AN ASSESSMENT OF URBAN AREA FLOOD SUSCEPTIBILITY

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Abstrakt

V príspevku sú predstavené dva prístupy k hodnoteniu náchylnosti územia na vznik povodne. Ide o územie povodia rieky Poprad, ako aj samotného mesta Poprad. Náchylnosť územia povodia rieky Poprad bola vyhodnotená na základe faktorov ako erózneho faktora účinnosti prívalovej zrážky, straty pôdy v dôsledku prívalovej zrážky vyjadrenej množstvom erodovanej pôdy, sklon terénu a využitie krajiny. Všetky tieto faktory boli klasifikované do tried na základe sily (váhy) akou vplývajú na vznik povodne. Z výsledkov hodnotenia náchylnosti na vznik povodne vyplýva, že na hodnotenom území sa nachádzajú nasledovné stupne nebezpečenstva vzniku povodne, ktoré sú vyjadrené ako percentuálny podiel ich výmery k celkovej výmere povodia: malé nebezpečenstvo (2) na ploche 25.57 % z celkovej plochy povodia, stredné nebezpečenstvo (3) na ploche 71.06 % z celkovej plochy povodia, vysoké riziko (4) sa vyskytuje na 3.37 % plochy z plochy celého povodia. Na vysokom podiely výmery plochy so stredným nebezpečenstvom vzniku povodne sa podieľajú najmä dva faktory: sklon terénu a erózny faktor prívalového dažďa (najmä vo vyšších nadmorských výškach). Tu popísaná metodika je vhodná pre použitie v akomkoľvek povodí. Limitovaná je len dostupnosťou dát o tomto území. Náchylnosť na vznik povodne v mestskom prostredí bola hodnotené na základe sociálnych, ekonomických a environmentálnych faktorov. Informácia a náchylnosti na vznik povodne je dôležitá pre krízových manažérov pre účely redukcie zraniteľnosti komunity žijúcej v predmetnej oblasti a plánovanie preventívnych opatrení a síl a prostriedkov pre zdolávanie povodne.

Abstract

In the article there is introduced two approaches for flood susceptibility assessment. They were performed for the area of Poprad river catchment as well as Poprad city area. The flood susceptibility of the Poprad river catchment was assessed based on the factors like erosive factor of torrential rain, soil losses due to the torrential rain expressed by the amount of eroded soil, terrain slope and land use. All of these factors were classified to the classes based on the magnitude (weight) of their impact on the flood formation. The results of the susceptibility to flood assessment showed that there are the followed degrees of flood danger in the catchment, which are expressed by the percentage rate of their area to the whole area of the catchment: low danger (2) on the area of 25.57 % of the catchment area, medium danger (3) on 71.06 % of the catchment area, high danger (4) on 3.37 % of the catchment area. On the high portion of catchment area extent with the medium danger have an impact two factors mainly: terrain slope and erosive factor of torrential rain (mainly in higher altitudes). Here presented methodology is appropriate to be used in conditions of any catchment. It is limited only with the availability of data about the area. The flood susceptibility of an urban area was assessed based on the social, economic and environmental factors. Information about susceptibility to flood of an area is important issue mainly for the crises managers to reduce the vulnerability of a community living in this territory and to plan the preventive measures as well as coping capacities to fight with the flood.

Kľúčové slová: GIS, manažment rizika, náchylnosť, povodeň, povodie.

Keywords: GIS, risk management, susceptibility, flood, catchment.

INTRODUCTION

Floods are a natural part of the hydrological cycle. Human life has always been very closely associated with water. Therefore, in the past, the buildings were built near the water, but not so close that they were threatened by water. Today, in a civilized country we have built up the valley down to the riverbed, we regulate the currents of water, build up waterworks. The infrastructure of the country we are building along the streams, we transform the country, deforest it, cultivate the land, possess the large property values. And therefore, voluntarily or under a pressure of civilization development, we are exposed to the risk, which the floods bring time to time. Partly, the flood risk is prevented by the flood protection – e.g. construction of dams, dikes, dry polders, and partly also by the land management. However, no protection is pure.

The harms, which the floods take with them on the health and lives of individuals, are tragedies which we forget over time and which remain only in the minds of their closest people (friends and family). With the property damages and the damages on the objects of our everyday needs we are coping progressively. Some of them are irreplaceable. Floods wash away and destroy the things that we associate with the past for ever. The "added value" to the environment is significant in the presence. Consider, for example, only the equipment of our homes, towns and villages and compare it to that we had before 100 or only 50 years ago. Mainly due to it we experience the floods so strongly and see the flood damage so tragically.

Also in the past there were major floods, just we were "built into the path of water" less barriers, people had more connections with nature and they probably better understood it. Therefore, the history and memory of old people have kept memories of the consequences of only the most damaging floods.

Of course, today we are interested not only in the fact whether the floods are destructive, but also whether they occur more frequently than it was in the past. The answer to this question is ambiguous. After about 15 years of relative peace, since the last years of the last century, we encounter reports about the floods and flood damages in our country and in the rest of the world every year.

On the one hand, it is true that the incoming climate change (which has been so much talked between experts and lay people) will bring even greater extremity in water circulation, i.e. we will have more frequent and stronger changes of drought and flood periods. On the other hand, the unprecedented media coverage of all events that occur in the world and its transmission to each household almost continuously for 24 hours every day, can distort our perspective to the repetition of extreme situations.

To confirm by the evidence of mathematical statistics the fact that the number of such events is increasing, it is not possible because it has elapsed still a short time. To know the answer we have to wait more time. In the presence we know to analyze the susceptibility of the territories to flood formation and also its impacts by a selected flood scenario. For this purpose, it is currently used the modeling.

This paper deals with the assessment of susceptibility to the flood in mountain and foothill areas of our highest mountain – the High Tatras Mts., as well as the Poprad city itself, which is situated directly in the Podtatranska Basin. For the assessment of susceptibility to flood, the Idrisi Taiga environment was used. Weights representing the influence of individual factors on the severity of flood danger were assigned based on the fuzzy logic principle. The resultant susceptibility is determined by considering the individual factors, adding together the individual weights. At the end, the resultant sum of weights was classified into 5 classes (grades) of susceptibility to the flooding (flood danger). It is relatively simple and quick method to estimate the initial risk of flooding associated with susceptibility of an area to flood occurrence.

PROBLEM

Flood risk management

The assessment of vulnerability as well as the susceptibility is a part of risk analysis. The risk analysis, risk assessment and measures for minimizing of flood risk represent the basic components of flood risk management (Fig. 1).

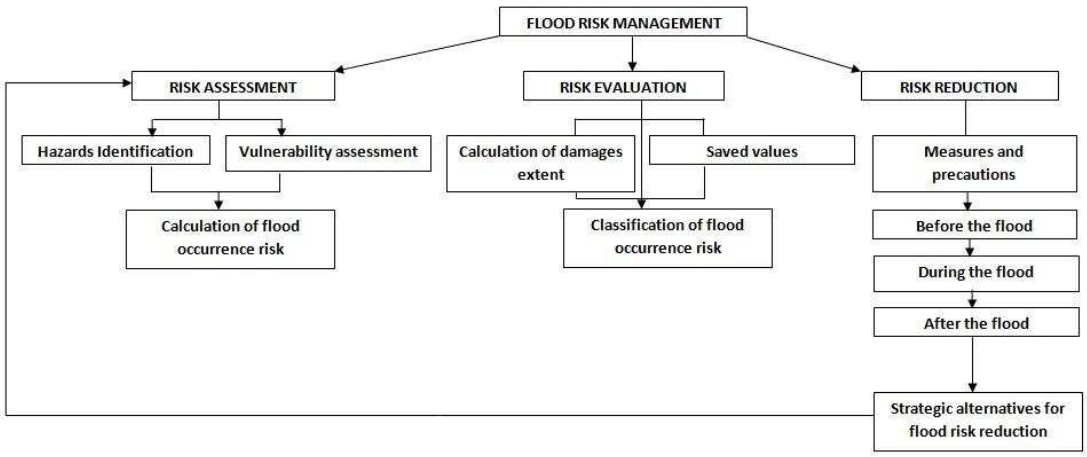

Fig. 1 Flood risk management

Risk management is a logic and systematic method of coherence specification in any activity, function or process related to the risks identification, their analysis, evaluation, reduction and running monitoring, to allow the losses to be minimized and the opportunities to be maximized (Šimák 2006).

Risk management represents culture, processes and structures oriented to the effective management of potential opportunities and possible negative impacts. It is an interactive process composed from procedures which allow the permanent improving quality of decisions by keeping the planned progression, followed by the improving of pursued processes results, too.

It should be the integral activity of every managerial practice, with no respect to the management level (from strategic up to the operational).

The increasing frequency and strength of natural disasters all around the world point out the vulnerability of communities and lack of their capacities to cope with these situations. If these situations have to be controlled in the future, it is required to know and understand more system features which are in mutual relationship – social, political, institutional, economical, technical and environmental.

In our conditions with the problem of risk management deal: Zelený (2006) who deals with the risk management in industry; Mikolaj (2001) and Šimák (2006) who deal with the risk management in general; Kostelný (2006), Lodňanová (2006) and Mika et al. (2008) who deal with the management of social risks.

In the world the risk management and the analysis of particular risk components is solved by many specialists: with the risk management deals Villgran de León (2008), with the risk components analysis and risk reduction deals Brauch (2005), Thywissen (2006), Birkmann (2006), Bohle (2007), Afifi, Warner (2008) and the other.

These specialists are joined together under the Institute of Environment and Human Security (UNU-EHS), which was established in December 2003. The Institute is a system part of the United Nations University. It is represented by the worldwide network of research and training institutes. Its main role is to enhance the security of population through the approaches based on the knowledge and experiences leading to the reduction of vulnerability and environmental risks. The UNU-EHS points out the risk, vulnerability and the population security aspect, as well as the complex environmental hazards impacts on the sustainable development. The work of the institute helps to enhance the deeper understanding of action - reaction relationship to find out the way how to reduce the risk and vulnerability.

Risk components

Risk is a function of hazard and the vulnerability of system: $R = f(H, Z)$. It could be expressed as a probability that the observed system will be destroyed or a probability of concrete hazard (negative phenomenon) occurrence. For calculation of this probability as mathematical as statistical methods can be applied. The probability of flood occurrence is often assessed based on the frequencies of flood occurrence in the past. This way is assessed the occurrence of 100-years flood mainly. The risk assessment is a base for building of flood warning systems. One of such a warning systems is the EFAS (European Flood Alert System). In Slovakia, there is progressively built the POVAPSYS warning system.

Every event or disaster begins with a hazard that could be known or unknown. There exist more way to characterize it. It is a threat not an event. No hazard itself can occur during the disaster. In other words, if the hazard would be measured as a real threat or harm, it is not more hazard. In that moment it becomes an event, disaster or catastrophe. Thus hazard is a danger or phenomenon that threatens the system in time of its surveying. In the case of flood, the hazard is represented by the flood itself (event) as well as its magnitude that could be expressed by the flow rate or the water level height, etc.

Another prerequisite of the negative event is the *vulnerability* except of hazard. The vulnerability is a dynamic, hidden characteristic of any community, which is composed from several components. The extent that represents is set based on the gravity of an event.

The vulnerability is a function of system exposure and susceptibility. It is independent of any particular magnitude, of specific natural disaster, but it is dependent of the situation context. The vulnerability could not be assessed in an absolute meaning (Rashed and Weeks 2003).

Due to the practical reasons, the vulnerability assessment is limited only to specific event scenario for what the analysis is performed. This looks like to be the appropriate way for vulnerability assessment, but the event scenario is influenced by the evaluator subjectivity many times.

The vulnerability, in the case of fire, could be assessed on the base of its impact on three important spheres: environment (environmental aspect), economy (economical aspect) and society (social aspect).

The vulnerability informs about the impacts of possible negative event, while the risk informs about the frequency or probability of concrete scenario occurrence.

The selection of appropriate approach to the risk assessment depends on the territory conditions, and therefore the selected method of risk assessment need to be adapted to these conditions.

To know the frequency or return period of any event allows the risk manager define the types of events which could be expected in the future and the level of acceptable impacts. This is the only way the risk manager to understand what type of events would occur in the future and how to prepare the society to them. For the decision making the information about the probability of negative events in the area is crucial.

The *exposure* could be understood as a number of people and or other elements (objects) in danger, which could be threaten by a disaster (fire). In the unsettled areas the exposure is equal to zero. Under the term exposure, the character of an area could be understood, too. It is the next characteristics related to the system. It is called susceptibility. The susceptibility is a subset of exposure.

In real life, the uprising damage or harm does not depend only on the hazard, vulnerability and exposure, but also on the coping capacity and resilience of elements in danger. In literature, there often occur the overlaps in definitions of both terms. They are many times used as synonyms.

The *coping capacity* includes the strategies and measures, which are used for the mitigation of disaster impacts or they are bringing efficient help during the event. There also belong the adaptation strategies, which purpose is to change the system behavior or performance to forestall damages.

The *resilience* is all mentioned above, but it is even enriched by the ability of system functionality outlast and its next total rehabilitation.

Experimental area

Poprad river catchment has an elongated rectangular shape with a distinct mountainous terrain and relatively evenly distributed surface on both sides of the river. The hilly terrain, climatic characteristics, water content and its temporal distribution and hydrobiology regime the Poprad river catchment is close to the catchments with an alpine hydrological character. It is particularly due to the high runoff coefficient, the occurrence of maximum water content in winter and the occurrence of maximum flows caused by rain and late snow melting in the last spring and early summer months.

There is the risk of flooding, especially during the torrential rainfall, when a large volume of water falls on a small territory, which will lead to a sharp increase in water levels of small rivers, which are sharply decreasing after passing flood wave.

METHODOLOGY

Methodology for determining the risk of flooding in the Poprad river catchment and on the area of Poprad city consists of several parts. Separately, there is performed the assessment of flood susceptibility of the Poprad river catchment and then of the area of Poprad city.

The assessment of vulnerability to the flooding is made on the basis of modifications of the methodology for determining the risk of floods in small catchments, published by David (2008). It is a methodology for assessment of flood risk caused by torrential rain.

In the assessment of flood susceptibility of the area, there were originally assessed the different groups of factors that have a substantial impact on the occurrence of flash floods (caused by torrential rain). The assessment was performed in Idrisi Taiga environmentThere were assessed the following factor groups:

- Meteorological conditions,
- Soil conditions,
- Terrain morphology,
- Land use.

Based on the mutual assessment of particular factors there was assessed the total flood susceptibility (flood danger) degree. The susceptibility (flood danger) was classified to 5 degrees following the international classification system.

In relation to the meteorological conditions, the rainfall parameters are possible to indicate for the key parameters. Thus, meteorological factor is derived based on statistical characteristics of precipitation for precipitation stations located in the area considered. For this purpose it is best to use the 24-hour totals, since the detailed data are not generally available (David 2008).

In Slovakia, these data can be daily downloaded from the website of the Slovak Hydrometeorological Institute. There are even data to forecast rainfall for the next three days (model Aladin). As in Slovakia is a relatively small number of precipitation stations it is appropriate to download the data for all rain gauge stations in Slovakia and to interpolate them to the entire territory of Slovakia in the first step, and then to use only a detail grid for analysis at the local level. This approach can be used for operational assessment of the risk of flooding in terms of weather development in flood sensitive areas.

For the purposes of susceptibility assessment, the approach through the classification of torrential rain erosion effect factor can be used.

By the rainfall-induced erosion processes, especially rain acts as the agent of erosion, which operates to the subject of erosion - soil. Among several characteristics of precipitation, the intensity of rain is the most important feature in relation to the erosion, because it allows express the kinetic energy of rainfall, which depends on the ability of raindrops to upset the soil aggregates and release the soil particles (the surface runoff only slightly releases particles). In addition, the raindrops also contribute to erosion indirectly, by reducing infiltration capacity of soils, because the loose particles are deposited on the soil surface and clog the pores, while the action of the other drops make them compact to form the crust. The transport of loose particles is caused by energy of draining water. Surface runoff is the difference between the intensity of rainfall and infiltration. Therefore, in the case of homogeneous soil properties, rainfall intensity reflects the potential of surface runoff (Fulajtár, Janský 2001). Effect of critical rainfall intensity is mainly determined by soil permeability and the effect of yield retention by its mechanical composition. During the rain, the current state of soil decides about the soil erosion progress (Zachar 1982).

Erosion is almost exclusively caused by rains with high intensity - torrential rain (downpours, torrential downpours, cloudburst), while rainfall with low kinetic energy (with low intensity and mainly with small drops) do not cause erosion (Fulajtár, Janský 2001). Short-term rainfalls with high intensity are much less harmful than long-term heavy rains (Malíšek 1990). However, the whole torrential rain is not participating in the erosion process, but only a part of it – the effective rainfall, which causes runoff and thereby creates conditions for erosion formation and progress, too. The limiting torrential rain intensity differs by authors. Wischmeier, Smith (1978) for the torrential rains consider those whose yield is greater than 12.5 mm, which are separated from the previous rainy season with a 6- and more hour break and their maximum intensity exceeds 24 mm / hour.; in the RUSLE manual (Renard et al. 1993) as the erosion rains are considered those, which amount is greater than 12.7 mm, and are separated from the other with a 6-hour rain break and their 15-minute maximum intensity exceeds 24.13 mm / hour.; Toman (1999), Hrnčiarová (2001) evaluated the cumulated rainfall with an amount over 10 mm and a maximum intensity of 20 mm / hour., which are separated by 6-hour break, because they have already produced loss of soil; other examples showed Fulajtár and Janský (2001) . The torrential rains occur only during the growing season in our climatic conditions (Alena 1986). In general, rain erosion efficiency increases with an increasing continental climate (Fulajtár, Janský, 2001). Slovakia is situated between coastal and inland continental climate, in the variable orographic conditions, therefore the solution of torrential rains issue is complex (Malíšek 1990).

In this model, USLE (RUSLE, etc.) the impact of rain is expressed as a factor of torrential rain erosion effect (R - factor - rainfall erodibility index - EI index). According to Wischmeier and Smith (1978) this factor expresses the product of total rainfall kinetic energy (E) and its maximum 30-minute intensity (Imax30):

$$R = \sum_{j=1}^{n} E \times I_{max30}$$

It is calculated in units MJ.ha-1.cm.hour-1.

The calculation of R – factor is time consuming, because the input data that come into calculation must be acquired from rain gauge records collected for not less than 50 years. Withal the rain intensity is changing during the torrential rain. Therefore the rain gauge curves are divided to segments with a similar intensity, while the energy is calculated for every segment individually. Therefore, every torrential rain and next also the effective rainfall must be interpreted.

The meteorological factor, based on the right described approach, can be classified to 5 classes in view of the flood susceptibility.

Weight – index	*R - factor*
0.0 – 0.2	0 - 5
0.2 – 0.4	5 – 12.5
0.4 – 0.6	12.5 – 17.5
0.6 – 0.8	17.5 – 22.5
0.8 – 1.0	22.5 – 27.5

By the R – factor derivation, there were used the following data:

- Digital relief model of the Poprad river catchment,

- Vector layers representing the climatic regions in Slovakia and the average precipitation amounts in Slovakia, which was created base on the cartography data and which was published in the Atlas of Landscape of the Slovak Republic (Lapin at al., 2002; Faško, Šťastný, 2002);

- Layer of rain gauge stations situated in Slovakia (86 stations), with recorded R – factor data, which were computed by Malíšek (1990).

Water erosion is of great importance for modeling character of the landscape as well as the degradation of agricultural soils fertilely properties (there comes to the release and subsequent transport of soil particles, which are relatively firmly fixed nutrients and organic matter on). Water erosion is demonstrated by reduction of the soil profile depth (in particular, the biologically active soil layer), loss of organic matter and nutrients, as well as the deterioration of soil structure. The effectiveness of soil conservation (the choice of appropriate anti-erosion measures) against water erosion is based on information about spatial distribution of soils affected by erosion and its intensity in specific site conditions.

In this case the evaluation of soil conditions was limited to the assessment of soil loss caused by torrential rain. The digital layers of these parameters have been obtained and derived from the Atlas of Landscape of the Slovak Republic (2002). Individual quantities of eroded soil were classified into 4 classes and they have been assigned the following weights according to their impact on the flooding occurrence.

Weight – index	*Soil loss [t/ha/year]*
0.00 – 0.25	0 - 4
0.25 – 0.50	4 - 10
0.50 – 0.75	10 - 30
0.75 – 1.00	more than 30

Terrain morphology plays an important role in process of torrential rain outflow from more aspects. Firstly, the slope conditions result from terrain morphology, and represent very important element owing to the rate of surface runoff and intensity of the infiltration process. Moreover, the catchment shape affected with the morphological conditions is significantly changing the course of the runoff process and considerably affects the shape of the resulting runoff hydrograph.

One of the most important geomorphological factors affecting the intensity of infiltration and retention of atmospheric precipitation is the slope. In general, with increasing slope, when the other conditions are not changing, the infiltration of atmospheric precipitation decreases at the expense of surface runoff.

For the slope raster derivation, there were used the digital relief model with the spatial resolution of 10 meters. For the purposes of this work, it was provided by the Topographic Institute in Banska Bystrica. The raster of slopes was produced by the “Surface” module in Idrisi Taiga environment. In the calculation the degrees were used as the metric units.

For the slope values the following classes and their weights were defined (mountainous relief):

Weight – index	*Slope range [°]*
0.0 – 0.2	0.0 – 7.0
0.2 – 0.4	7.0 – 18.0
0.4 – 0.6	18.0 – 31.0
0.6 – 0.8	31.0 – 50.0
0.8 – 1.0	more than 50.0

The land use has an impact on runoff conditions associated with the development of flash floods from several aspects. Firstly, it affects the infiltration process, which may be reduced to a minimum or fully eliminated in some types of land use. In another aspect, the different types of land use are largely associated with an appearance and volume of microdepressions affecting the share of causal rainfall, which is a part of surface runoff. Another important element in terms of flood flows is the fact that the types of land use can be correlated with the surface roughness. It plays an important role in the speed of water flow on the surface, and thus largely contributes to influencing the speed of water runoff from the catchment area (David 2008).

The raster representing the land use of the Poprad river catchment territory was assessed based on the classification of ortho photo images in ArcGIS environment. For the classification purposes, there was used the method of maximum likelihood. The ortho photo images were classified to the following categories: forest, agricultural land, meadows and grasslands, urban and industry areas (also the traffic infrastructure) and water bodies. Based on their retention capabilities, they were then assigned with the weights (0 - 1 interval) representing their impact on the flood susceptibility.

Weight – index	*Land use*
0.0 – 0.2	Forest (based on the tree species composition)
0.2 – 0.4	Meadows and grasslands
0.4 – 0.6	Agricultural land (with field crop and non sowed)
0.6 – 0.8	Urban and industry areas
0.8 – 1.0	Water bodies

Soil erosion is a natural process that is often demonstrated by irreversible changes in physical, chemical and biological properties of soil (Bielek 1996). It is a physical phenomenon resulting in removal (transposition) of soil particles by mechanical action of exogenous factors having a kinetic energy, such as rain, flowing water (surface runoff) and the wind, rarely ice, melting snow and animals (Fulajtár, Janský 2001). In our soil and climate conditions water erosion occurs most frequently. The erosion process includes partial sub-processes, which are represented by a loose (disintegration of the soil surface), transported (on the soil surface) and accumulated (sediments in the slope depressions) soil material.

The assessment of susceptibility to the flooding was performed using the map algebra tools and fuzzy logic in Idrisi Taiga environment.

The resultant susceptibility is determined by considering the individual factors (adding together the individual weights using the “Map Calculator” module in Idrisi Taiga environment. The resultant sum of weights was classified into 5 classes (grades) of susceptibility to the flooding (flood danger), using the "Reclass" module.

For evaluation of susceptibility to flood occurrence directly the urban environment, the methodology used in the study published by UNESCO-IHE (2010) was applied.

The susceptibility was assessed on the base of factors:

- *Social* (literacy level, preparedness, awareness of danger, industrial population, trust in institutions, hospitals, population with an access to sanitation, population with an access to the water sources, quality of water sources, quality of energy sources, population growth, health state of population, urban planning),
- *Economic* (unemployment, salaries, quality of infrastructure, average age of population, urban growth, regional GDP/capital),
- *Environmental* (natural reserves, average age of population, quality of infrastructure, health state of population, urban growth).

Information on each factor were obtained at the Municipal Office in Poprad, the Department of Civil Protection and Crisis Management of the District Office in Poprad and derived from the available digital data.

Data assigned to individual factors and the way of their acquisition:

- *Educational level (Literacy level)*: lower to a low level of literacy is expected, especially in the gypsy community, therefore localities inhabited by gypsies were identified as most susceptible to flood.
- *Preparedness*: it was evaluated in terms of availability and ability to use the necessary material and technical equipment, as well as a sufficient number of capacities to cope with the flood. The necessary data were obtained from the Department of Civil Protection and Crisis Management of the District

Office in Poprad. These data are updated annually. In terms of emergency works, the planned number of forces and means was evaluated as sufficient for the 100-years flood. The problem can be expected by a 500-years flood in terms of emergency and safety works, there will be a problem with the supply of sand bags, especially during the flood, as well as the number of coping capacities that will be insufficient.

- *Awareness of danger*: it was assessed based on the survey among citizens of Poprad city. Overall, it was collected and evaluated totally 550 questionnaires. The survey respondents were approaching directly in the streets (430 respondents) or through the social network - Facebook, where they have been linked to the website to complete the questionnaire. Totally, 120 questionnaire forms were completed online. Selected number of respondents was determined on the basis of compliance with the representativeness of the studied sample. Data collection for questionnaire took place in the terrain in all urban areas in the period November 2009 - June 2010. Data collection via Internet took place from the beginning of March 2010 to the middle of June 2010.
- *Trust in institutions*: it was assessed on the basis of consultation with staff of the Municipality of Poprad, the District Office in Poprad and members of District Directive of Fire and Rescue Service in Poprad. The confidence level was evaluated as a fair.
- *Hospitals*: in the city of Poprad there were identified two medical centers of this type - Hospital Poprad, s. c. (capacity of 622 beds), Clinic ADUS.
- *Population with an access to sanitation*: it was assessed on the basis of consultation with staff of the principal architect of the Poprad city. Overall, the situation with access to sanitation in the Poprad city was evaluated as very good. For areas with a reduced access to sanitation were selected areas inhabited by the gypsy community and gardening and cottage areas.
- *Population with an access to the water sources*: was assessed on the basis of consultation with staff of the principal architect of the Poprad city. The situation can be assessed as very good, as almost all residents (99.9%) have access to drinking water, about which takes care the Podtatranska Water Company. Problems with an access to drinking water occur in gardening and cottage areas only.
- *Quality of water sources*: it was assessed on the basis of consultation with staff of the principal architect of the Poprad city. The quality of water supply was evaluated as very good, in comparison with other EU countries.
- *Quality of energy sources*: was established on the basis of consultation with staff of the principal architect of the Poprad city and on the information contained in the “Analysis of Poprad district territory related to the possible emergencies”. Over the territory of the Poprad district is led an energy grid of 400 kV, 220 kV, 110 kV and 22 kV. The quality of energy sources can be considered as sufficient. Impaired access is only in the areas inhabited by the gypsy community, cottage and gardening areas. All the city wards are connected to gas and electrical wiring. Over the Poprad district are also led the gas pipelines. Distribution of public water and public sewers provides Podtatranska Water Company situated in Poprad. Wastewater treatment plants are provided by individual towns and municipalities in the Poprad district, under its jurisdiction.
- *Buildings utilization*: data on the buildings use were saved in the numeric code in the attribute table corresponding to the vector layer of buildings situated in the territory of the Poprad city. It was obtained from Topographic Institute in Banska Bystrica. From the flood protection and possible evacuation point of view as the most critical objects were identified schools, medical facilities, institutional facilities, cultural monuments, museums and galleries.
- *Population growth*: data were obtained from the website of the Statistical Office of the Slovak Republic. As in Slovakia as in Poprad city appears gradual decline in population growth due to lower birth rate.
- *Health state of population*: data obtained from the website of the Statistical Office of the Slovak Republic. In Slovak population (and hence in Poprad) for the previous period incidence of obesity, high blood pressure decreased only very slightly and minimally decreased also the number of people with higher level of total cholesterol. Smoking in our society is still increasing. Similarly, the stress load

is increasing, especially by people with tertiary education and women. This is also related to the growing number of depression. Great impact on the health status of the population has evidently the workout and eating habits. Based on these facts the health of the population was rated as less satisfactory.

- *Urban planning and urban growth*: data were obtained from the staff of the principal architect of the Poprad city. With a city growth, and thus the enlargement of urban zones is planned for housing development in the housing estate called South 4, where is planned the building of new four-storey block of flats and houses, next in the housing estate called South 3, where is planned building of 8 - to 13 - storey block of flats in the direction to Teplica. In Velka, near the cemetery, is planned building of a new street of houses. The building of new houses is currently being planned in Spisska Sobota. The building completion is planned for housing estates called South 5 and 6, and West near the shopping center. In all three cases the building of residential houses is planned. In Kvetnica the reconstruction of original family houses is planned. Near the "Obalovacka" locality, towards Kvetnica, on the left side is considered the building of new houses, on the right side is considered the individual housing development for about 60 families.
- *Unemployment*: data were obtained from the records of the District Labour Office (OUP) in Poprad. The unemployment rate was 16.2% in Poprad in the end of April 2010. According to the records of the District Labour Office (OUP) in Poprad, there were 8414 unemployed persons in the evidence at the end of April 2010. Almost the 53% of all unemployed persons are those who do not work for a long time.
- *Salaries*: data obtained from a questionnaire survey of Merces.sk, which is operated by the Profesia portal. Results of the questionnaire survey showed that the average gross salary in the Prešov region is around 605 EUR, which ranks the region among the areas with the lowest incomes in Slovakia. But on the other hand, there are lower property and goods prices like in Bratislava and Trnava region, where the salaries are from 40 to 60% higher.
- : it was assessed on the basis of consultation with the staff of the principal architect of Poprad city and on the information contained in the “Analysis of Poprad district territory related to the possible emergencies”. The road network in the district of Poprad is provided by the roads of the 1st class, 2nd class, 3rd class and motorway between Štrba and Jánovce. In this section of motorway there is also situated a motorway tunnel Borik with a length of 999 m (Mengusovce). The situation is satisfactory only on the highway and roads of the 1st class, which are under the administration of the Ministry of Transport. Roads of the 2nd and the 3rd class are under the administration of the Prešov region. Railroads existing in the district of Poprad are provided as twin track electrified railway, monorail and monorail electric railway. Air transport in the district of Poprad is provided by the airport Poprad – Tatry, situated in the northwestern part of Poprad city.
- *Regional GDP/capital*: data were obtained from the Eurostat evaluation. The Prešov region lags in economic development and salaries of the population behind the level of the Slovak Republic. Prešov region contributes nine percent of capacity on production of a national gross domestic product (GDP), what represents the smallest share of all eight regions of Slovakia. This results from the evaluation of Eurostat. Regional GDP is growing gradually, but nevertheless is still a below-average in the EU. Poprad is one of the most developed areas of the Prešov region.
- *Land use*: it was evaluated based on results of land use classification of ortho photo images. The most vulnerable is the urban area (in case if the drainage fails) and agricultural land in terms of torrential rain or long-term rainfall. The highest retention capacity has forest.
- *Degradation area*: on the area of Poprad city there is no degradation area.
- *Population of the Poprad city*: 52 590 citizens (towards the March 31st, 2010). The data was obtained from the evidence of Municipality Office of Poprad city.
- *Population in poverty and poor areas*: identified were localities populated with the gypsy communities. These are concentrated in Lidicka street in Matejovce city ward, near the administrative building of the

Slovak Water Management Enterprise in Straze pod Tatrami city ward and in the Social Centre in the Levocska street in housing estate called Banicka.

- *Urbanized area percentage*: percentage share was calculated as a proportion of industrially developed area of the city to the total area of the city. From the results figures that approximately 90% of the city is represented by the urbanized area, the remaining 10% is agricultural land.
- *Industrial population*: in this case in a GIS environment were identified the industrial, manufacturing and storage facilities. Large industrial park was built in Matejovce city ward. Except it, there are also Tatravagonka, s. c. Poprad, TATRAMAT, s. c. Poprad, Whirlpool Slovakia Ltd. Poprad, Baliarne obchodu Poprad, s. c. Poprad, TATRAKON, Ltd., Poprad.
- *Percentage share of a young and elder generation*: it was set on a base of register managed by the Municipality Office of Poprad city. Children (0-18 years) = 9,574 persons = 18%, adults (18-60 years) = 35,033 persons = 67% and the generation over 60 years = 7,983 persons = 15%.

RESULTS AND DISSCUSION

Flood susceptibility of the area was evaluated based on an assessment of meteorological conditions, soil conditions and geomorphology and land use parameters. It is a methodology appropriate for the assessment of flood risk caused by torrential rain.

The assessment of susceptibility to flood was performed in terms of meteorological factors was carried out based on a factor of torrential rain erosion effect - the R - factor. Results of the analysis pointed to the fact that the considered territory and there are two levels of flood danger in the analyzed area – the medium and high danger. Medium risk area occupies 71.73% of the total area of Poprad river catchment. Very susceptible to flood localities occupies 28.27% of the total catchment area.

In the terms of soil conditions, for the assessment of susceptibility to flood, there was applied an approach which evaluates the loss of soil caused by torrential rain, calculated as an amount of eroded soil (t / ha / year).

Based on the results of susceptibility assessment, taking into consideration the soil conditions, it can be concluded that on the analyzed area were found only one degree of flood danger - low danger, in which it is intended that the soil in the volume of 0 - 4 tons / ha / year will be carried away. Endangered area occupies 47.11% of the total area of Poprad river catchment.

In terms of assessing the terrain morphology, where the susceptibility to flooding was expressed by terrain slope, it was found that there are four degrees of flood danger - no danger, low danger, medium danger and high danger. The area with no danger occupies 15.76% of the total area of the Poprad river catchment, low danger area occupies 14.47%, medium flood danger occurs on 14.79% of the area and high flood danger occupies 54.98% of the catchment area.

Type of land use was assessed for particular classes which were obtained by classification of the ortho photo images in ArcGIS environment. The images were classified to categories: forest, agricultural land, meadows and grasslands, urban (municipal) and industrial areas (including transport infrastructure) and the rivers and lakes.

Medium risk is represented in terms of agricultural land low water retention capacity. High risk was assigned to water bodies existing on the area of Poprad river catchment. Particular flood danger degrees cover the following areas: no danger areas occupy 59.75% of the catchment total area, low danger occupies 11.66% of the total area, medium danger 17.58%, high flood danger occupies 5.91% and very high risk occupies 5.11% of the Poprad river area.

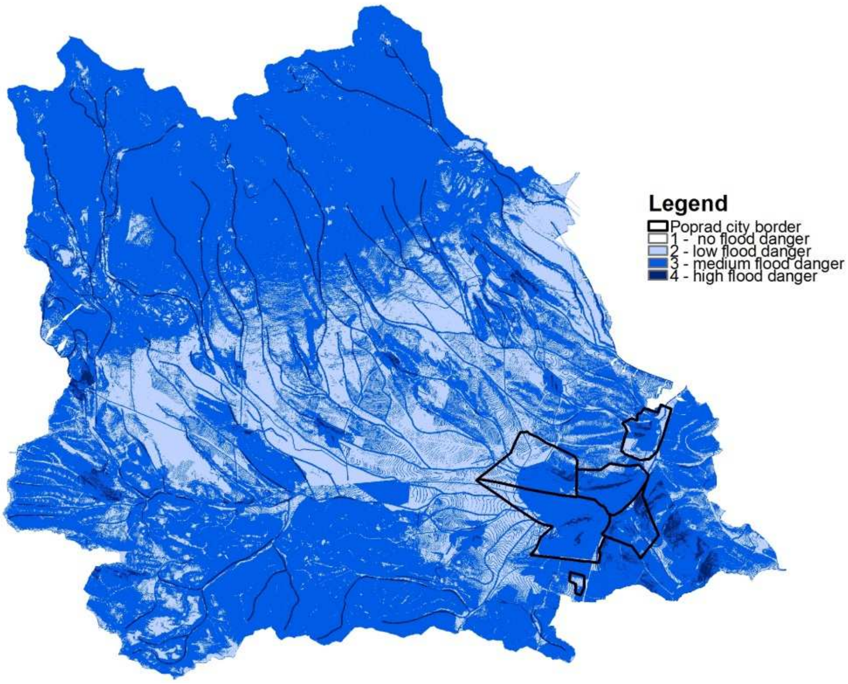

Fig. 2 Results of the flood susceptibility assessment for the area of Poprad river catchment

The resulting susceptibility to flood of the Poprad river catchment was calculated as the sum of the weights of the factors considered. In this way, that sum was re-classified into 5 degrees of flood danger, based on the following intervals: 1 (0.0 - 0.2), 2 (0.2 - 0.4), 3 (0.4 - 0.6), 4 (0.6 - 0.8), 5 (0.8 - 1.0). Analysis result is shown in Fig. 2 in the form of a map output.

The overall assessment of the flood susceptibility showed that the following flood dangers exist in the analyzed catchment: low danger (2) occupies 25.57% of total catchment area, medium flood danger (3) was found on 71.06% of the area, and high flood danger (4) occupies 3.37% of the catchment area. The high proportion of catchment area with a medium flood danger is caused by two particular factors mainly: slope of the terrain and the erosion factor of torrential rain which is related to high altitudes in particular.

Information about the flood susceptibility of an area should belong among the elementary data of crises managers for the planning of preventive flood protection measures.

The assessment of susceptibility to flood for the urban area of Poprad city was performed based on the application of the UNESCO – IHE methodology for an assessment of vulnerability to flooding. There were evaluated the particular factors which are shown in Table 1 together with the weights assigned to them based on the subjective evaluation of current state and considering also the number of inhabitants threaten by a negative factor compared to the overall population of Poprad city.

Tab. 1 Weights assigned to factors (0 – no flood danger, 1 – very high flood danger)

Factor group	Factor	Assigned weights
Social	Educational level (Literacy level)	0.05
	Preparedness	0.3
	Awareness of danger	0.9
	Industrial population	1
	Trust in institutions	0.5
	Hospitals	1

Factor group	Factor	Assigned weights
	Population with an access to sanitation	0.05
	Population with an access to the water sources	0.05
	Quality of water sources	0.01
	Quality of energy sources	0.05
	Population growth	0
	Health state of population	0.5
	Urban planning	0.3
Economic	Unemployment	0.4
	Salaries	0.8
	Quality of infrastructure	0.3
	Average age of population	0.4
	Urban growth, Urban planning	0.3
	Regional GDP/capital	0.5
Environmental	Natural reserves	-
	Average age of population	0.3
	Quality of infrastructure	0.2
	Health state of population	0.5
	Urban growth	0.3
Physical	Buildings utilization	-

The evaluation was not elaborated in graphical form, because not all the factors could be expressed graphically. Therefore it was done only in text form. When we are assessing the susceptibility to flood in urban area, we should evaluate it based on the community vulnerability, because the susceptibility is a component of vulnerability. Therefore the vulnerability can also be calculated based on the formula: Vulnerability = Exposure + Susceptibility – Resilience. Vulnerability should be also expressed as a function of susceptibility. We have used this approach to evaluate the susceptibility of the Poprad city urban area to flood.

The susceptibility to flood was assessed based on the data that were obtained from relevant administration offices and their documents. The results showed that the overall susceptibility to flood was evaluated as low (low flood danger). The low flood danger (2) was found out also by evaluation of social and environmental factors. It is mainly caused by the low level of danger awareness, relatively low level of confidence to institutions and the worse health state of population, The evaluation of economic factor indicated medium flood danger (3). It is mainly due to the low regional GDP and low salaries, in comparison to the other regions of Slovakia.

As the most susceptible to flood were indicated the localities populated by gypsy communities and mainly due to their low level of literacy, problems with an access to sanity, energy and water sources.

Serious problem, in terms of flood susceptibility (vulnerability), is the relative low level of flood danger awareness. It was shown in results of the survey that was performed in all city wards. More than one-half of the respondents have no information about the flood danger in the area of living or working.

The only way how to reduce the susceptibility of the Poprad city citizens to flood is to prepare some courses teaching people how to cope with flood and to know about the flood danger in the place of their living, and which next preventive measures they should carry out to protect their property.

CONCLUSIONS

Flood activity, which could be observed at the end of the first half of year 2010, belonged among the largest floods in Slovakia over the past 40 years. Today, the question of the climate change impact on development of the flood situations comes to the interest of many specialists. It is due to the increased flood activity not only in Slovakia but also in Europe. Impacts of climate change are becoming more significant, its intensity already could be felt at the local level.

In the future, based on the prognoses of climate change progress it is required to reflect and prepare themselves for more and more frequent occurrence of extreme weather, from drought to extreme rainfall, whether in the form of long-lasting rain or torrential rain or their combination leading to a flood occurrence also in the locations where there exist no water flow and where floods have never seen.

To know the hazards and susceptibility of the areas for their formation, which in the case of proper precautions lack can lead to large-scale incidents, is the important prerequisite for the vulnerability reduction and design and implementation of suitable and sufficient preventive measures. Implementation of GIS tools in the risk assessment and management is a logical choice, considering all its functions and tools.

In the article there were introduced two approaches to the flood susceptibility assessment. The first approach is more appropriate for assessment of the natural environment. The second one is the most suitable for its application for urban areas.

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