THE FUNDAMENTALS OF RISK ASSESSMENTS ON THE GEOHAZARD CONSEQUENCES

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Abstract: This paper provides the basis for possible geohazards assessments and geohazard risks, as well as a description of measures that need to be implemented in the event of the formation of debris flow and mudflow in a particular area. The most common causes of the formation of debris flow and mudflow in a certain area can be the consequence of slipping or landslides in certain valleys. Therefore, the paper will describe the possible consequences of geohazard, as well as the process of hazard analysis and organizational resilience of the community to the consequences of landslides. The paper describes the general procedure of risk management from possible formation of debris flow and mudflows. The methodology on which the assessment of geohazards in a particular area is based includes Quantitative and Qualitative Risk Analysis from the consequences of rock mass slippage. Qualitative risk analysis uses a descriptive pattern, descriptive or numerical scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur. The quantitative risk analysis is based on numerical values of probability, vulnerability, consequences and the resulting numerical values of risk.

Keywords: landslide risk, risk assessment, hazard assessment, landslide zoning, vulnerability, risk management.

INTRODUCTION

The key to understanding the analysis of vulnerability and risk from the consequences of natural disasters is the overall consideration of hazard analysis, ie a multidisciplinary approach to the consideration of risk management issues. The main purpose of managing the risk of possible consequences of natural disasters is to: (i) provide a framework for understanding the nature and consequences of natural and man-made hazards on people, built property, infrastructure and the environment, and (ii) examine strategies that can protect individuals, organizations, communities, ie a wider area in order to reduce the negative consequences of natural hazards and encourage sustainability. Hazard identification provides specific information about the nature and properties of hazardous events within the community (Žic, 2015).

Vulnerability analysis is the analysis of combinations of consequences and related uncertainties with respect to the initial (hazard) event. It can be focus on physical, political, economic and social vulnerability. Vulnerability is the degree of sensitivity and resilience of a community and the environment to the consequences of danger (Pine, 2008). Vulnerability analysis identifies geographic areas that may be affected by hazards, individuals that may be subject to injury or death, as well as buildings and the environment that may be vulnerable to natural disasters. Vulnerability assessment is an assessment of the exposure or sensitivity or resilience of a community to the consequences of hazards (Roberds, 2005; Crozier and Glade, 2005). Risk analysis is the systematic use of information to determine the initial event, the causes and consequences of the initial event and to express risk. Risk analysis provides the basis for risk evaluation, treatment and acceptance. It represents the determination of the likelihood of possible consequences that may be based on previous historical events, local experiences and the best currently available technological information (Pine, 2008). Quantitative definition of risk (R) can be represented as the product of the probability of occurrence of hazard (H), sensitivity (V) and social elements of hazard (E): $R = E * H * V$.

METHODS OF HAZARD ASSESSMENT SINCE LANDSLIDE

The paper presents the key components of Quantitative Risk Analysis (QRA) for landslide and landslide hazards, which allows scientists and engineers to quantify risk in an objective and reproducible way. The QRA approach is not necessarily accurate in relation to a qualitative assessment, the probability of which can be calculated based on personal judgment. The large and numerous human losses and material damage that have occurred throughout history have led to the current national and international needs to reduce hazards from natural disasters.

Landslide susceptibility is the probability of landslides occurring in a particular area due to characteristic local terrain conditions, while landslide hazard is the probability of landslides occurring that can create potential damage to a particular area over a period of time. Hazard as such directly involves: (i) the strength of the slip (magnitude and intensity), (ii) the geographical location of the slip, and (iii) the frequency of events (Guzzetti et al., 2005). Different approaches in considering landslide hazard assessment have led to a number of classification methods for landslide hazard assessment. One of the first such classifications was developed by Hansen (1984) who divided landslide hazard estimation methods into direct and indirect. The direct method of geomorphological mapping identifies past and present landslides, creating subjective assumptions about where new landslides could occur in the future. Indirect methods consist of assigning weight factors to the causes of landslides. These methods include heuristic methods, experiential methods, statistical and deterministic methods (Crozier and Glade, 2005). Landslide hazard analysis and zoning involves spatial analyzes of landslide probability and a graphical representation of the results in the form of zoning a specific area with respect to the relative hazard of a landslide. Landslide susceptibility analyzes phenomena that have occurred in the past, while landslide hazard assessment consists of predicting what will happen in the future. Risk represents the consequences of the effect of hazard on risk elements taking into account temporal and spatial probability and their vulnerability (Roberds, 2005). Figure 1 shows landslide hazard assessment methods that can be broadly divided into qualitative, semi-qualitative and quantitative methods. They can be distinguished on the basis of defining the cartographic units on which the assessment is carried out: terrain units, mapping units, homogeneous domains or on the basis of distinguishing hazard categories.

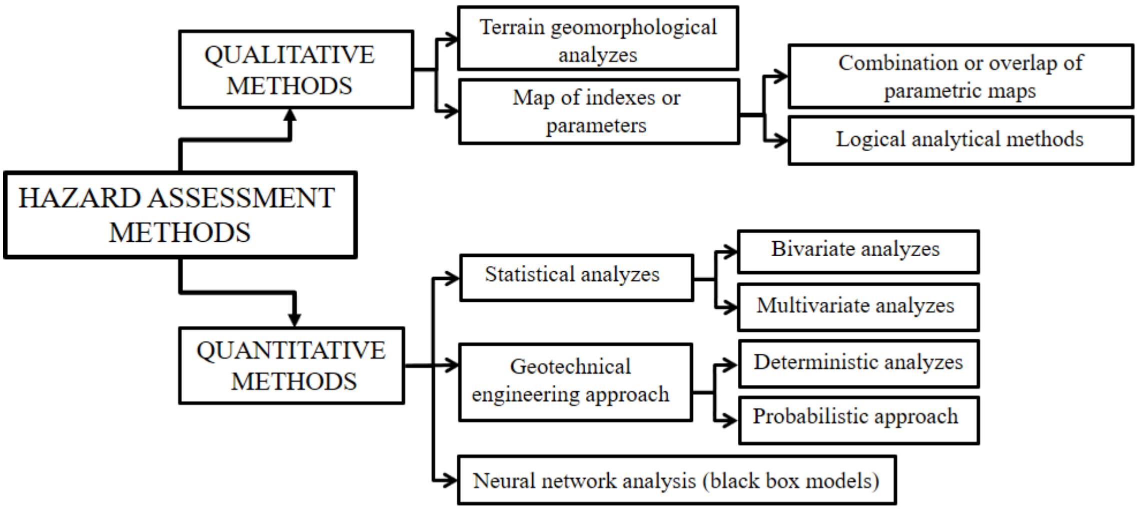

Figure 1. Methods for estimating landslide hazards

A basic feature of a qualitative hazard assessment methodology is the assessment that one or more landslides will occur in an area (Fall et al., 2006). The main disadvantage of this approach is manifested in the subjectivity of researchers in the selection of input data and the creation of results.
Qualitative hazard assessment methodology takes into account the following landslide factors: geological structure, slope inclination, land use (cover layer), vegetation and hydrogeological conditions (Figure 2). All these factors affect the identification of areas that are prone to landslides of similar geological and geomorphological features (index methods). Field implementation of geomorphological analysis is the first form of qualitative approach that allows a rapid assessment of the stability of a particular area, taking into account a large number of influencing factors. Quantitative methodology is based on mathematical expressions and establishes a correlation between causal factors and landslides. The two most commonly used types of quantitative methodology are the statistical and deterministic approaches (Caniani et al., 2008). Statistical (probabilistic) methods are based on the relationship of each factor and the distribution of landslides in the past, which includes mapping existing landslides and combinations of factors that are directly or indirectly related to slope stability. These methods include bivariate methods (Brabb, 1984), multivariate methods (van Westen et al., 1997), discriminant methods (Carrara et al., 1995), so-called Boolean approach

that uses logistic regression (Ayalew and Yamagishi, 2005) and the so-called Bayesian method that uses neural networks to determine the probability of landslides (Lee et al., 2006). The application of GIS can facilitate a deterministic and statistical approach as part of a landslide hazard assessment methodology.

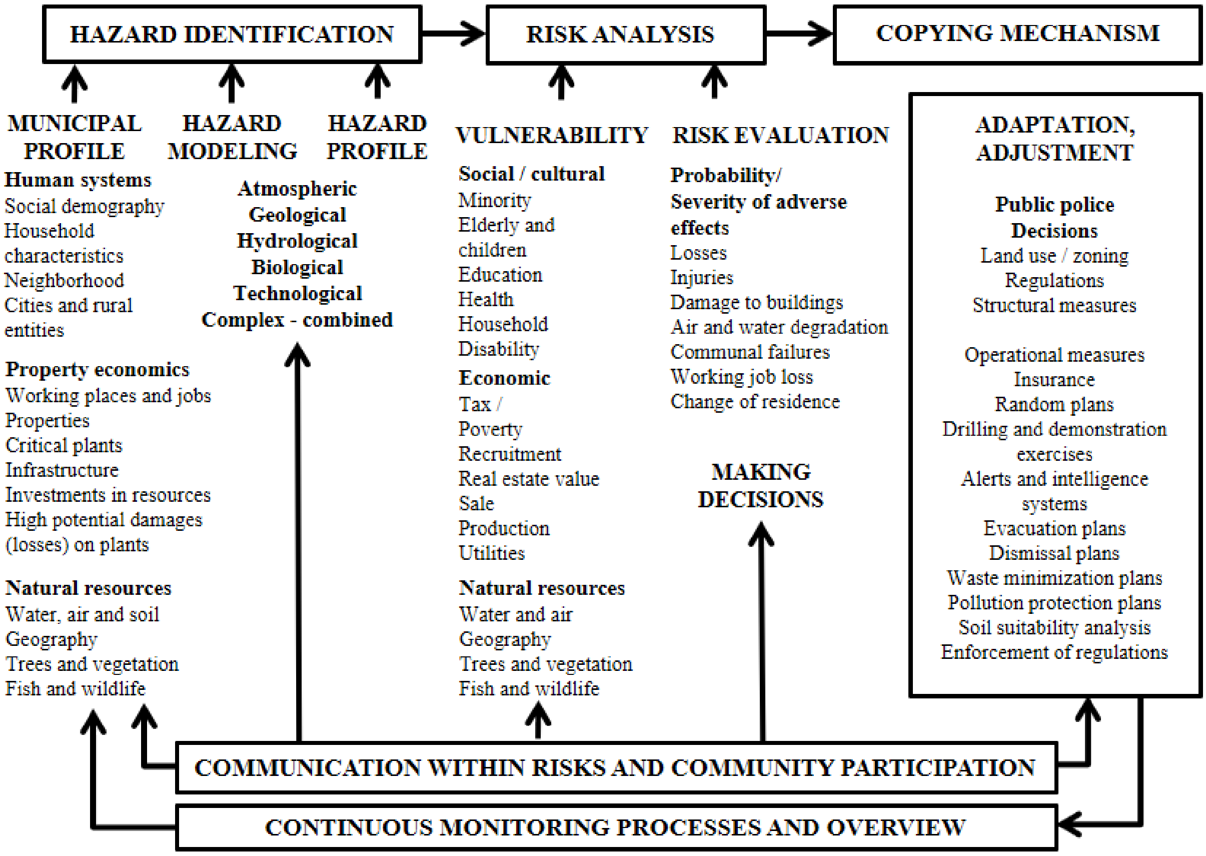

Figure 2. Hazard analysis process and community organizational resilience (modified according to Pine, 2008)

DISCUSSION

The risk of landslide consequences for an individual building or area must be calculated with regard to a certain period of time within which a hazardous event of a certain intensity is expected to occur in relation to the estimated minimum established values (Figure 3). In this regard, there is a growing need to conduct a Quantitative Risk Analysis (QRA). Compared to qualitative risk analysis, which gives results in terms of weighted indicators in certain classes or numerical classification, QRA quantifies the probability of a certain degree of loss and associated uncertainty. The QRA requires accurate input of geological and geomechanical data and a quality digital terrain model for a good assessment of possible scenarios, event calculations and return periods. The risk for a landslide scenario R of strength M_i on the risk element located at a distance X from the landslide source can be expressed analytically:

$$R=P(M_i)P(X_j|M_i)P(T|X_j)V_{ij}C \tag{1}$$

where $P(M_i)$ is the probability of landslides of a certain strength M_i, $P(X_j|M_i)$ is the probability of landslides to a point located on the distance X from the landslide starting source with intensity j, $P(T|X_j)$ is the probability of the element at the place X at the time of landslide, V_{ij} is the vulnerability of the landslide element of intensity i and j, while C is the value of the hazard element. The three basic components that appear in Eq. (1) must be specifically considered when making a hazard assessment, the exposure of hazard elements and their vulnerability. Elements of risk are the population, buildings, economic activities, including public services, or any other persons who are directly exposed to hazard in a particular area.

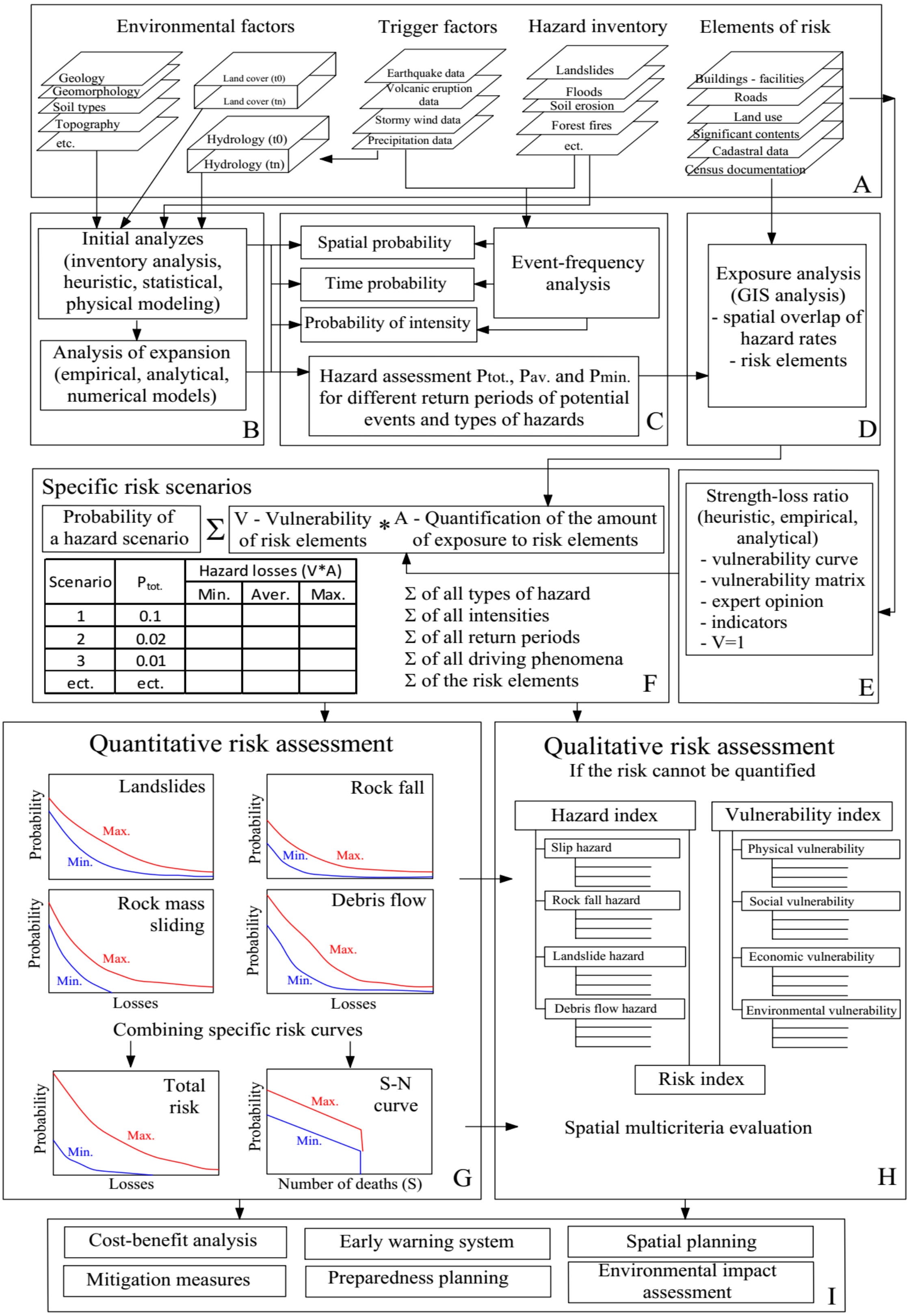

Figure 3. Indicative overview of multi-hazard assessment of landslide risk analysis; A - input data for landslide assessment, B - sensitivity assessment, C - landslide hazard assessment, D - risk element exposure analysis, E - vulnerability assessment, F - integration of hazards, vulnerabilities, nature and quantity of risk elements, G - quantitative risk assessment approach , H - qualitative approach to risk assessment, I - use of risk information in risk management (modified according to Van Westen et al., 2005)

The interaction of hazards and risk elements includes their exposure and vulnerability. The general QRA framework includes a complete risk assessment process and risk management. Risk analysis uses available data to assess a particular risk, population, assets or environment from hazard. It typically contains the following steps: hazard identification assessment, list of risk and risk exposure elements, vulnerability assessment and risk assessment. Because all of these steps have an important spatial component, risk analysis often requires spatial data set management. Risk assessment is the state in which values and judgments enter the decision-making process (explicitly or implicitly), including considerations of the importance of the assessed risks and the associated social, environmental and economic consequences in order to identify a range of risk management alternatives.

Figure 3. based on the work of Van Westen et al. (2005) provides a framework for estimating multiple landslide risk hazards simultaneously, indicating different steps (from A – H). The first step (A) includes the input data needed to assess the risk of multiple hazards simultaneously, with an emphasis on the data needed to generate sensitivity and range of slip mass, trigger factors, multi-time inventories and hazard elements. The second step (B) focuses on sensitivity assessment and is divided into two components. The first, which is most commonly used, deals with the modeling of potential drivers of a particular area (sensitivity initiation), which can use different methods (based on landslide inventory, heuristic, statistical, deterministic methods). The maps that are created show the areas for further modeling of the range of the sliding mass (range probability). The third step (C) includes a landslide risk assessment, which largely depends on the availability of the so-called landslide inventory, based on the same or similar landslide events that have occurred predominantly in the past. By linking landslide distributions to the time probability of activated events, it is possible to perform frequency range analysis. Landslide inventory based on past events, among other factors, is also used to determine the spatial probability of a landslide, ie its start-up and the extent of the landslide mass. The fourth step (D) is the analysis of the exposure of risk elements, which includes the production of hazard maps and risk elements using the GIS environment. Step (E) focuses on vulnerability assessment and indicates various types of vulnerabilities and provides solutions that can be used. The focus is on the use of expert opinion, empirical data and physically based analytical and numerical models in defining vulnerabilities, and the application of available vulnerability curves or vulnerability matrices. Other types of vulnerabilities (eg social, environmental and economic) are mainly analyzed using spatial multi-criteria assessment as part of a qualitative risk assessment (step H). Step (F) integrates hazards, vulnerabilities and the nature and number of elements at risk (whether as the number of persons, the number of buildings or the economic value). The risk for each individual element (specific risk) is determined based on many different situations and refers to the type of landslide, volume, return period of event initiation, type of hazard element and the like. The integration in step (G) shows a quantitative risk assessment approach in which the results are presented in the form of hazard curves that plan the expected losses according to the probability of occurrence for each type of landslide, and are expressed through uncertainty of input data in risk analysis. This can be illustrated by generating two loss curves that express the minimum and maximum values for each trigger event for different return periods or the associated annual probability. Individual risk curves can be integrated into total risk curves for a particular area and population loss can be expressed via the S-N curve (Figure 3). Risk curves can be created for different basic units such as individual slopes, roads, settlements, municipalities, regions or counties. Step (H) provides an overview of methods for qualitative risk assessment, which are based on the integration of hazard index and vulnerability index using spatial multicriteria assessment. The last step (I) concerns the use of risk information at different stages of natural disaster risk management.

CONCLUSIONS

For adequate analysis of landslide hazard it is necessary to conduct a good geotechnical and engineering geological assessment, geomorphological and geographical analysis, political and economic perspective of the area development, as well as economic and social circumstances in the analyzed area and know the factors influencing spatial and temporal variation of the threatening process. The accuracy of landslide hazard estimates depends on the quality and quantity of available data, the time spent collecting and processing data, conducting the necessary analyzes, as well as the financial resources needed to investigate the elements needed to obtain input parameters. When estimating landslide hazard predictions, various methods are available today, developed over the last 40 years or so that are clearly presented in this paper. As a result of the landslide hazard assessment, a landslide hazard map is made. It shows the spatial distribution of different degrees of landslide hazard, including information on the probability or return period of possible landslides.

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REFERENCES

Ayalew L. & Yamagishi H. 2005 The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan, Geomorphology, 65, pp. 15-31.

Brabb E. E. 1984 Innovative approaches to landslide hazard mapping. In: 4th International Symposium on Landslides, Toronto, Canada, 16-21 Sept. 1984, 1, pp. 307-324.

Caniani D., Pascale S., Sdao F. & Sole A. 2008 Neural networks and landslide susceptibility: a case study of the urban area of Potenza, Natural Hazards, 45, pp. 55-72.

Carrara A., Cardinali M., Guzzetti F. & Reichenbach P. 1995 GIS technology in mapping landslide hazard. In: Geographical Information Systems in Assessing Natural Hazards, pp. 135-175.

Crozier M. J. & Glade T. 2005 Landslide hazard and risk: Issues, Concepts and Approaches, In: Landslide Hazard and Risk, Glade T., Anderson M. & Crozier M. J. (eds.), John Wiley & Sons, New York, pp. 1-40.

Fall M., Azam R. & Noubactep C. 2006 A multi-method approach to study the stability of natural slopes and landslide susceptibility mapping, Engineering Geology, 82(4), pp. 241-263.

Guzzetti F., Reichenbach P., Cardinali M., Galli M. & Ardizzone F. 2005 Landslide hazard assessment in the Staffora basin - northern Italian Apennines, Geomorphology, 72, pp. 272-299.

Hansen A. 1984 Landslide hazard analysis. In: Slope instability, Brunsden D. & Prior D. B. (eds.), John Wiley and Sons Ud, pp. 523-602.

Lee S., Ryu J. H., Lee M. J. & Won J. S. 2006 The application of artificial neural networks to landslide susceptibility mapping at Janghung (Korea), Mathematical Geology, 38, pp. 199-220.

Pine J. C. 2008 Natural Hazards Analysis - Reducing the Impact of Disasters. Auerbach Publications, Taylor & Francis Group, p. 314.

Roberds W. 2005 Estimating temporal and spatial variability and vulnerability. In: Landslide Risk Management, Hungr O., Fell R., Couture R. & Eberhardt E. (eds.), Taylor and Francis, London, pp. 129-158.

van Westen C. J., Rengers N., Terlien M. T. J. & Soeters R. 1997 Prediction of the occurence of slope instability phenomena through GIS-based hazard zonation, Geol. Rundesh, 86, Springer-Verlag, pp. 404-414.

van Westen C. J., Van Asch T. W. J. & Soeters R. 2005 Landslide hazard and risk zonation: why is it still so difficult?, Bulletin of Engineering Geology and the Environment, 65(2), pp. 167-184.

Žic E. 2015 Prilog modeliranju potencijalnih poplavnih tokova i tokova krupnozrnatog materijala u slivu vodotoka Rječine (Contribution to modeling of potential flood flows, debris flow and mudflow in the Rječina River Basin). PhD thesis, Faculty of Civil Engineering, University of Rijeka, Rijeka, 281 pages.