FLOOD DAMAGE ASSESSMENT

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ABSTRACT
Floods are among the extreme manifestations of the circulation of water in nature, flood protection is also a process which is never ending for human civilization. It began long ago in the distant past and will always be, unfortunately with very uncertain results, a component of each successive stage of the development of society. At present trends around the globe appear to be indicating that in subsequent periods the danger from flooding will increase. The range and extremity of flood episodes demonstrate the necessity for a complex proposal for building or supplementing flood protection measures in potentially flooded territories. In association with research of flood risk and meeting the targets of the Directive, more and more attention is continually being paid to methods focused on the assessment and analysis of risk, because they enable us to assess the effectiveness of costs of mitigating measures, and thus optimize investments. The analysis of flood risk can also be derived independently of the relation of the object of risk to the unwanted events, or floods. The paper deals with the resolution of the problem of managing flood risk with the aim of effective management focusing on reducing flood risks and thus increasing the measure of flood protection. It is elaborated in the sense of currently valid Slovak legislation in the field of flood protection, primarily according to the already mentioned Directive 2007/60/EC on the assessment and management of flood risks.
Keywords: flood damage, economic flood damages, loss curves, Bodva river basin.

1 INTRODUCTION

Just as floods are among the extreme manifestations of the circulation of water in nature, flood protection is also a process which is never ending for human civilization. It began long ago in the distant past and will always be, unfortunately with very uncertain results, a component of each successive stage of the development of society. At present trends around the globe appear to be indicating that in subsequent periods the danger from flooding will increase. The range and extremity of flood episodes demonstrate the necessity for a complex proposal for building or supplementing flood protection measures (FPM) in potentially flooded territories. In association with research of flood risk and meeting the targets of the Flood Directive [1], more and more attention is continually being paid to methods focused on the assessment and analysis of risk, because they enable us to assess the effectiveness of costs of mitigating measures, and thus optimize investments. The main aim of risk analysis of flooded territories is to estimate the need for protective measures. The analysis of flood risk can also be derived independently of the relation of the object of risk to the unwanted events, floods. Slovakia belongs to the countries which are increasingly being affected by floods (Zeleňáková [2], [3]). Floods constantly point to the fact that the society is very vulnerable, but it has been proved that flood-related problems could be solved through planning studies and detailed projects about flood prone areas (Hanák and Korytárová [4], Hlavčová et al. [5], Korytárová et al. [6], Solín [7]). Achieving the goals of directive 2007/60/EC [1] is implemented in the legislative of the Slovak Republic Act no. 7/2010 on the flood protection [8].

Floods endanger the lives and health of the population, cultural heritage and the environment and cause damage to property while limiting economic activity. It is not possible be prevent all flooding, but we can determine the amount of flood damage and subsequently

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estimate the measure of flood risks. Determining the measure of flood risks is desirable particularly for the proposal of effective flood protection measures.

The total amount of damage caused by flooding is used primarily for the needs of compensation for flood damage, for international comparisons and likewise enter into statistics which deal with the registering the damage caused by floods and other natural disasters. It is not possible to express the objective (so-called completely exact) amount of damage caused by floods, because we are not capable of valuing a significant portion of damages or the valuation techniques are so complicated that we back away from such processes. This is especially true regarding estimates of destroyed cultural values, loss of human line and damage to the environment.

The main goal of the contribution is the proposal of a process of assessment of flood risk with the aim of reducing adverse consequences on human health, the environment and economic activities associated with floods.

2 MATERIAL AND METHODS

Methods and approaches to risk analysis are in general and in application well developed. Likewise, many projects focused on the assessment of flood risk and the determining of flood damage for the protection of people and their property in flood territory has been resolved. This subject has been elaborated in several publications e.g. Dráb [9], Drbal et al. [10], [11], Satrapa et al. [12], Dráb [9], Říha et al. [13]. Generally, it can be stated that the majority of methods for determining of potential flood damage (material damage) used in the world come from the same principle of application of the method of loss curves (Horský [14], Gaňová [15], Zeleňáková et al. [16]). The methods express, using loss functions, the size of the damage directly in money depending on the hydraulic parameters of the flood (depth, speed, duration) (Nascimento et al. [17], Meyer and Messner [18]), the size of the damage by percent of damage from the price of the object per measured unit (Horský [14]), or by percent of damage from the maximum amount of damage to an object.

The use of mathematical models and geographical information systems has become a completely common instrument for the assessment and interpretation of data in flood management. The goal of deploying these resources lies particularly in speeding up the processing of risk analysis of flooded territories and subsequently the creation of maps of flood damage and risks. Equally, a goal is to use those data sources which would be easily accessible, maintained over time and that have a unified form for the entire territory. Likewise, multi-criterial analysis has also become a common tool used in flood management, or an aid in the decision-making process.

The methods which are used in the contribution come from practical experience as well as knowledge obtained from the available literature and consultations with experts dealing with the given issue in practice. A methodological process for selecting effective flood protection measures in order to implement the aims of flood-risk management is proposed. The proposal of a process for selection of the most effective combination of measures with respect to reducing the impact of floods on human health, the environment and property consists in calculation of loss of human life as well as environmental and economic damage. This process can serve as a foundation when elaborating plans for management of flood risks with regard to the requirements of implementing Directive 2007/60/EC [1].

The objective of the paper is to develop a general methodology for preliminary flood risk assessment of flash floods and to select effective flood protection measures according the objectives of flood risk management.

On the basis of the determined consequence (potential flood damage) for the selected flood event it is possible to determine the measure of flood risk. Method of expressing flood risk depending on the consequence. Generally, we can express risk as the product of probabilities of occurrence of an adverse event and the consequences of this event according to the eqn (1):

$$risk = probability \times consequence\,. \tag{1}$$

Risk thus has the same dimension as the consequence, which expresses the loss or damage arising, in monetary or physical units (number of accidents, deaths, etc.). From this it follows that in the case of calculation of the average annual risk, the probability is still the same; the difference is in the consequence, as is presented in Table 1.

For calculation of direct potential flood damage to property a general formula is used (Horský 2008 [14]):

$$D_{Pik} = S_{ik} P_k L_k\,, \tag{2}$$

where: D_{Pik} isthe value of quantified damage to the given object i in category k [€]; i is index of the building in the given category k; k is index of individual assessed categories described below; S_{ik} is size or amount of the affected object according to category [unit, m, m^2, m^3]; P_k is unit price of the measured unit according to the assessed category [€/unit; €/m; €/m^2; €/m^3]; L_k is loss for individual categories expressed in dependency on the floods or depth of flooding [%]. The total damage to property in the assessed territory is calculated as the sum of damage to the individual categories of property (buildings and engineering constructions).

With the calculation of risk, the distribution function of the annual culmination of overflows is defined by relationship (2) (Satrapa et al. [12]):

$$F(Q_x) = \int_0^{Q_x} f(Q)dQ\,, \tag{3}$$

where $F(Qx)$ is the value of the distribution function for overflow Qx, that is, the probability that an overflow Qx will not be exceeded in a given year, which is given using relationship (4) Satrapa et al. [12]:

$$P\,(Q) = 1 - 1/N(Q), \tag{4}$$

where $N(Q)$ is the period of recurrence of the N-th year overflow Q.

In the following is assessed economic, environmental and social risk in consequence of floods.

In the case of damage to property risk is expressed from an economic point of view as the average annual flood risk ERp presented in units of €/year. Risk is calculated according to equation (4), which comes out of dividing the probability of annual peak overflows (Drbal et al. [10], [11], Satrapa et al. [12]):

$$ERp = \int_{Q_a}^{Q_b} D_E(Q)dF(Q) = -\int_{Q_a}^{Q_b} D_E(Q)dP(Q) = -\int_a^b D_E(N)d\frac{1}{N}\,, \tag{5}$$

where: ERp is average annual economic flood risk [€/year], $D_E(Q)$ is a value of economic damage during overflow Q_N, Q overflow [m^3/year].

Relationship (5) is easily solvable numerically. Damage $D_E(Q)$ linked to the course of an overflow is appropriate to relate to the period of recurrence $D_E(N)$. For further derivation it is possible to accept the assumption that the amount of damage $D_E(N)$ is linearly dependent

Table 1: Method of expressing flood risk depending on the consequence.

Risk	Consequence	Method of expressing risk
Economic risk ER	Damage to property	Economic expression of risk in monetary units – in euro.

on the logarithm of the period of recurrence in the interval between the values *a* and *b*, for which damage is known.

Damage $D_E(N)$ is then calculated according to the following relationship (6) (Satrapa et al. [12]; Horský [14]):

$$D_E(N) = D_{Ea} + A(\ln N - \ln a), \tag{6}$$

where: $D_E(N)$ is economic damage with overflow with a period of recurrence N; N, a, b are marginal values of the interval of the period of recurrence; A is the direction of the vector in the interval between ln$a$ and ln$b$ on the x-axis (the damage gradient), which is calculated according to the eqn (7):

$$A = (D_{Eb} - D_{Ea})/(\ln b - \ln a). \tag{7}$$

Economic risk can be expressed for the interval of periods of repeating (a, b) in the form of (8):

$$ERp_i = -\int_a^b (D_{Ea} - A\ln a + A\ln N)\,d\,\frac{1}{N}. \tag{8}$$

Economic flood risk is determined for each interval individually. The total economic flood risk is then given by the sum of risks in individual component intervals *ERp*, according to the determined economic flood damage to property.

The processing and analysis of input data as well as visualization of the achieved results is done in the GIS environment (ArcGIS) in integration with a spreadsheet program (Microsoft Excel).

Assessment of the effectiveness of flood-protection measures (FPM) is also done. In the case of economic risk, which is expressed in monetary form, the effectiveness of FPM is assessed from an economic point of view.

3 STUDY AREA

For practical application of the methodological process of selecting flood-protection measures with a focus on lowering the potential adverse consequences of floods on human health, on property and on the environment the town of Medzev in the component Bodva basin is selected. Medzev was in the scope of a preliminary assessment of flood risk in Slovakia evaluated as an area with the existing potential for significant flood risk.

The town of Medzev (Fig. 1) is found in the Košice District and its surrounding in the Košice Region. The River Bodva flows through the town with a left-side inflow from the Štósky, Porča, Piverský and Zlatná streams and a right-side inflow from the Grunt and Šugovský streams. The Bodva and the Zlatná and Piverský streams are assigned among the significant watercourses in water-management and at the same time are on the list among the managed watercourses.

Since Medzev is on the basis of preliminary assessment of flood risk ranked among areas with an existing flood risk, it is necessary to give priority to resolution of this area. In this

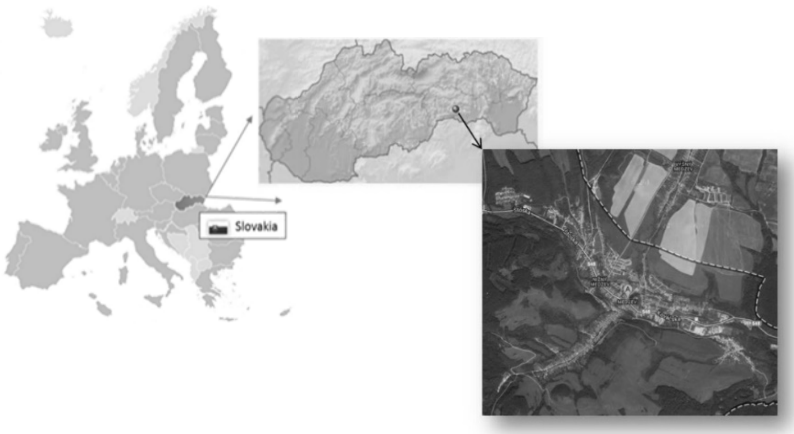

Figure 1: Localization of Medzev in Bodva river basin in Slovakia.

area it is necessary to construct flood-protection measures which will be effective not only in terms of protection but also from economic, social and environmental points of view.

4 RESULTS AND DISCUSSION

The goal of this portion of the contribution is an objective quantification of flood damage and flood risk in the studied location which is subsequently classified from the viewpoint of effectiveness and measure of acceptability. According to the proposed methodology the content of this part is divided into three steps:

- To calculate flood risk which comes from assessment of the range of damages for the determined flooded area and the probability of their occurrence.
- The selection of economically effective measures for flood protection.
- The result is the proposal of possible FPM which will be effective from the viewpoint of protection (economic as well as environmental).

In the following Table 2 the calculated values of potential flood damage are presented in the interval values in which the actual damage (min, max) should move in euro for the flow of Q_{100}. Damage is listed for the individual categories of property and in a total sum for the studied location.

Table 2: Resultant flood damage to individual categories of property.

Object		**Unit**	**Flooded by Q_{100}**	**Potential damage [€]**	
				min	**max**
Buildings		piece	106	838 069	1 754 652
Engineering constructions	Surface roads	m^2	3686.75	14250	28422
	Engineering networks	m	473.50	4900	5812
Agriculture		ha	6.93	1766	9600
Total flood damage				**848 835**	**1 798 486**

Table 3: Resulting value of total economic risk *ER*.

Measure of protection of potential FPM	Risk [€/year]	
	ER before FPM implementation	*ER* after FPM implementation
Q_{100}	72493	8494

Risk is quantified for the current state, i.e. before implementation of FPM and for the state after possible implementation of FPM. The higher the proposed measure of flood protection is, the lower is the value of the measure of flood risk after the measures are implemented (Table 3).

The goal of selecting effective flood protection measures in the studied territory include:

- the removing of soil deposits from the water channel and vegetation from the bank of the watercourse, thus securing the overflow capacity of the watercourse,
- for the unaltered sections of the watercourse to make modifications, e.g. to reinforce the slopes of the water channel,
- if necessary construction of a reservoir above the town which lowers the maximum overflow during increased water stages.

The construction of reservoir – dry basin above the municipality seems to be the most effective flood protection measure in the area. The cost of the construction would have been lower that max calculated potential flood damages, so less than 1,798,486 €.

5 CONCLUSION

Floods, the frequency of which has shown an increasing tendency in the past decades and whose consequences accounting for environmental and economic losses, have a very special place in the field of natural catastrophes. And for these reasons the resolution of questions of flood protection are quickly acquiring a broader international dimension, and pressure is increasing for the implementation of complex and systematic measures of protection. The transition from flood protection to complete flood management is reflected most of all in Guideline 2007/60/EC on the assessment and management of flood risk. The Guideline consolidated national approaches to flood management and control and likewise brought parallel development in the field of assessment and management of flood risk of member states of the European Union.

The submitted contribution deals with the current subject of floods, which follows not only from their occurrence but also due to implementation of the mentioned Guideline 2007/60/EC. The main objective of the contribution is proposal of a methodological approach to controlling flood risk, which is in the case of available documents usable in practice. Obtaining knowledge about the kinds of potential flood damage on property, the environment and human lives is important primarily for the professional public, especially with decision-making or whether it is necessary to build FPM or if the proposed FPM will be gainful.

The proposed methodological approach is applied in a modelled territory. Assessment of potential flood damage and subsequent determining of the measure of flood risk is carried out for the town of Medzev, which was in the scope of preliminary assessment of flood risk in Slovakia evaluated as an area with an existing potentially significant risk of flood. Given the preliminary results, we can state that in the studied location Medzev the building of FPM makes sense, mainly in relation to the protection of property and the environment Zeleňáková et al. [19], and Zeleňáková [20]. In regard to the second question about what measure of flood protection should FPM be designed, in this case the decisive factor is economic effectiveness, since social risk does not need to be reduced and the measure of environmental risk is lower than with Q_5. Because the actual proposed FPM, and thus their costs, are not known, it is not possible to assess this effectiveness. For determining effectiveness, it is necessary to obtain documents on the proposed solutions of flood protection measures and subsequently assess the economic effectiveness of the individual assessed FPM variants. The obtained results can then be subsequently applied during the selection of the final FPM solution in the studied location.

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