GEO-INFORMATION TECHNOLOGY FOR DISASTER RISK ASSESSMENT

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Abstract

The Serbian territory (including the territory of the former Yugoslavia) has been continuously exposed to different hazards, often with tragic consequences. Earthquakes and floods, usually followed by landslides, are the most dominant hazards in that region. Disaster risk reduction, prevention and early warning, as an integral part of sustainable development, do not exist in Serbia. That is one of the main reasons why the disaster-related damage is high. Despite very long experience in engineering and resources management in Serbia, there are no scientifically supported and standardized disaster risk-assessment procedures. Expertise only exists in the field of engineering-based hazard assessment.

The risk-assessment method proposed in this research includes, apart from hazards, parameters such as vulnerability, exposure and safety. It considers the environmental and social components of risk management. The proposed method, implementing combined mathematical and 3D GIS tools, was applied for the Danube River, Petrovaradin (the city of Novi Sad) area, for which data were available. The relationship between the risk parameters is calculated and graphically presented. Methods like this one should contribute to a shift from a passive disaster-related defense to a proactive disaster risk management, as well as from emergency management only, to disaster prevention, preparedness and mitigation activities, in Serbia and the Western Balkan Region.

keywords

hazard, vulnerability, safety, resilience, coping capacity, risk assessment, risk management, geographic information systems, earthquake, landslide, flooding, exceedance

1 INTRODUCTION

The number of natural disasters is ever increasing. According to the CRED EM-DAT, there were 6387 natural disasters between 1974 and 2008, worldwide, not counting epidemics. This resulted in the following consequences: more than 2 million people lost their lives; 1.5 billion people were affected; 182 million people were made homeless; and economic damage estimated was US$ 1.38 trillion (Guha-Sapir et al., 2004).

An increasing trend in the number of natural disasters is evident over the past 50 years globally (CRED EM-DAT). As the global population is constantly increasing, so the number of people exposed to the same types of hazard has also increased.

The Western Balkan Region is experiencing the same trend. Its territory (including the territory of the former Yugoslavia) has been continuously exposed to different hazards, often having tragic consequences (Table 1).

Table 1. Natural disasters in the Western Balkan Region over the past 50 years (CRED EM-DAT).

Disaster	Date	No. Killed
Earthquake	07/1963	1100
Earthquake	04/1979	121
Flood	03/1981	70
Extreme temperature	07/1988	38
Epidemic	03/1972	35
Flood	11/1979	22
Earthquake	10/1969	15
Earthquake	02/1983	12

Table 2 shows number of people affected by natural disasters, for the past 50 years, in the Western Balkan region. It is obvious that earthquakes and floods are the most frequent hazards. Those two events have accumulatively affected close to one million people (CRED EM-DAT).

Table 2. People affected by natural disasters in the Western Balkan for the past 50 years (CRED EM-DAT).

Disaster	Date	People Affected
Earthquake	04/1979	310100
Earthquake	10/1969	286116
Flood	10/1964	240000
Flood	05/1965	95000
Earthquake	11/1967	21870
Earthquake	11/1968	15030
Flood	11/1979	12000

Earthquakes and floods, followed by landslides, were not the only natural disaster in the Western Balkan territory. Summer heat and extreme summer temperatures have been recorded for the past few years. Departures from the maximum annual temperatures were significant. The day and night maximum temperatures significantly exceeded those recorded in the past. It has also resulted in an increased number of dry spells and forest fires, especially in the summer of 2007 (Republic Hydrometeorological Services of Serbia).

The cost of those recorded disasters has an increasing trend. The reasons for this are twofold: the number of natural disasters has increased (Guha-Sapir et al, 2004) as has the value of the built infrastructure (as a result of the increased urbanization and industrialization).

Disaster response in Serbia has been chaotic and disorganized. Each time it is another disaster on its own. The disaster-related legislation and regulations are, by their nature, "reactive", based on the civil protection legislations, covering only the right-hand side of the Disaster Management Cycle. There is a continuous lack of horizontal and vertical coordination in the disaster risk management. One very fresh example is the disasters in Serbia in February and June 2010.

Why this research was conducted?

Disaster risk reduction, prevention and early warning do not exist in Serbia. That is one of the main reasons why the disaster-related damage is very high. Despite the very long experience in hazard engineering and resource management in Serbia, there are no scientifically supported and standardized disaster risk-assessment procedures. Expertise exists only in the field of engineering-based hazard assessment.

This paper presents the results of risk-assessment research involving vulnerability as one of the most important risk parameters (Turner et al., 2003; Birkmann and Bogardi, 2004; Cannon et al., 2005), with the main goal to address the risk accordingly. These results will be used to maximize the prevention and mitigation activities, based on the best possible interdisciplinary experience and knowledge, methods, models, as well as information technologies. The proposed geographical area is the Republic of Serbia, with the intention to expand the implementation of this model to the Western Balkan Region.

2 THEORETICAL BACKGROUND

Generally, risk can be represented as a temporal-spatial function of a series of complex parameters (Turner et al, 2003; Birkmann and Bogardi, 2004; Cannon et al, 2005):

$$R = f\,(H, V, E, CC, Re, etc.) \qquad (1)$$

Where R is the Risk, H is the Hazard, V is the Vulnerability, E is the Exposure, CC is the Coping Capacity and Re is the Resilience.

The likelihood of hazardous events can hardly be affected. It increases year after year. To assess risk adequately, data about the underlying hazardous event should be collected first. For an accurate assessment of the probability of occurrence it is necessary to have the largest possible number of measurements (historical registry) for every hazardous event. According to the law of large numbers, with an increase of the sample, the deviation will decrease, which results in a more accurate frequency of an event.

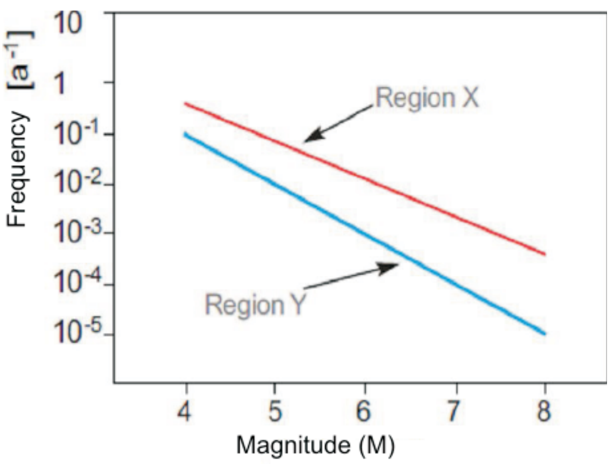

Figure 1. Frequency-Magnitude relation for a particular hazard.

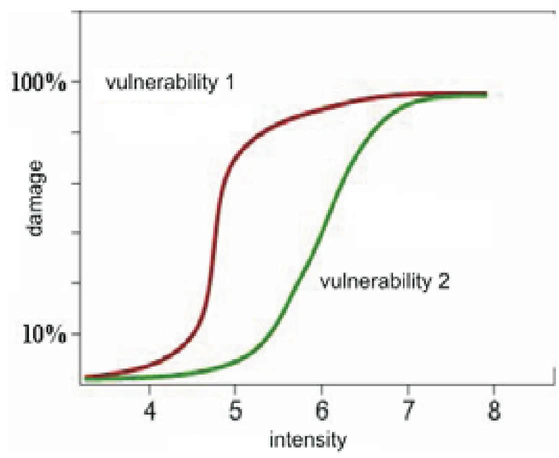

Figure 2. Vulnerability damage-intensity relation.

To determine it quantitatively, every hazard magnitude is related to a certain frequency. The location or region is continuously characterized by the connection between the magnitude and the frequency of a certain hazard, as shown in Figure 1 (Thywissen, 2006).

The largest contribution to risk reduction could be achieved through four different types of vulnerability reduction: Infrastructural vulnerability, Environmental vulnerability, Economic vulnerability and Social vulnerability (Birkmann and Bogardi, 2004; Cannon et al., 2005).

The vulnerability component, along with the exposure analysis, is related to the possible damage caused by the effects of hazardous events on certain systems and their operation. Vulnerability is a dynamic and characteristic property of any community (or household, region, nation, infrastructure or of any other risk element), itself consisting of a multitude of components. It is a continuous and dynamic feature, revealed to the certain extent during the event, depending on the intensity of the harmful event.

Understanding the damage pattern of a certain society, without knowing the event's magnitude, prevents us from making accurate conclusions regarding the vulnerability of society. Hence, the threatened element's (community, household, nation, infrastructure, etc.) vulnerability is reflected in the damage-intensity relation (Thywissen, 2006; Figure 2).

A vulnerability assessment starts with a historical analysis of events with disastrous effects, identifying and systematizing the conditions of vulnerability from data about the damage and loss of the entity (household or community). It is very important to obtain the largest possible number of damage data, since the function of vulnerability on specific hazard levels can be expressed according to those data.

Along with hazard and vulnerability, exposure is another prerequisite of risk and disaster. Exposure implies the number of people and/or other elements under risk, which may be affected by a certain event. While the level of events effecting the elements under risk is determined by vulnerability, the final level of damage or harm is determined by exposure.

In everyday life, the damage does not depend only on the hazard, vulnerability and exposure, but also on the safety of the elements exposed to the hazard. Safety is seen as a function of resilience and resistance. Resilience consists of strategies and measures that directly help to mitigate the damage during an event. The degree of a system's resilience depends on what has been done to cope with the hazard.

2.1 EQUATION REVIEW

There are many variations of the generic risk equation (1). For example, ISDR (2004) proposed the most simple risk equation:

$$Risk = Hazard \cdot Vulnerability \qquad (2)$$

Alexander (2000) defined risk as “the likelihood, or more formally the probability, that a particular level of loss will be sustained by a given series of elements as a result of a given level of hazard”. Total risk would then consist of the sum of the predictable casualties, damages and losses, represented by the equation:

Total Risk = ∑element at risk · Hazard · Vulnerability (3)

Recent publications have incorporated Coping Capacity, Exposure and Susceptibility in calculating risk. For example, one typical equation, implemented by many authors (such as Birkmann, 2006; Thywissen, 2006) is:

Risk = Hazard · Vulnerability / Coping Capacity (4)

Coping Capacity refers to the means by which people and/or institutions use the available capacities and resources to face adverse consequences related to a disaster.

Dilley et al. (2005) represents Risk as the combination of Hazard, Exposure and Vulnerability:

Risk = Hazard · Exposure · Vulnerability (5)

Hahn (2003), using Hazard, Exposure, Coping Capacity and Vulnerability, has developed the following equation to calculate risk:

Risk = Hazard + Exposure + Vulnerability - Coping Capacity (6)

An interesting formulation concerning vulnerability was proposed by White et al. (2005). Vulnerability itself is a combination of Exposure, Coping Capacity and Susceptibility:

Vulnerability = Exposure · Susceptibility / Coping Capacity (7)

Theoretically, a risk assessment would be more accurate if it involved more parameters. On the other hand, it makes the assessment more complex and more difficult to implement, very often having a nonlinear relation between those parameters. There is always one more practical difficulty: the availability of the input data for

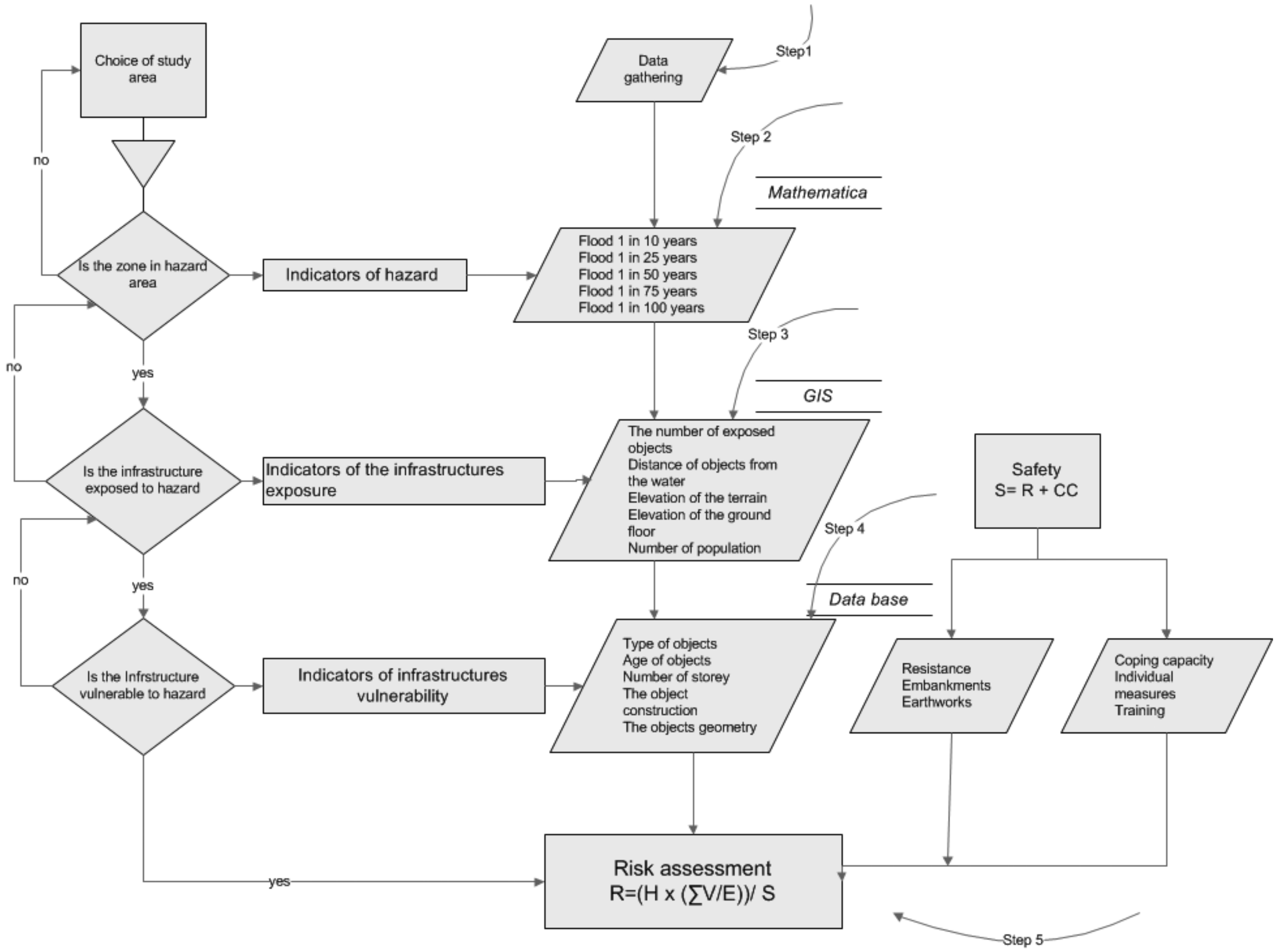

Figure 3. Risk-assessment model implemented in this research.

the calculation of the selected parameters. It was an obstacle in our research, forcing us to modify the risk equation we wanted to select.

3 METHOD AND MODEL

After a detailed analysis of the various risk equations, and being realistic regarding the data availability for Serbia and the Western Balkans, we decided to implement the following risk parameters: Hazard, Vulnerability, Exposure and Safety, implemented using the following formula:

$$Risk = \frac{Hazard\, x \left(\dfrac{\sum Vulnerability}{Number\, of\, exposed\, objects} \right)}{Safety} \qquad (8)$$

Expression *∑Vulnerability / Number of exposed objects* represents an average vulnerability.

As per equations (2), (3), (4) and (5), hazard and vulnerability are the factors contributing risk. On the other hand, safety (incorporating coping capacity) is inversely proportional to risk. This approach was the most practical for implementation in the selected pilot area of Petrovaradin.

The risk-assessment procedure is given by the flowchart (Figure 3) and consists of the following 5 steps:

1. Select study area
2. Select indicators to assess hazard
3. Determine exposure indicators
4. Determine vulnerability indicators
5. Perform risk assessment.

To enable a spatial dimension of the risk assessment proposed, a Geographic Information System (GIS) was implemented, with components of the architecture required for a 3D spatial view (Figure 4). The focus was on the following requirements:

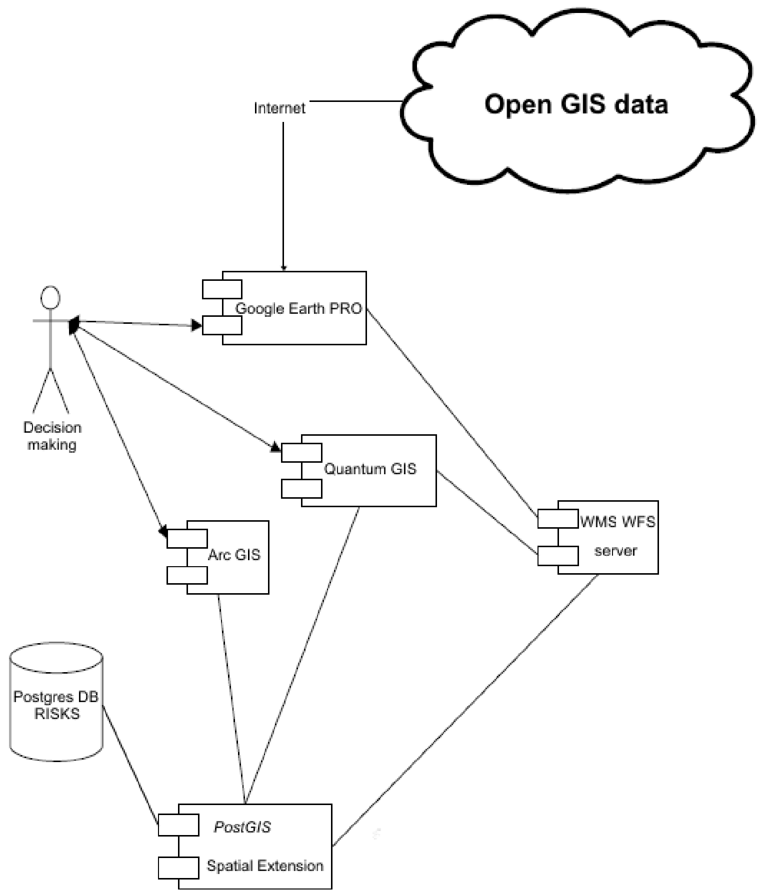

Figure 4. GIS system architecture applied in this research.

- Representation of different types of GIS-related geographical data;
- Representation of the map or chart containing the elements and explaining their relation according to the geographic position;
- Representation of the model resulting from the application of specific analytical functions on well--known data;
- Representation of the full 3D model.

4 RESULTS

The study area was defined first. It is a part of the Petrovaradin settlement (City of Novi Sad, Figure 5), on the bank of the Danube River, a place with considerable exposure to flooding. Here, both residential and industrial objects, traffic, arable and forest land, orchards and vineyards are threatened by flooding, making the area increasingly interesting.

Data were collected for the investigated area regarding the water level measured at the "Novi Sad" gauging station. The maximum water level of 778 cm was recorded in1965. The terrain "0" height above which the water level is measured at the "Novi Sad" gauging station, the closest to the Petrovaradin area, is 71.73 m above sea level (a.s.l.). The maximum or absolute height of the Danube near Novi Sad was 79.51 m.a.s.l., which occurs once in 88 measurements. The flood is considered a 100-year flood if the absolute height is 80 m above sea level. The flood hazard indicators were determined according to this data. Data on the water-level height, based on which the charts on return periods and the exceedance probability were calculated (MATHEMATICA software, Figures 6 and 7):

To determine what was exposed to flooding regarding the above-mentioned water levels of the Danube, GIS software was used as a tool to construct the Digital Elevation Model (DEM). The terrain's digital model was covered by aerial ortophoto snapshots of the studied area. These ortphoto snapshots were in the geoTiff format in a scale of 1:5000 with coordinates in the Gauss-Krüger system. The geo referencing was carried out manually (Figures 8 and 9):

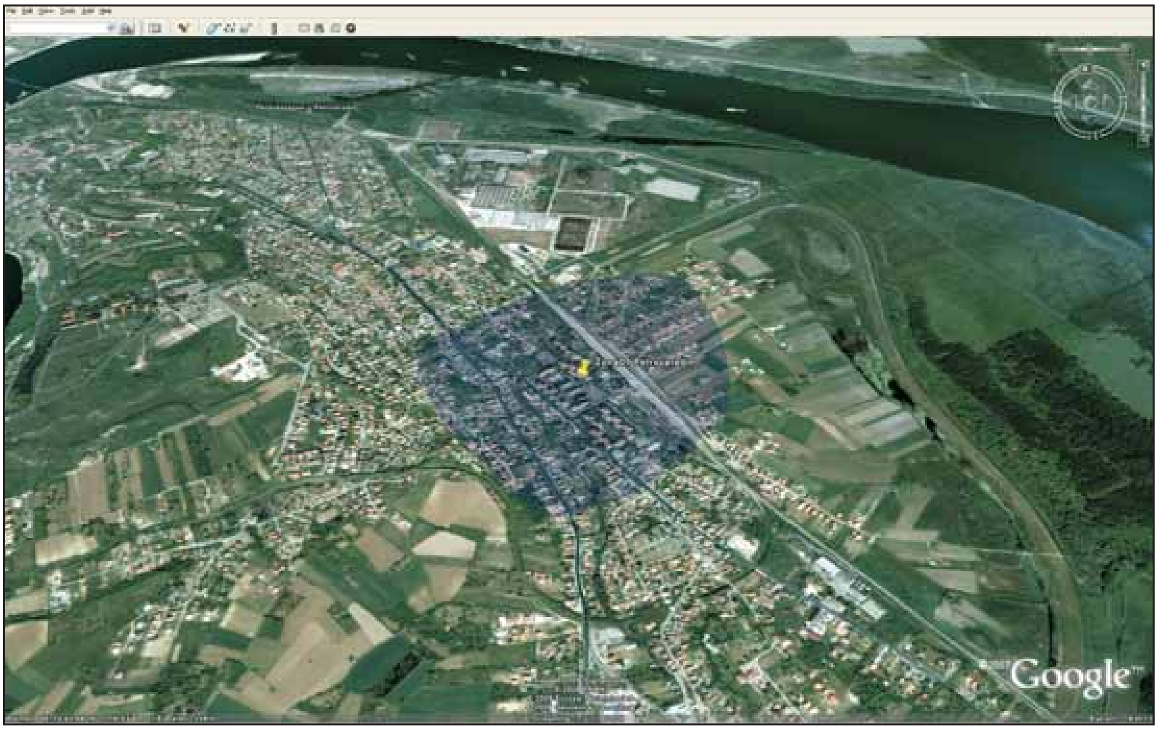

Figure 5. Petrovaradin area (by Google Earth).

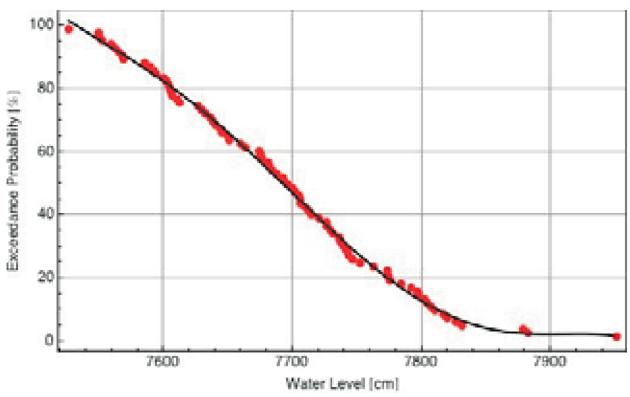

Figure 6. Exceedance probability for the Novi Sad gauging station.

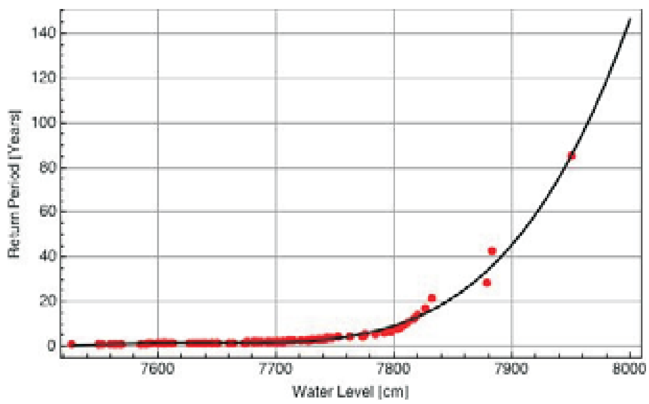

Figure 7. Return period for the Novi Sad gauging station.

Unfortunately, whenever there was a flood on Serbian territory, a systematic damage assessment was never conducted. Here and there some damage data exists, but there was no possibility to structure them and do a correlation analysis. The damage-magnitude (Figure 10) was obtained by comparing the most similar hydrological conditions for the Danube River, near the City of Novi Sad, and the Rheine River in Germany, near the City of Cologne, for the same infrastructure object types. The German Federal Ministry have been continuously recording the damage whenever a flood occurred.

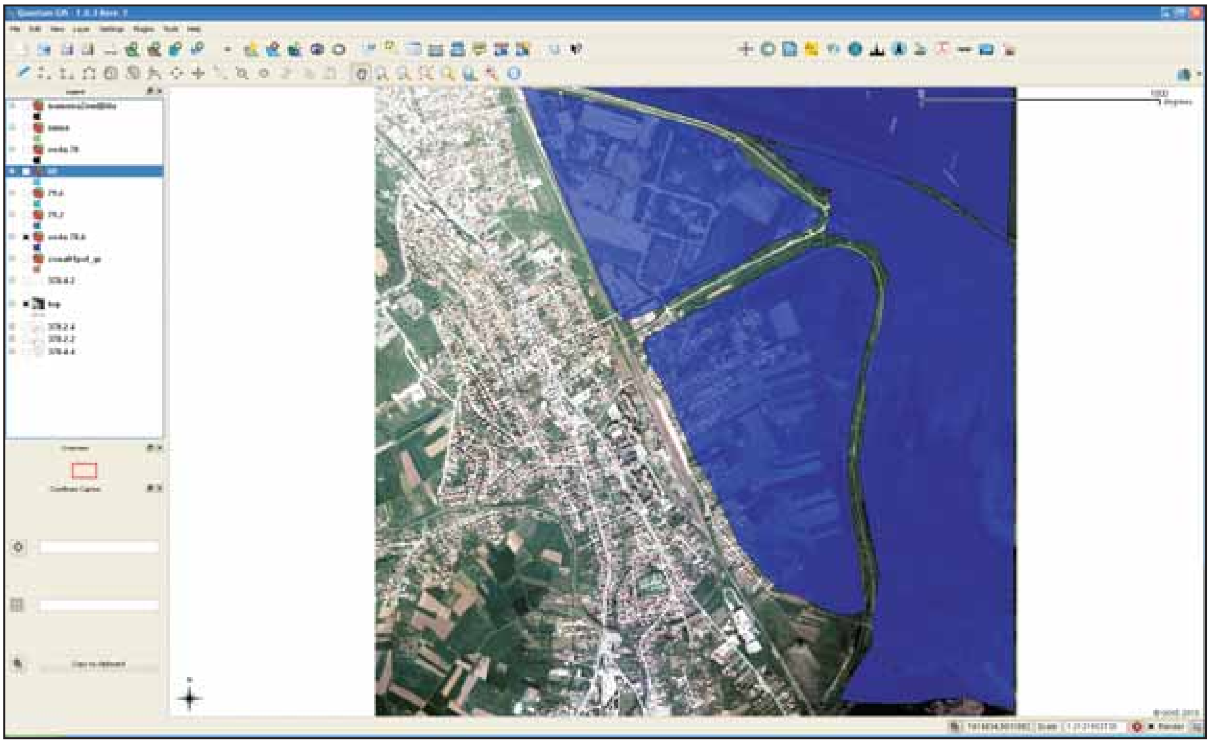

Figure 8. Exposed object at 78 m.a.s.l. for Petrovaradin.

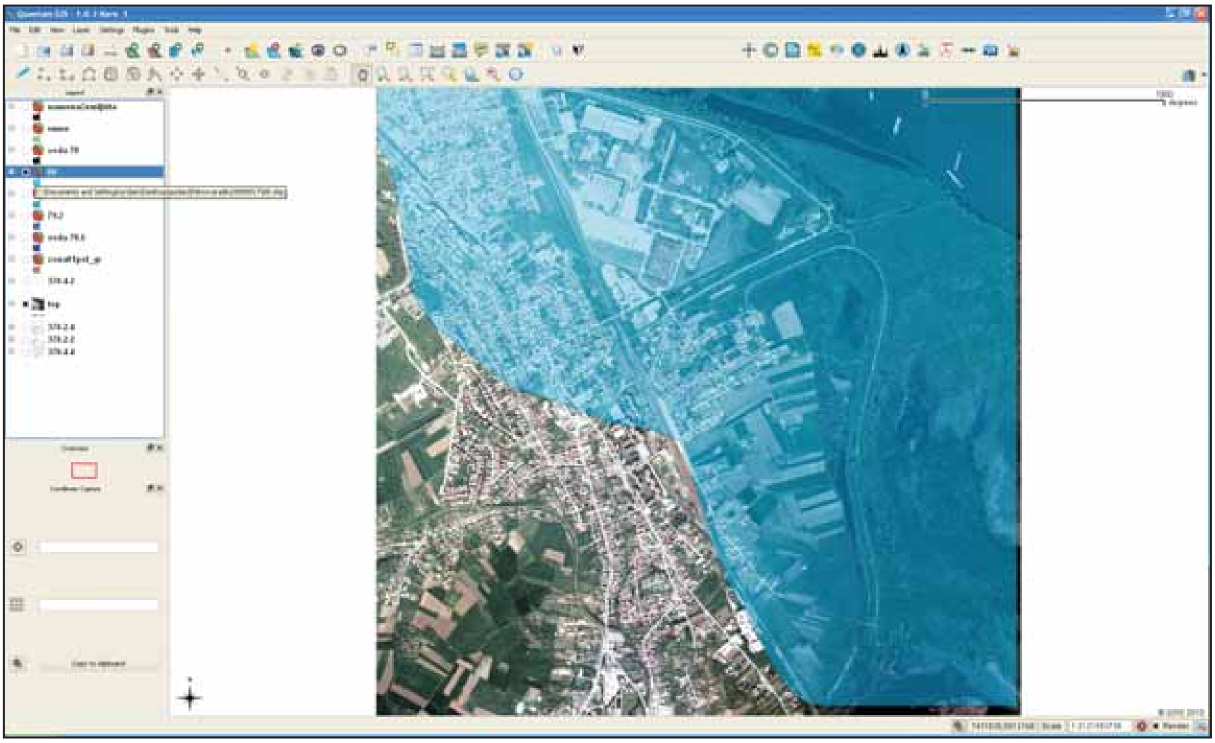

Figure 9. Exposed object at 80 m.a.s.l. for Petrovaradin.

To determine the vulnerability of objects to a flood, this model uses data that were collected through the GIS and through field inquiries. The most important indicators of the infrastructural vulnerability assessment were the following: the Depth of flooding; the Duration of flooding; the Object's surface area; the Elevation of the terrain; the Elevation of the object's ground floor; the Object type; the Type of material; the Number of floors; and the Construction elements.

The degree of vulnerability was expressed through a coefficient that ranges from 0 to 1, after the normalization. This means that the coefficient of vulnerability for a specific depth was read from the depth-damage relation. Based on data from the infrastructural objects' attribution table, as well as on the vulnerability graph (Figure 10), the damage to objects at a particular flooding depth was estimated and the coefficient of vulnerability was determined.

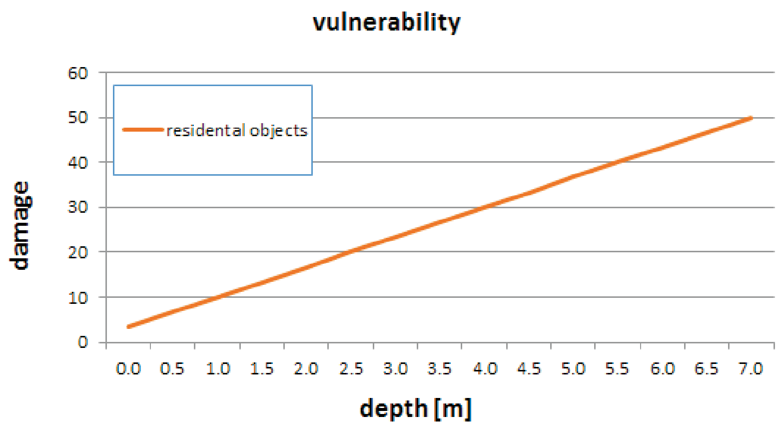

Figure 10. Historical vulnerability expressed by a damage-magnitude (depth) relation.

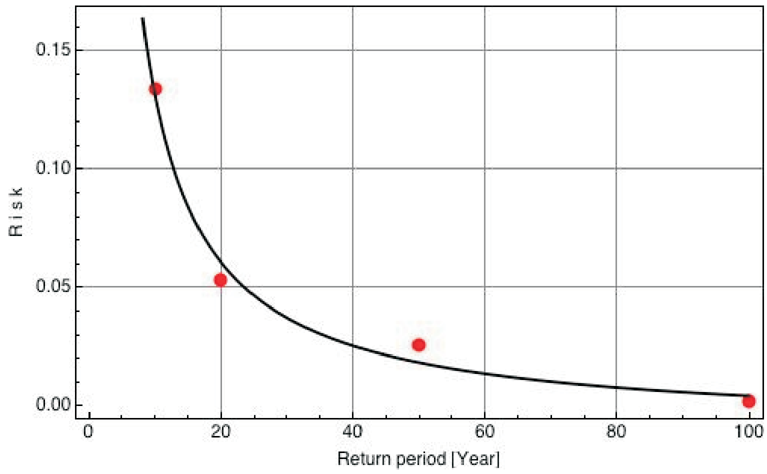

Figure 11. Relation between risk and return period for the Petrovaradin area.

Finally, risk, in relation with vulnerability, exposure and safety, and expressed in terms of the return period (10, 20, 50 and 100 Years) were calculated according to equation (8), and the following relation (9) was obtained (Figure 11).

$$R = (1.42/x) - 0.01 \qquad (9)$$

where: x = Return Period [Years]

5 CONCLUSIONS AND RECOMMENDATIONS

For decades, disaster risk assessments in Serbia were based on a hazard assessment only. It was mostly done by engineers, following basic engineering principles. No attention was paid to the environmental or social components of a particular hazard, such as earthquake, flood or landslide. Parameters, such as vulnerability, exposure, coping capacity, resistance or resilience were never considered. Still today, official institutions and related legislations are in the sphere of hazard-related defense and civil protection.

The main purpose of this research was to show the significance of those risk parameters, other than hazard, and their contribution to the overall risk assessment. Highlighting the importance of vulnerability, exposure, and safety, and confirming it in this, and similar research, proof needs to shift from hazard-related defense to disaster-risk management, as well as from emergency management only, to disaster prevention, preparedness and mitigation activities.

The proposed equation (8) has those parameters included. Considering the relation between risk and flood the return period was calculated and graphically presented for the Petrovaradin area. This enables a graphical and analytical determination of the risk value for a particular return period.

ADVANTAGE

Disaster risk assessment is a much more complex event than just an engineering analysis of, for example, slope stability, or flood wave and flood routing, or return period. The method proposed in this paper involves different dimensions of risk assessment, involving vulnerability, exposure and safety. It certainly gives a better multidimensional risk assessment. The results should be the input parameters for a proactive disaster risk management in Serbia.

DISADVANTAGE

Involving more risk parameters requires more and more input data for the calculation. This type of data has not been systematically collected in Serbia. To enable this type of data collection will require a modification to the existing national and local disaster risk management structure.

RECOMMENDATIONS

To make an implementation of the proposed disaster risk-assessment method sustainable, we recommend the following:

- To systematize disaster risk-assessment models in a multi-hazard framework: The common practice, from many countries, is to perform a risk assessment for most frequent hazards, one by one. It is more costly, requires repetition of data relations and database design, and field data collection. The optimum way is to do a multi-hazard risk assessment.
- To adopt those most suitable for Serbia and its environment: There are no recipes for disaster risk assessment. Every natural surrounding is unique, and requires modification of the generally accepted methodologies.
- To structure basic input-data measurements and collection: Disaster risk assessment, especially a vulnerability assessment, requires interdisciplinary skills. Different disciplines (i.e., social science and engineering) have their own terminology, methods and indicators. To avoid misunderstanding and duplication, some framework in the field of data collection is required.
- To officially task governmental institution to continuously manage a multi-hazard risk assessment: The proposed disaster risk assessment is a result of academic research. The practical implementation of such a method will require a custodian institution. The most appropriate will be an existing national disaster risk-management institution.

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