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FLOOD RISK ASSESSMENT AND FLOOD DAMAGE EVALUATION – THE REVIEW OF THE CASE STUDIES

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This article presents a brief overview of selected flood risk and flood damage assessment studies. The assessment on the Luvuvhu River focused on risk assessment based on hazard and vulnerability parameters. To these parameters was added another parameter, the exposure parameter in the assessment in the study of Sri Lanka. Hazard, vulnerability and exposure assessment were also performed on the Yangtze River in China, where the authors presented a proposal for a multi-index flood risk assessment concept. The output of these studies are flood risk maps for each indicator, as well as individual risk assessments in the given area. The next section is focused on the flood damage evaluation. The main tool for calculating flood damage in a study conducted in Beijing is flood risk. The calculation process focuses on the Integrated Flood Management (IFRM) method, which consists of risk identification, damage assessment and flood management to design flood protection measures. In flood management, the term vulnerability often occurs, which is a weakness or shortcoming that allows the hazard to be applied. Closely related to this concept is the sensitivity parameter, which can be used to estimate flood damage in the next case study in affected area in Netherland. The last of selected studies presents the application of the RESTful Application Program Interface (API) for the financial estimation of building damage. The API web service allows you to calculate flood damage to buildings without determining the flood risk.

KEY WORDS: flood, flood risk assessment, flood damage calculation, vulnerability, damage

Introduction

One of the most widespread natural disasters is floods, which also bring with them a certain level of risk. One of the most discussed topics is the protection of people and property against floods, as well as mitigating the negative impacts of floods on environmental components. An effective defence mechanism can be to prevent floods by building flood protection measures, or to be aware of the need for information on the causes and consequences of floods.

The degree of risk can be expressed in several ways and also at several levels. The flood risk assessment equation also includes a number of variables that vary depending on the assessed region or input data. However, the issue of flood risk is also focused on the assessment of flood damage that occurs in the event of a flood. The presented paper in the first part briefly describes several selected studies, which are based on flood risk assessment, the second part is devoted to flood damage and how to determine them. Selected studies provide an interesting view of the assessment, whether risks or damages, because, despite global differences, they have a common denominator.

Material and methods

Flood risk assessment

According to the generally accepted definition, risk can be expressed as a combination of the probability of damage occurring and its consequence. The risk is most often expressed by multiplying the value of the probability of the occurrence of a negative phenomenon P and the value of the severity of its consequence C (Zvijáková and Zeleňáková, 2015). A similar equation is used to express flood risk, but is supplemented by other relevant values.

Luvuvhu river catchment

A study carried out in South Africa (Ntanganedzeni and Nobert, 2020) focused on the analysis of flood frequencies and the assessment of flood risk in the Luvuvhu river basin, which covers an area of 4 826 km^2. The Luvuvhu River springs in the south-eastern slopes of the Soutpansberg mountain range and flows through the Kruger National Park. On the border between Mozambique and Zimbabwe, it flows into the Limpopo River. The northern border of the river Luvuvhu is formed by a dominant topographical element – the Soutpansberg mountain range. The highest and steepest slopes of this mountain range are located at

the top of the basin. The variable topography has a significant impact on the overall hydrological conditions in the river basin.
Based on the availability and distribution of data, 4 stations were selected in the river basin, where a vulnerability and hazard analysis were carried out. The main goal of the vulnerability analysis was to identify risk elements in the studied area. However, in terms of the scope of work, the study included only an analysis of spatial vulnerability. The vulnerability aspect was analyzed by determining the use of the area to be exposed to the flood and the total area flooded at the time of the flood. The vulnerability aspect has been identified for specific land uses.
To assess the flood risk, the authors of the study used the method of Gilard and Givone, which consists in combining the results of the hazard analysis and the vulnerability analysis. The combination is based on the existing relationship between flood hazard classes and vulnerability classes of land use in the area addressed. Flood hazard, the first aspect of flood risk, analyzes the determination of hydraulic parameters such as the extent of the flooded area or the depth of the flooding. This aspect suggests that a particular flooded area will be affected by a flood with the same hydraulic parameters, regardless of what the area (land) is used for. The vulnerability of land use as a second aspect points to the sensitivity of individual land use classes. This means that floods present a different level of risk depending on land use.
For the purposes of this study, the hazard was determined using an analysis of the frequency of floods, flooded areas and a map showing the hydraulic parameters of floods. Vulnerability was determined by analyzing the use of land exposed to floods.
The results of the study show that although a flood with the same hydraulic parameters will occur in the entire floodplain, the level of risk will not be the same in the entire study area, due to land use. For this reason, flood classes with a risk value were determined based on the flood depth analysis.

West province of Sri Lanka

In the study by Weerasinghe (Weerasinghe et. al., 2018), the exposure parameter was also assigned to the hazard and vulnerability parameter. The study presents the results of a qualitative assessment of flood risk based on the expression of the mentioned parameters.
Data on topography, precipitation intensity, land cover and geology were used to analyze the flood risk. Thematic maps, on the creation of which selected input parameters were used (flow accumulation, precipitation intensity, land use, slope, altitude, length of the drainage system) were generated using the GIS platform. Each selected parameter was assigned a weight rating according to the extent to which it contributes to the flood. The total value of the hazard is expressed as the sum of the products of individual parameters with their weight rating. The exposure analysis consisted of identifying the elements at risk of flooding. The elements were categorized into two groups – real estate and population. The elements were further quantified on the basis of the ratio between the total number (real estate and population) in the addressed area and the number of endangered elements in the area.
The authors of this study took into account 3 types of the vulenrability in the analysis: social vulnerability, economic vulnerability and housing vulnerability. The social vulnerability index was calculated on the basis of the claim that society's ability to cope with natural risks depends on the wealth factor. Although vulnerability (not only the territory) is influenced by many other factors, the authors of this study relied mainly on the financial possibilities of the population in the area. The indicator of social vulnerability was the age of the population, in this case gender was not taken into account. Each age group was assigned a weight score based on qualifications, as well as subjective perception. The total social vulnerability index was calculated in a standard way - the sum of the products of each age category with a weighted rating. The analysis of economic vulnerability consisted in dividing the population according to economic status into employed, unemployed and economically inactive (children and pensioners). The basic assumption for the evaluation was that unemployed and economically inactive people depend on employed people, and thus the expression of economic vulnerability is the ratio of the sum of unemployed and economically inactive population to the sum of employed population. The last vulnerability assessed was the vulnerability of housing. The indicator was the number of housing units with low resistance to hazards, on the basis of which housing units were divided into permanently inhabited, temporarily inhabited and uninhabited. According to the claim that temporarily inhabited and uninhabited units are often damaged by floods, housing vulnerability was quantified by the ratio of the sum of temporarily inhabited and uninhabited housing units to the sum of inhabited units.
The overall flood risk was finally determined by the product of hazard, exposure and vulnerability. In this case, the partial results were summed and fitted to the final equation.

Yangtze river catchment

A risk assessment procedure based on hazard, vulnerability and exposure parameters was also used in a case study on the Yangtze River in China (Zhang et. al., 2020). This river is one of the largest rivers in the world, with a catchment area of approximately 1.8 million km^2. The river springs in the north of the Tanggula Mountains and flows through 11 regional provinces. Its range is more than 6 300 km, and eventually flows into the East China Sea on the island of Chongming in Shanghai. As its other tributaries extend to other areas, the river eventually flows through 19 regional provinces and occupies approximately 18.75% of China's total area.
A study carried out on this river looked at the development of a multi-index concept (MIC) based on GIS modeling. The MIC consists of three layers – the object layer, which includes the Yangtze River; an index layer that includes hazard, vulnerability and

exposure parameters, and the last is an indicator layer that contains 13 flood risk indicators. These 13 indicators are divided between the index layer as follows: the hazard parameter contains an indicator of the cumulative average of precipitation in a maximum of 3 days. The vulnerability parameter includes data on absolute elevation between a point and the Yellow Sea level, relative elevation (difference between absolute heights of two points), runoff density (depending on the density of the river network in the area), surface runoff factor and surface coverage, financial returns, financial savings, health service levels and the monitoring and warning system. The last exposure parameter contains data on population density, GDP, degree of soil erosion and risk of soil contamination.
To assess the relative importance of flood risk indicators, the method of the AHP analytical hierarchy was subsequently used, which assigned a weight rating to each indicator. After normalization, the data were transferred to the GIS environment, from which flood risk maps for each indicator were subsequently generated.

Flood damage evaluation

Identification of flood risk in Beijing

Flood damage is also very closely linked to flood risk. In the study (Wang et. al. 2021), flood risk is the main element for calculating the damage caused by floods. The authors of the study come up with the IFRM (Integrated Flood Management) method, which includes the identification, assessment and management of flood risk with a focus on 3 objectives:

1. Identification of significant areas with a high flood risk through the use of flood risk identification.
2. Assessment of economic damage caused by floods in significant areas by means of flood risk assessment.
3. Use of flood risk management to select the best design measures to improve the capacity of the drainage system.

The first stage of the process begins with the identification of flood risk based on available flood data, flood risk maps and the definition of significant areas where there is a high probability of flood risk. Due to the extent of the results achieved, the proposed methodology is recommended to be implemented at the city level.
The flood risk assessment itself is described in the second stage, which includes the hazard analysis, the assessment of the underlying exposure element, the vulnerability analysis and the quantification of the data. The flood risk analysis contains information on the extent and intensity of the flood situation. While the extent is determined by the spatial flooding of the area, the intensity carries information about the depth of the flood. The expression of the supporting element of exposure means the identification of the element which contributes most to flood damage, especially to economic damage. The analysis of the exposure exposure element consists of the following steps:

- identification of the factors that have the greatest impact on the economic damage caused by floods,
- determination of the influence factor of the exposure element,
- obtaining the spatial distribution of the supporting element of the exposure.

Once the load-bearing element of the exposure is defined, a vulnerability analysis is performed to determine the damage depth curve. In this study, vulnerability include economic damage caused by floods, from which a curve is generated expressing the relationship between the depth of the flood and the economic damage (the so-called damage depth curve). This curve is also generated for each exposure carrier. As there are different types of buildings in the studied area, their economic value is also different. Said damage depth curve is therefore used to calculate the vulnerability of buildings in the addressed area. The quantification of flood damage is the result of all previous analyzes, and at the same time it carries with it the assumption that the amount of damage depends on the recurrence of floods.
Flood risk management belongs to the third stage of this methodology. In the understanding of this study, flood risk management involves the construction of design measures to achieve flood mitigation. The aim of this study was to select a design measure that will include the best possible engineering benefits to improve urban drainage systems. Engineering benefits in this case are defined as the ratio of flood mitigation to investment in measures.

The estimation of the expected potential flood damage

In flood management, the term vulnerability often occurs, which is a weakness or shortcoming that allows a hazard to be applied. Closely related to this concept is the sensitivity parameter, which can be used to estimate flood damage (de Moel, et al., 2012). In the case study, flood damage is defined by a combination of a failure model, a flood model and a damage model. These three models are implemented in the MC framework in order to determine the sensitivity of the model chain to different assumptions, and to assess the uncertainty regarding the resulting damage estimate.
The following data are required to assess the expected potential damage: information on hydraulic loads and the probability of their occurrence (shock wave with water level), a model simulating an increase in dam failure in the event of a collapse, a hydraulic model simulating an increase in flooding in the event of a dam collapse, and a damage model simulating flooding with damage estimation.
The analysis was carried out in the western part of the Netherlands, whose territory is prone to floods. In the studied area there are dams and low-lying polders, which are exposed to storm floods. This area is divided into 53 so-called dam circuits (the area surrounded by dams), which have a high level of flood protection. For the purposes of this study, circuit 14 was selected, which includes the 3 largest Dutch cities and the main airport. The flood situation in the study area can occur for several

reasons: the western part can be flooded by the North Sea, the inland area near Rotterdam is exposed to storms, and the southern part of the study area can be affected by floods from the Lek River and the Rhine River. In addition to dams, there are several polders in this area, some of which reach an elevation of up to 6.5 m above sea level.

The combination of the astrological tide with the increase in storms is considered to be an estimate of the volume of the shock wave and the height of the water level after the failure of one of the dams. An estimate of the volume of running water is also related to the dam failure, but the dam failure may depend on the water level on both sides of the dam and also on the material itself from which the dam is made. The water level difference is determined by raising the water level directly inside the damaged dam and subtracting from the water level on the other side of the dam.

To construct a flood height estimation model, a new approach has been proposed that directly calculates the value of the direct result of a regular two-dimensional flow, the maximum flood depth of an area, and a given specific volume. The mentioned new model approach was designed to simulate flooding in areas surrounded by dams and other protective structures. The second setting was to allow modeling of a large amount of flood estimation at different volumes.

The last link in the model chain was the damage estimate, for which two vulnerability parameters were proposed – the maximum risk value and the shape of the depth damage curve. Uncertainty estimates were derived from the available literature, which consists of a combination of several methodologies for estimating the damage depth curve and a factor estimating the magnitude of the uncertainty.

Flood damage calculation

The common parameter for estimating flood damage in the Canadian study (McGrath et. al., 2019) and in the study mentioned in the previous subchapter is the depth of the flood. Many studies deal mainly with flood risk, but it is also important to have data on flood damage. The present study presents the application of the RESTful Application Program Interface (API) for the financial estimation of building damage. The API web service allows you to calculate flood damage to buildings without determining the flood risk.

The API application programming language is Python Script, which contains a database of input parameters. Input parameters include information about buildings – classification of buildings according to occupancy (how many residential units are in the building), number of floors in the building, year of construction, existence and use of the basement and garage. The application offers the user the possibility to calculate the flood damage using the damage depth curve, if the depth of the flood is known. If this data is not available, the calculation is based only on the expected depth of the flood in the area (after substituting other necessary data). In the second case, the estimate of the depth of the flood is identified as a percentage.

Results and discussion

Flood risk assessment

Selected studies presented in this article assessed flood risk at various levels. The study carried out on the Luvuvhu River, unlike the others, contained only two parameters according to which the flood risk was assessed. However, the differences in the studies are not only in the number of evaluation parameters, but also in the method of flooding. In contrast to the flood risk on the Luvuvhu River and the Yangtze River, where river floods were taken into account, in the western province of Sri Lanka, an assessment of the flood risk caused by torrential rain floods was considered.

As the assessments were based on different input data and different indicators, these results cannot be unambiguously generalized. Therefore, the results of the studies are presented as separate subchapters.

Results of the flood risk analysis in the Luvuvhu river basin

The flood risk in this study was analyzed on the basis of hazard and vulnerability parameters. However, in terms of the scope of work, only spatial vulnerability was addressed. The authors of the study were based on data on land use, and on the consequences of flooding given types of land use. The result of the study is that even if the flood floods the whole area, the flood risk will not be the same in all places. Therefore, based on the flood depth analysis, the following classification was established:

- flood depth <2 m – low level of risk,
- flood depth 2–4 m – medium level of risk,
- flood depth 4–6 m – high level of risk,
- flood depth >6 m – very high level of risk.

In this case, the damage depends on the depth of the flood, regardless of the purpose of land use. The results of the study testify to the truth of this statement.

Results of the flood risk analysis in the western province of Sri Lanka

The authors of the study took into account the parameters of risk, vulnerability and exposure when analyzing the flood risk. The parameters of vulnerability were based on the state of the population in terms of social, economic, and in terms of housing. The exposure parameter was divided into asset and population exposure. The result of this study is flood risk maps that apply to each type of assessment parameter. These 3 maps are individually analyzed, the results relate to the area addressed. The flood risk value is determined on a rating scale from 1 to 5, where a value of 1 indicates a very low risk and a value of 5 indicates a very high risk. In the results of the analysis for the population, economic vulnerability appears to be a better indicator compared to social vulnerability. The results of this study serve to prepare for the planning of measures aimed at early warning of natural disasters, have an informative character for the population and also provide a basis for the allocation of funds to mitigate the consequences of natural disasters.

Results of the flood risk analysis in the Yangtze river catchment

In this study, too, the parameters of risk, vulnerability and exposure were included in the flood risk analysis. In this case, however, the authors proposed a multi-index concept, which consists of 3 layers, namely the object, index and indicator layer. The results of this study can be summarized as follows: the flood risk posed by the Yangtze River depends smoothly on precipitation. GDP indicators, the surface runoff and land cover factor, as well as the degree of soil erosion also play an important role. Separate risk values were also determined for each parameter. The risk of exposure has changed significantly over time, while the risk of vulnerability and exposure has changed relatively less over time. The main advantages of the proposed procedure include its comprehensive proposal for the selection of indicators for flood risk assessment, and the output of maps from the GIS environment.

Flood risk analysis

Above mentioned studies focused on the flood risk analysis in term of the available and data diversity. The common parameters of the analysis are hazard and vulenrability in all three selected cases, the parameter of exposure is added in Sri Lanka and Yangtze river catchment flood risk assessment. The results of the mentioned studies shows that there are similar input data, but the assessed parameters are different, so there are different results for each study city. Based on the flood risk analysis in the Yangtze river catchment, the flood risk assessment in Slovak condition will be prepared, considering parameters such as hazard, vulnerability and exposure. Table 1 represents a brief summary and comparison of mentioned flood risk assessment studies.

A big difference between case studies are in input data. While studies performed at Luvuvhu and Yangtze river consider especially hydraulic parameters, the study in Sri Lanka reflect social related data. MIC analysis mentioned in the Yangtze river study can be modified, and it is the most suitable for the further utilization. According to Yangtze river study, the further studies will be developed.

Results of identification of flood risk in Beijing

In the identification of flood risk, 20 high-risk areas were identified in the city of Beijing, one of which was defined as a significant area with a higher flood risk. By combining the parameters found in the second stage, the expected amounts of flood damage for different payback periods were calculated. According to the economic results of the flood damage obtained in the second stage, it is assumed that the drainage system should contribute to the reduction of the damage caused. Flood risk management was used to assess the engineering benefits of design measures. The proposed increase in the capacity of the drainage system has proved to be the most economical design measure in terms of the ratio of flood mitigation to investment in the design measure. The IFRM method in this study was used to identify the most risky area, calculate the economic losses caused by floods, identify the design measures with the best engineering advantage and support flood risk management in Beijing. However, the assessment was carried out only at the level of direct economic damage to buildings. In the subsequent use of this methodology, indirect damages, which include transport and electrical infrastructure as well as the sewerage and water supply system, should also be considered in the assessment.

The results of the estimation of the expected potential flood damage

In this study, damage estimation was performed according to the MC model with the implementation of model simulation. The area addressed was the western part of the Netherlands with selected areas that are prone to floods. To facilitate the process, a new approach has been developed to calculate inundation depths, as well as to model simulations requiring large amounts of input data.

The conclusion of the mentioned study was to perform several model estimates in each solved area with the percentage expression of uncertainties. Finally, the results of modeling in case the dams in the solved area were not damaged are also compared and the scenario when the dams were damaged was also considered, and based on these assumptions the model situations were simulated and subsequently compared with each other. The combination of uncertainty and sensitivity analyzes provided a better overview of which parameters are important in estimating damage.

The results of the flood damage calculation

The API application was designed primarily to facilitate access to information on possible flood damage, and was used in this study to assess flood damage in Gatineau and Fredericton. In both cases, the flood damage was estimated at several million USD, and at the same time was compared with the real flood damage, which was quantified during the floods in the period under review. The difference between real and projected flood damage is about 13%.

Flood damage analysis

Submitted flood damage case studies describes a different way to determine flood damage in the conditions of the study area. All three studies are specific, because of the approach to calculate or assumpt the flood damages. We can see the similarity in the input data, but as well as in the flood risk assessment above mentioned, the differences between input data and the results are also obvious. Table 2 represents a brief comparison of

Table 1. Summary and comparison flood risk assessment studies

Flood risk assessment				
		Luvuvhu river catchment	West province of Sri Lanka	Yangtze river catchment
Assessed parameters		hazard + vulnerability	hazard + vulnerability + exposure	
Input data	*hazard*	hydraulic parameters (depth of the flood, extent of the flooded area)	flow accumulation, precipitation intensity, land use, slope, altitude, length of the drainage system	cumulative average of precipitation in a maximum of 3 days
	vulnerability	flood exposed area	social vulnerability – age of the population economic vulnerability - employed, unemployed and economically inactive population housing vulnerability – permanently inhabited, temporarily inhabited and uninhabited	absolute and relative elevation, runoff density, surface runoff factor, surface coverage, financial returns, financial savings, health service levels, monitoring and warning system
	exposure	-	real estate, population	population density, GDP, degree of soil erosion, risk of soil contamination
Results		the damage depends on the depth of the flood, regardless of the purpose of land use	flood risk maps that are applied to the each type of assessed parameter	the flood risk depends smoothly on precipitation, GDP indicators, the surface runoff and land cover factor, as well as the degree of soil erosion also play an important role
Advantages		the results could be modified and used to the similar flood risk assessment with the same parameters	-	modified – the MIC analyse may be used at various level of input data and parameters
Disadvantages		contains only hazard and vulneability index	a few flood related parameters, analyzed are mostly social parameters (especially vulnerability and exposure index)	-

flood damage analysis.

All selected studies briefly described in Table 2 performed damage analysis on their own input data. The one common parameter is flood depth, from which the next steps follow. Study performed in Beijing could have a wider utilization because of the three stages of flood risk assessment. Economic damage can be extended by other damage asets (soil, infrastructure, people, etc). The API offers very simply flood damage analysis, especially for the citizens of the affected area. The study in Netherland is special, because of the considering the dam circuits.

Table 2. **Comparison of flood damage analysis**

Flood damage analysis		
Beijing	Western part of Netherland	Canada
flood depth		
considered flood risk		without considering flood risk
a curve is expressing the relationship between the depth of the flood and the economic damage	flood damage is defined by a combination of a failure model, a flood model and a damage model	the API offers the user the possibility to calculate the flood damage using the damage depth curve, if the depth of the flood is known
related only to type of the building	analysis performed under special conditions (dams)	consider only the know or expected flood depth
consists three extended stages (flood risk areas, economic damage, design measures)	consists of failure, flood and damage model	input parameters contains information about buildings and flood depth
wider utilization	analysis is performed and used under the special conditions (dams)	using only on the build flood damage assessment

Conclusion

Flood risk assessment and flood damage calculation can take place at different levels and on the basis of different available data. This article focuses on a brief overview of case studies that focus on the determination of flood risk, but also on the assessment of flood damage. Differences in the assessment and assessment of flood risk can be visible already in the selection of assessment parameters, but despite the same assessment parameters, the results will always be different. Hazard, vulnerability and exposure are abstract concepts to which each assessor can assign their own indicators on the basis of which their assessment will be made. However, the differences may not only be in the input indicators, but also in the scope of the evaluation. The flood risk can therefore be determined for the river basin, which covers an area of several thousand km^2, but also in an area smaller than the cadastral area of a small village. However, the definition of risk remains the same, the difference may be in its interpretation. The damage caused by floods is also very closely related to the flood risk. In the presented article, selected procedures for flood damage assessment are based on the identification of the risk in the endangered area. In each of the selected studies, the authors focused on a specific goal – flood damage, but each of them chose different parameters for their interpretation. The issue of flood damage is as important and extensive as the issue of flood risk. On the basis of this review contribution, it is possible to further direct future research with a focus on the aforementioned flood damage and risks with regard to the development of a methodology for flood damage assessment. Submitted paper serves as a theoretical base to the further research. The aim of the paper is to provide a brief review of the actual studies of flood risk assessment and flood damage calculation. By the combination of the above mentioned studies, the new approach to flood risk assessment and flood damage evaluation will be developed.

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