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Assessing Flood Mitigation Alternatives in Brezovička Village in Slovakia

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Abstract

Flooding due to extreme rain events in urban environments is a problem and a growing concern. There is an increasing demand for a new paradigm to improve flood-mitigation decision processes that calls for risk-reduction strategies at several levels. Therefore is a challenge in assessing and comparing different flood mitigation measures. The aim of this paper is to explore a new method to improve an environmental impact assessment of flood-mitigation measures in decision processes by risk analysis method.

Key words: flood mitigation measures, environmental impact assessment (EIA), alternatives, risk analysis (RA)

1 Introduction

Extreme rain events have always been a problem and a challenge in the urban society. When they occur in urban areas the consequences can be striking with severe flooding and damage to properties and infrastructure. There are two main categories in flood mitigation measures: structural and non-structural. Structural measures reduce flood risk by constructed objects or modifications that control the surface water flow while non-structural measures reduce flood risk by keeping people safe through better planning and urban development. Examples on structural measures are embankments, barriers, conveyance of surface water and flood storage while examples on non-structural measures are emergency planning, awareness campaigns, flood warnings systems and land planning [1]. For undeveloped areas there are naturally better possibilities to introduce risk reducing design by safe flow route planning and sustainable urban drainage systems. For developed areas there is often a greater challenge to implement solutions and reduce the risk because of, for instance, lack of space and difficulties to change existing constructions. But also small and inexpensive changes in the landscape may create relatively safe flow routes and alleviate flood consequences [2].

In 2010, severe floods hit village Brezovička. Therefore, the municipality decided to propose flood protection measure in Brezovička by adjusting the river in the village. Adjust the water course aimed at flood protection is, according to the Annex. 8 of Act No. 24/2006 Coll. on environmental impact assessment and amending some other laws, proposed activity included in the field of water management as flood mitigation measures.

The aim of this paper is to apply the definition of risk for analysis linked to the environmental impact assessment of flood protection measures. This work involves calculation of the risk posed by hydraulic structures and the degree of flood protection they provide, and it presents the benefits in terms of the environmental assessment of these measures.

2 Material and methods

In the literature there are several studies considering risk analysis in construction projects [3], but risk analysis involving hydraulic structures, especially flood mitigation measures, is very limited. In classical project risk analysis techniques, risk rating values are calculated by multiplying probability and impact values, but direct analysis of the linguistic factors involved is often neglected [4].

This paper introduces a new approach for risk assessment of hydraulic structures (flood mitigation measures projects) using risk analysis. Risk analysis involves developing an understanding of the risk. It provides an input to risk evaluation and to decisions on whether risks need to be treated, and on the most appropriate risk treatment strategies and methods. It can also provide an input into making decisions where choices must be made and the options involve different types and levels of risk [5]. Risk analysis is an appropriate tool to determine the level of the risk of the proposed flood mitigation measures and through which it is possible to choose the alternative with the lowest level of risk for the environment.

2.1 Evaluation criteria of risk factors

Twenty-three risk criteria were identified and defined in flood mitigation measures proposal based on expert interviews, field studies and literature review. The risk criteria and their proposed values for risk analysis (RA) are listed in Table 1. The risk factors include the following, mainly technical, characteristics:

- *hydrological* (maximum specific drainage, 100-year flow, designated flow, average annual rainfall),
- *morphological* (morphological type of stream by Rosgen classification, coefficient of saturation in the basin, category of flow rate, average longitudinal gradient flow, type of basin),
- *ecological* (ecological significance of the area, occurrence of protected species of flora and fauna in the area, influence of intended activity to future appearance of landscape, cultural and historical importance of the territory, number of archaeological and paleontological sites and important geological sites),
- *territorial* (permanently resident population, coefficient of built-up area, type and importance of transport, infrastructure in the village, production activity of the territory),
- *technical* (distance of hydraulic structures from built-up areas, technical flood protection measures, degree of environmental protection, total cost of mitigation measures).

Table 1: Evaluation criteria of risk factors linked with flood mitigation measures

Risk criteria		Score of criterion				
		(0.2)	(0.4)	(0.6)	(0.8)	(1.0)
A	Maximum specific drainage q_{max}(m^3.s^{-1}.km^{-2})	≤ 10	11 – 50	51 – 90	91 – 140	≥ 141
B	100-year flow Q_{100} (m^3.s^{-1})	≤ 20	21 – 70	71 - 120	71 - 120	≥ 201
C	Designated flow Q_n (m^3.s^{-1})	≥ Q_{100}	< Q_{100}	< Q_{50}	< Q_{20}	≤ Q_5
D	Average annual rainfall H_z (mm)	≤ 500	501 – 600	601 - 700	701 - 800	> 801
E	Morphological type of flow by Rosgen classification	Aa+, A	B, C	D, DA	E	F, G
F	Coefficient of saturation in the basin *S* (mm)	≥ 21	16 – 20	11 – 15	6 – 10	≤ 5
G	Stream flow character (-)	stream	torrent	middle torrent	strong torrent	very strong
H	Average longitudinal gradient flow *i* (%)	≤ 10	11 – 20	21 – 30	31 – 40	≥ 41
I	Type of the basin (-)	-	elongated	transitional	feathery	-
J	Ecological significance of the area (-)	very small (area of 1st degree of protection)	small (area with 1st degree of protection)	large (area with 2st degree of protection)	very large (area with 3st degree of protection)	extremely large (area with 4st - 5st degree of protection)
K	Occurrence of protected species of flora and fauna in the area (-)	≤ 3	4-6	7-9	10- 12	≥ 13
L	Influence of intended activity to	without disturbing elements -	not intrusive	risk of a interference	risk of a negative interference	presence of symptoms, disturbing

	future appearance of landscape (-)	preserved harmonious landscape				elements in the country
M	Cultural and historical importance of the territory (-)	local	regional	national	national and sub-regional	international and national
N	Number of archaeological, paleontological sites and important geological sites (n)	0	1	2	3	≥ 4
O	Permanently resident population (number)	< 100	101 - 250	251 - 500	501 - 1000	> 1000
P	Coefficient of built-up area (%)	≤ 0.02	0.021 – 0.025	0.026 – 0.03	0.031 – 0.035	> 0.035
Q	Type and importance of transport (point)	≤ 1	2	3	4	≥ 5
R	Infrastructure in the village (point)	0 - 1	2 - 3	4 - 5	6 - 7	8
S	Production activity of the territory (point)	0 - 2	4	6	8	10
T	Distance of hydraulic structure from built-up areas (km)	> 5	1.1 – 5	0.51 – 1	0.11 – 0.5	do 0.1
U	Technical flood protection measures (-)	Constructio n of a polder and stabilization of the stream	Regulation and stabilization of the stream in an urban zone	Ensure the regulation of runoff water and flow capacity in the stream	Maintenanc e of the river basin, the river bed and riparian vegetation	No technical flood protection measures are implemente d
V	Degree of environmental	Significant losses of	Loss of human life	Loss of human life	Loss of human life	Significant losses of

	protection (-)	property and human life are not expected	and envi. damage is insignificant	and damage to the environment is unlikely	and damage to the environment is likely	property and human life are expected
Z	Total cost of measures (EUR)	0 – 100 000	100 001 – 400 000	400 001 – 800 000	800 001 – 1 200 000	> 1 200 000

These risk criteria were defined based on field studies and basic hydrological knowledge as well as resources [6], [7], [8], [9].

2.2 Importance of risk factors

In order to determine the relative importance (weight) of the risk criteria, a survey was conducted with water management experts and professionally-qualified persons who have experience in the construction of flood protection measures. Twenty experts participated in this survey. The participants were asked to grade the importance of the risk criteria regarding their impact and seriousness of concern. They graded the risk factors using a scale between 1-4, where 1 represents "low" and 4 "very high". The experts ranked the designated flow and basic technical flood protection measures as the most important risks linked with flood protection measures (Fig. 1).

The calculation of the standard weight criterion $W_j^{(N)}$ was based on the following equations (1) and (2):

$$W_j^{(N)} = \frac{w_j}{\sum_{j=1}^{n} w_j} \qquad (1)$$

$$\sum_{j=1}^{n} W_j = \frac{n}{2} \cdot (n-1) \qquad (2)$$

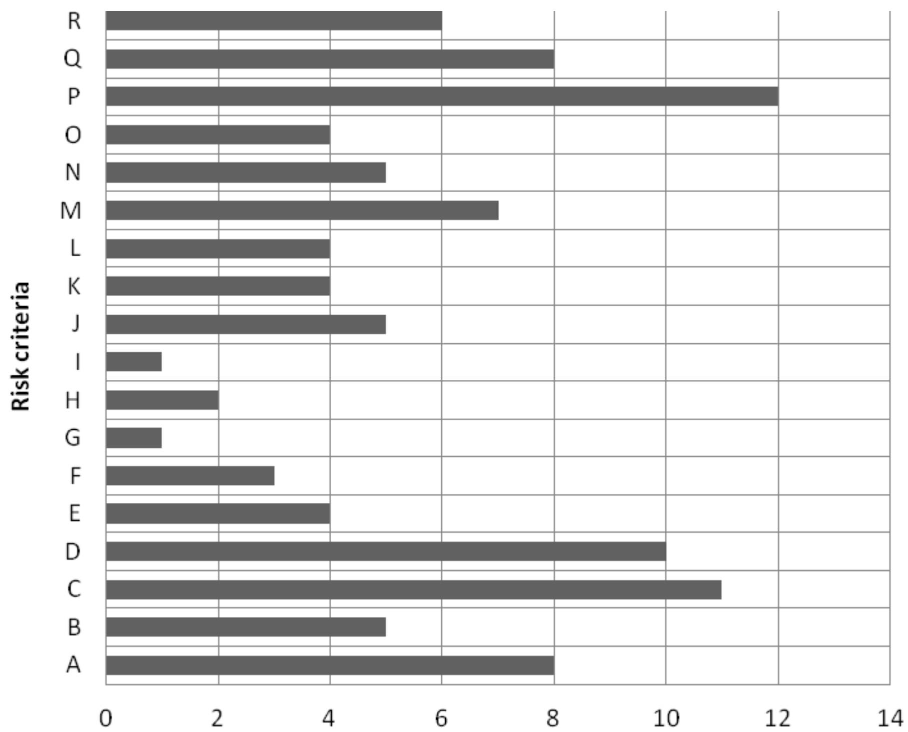
where: W_j^N - standardized weight of the risk; W_j - score (points) associated with *j* criterion; *n* - total number of assigned priorities.

Each risk criterion is assigned by relative importance (weight), which is entered, into the calculation of risk index *r* (more in Table 2). The proposed calculation of the risk index *r* applies weighting method and uses the proposed formula (3),

$$r = (A.w) + (B.w) + (C.w) + (D.w) + (E.w) + (F.w) + (G.w) + (H.w) + (I.w) + (J.w) + (K.w) + (L.w) + (M.w) + (N.w) + (O.w) + (P.w) + (Q.w) + (R.w) + (S.w) + (T.w) + (U.w) + (V.w) + (Z.w) \qquad (3)$$

where *r* is risk index, *A* – *R* are coefficients according Table 1 (0.2, 0.4, 0.6, 0.8 and 1.0) for each risk criterion, *w* is relative importance (weight) for each risk criterion.

The risk index *r* values calculated by using this method based on expert rating produce a 4-grade evaluation system: low risk having *r* values between 0.036 and 4.526; medium risk is between 4.527 and 9.017; high risk is between 9.018 and 13.508; extreme risk is between 13.509 and 18.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Relative importance (%)	8	5	11	10	4	3	1	2	1	5	4	4	7	5	4	12	8	6

Relative importance (%)

Figure 1: The importance of risk factors linked with flood protection measures based on the survey results

Calculation of the risk index *r* determines the risk posed by hydraulic structures for environment. It is directly related to the environmental impact assessment of activities under Law No. 24/2006 Coll. Under this law it is necessary to compare alternatives for the proposed activity and produce a proposal for the optimal alternative [10]. This proposal of the activity, which involves creating a set of criteria of risk factor to determine the assessment of each alternative, can be used as a reference element for selection of the optimal alternative, or to determine the suitability of the assessed alternative. It serves as a basis for justification of the optimum alternative.

3 Result and discussion

The proposal of this procedure using risk analysis for determining the risk of flood mitigation measures and choosing the best alternative of the activity is applied for flood mitigation measures proposal in the village of Brezovička. Brezovička is situated near Sabinov in north-eastern Slovakia, through which flows the stream called Slavkovský creek. This stream is a constant threat of flooding in the village. Therefore, the purpose of the screening activities

(according to Law No. 24/2006 Coll., [10]) is the regulation of Slavkovský creek to increase flood protection in the village.
Brezovička village (Fig. 2) is situated in the eastern part Levočské Mountains (Levočské vrchy) in the valley of the eponymous creek at an altitude of 467 meters. The population is about 420. It belongs to the administrative district of Sabinov in Prešov region.
Slavkovský creek flows through the village and is a right – side tributary of Torysa River. It belongs to Torysa catchment. The total length of the proposed regulation of Slavkovský creek is a 1 842.0 m.

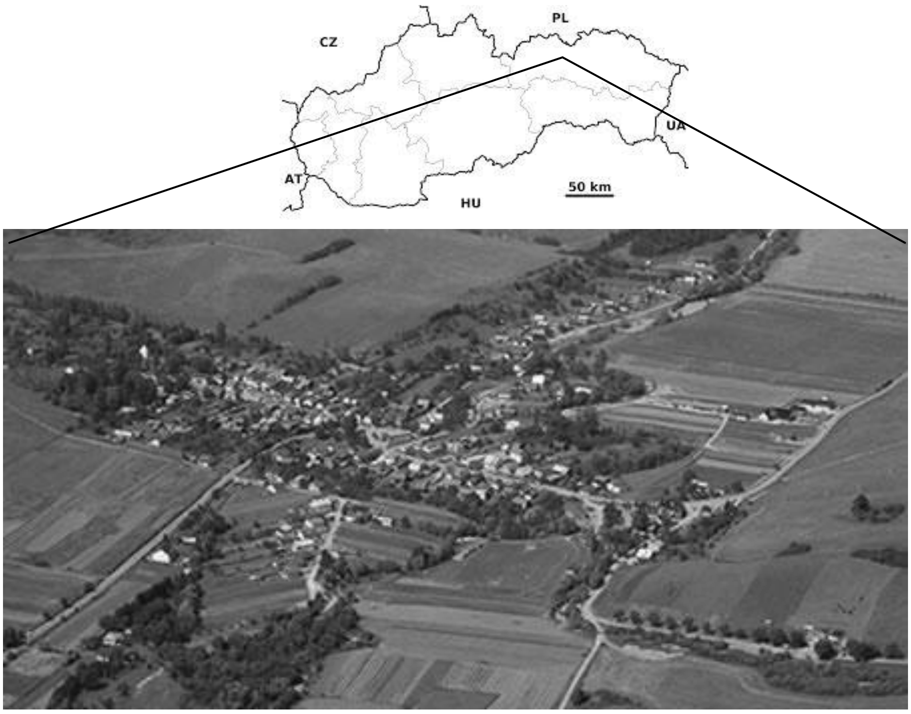


Fig. 1 Localisation of Brezovička village in the Slovak republic

In designing a route, as far as possible is used the routing of the existing river bed with accepting existing bridges on the stream. The purpose of the construction is to modify the flow profile of the stream Slavkovský creek in Brezovička urban community in order to safely transfer a designated value of capacity flow Q_{100} = 72 m^3/s, resp. Q_{50} = 60 m^3/s.

3.1 Risk analysis of proposed alternatives in Brezovička village for Slavkovský creek

The preliminary environmental study must contain two alternatives of the proposed activity at least, as well as the zero alternatives (alternative of the state that would occur if the proposed activity had not been carried out) [10].
Proposed alternatives for proposed activity "flood mitigation measures" in Brezovička village are:

- Alternative 0: stream bed will not be regulated – the current situation.
- Alternative 1: stream bed will be regulated by quarry stone bank stabilization with vegetation for Q_{100}.

– Alternative 2: stream bed will be prepared by quarry stone bank stabilization with vegetation for Q_{50}.

In Table 2 each risk criterion (*A* – *Z*) is evaluated using data from [11] as well as our own calculations.

Table 2: Risk analysis application for proposal of flood mitigation measures

Risk criteria	Score of criterion for alternatives			Relative importance index w_j	Risk indices for alternatives		
	0	1	2		0	1	2
A	0.2	0.2	0.2	0.08	0.016	0.016	0.016
B	1.0	1.0	1.0	0.05	0.050	0.050	0.050
C	0.6	0.2	0.4	0.11	0.066	0.022	0.044
D	0.8	0.8	0.8	0.08	0.064	0.64	0.064
E	0.4	0.4	0.4	0.04	0.016	0.016	0.016
F	0.6	0.6	0.6	0.03	0.018	0.018	0.018
G	0.6	0.6	0.6	0.01	0.006	0.006	0.006
H	0.6	0.4	0.4	0.02	0.012	0.008	0.008
I	0.4	0.4	0.4	0.01	0.004	0.004	0.004
J	0.4	0.4	0.4	0.01	0.004	0.004	0.004
K	0.2	0.4	0.4	0.02	0.004	0.008	0.008
L	0.8	0.4	0.4	0.01	0.008	0.004	0.004
M	0.6	0.6	0.6	0.01	0.006	0.006	0.006
N	0.4	0.4	0.4	0.01	0.004	0.004	0.004
O	0.8	0.8	0.8	0.05	0.040	0.040	0.040
P	1.0	1.0	1.0	0.03	0.030	0.030	0.030
Q	0.2	0.2	0.2	0.04	0.008	0.008	0.008
R	0.8	0.8	0.8	0.07	0.056	0.056	0.056
S	0.4	0.4	0.4	0.05	0.020	0.020	0.020
T	1.0	1.0	1.0	0.03	0.030	0.030	0.030
U	1.0	0.4	0.4	0.12	0.120	0.048	0.048
V	0.8	0.4	0.4	0.07	0.056	0.028	0.028
Z	0.2	1.0	1.0	0.05	0.010	0.050	0.050

The table shows the calculations of risk index *r* for three alternatives of flood mitigation measures using risk analysis. The numerical result of each calculation is known as the risk index (*r*). This index is used to compare different alternatives and to prioritize the alternative which has the lowest risk index value.

3.2 Recommendation of alternative for the implementation of the proposed activity

The obtained results (Table 3) represent the overall state of risk for the environment after implementation of flood mitigation measures for regulating Slavkovský creek in Brezovička village (Slovakia) by risk analysis. Unacceptable risk is assumed for Alternative 0 (the highest numerical value of the risk index). Risk is characterized as acceptable for Alternative 1. Alternative 2 can be characterized as undesirable (middle value of the risk index).

Table 3: The resulting risk acceptability

Alternative	Risk index	Risk for environment
0	0.582	low
1	0.462	low
2	0.484	low

Based on the evaluation of each risk criterion for flood mitigation measures in Brezovička village, we recommend the implementation of Alternative 1 because it achieves the lowest value of risk index. That means the lowest risk for the environment of village Brezovička from among the evaluated alternatives of flood mitigation measures.

4 Conclusion

The impacts of flooding on cities and towns can be devastating and deadly, resulting in the need to design and assessment of flood mitigation measures [12, 13]. Flood protection construction projects are a modern trend in flood protection and prevention in developed countries around the world. The unquestionable advantages of the measures involved are their sophistication, environmental friendliness and sustainability of land use. In their assessment it is necessary to ensure consistent application of the environmental impact assessment (EIA) in accordance with Law No. 24/2006 Coll. on EIA, as amended, so as to ensure the validity of the assessment. This paper suggests a new approach for RA of flood mitigation construction projects. Integrating RA and EIA is a potentially strong approach to improving decision-making for recommendation of alternative for the implementation of the proposed activity [14].

Application of the calculations for Slavkovský creek in the village of Brezovička revealed that Alternative 0, Alternative 1 and Alternative 2 have different values of risk indices. Based on the risk index the suggested variants can be compared with each other, and thus we recommend Alternative 1, which represents the lowest risk to the environment.

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