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Territorial Risk Analysis and Mapping

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The aim of this contribution is to present the principles of risk analysis for territories that may have different sizes, e.g. municipalities, towns, districts and regions. The article summarises approaches to the issues of major risk assessment for stationary and mobile risk sources and natural disasters having effects on human health and life, property and the environment.
Vulnerability and risk mapping is usually carried out using the HVA (Hazard Vulnerability Analysis) method. For territorial assessment this method was promoted by the project SIPROCI (International Response to Natural and Man-made Catastrophes SIPROCI), which in the years 2004-2007 asked participating countries to predict, prevent and respond to natural and man-made disasters. One of the project outputs was the development of a uniform method for risk mapping.
The SIPROCI method of risk mapping works with the calculation of individual values of hazard, vulnerability and subsequently risk and their integration into the form of an index that can be simply graphically represented on maps. The SIPROCI method is relatively general – creates merely a certain methodical framework that is to be adapted for use in specific countries. During index selection, both national specifics concerning the organization of individual rescue services of risk sources and data available for the use of the method should be respected.
The application of the SIPROCI method in conditions of the Czech Republic and the pilot application of the method were carried out by the Fire and Rescue Service of the Moravian-Silesian Region. The article mainly deals with the presentation of a proposal for the method of optimized risk mapping, the results of which can be transferred through target indexes to a GIS map layer.

1. Introduction

Territorial risk analysis and mapping represent a problem that is, in connection with considerations about the protection of territorial critical infrastructure, becoming increasingly important. Traditionally, risks following only from a certain considered scenario of an accident, e.g. in the chemical industry (loss of control over hazardous substances) and impacts of natural disasters, such as floods in the territory, are understood merely separately (Vallée and Duval, 2012; Renni et al., 2010).
With time, we have found that some independent events have a potential for significant increasing negative consequences (synergic effects), whereas others can result in a cascade of failures (domino effect). Thus, if we want to assess risks in a certain territory, we have to do this comprehensively for all risks simultaneously.
This approach began to gain ground at the beginning of the 21st century. In this context, we can mention the Swiss KATARISK (BZS, 2003) and perhaps the HVA method, sometimes designated as the HVE method - H – hazard, V – vulnerability, E – value of the elements at risk (SIPROCI, 2007). For territorial assessment the SIPROCI project (International Response to Natural and Man-made Catastrophes SIPROCI) promoted this method; in the years 2004 – 2007, the project was aimed at helping participating countries predict, prevent and respond to natural and man-made disasters. One of the project outputs was the development of a uniform method for risk mapping.

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2. HVA Method in the Czech Republic

The SIPROCI method for risk mapping works with the calculation of individual values of hazard, vulnerability and subsequently risk and their integration into the form of an index that can be simply graphically represented on maps. The method calculates the value of risk as a function of hazard, vulnerability and value of the element at risk, see Eq. 1 and 2.

$$R = f(H, V, E) \qquad (1)$$

$$R_s = f(H, V) \qquad (2)$$

where: R risk
R_s simplified risk
H hazard
V vulnerability
E value of the element at risk.

The HVA is relatively general; it creates merely a certain methodical framework that is to be adapted for use in specific countries. In the course of application, national specifics of the organisation of individual rescue services of risk sources and also data available for processing are to be respected.

The HVA method was applied in conditions of the Czech Republic by Krömer et al. (2010) together with a pilot study of the Moravian-Silesian Region. This application of HVA method will be henceforth referred to as HVA CZ. From the point of view of concept of risk, the method works with a simplified risk – thus it ignores the value of the element at risk. For particular types of hazards, Krömer et al. determine the risk according to Eq. 3. In contrast to the HVA method itself, it however also deals with the cumulation of individual risks for the given part of the territory (see Eq. 4).

$$R_i = MR_i \cdot Z \qquad (3)$$

$$R_{kum} = \sum_{i=1}^{n} R_i \qquad (4)$$

where: R_i risk associated with the given type of hazard
R_{kum} cumulative risk for the assessed part of territory
MR risk level
Z territorial vulnerability.

Unlike the HVA method, Krömer et al. (2010) also propose the introduction of indexes that are easy to visualise using GIS tools and that describe basic characteristics of the territory under evaluation. It is above all a case of vulnerability index describing the proneness of the territory to damage, preparedness index describing the ability of rescue services to respond to emergencies and minimise thus their consequences. In the figure given below (Figure 1), a final map of cumulated risk is given as an example.

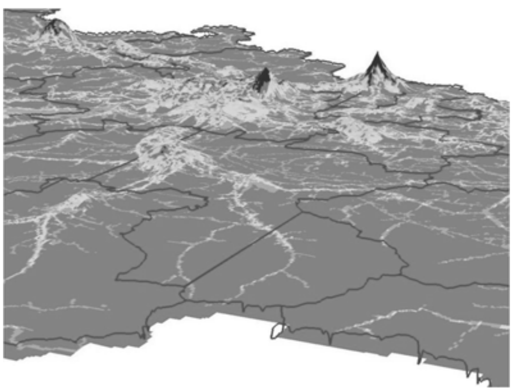

Figure 1: Map of cumulated risk

3. Other Methods of Territorial Risk Analysis

3.1 Comparison of KATARISK and HVA CZ Methods

The KATARISK takes into account altogether 22 hazard types, whereas the HVA CZ considers merely 15 hazard types. In spite of this, differences are not too great and are caused rather by regional differences. For instance, in the Czech Republic earthquakes do not threaten and meteorite impacts and some hazards included in the social area, such as migration problems are not considered.

Much larger differences between both the methods consist in measurement of the extent of possible damage. The KATARISK takes into account five indicators, namely the number of affected people, the number of evacuees, the number of people who are a result of an extraordinary event in need, the extent of the affected environment and damage. For the considered scenarios, these indicators are quantified, subsequently converted into money, and the consequence is classified, according to the severity, extent and incidence, into one of five classes.

The HVA CZ proceeds philosophically in a different way; it uses six indicators, namely the hazard to the population, the affected area, the extent of the affected environment, the hazard to buildings and estates, the hazard to animal husbandry, the interruption of transport. In contrast to the KATARISK, the dimension of the class of events is missing here. This is given by the orientation of the whole method to the use of GIS means – consequences are simply put as needed into map bases. The second difference is intentional avoidance of the necessity of a financial expression of consequences of the considered scenarios, because such an expression requires the long-term collection and evaluation of statistical data on extraordinary events and their consequences.

3.2 General Methods

Another significant tool is the method of Spatial Development Safety Assessment that was developed in the framework of a habilitation thesis (Rehak, 2011). The method is based on the principle of semi-quantitative assessment of potential negative aspects of spatial development and areas of their possible impact. The aim of the method is to assess realistically a potential risk following from spatial development, and to contribute thus to ensuring social, environmental and technical safety. The method calculates the level of risk as a function of probability of occurrence and severity of impact of an undesirable event due to the influence of negatively acting spatial development and the sum of adopted safety measures, see Eq. 5.

$$R = \frac{f(R_S, R_E, R_T)}{\sum_{i=1}^{n} S_i} = \frac{f[\,f(P_S, RI_S), f(P_E, RI_E), f(P_T, RI_T)]}{\sum_{i=1}^{n} S_i} \tag{5}$$

where:
- $R_{S(E,T)}$ level of the potential risk of breach of social (environmental, technical) safety due to negatively acting spatial development,
- $P_{S(E,T)}$ probability of interaction between negatively acting spatial development and population (the environment, technical infrastructure),
- $RI_{S(E,T)}$ severity of the impact of undesirable interaction on population (the environment, technical infrastructure),
- S_i degree of specific safety measure.

The final level of the risk of negative acting of spatial development on population (the environment, technical infrastructure) is illustrated in a matrix of the influence of spatial development using three possible categories of risk level. *Category A* signals a low risk that is evaluated as acceptable, it means that the intended spatial development project can be fully implemented. *Category B* signals an increased risk that will have to be reduced, i.e. the intended spatial development project has to be analysed, re-planned and newly evaluated. *Category C* signals a high risk that is evaluated as inadmissible, i.e. by the intended implementation of spatial development project, the population, environment and engineering infrastructure would be damaged.

3.3 Specific Methods

One of significant specific areas of territorial risk analysis is flood risk assessment. Objective procedures for the assessment of flood hazard level, the expression of flood risk and the determination of the amount of possible damage belong to highly topical problems of importance to the whole society. The Directive of the European Parliament and of the Council on the assessment and management of flood risks (Directive, 2007) requires Member States to assess gradually flood hazards and risks in their territories, and to process acquired information into the form of a relevant map expression. Final flood risk management

plans are to be completed by the 22nd December 2015. For their preparation, a risk matrix method was recommended in the Czech Republic (Beffa, 2000; Riha et al., 2005).
The risk matrix method is one of the simplest procedures for the assessment of potential hazard and risk in floodplains. The method does not require any quantitative estimate of damage caused by the overflow of rivers, but it expresses the flood risk by means of a four-level scale. In the first step, the result of the risk matrix method is hazard maps that show by means of a colour scale hazard categories for areas in a floodplain (Drbal et al., 2005). These categories enable the assessment of suitability of existing and future functional land use and of recommendations for limiting potential activities in areas in a floodplain having rather high hazard levels. This procedure can be utilised, e.g. in the spatial planning process, in the proposal for flood protection measures, and others.
In the risk matrix, the hazard level is given by combination of flood event probability and suitable expression of flood hazard and consequences. Those can be expressed by the above-mentioned flood intensity or by verbal evaluation of the hazard in a pre-selected range. The final hazard RI is evaluated in this case as the maximum value of particular partial hazards RI_i corresponding to the i-th scenarios of hazard (passage of the N-year peak discharge) according to Eq. 6:

$$RI(x,y) = \max_{i=1}^{\mathbf{n}} RI_i(x,y) \tag{6}$$

where: n stands for the number of evaluated (input) flood hazard scenarios.

The levels of hazard and risk are plotted on hazard and risk maps. With individual risk levels expressed in colours or figures, recommendations and limits for the use of a relevant territory are associated.
In connection with the risk matrix method, a method for the determination of flood risks and potential damage in a floodplain (Drbal et al., 2008) was developed in the framework of the project DIBAVOD in the year 2008. The essence of this method is an estimate of risk on the basis of potential flood damage. For this purpose, potential damage is determined according to the categories of property and includes damage to buildings, roads, public utilities, bridges and water management infrastructure, agriculture, industries, facilities of buildings (dwellings and amenities), areas for sports and to large economic entities. The expression of the flood risk on the basis of potential damage is then based on the distribution of probability of annual peak discharge and is calculated by means of the following Eq. 7:

$$R = \int_{Qn}^{Qext} D(Q) \cdot f(Q) \cdot dQ \tag{7}$$

where: R average annual economic flood risk in [CZK/year],
D(Q) damage [CZK] at discharge Q [m^3/s],
f(Q) density of annual peak discharge probability,
Qn minimum discharge at which damage occurs,
Qext extreme discharge at which damage probability is close to zero.

Procedures applied in the method focus largely on key flood factors, namely the *flood hazard*, which results in flooding, *territorial vulnerability*, which manifests itself in the proneness of buildings and facilities to damage owing to low resistance to extreme flood load and owing to so-called *exposure*, moreover the already-mentioned *flood risk*, which can be expressed, among other matters, by the level of probability of occurrence of the undesirable event, and finally, *flood damage*, evaluated implicitly as direct effects of the flood event that adversely affect a certain territory.

4. Proposal for Improving the HVA CZ Method

The authors of the HVA CZ replace the financial evaluation of indicators by the introduction of dimensionless coefficients of intensity level of the manifestation of the given scenario in the given indicator. As a result the calculated risk is then necessarily dimensionless as well. A weakness of the procedure is just the determination of a function of the behaviour of the coefficient and also the significance of individual indicators, to which the method applies weight coefficients. The weight value itself is another problematical point of the method, because in this case, the weight contains both the technical aspect of the subject matter and the dimension of social acceptance of impacts.
The outputs of the method are then easy to compare from the point of view of individual indexes of observed characteristics. On the other hand, the back identification of causes – what is the reason, is very difficult with the HVA CZ.

Another significant proposal for a modernisation of the HVA CZ method is the extension of it by the evaluation of already applied safety measures. As a consequence, the method will be usable in the cyclic process of risk management, because in the existing form it is applicable only on the project base, i.e. once for all. On this basis, a new formula for the calculation of territorial cumulative risk is proposed, see Eq.8.

$$R_{kum} = \frac{\sum_{i=1}^{n} MR_i \cdot Z}{\sum_{i=1}^{n} S_i} \tag{8}$$

where: R_{kum} cumulative risk for the assessed part of territory,
MR_i level of risk for the given type of hazard,
Z territorial vulnerability,
S_i degree of specific safety measure.

Generally, it is the acquisition of statistical data on extraordinary events for the need of these methods of risk analysis that is a problem. Although in the Czech Republic, detailed statistics are kept, they are kept by various institutions, especially the Fire and Rescue Service of the Czech Republic and insurance companies. For successful quantification, data from these statistics should be processed together. However, this requires a broad consensus on the provision of these data and also the method of evaluation of the data, and last but not least, time and financial means. In such a case, cooperation should be ensured by the state as e.g. in Switzerland.

The second reason is more complicated and its cause can be found in understanding the position of the state and its inhabitants. Inhabitants in the Czech Republic in principle expect the state to take care of them. In such environment, information that the risk of life hazard cannot be fully eliminated and that emphasis should be put during the implementation of protection measures also on their financial effectiveness is then disclosed only with difficulty. In the Czech Republic, this leads to the top level of safety (e.g. in the area of protection of building constructions from the effects of the fire, in technical safety of large transport construction works, such as road tunnels) and, on the other hand, such an approach does not motivate investors (above all the state) to invest effectively, i.e. what is generally taken as a problem and not necessarily what is technically justified as a problem is solved.

5. Discussion

The above-mentioned methods have one element in common – they deal with the problems of risk in a pure technical way. Specific quantities will be quantified, put into formulae, and a cumulative risk value at a chosen geographic scale will be the result. The value of resulting cumulative risk will enable us to compare individual territorial units for which the calculation was performed (to decide which territory is more or less at risk).

Such a piece of information is undoubtedly useful as such. However, the acquisition of it is not easy if the assessment is to correspond to reality (especially in the sense of derivation of individual coefficients for calculations). For this reason, certain simplifying assumptions are adopted in the case of application of the methods in practice, e.g. assumptions of the character of development (e.g. the number of storeys of blocks of flats, the number of persons living in the territory being assessed, etc.) in the case of flood risk assessment.

When applying the above-mentioned methods, input data is assumed to be burdened with the random error that will be compensated in a sufficiently large territory. However, let us ask the question to ourselves**: what are we able to do with the risk?** The general theory of risk says that we can accept the risk, try to reduce it by protection measure implementation or to prepare ourselves for handling extraordinary events (preparation of reserve funds, etc.). Nevertheless, the value of cumulative risk for the selected territorial unit does not make it possible to reveal back (in the sense of simple revelation) the essence of risk – e.g. is the major risk a flood with estimated consequences or the presence of a risky chemical works that uses a large amount of hazardous materials?

Subsequently, for ascertaining the details on possibilities and effectiveness of measures of protection against individual risks, either the use of alternative methods based on the economic aspects of solving (e.g. Cost-Benefit Analysis) or the use of a method of mapping the preferences of the population (Willigness to Pay or Willigness to Accept) is necessary so that the soft component of risk perception by the population may be considered as well.

6. Conclusion

The main advantage of risk mapping application in connection with other analytical methods is the strengthening of making decisions on protection measures made by public and government authorities. Risk mapping can help select the areas that have the highest cumulative risk levels and in which priorities for investment will be established. *Thus, we are able to answer the question where to invest.* The detailed analysis of the selected territories will then specify the allocation of financial means to individual bodies managing the identified key risk sources (e.g. specific ministries, regional authorities, and others).

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