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Geoinformatic Assessment of the Consequences of Extreme Flood in August 2002 in Otava River Basin

JAKUB LANGHAMMER

Charles University in Prague, Faculty of Science
Department of Physical Geography and Geoecology

Abstract

The article presents application of geoinformatic and geostatistical techniques in finding relations between observed consequences of the extreme flood in August 2002 and the set of causal factors – anthropogenic transformation of the landscape and physicogeographical features. The indicators of anthropogenic transformation of landscape were acquired from major analytical projects solving individual aspects of extreme flooding in August 2002 in the Otava river basin as the core zone of the flood – analysis of long-term landuse changes, river network shortening, anthropogenic transformation of riverbed and floodplain and mapping of geomorphological evidences of the flood. For finding spatial and statistical relations between individual factors and flood consequences the rule-based classification and cluster analysis in the GIS environment were applied. The results show the spatial and statistical differentiation of the effect of individual landscape modifications on the flood consequences according the physicogeographical features and observed flood extremity. The presented approach could help in assessing the impact of anthropogenic changes in landscape on runoff process in large-scale, heterogeneous river basins and improve the land management and flood protection planning process.

Key words: GIS, floods consequences, geostatistics, hydrology, hazards

1. Introduction

The geoinformatic analysis was considered as one of the key components of the project of assessment the impact of the changes in landscape on the progress and consequences of the extreme flood in August 2002. The role of application of the geoinformatic techniques consisted in design of the framework geodatabase, integration of geospatial data of different origin, format and spatial extent, coordination of geodata exchange and sharing, application of various analysis methods and support of final interpretation of results.

Within the project solution there were analyzed multiple data sources as various indicators of landscape modifications with regard to the flood risk together with information on flood course and observed consequences, e.g.: intensity and character of stream and floodplain transformation, historical shortening of river network, long-term evolution of land use, land cover quality changes, geomorphologic effect of the flood, observed flood consequences, physicogeographic features of landscape, information on historical floods and others. Such indicators formed the main components of the multicriterial assessment process aimed at identifying statistical and spatial relationships between observed flood consequences and the intensity of landscape transformation.

The application of geoinformatic techniques importantly influenced the quality and speed of project solution, allowed implementation of advanced analysis techniques and brought important information for the interpretation of the process of extreme flooding.

2. Material and Methods

The background material used for project solution was based on a broad range of different data sources – field mapping, historical data analysis, remote sensing data, digital elevation model or digital cartographic products.

The main prerequisite was to define a data source structure that would allow interlinking pieces of information of different geometrical characteristics and spatial representation.

The procedure involved the following steps:

- Selection of source data and definition of geodatabase structure
- Design of the methodology of field data collection and GIS integration
- Digititalization and integration of the data into GIS
- Data quality checking and preprocessing
- Geostatistical assessment

2.1 Source Data

The integrated project geodatabase was built upon the Digital civil map (ZABAGED) consisting of a complex set of topographic layers and digital elevation model with precision corresponding to scale 1:10 000. Into this topological base were consequently integrated all available geodata sources. The geoinformatic analysis integrated data from multiple sources – the available geodatabases and the results of individual project tasks.

The solution was based on following data sources:

- Digital data
  - Basic topography – Digital civil map
  - Digital elevation model
- Thematic cartography
- Land cover – CORINE geodatabase
  - Digital water management map
  - Landsat TM satellite images – results of interpretation of remote sensed data time series (Hais, Králová, Macháčková, 2005 in this volume)
- Historical records
  - Results of river network shortening analysis from historical maps (Langhammer, Vajskebr, 2006, in this volume)
  - Results of Land use historical changes analysis from historical maps (Bičík, Kupková and Štych, 2006, in this volume)
- Field mapping

- Results of field mapping of watercourse and floodplain transformation (Langhammer, 2006, in this volume)
- Results of field mapping of geomorphological effects of the 2002 flood (Křížek, Engel, 2006, in this volume)

2.2 Data Integration

Assessment was mainly focused on watercourse segments subject to mapping of river network and floodplain anthropogenic modifications. The individual watercourse segments remain the smallest spatial units for the assessment while for needs of analysis they can be easily merged into larger units corresponding for example to individual river basins, watercourses, administrative units etc.

To integrate the data of different geometric characteristics, each segment was provided with a buffer zone in which were integrated the information from individual analytical layers – geomorphological mapping, assessment of the river network shortening, analysis of land use changes and current state, relief digital model analysis etc. The width of the buffer zone was set to 500 meters. Such extent of the buffer enabled to integrate all of the required information from the floodplain whose extent was generally lower than the extent of the buffer. In special the cases where the floodplain exceeded the buffer zone its perimeter was extended to include all necessary information. The main concept of data integration into individual segments is specified in Fig. 1.

The geodatabase maintainance, data sharing, analysis and visualization of results was performed on the MapInfo Professional platform. For particular analyses were used using various software packages, e.g. ArcGIS with extensions 3D Analyst, Spatial Analyst, Geostatistical Analyst, MapInfo extensions Vertical Mapper or Grid Analyser, Surfer, ENVI, PCI, Idrisi and others. The map sources in the geodatabase were maintained in Non-Earth cartographic projection S-42.

3. Results

3.1 Correlation Analysis

As first step of the data analysis there was performed correlation analysis to highlight the main links between the individual factors. However, the results showed that the correlation strength between the intensity of consequences and rate of anthropogenic modification was mostly indistinct and difficult to use for the explanation of causal relations (Fig. 2). The relations between individual parameters proved to be complex and difficult to describe by simple linear relations.

3.2 Rule-based Classification

To study the spatial and statistical relations between identified flood consequences and selected driving factors there was applied the rule-based classification. The rule-based classification is based on user-defined set of rules for classification of in-

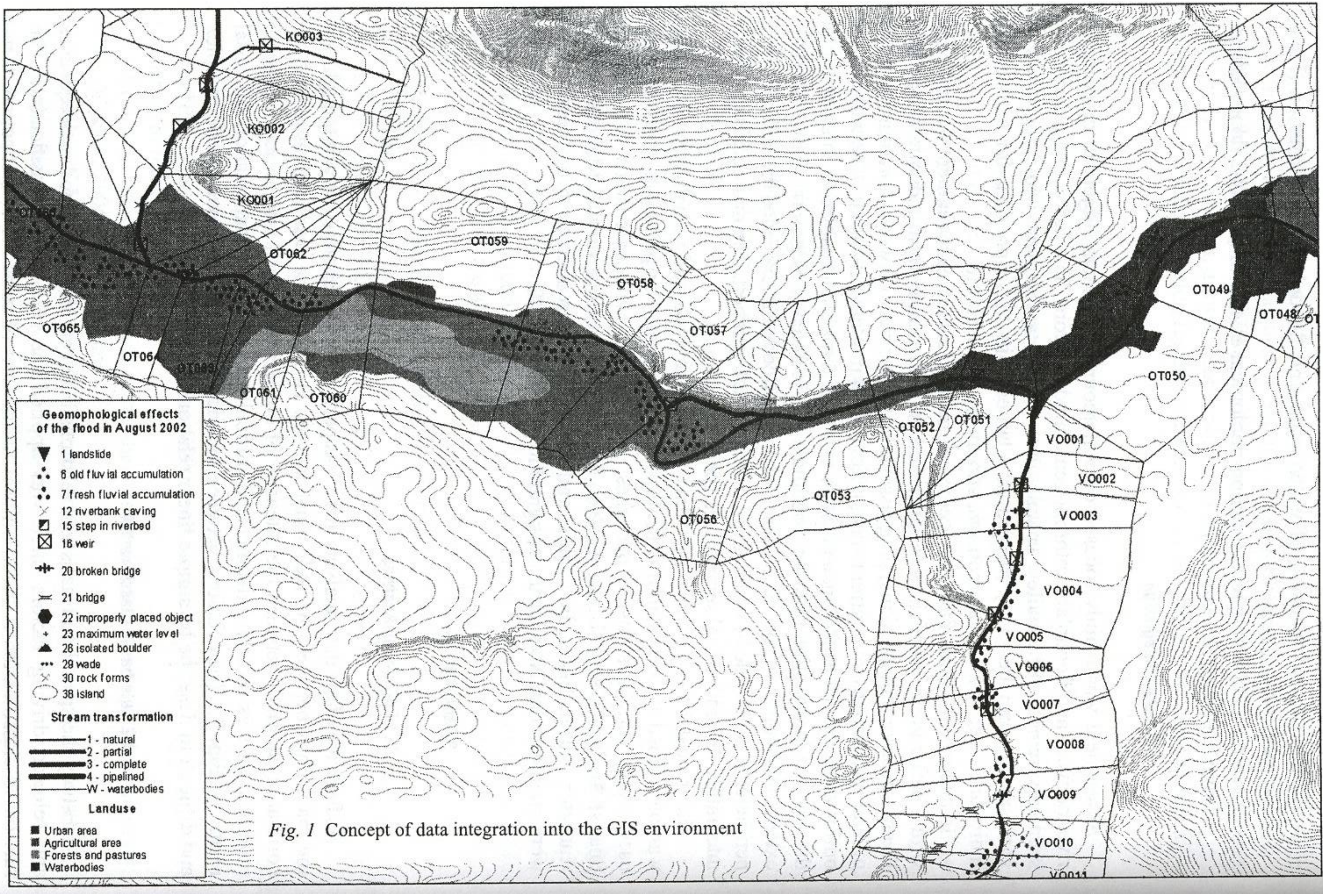

Fig. 1 Concept of data integration into the GIS environment

	H_mean	slope	mod_riverbed	mod_route	mod_long_prof	mod_floodplain	#_accums	#_bank_cavings	#_weirs	#_improp_placed	#_dam_bridge	#_bridges	#_landslides	#_rock_steps	share_urban	share_arable	share_agric	share_meadows	share_forest	share_water	short_1844_1876	short_1844_2002	short_1876_1952	short_1876_2002	short_1952_2002
H_mean	1.00																								
slope	0.57	1.00																							
mod_riverbed	-0.26	-0.08	1.00																						
mod_route	-0.10	-0.03	0.29	1.00																					
mod_long_prof	-0.17	-0.09	0.33	0.11	1.00																				
mod_floodplain	-0.12	-0.04	0.31	0.96	0.24	1.00																			
#_accums	-0.12	-0.11	-0.09	-0.08	-0.03	-0.08	1.00																		
#_bank_cavings	-0.09	-0.09	0.01	0.00	0.04	-0.01	0.32	1.00																	
#_weirs	-0.16	-0.11	0.21	0.06	0.42	0.09	0.02	0.07	1.00																
#_improp_placed	-0.05	-0.03	0.02	-0.03	-0.01	-0.01	0.04	0.04	-0.03	1.00															
#_dam_bridge	-0.03	-0.03	-0.03	-0.01	-0.03	-0.01	0.15	0.22	0.01	-0.01	1.00														
#_bridges	-0.05	-0.05	0.17	0.01	0.15	0.03	0.06	0.15	0.29	0.17	0.03	1.00													
#_landslides	0.07	-0.03	-0.04	-0.06	0.01	-0.06	0.02	-0.02	-0.03	-0.01	-0.01	-0.03	1.00												
#_rock_steps	0.06	0.00	-0.02	0.00	0.01	0.00	-0.02	0.04	0.03	-0.01	0.08	0.01	-0.01	1.00											
share_urban	-0.20	-0.15	0.34	0.19	0.24	0.20	-0.09	0.02	0.19	0.02	0.02	0.22	-0.03	-0.03	1.00										
share_arable	-0.59	-0.39	0.14	-0.02	0.05	0.00	0.08	0.02	0.05	0.10	-0.05	0.03	-0.03	-0.03	-0.11	1.00									
share_agric	-0.62	-0.44	0.10	-0.02	0.06	0.00	0.16	0.09	0.06	0.09	0.02	0.01	-0.05	-0.05	-0.27	0.73	1.00								
share_meadows	0.15	0.08	-0.05	0.01	0.00	0.01	0.03	0.07	0.01	-0.03	0.05	-0.02	-0.03	0.01	-0.13	-0.36	0.06	1.00							
share_forest	0.73	0.53	-0.28	-0.06	-0.18	-0.09	-0.10	-0.09	-0.17	-0.10	-0.03	-0.13	0.05	0.06	-0.27	-0.68	-0.84	0.02	1.00						
share_water	0.04	-0.06	-0.09	-0.13	-0.02	-0.14	-0.05	-0.02	0.01	-0.03	-0.04	0.00	0.10	0.01	-0.01	-0.04	-0.14	-0.08	0.01	1.00					
short_1844_1876	0.10	0.13	-0.11	0.04	-0.03	0.02	0.03	0.04	0.01	0.08	0.06	0.07	-0.04	0.01	-0.07	-0.10	-0.09	0.03	0.13	-0.02	1.00				
short_1844_2002	-0.41	-0.29	0.26	0.01	0.12	0.02	-0.02	0.01	0.16	0.02	0.02	0.10	-0.02	-0.02	0.11	0.33	0.30	-0.11	-0.36	0.04	-0.03	1.00			
short_1876_1952	-0.30	-0.23	0.26	-0.01	0.09	0.01	-0.09	-0.06	0.13	0.00	-0.04	0.06	0.01	-0.03	0.13	0.25	0.19	-0.07	-0.27	0.06	-0.47	0.82	1.00		
short_1876_2002	-0.42	-0.32	0.28	0.00	0.12	0.02	-0.03	0.00	0.16	-0.01	-0.01	0.08	0.00	-0.03	0.14	0.34	0.30	-0.11	-0.38	0.05	-0.42	0.91	0.95	1.00	
short_1952_2002	-0.42	-0.31	0.12	0.04	0.12	0.04	0.16	0.18	0.21	-0.02	0.09	0.14	-0.02	-0.01	0.04	0.30	0.37	-0.12	-0.40	0.02	0.12	0.47	0.10	0.39	1.00

Fig. 2 Correlation table showing realations between intensity of landscape modifications and flood effects

dividual objects in predefined cause-effect categories. The set of rules and thresholds for classification is based on the knowledge of assessed process, the empirical experience or the expert's choice. The classification procedure is performed in the GIS environment using SQL database querying. The classification rules might combine data from different sources that are integrated either in the same river segment or in a series of consequent segments, e.g. while examining impact of river structures on flood effects observed in consequent segments.

This classification was applied to assess the following relations:

- River network shortening vs. flood consequences
- Riverbed transformation vs. flood consequences
- Floodplain transformation vs. flood consequences
- Longitudinal profile transformation vs. flood consequences
- Flow obstacles vs. flood consequences.

For all of the above mentioned relations there was defined a set of thresholds and performed a rule-based classification with analysis of spatial distribution of observed phenomena.

3.2.1 River Network Shortening and Flood Consequences

The assessment of links between watercourse shortening and flood consequences intensity was built on result of analysis of historical river network shortening in main stages (see Langhammer, Vajskebr, 2005 in this volume) and results of mapping of flood consequences identified by mapping geomorphologic flood consequences (fresh fluvial accumulations, bank cavings, landslides, damaged structures etc.) were integrated into the buffer zone.

The general statistical assessment of the whole river basin didn't show any significant correlations between the watercourse shortening intensity and percentage rate of the 2002 flood consequences.

However the empirical experience from assessment of extreme runoff processes prove that water course rectification is often accompanied by acceleration of erosive and

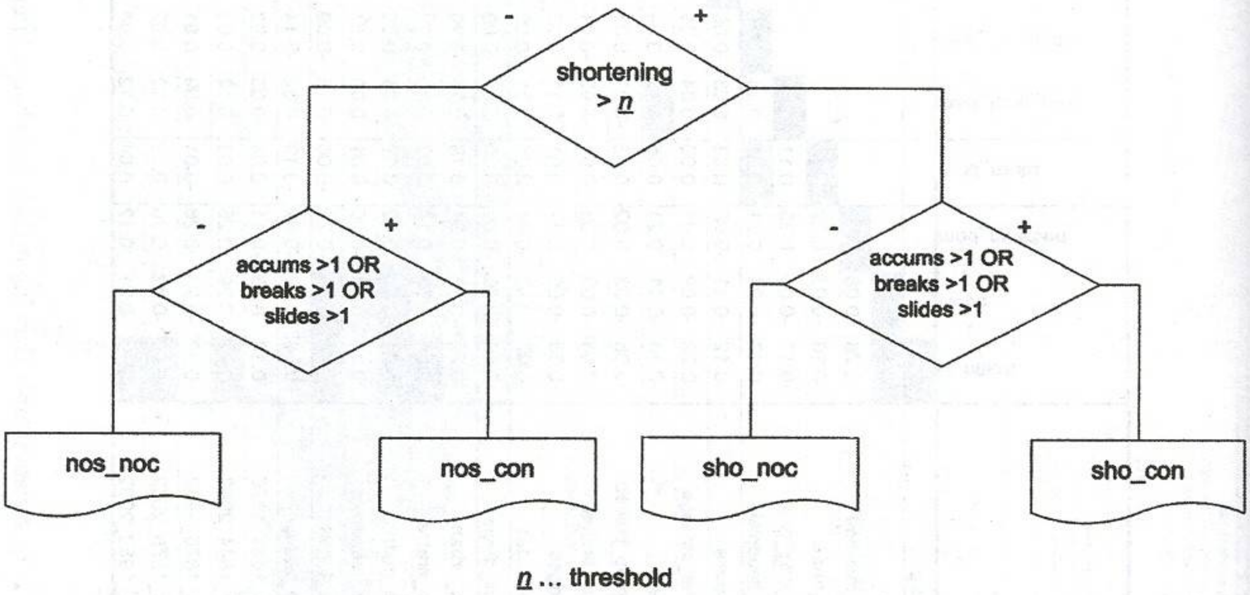

Fig. 3 Decisive rules for classification of watercourse shortening and flood consequences

accumulative processes. Therefore, we refrained from searching for relations between the flood consequences percentage rate and rectification intensity for the classification purposes. It is evident that fluvial accumulations or bank cavings are caused also by other factors, mainly by local morphology, river-bed characteristics, and geographical location and we should also account for mapping differences in specific river basin areas. With respect to classification, what matters is the occurrence of at least one of the above-mentioned flood consequences (accumulation, bank caving, landslide, river facilities destruction) and not the number of such cases.

The classification results showed that relations between watercourse shortening intensity and flood consequences depended on the threshold value of river network shortening used as an input criterion. The most numerous occurrences of flood consequences in modified segments were detected at the minimum shortening level.

Limiting the selection by the level of 2% segment shortening over the whole assessed period (the last 160 years) resulted in 94% of segment that are affected by fresh erosive or accumulative processes. However, 2% shortening was detected in the vast majority of river segments within the Otava river basin, including mountainous areas in natural or protected areas where this level of shortening is more the result of inaccuracies gained from historical map analysis.

Shifting the threshold up to 5% shortening of the segment compared to the original length the number of segments affected by flood effects dropped to 66%.

Shifting the threshold further to 10% which covered segments shortened by more than the overall average of the Otava river basin – 9.1% shortening, the percentage of segments affected by flood activities dropped to 20%.

Tab. 1 Watercourse segments ranked by shortening intensity and flood consequences

	Shortening > 2%	**Shortening > 5%**	**Shortening > 10%**
Shortening → consequences	42.9%	30.1%	9.4%
Shortening → no consequences	52.7%	32.8%	14.8%
No shortening → consequences	2.8%	15.6%	36.3%
No shortening → no consequences	1.7%	21.5%	39.6%
Share of shortened segments	95.6%	62.9%	24.1%
Share of segments with flood consequences	45.7%	45.7%	45.7%
Share of the shortened segments on the segments with consequences	94.0%	65.9%	20.5%
Share of the consequences in shortened segments	44.9%	47.8%	38.9%

3.2.2 Riverbed Transformation and Flood Consequences

Relations between riverbed and floodplain transformation and flood consequences differ in individual assessed parameters of modification and in various geographical conditions. Important factor is here also the intensity of anthropogenic transformation of the river system. Relations are closer on partially modified watercourses on intensively or completely modified watercourses the relations are weaker.

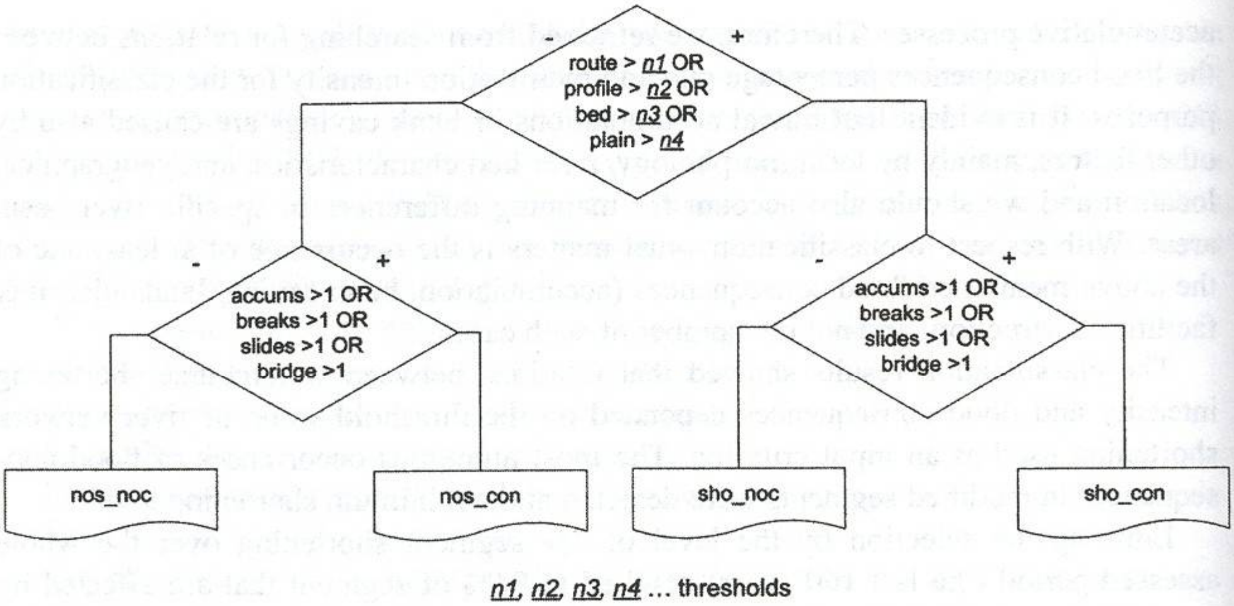

Fig. 4 Decisive rules applicable to classification of watercourse modification and flood consequences

The classification was performed according to set of decisive rules and respective thresholds. The thresholds of transformation intensity can be set independently for individual parameters in decisive rules (see Fig. 4), for the presented analysis were applied uniformly for the whole set of parameters. The selected threshold was based on occurrence of at least one of following forms proving geomorphologic evidence of flood: fresh fluvial accumulation, bank cavings, land slides, damaged bridge or structure.

For classification purposes it was necessary to transfer the mapping results into a continuous numerical scale. It is necessary to note the difficult comparability of individual parameters and to realize that attributed values couldn't be mechanically assessed as identical manifestations of anthropogenic modification per given aspect of the watercourse. The easiest parameters to quantify were the intensity of anthropogenic modifications of the longitudinal profile and the river-bed. With respect to steps in the river-bed, we applied the same scale as in mapping and classified steps in terms of their height.

The *river-bed modifications* were classified as follows: 1 – natural, 2 – partially modified, 3 – entirely modified, 4 – pipelined. Segments draining artificial water works or natural lakes were marked by 0. Classification of the floodplain modification and river-bed routing was more difficult. *The floodplain modification* intensity was classified as follows: 1 – natural areas, 2 – agricultural areas, 3 – scarce settlement and 4 – intensive settlement. With respect to *stream routing*, 1 indicated braided and branched segments, 2 marked meandering segments, 3 was attributed to sinuous segments, and 4 to straight segments. In this parameter the classification categories does not directly reflects the intensity of anthropogenic interventions. The resulting type of stream routing might be of different origin – e.g. sinuous routes could result from anthropogenic modifications as well as from natural development.

Among individual assessed parameters, there were significant differences in the overall stream modification intensity which were reflected also in the statistical assessment (see Tab. 2). In terms of stream route and flood plains modifications, the vast majority of water courses showed deviations from a natural state. With respect to river-bed modifications, only 50% of segments were partially modified, while only 25% of segments showed modifications in the longitudinal profile. The number of highly modified segments in terms of such parameters was significantly lower.

Tab. 2 Classification of watercourse modifications and flood consequences

	Stream routing >1	**Longitud. profile >1**	**Riverbed modif. >1**	**Floodpl. modif. >1**	**Overall modif. >1**	**Overall modif. >2**
Modification → consequences	37.5%	10.0%	21.7%	26.2%	40.5%	36.9%
Modification → no consequences	41.9%	10.7%	24.0%	29.4%	48.1%	44.4%
No modification → consequences	6.5%	34.0%	22.3%	17.9%	3.5%	7.1%
No modification → no consequences	14.1%	45.2%	32.0%	26.5%	7.8%	11.6%
Share of modified segments	79.4%	20.7%	45.7%	55.6%	88.7%	81.3%
Share of segments with flood consequences	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%
Share of the modified segments on the segments with consequences	85.2%	22.7%	49.3%	59.5%	92.1%	83.8%
Share of the consequences in modified segments	47.3%	48.3%	47.5%	47.1%	45.7%	45.4%

The overall anthropogenic modification classification reflects river-bed modifications in at least one of the assessed parameters, limited by the threshold value. Deviations from natural river-bed characteristics in terms of at least one of assessed parameters were found in 88% of segments. Almost 50% of these segments were affected by flood consequences – fluvial accumulations, bank cavings, damaged bridges etc. Increasing modifications intensity, their percentage didn't change significantly (45% under intensity rate 3 and higher according to any parameter).

With respect to relations between watercourse modifications and flood consequences, it was of a vital significance to find that over 92% of identified flood consequences were located in segments partially modified by anthropogenic activities according to at least one parameter.

The analysis of parameters indicated the strongest relation in the case of floodplain and stream route modifications.

With respect to the stream route parameter, over 85% of identified flood consequences were located in straight or meandering segments. Regarding the floodplain modifications, almost 60% of detected flood consequences were located in segments affected by agriculture or settlement. Relations between intensity of river-bed modifications and the percentage rate of segments marked by flood consequences dropped inversely to modifications intensity. While segments affected by partial or moderate modifications (level 2 and higher) comprised 49% of segments with flood consequences, in case of entirely modified or pipelined segments (level 3 and higher) it was only 11%.

With respect to all assessed parameters as well as to the overall assessment, segments affected by flood consequences in all modified parts reached 45%. More than half of all modified segments thus remained free of any flood consequences.

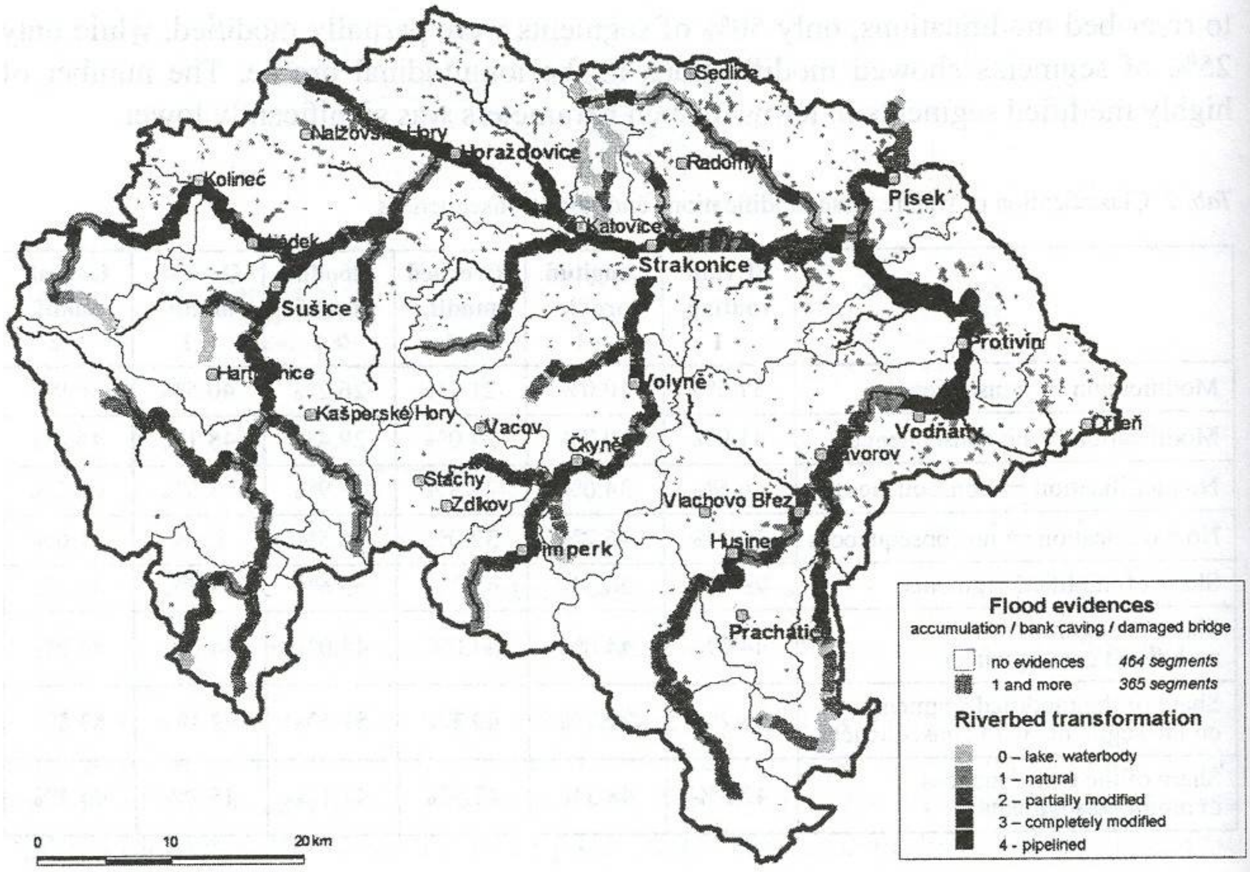

Fig. 5 River-bed modifications and flood consequences

Classification proved flood consequences occurrence to be closely linked to watercourse and floodplain modifications. Almost 90% of consequences were found in segments marked by moderate or high modification intensity in at least one of assessed parameters. Although consequences and their characteristics are highly influenced by spatial aspects, this finding represents a strong argument in favour of enhancing flood control through watercourse revitalisation.

3.2.3 Impact of Steps and Weirs on Flood Consequences

Assessment results proved the importance of presence of structures in river bed with regard to the flood consequences. Special importance has here the consecutive occurrence of steps in subsequent segments. Evaluating the impact of steps on occurrence of fluvial accumulations and bank cavings in the framework of one river segment we detected such occurrence at 8% of the total number of segments in the whole river basin. If we extend the detection area also on the preceding river segment the rate of segments with respective flood consequences will increase to 13%.

The flood consequences related to the weirs are well differeciated according the character of prevailing geomorphological process while the accumulative processes are dominant (see Fig. 6). The most frequent effects are fluvial accumulations (58%) followed by bank cavings (23.5%). Simultaneous occurrence of both accumulations and bank cavings is recorded in 18% of segments affected by presence of steps or weirs.

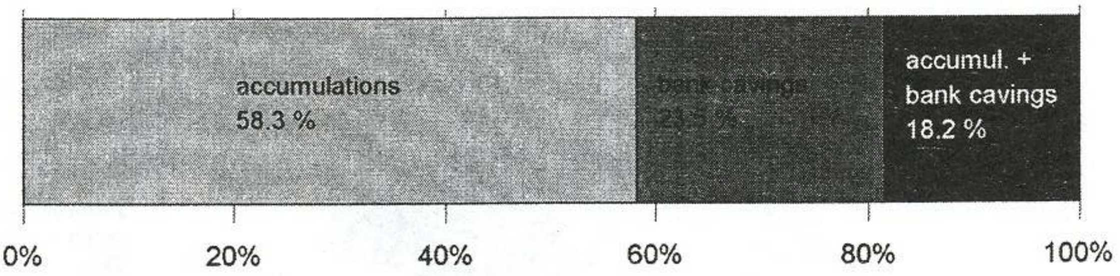

Fig. 6 Structure of flood consequences related to the occurrence of steps and weirs

Among the segments with weirs or steps the share of segments affected by erosive or accumulative flood consequences activities represent 54% of the total number. Here the share resulting from the assessment of individual segments – 53% doesn't differ significantly from assessment results in two consecutive segments 54%.

3.2.4 Obstacles in Floodplain and Flood Consequences

For the occurrence of flood consequences and mainly for the total cost of the flood damages is crucial presence of obstacles impeding water flow in the flood plain. Structures and objects located in the flood plains, located in normal conditions outside the inundation zone, turn during extreme flood events into flow obstacles. Inadequately designed bridges, weirs, and improperly located objects in flood plains in combination with material carried by the flood cause temporary blockages, which after their break trigger the flash flooding. Such processes accelerate accumulative and erosive processes. Destroyed structures become sources of material carried by the flood wave and cause problems further down the stream.

For the geoinformatic assessment of this phenomenon, we used the results of geomorphologic mapping that indicated the following structures as potential flow obstacles in river-beds and flood plains:

- Steps in river-beds
- Weirs
- Bridges
- Improperly located objects

The rule-based classification was based on segmentation according the presence and also the nature of flood consequences. As in the case of analysis of impact of longitudinal profile modifications, there was proceeded classification in the framework of the same river segments plus the classification detecting the possible obstacles in preceding and current segment.

Evaluating all potential flood course obstacles we find that the percentage of segments affected by the flood consequences reach 17% of total river segments. Segments affected by erosive or accumulative flood activities accounted for 51.5% of segments with potential flow obstacles.

With respect to all potential flow obstacles in river-beds and flood plains – steps and weirs, bridges and improperly located structures, the share of segments affected by detected consequences to the overall number of segments with obstacles was almost the same, although the absolute frequency of individual barrier types was very different. It's clear that many potential flow obstacles didn't have any direct impact. To the contrary, quite a number of flood consequences were caused by other factors.

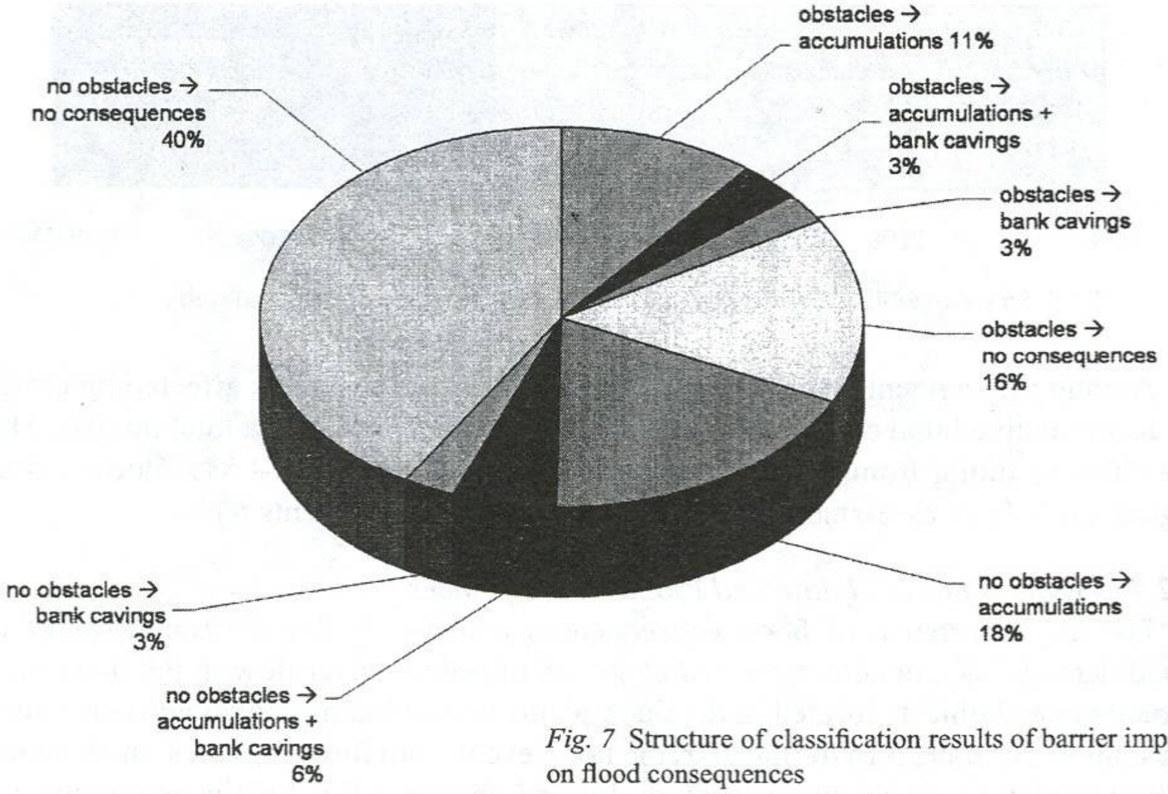

Fig. 7 Structure of classification results of barrier impact on flood consequences

Tab. 3 Overview of classification results of flood obstacles impact on flood consequences

	Weir	**Bridge**	**Improperly placed object**	**Any obstacle (weir/bridge/ imp. object)**
Obstacle → accumulation	8.1%	7.1%	1.1%	10.6%
Obstacle → bank caving	3.3%	1.6%	0.2%	2.5%
Obstacle → bank caving and accumulation	2.5%	2.2%	0.4%	3.4%
Obstacle → no consequences	11.8%	10.5%	1.3%	15.7%
No obstacle → accumulation	20.6%	21.6%	27.6%	18.1%
No obstacle → bank caving	5.7%	3.6%	4.9%	2.7%
No obstacle → bank caving and accumulation	2.7%	6.8%	8.6%	5.5%
No obstacle → no consequences	45.4%	46.7%	55.9%	41.5%
Share of segments with obstacle	25.7%	21.4%	3.0%	32.2%
Share of segments with flood consequences	42.8%	42.8%	42.8%	42.8%
Share of the modified segments on the segments with consequences	32.4%	25.4%	3.9%	38.6%
Share of the consequences in modified segments	54.0%	50.8%	56.0%	51.3%

3.3 Flood Risk Zoning

To cover all complex relations between flood consequences and potential driving factors, it's vital to take into account anthropogenic modifications as well as other factors, particularly land use changes, physicogeographic properties and geographical location.

For such a task there was applied cluster analysis allowing classifying the individual watercourses into groups with specific character of anthropogenic modification intensity, landscape features, and geography and flood consequences. As an input matrix were used the information layers stored in the project geodatabase together with results of above mentioned geostatistical and geoinformatic analysis. The results of clustering were reciprocally integrated with GIS geodatabase as new information layer.

To generate the input matrix, there was performed a spatial analysis in the geodatabase. For individual elementary watercourse segments, based on the mapping structure of the river network anthropogenic modifications, were extracted from individual analytical layers using the overlay in the stream segment buffer zone. The following parameters were selected:

- Segment mean height
- Mean slope
- River-bed modification
- Stream routing
- Segment modification in the longitudinal profile
- Flood plains modification
- Number of weirs
- Number of bridges
- Number of improperly located structures
- Number of rocky steps in the river-bed
- Percentage of urbanized areas
- Percentage of arable land
- Percentage of all agricultural land
- Percentage of meadows
- Percentage of forests and water areas
- River network shortening in time periods 1844–1876–1952–2002
- Number of identified accumulations after the 2002 flood
- Number of bank cavings
- Number of destroyed bridges and landslides.

Watercourses were classified into five categories. The classification was performed off the GIS environment using the K-means algorithm. The classification results were integrated back to the source geodatabase for further analysis and visualization.

Cluster analysis resulted in 5 categories that proved close relations of physiogeographical features of assessed segments to their anthropogenic transformation rate and observed consequences of the 2002 extreme floods.

Tab. 4 Resulting clusters as the flood risk zones

Class	Cluster ID	Total length
Lowland streams	2	36.4%
Hilly streams	5	28.3%
Submontane streams	3	14.4%
Mountainous streams	1	13.6%
Headwater streams	4	7.3%

Classification results were highly influenced by watercourse segment slope, average elevation above the sea level, and parameters of artificial modification determining the character of flood consequences.

Lowland streams are represented by the largest extent. They were marked by the highest average river-bed modifications, transformation in the longitudinal profile, and flood plains modifications. The flood progress in such areas was negatively affected by many improperly located structures and the highest number of weirs and bridges. In terms of observed 2002 flood evidences, these areas were marked by the highest average number of bank cavings, the second highest average amount of flood accumulations, and many damaged bridges.

The highest average number of recent fluvial accumulations was found in hilly streams comprising river segments in hilly areas located prior the lowland streams. Here was found the highest number of improperly located structures in watercourses and flood plains impeding flood progress.

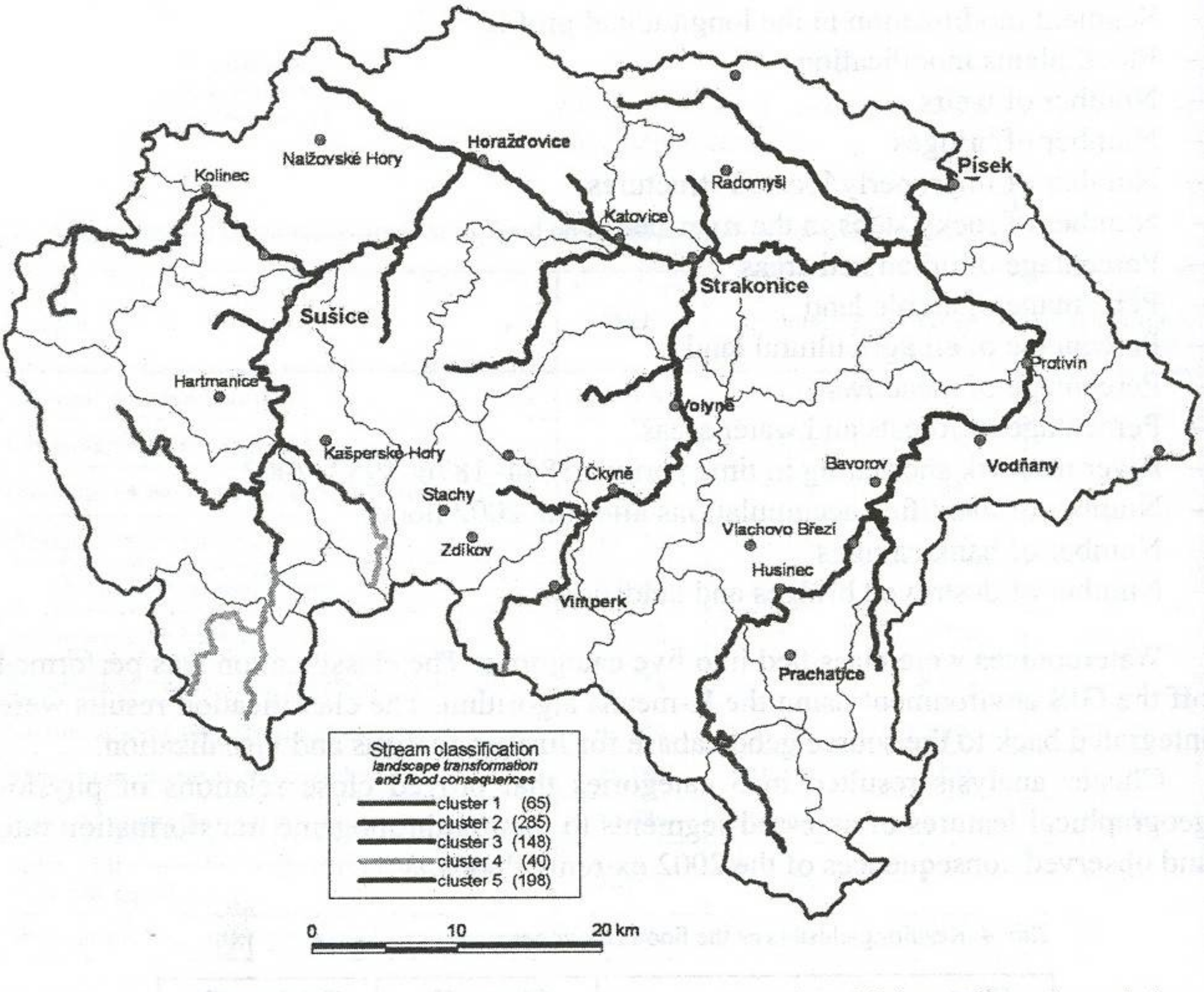

Fig. 8 Zoning of watercourses in Otava river basin according the intensity of their transformation and observed consequences of the flood in August 2002

The *submontane streams* are representing watercourses running from steep hills of the Šumava mountains. Their river-beds were seriously damaged and newly shaped by the flood wave in August 2002. Streams in this cluster show the highest percentage of meadows in flood plains, the second highest number of bank cavings, and the largest percentage of destroyed or damaged bridges. The rate of long-term river network modifications in such segments could be described as average. Watercourse shortening in this region was done mostly at the beginning of the 20th century.

Mountainous streams. The watercourses in peak areas of Šumava mountains are typical by high average slope values. However, anthropogenically modified areas here represent only marginal part of flood plains. This category showed the lowest average river-bed modifications, modifications in the longitudinal profile, and watercourse routing. This was the core zone of the precipitation causing the flood and therefore the flood consequences, both erosive and accumulative, were extensive.

Headwater streams shows only negligible share of the overall flood damages due to low intensity of settlement and infrastructure. Anthropogenic modification of streams here is the lowest and average forest cover percentage was close to 90%. However, watercourse shortening in headstream regions was already since the end of the 19th century quite significant because of intensive forestry management techniques. As the flood waves are formed in this area, watercourses are affected only by erosive flood evidences.

4. Discussion

The classification of the impact of watercourse shortening, river-bed and flood plains anthropogenic modification and flow obstacles on observed flood consequences proves surprisingly weaker relations in the areas of high intensity of anthropogenic modification of river-beds and flood plains. This applies mainly to the downstream areas of the Blanice and Otava, the two main watercourses of the river basin. Here is recorded maximum intensity of watercourse, riverbed and flood plains modifications, but relations between the state of anthropogenic transformation and flood consequences aren't clearly proved.

This may be caused by unprecedented extremity of the flood in August 2002. In downstream areas, the flood wave filled the whole area of the flood plains with water levels exceeding by several meters the level of floodplain. Therefore the impact of anthropogenic modifications of watercourses was weakened. To the contrary, in upstream and midstream areas, where flood wave waters mostly did not leaved the river-beds or spilt into a narrow floodplain area, the impact of anthropogenic interventions on flood consequences increased.

5. Conclusions

The methodology of watercourse modifications and flood consequences field mapping, as presented and applied, proved to be useful for a comprehensive analysis of extreme rainfall-runoff processes and their landscape manifestations. The approach allows for a general application of this method also in areas with different physicogeographical conditions and different level of socioeconomic pressure on landscape. Integration of mapping results and analysis of historical and remote data in the GIS environment permits to use such information for the analysis and objective geostatistical classification of area flood vulnerability, flood consequences assessment, and analysis of potential driving factors of flooding.

The geoinformatical analysis of relations between watercourse modifications and the 2002 flood consequences, drawing on a new field mapping methodology in combination with historical and remote data, showed links between physiogeographic watercourse characteristics, their artificial modification rate and observed flood consequences. Classification based on a cluster analysis proved that different flood manifestations in different parts of the river basin depend on the respective features of landscape and mainly on intensity and character of river-bed and flood plain artificial modifications.

The resulting typology can be used as a information material for designing suitable flood prevention and control measures with respect to the watercourse natural diversity and needs of differentiated approach and management tools for efficient flood prevention in individual stream categories.

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GEOINFORMATICKÉ HODNOCENÍ NÁSLEDKŮ POVODNĚ V SRPNU 2002 V POVODÍ OTAVY

Résumé

Významnou součástí projektu hodnocení vlivu změn v krajině na průběh a následky povodní je vyhodnocení následků povodně a upravenosti toků pomocí metod geoinformatické analýzy. Geostatistická analýza v prostředí GIS umožnila integrovat a následně analyzovat data různého původu a různé geografické a geometrické povahy a výsledky využít pro interpretaci procesů, probíhajících v krajině.

Jednotlivé analytické složky byly integrovány do prostředí GIS, což umožnilo provedení syntetické typologie toků pomocí nástrojů geostatistické analýzy, jejímž výsledkem je rozčlenění toků a jejich úseků do skupin s příbuznými fyzickogeografickými vlastnostmi, charakterem antropogenní transformace a obdobným charakterem následků při povodni.

V rámci realizovaného projektu se konkrétně jednalo o integraci výsledků analýzy mapování upravenosti říční sítě a příbřežní zóny, mapování následků povodně, analýz historického zkrácení říční sítě, analýzy využití území údolní nivy a analýzy fyzickogeografických parametrů povodí. Cílem klasifikace bylo ověřit přítomnost a charakter vzájemných vazeb a zjistit, do jaké míry lze nalézt statistické a prostorové souvislosti mezi konstatovanými následky povodně a stavem krajiny, zachyceným pomocí vybraných indikátorů antropogenní transformace.

Pro řešení byla použita množina vstupních podkladů, vycházejících z odlišných zdrojů – terénního mapování, analýzy historických map, dat DPZ a digitálních vektorových vrstev GIS.

Pro hodnocení byly využity dvě hlavní geostatistické techniky – klasifikace na základě rozhodovacích pravidel a shluková analýza.

Pomocí klasifikace podle rozhodovacích pravidel byly identifikovány statistické a prostorové vazby mezi intenzitou a charakterem následků povodní, zjištěných pomocí terénního mapování a indikátory změn krajiny, zjištěnými na základě analýzy historických podkladů, digitálních dat a terénního průzkumu. Zjišťovány byly vazby mezi potenciálními příčinami zvýšené intenzity následků povodně – zkrácením říční sítě, antropogenní upraveností koryta toku a údolní nivy a přítomností překážek proudění v korytě a údolní nivě. Shluková analýza byla použita pro komplexní typologii toků podle vybrané matice indikátorů – intenzity a charakteru následků povodně, fyzickogeografických charakteristik území a indikátorů upravenosti krajiny a říční sítě.

Výsledky ukázaly na rozdílný vliv jednotlivých indikátorů upravenosti krajiny na následky povodně. Jednoznačně se projevil vliv mimořádné extremity povodně v srpnu 2002, díky které byl do značné míry setřen účinek zkrácení říční sítě či upravenosti koryta toku. Naproti tomu dobře se ukazuje souvislost mezi upraveností údolní nivy a zejména přítomností překážek proudění s konstatovanými následky povodně.

Klasifikace na základě shlukové analýzy prokázala, že v různých částech povodí zaznamenáváme odlišné projevy povodně, že tyto odlišné následky mají vazbu na geografickou polohu, nadmořskou výšku, intenzitu a charakter antropogenní upravenosti koryt toků a údolní nivy.

Provedená typologie může být využita jako podklad pro plánování vhodných preventivních opatření protipovodňové ochrany, neboť tato opatření musí respektovat přirozenou diverzitu toků. Jednotlivé typové kategorie toků vyžadují odlišný přístup k protipovodňové ochraně, umožňují její lepší diverzifikaci, což přispívá k její vyšší efektivitě, stejně jako k ekonomické účelnosti.

Author's full address:
JAKUB LANGHAMMER
Charles University in Prague, Faculty of Science
Department of Physical Geography and Geoecology
Albertov 6, 128 43 Prague 2, Czech Republic
langhamr@natur.cuni.cz