Risk Analysis and Flood Hazard Assessment in the Hornád River Basin

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Abstract. The paper focuses on assessing the effects of floods on selected components of the environment in the Hornád river basin: the impact of floods on population, water conditions, soil, fauna, flora and their habitats, structure and use of land and landscape, protected areas and their protection zones, the territorial system of ecological stability, urban complexes and land use, cultural and historical heritage, cultural values of an intangible nature, and archaeological and paleontological sites and important geological localities. The assessment was performed using the risk analysis method. The risk index was calculated by summing the products of probabilities and consequences for each impact of flooding on the components of the environment, and the total value of the risk index is 5.5 (average risk). The hazard index was determined by quantification of industrial sources of pollution in the river basin: each source of pollution was assigned a point score; the total hazard is represented by the sum of the points for these sources of pollution, and is equal to 19. The total risk index is then represented by the product of the risk and hazard indices, i.e. 104.5. This value indicates a low level of flood damage risk in the Hornád river basin.

1. Introduction
From time immemorial, floods and the hazards associated with them have been part of our lives [1, 2]. Many of us still remember the events of 2010 in Slovakia, when the biggest flood in the last two decades caused significant economic, social and environmental problems. At present, efforts are being made to mitigate the impact of the adverse effects of floods, not only by means of legislation but also involving experts and the general public [3, 4].

Many international researchers investigate flood risks assessment. The authors in [5] call for the development of a consistent European framework that will apply procedures from existing models. The assessment of the economic and social impacts of floods can also be carried out using models made from topographic data of the area [6]. The study of authors [7] estimates the direct damage caused by the occurrence of three floods at different times, which speaks of emphasizing the need to improve...
spatial plans. The study [8] proves that floods are one of the most devastating natural disasters, causing enormous damage to property and, in some cases, loss of life. Climate change has an impact not only on individual components of the environment, but also on the social sphere [9].

The research in this paper was developed according to the Flood Environmental Impact Risk Analysis (FEIRA) process, where the probability and consequence of the negative impact of floods on environmental components are determined on the basis of analysis of selected stressors [10]. From these indicators, the degree of risk in the Hornád river basin (eastern Slovakia) in the event of flooding is subsequently determined. Since there are several industrial sites in the assessed area which can cause extensive pollution of watercourses in the event of flooding, this work also presents the calculation of an environmental hazard index according to the point evaluation of pollution sources. A combination of the FEIRA process and the proposed methodology for the assessment of flood environmental damage proposed in [11] enabled the overall risk of environmental damage due to flooding in the Hornád basin to be determined.

However, it is not possible to clearly define which environmental component would be most damaged by flooding, as each represents a certain value for the whole system. Moreover, a negative effect can also be caused by disruption of just one of the smallest components.

2. Materials and Methods

2.1. Study area
The Hornád is the fifth longest river in Slovakia. It springs at an altitude of 1050 m asl. near the village of Vikartovce in Poprad district. The Hornád itself flows east through Spišská Nová Ves and Krompachy, partly forming the Ružín reservoir, then turns south before Košice and leaves the territory of the Slovak Republic southeast of the village of Milhost [12]. It has an average flow rate of 31 m³/s with a maximum of 689 m³/s and a minimum of 2.5 m³/s.

Figure 1. Study area – Hornád river catchment.
The main right-hand tributaries are the Veľká Biela Voda stream from the Slovak Paradise area (13 km), the Hnilec river from Kráľová hoľa Fell (89 km) and Myslavský potok stream from Volovské vrchy Hills (20 km). The principal left-hand tributaries are Levočský potok stream from the Levočské vrchy Hills (27 km), Veľká Svinka river from the Branisko hills (51 km), the Torysa river also from the Levočské vrchy hills (129 km) and the Oľšava river from the Slanské vrchy hills (50 km).

The Hornád river catchment (Fig. 1) covers a total area of 4,414 km², mainly within the territory of Slovakia with the final meandering reach in Hungary. The river has a length of 193 km in Slovakia and 93 km in Hungary.

2.2. Methodology

Flood risk assessment according to the FEIRA process (analysis of the risk of impact of flooding on the environment) is presented in Figure 2. Probability is influenced by stressors which have an adverse effect on the environment during a flood event. Subsequently the consequence (magnitude of impact) is determined based on qualitative or quantitative indicators. These two parameters together indicate how much risk of serious impact there is in the Hornád basin in the event of a flood.

![Flowchart of the methodology.](image)

The methodology for assessing the state of the environment is based on the literature [13], where the probabilities and consequences of impacts on environmental components are determined. In combination with the methodology of flood environmental damage assessment proposed in the thesis [14], the FEIRA methodology was designed and applied in this paper.

This methodology consists in determining the probability and consequence of the impact of stressors on selected components of the environment, from which the risk index is subsequently calculated as the product of these indicators. The hazard level is determined by the product of the qualitative assessment of individual categories of pollution sources with the appropriate point scores. Subsequently, the final risk index is determined, which is represented by the product of the values of the risk index and the hazard index.

The following subchapters examine the probabilities and consequences of floods in the Hornád basin and calculate the risk to the population, water conditions, soil, fauna, flora and their habitats, landscape, protected areas and their protection zones, territorial system of ecological stability, urban complexes and land use, cultural and historical heritage, cultural values of intangible nature, archaeological and paleontological sites and important geological sites.
3. Results

3.1. Risk index

Probability is an expression of the possibility of the occurrence of a certain phenomenon. The starting point of this methodology is the qualitative determination of probability from the lowest value = 0.25 to the highest value 1. This level, i.e. the probability value, represents a certain expectation of whether the phenomenon will happen or can happen. How the negative stressor affects selected components of the environment is expressed by the consequence. It is expressed qualitatively as well as the probability.

All assessed effects with values of causes $P_i$ and their consequences $C_i$ are summarized in Table 1.

| ID | Impact of stressors on components of the environment | Determination of probabilities | Determination of consequences |
|----|-----------------------------------------------------|-------------------------------|------------------------------|
| 1  | Impact of flooding on the population                 | $P_1$                         | $C_1$                        |
|    | Local potential for flooding (-)                     | 0.5                           | 1                             |
|    |                                                       | medium                        | $\geq 5$                      |
| 2  | Impact of flooding on water conditions               | $P_2$                         | $C_2$                        |
|    | Number of announcements of highest level of flooding (per year) (-) | 1                             | Capacity flow $Q_n (m^3.s^{-1})$ |
|    |                                                       | $\geq 4$                      | $\geq Q50$                   |
| 3  | Impact of flooding on soil                          | $P_3$                         | $C_3$                        |
|    | The status of flood protection facilities (-)        | 0.5                           | Permeability of soil (-)      |
|    |                                                       | good                         | 0.5                           | Less permeable |
| 4  | Impact of flooding on flora, fauna and their habitats| $P_4$                         | $C_4$                        |
|    | Local potential for flooding (-)                    | 0.5                           | Vulnerability of fauna and flora and their habitats (-) |
|    |                                                       | medium                        | 0.75                         | medium         |
| 5  | Impact of flooding on landscape - structure and land use, landscape character | $P_5$                         | $C_5$                        |
|    | Local potential for flooding (-)                    | 0.5                           | Changes in the landscape (-)  |
|    |                                                       | medium                        | 0.75                         | significant    |
| 6  | Impact of flooding on protected areas and their buffer zones | $P_6$                         | $C_6$                        |
|    | Local potential for flooding (-)                    | 0.5                           | Location of the proposed activity (-) |
|    |                                                       | medium                        | 0.75                         | significant    |
| 7  | Impact of the flooding of the territorial system of ecological stability (TSES) | $P_7$                         | $C_7$                        |
|    | The status of flood protection facilities (-)        | 0.5                           | Impacts on TSES (point – effects on biocorridors, biocentres, interactive elements) |
The risk index $IR$ is calculated as the product of the probability and the consequence of individual stressors expressed by the following formula:

$$IR = P_i \times D_i$$

The probability $P_i$ expresses the value of each selected stressor effect, and the consequence $D_i$ expresses the value of the stressor effect on the individual components. The $IR$ value is the product of the probability and consequence values. The numerical calculation of the risk is given in Table 2.

According to the qualitative analysis of the level of risk to the state of the environment, the level of risk for parts of the environment in the assessed area is low for soil, TSES. The risk is medium for fauna, flora and their habitats, structure and use of the landscape, landscape character. There is a high level of risk for the population, water conditions, protected areas and their protection zones, urban complexes and land use, cultural and historical heritage, cultural values of intangible nature, archaeological and paleontological sites and important geological sites.

According to the proposed categories, the total risk level in the examined area of the Hornád river basin is assessed with an index equal to 5.5, which represents a medium level of risk.

### 3.2. Hazard index

If a flood occurs in any area, it can also cause pollution of surface and groundwater and the subsequent spread of this pollution further down the watercourse, especially if there are sources of pollution in the endangered area. According to the source of pollution, we distinguish the pollution of watercourses as point, diffuse, accidental.

There are several industrial sites in the Hornád sub-basin which may pose a risk of environmental pollution in the event of flooding. According to the categorization, each source of pollution is assigned the appropriate number of points: the $H_i$ score (Table 3).
Table 2. Calculation of the risk index.

| ID | Probability $P$ | Consequence $D$ | Risk index $IR$ |
|----|-----------------|-----------------|-----------------|
| 1  | 0.5             | 1               | 0.5             |
| 2  | 1               | 0.75            | 0.75            |
| 3  | 0.5             | 0.5             | 0.25            |
| 4  | 0.5             | 0.75            | 0.375           |
| 5  | 0.5             | 0.75            | 0.375           |
| 6  | 0.5             | 1               | 0.5             |
| 7  | 0.5             | 0.5             | 0.25            |
| 8  | 0.5             | 1               | 0.5             |
| 9  | 1               | 1               | 1               |
| 10 | 1               | 1               | 1               |

$\sum_{i=1}^{n} IR_i = 5.5$

Table 3. Pollution sources with assigned number of points.

| Category of source of pollution | Source of pollution | Criteria | Point evaluation $H_i$ |
|--------------------------------|---------------------|----------|------------------------|
| Industrial plants              | Area of VSE – Machinery production plant Krompachy | unclassified | 5 |
| Wastewater treatment plants (WWTP) | WWTP Harichovce, WWTP Vajkovce, AGROKOV PLUS Košice, WWTP Rožkovany, WWTP Jakubova Voľa, WWTP Spišské Vlachy, WWTP Povodňového dvora Krompachy, WWTP IMUNA PHARM Šarišské Michaľany | $< 2,000$ population equivalent | 1 |
|                                | WWTP Spišská Nová Ves | $2,000 - 10,000$ population equivalent | 2 |
| Agriculture                    | Vegetation cover     | 10-40% of flooded area | 1 |
| Environmental burden           | KOVOHUTY copper smelter Krompachy | Environmental burden is likely | 3 |
|                                | SEZ Krompachy – electrical equipment production plant | Land reclamation | 3 |
| Urban areas                    | Population without sewerage | 10-40% from all population in the study area | 1 |

$\sum \Sigma = 19$

The sum of the points evaluation of pollution sources in the examined area comes to a value of 19.
3.3. Risk calculation
The value of the total risk of environmental damage in the event of floods is determined by the following formula:

\[ R = \sum_{i=1}^{n=10} (P_i \times D_i) \times H_i \] (2)

The sum of the multiplied values of individual causes and consequences produces the risk index \( IR = 5.5 \), which is subsequently multiplied by the hazard index \( H = 19 \). The product of these two values is the resulting value representing the total risk index \( R = 104.5 \).

4. Conclusions

The first part of the paper presents an analysis of individual stressors which have negative impact on selected components of the environment. For each stressor, the probability and consequence (magnitude) of its effect were determined.

The values were then multiplied together and the sum of the resulting values represents the risk index \( IR \). According to the proposed categories, the flood impact risk index in the examined area of the Hornád river basin was found to have a value of 5.5, which represents a medium level of risk.

In the next part, the magnitude of environmental hazard was established according to the methodology of flood environmental damage assessment. Sources of pollution were identified in the assessed area, to which point scores were assigned. The resulting hazard index is represented by the sum of the partial results. In the Hornád sub-basin, a low potential damage level applies with a hazard index \( H = 19 \).

The final part is concerned with determining the overall risk level. The final risk index is the product of the preceding indices of probability, consequence and hazard. According to the FEIRA methodology, the first category of risk level is calculated as \( R = 104.5 \), which means a low level of flood damage risk.

Inspite of low level of flood damage in Hornár river catchment the flood protection measures should be proposed and implemented in the study area. The paper present an innovative way of flood risk determination in the territory.

5. References

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