An assessment of hucava mountain stream catchment susceptibility to flooding

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ABSTRACT: The paper deals with an assessment of the Hucava mountain stream catchment susceptibility to flooding. The model catchment of the Hucava mountain stream is located in the Polana Protected Landscape Area – Biosphere Reserve, situated in the central part of Slovakia. The assessment of overall susceptibility of the model area to flooding is based on the multi-criteria evaluation of environmental factors, which crucially affect the hydrological cycle. These are represented by the geology, soil types, slope, forest type group, degree of ecological stability, exploitation of non-forest landscape and potential runoff in the model area. The methodology is based on the synthesis and subsequent processing of data in the GIS environment. The result is represented by the specification of categories (degrees of flood risk) to classify the model area to five degrees of overall susceptibility to flood as well as by the creation of maps representing the spatial distribution of different categories in the Hucava catchment.

Keywords: flood; catchment; susceptibility; Hucava; GIS

Floods are a natural phenomenon which has accompanied and guided the human society since time immemorial. The development of human civilization is linked to the increasing interference in the natural environment and colonization of larger and larger areas along the watercourses, but also beyond them, and is closely connected with the increasing risk of flooding and vulnerability to flooding.

In the world the disaster risk (also flood risk) management and the analysis of particular risk components, both in theory and in practice, is solved by many specialists: Villgran de León (2008) dealt with the risk management, while Brauch (2005), Thywissen (2006), Bohle (2007), Birkmann (2009), Afifi and Warner (2008) and the others studied the risk components analysis and risk reduction. Here we introduce the theory of basic components of risk which are often used in the practice of disaster risk management.

Hazard is a threat, not an incident (negative event). Vulnerability indicates the potential of damage and is the prospective variable. In the case of flooding, it may be evaluated based on its impact on three important spheres: the environment (environmental aspect), the economy (economic aspect) and the society (social aspect). Along with the vulnerability and hazard, there exists another prerequisite of the risk and negative event, and/or disaster occurrence. It is exposure, which includes the susceptibility as a further feature of the system. Exposure can be understood as the number of people and/or other elements (objects) in jeopardy who may be affected by the incident (Lubinszká 2010).

Previous activities of people in the landscape have adversely affected the water regime to a varying extent. Forecasts show that the determining factor in the future economic, social and cultural development of countries and regions will be a stable hydrological

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regime in the rivers that will be more capable to withstand extreme weather conditions, without extreme floods, drying process in the landscape and without the risks of other natural disasters. Such a desirable state of the landscape can only be achieved by applying the ecosystem processes that enhance the biodiversity, improve the hydrological regime and rely on integrated water management in the process of economic activities in the catchment/region/landscape (Úrad vlády … 2010). The integrated management of catchments represents an approach to the resource management in the catchments, integrating the environmental, economic and social issues. Its main tasks are to protect natural resources, especially water sources, to minimize potential adverse impacts and to ensure sustainable benefits for future generations (Lepeška 2010).

The land's ability to slow down and retain atmospheric precipitation and consequently to promote its infiltration into the lower layers can be termed as landscape hydric function. It is the landscape's overall impact on drainage, which is reflected in the balancing of runoff extremes, either the minimum ones, resulting in water shortages in the landscape or the maximum ones, resulting in the formation of flood flows. In assessing the landscape hydric function several components must be taken into account. The determinant factors are the geology and soil conditions, climatic conditions (precipitation, temperature, etc.) and the character of forests and structure of non-forest landscape, which are located in the territory (Lepeška 2010).

The assessment of susceptibility to flood was also done in work of David, who tackled the problem and designed the methodology to assess the flood risk in small catchments. He elaborated and used the methodology for assessing the risk of floods caused by the torrential rain. This problem is also solved and the methodology was also designed in the framework of the COST programme Flood risks and prevention in the small catchments.

The aim of the presented research work was to name, determine, describe and quantify the various factors that have a direct impact on area susceptibility to flooding through their properties. It is especially their direct relationship to the retention, accumulation and infiltration of precipitation and the ability to slow runoff and affect the runoff balance. The aim of the work was also to describe a simple method to determine the overall susceptibility to flooding in the model catchment. The assessment is based on the multi-criteria evaluation of several factors, on processing and subsequent synthesis of data in the environment of geographical information systems (GIS).

The development of information technologies, namely GIS, has brought an opportunity to provide analyses of landscape's different features, entering the complex system of water circulation in the landscape. The use of GIS software for the purposes of flood modelling and natural disaster risk assessment has already been presented in the works of the following authors: Gallay (2009), Lepeška (2010) and Lubinszká (2010).

MATERIAL AND METHODS

Experimental area

The Hucava mountain stream springs in the geomorphologic unit Polana, in the subassembly High Polana, at an altitude of 1,330 m. It belongs to the Hron River catchment and is the fifth order water flow. The catchment area is about 41.45 km^2, including the forest area of 32.33 km^2 (78% of the catchment area). The foreclosing flow profile of the experimental catchment is the limnigraph, located near the Hrochotsky mill, in the river kilometre 13.80 and at an altitude of 522.54 m.

The model area is built of Neogene volcanics. The top layers of the Polana stratovolcano are represented by diorite porphyries. The central part of the stratovolcano is built of rhyolites and rhyodacites and the bottom is represented by pyroxene-amphibole andesites.

The northern part of the Hucava catchment is covered by the ando soil. In the southern part of the catchment there is podzolic Cambisol. The central part of the catchment is covered by modal Cambisol and saturated to acidic Cambisol. In the catchment, there also occur sandy-loam soils that are moderately stony (20–50%) and also loamy soils (non-skeletal to slightly stony, 0 to 20%) occurring in the southern part (Šály, Šurina 2002).

The Hucava catchment is quite differentiated due to the climate. The average annual temperatures range from 6.7 to 2.5°C. July average temperature should range from 16.5 to 11.5°C, the growing season (average daily temperature is above 10°C) in the Hucava catchment lasts from 65 to 155 days. The average daily rainfall is in the range of 720 to 1,200 mm, average annual rainfall per growing season is 475 to 630 mm. Snow cover in this area lasts on average from 135 to 190 days.

The analysed catchment is located within two climatic regions. A moderately warm region (M6 district – moderately warm, moist, upland) is represented in the Hrochot part of the valley and on

Table 1. Categories of rocks based on the hydric efficiency

Degree	Description
1	carbonate rocks (limestone, dolomite)
2	deep igneous and metamorphic rocks (granite, gneiss, etc.)
3	neogene – tertiary neovolcanites (andesites and pyroclastics, rhyolites, etc.)
4	neogene – Pliocene splitless, unpaved sediment basins
5	palaeogene – Magura and central-Carpathian flysch and other flysch forms

southern slopes of Bukovina. The major part of the catchment belongs to a cold climatic region, which includes C1 district – moderately cold (the valley part of the caldera and northern slopes) and C2 district – cold mountainous, covering the ridge parts of Polana massif (Škvarenina, Minďáš 2001).

In the representation of particular forest vegetation gradients, the 4th beech forest vegetation gradient predominates in most areas of the catchment. In the southern part of the catchment the 2nd beech-oak forest vegetation gradient occurs and the highest locations in the north of the catchment are occupied by the 5th fir-beech forest vegetation gradient.

Methodology

The susceptibility to flooding was assessed based on the interaction of several factors: geology, soil types, forest type group (FTG), degree of ecological stability (DES), terrain slope, runoff potential and exploitation of non-forest landscape. A classification scale with 5 degrees was created for each factor, where value 1 represents the best property of a factor, the lowest = very low susceptibility to flooding, and factor 5 represents the worst characteristics of a factor, thus the highest = very high susceptibility. Combining all these factors, with regard to their significance, we can also calculate and classify the overall susceptibility to flooding.

The methodology for assessment of the Hucava mountain stream susceptibility to flood is based on the synthesis and subsequent processing of data in the GIS environment.

The methodology can briefly be summarized as follows:

Assignment of factors affecting the overall flood susceptibility assessment

– accounting for the various factors and their classification into the categories

The outflow is affected the most significantly by the rocks occurring in a catchment. The rocks directly affect the retention and retardation of rainwater, penetration and infiltration of water into the deeper layers and formation of groundwater. They also indirectly affect the occurrence of soil species and types, their infiltration and retention parameters.

The rocks were classified to 5 categories (Table 1) based on the value of hydric efficiency index C_H. It is a relative number which represents the geology retention and retardation parameters (Valtýni 1995).

To assess the ability of soil to infiltrate and retain atmospheric precipitation, the attention was focused on soil types. Soil types, based on the grain size, were divided into 5 categories with respect to their permeability (Table 2).

These categories of soil types were specified based on the values of the P coefficient expressing the permeability of soils in the catchment to determine the nature of the flow (Jakubis 1996; Valtýni, Jakubis 1998) and CN method hydrological category that is used to calculate the surface runoff (Chow 1964; Antal 1997; Jakubis 2002).

The amount of water drained from the forest as well as flood flow is affected not only by the forest cover but also by age, stem density (stocking), representation of tree species, structure and other characteristics of forest stand. The characteristics of a forest are expressed by the forest type group (FTG). Each FTG has a specific effect on runoff. Some FTGs may affect drainage in the same way, others quite differently. Therefore their hydric flood potentials are different. The categories representing the significance of FTG factor (Table 3) were created on the basis of hydric significance of

Table 2. Categories of soil types based on permeability

Degree	Description
1	sandy soil, sand, gravel
2	loamy sand soil, sandy loam soil
3	clayey loam soil, loam soil
4	clayey soil, clay
5	rocks, urban areas, paved roads

ecological series, which the FTG is assigned to, taking into account the research results published in Valtýni (1981, 2001).

This classification corresponds to the knowledge of the importance of fertile humification and overlying humus for the retention of rain water in the forest soil, and retention effect of forest types typical of particular typological series. These factors are also taken into the account by calculating the degree of ecological stability (Kulla et al. 2006). Therefore we can conclude that the more stable forest performs better hydric functions (Table 4).

Geomorphological conditions are an important feature of the landscape which greatly affects drainage conditions and the ability to infiltrate the rainwater. Mostly, the slope has an influence on the intensity of precipitation infiltration and retention. In general, we can say that with the increasing slope, when the other conditions are not changing, the infiltration of precipitation decreases at the expense of surface runoff.

The slope categories (Table 5) are determined based on the curve of surface runoff dependence on the slope (Midriak 1988). According to Lepeška (2010), on the slope of 7° and less there is no surface runoff (rainwater is infiltrated into the soil), on the slope of about 7° to 18° the intensity of surface runoff gradually increases almost linearly. The next point at which a significant increase in surface runoff can be observed, is the slope of about 31°. On the slope of 50° and more, only small amounts of rainwater are infiltrated into the soil.

The most important source of water for the territory of Slovakia is the atmospheric precipitation, especially rain and snow. Rainfall, which is available for potential runoff, was determined from the fundamental equation of area water balance:

$$R_p = P - \bar{E}$$

where:
R_p – runoff potential (mm),
P – average annual precipitation total,
$\bar{E}$ – average annual potential evapotranspiration total.

Values for each category of potential runoff factor (Table 6) are taken from the work of Lepeška (2010).

To calculate the long-term average value of potential runoff, the data from the Atlas of Landscape of the Slovak Republic were used (Lešková, Majerčáková 2002). The data for the Hucava catchment were obtained by the geostatistical (regression) analysis of long-term average annual values of precipitation totals and long-term average annual values of potential evapotranspiration in the IDRISI environment (Eastman 2000).

Land cover represents the physical condition of the current landscape, composed of natural and man-modified and created objects. It is a very good indicator of current land use (Feranec, Oťahel 2001). The ability of landscapes to infiltrate rainfall water depends both on the properties of the natural environment and on the type and intensity of exploitation of this landscape by man. According to the ability of different types of land cover to infiltrate the precipitation into the soil and definitions of land cover classes introduced in the work of Feranec and Oťahel (2001), we have created five categories (Table 7) of non-forest landscape.

Table 3. Categories of the forest type group (FTG) factor

Degree	Description
1	series C – nitrifying; range A – acid
2	series B/C – semi-nitrifying
3	series B – fertile
4	series A/B – semi-oligotrophic
5	series A - acid; set a; set c

Table 4. The degree of forest ecological stability

Degree	Description
1	highly stable ecosystems
2	stable ecosystems
3	ecosystems with reduced stability
4	unstable ecosystems
5	extremely disturbed ecosystems

Table 5. Categories of terrain slope

Degree	Value range (°)
1	0–7.0
2	7.1–8.0
3	18.1–31.0
4	31.1–50.0
5	50.1 and more

Table 6. Categories and values for potential runoff

Degree	Value range
1	–451 and less
2	–450–0
3	0–450
4	451–1,100
5	1,101 and more

Data preprocessing

– collection of data from the model area, their digitization, geodatabase creation, rasterization,
– landscape classification – classification of the orthophotos from the area of Hucava catchment in the Definiens Professional v. 5 using a maximum likelihood classifier,
– creating rasters of rainfall and evapotranspiration based on the results of regression analysis in the IDRISI environment. Maps of precipitation and evapotranspiration distribution in the area were created using the Map Algebra tools,
– extracting the data from raster layers for individual forest stands and non-forest landscape features. The zonal statistics tools for data extraction from particular rasters were used in the Arc GIS environment. The resulting values were assigned both to individual forest stands and to non-forest features.

Assessment of total susceptibility of the area, creating maps and tabular outputs

For the assessment purposes, a decision-making object-oriented mathematical model was created in the NetWeaver environment. The flood susceptibility assessment of Hucava catchment is based on multi-criteria evaluation of the factors listed above, according the following equation:

$$\text{susceptibility} = \frac{\text{geology factor} \times \text{weight} + \text{soil factor} \times \text{weight} + \text{slope factor} \times \text{weight} + \ldots + \ldots}{\sum \text{weight}}$$

The weights were assigned to each factor based on the significance of its influence on the hydric potential of the model area. The resulting values were classified into 5 categories – degrees of flood susceptibility. These values were used to create the map of overall flood susceptibility of the catchment.

RESULTS AND DISCUSSION

The spatial scale used for this assessment is represented by a forest unit – individual forest stand. In the catchment, 1,165 stands were identified. For the remaining area of the catchment – non-forest landscape, the polygons representing the non-forest landscape elements (originating from segmentation and classification of orthophotos) were used as the basic unit for determining the flood susceptibility.

According to the results of flood susceptibility assessment, we can point out that only three categories of flood susceptibility are represented in the Hucava catchment (Table 8): category 2 – low flood susceptibility (low probability of flood flow occurrence); category 3 – medium flood susceptibility (probable occurrence of flood flow) and category 4 – high flood susceptibility (very probable occur-

Table 7. Categories for non-forest landscape

Degree	Description
1	semi-natural landscape
2	agricultural landscape with a high representation of native vegetation
3	agricultural land
4	unreinforced forest roads
5	urban areas, rocks, unpaved roads with impervious cover

Table 8. The results of overall flood susceptibility assessment of the Hucava catchment

Degree	Category	Forest		Non-forest		Total	
		(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
1	very low	0.00	0.00	0.00	0.00	0.00	0.00
2	low	0.65	2.00	0.40	4.34	1.05	2.53
3	medium	31.48	97.37	8.69	95.30	40.17	96.91
4	high	0.20	0.63	0.03	0.36	0.23	0.56
5	very high	0.00	0.00	0.00	0.00	0.00	0.00
Total		2.33	32.33	100.00	9.12	100.00	41.45

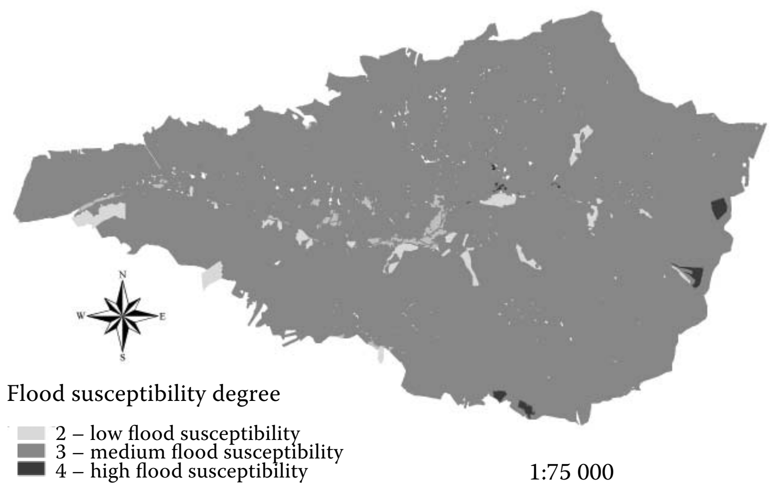

Fig. 1. The Hucava catchment susceptibility to floods

rence of flood flow). Spatial distribution of flood susceptibility categories is shown on Fig. 1.

The second group of factors is represented by other factors (FGT, DES, non-forest land cover, runoff potential), which could be regulated by appropriate measures within integrated water management and therefore we could use them, but only to a certain extent, to reduce the negative effect of the group of immutable factors.

In the Hucava catchment the area assigned to category 2 (low susceptibility to flooding) takes up 1.05 km^2 (2.53%): 0.65 km^2 (61.9%) of this area is covered by forests and 0.40 km^2 (38.1%) by the non-forest elements. The most represented category in the catchment, with an area of 40.17 km^2 (96.91%), is category 3 – medium susceptibility to flooding. This category accounts for 78.37% (31.48 km^2) of forests and 21.63% (8.69 km^2) of non-forest landscape. Category 4 (high susceptibility to flooding) covers an area of 0.23 km^2 (0.56%), of which 0.20 km^2 (86.96%) is covered by forests and 0.03 km^2 (13.04%) by other land cover types.

The dominant position of category 3 results from the nature of the geology in particular (dominant is flood susceptibility category 3), which in turn affects the representation of soil types in the catchment and also predetermines the dominant representation of soil types under flood susceptibility category 3. The respective geomorphological conditions are also of great importance in the representation of particular flood susceptibility categories in the model area, which are characterized by slope in this case. This factor belongs, in our opinion, among the dominant factors determining the flood susceptibility of the model area. It is unfortunately assigned to a group of factors that cannot be influenced or changed.

We realize that the choice of the factors considered in the proposed methodology may not be final – it is an opened system. More attributes can be incorporated into the methodology or existing factors may be replaced by other factors – factors with higher informative value for assessment of susceptibility to flooding. The categories of particular factors may also be completed by other characteristics or further more detailed classification schemes.

CONCLUSIONS

In the present paper a methodology was proposed to assess the susceptibility to flooding. The Hucava small mountain stream catchment was selected as the model area. In the assessment of flood susceptibility we have taken into account the factors that affect the catchment hydric potential. This is the geology, soil types, slope, forest type group, degree of ecological stability, non-forest landscape features and runoff potential in the model area.

We realize that the issue of flood susceptibility assessment of forests is difficult and demanding because of expertise in the assessment due to a number of factors directly or indirectly affecting it. On the other hand, it is due to the labour-consuming collection of input data as well as to ensuring their accuracy for flood susceptibility assessment purposes. We think that despite of this fact, it would be interesting to develop this methodology or to complete it by new factors, by which the impact of forests and also of non-forest landscape on the overall water regime in the landscape could be objectively assessed.

The research results can be applied in forestry practice, integrated water management, or they can serve as the primary base for further development of this methodology in future research projects in this field.

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