COMPARISON OF TWO FLOOD RISK ASSESSMENT METHODS IN THE CASE OF THE TURIEC RIVER, SLOVAKIA

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ABSTRACT

Floods are the most common natural process causing damage to property and loss of life in our geographical area. Efforts to reduce the risk of flooding require methods for assessing the flood risk. Application and comparison of these methods in the same area allows us to describe the differences which could not be discovered only by studying the procedure of these methods. Two methods of flood risk assessment and their outputs were compared in one part of the Turiec River in Slovakia. Results of these methods are different flood risk maps while the key difference is the definition of risk. Risk is defined on the entire surface of the modelled scenarios in the case of the risk map based on Method I. In Method II, flood risk represents an area with unacceptable risk which means the risk where the threshold value has been exceeded. The two methods obtained similar results regarding areas subject to the greatest risk of flood damage. However, Method II appears to be more effective. It uses flood depth and flood velocity information and includes creation of a Flood danger map – a suitable tool for urban planning. The method focuses only on the localities where it is urgent to reduce the flood risk.

Keywords: Flood risk assessment, Flood hazard map, Flood risk map, HEC-RAS, Turiec

1. Introduction

The recent floods in Europe, especially on the Odra and Morava (1997), Elbe (2002), Rhone (2003), Danube (2006) and in the UK (2000) brought the need for a common strategy for flood risk management at European level (Pender et al. 2011). The answer was the European Directive on the assessment and management of flood risks (Directive 2007/60/EC) with the unofficial name – Flood Directive, which was reflected in the laws and regulations at national level and is currently being implemented in EU member states, not excluding the Czech and Slovak Republic. The first phase of the Flood Directive ended in 2011 and was aimed at creating Preliminary Flood Risk Assessment. The second phase was done in the end of the year 2013 and brought requirement for the creation of flood hazard and flood risk maps and finally the third phase is aimed at producing Flood Management Plans with the end of 2015 deadline (Directive 2007/60/EC). Consequently, there was a need for new methodologies for creating flood hazard and risk maps and Method II used in our evaluation is the result of this process in the Czech Republic (ENV 2009). It was confronted with an older method by Gilard and Givone (1997) which was applied to the study area by Ruman (2011).

There are a considerable number of similar and different methods for flood risk assessment, created by the demands of different groups of interest (insurance companies, governments ...), an overview is provided by Říha (2005) in his work. There is also notable amount of literature focused on the comparison of different approaches to this problem, such as the Barets's work (Barets et al. 2013), the parametric approach and an approach based on the output from the hydraulic models in one area were compared; and the Moel's work (Moel et al. 2007) where the author evaluated the degree of development in flood risk assessment of the EU member states. Comparison of methods creates an image of different approaches to the flooding issue and eases the selection of an adequate methodology for solving a given problem in a specific region.

2. Methodology of evaluation

For comparison purposes, two methods of flood risk assessment have been chosen and are described below. Steps of evaluation have been as follows:

- Creation of flood extents, flood depths and flood velocity maps
- Explanation and comparison of procedures and techniques of both methods leading to creation of Flood Risk maps
- Access of input data
- Confrontation of created Flood Risk Maps
- Comparison of area of risk within the highest risk categories

Creation of flood extent, flood depth and flood velocities maps were done by one dimensional hydraulic modelling (HEC-RAS) of all simulated scenarios.

Because it was intended to evaluate both methods, several input data were set up equal. Firstly, there were

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simulated scenarios of return period. The original return periods in Method I were as follows: T_1, T_2, T_5, T_{10}, T_{50} and T_{100} (where T is the return period), while in Method II they were: T_5, T_{20}, T_{50}, T_{100} and T_{500}. The flows of all return periods are displayed in Table 1. One of the goals of this work has been to create risk map based on Flood Directive. However, at the time of creation there was no Slovak methodology implementing Flood Directive in the context of the Slovak Republic and we have only adopted return periods defined in the Slovak legacy (SR, 2010) – T_5, T_{20}, T_{50}, T_{100} and T_{1000}. Secondly, there were categories of land use which were applied from Method II.

The land use category Water was delineated too. However, there was no assessment of risk connected with water areas, because both methods evaluate risk on water equal to zero. Computation of the whole equation was ongoing in ArcGIS interface and an inundation created by T_{1000} was marked as residual due to low probability of occurrence of such a big event.

3. Study area

The river Turiec is 77.4 km long, situated in northern Slovakia. Flow regime is rain-snow (Šimo and Zaťko in Atlas Krajiny SR, 2002) and mean annual flow at gauging station Martin – Turiec (river stationing 6.55 km) is 10.9 m^3/s. Part of the river – 13.15 km long segment – was chosen for comparison purposes. The segment begins at Turiec mouth on the river Vah and ends just after the village called Košťany nad Turcom. In the study area, the river flows through the towns Martin and Vrutky and through the village Košťany nad Turcom (Figure 1). The river channel characteristics are clearly urban at this point. From the outlet up to the river station 1.0 km the sides of the channel are covered by concrete and the river bottom is covered by stones. Afterwards, the river straightens out and the banks are covered by grass, the bottom by stones, the channel is trapezoidal in shape. Levees were built at several places sometimes 3 m high above the ground. There are 14 big bridges and two small dams designed for T_{50} flows and other small structures. In the landscape, mainly in meanders, the sides are beaded by stones, covered by grass or roots of trees.

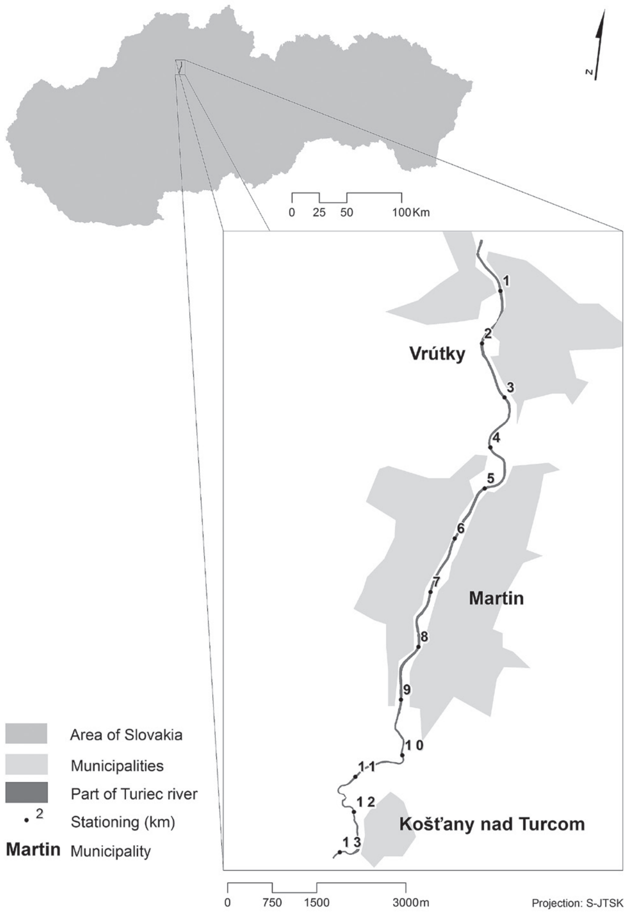

Fig. 1 Map of study area.

4. Creation of flood risk map based on Method I

Method I is based on the work of Gillard and Givone (1997), later developed by Trizna (1998), Pfefferova (2010) and applied to Turiec river study area (Ruman 2011). The method is quantitative and flood risk is shown using a scale. Detailed methodology is explained in the mentioned works and the sequence of main steps is as follows:

- Creation of land use map
- Creation of price map
- Vulnerability assessment
- Flood risk identification

Ten original land use categories have been delineated in this method, namely, Housing, Public Facilities, Manufacture and Fabrication, Transport, Sport and Recreation, Meadows, Broadleaf Forest and Arable Land. However, these have not been used in the comparison. Land use categories were adopted from Method II and are displayed in Table 1.

Price map has been based on prices of land in urban areas from the year 2011 (Špirk, 2011) and due to absence of up-to-date data the land prices in countryside have been taken from the year 1998 (HP, 2011).

It is necessary to define the vulnerability, i.e. the predisposition of the area to damages caused by low resistance against the flood. The vulnerability assessment has been based on the relation: $V = W \times P$, where V is vulnerability, W is weight and P is price of land. The weights have been assigned to all land use categories (Table 1) in order to highlight the vulnerability. The higher the weight, the higher the importance of the category. To eliminate the subjectivity during this process we have used the Saaty

Tab. 1 Land Use categories used in both methods, Weight Assigned (Method I) and Acceptable Risk (Method II).

Method I and Method II		Method I	Method II
Type of land use	% of area	Weight assigned	Acceptable Risk
Housing (HO)	27.72	0.22	Low
Manufacture and Fabrication (MF)	15.90	0.11	Low
Public Facilities (PF)	5.96	0.11	Low
Transport (including stations) (TS)	2.52	0.06	Low
Sport and Recreation (SR)	1.09	0.03	Medium
Green	36.10	0.01	High
Water	9.98	x	x

(1977) method. The result of this step has been the map of vulnerability.

Risk in the study area was obtained by the combination of vulnerability (V), threat (T) and area (A), thus: $R = V \times T \times A$. The threat is defined as an average annual frequency in percentage (Table 2) of particular scenario and the Threat map is the map of the scenario extent. The area A is expressed in m^2 and represents the area obtained by the intersection of the Threat map and the Vulnerability map in ArcGIS interface.

Afterwards, 7 categories of risk were created marked from II to VIII, while the criterion for intervals was to achieve similar number of risk values in all intervals. The original method contains 7 risk categories, but we have added another one labelled I. Category I covers the inundation caused by T_{1000} and is referred to as the residual risk. The risk is gradually increasing through the category II up to the category VIII (meaning the highest risk).

5. Creation of flood risk map based on Method II

Method II has its origins in the Swiss methodology (FOWM, 1997), adjusted for the context of the Czech Republic (ENV, 2009). It is a semi quantitative method which does not need to conduct a quantitative evaluation of damages caused by an inundation and where the flood risk is expressed by scaling. However, this method is based on a risk matrix in combination with principles based on expressing the maximum acceptable risk.

The steps of this method are as follows:

- Quantification of flood hazard – calculation of flood intensity
- Assessment of flood danger by risk matrix
- Vulnerability determination based on land use
- Designation of areas with an acceptable risk

Flood hazard can be defined as a threat of flood which causes loss on life and damage to property or landscape. The quantification of flood hazard has been achieved by calculation of flood intensity (FI). FI is the parameter which expresses the flood hazard and it is the function of flood depth d [m] and flood velocity *v* [m/s] (FOWM 1997; Dráb, Říha 2010).

Flood danger is the combination of the probability of the flood occurrence and the flood hazard. The main difference between the danger and the risk is, the danger is not related to the land use. Partial flood danger Di was calculated for i-modeled scenario equal likelihood discharge with return period Ti and with likelihood of probability pi. Procedure has to be repeated for all modelled scenarios and finally the overall danger is computed. Values of danger are divided into four categories and the Flood danger map is created.

Vulnerability, similarly as in Method I, is defined as the predisposition of the area to the damages caused by low resistance against the flood. In Method II 8 vulnerability categories are defined, namely, Housing, Mixed Areas, Public Facilities, Technical Infrastructure, Manufacture and Fabrication, Transport, Sport and Recreation and Green. Categories found in the study area are displayed in Table 1. Furthermore, the so called Sensitive objects are defined in Method II. These are the objects with particular importance, such as hospitals, police stations, schools, etc. (altogether 7 categories). However these objects were not used during our assessment, therefore they are not displayed in the final map.

The risk is the synthesis of the effect of flood danger, vulnerability and exposure. Exposure is a state when the objects in the inundation area are exposed to the flood hazard. Furthermore, Method II uses a term "acceptable risk", with an aim to delineate areas where flood measurements should by done first, e.g. to delineate areas where

Tab. 2 Selected characteristics of modelled scenarios.

Modelled scenario	T_5	T_{10}	T_{50}	T_{100}	T_{1000}
Flow (m^3/s)	150.00	190.00	285.00	335.00	500.000
Area of inundation (m^2)	121,510.00	872,355.40	1,283,755.00	1,458,155.00	4,651,155.000
Whittled areas of scenarios (m^2)	121,510.00	750,845.40	411,400.00	174,400.00	3,193,000.000
% of all area	2.61	16.14	8.85	3.75	68.650
Probability	0.50	0.10	0.02	0.01	0.001
Average annual Frequency in %	50.00	10.00	2.00	1.00	0.100

the risk is unacceptable. In our case this term refers to land use categories which are accepted to be flooded (Table 1). Unacceptable risk has two categories, middle and high. For more detailed information about procedures in Arc GIS see work of Dráb (2006).

6. Results

6.1 Evaluation of both methods

Method I utilizes the probability and is quantitative while Method II uses an average annual frequency in percentage and is semi-quantitative. Originally they are using different land use categories and different return periods, however, for comparison purposes the land use categories were used from Method II and the return periods from the Slovak legacy.

In Method I, the flood hazard is defined as the flood scenario with annual average frequency in percentage, in the latter it is the function of flood intensity.

Both methods are able to assess flood risk in the study area and there is a possibility to propose flood defences. Nevertheless, there is still a demand for further research to investigate cost-benefits of these defence structures. However, proposals are easily made when using Method II, because only the localities with unacceptable risk are displayed.

Method I is a little bit more data demanding due to the requirement to obtain land price information. However, procedures in the Method I are more difficult and both methods require GIS software for processing.

There are also disadvantages in both methods; mainly broad definition of land use category (category Green) which includes forests, grassland as well as agricultural land. The reason can be found in preference of risk in built up areas in Method II.

There is a connection between the set up of categories with unacceptable risk and the use of price map and weights which clearly shows dominant economical and social aspects in overall assessment. Although in case of Method II there can be displayed the sensitive objects which bring further aspects into the assessment.

Advantages and disadvantages of both methods

A. Method I:

Advantages
- Value of area (m^2) at risk is included in the assessment. There is clearly a correlation between the area and the resulting value of flood risk.
- The price of land parcels forms part of the assessment.
- Original method utilizes more land use categories covering wider range (arable land, meadows etc.).

Disadvantages
- Depth and velocity of flow are important factors influencing the scale of damages. However, the method, assumes that the same risk applies to the locality with depth of 5 cm as to the one with depth of 2 m.
- The weight given to each land use category should be rather based on an expert estimation and agreement of scientists from various disciplines.
- The list of defined land use categories is not complete. In different areas can be found other categories (coniferous or mixed forest, mixed areas, etc.).
- The definition of intervals is based just on the data from the study area. Clearly we need a definition which takes into account all possible values also in other areas.
- The price of land in countryside is taken from the year 1998 which is clearly not up-to-date.
- In this condition the method is suitable only for local risk assessment when the comparison with other areas is not necessary.

B. Method II:

Advantages
- Information about flood depths and velocities is included.
- Expert estimation is made out of acceptable risk in land use categories.
- "Flood danger map" is a useful tool for urban planning.
- Unacceptable risk highlights areas where the flood control measures should be made first.
- Sensitive objects can be included into the map, bringing the information about the important objects in the study area.
- Risk assessment on national level.

Disadvantages
- Broad definition of land use category Green.

6.2 Evaluation of flood risk maps

Flood risk maps differ significantly, see Figure 2. The main difference is that either whole area affected by flood scenario lies within the explicit risk category (Method I)

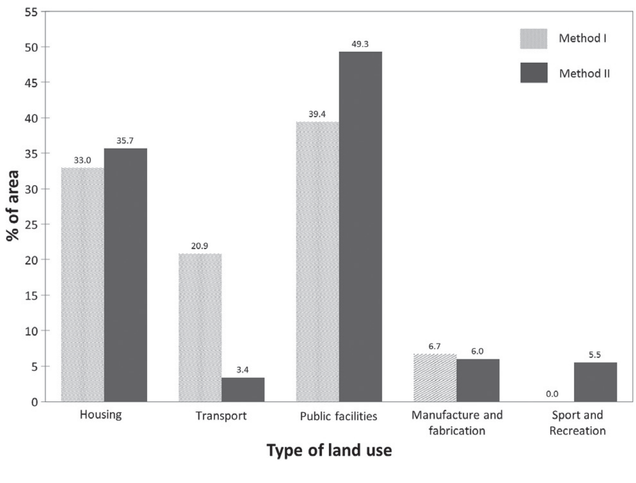

Fig. 2 Comparison of land use categories from both methods in categories "VIII" and "High" (Types of Land use are according to Table 1).

or the risk is designated at places, where the unacceptable risk was found.

A comparison of the risk areas with the highest risk (category VIII and High) of both methods shows that the area which fall into the category VIII and High, is very similar (Table 3). It is located exclusively in urban areas of debated municipalities. The area, which is identically identified by both methods covers 3.54% (164,560.97 m^2) out of the total considered area (Figure 3). This can be caused by two reasons. Firstly by ranges of risk intervals in Method I. Secondly by weighted factor assigned to categories of land use for the Method I and the definition of acceptable risk for land use categories in Method II, as shown in Diagram 1. Diagram 1 shows that the areas of land use categories in the two highest categories of risk methods are very similar. There remains the question of how important the setup of ranges in risk intervals was in case of Method I. The answer would require expanding of comparison to other territories.

Land prices considered in Method I appear to have no significant effect on the results. To some extent, this can be explained by the fact that the highest price of land can be expected in the category "Housing", while the lowest in the category "Green" (what does not always correspond to the reality). Clearly, application of the not up-to-date price in the countryside highlighted these areas too.

Tab. 3 Comparison of highest risk categories areas from both methods.

Name of method and type of category	Area (m^2)	% of all assessed area
I. (VIII)	236,471.05	5.08
II. (High)	204,834.70	4.40

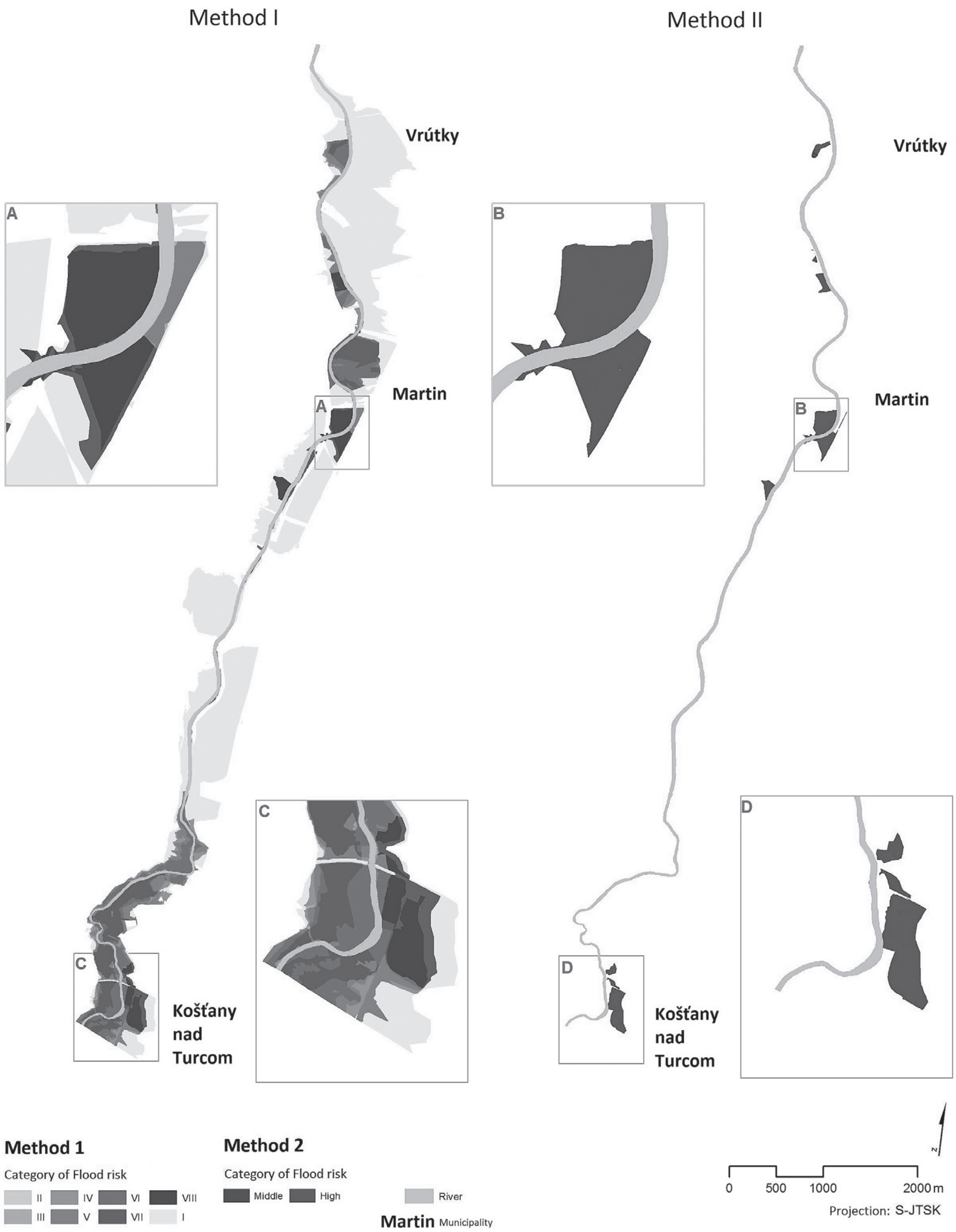

Fig. 3 Comparison of flood risk map assign by Method 1 and Method 2.

7. Discussion and conclusion

Different flood risk maps have been developed as a result of application of two methods of flood risk assessment in the 13.15 km long part of the river Turiec. The fundamental difference is the aim of the methods. While the first one pretends to assess the risk in whole flood scenarios, Method II shows only areas where the attention should be paid.

This means, the decision where to locate flood defenses or to adopt flood control measures is easily made in Method II, while in Method I it is not so clear.

Even though both methods use different procedures in the assessment process, similar results were obtained when comparing the areas in the highest risk categories, Method II is more effective than the first one. It takes into account flood depth and flood velocity maps and one of the results is Flood danger map as a base for urban planning.

Method I is a little bit more data demanding due to the requirements to obtain land price information. However, procedures in Method II require better knowledge of Arc GIS.

The resulting flood risk maps may be affected by several factors which may be divided according to the data entering the process into two groups: the factors affecting hydraulic calculations and the factors affecting risk assessment. The factors affecting hydraulic calculations are mainly associated with possible changes in the shape

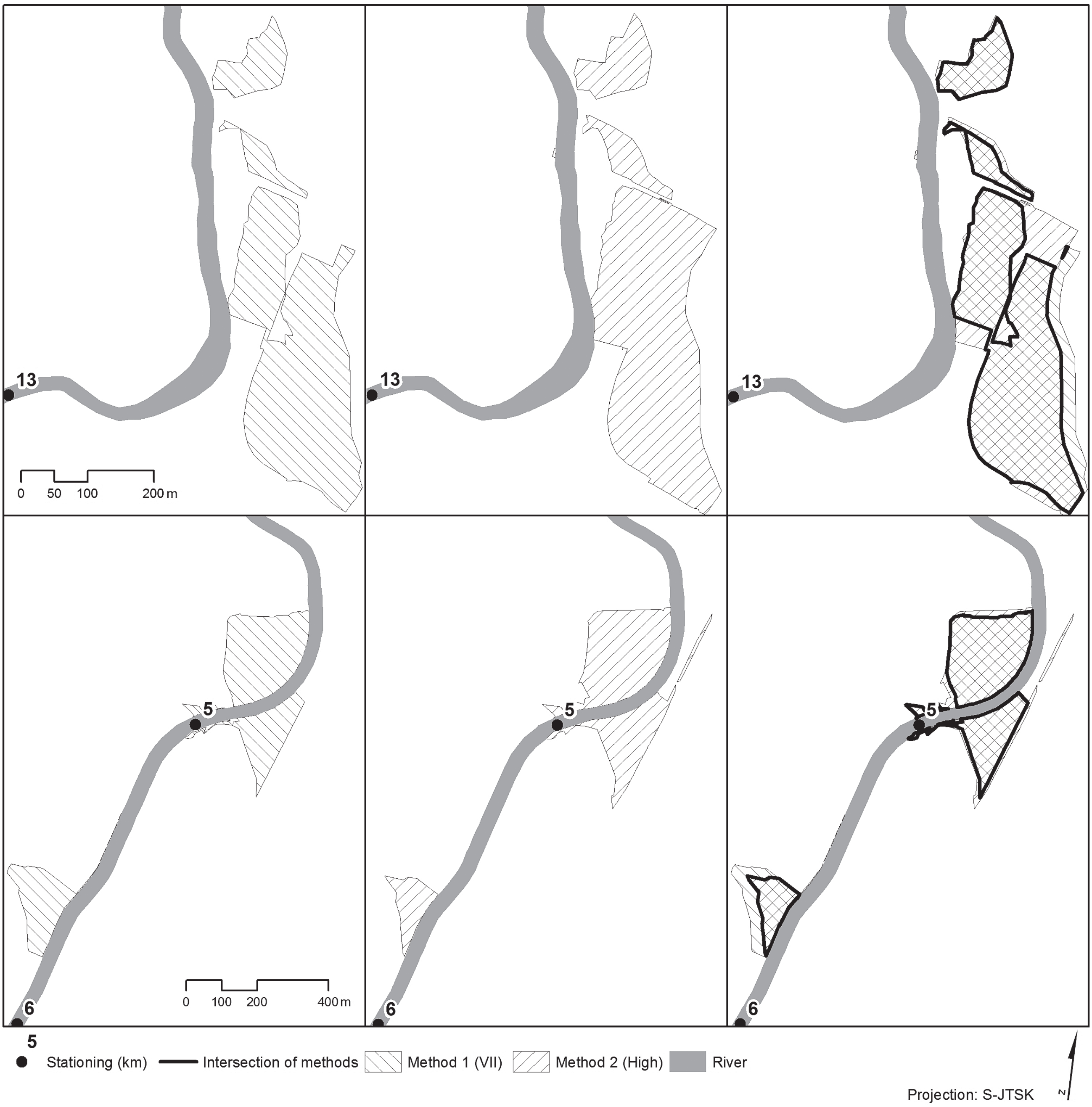

Fig. 4 Differences in areas of flood risk cathegories (VII and High) identified by both methods.

of the river channel, roughness conditions (land use), the construction of new flood defenses, the uncertainty of input data and the choice of hydraulic model (Horits and Bates 2002). In particular, uncertainty in DEM significantly distorts the extent of floodplains as well as depth and velocity (Cook and Merwade 2009; Sanders 2007). In our case, the obtained DEM had vertical accuracy of 0.8 m. Also the usage of a hydraulic model in the process of flood risk management enables us to assess the current state of the system. Nevertheless, it is clear, processes occurring in the floodplain and in the river channel itself are dynamic in nature and therefore non-stationary (Pender et al. 2011).

The latter group is formed by factors affecting data entering into the process of risk assessment itself. These are particularly the topicality of urban plans, the land use in open country and land prices. Here it is necessary to note, that when creating the risk map there were used only actual land use categories based on the current state of urban plans in municipalities. However, in case of both methods it is possible to consider possibilities for development. Risk maps are subjects of change and Method II requires repeated generation of these maps every six years (ENV, 2009).

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RESUMÉ

Porovnání dvou metodik hodnocení povodňového rizika na příkladu řeky Turiec, Slovenská republika

Směrnice Evropského parlamentu a Rady ze dne 23. října 2000 2007/60/ES o vyhodnocování a zvládání povodňových rizik (Directive 2007/60/EC) je v současnosti implementovanou strategií v oblasti povodňové problematiky v zemích Evropské unie. Strategie je rozdělena na tři hlavní fáze s přesně definovaným termínem ukončení. Fáze jedna – Předběžné vyhodnocení povodňových rizik (2011), Fáze dvě – Mapy povodňového nebezpečí a povodňových rizik (2013) a Fáze tři – Plány pro zvládání povodňových rizik (2015). Pro splnění druhé fáze bylo nutno vytvořit postup tvorby těchto map. Metodika, která je výsledkem zmiňovaného procesu v České Republice (v příspěvku s názvem: Metoda II), je v předkládaném článku konfrontována s metodikou dle Gilarda a Givone z roku 1997 (v práci s názvem: Metoda I).

Pro porovnání byl zvolen 13,15 km dlouhý úsek řeky Turiec situovaný na severním Slovensku protékající městy Martin, Vrútky a obcí Košťany nad Turcom.

Prvním krokem hodnocení bylo vytvoření map hloubek a rychlostí na zkoumaném úseku s povodňovými scénáři představujícími N-leté vody (N_5, N_{20}, N_{50}, N_{100} a N_{1000}) pomocí jednodimensionálního hydraulického modelu HEC-RAS. Následně byly porovnány postupné kroky obou metodik, výsledné mapy rizika a zhodnocena náročnost metodik na vstupní data. Posledním krokem analýzy bylo porovnání rozlohy území zařazených do kategorie s nejvyšším stupněm povodňového rizika.

Obě metodiky uvažují s pravděpodobností a jsou schopné určit povodňové riziko a na jeho základě navrhnout případné protipovodňové opatření, resp. zaměřit se na nejvíc rizikové plochy. V případě Metody II je však identifikace těchto ploch výrazně snadnější. Nicméně pro určení efektivnosti opatření by bylo potřebné vypracovat kvantitativní analýzu škod způsobených povodní.

Z hlediska sběru dat je o něco náročnější Metoda I, která vyžaduje i cenové mapy oblasti. Avšak náročností zpracování dominuje Metoda II vyžadující údaje o rychlosti proudění a hloubky vody v toku a inundaci. V obou případech bylo použito nástrojů GIS. Jako nevýhodné se jeví značně široké definování kategorie využití země „zeleň". Ta zahrnuje lesy, louky, ale i ornou půdu. Jak Metoda I používající cenové mapy, tak Metoda II aplikovaná v ČR definující přijatelné riziko pro jednotlivé kategorie využití země, poukazují na převládající ekonomické a sociální hledisko vyjádření rizika.

Výsledné mapy povodňového rizika se výrazně odlišují. Metoda I vychází z předpokladu, že celá oblast zasažená povodňovým scénářem má definován určitý stupeň (kategorii) rizika. Metoda II však určuje stupeň rizika na základě překryvu mapy využití země (s definovaným přijatelným rizikem) a mapy ohrožení.

Rozloha ploch s nejvyšším povodňovým rizikem je v obou metodikách přibližně shodná. Tyto plochy jsou situovány výhradně v intravilánech zkoumaných obcí. Podobnost těchto výstupů může být dána jednak definováním intervalů rizika v Metodě I a jednak určením stupně významností pro jednotlivé kategorie využití země v případě Metody I a přijatelného rizika, které je definováno pro každou kategorii využití země, v případě Metody II. Ceny pozemku uvažované v Metodě I pravděpodobně nemají značný vliv na výstupy (Mapy povodňového rizika). Do určité míry je možno tento jev vysvětlit skutečností, že nejvyšší cenu pozemku lze očekávat v kategorii „Bydlení", nejnižší v kategorii „Zeleň" (to však ne vždy musí odpovídat realitě).

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