

**MULTI-HAZARD ASSESSMENT USING GIS IN THE URBAN AREAS:
CASE STUDY - BANJA LUKA MUNICIPALITY, B&H**

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Abstract: The research presents a techniques for natural hazard assessment using GIS and cartographic approaches with multi-hazard mapping in urban communities, because natural hazards are a multi-dimensional phenomena which have a spatial component. Therefore the use of Remote Sensing and GIS has an important function and become essential in urban multi-hazard assessment. The first aim of this research was to determine the geographical distributions of the major types of natural hazards in the study area. Seismic hazards, landslides, rockfalls, floods, torrential floods, and excessive erosion are the most significant natural hazards within the territory of Banja Luka Municipality. Areas vulnerable to some of these natural hazards were singled out using analytical maps. Based on these analyses, an integral map of the natural hazards of the study area was created using multi-hazard assessment and the total vulnerability was determined by overlapping the results. The detailed analysis, through the focused research within the most vulnerable areas in the study area will highlight the administrative units (urban centres and communes) that are vulnerable to various types of natural hazard. The results presented in this article are the first multi-hazard assessment and the first version of the integral map of natural hazards in the Republic of Srpska.

Key words: Natural hazard, Vulnerable areas, Multi-hazard assessment, Banja Luka Municipality.

Introduction

The increased vulnerability by natural hazards in many urban areas, especially in developing countries is a major reason of concern. Therefore emphasis should be given to the reduction of vulnerability in urban areas, which requires multi-hazard assessment in order to make recommendations for prevention, preparedness and response. The territory of BiH has not been included in most of the recent studies examining natural hazards within Balkan region (Abolmasov et al., 2011; Dragicevic et al., 2011; Muco et al., 2012; Milevski et al., 2013), Europe (Grimm, 2002; Schmidt-Thomé and Kallio, 2006; Barredo, 2007; Gaume et al., 2009) and globally (Berz et al., 2001; Peduzzi et al., 2005; Mosquera-Machado and Dilley, 2009). Therefore, it was necessary to create a preliminary multi-hazard map of the BiH area. The previous research showed that the territory of BiH is vulnerable to various types of natural hazards (Tošić et al., 2011, 2012, 2013). Seismic hazards, landslides, excessive erosion, floods, torrential floods, rockfalls, droughts and forest fires are some of the significant natural hazards within the territory of BiH.

The International Strategy for Disaster Reduction (ISDR, 2004) welcomes research to promote protection of the environment to reduce vulnerability to disasters. Although there is a growing recognition that similar research can help to mitigate damages caused by vulnerability to hazards, but we still do not have a multi-hazard map and cadastre of natural

hazard for the BiH territory for spatial and urban planning. The basic idea is to perform a detailed analysis of the vulnerability of the territories of Banja Luka Municipality to various types of natural hazard and to identify the most vulnerable zones. The results can be applied in the field of spatial and urban planning, water and soil management on the local and regional level.

Study Area

The Banja Luka municipality is a territorial subject of the internationally recognized state of Bosnia and Herzegovina. The study area is located in South-East of Europe within a location of 44°43'06" and 44°50'15"N, 17°08'46" and 17°16'06" E; its area is 55.47 km², having around 226450 inhabitants.

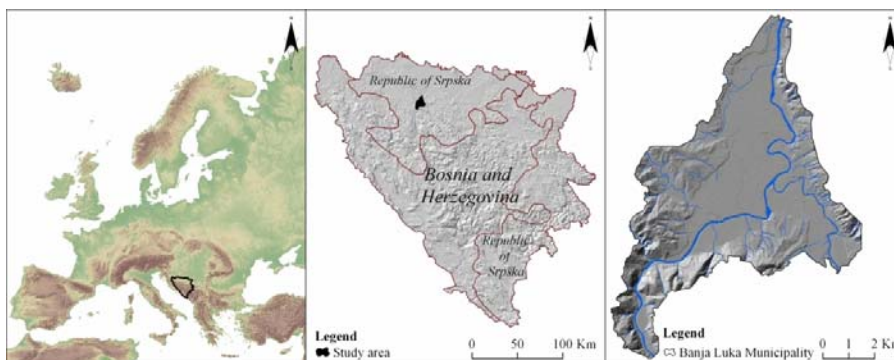


Fig. 1. Location of the study area - urban area of Banja Luka municipality.

The whole area of Banja Luka municipality belongs to the large morphologic cluster - Pannonian region. According to morphostructural characteristics, study area is a neotectonics depression which formation begun during Neogene tectonic activity (Mojićević et al., 1976; Trkulja, 1998). Based on lithogenetic criteria the territory of study area contains: fluvial sediments, proluvial sediments, deluvial (slope) sediments, flysch sediments, Neogene sediments, and Mesozoic rocks. Basis for Quaternary sediments are: Neogene indigenous rock mass (slightly calcareous mudstone, marlstone, sands, pebbles, etc), Cretaceous rocks (limestone, slightly argillaceous limestone, calcarenite, breccia and other), and then diabase-hornstone complex (serpentinite, hornstones, diabase, dolomite rocks, etc.). The greatest spatial stretch of all indigenous rock masses has Neogene sediments 9.87 % out of total study area. Over above mentioned indigenous rock masses the largest spatial distribution has fluvial sediments located in the centre of study area, while proluvial and deluvial sediments are located in peripheral parts of alluvial plain and on the slopes.

The terrain is ranging from 137 m to 432 m above sea level. Flat terrain, that is in fact unique alluvial plain of the rivers Vrbas, Vrbanja and Crkvena with slopes less than 5°, is dominant all over territory of study area. Hilly terrain encompasses slightly rippled sides of peripheral parts of Banja Luka depression. Northern and north-western slopes have inclinations between 5°-15° and only sporadically there are slopes with inclination over 20°. Slopes where dominant inclinations are over 20° are located in south-western and southern parts of study area and intermittently in south-east parts.

According to dominant denudation process, slopes of south-western and southern parts of Banja Luka depression and river valley sides are submissive to linear erosion. In higher parts of the slopes there are ravines present, while torrents are often formed in the

middle and lower parts. North-western parts of study area that are composed by Neogene sediments do not experience extensive linear erosion processes, but frequently do have landslides occurrences.

The climate has the characteristics of moderate-continental climate with an average annual temperature above 10°C and rainfall of 1050 mm. Basic hydrographical features of the study area terrain are rivers Vrbas and Vrbanja and smaller watercourses of Crkvena, Široka rijeka and other. The dominant soils are Planosols-pseudogley, Fluvisols, Gleysols-dystric, eutric and mollic ones.

Methodology

Multi-hazard mapping is a good approach for observing several hazards on one place in which each hazard could be observed separately and integrally (Blinkov and Mincev, 2010). Given the well-known fact that natural disasters occur suddenly, independently of each other or in the mutual relationship (synergy), it was necessary to make the assessment analysis of the most significant natural hazards in the selected areas. Areas vulnerable to some of these natural hazards were singled out using analytical maps; their area relative to the total area of Banja Luka Municipality was defined, along with the total surface area that is vulnerable to each type of natural hazard. Upper values of intensity for each natural hazard were determined, as this value represents the limiting factor on surface use for the given level (Dragicevic et al., 2010; 2011, 2013).

For seismic activity (Trkulja, 1998), areas in which the strength of the seismic hazard was above VIII on the MCS-64 scale were singled out. The intensity of recent geomorphological processes was assessed using the Gavrilovic's erosion potential model (EPM) for the calculation of gross annual erosion and sediment yield. The quantitative values of the erosion coefficient (Z) have been used to separate erosion intensity to classes or categories (Tošić & Dragičević, 2012a).

The areas which are potentially at risk of landslide process (landslide susceptibility zonation) in the study area were determined by heuristic method - Index based method. The index-based method (IBM) using simple ranking and rating methods for landslide susceptibility zonation. In this method, causative factors of slope instability of the study area are selected in the first step. Each causative factor is considered as a parameter map. The relative importance of each parameter map for slope instability is evaluated according to subjective experts' knowledge. On the basis of comparisons of different parameters, weight values are assigned to each parameter map. Next, each parameter map is classified into a number of significant classes based on their relative influence on mass movements and rating values are assigned to each class depending on their influence on slope instability. The rating values are also fixed by expert opinion (Anbalagan, 1992; Turrini and Visintainer, 1998; Barredo et al., 2000). Finally, the integration of the various factors and classes in a single landslide susceptibility index (LSI) is accomplished by a procedure based on the weighted linear sum (Voogd, 1983):

$$LSI = \sum_{j=1}^n (W_j \cdot w_{ij}) \quad (1)$$

Where: LSI: Landslide susceptibility index; W_j: weight value of parameter j; w_{ij}: rating value or weight value of class i in parameter j; n: number of parameters. All LSI values were than separated into four classes using natural breaks algorithm (ArcGIS) to present four categories (low, moderate, high, very high) of the landslide susceptibility zone (LSZ).

Floods and torrential floods are the most frequent phenomena of the "natural risks" in Republic of Srpska. Total of 187 torrential watersheds were registered in Republic of Srpska

on the basis of an investigation carried out in last 30 years. In the Cadastre of the torrential river were registered 16 torrential river in the study area (Tosic, 2012).

In this research a detailed analysis of existing hydrological data the Vrbas river and its tributaries was carried out. A typical high water discharges in the urban and suburban area of Banja Luka Municipality were analyzed. The data obtained with the digital elevation model (DEM) and the underlying space geodetic survey (1:1000) provided an analysis of the characteristic of high water levels and high water following return period (T) 1/1000, 1/500, 1/100, 1/10.

Rockfalls occur on several locations, mostly in areas dominated by carbonate rocks at the sides of canyon and at a few localities dominated rock diabase - chert formation. The above locations are positioned and recorded as polygons using GPS / GIS devices.

The concept of geographic information systems (GIS) is not new in geohazard assessment. There are many kinds of GIS software, some more suitable for integrated development planning studies and natural hazard management than others. In this research we used ArcGIS 10 software and data was in vector and raster format. One basic way to create or identify spatial relationships is through the process of spatial overlay. Spatial overlay is accomplished by joining and viewing together separate data sets that share all or part of the same area. The result of this combination is a new data set that identifies the spatial relationships. There are two methods for performing overlay analysis-feature overlay and raster overlay. In raster overlay, each cell of each layer references the same geographic location.

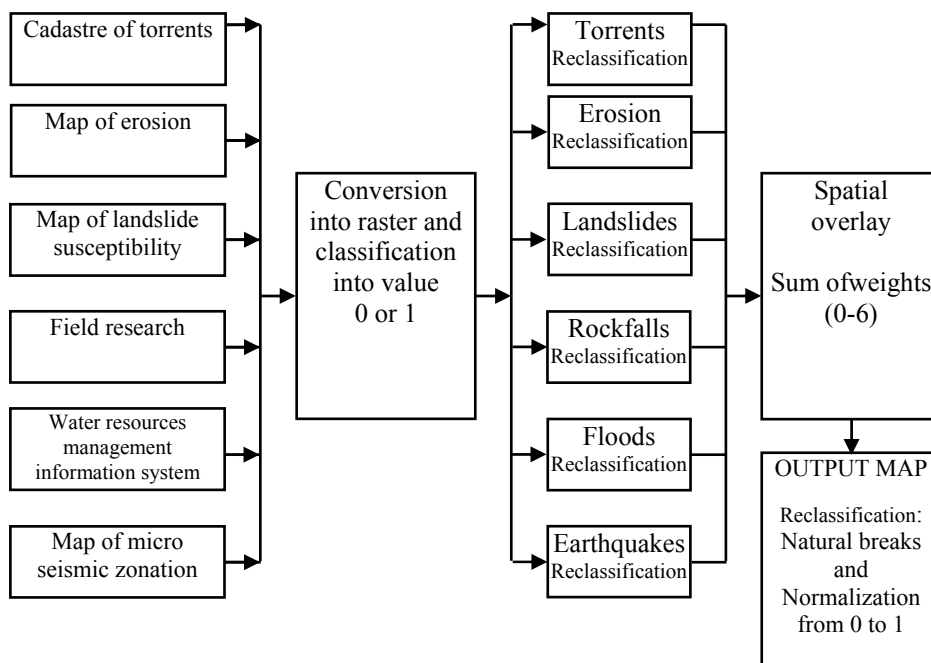


Fig. 2. The integral map flowchart.

That makes it well suited to combining characteristics for numerous layers into a single layer. In our research, six input raster's added together to create an output raster with the values for each cell summed. By applying the tools of ArcGIS software was done normalization to a scale 0-1 while retaining distribution shape. All values on synthetic map

of vulnerability were separated into five classes using natural breaks algorithm (ArcGIS) to present four categories of vulnerability - low, moderate, high, and very high.

The recent state of vulnerability of the study area to natural hazards was shown using analytic maps and then a synthetic map was made. The areas that were vulnerable to some natural hazards were singled out and their percentage of the total area of the study area was defined, along with the total surface area that was vulnerable to natural hazards. By superposing the results, we determined the total vulnerability.

Results And Discussions

Basic characteristics of **seismic activity** in study area are defined on the basis of data of earthquakes that have occurred in the past. For the study area were carried out detailed analyzes of earthquake intensity $M \leq 4.0$ in the last 40 years, with the aim of determining the detailed spatial distribution of the earthquake hot spots. All earthquakes from 1900 to the present are examined in detail and provide the ability to define the seismic characteristics of the study area. According the data of the earthquake epicenters, were created a maps with spatial distribution of the earthquake in the Banja Luka region. These data were used for separation seismic area with the maximum size of magnitude. On the map of microseismic zonation has been allocated a number of seismic zones and defines their characteristics.

According to the Map of microseismic zonation of Banja Luka Municipality, which expresses the maximum expected intensity of the earthquake (modified by MCS-64 scale) for return period of 100 years, the most vulnerable seismic activity (8,5 MCS-64) of study area occupies 20.93 km². The earthquakes with a magnitude of 7,5 MCS may occur in 10.33 km², and with a magnitude of 8 MCS about 24.50 km².

Based on the Map of **erosion**, 12.27 km² of the study area is high erodible (when the value of the erosion coefficient (Z) is more than 0.5). The erosion hazard is great in Neogene deposits and in the deluvial deposits on high slopes. In areas with developed forest vegetation and on the areas with meadows and pastures the erosion potential is very weak or weak.

Having regard to the main characteristics of study area, **torrential floods** are very important natural hazard, particularly if we take into account their frequency and damage that have caused in the past. In the study area was registered 16 torrential watercourses, it is the small rivers, in which the exception Crkvena river, watershed area does not exceed 3 km².

Out of a total of sixteen watercourses, the nine flowing by their lower course through the narrowest metropolitan area, while the other seven in the immediate near the town or passing through the suburbs. Intensity of erosion processes in the catchment area stand out Đurđevački stream, stream Dubrovnik and Skorići stream, it is typical torrential streams with the dominant erosion. Strong erosion in the basin, followed by collapsing banks and transport of large amounts sediment load point is 4 torrential watercourses: Novoselija Zmijinjak, Rujište, Suhi potok that particularly endanger highway Banja Luka-Jajce and could break it.

Other torrential watersheds in the area of Banja Luka are with weaker intensity of erosion: Crkvena stream which flows into the Vrbas in the center of town, torrents Ularac and Rebrovac, torrent Podstranac and torrents Močila, Pećinski stream, Sitarski stream and Dubočaj. Some of the mentioned torrential streams were making a lot of damage in town (Crkvena, Ularac, Močila) in the past. On the whole, 11.2 km² surface area of research is endangered by torrential floods.

Organized solve the problem of **flood** began in the late 19th century, and throughout the 20th century flood protection in urban and agricultural areas was one of the most

important activities. During this period, hydro-technical works decreased the risks of flooding in many river valleys, especially the urban areas. However, due to lack of planning measures of responsible behavior in the floodplain area in the war and post-war period, especially the tendency of descent settlements and roads and commercial buildings in the vulnerable zone, and even the inundation areas, caused in some areas increased the risk of flooding. In all of this, climate change has made them more complex were situation, leading to an increased risk of devastating floods (INCC-BiH, 2010).

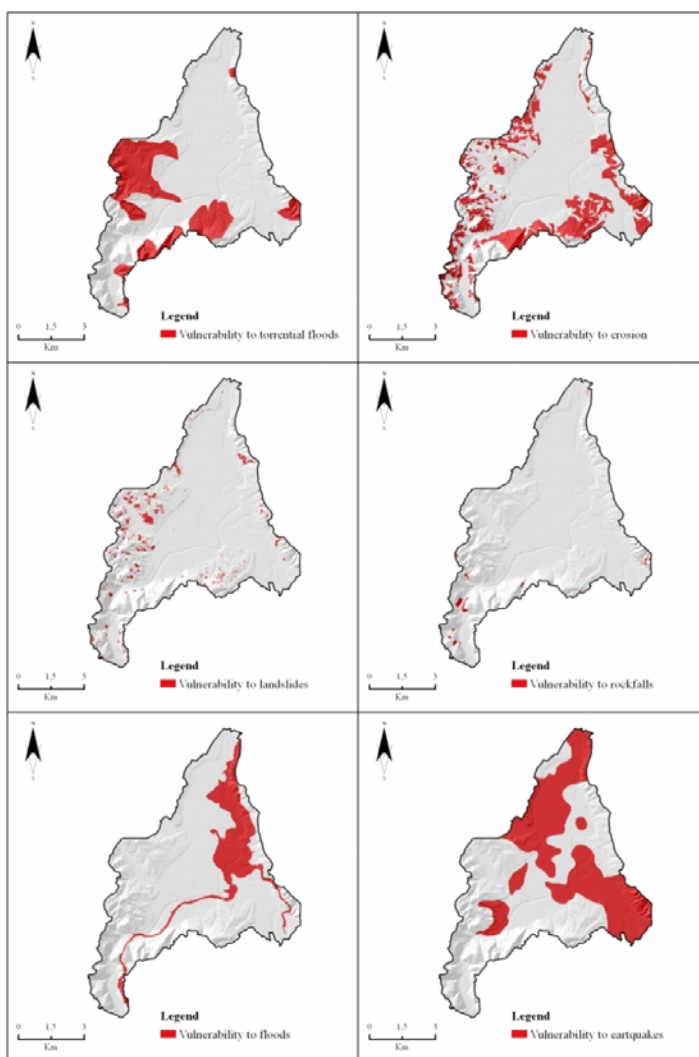


Fig. 3. Vulnerability of urban area of Banja Luka municipality to various types of natural hazards.

Tab. 1. Areas vulnerable to various types of natural hazards in the study area.

Hazard	Area (km²)	%
Torrential floods	11.25	20.17
Excessive erosion	12.27	22.01
Landslides	1.70	3.05
Rockfalls	0.36	0.65
Floods	7.98	14.31
Seismic hazard	20.93	37.53

For the **landslide** susceptibillity assessment, the first step was to create landslide inventory map of active landslide in the study area. We identified 216 landslides with total surface of 2.9 km². Most of landslide are detrusive, with depts between 1-15 m. The main characteristics of landslides in the study area that do not appear as isolated phenomena, individually, but it is usually a collection of phenomena and to the slopes of the valley sides or sources of surface flows.

Analysis of the spatial distribution of landslides can be identified a several locations in the study area dominated by a group of landslides, as well as some smaller localities where they occur in isolation or individually. The first location is a settlement Novoselija - southeastern and southwestern part of the study area, on the left side of the river Vrbas valley in the settlement (the south-western part) dominated mostly shallow landslides on deluvial sediments. On the other side of the river Vrbas valley in this part of the settlement - the southeastern part of the study area, in the flysch sediments, and in the deluvial and proluvial sediments, there are a number of landslides. The second location where is present a larger number of landslides, occupies the eastern part of the study area and landslides were developed on deluvial sediments with the slope of 15 to 20. The third location where occurs a larger number of landslides is northeast study area, which is dominated by Neogene-sand-clay sediments. Surfaces that were made of Neogene sediments are characterized by a larger number of landslides. The fourth location in which occur landslide is located in the western part of the study area, on the left and right side of the Crkvena valley. On the slopes of the left side of the valley were formed deep landslides. These landslides were more than 10 m deep and affect only deluvial sediments, but also degraded by Neogene sediments. Thus, this is a complex slides temporarily mollified, but their activity is clearly based on a number of morphological indicators of the process of sliding. The fifth location in the which it appears smaller number of landslides, and most of them individually, the northwestern part of the study area. Landslides at this site appear in the deluvial gravels, which lie across the Neogene sediments, the depth is up to 10 meters. The present active landslide at this site were developed in deluvial-gravel sediments, mainly caused by wetting the lower bound of gravel to waterproof Neogene clay.

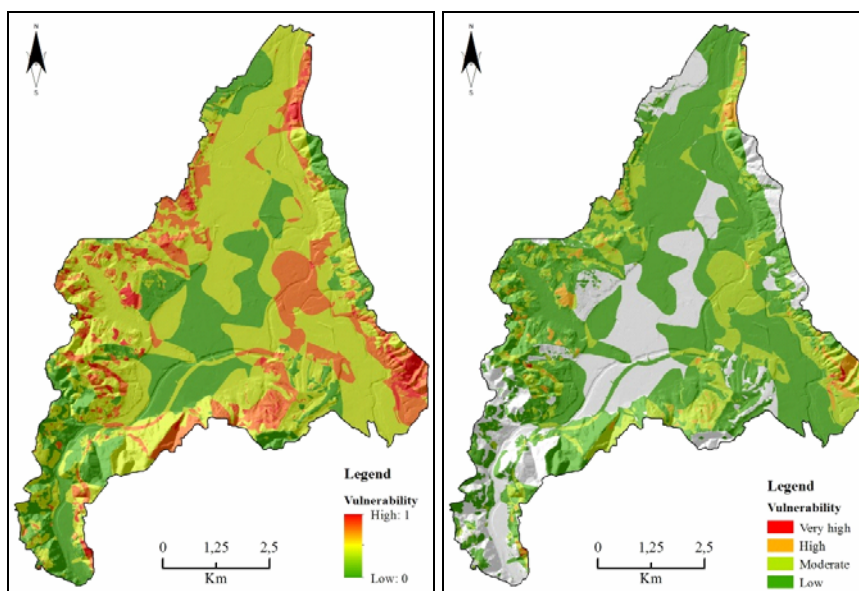


Fig. 4. The integral map of natural hazards in urban area of Banja Luka municipality.

In Banja Luka municipality, 41.33 km² of the territory is vulnerable to natural hazards, representing 74.11% of its total area (Tab. 2). The high degree of vulnerability is primarily caused by the seismic hazard that occupies more than 38% of all vulnerable areas, while torrential floods and excessive erosion are dominated on the 43.15 %.

Tab. 2. Categories of vulnerability by natural hazards in the study area.

Vulnerability	Area (km ²)	%
1. Low	29.78	53.43
2. Moderate	9.97	17.88
3. High	1.50	2.70
4. Very high	0.06	0.11
Total	41.33	74.11

Conclusion

The results of a complex analysis of the vulnerability of the municipality of Banja Luka territories to natural hazards indicated that their area is vulnerable to various types of natural hazards. To accurately assess the vulnerability of a space (i.e., the limitations for its use), the next step should be to create a cadastre of the natural hazard risks for spatial and urban planning. This cadastre would allow an acceptable level of risk to be defined for all levels and in all phases of planning. Then, the system of preventive, organisational and other measures and instruments could serve to lessen the consequences from disasters to an acceptable level.

Therefore, it is necessary to adopt the strategy of integral protection from natural hazards, in the following period, that would, along with the appropriate planning and other measures and instruments, have to be supported by corresponding legal, spatial-planning, urban and technical regulations, particularly related to the policy of land use, construction of facilities and technical infrastructure.

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