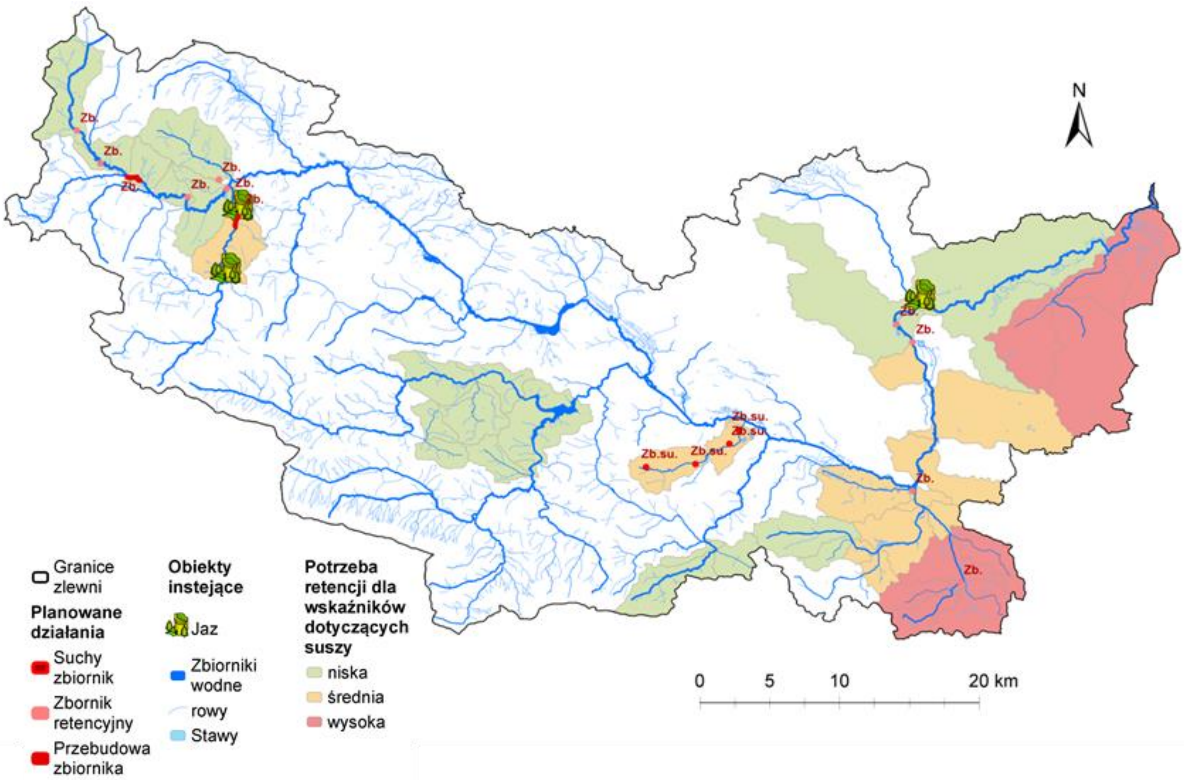


Fig. 10 Map for identifying drought indicators weight

The largest number of farmers crop damage compensation applications was received by the Świętokrzyska Chamber of Agriculture from the eastern part of the catchment. In addition, this area was indicated in the Drought Impact Mitigation Plan (DIMP) for the central Vistula region as an area with small water retention facilities limiting the effects of drought planned for implementation. Therefore, the entire eastern part of the basin, where water retention possibilities are occurring, was considered as areas with high and moderate water retention demands. Also in the central and western part of the DIMP small water retention facilities are planned for implementation, therefore, on the basis of the map of existing and planned small water retention facilities, these areas have been appropriately classified.

4. Description of workflow

4.1. SPU Selection

The choice of SPU was made on the basis of the following factors:

- the purpose of analysis,
- the scale and quality of available input data
- justification for the physical division used by the analysed indicators
- time and computing capacity

The following layers were used for the tests:

- Surface Water Body (SWB) - 32 pcs.
- Hydrological Response Unit (HRU) -1465 pcs.
- Elementary catchments -187 pcs.

SWB is often used for carrying large-scale valorisations (for a province or country), however, for the analysis of a catchment area of 2000 km^2, it was found too small and due to the modest number of polygons it caused problems when classifying and selecting weights. On the other hand, the HRU layer (Fig. 11) which consists units with the same land use, soils and similar slope, turned out to be too detailed and caused many problems resulting from a lengthy computation time. Finally, the division into 187 elementary catchments was chosen (Fig. 12).

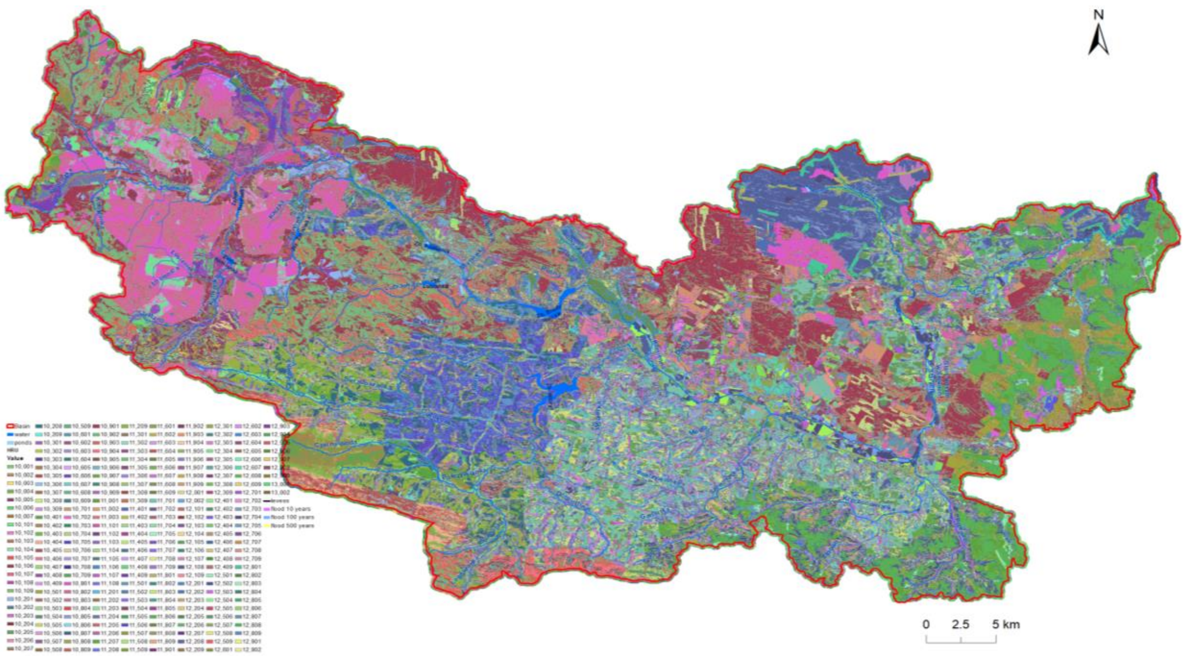


Fig. 11 Division of Kamienna catchment into Hydrological Response Units

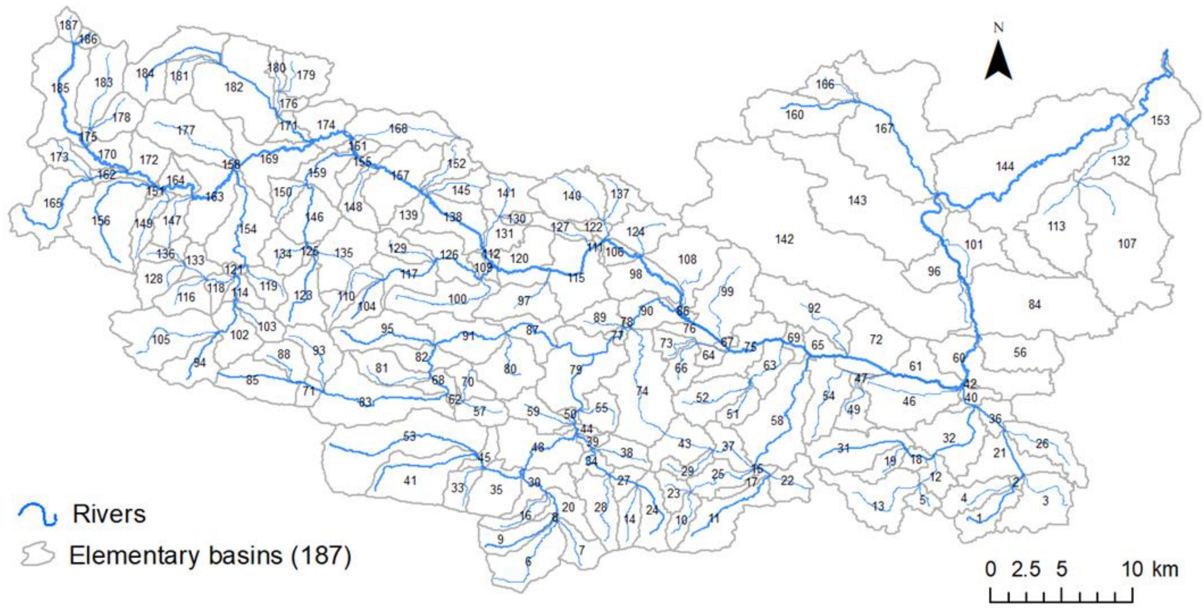


Fig. 12 Division of Kamienna catchment into elementary catchments

4.2. Selected indicators

During the FroGIS tool testing, 35 out of 37 available indicators were tested. Two of them were not tested due to the lack of BedRHS and GraniteRatio data. After rejection of the correlated indicators used for calculation of the general objective, 30 were left. For the drought and flood goal 19 indicators were used out of that group. A detailed list of selected indicators is included in Tab. 3.

Tab. 3 List of selected indicators

Name	General	Drought	Flood
ArableRatio	x	x	x
BFI			
CWB	x	x	
DrainageD	x		x
EcoAraBuf20mRatio	x		
EcoAreaRatio			
EcoCombined			
EcoNumRatio	x		
FloodRiskAreaRatio	x		x
FlowMinAvgRatio			
FlowMaxAvgRatio			
FlowMinMaxRatio	x	x	x
FlowVarRatio_m	x	x	
ForestRatio	x	x	x
GRR	x	x	
LakeRatio	x	x	x
LakeCatchRatio	x		x
LandSlope	x		x
MeanderRatio	x		x
NonForestedRatio	x		x
Pre_Var_a	x	x	
Pre_Var_m	x	x	
PrecFreqLow75	x	x	
OrchVegRatio	x	x	x
RainFallErodibility	x		x
ReclaimedRatio	x	x	x
RiverSlope	x		x
SoilErodibility	x		x
SRI	X	x	x
SWR	X	x	
TWI	X	x	x
UrbanRatio	X	x	x
WaterYieldAvgFlow	X	x	
WaterYieldMinFlow	X	x	
WetlandRatio	X	x	x

4.3. Input data

The data collection process adopted the principle of using generally available data on a scale not smaller than 1: 25,000 and covering the entire analysed area. Most of the data was obtained without costs under applicable laws and agreements, some of them for a small fee (eg water quality measurements), only the purchase costs of soil maps were significant. A detailed list of data is included in Tab. 4

Tab. 4 List of input data

Name	Source	Data type	Accuracy
Hydrological and meteorological data	Institute of Meteorology and Water Management, (for water gauges and meteorological stations)	Time series in point	7 gauges; daily
Water quality monitoring	Inspector of Environmental Protection	Time series in point	30 location
Length of the growing season	Geoportal for climate change (www.atlas.impact2c.eu)	raster	
Soil data	Institute for the Cultivation of Fertilization and Soil Science in Puławy	polygon	1:25000
Effective infiltration of precipitation into groundwater	Polish Geological Institute	polyline	
Hydrographic division map	Polish State Water Farm	polyline/polygon	1:10000
Flood hazard maps	Polish State Water Farm	polygon	1:10000
Digital Elevation Model (LIDAR)	Polish Head Office of Geodesy and Cartography	raster	10x10m; h=0.15m
Land use	Chief Inspectorate of Environmental Protection, Corine Land Cover 2012	polygon	1:25000

The collected data are in a form of point, vector (linear or polygonal) and raster layers. The most time-consuming calculations concerned hydrological, meteorological and climatic characteristics due to the fact that they had to be carried out on long-term daily or monthly data.

The hydrological data included long-term, daily streamflow data for seven water gauging stations (Fig. 13): Brody iłżeckie, Bzin, Czekarzewice, Kunów, Nietulisko, Wąchock, Rzepin. In the first stage, data was verified to remove any measurement errors. The next steps were completed according to the FroGIS Manual and a specially designed spreadsheet. Finally, for each water gauging station, five streamflow characteristics were determined: swMLQ, swMMQ, swMHQ, swLMQ, swHMQ as well as the index of share of underground flow in the river streamflow (BFI).

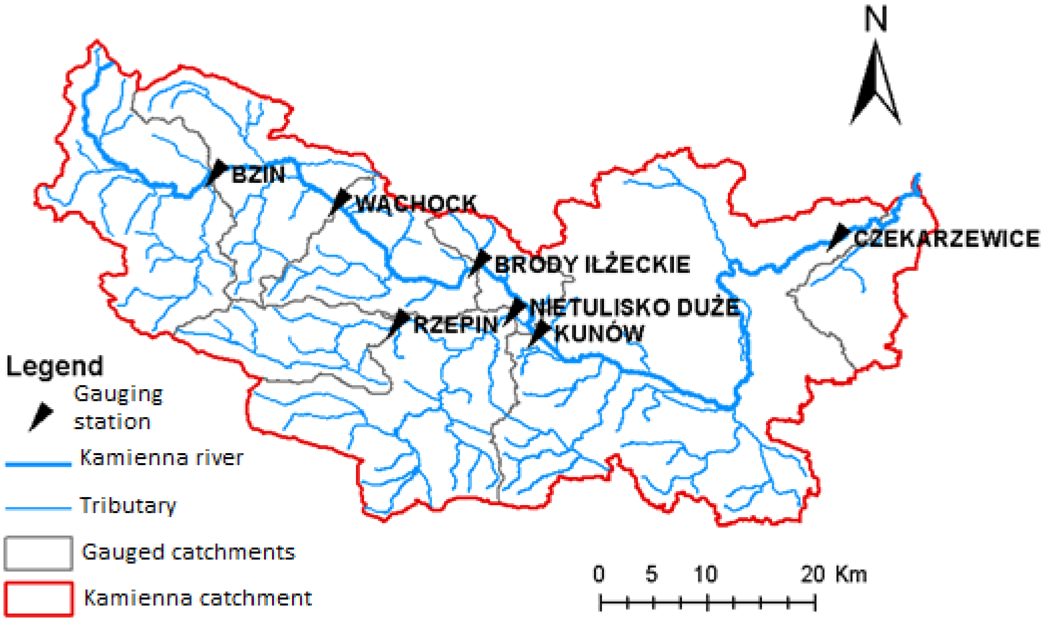


Fig. 13 Location of water gauging stations in the Kamienna catchment

Due to negative values of incremental flow in flooded subcatchments the calculations were carried out on the basis of 3'th method described in the FroGIS Manual. The results for streamflow were given in mm / year and placed in the layer of incremental catchments.

Multiannual precipitation sequences were obtained for 29 stations located in the analysed catchment and beyond it. Rainfall characteristics (pAvgAnn, preVar_a, pAvgVeg, pMinVeg, pFreqLow50) were calculated according to FroGIS Manual for years 1981-2016. The results were placed in a point layer representing the locations of precipitation stations.

Data (i.e. min and max daily air temperature) for calculating Climatic Water Balance (CWB) was obtained from 3 climatic stations. Calculations of reference evapotranspiration (ETo) were carried out with the use of e.g. Hargreaves method. Finally, the entire CWB calculation was carried out in the SWAT (Soil and Water Assessment Tool) model. Actual evapotranspiration and land use from the CLC layer was used as model input. The results were placed in a raster layer with a resolution of 50x50m.

Preparation of the remaining data was mainly about extracting important data, removing unnecessary attributes and repairing the geometry of the polygon because some of this data (i.e. flood risk) came from a conversion of a raster layer.

4.4. Correlation matrix

The aim of this part of the analysis is to capture the areas with similarly scattered values of indicators (correlated) and to remove one of them in further analyses. Correlation analysis allows to determine if indicators tend to change at the same time. A correlation coefficient of -1 or 1 signposts a 100% correlation between two indicators. On the other hand, values close to 0 indicate a low correlation.

The calculations were carried out using the FroGIS application and MS Excel 2010. Both results gave similar results (Fig. 14).

The following criteria for rejecting indicators were adopted:

- only the indicators correlated above / below ± 0.8 were analysed
- an indicator of greater significance for a given goal is left
- if criterion 2 was difficult to implement, the indicator which had more accurate input data was kept
- if criteria 2 and 3 could not be applied, the index which is strongly correlated with a larger number of indicators is removed

FroGIS application users ultimately determine the significance of the indicator in a given analysis, however „LookUpTable of indicator & input data & goals” workbook annexed to the valorisation methodology, specifies these dependencies.

For the general-purpose, the following indicators were rejected: EcoAreaRatio, EcoCombined, FlowMinAvgRatio, FlowMaxAvgRatio.

Indicator	ArableRatio	~~BFI~~	CWB	DrainageD	EcoAraBuf20mRatio	~~EcoAreaRatio~~	~~EcoCombined~~	EcoNumRatio	FloodRiskAreaRatio	~~FlowMinAvgRatio~~	~~FlowMaxAvgRatio~~	FlowMinMaxRatio	FlowVarRatio_m	ForestRatio	GRR	LakeRatio	LakeCatchRatio	LandSlope	MeanderRatio	NonForestedRatio	Pre_Var_a	Pre_Var_m	PrecFreqLow75	OrchVegRatio	RainFallErodibility	ReclaimedRatio	RiverSlope	SoilErodibility	SRI	SWR	TWI	UrbanRatio	WaterYieldAvgFlow	WaterYieldMinFlow	WetlandRatio
ArableRatio	1.00																																		
~~BFI~~	0.29	1.00																																	
CWB	-0.48	-0.63	1.00																																
DrainageD	-0.08	-0.15	0.05	1.00																															
EcoAraBuf20mRatio	0.46	0.20	-0.24	0.05	1.00																														
~~EcoAreaRatio~~	-0.81	-0.24	0.55	-0.14	-0.42	1.00																													
~~EcoCombined~~	0.77	0.21	-0.53	0.10	0.45	-0.93	1.00																												
EcoNumRatio	-0.66	-0.07	0.42	-0.11	-0.38	0.83	-0.83	1.00																											
FloodRiskAreaRatio	-0.10	0.21	-0.13	0.37	-0.11	-0.10	0.06	-0.01	1.00																										
~~FlowMinAvgRatio~~	0.11	0.92	-0.58	-0.15	0.11	-0.10	0.09	0.02	0.22	1.00																									
~~FlowMaxAvgRatio~~	-0.02	-0.80	0.55	0.12	-0.06	0.03	-0.03	-0.04	-0.19	-0.86	1.00																								
FlowMinMaxRatio	0.10	0.91	-0.57	-0.15	0.10	-0.09	0.09	0.02	0.21	0.97	-0.95	1.00																							
FlowVarRatio_m	0.25	0.74	-0.53	-0.10	0.17	-0.22	0.22	-0.07	0.20	0.81	-0.54	0.68	1.00																						
ForestRatio	-0.76	-0.28	0.58	-0.16	-0.36	0.95	-0.86	0.78	-0.14	-0.12	0.05	-0.11	-0.20	1.00																					
GRR	-0.62	-0.63	0.68	0.03	-0.34	0.58	-0.54	0.41	-0.12	-0.55	0.42	-0.50	-0.72	0.59	1.00																				
LakeRatio	-0.01	-0.09	-0.18	-0.08	0.10	-0.05	0.06	-0.07	-0.02	-0.02	-0.01	-0.01	0.01	-0.04	0.02	1.00																			
LakeCatchRatio	-0.41	-0.77	0.68	0.02	-0.24	0.41	-0.36	0.23	-0.19	-0.60	0.52	-0.56	-0.60	0.46	0.72	0.12	1.00																		
LandSlope	0.09	-0.48	0.32	0.00	-0.01	-0.08	0.05	-0.16	-0.23	-0.49	0.44	-0.48	-0.29	-0.01	0.02	0.08	0.25	1.00																	
MeanderRatio	0.15	0.38	-0.37	-0.08	0.21	-0.08	0.08	0.03	0.06	0.40	-0.36	0.39	0.37	-0.09	-0.36	0.07	-0.34	-0.19	1.00																
NonForestedRatio	0.27	-0.20	-0.17	0.11	0.06	-0.43	0.43	-0.48	-0.08	-0.22	0.24	-0.23	-0.08	-0.40	-0.19	0.13	-0.07	0.64	-0.16	1.00															
Pre_Var_a	0.13	0.00	-0.05	0.07	-0.12	-0.11	0.08	-0.10	0.03	-0.05	0.10	-0.09	0.05	-0.16	-0.19	-0.02	-0.14	0.01	0.02	-0.07	1.00														
Pre_Var_m	-0.11	0.00	0.11	0.09	0.11	-0.01	-0.06	0.03	0.16	-0.18	0.09	-0.11	-0.16	-0.06	0.06	-0.06	-0.07	-0.05	-0.08	-0.05	-0.10	1.00													
PrecFreqLow75	-0.03	-0.11	0.08	-0.06	-0.24	0.12	-0.10	0.09	-0.03	0.11	-0.03	0.05	0.20	0.18	-0.01	0.01	0.25	0.03	-0.01	-0.09	0.26	-0.78	1.00												
OrchVegRatio	0.17	0.17	-0.15	-0.08	-0.02	-0.15	0.18	-0.12	0.21	0.14	-0.11	0.13	0.14	-0.12	-0.10	-0.02	-0.15	-0.11	0.03	-0.03	0.00	-0.10	0.11	1.00											
RainFallErodibility	-0.29	-0.17	0.45	-0.05	-0.20	0.31	-0.29	0.38	-0.07	-0.20	0.19	-0.20	-0.19	0.31	0.45	-0.03	0.26	0.00	-0.15	-0.16	-0.31	0.15	-0.18	-0.03	1.00										
ReclaimedRatio	0.05	0.03	-0.08	0.18	-0.12	-0.01	-0.06	0.01	0.03	-0.02	0.02	-0.03	-0.09	-0.22	-0.09	-0.08	-0.09	-0.10	0.13	-0.04	0.26	-0.06	0.03	-0.06	-0.04	1.00									
RiverSlope	0.05	-0.24	0.26	0.08	0.08	0.08	-0.07	0.04	-0.23	-0.23	0.18	-0.21	-0.11	0.16	-0.03	-0.12	0.17	0.45	0.13	0.10	0.00	-0.05	0.04	-0.06	0.03	-0.22	1.00								
SoilErodibility	0.66	-0.07	-0.08	0.01	0.33	-0.52	0.56	-0.48	-0.26	-0.18	0.28	-0.20	-0.02	-0.45	-0.29	-0.04	-0.06	0.36	-0.07	0.41	0.11	-0.15	-0.07	0.02	-0.17	-0.03	0.22	1.00							
SRI	-0.23	-0.35	0.29	0.08	-0.07	0.20	-0.14	0.02	-0.05	-0.14	0.13	-0.10	-0.09	0.29	0.35	0.13	0.57	0.08	-0.11	-0.03	0.00	-0.11	0.32	-0.09	-0.25	-0.28	0.07	0.01	1.00						
SWR	0.57	0.20	-0.36	0.06	0.35	-0.50	0.56	-0.44	-0.13	0.07	-0.03	0.08	0.11	-0.49	-0.44	-0.03	-0.30	0.00	0.02	0.21	0.17	-0.05	-0.17	0.02	-0.22	0.10	0.08	0.67	-0.14	1.00					
TWI	0.00	-0.02	-0.01	0.17	0.06	-0.06	0.08	-0.04	0.01	0.03	-0.01	0.04	-0.07	-0.06	0.12	0.05	0.11	-0.16	0.04	-0.07	-0.15	-0.07	0.01	0.05	0.04	0.04	-0.02	-0.06	0.10	-0.08	1.00				
UrbanRatio	-0.26	0.05	-0.05	0.28	-0.07	-0.21	0.16	-0.09	0.40	0.11	-0.08	0.09	0.07	-0.25	-0.01	0.02	-0.02	-0.15	0.03	0.02	0.08	0.22	-0.07	-0.06	0.03	0.10	-0.24	-0.30	0.01	-0.17	0.02	1.00			
WaterYieldAvgFlow	-0.72	-0.31	0.50	0.03	-0.31	0.64	-0.56	0.48	-0.03	-0.10	0.11	-0.15	-0.15	0.66	0.75	0.06	0.49	-0.16	-0.17	-0.31	-0.14	-0.10	0.16	-0.10	0.42	-0.18	-0.08	-0.39	0.42	-0.46	0.06	0.10	1.00		
WaterYieldMinFlow	-0.43	0.26	0.01	-0.05	-0.14	0.37	-0.31	0.34	0.12	0.51	-0.32	0.39	0.59	0.41	0.09	0.08	-0.01	-0.33	0.14	-0.29	-0.08	-0.25	0.32	0.01	0.16	-0.20	-0.14	-0.35	0.29	-0.31	0.01	0.14	0.70	1.00	
WetlandRatio	-0.30	-0.20	0.33	0.13	-0.27	0.47	-0.47	0.42	0.05	-0.19	0.09	-0.16	-0.31	0.38	0.30	-0.05	0.19	0.03	-0.14	-0.11	0.08	0.07	-0.03	-0.06	0.11	0.29	-0.06	-0.13	-0.04	-0.14	-0.07	-0.19	0.17	-0.07	1

Fig. 14 Correlation matrix for all indicators used to assess water retention needs and possibilities in the Kamienna catchment

4.5. Classification and aggregation method

The next step in the valorisation methodology is to calculate the statistics of the value of the indicators for verifying whether or not errors have been made and what is their distribution. At this stage, a decision is made on the number of classes (intervals) for indicator values and what weight to assign them. As a result of those tests, it was determined that this is a very important task, because the selection of too many classes for poorly distributed indicators, i.e. derived from data with little differentiation, or due to the small share of some land uses (such as lakes, orchards, wetlands), results in the appearance of only min or max classes. This can be observed when the average value is close to the minimum or maximum value and the standard deviation has a relatively low value (see OrchVegRatio in Tab. 5.). In this case, it is worth considering removing this indicator. The choice of the number of classes is also influenced by the number of SPUs, if it is less than 40, it is recommended to use 3 classes, if more, than additional classes can be used. Five classes were selected in the analysed case.

Another important component is the selection of one of the three aggregation methods:

- Classes of equal width
- Quantiles (breaks at 0.20, 0.40, 0.60 and 0.80 percentiles)
- Natural breaks (Jenks)

In the spatial data presentation, the Naturals Breaks method or the division into equally even intervals, which can be obtained by calculating quantiles, are the most recommended. In the testing process, all three methods were used and the results of their statistics are presented in

Tab. 6. The values in the Counts column were marked to show a parallel SPU breakdown into individual classes. The results show that Quantile has the best distribution of units when the maximum value of the index is less than 1, as a result of rounding up to two decimal places some classes are omitted in the distribution - which was reported as a bug. In addition, the result of the division into classes from the FroGIS application (only for Equal Width and Quantile) was compared with the results obtained in the MS Excel program, which confirmed the above-mentioned problem with the division into Quantile. Finally, all indicator values are included in Fig. 15 maps where the red colour always shows the high potential of water retention needs and to allow visual assessment of the input data.

Tab. 5 Statistics of indicator values

Short name indicator	Statistic			
	Min	Max	Mean	Stdv
ArableRatio	0	87	33	30
BFI	0.33	0.55	0.44	0.09
CWB	87	211	145	27
DrainageD	0.04	4.24	0.69	0.54
EcoAraBuf20mRatio	0	3.02	0.29	0.53
EcoAreaRatio	0	100	43	34
EcoCombined	1	5	3	1.4
EcoNumRatio	0	100	37	24
FloodRiskAreaRatio	**0**	**90.5**	**2.9**	**10.1**
FlowMinAvgRatio	0.16	0.42	0.31	0.1
FlowMaxAvgRatio	4	17.1	8.2	4.5
FlowMinMaxRatio	0.01	0.1	0.06	0.04
FlowVarRatio_m	0.17	0.38	0.29	0.08
ForestRatio	0	100	35	33
GRR	67	105	85	14
LakeRatio	**0**	**11.2**	**0.18**	**1.18**
LakeCatchRatio	0	100	63	47
LandSlope	0.2	4.5	1.7	0.8
MeanderRatio	60	100	85	8
NonForestedRatio	0	59.4	8.9	13.5
Pre_Var_a	1.6	2	1.8	0.1
Pre_Var_m	0.55	0.75	0.64	0.05
PrecFreqLow75	1	6	2.8	1.4
OrchVegRatio	**0**	**8.3**	**0.1**	**0.8**
RainFallErodibility	591	1488	749	215
ReclaimedRatio	0	29.7	2.4	4.4

Short name indicator	Statistic			
	Min	Max	Mean	Stdv
RiverSlope	0.1	3.6	0.72	0.63
SoilErodibility	0.08	0.18	0.14	0.03
SRI	0.02	0.35	0.23	0.07
SWR	107	525	431	61
TWI	0.13	0.47	0.22	0.05
UrbanRatio	0	89.6	9.1	14.2
WaterYieldAvgFlow	133	204	160	28
WaterYieldMinFlow	63	113	85	14
WetlandRatio	0	39.6	4.2	6.4

Tab. 6 Results of division of indicator values into five classes

Indicators	Cla-sses	Equal Widht			Natural Breaks			Quantile		
		Count	Min	Max	Count	Min	Max	Count	Min	Max
ArableRatio	1	78	0.0	17.1	66	0.0	8.0	38	0.0	0.1
	2	24	18.3	34.6	24	8.8	24.4	37	0.2	14.0
	3	22	37.5	52.0	18	25.2	41.7	37	14.2	46.7
	4	31	52.4	69.5	42	43.3	65.3	37	47.0	65.2
	5	32	69.6	86.9	37	66.1	86.9	38	65.3	86.9
BFI	1	61	0.5	0.6	61	0.5	0.6	38	0.5	0.6
	2							37	0.4	0.5
	3	49	0.4	0.4	49	0.4	0.4	37	0.4	0.4
	4							37	0.4	0.4
	5	77	0.3	0.4	77	0.3	0.4	38	0.3	0.4
CWB	1	8	187.3	211.1	10	185.8	211.1	38	174.5	211.1
	2	52	162.0	186.1	52	158.5	183.6	37	149.2	173.8
	3	47	136.6	160.4	50	133.6	157.7	37	133.6	148.7
	4	64	113.8	136.6	60	111.5	132.7	37	120.6	132.7
	5	16	86.9	111.5	15	86.9	111.2	38	86.9	120.3
EcoAreaRatio	1	38	80.4	100.0	35	83.7	100.0	38	80.4	100.0
	2	24	60.0	75.7	24	61.7	82.0	37	52.8	75.7
	3	29	42.2	59.9	33	39.9	61.5	37	27.0	52.6
	4	33	21.0	39.9	39	16.3	39.2	37	7.7	26.8
	5	63	0.0	19.7	56	0.0	16.0	38	0.0	7.6
EcoNumRatio	1	9	83.3	100.0	21	71.4	100.0	35	57.1	100.0
	2	21	60.0	80.0	36	47.1	68.0	42	41.2	55.6
	3	56	40.0	58.8	55	30.0	46.7	35	30.0	40.0
	4	59	20.0	38.5	48	12.5	29.4	40	16.7	29.4
	5	42	0.0	18.2	27	0.0	11.1	35	0.0	14.3
FloodRiskAreaRatio	1	179	0.0	15.6	170	0.0	6.9	124	0.0	0.0
	2	5	18.5	34.9	10	7.3	18.5			
	3	1	51.1	51.1	3	18.7	30.6			
	4	1	67.2	67.2	2	34.9	51.1	25	0.0	1.8
	5	1	90.5	90.5	2	67.2	90.5	38	1.8	90.5
FlowMaxAvgRatio	1	102	4.0	4.9	101	4.0	4.9	38	4.0	4.4
	2	8	7.9	8.0	8	4.9	7.9	37	4.4	4.4
	3	32	10.7	11.6	32	8.0	11.6	37	4.4	11.5
	4	32	13.4	13.6	32	11.6	13.6	37	11.5	13.5
	5	13	17.1	17.1	14	13.6	17.1	38	13.5	17.1
FlowMinAvgRatio	1	81	0.4	0.4	81	0.4	0.4			
	2	21	0.3	0.4	30	0.2	0.4	75	0.4	0.4
	3	8	0.3	0.3	13	0.2	0.2	37	0.2	0.4
	4	13	0.2	0.2	33	0.2	0.2	37	0.2	0.2
	5	64	0.2	0.2	30	0.2	0.2	38	0.2	0.2

Indicators	Cla-sses	Equal Widht			Natural Breaks			Quantile		
		Count	Min	Max	Count	Min	Max	Count	Min	Max
FlowMinMaxRatio	1	102	0.1	0.1	61	0.1	0.1	38	0.1	0.1
	2				42	0.0	0.1	37	0.1	0.1
	3				8	0.0	0.0	37	0.0	0.1
	4	8	0.0	0.0	33	0.0	0.0	37	0.0	0.0
	5	77	0.0	0.0	43	0.0	0.0	38	0.0	0.0
FlowVarRatio_m	1	81	0.4	0.4	20	0.4	0.4	35	0.4	0.4
	2				62	0.3	0.4	40	0.4	0.4
	3	8	0.3	0.3	54	0.2	0.3	37	0.2	0.4
	4	47	0.2	0.3	32	0.2	0.2	37	0.2	0.2
	5	51	0.2	0.2	19	0.2	0.2	38	0.2	0.2
ForestRatio	1	27	80.1	100.0	25	84.4	100.0	27	80.1	100.0
	2	18	60.0	76.1	21	58.0	80.1	18	60.0	76.1
	3	34	40.4	58.0	38	35.8	56.3	34	40.4	58.0
	4	25	20.8	39.0	30	12.1	35.1	25	20.8	39.0
	5	83	0.0	19.4	73	0.0	11.9	83	0.0	19.4
GRR	1	53	98.8	105.0	52	104.4	105.0			
	2				2	84.1	98.8	75	83.6	105.0
	3	76	82.7	84.1	77	78.6	84.1	48	82.8	83.6
	4	11	75.7	81.2	11	67.4	75.9	26	67.1	82.8
	5	47	66.9	72.9	45	66.9	67.2	38	66.9	67.1
LakeCatchRatio	1	115	81.1	100.0	115	81.1	100.0	115	81.1	100.0
	2	1	70.2	70.2	1	70.2	70.2	1	70.2	70.2
	3	2	46.3	48.9	2	46.3	48.9	2	46.3	48.9
	4	4	22.8	38.3	4	22.8	38.3	4	22.8	38.3
	5	65	0.0	0.0	65	0.0	0.0	65	0.0	0.0
LakeRatio	1	2	10.6	11.2	2	10.6	11.2	2	10.6	11.2
	2				4	1.9	3.0			
	3				1	1.1	1.1			
	4	3	2.5	3.0	1	0.2	0.2	3	2.5	3.0
	5	182	0.0	1.9	179	0.0	0.1	182	0.0	1.9
LandSlope	1	38	0.2	1.0	37	0.2	1.0	38	0.2	1.0
	2	86	1.0	1.9	56	1.0	1.6	37	1.0	1.4
	3	48	1.9	2.7	49	1.6	2.1	37	1.5	1.8
	4	8	2.9	3.5	32	2.1	3.0	37	1.8	2.2
	5	7	3.8	4.5	13	3.0	4.5	38	2.2	4.5
MeanderRatio	1	6	59.6	67.2	8	59.6	68.5	38	59.6	78.7
	2	20	67.8	75.5	26	68.7	77.5	37	78.8	84.7
	3	39	75.9	83.7	47	77.7	85.2	37	84.8	88.6
	4	75	83.8	91.3	58	85.3	91.3	37	88.7	92.7
	5	47	91.7	99.7	48	91.3	99.7	38	92.7	99.7

Indicators	Cla-sses	Equal Widht			Natural Breaks			Quantile		
		Count	Min	Max	Count	Min	Max	Count	Min	Max
NonForestedRatio	1	139	0.0	11.4	103	0.0	3.4			
	2	23	12.1	23.1	36	3.9	11.4	75	0.0	0.5
	3	12	24.3	34.6	24	12.1	24.3	37	0.8	4.9
	4	8	35.9	46.8	16	24.5	40.7	37	5.0	15.9
	5	5	49.7	59.4	8	42.0	59.4	38	16.1	59.4
OrchVegRatio	1	184	0.0	1.0	183	0.0	0.0	183	0.0	0.0
	2									
	3	1	4.6	4.6						
	4	1	5.6	5.6						
	5	1	8.3	8.3	4	1.0	8.3	4	1.0	8.3
Pre_Var_a	1	1	1.6	1.6	3	1.6	1.7	38	1.6	1.8
	2	27	1.7	1.8	47	1.7	1.8	37	1.8	1.8
	3	63	1.8	1.8	75	1.8	1.9	37	1.8	1.9
	4	59	1.8	1.9	52	1.9	1.9	37	1.9	1.9
	5	37	1.9	2.0	10	1.9	2.0	38	1.9	2.0
Pre_Var_m	1	15	0.7	0.7	16	0.7	0.7	37	0.7	0.7
	2	46	0.7	0.7	94	0.6	0.7	45	0.7	0.7
	3	54	0.6	0.7	17	0.6	0.6	30	0.6	0.7
	4	21	0.6	0.6	34	0.6	0.6	42	0.6	0.6
	5	51	0.6	0.6	26	0.6	0.6	33	0.6	0.6
PrecFreqLow75	1	63	1.0	2.0	47	1.0	1.5	38	1.0	1.1
	2	46	2.0	3.0	37	1.5	2.4	37	1.2	2.2
	3	58	3.0	4.0	38	2.5	3.4	37	2.2	3.0
	4	8	4.0	4.9	49	3.5	4.0	37	3.0	4.0
	5	12	5.1	6.0	16	4.2	6.0	38	4.0	6.0
RainFallErodibility	1	153	591.3	734.5	47	591.3	625.2	47	591.3	625.2
	2	11	837.7	837.7	94	655.5	688.8	31	655.5	669.1
	3				6	709.7	730.4	36	673.7	677.4
	4	18	1269.8	1269.8	17	734.5	837.7	39	682.3	734.5
	5	5	1360.1	1488.1	23	1269.8	1488.1	34	837.7	1488.1
ReclaimedRatio	1	160	0.0	5.5	127	0.0	1.8	160	0.0	5.5
	2	19	6.1	10.8	33	1.8	5.5	19	6.1	10.8
	3	6	12.0	15.0	18	6.1	10.3	6	12.0	15.0
	4				6	10.8	14.3			
	5	2	28.1	29.7	3	15.0	29.7	2	28.1	29.7
SoilErodibility	1	43	0.1	0.1	44	0.1	0.1	38	0.1	0.1
	2	37	0.1	0.1	35	0.1	0.1	37	0.1	0.1
	3	24	0.1	0.1	24	0.1	0.1	37	0.1	0.2
	4	14	0.1	0.2	17	0.1	0.2	75	0.2	0.2
	5	69	0.2	0.2	67	0.2	0.2			

Indicators	Cla-sses	Equal Widht			Natural Breaks			Quantile		
		Count	Min	Max	Count	Min	Max	Count	Min	Max
SRI	1	8	0.0	0.0	9	0.0	0.1	38	0.0	0.2
	2	4	0.1	0.1	14	0.1	0.2	37	0.2	0.2
	3	81	0.2	0.2	70	0.2	0.2	35	0.2	0.2
	4	53	0.2	0.3	52	0.2	0.3	39	0.2	0.3
	5	41	0.3	0.3	42	0.3	0.3	38	0.3	0.3
SWR	1	81	442.5	525.4	61	475.4	525.4	38	501.0	525.4
	2	91	358.9	435.3	29	423.6	472.9	37	449.4	500.5
	3	13	282.2	356.8	73	373.6	423.3	37	409.3	448.0
	4	1	239.4	239.4	23	239.4	372.0	37	385.4	408.9
	5	1	107.0	107.0	1	107.0	107.0	38	107.0	385.1
TWI	1	12	5.8	6.7	7	9.9	10.8	38	8.9	10.8
	2	58	6.8	7.8	28	9.0	9.7	37	8.2	8.9
	3	70	7.8	8.8	43	8.2	9.0	37	7.8	8.2
	4	40	8.8	9.7	75	7.3	8.1	37	7.4	7.8
	5	7	9.9	10.8	34	5.8	7.2	38	5.8	7.3
UrbanRatio	1	162	0.0	17.8	108	0.0	5.9			
	2	14	18.7	35.1	52	5.9	16.0	75	0.0	2.4
	3	7	36.6	52.5	13	16.5	29.3	37	2.6	6.4
	4	2	64.1	69.0	9	31.2	49.9	37	6.4	12.6
	5	2	79.2	89.6	5	52.5	89.6	38	13.3	89.6
WaterYieldAvgFlow	1	52	190.9	203.8	32	201.6	203.8	38	191.6	203.8
	2	21	176.8	181.7	21	181.7	191.6	37	162.4	191.6
	3	8	161.7	162.6	21	162.6	178.0	37	140.3	162.2
	4				8	140.9	162.4	37	134.5	140.3
	5	106	132.9	140.9	105	132.9	140.4	38	132.9	134.5
WaterYieldMinFlow	1	20	112.8	113.3	20	112.8	113.3	38	95.0	113.3
	2	32	94.0	95.1	33	88.1	95.1	37	86.0	95.0
	3	70	83.7	88.1	70	78.3	86.0	37	85.5	86.0
	4	20	77.7	78.3	20	70.1	78.3	37	69.9	85.5
	5	45	63.2	70.1	44	63.2	70.0	38	63.2	69.9
WetlandRatio	1	1	39.6	39.6	2	27.6	39.6	1	39.6	39.6
	2	2	24.0	27.6	17	14.1	24.0	2	24.0	27.6
	3	13	15.9	21.8	18	7.5	13.4	13	15.9	21.8
	4	20	8.1	15.7	43	2.2	7.4	20	8.1	15.7
	5	151	0.0	7.5	107	0.0	2.2	151	0.0	7.5

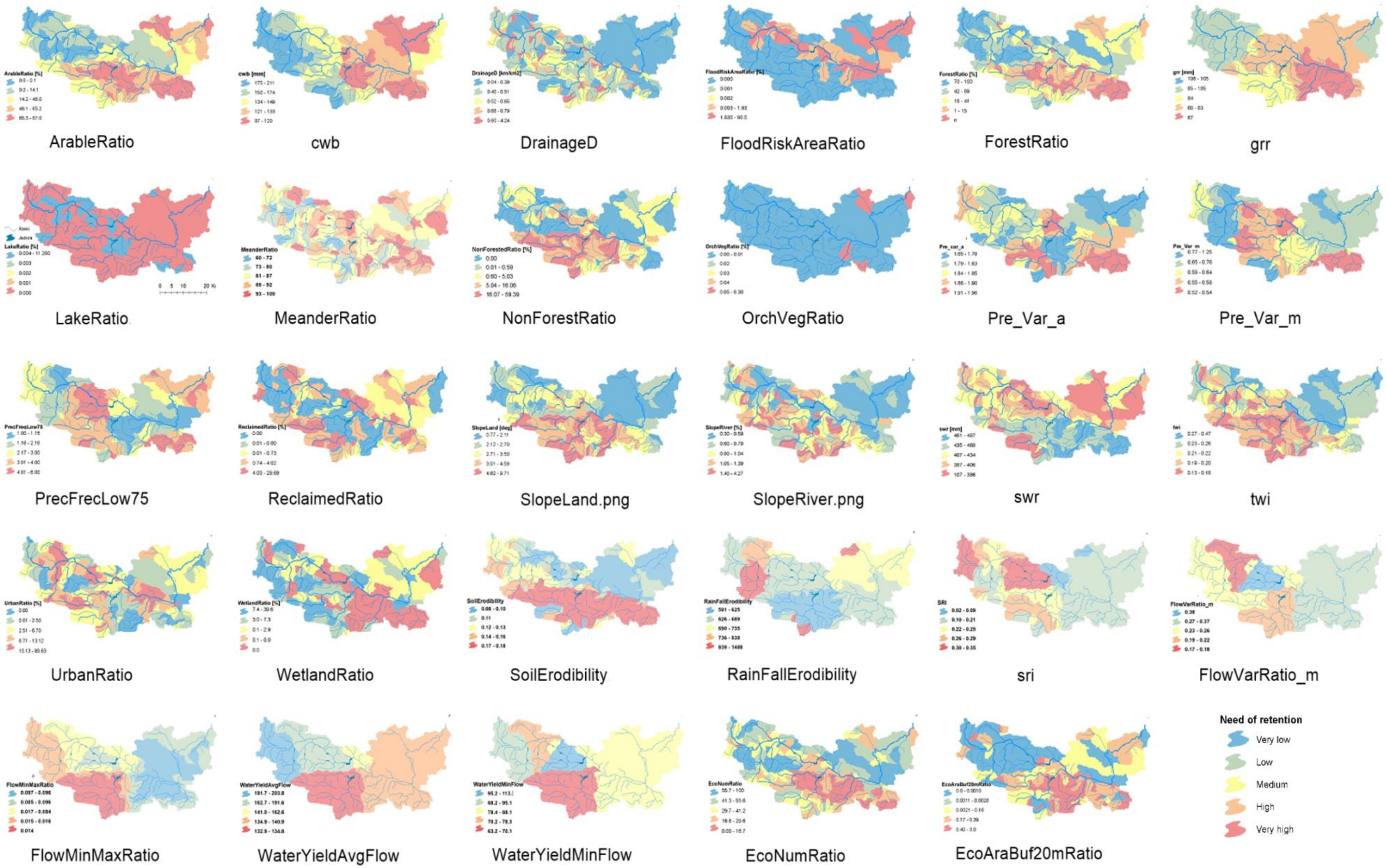


Fig. 15 Indicator values maps

5. Analysis of variants

In the next stage, tests were carried out to check the operation of the FroGIS application and to develop advice/tips (default values) for future users, which will allow them to find answers to the following questions:

- What method of class division should I adopt?
- What number of classes should I implement?
- How to determine weights?

Therefore, the analyses were divided into four variants (G, D, F, WQ) depending on the valorisation objective and a maximum of six sub-options. For the drought and flood goal, six sub-options were used. They were a combination of 3 classification methods and 2 weighting choices (broken down into 5 classes):

1. EW.Wht1 division into classes by equal width for constant weight,
2. EW.Wht01 division into classes by equal width for variable weight,
3. NB.Wht1 division into classes by natural breaks for constant weight,
4. NB.Wht01 division into classes by natural breaks for variable weight,
5. Q.Wht1 division into classes by quantiles for constant weight,
6. Q.Wht01 division into classes by quantiles for variable weight.

For the general and water quality objective, only three variants were prepared without selecting variable weights:

1. EW.Wht1 division into classes by equal width for constant weight,
2. NB.Wht1 division into classes by natural breaks for constant weight,
3. Q.Wht1 division into classes by quantiles for constant weight.

5.1. Proposed selection of weight coefficients for indicators

The most difficult task was the development of a methodology for the selection of weight coefficients, which must be done manually in the FroGIS application and requires changing the values of weights multiple times and comparing with the maps developed in Chapter 3 (Fig. 9 and Fig. 10) for verification. Therefore, during the tests, a different methodology was developed that runs in MS Excel. To use it the following data is required:

- Classification results for each indicator obtained from the .csv report of the FroGIS application
- Maps with identified several SPUs with high or low water retention needs and capabilities

Afterwards input data has to be copied to spreadsheet (one table related by SPU number) which allows to calculate the class sum multiplied by weights. Next, they were divided into two groups: with high water retention needs (G1) and others (G2). Solver tool creates weights for indicators using NonLinear GRG function for all indicators. Target for the solver function will be established on the basis of the difference between group G1 and G2. These values for solver target can be obtained by using mean or median function. In this study both functions were tested but finally median function was chosen because it does not depend on the number of SPUs and it resulted in giving a better distribution of weight coefficients.

Produced evaluation needs to be compared with maps available in this example in Fig. 9 or Fig. 10. If the evaluated area has high water retention needs and possibilities in case of flood or drought risk and it coincides with area goals and indicator classes than evaluation values were calculated properly. In alternative case, all indicators must be checked or additional criteria for the solver function can be included. For example, we can give relevant indicators, a rule that the weight must be greater than 0.5. Some of them can be removed or have improper values, for example: low resolution and quality of elevation points in the DEM. Z The obtained results show that for the drought goal the highest weight was assigned to indicators: ArableRatio, WetlandRatio, OrchVegRatio, PrecFreqLow75, CWB, GRR. While for flood goal the following indicators: ArableRatio ForestRatio LandSlope DrainageD. Calculation results are included in Tab. 7.

Tab. 7 Obtained weight coefficients for different classes aggregation methods

Indicator	Drought			Flood			Water quality	General
	Equal Width	Percentyl	Natural Breaks	Equal Width	Percentyl	Natural Breaks	All methods	All methods
ArableRatio	1.0	1.0	1.0	0.9	0.9	1.0	1.0	1.0
CWB	0.4	1.0	1.0				1.0	1.0
DrainageD				0.6	1.0	1.0	1.0	1.0
EcoAraBuf20mRatio							1.0	1.0
EcoNumRatio							1.0	1.0
FloodRiskAreaRatio				0.1	0.1	0.1	1.0	1.0
FlowMinMaxRatio	0.1	0.1	0.1	0.5	0.3	0.4	1.0	1.0
FlowVarRatio_m	0.1	0.1	0.1				1.0	1.0
ForestRatio	0.3	0.3	1.0	1.0	1.0	1.0	1.0	1.0
GRR	0.8	1.0	1.0				1.0	1.0
LakeRatio	0.7	0.2	1.0	0.1	0.7	0.1	1.0	1.0
LakeCatchRatio				0.1	0.1	0.1	1.0	1.0
LandSlope				1.0	1.0	1.0	1.0	1.0
MeanderRatio				0.1	0.9	0.8	1.0	1.0
NonForestedRatio				0.1	0.4	0.3	1.0	1.0
Pre_Var_a	0.3	1.0	1.0				1.0	1.0
Pre_Var_m	0.5	0.1	0.1				1.0	1.0
PrecFreqLow75	0.7	1.0	0.8				1.0	1.0
OrchVegRatio	1.0	1.0	1.0	0.1	0.1	0.1	1.0	1.0

Indicator	Drought			Flood			Water quality	General
	Equal Width	Percentyl	Natural Breaks	Equal Width	Percentyl	Natural Breaks	All methods	All methods
RainFallErodibility				1.0	0.2	0.7	1.0	1.0
ReclaimedRatio	0.2	1.0	0.9	0.7	0.8	0.2	1.0	1.0
RiverSlope				0.5	0.2	0.8	1.0	1.0
SoilErodibility				0.3	0.1	0.1	1.0	1.0
SRI	0.2	0.1	0.4	0.2	0.2	0.1	1.0	1.0
SWR	0.1	0.2	0.1				1.0	1.0
TWI	0.1	0.1	0.2	0.1	0.2	0.5	1.0	1.0
UrbanRatio	0.1	0.1	0.1	0.1	0.1	0.1	1.0	1.0
WaterYieldAvgFlow	0.2	0.1	1.0				1.0	1.0
WaterYieldMinFlow	1.0	0.9	0.1				1.0	1.0
WetlandRatio	1.0	1.0	1.0	0.1	0.1	0.1	1.0	1.0

5.2. Variant G: Valorisation for general purpose (5 classes)

The results of variant G (general goal) are presented on three valorisation maps in Fig. 16, each representing a separate sub-option. Those maps display few differences, however regions with high water retention priority are always located in the southern and north-eastern part of the catchment area. On the basis of visual analysis it’s impossible to indicate which class division method is better.

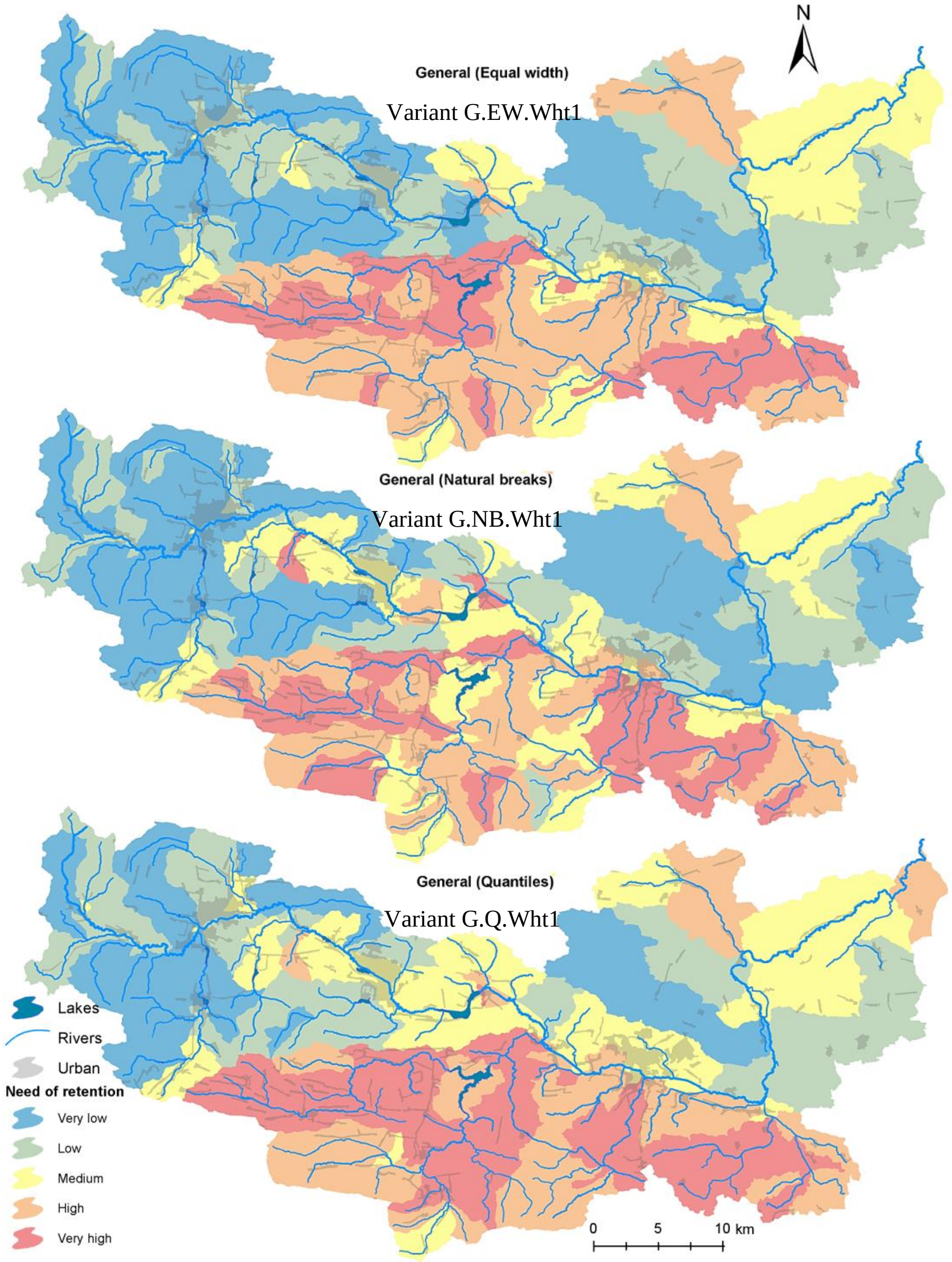


Fig. 16 Final valorisation map for general goal with constant weight (Wht1) differentiated by the methods of division into classes (EW- equal width, NB- natural breaks, Q- quantiles)

5.3. Variant D: Valorisation for drought mitigation purpose (5 classes)

The results of variant D (drought goal) are presented on six valorisation maps in Fig. 17, each of which represents a separate sub-option. These maps show few differences, however regions with high water retention priority are always located in the southern and north-eastern part of the catchment area. On the basis of visual analysis, it is impossible to indicate which class division method is better. Variant F.Q. shows the greatest variation and variant F.NB. the smallest. It was observed that the introduction of weight coefficients usually reduces the SPU surface area with high water retention potential.

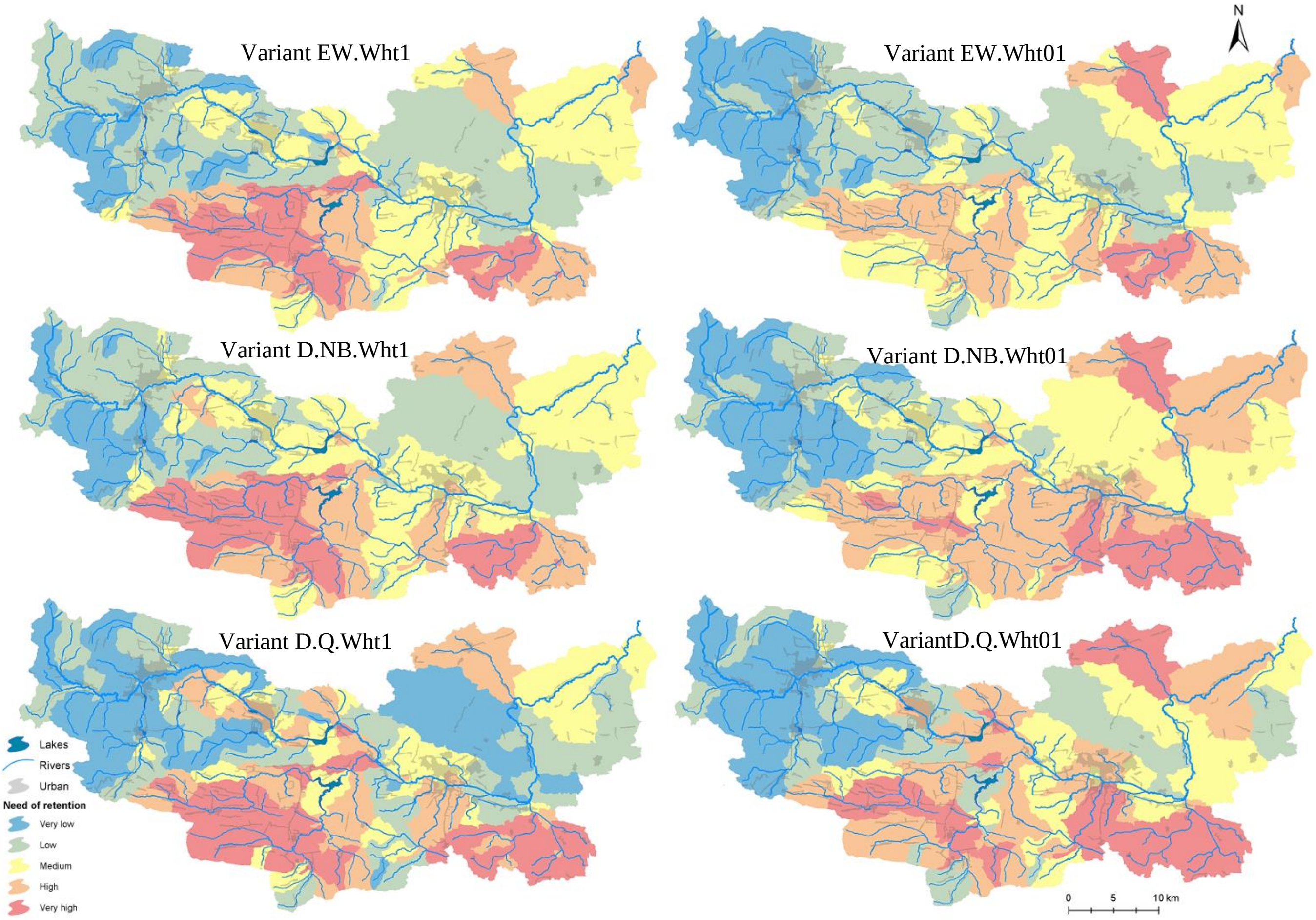


Fig. 17 Final valorisation map for drought goal differentiated by weight and by the methods of division into classes (Wht1 - constant =1 weight, Wht01- variable weight, EW- equal width, NB- natural breaks, Q- quantiles)

5.4. Variant F: Valorisation for flood mitigation purpose (5 classes)

The results of variant F (flood goal) are presented on six valorisation maps in Fig. 18, each representing a separate sub-option. These maps show few differences, however, the region with a high water retention priority is always located in the southern part of the catchment. On the basis of visual analysis it's impossible to indicate which class division method is better. Variant F.Q. shows the greatest variation and variant F.NB. the smallest. It was observed that the introduction of weight coefficients usually reduces the SPU surface area with high water retention potential.

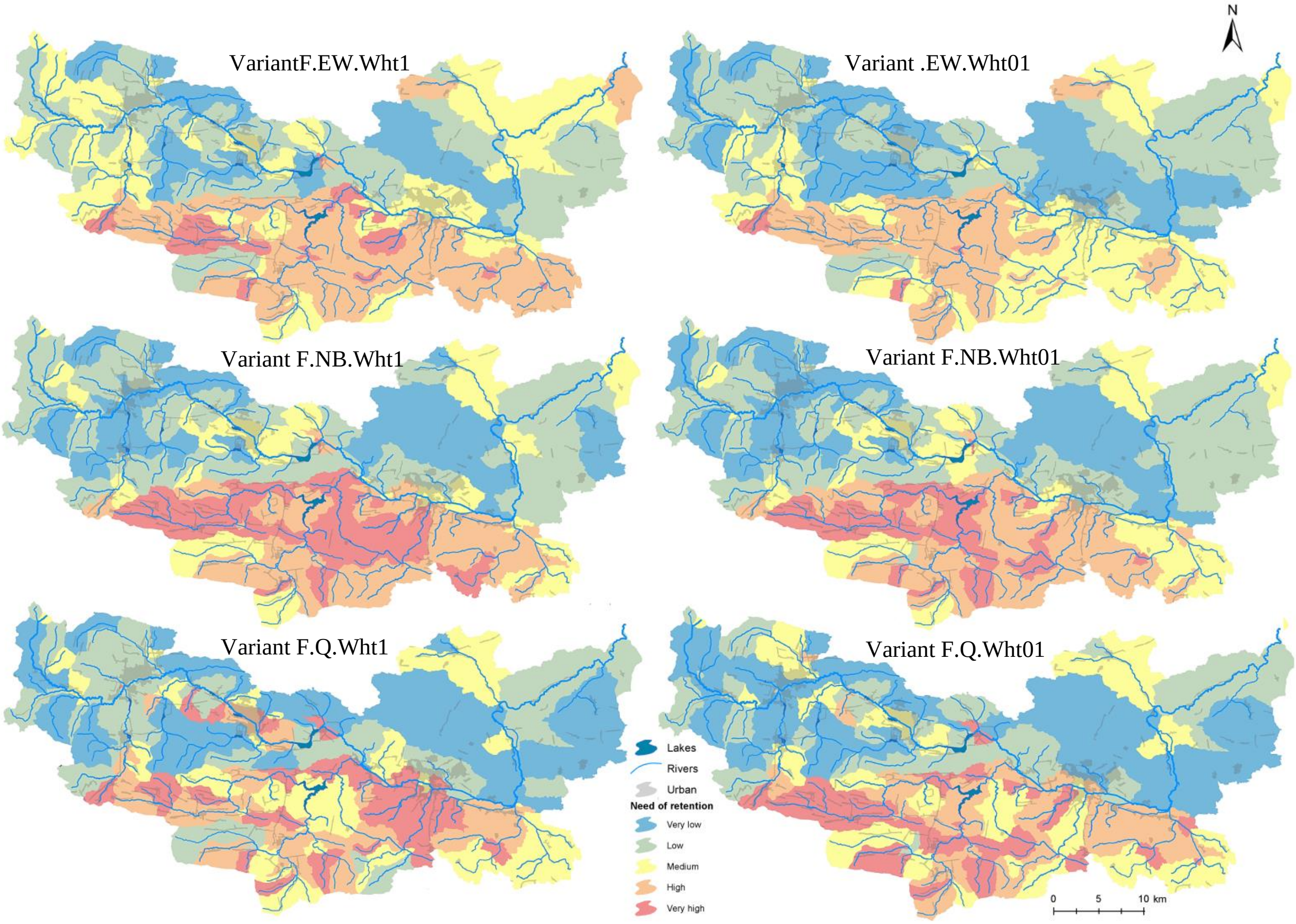


Fig. 18 Final valorisation map for flood goal differentiated by weight and by the methods of division into classes (Wht1 - constant =1 weight, Wht01- variable weight, EW- equal width, NB- natural breaks, Q- quantiles)

5.5. Variant WQ: Valorisation for water quality improvement purpose

The results of the WQ (water quality goal) variant are presented on three valorisation maps in Fig. 19, each of which represents a separate sub-option. These maps show few differences, however, the region with a high water retention priority is always located in the southern part of the catchment with agricultural land use. On the basis of visual analysis, it's impossible to indicate which class division method is better. Variant F.Q. shows the greatest diversity. It was observed that variant F.NB. has the largest share of SPU surface area with high and very high level of water retention needs and variant F.EW. on the contrary, the lowest.

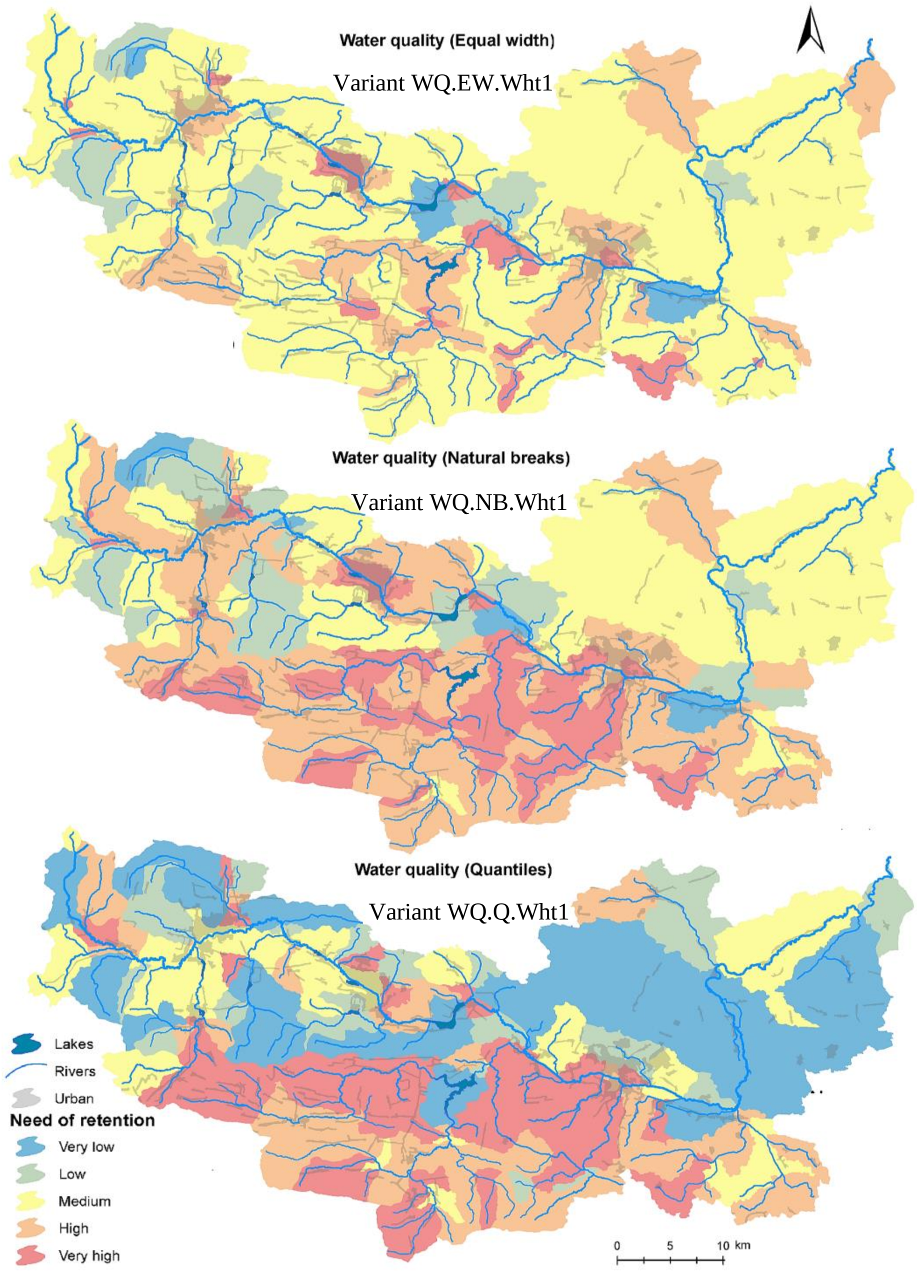


Fig. 19 Final valorisation map for water quality goal differentiated by the methods of division into classes (Wht1 - constant =1 weight, EW- equal width, NB- natural breaks, Q- quantiles)

6. Comparison and description of results

In order to find an answer to the questions asked in the third chapter, a variant comparison was carried out. In the first analysis, the results of calculations were compared in order to find which method of division into classes should be adopted. For this purpose, four types of errors were calculated in Tab. 8 and

Tab. 9 showing the difference between:

- variant obtained as a result of changing weights and variant with set and constant weight (Wht01-Wht1)
- field recognition goal and variant with the set, constant weight (= 1)
- field recognition goal and variant with changeable weight

In conclusion, the comparison of error values (in Tab. 8 and

Tab. 9) obtained for different class divisions showed that in four out of six cases, the EQ method gave the lowest errors, and the NB method only in two. The biggest errors were present in the quantile method. The Wht01-Wht1 comparison shows that the introduction of weights changes the valorisation map by about 20%. On this basis, it can be concluded that analysis without weight adjustment is in 80% similar to that after the introduction of weights. However, it can be observed that the distances from the purpose of individual variants in the analysis for drought deviates by 27% from the target, and the analysis for flood by 82%. This happens when the number of SPUs selected as field recognition goals exceeds 10% of all SPUs.

Tab. 8 Comparison of final classification (valorisation map) for drought goal (variant D)

Variant D Drought		Wht01-Wht1			FieldRecognitionGoal-Wht1			FieldRecognitionGoal-Var.Q.Wht01		
Name of errors	Short n.error	Var.EW	Var.NB	Var.Q	Var.EW	Var.NB	Var.Q	Var.EW	Var.NB	Var.Q
Mean Absolute Deviation	MAD	0.47	0.55	0.50	1.11	1.21	1.16	1.21	0.58	0.84
Mean Square Error	MSE	0.51	0.56	0.57	1.63	1.84	2.42	1.74	0.68	1.37
Root Mean Square Error	RMSE	0.72	0.75	0.75	1.28	1.36	1.56	1.32	0.83	1.17
Mean Absolute Percentage	MAPE	18%	22%	20%	25%	27%	26%	27%	13%	19%
Total (good bead)		1.88	2.09	2.02	4.26	4.68	5.40	4.53	2.22	3.57

Tab. 9 Comparison of final classification (valorisation map) for flood goal (variant F)

Variant F Flood		Wht01-Wht1			FieldRecognitionGoal-Wht1			FieldRecognitionGoal-Var.Q.Wht01		
Name of errors	Short n.error	Var.EW	Var.NB	Var.Q	Var.EW	Var.NB	Var.Q	Var.EW	Var.NB	Var.Q
Mean Absolute Deviation	MAD	0.47	0.24	0.50	1.02	1.07	1.18	0.87	0.96	1.13
Mean Square Error	MSE	0.48	0.24	0.64	1.82	1.96	2.51	1.49	1.53	2.20
Root Mean Square Error	RMSE	0.69	0.49	0.80	1.35	1.40	1.58	1.22	1.24	1.48
Mean Absolute Percentage	MAPE	23%	10%	20%	77%	76%	82%	65%	64%	75%
Total (good bead)		1.87	1.06	2.14	4.96	5.18	6.09	4.22	4.37	5.56

Another analysis concerns the compatibility of the EQ and constant coefficient weight (= 1) variant. It was carried out for four conditions in which the difference between the EQ and NB or Q variant classes is equal to: "0", "0 or ± 1", "0 or -1", "0 or 1". Results show that by using a different method of selection other than EQ, the consistency of the results matching the condition "0" remains at a very low level (26% -77%) and expressed the worst results for the low number of indicators introduced in the Water Quality variant. If we reduce the precision of the comparison to the condition "0 or ± 1", then compliance increases to the level of 71-100%. The above analysis was carried out for the division of maps into 5 classes. It should be assumed that the use of a smaller number of classes can improve the statistic and increasing the number of classes can make them worse.

Tab. 10 Compatibility with the constant coefficient weight (=1) variant (good bead)

Condition (difference equal)	General		Drought		Flood		Water quality	
	G.EQ-G.NB	G.EQ-G_Q	G.EQ-D_NB	D.EQ-D_Q	D.EQ-F_NB	F.EQ-F_Q	F.EQ-WQ_NB	G.EQ-WQ_Q
0	59%	59%	77%	54%	56%	42%	41%	26%
0 or ±1	100%	96%	101%	99%	100%	94%	96%	71%
0 or -1	95%	77%	91%	67%	81%	61%	86%	55%
0 or +1	63%	77%	86%	86%	75%	75%	51%	42%

7. Summary

During the testing phase it was found that FroGIS application runs smoothly on a catchment with an area of 2000 km^2 broken down into 200 SPUs and with raster resolution larger than 50 meters. The problems that occurred during the tests were often caused by geometry errors and the use of non-referenced coordinate systems. All of them are described in the FAQ file available from the application level.

It is recommended to improve the functionality of the application in the following areas:

- Add SPU numbers to the report file
- Improve the Quantile method by increasing the precision of boarder values
- Increase the size of the output map and supplement the legend with:
  - Very low potential for water retention
  - Very high potential of water retention
- Add more warnings:
  - Less than 40 SPUs is not recommended due to problems with division into classes
  - The number of SPUs greater than 500 is not recommended because it hasn't been tested and the calculations may exceed the system capability
  - A smaller number of selected indicators is not recommended due to problems with division into classes
- Remove indicators: CWB_Var_a; CWB_Var_m
- Mark default or recommended values

As a result of tests, it was found that the best results were obtained from the equal width method of division into classes, second best results were acquired from natural breaks method. The use of weights corrects only 20% of SPU. The developed method of class selection should be included in the valorisation methodology, with the condition that the number of cells selected for field recognition does not exceed 10%, because a higher value causes the optimisation to be ineffective. The division into 5 classes seems to be most suitable for the final classification map. It is recommended to divide indicators into 3 classes, because it works well even for poorly spatially differentiated indicators.