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VALIDATION OF LANDSLIDE SUSCEPTIBILITY MAPS (CASE STUDY: URBAN AREA OF THE MUNICIPALITY OF BANJA LUKA - B&H)

Abstract: Landslides represent a serious geo-hazard in many areas of the world. They are one of the most damaging and most significant geo-hazards in Bosnia and Herzegovina. In the previous research, three GIS-based methodologies (Index based method, Statistical index method, and Landslide susceptibility analysis), have been used to assess the landslide susceptibility in urban area of the Municipality of Banja Luka. Validation technique is performed by comparing existing landslide data from 2012 with obtained landslide susceptibility maps. In this research, the landslide susceptibility maps were supplemented by landslide susceptibility map which is prepared using a GIS Matrix method. The area and percentage distribution of the susceptibility classes in the study area were determined as a result of the four different techniques. The Statistical index method has provided the most satisfying results. As a consequence of heavy rains during the period from May to August 2014, 126 landslides occurred in the study area, and they offer a good opportunity to validate obtained landslide susceptibility maps of the study area with landslides that occurred in different periods of time. Validation was performed by using a 'degree of fit' method. The values of the degree of fit in high and very high category in all used methods are over 80%, except for GIS matrix method, where the percentage is 60%. The validation of obtained landslide susceptibility maps suggests that the applications of all the used techniques provide a good basis for creation landslide susceptibility maps, but the best results are given by using a Statistical index method.

Key words: landslide, landslide susceptibility maps, GIS matrix method, validation, B&H.

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Introduction

With floods and torrents, landslides are one of the most widespread and damaging natural hazards in Bosnia and Herzegovina (Tosic et al., 2012; Tošić et al., 2014). In many countries, the economic losses and causalities due to landslides generate a loss of property larger than any other natural hazards. The recent trend towards the development of warning systems and land utilization regulations aimed at minimizing the loss of lives and property damage (Luzi & Pergalani, 1999; Crozier & Glade, 2005; Dragicevic et al., 2009; Dragicevic et al., 2010; Zorn & Komac, 2011). The first step in landslide mitigation project is the landslide susceptibility zonation. It can be considered as one of the most powerful tools to improve land-use planning and the most efficient and economical way to reduce future damage and loss of lives (Cascini, 2005; Cascini, 2008). However, this type of research has not been applied in Bosnia and Herzegovina until 2012, the investigation and study of landslides was based only on the geo-technical approach.

A large number of landslides on urban territory of the Municipality of Banja Luka were activated during the spring and autumn of 2012. Landslide susceptibility zonation was the first stage of helping the community to reduce landslide effects. After collecting data of 216 landslides which appeared in 2012, and analysis of influencing factors divided into three main categories: topographic, geological and environmental, using the Index based method (IBM), Statistical index method (SIM) and Landslide susceptibility analysis (LSA), landslide susceptibility maps were created for study area (Tošić et al., 2014). In this research, validation was carried out with the same set of landslide data that were used for the developed landslide susceptibility maps, but it is known that the best way to check the accuracy of final landslide susceptibility maps would be to use independent landslide data (Tošić et al., 2014).

In May 2014, in the northern part of Bosnia and Herzegovina, the largest amount of rainfall has been registered since 1892. Extremely heavy rainfall with over 120 mm/day and the cumulative rainfall of 729 mm from May to August (70% of one year's amount) were the main trigger factor for occurrence of landslides in the northern part of Bosnia and Herzegovina. Activation of numerous landslides has highlighted the lack of attention on landslides as natural disasters and especially on the preparation of spatial planning documents. However, the landslides events of 2014 has enabled validation of landslide susceptibility maps that were created in 2012, as well as the creation of a new landslide susceptibility map based on new events and discoveries stemming from the validation. Based on the previously mentioned, the main objective of this study is: 1) the validation of landslide susceptibility maps from 2012, which were obtained by using three methods, (2) the application of GIS matrix method (GMM) for creating a new landslide susceptibility map with data from 2012 and validation, (3) the comparison of the results of different approaches for landslide susceptibility assessment.

Study area

The Municipality of Banja Luka is a territorial subject of the internationally recognized state of Bosnia and Herzegovina. According to the census in Bosnia and Herzegovina from 2013, the Municipality of Banja Luka has 199,000 inhabitants. The study area - urban area of the city of Banja Luka occupies about 55 km^2 , and it is located in South-East of Europe within a location of 44°43' 06" and 44°50' 15" N and 17°08'46" and 17°16'06" E.

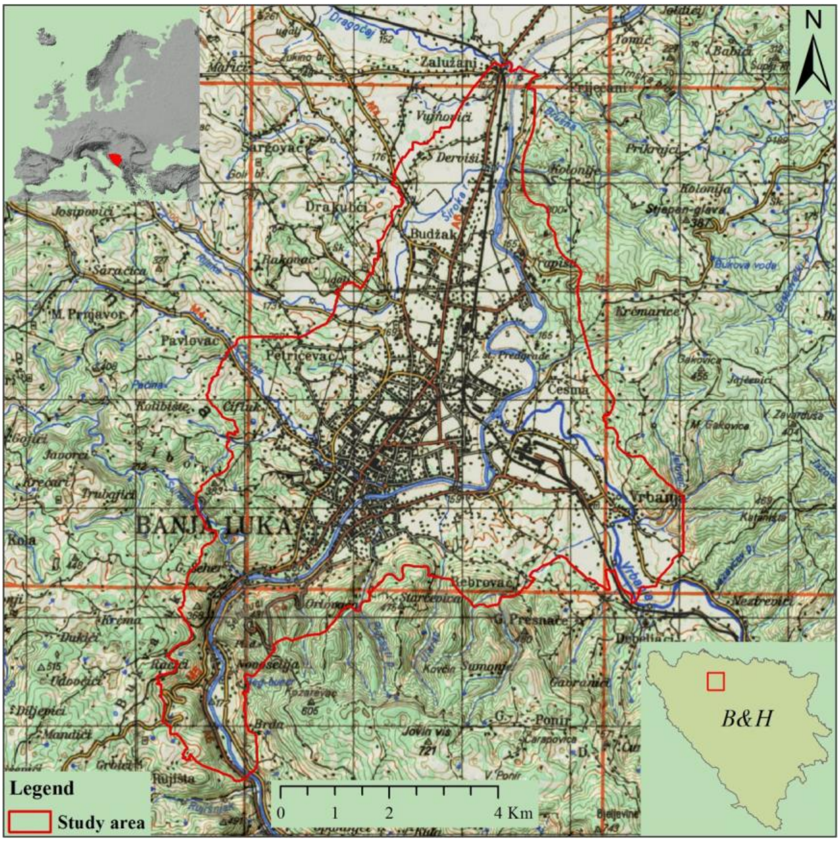

Fig. 1. Location of the study area - urban area of the Municipality of Banja Luka

Study area is a neotectonic depression whose formation began during Neogene tectonic activity (Mojićević et al., 1976; Trkulja, 1998). Based on lithogenetic criteria the study area contains: fluvial sediments, proluvial sediments, slope sediments, flysch, 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 has Neogene sediments (Mojićević et al., 1976).

Flat terrain with slopes less than 5° is dominant all over the Banja Luka depression. Hilly terrain encompasses slightly rippled sides of orbital parts of the 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.

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 are river flows of Vrbas and Vrbanja and smaller flows of Crkvena, Siroka rijeka etc. The dominant soils are Planosols-pseudogley, Fluvisols, Gleysols-dystric, eutric and mollic ones (Burlica & Vukorep, 1980).

Data and methodology

Various spatial data sources were used within this study. The ten influencing factors were considered: lithology, land use, slope, aspect, relative relief, distance from faults, distance from streams, curvature (profile curvature), elevation and seismic zone. The data of elevation, slope, aspect, relative relief, and curvature (profile curvature) were derived from digital elevation model (DEM) 5 meters resolution using the ArcGIS 10.1. Distance from the streams was found using the topographic database. The lithology map was prepared from a 1:10,000 scale geological map (Mojićević et al., 1976; Trkulja, 1998). The distances from the faults were found using geological map. The seismic map was prepared by using the map of seismic micro-regionalization of the Municipality of Banja Luka (Mojićević et al., 1976; Trkulja, 1998). Land use was determined according to CORINE classification hierarchy, classification was generated from digital orthophoto of the Municipality of Banja Luka at the 1:1,000 scale. Thematic map with all influencing factors and their characteristics is illustrated in Fig. 2. (Tošić et al., 2014).

Landslide inventory maps display areas where landslides have occurred. The maps can simply denote areas of past landslides or include detailed information such as components of individual landslide. The product of a landslide inventory map is a spatial distribution of landslides. A typical landslide inventory map is based on aerial photograph interpretation, ground survey, and/or a database of historical movements within the area. Inventory maps help to identifying areas for detailed studies, and are fundamental in landslide susceptibility mapping (Highland & Bobrowsky, 2008).

In this study, landslide inventory map was completed using orthophoto images, topographical maps (1:1,000; 1:2,500; 1:5,000) and terrain survey. During the preparation of landslide inventory in 2012, 216 landslides have been identified with total area of 2.9 km^2. Most of landslides had depths between 1 and 10 meters. During the period from May to August 2014, based on the terrain surveys in the same area of research, the new data were collected for the occurrence of landslides. A total occurrence of 126 new landslides has been identified, with a total area of 0.20 km^2.

Many landslide susceptibility assessments have been carried out internationally, and these involve a wide range of both qualitative and quantitative techniques which have developed over time (Varnes, 1984; Crozier, 1986; Hutchinson & Chandler 1991; Carrara et al., 1991; van Westen 1993; Dietrich et al., 1995; Hutchinson 1995; Dikau et al., 1996; Cruden & Varnes 1996; Soeters & van Westen 1996; van Westen, 1997; Guzzetti et al., 1999; Aleotti & Chowdhury 1999; Foumelis et al., 2004; Crozier & Glade, 2005; Zorn & Komac, 2009; Dragicevic et al., 2012; Tošić et al., 2014). Traditional procedures for landslide susceptibility assessment were laborious and time-consuming as data were handled and processed manually. Due to developments of geographic information systems (GIS) and computer applications, it is now easier to carry out landslide susceptibility analysis (Dahal et al., 2008).

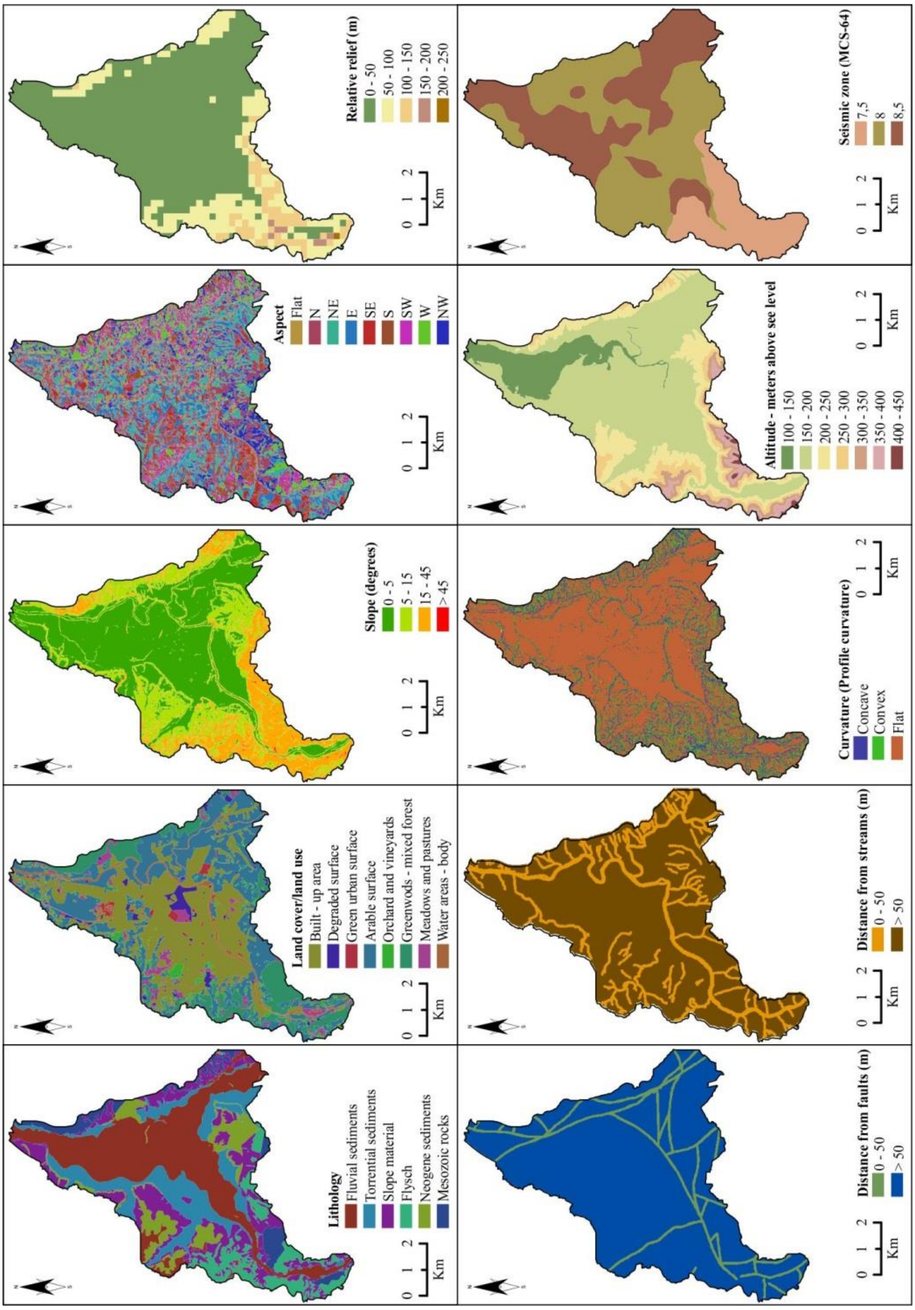

Fig. 2. Thematic maps of the causative factors used for the estimation of susceptibility to landslide in the study area (Tošić et al., 2014).

A geographic information system (GIS) allows the storage and manipulation of information concerning the different influencing factors as distinct data layers and thus provides an excellent tool for landslide susceptibility zonation (Soeters &, van Westen, 1996). Generally a GIS consists of the components of data input and verification, data storage and data-base manipulation, data transformation and analysis, and data output and presentation.

In this research for landslide susceptibility zonation several methods have been used: Index based method (IBM), Statistical index method (SIM), Landslide susceptibility analysis (LSA), and GIS matrix method (GMM). In previous research in the study area (Tošić et al., 2014), Index based method, Statistical index method and landslide susceptibility analysis were explained in details, therefore, those methods will not be re-elaborated in this paper. By applying these methods, Landslide susceptibility zonation maps for the study area - urban area of the Municipality of Banja Luka were made. Besides the above mentioned methods, landslide susceptibility map was elaborated in this research, using GIS matrix method with data from 2012.

GIS matrix method is a quantitative method which uses a statistical analysis to establish the susceptibility model index to this phenomenon in an observed area. Although, this model cannot define susceptibility in absolute terms, it can recognize a potential relative susceptibility, which is calculated for the entire observed surface using a series of measurable relevant factors of this phenomenon GIS Matrix Method, which operates entirely in a GIS environment, is based on the analysis of three matrices: landslide matrix (LM), total surface of the study area matrix (TSM) and susceptibility matrix (SM). This model is based on the determination of all possible combinations between different types of factors that influence the occurrence and development of landslide. The result is a differentiated space in which each unit area indicates its estimated relative susceptibility, which corresponds to a combination of determination factors within that area. Each SM value shows the percentage of source area in each combination in relation to the entire observed surface, which is presented through a combination of determination factors of the phenomenon and development of landslides. The use of a classification method in the ArcGIS environment (natural breaks method) will obtain results that can be further reclassified. Based on these, different levels of landslide susceptibility can be shown visually (very low 0 - 1, low 1 - 5, medium 5 - 15, strong 15 - 25, and very strong 25 - 100) (Irigaray et al., 1999, 2000, 2007).

A few basic techniques can be used to obtain an independent sample of landslide in order to validate a landslide susceptibility maps. First, the original landslide inventory can randomly split in two groups, for susceptibility analysis and for validation. Second, the analysis carried out in a part of the study area and the susceptibility map thus prepared can be tested in another part with different landslide. Thirdly, the landslide susceptibility analysis can be made using landslides generated in a certain period and validation can be performed by means of landslide that occurs in a different period (Remondo et al., 2003).

The most commonly acknowledged triggering factor is heavy rainfall. Heavy rainfall caused flooding and landslides in May and August 2014 in the northern part of Bosnia and Herzegovina. Banja Luka is one of the municipalities which has been mostly affected by natural disasters. In the period from May to August 2014, on the study area was recorded more than 729 mm of rainfall. On August 5, 2014 in less than 24 hours more than 105 mm was recorded, which triggered a large number of shallow landslides. Therefore, rainfall was the trigger for the appearance of a large number of shallow landslides, which have been used in the validation of landslide susceptibility maps.

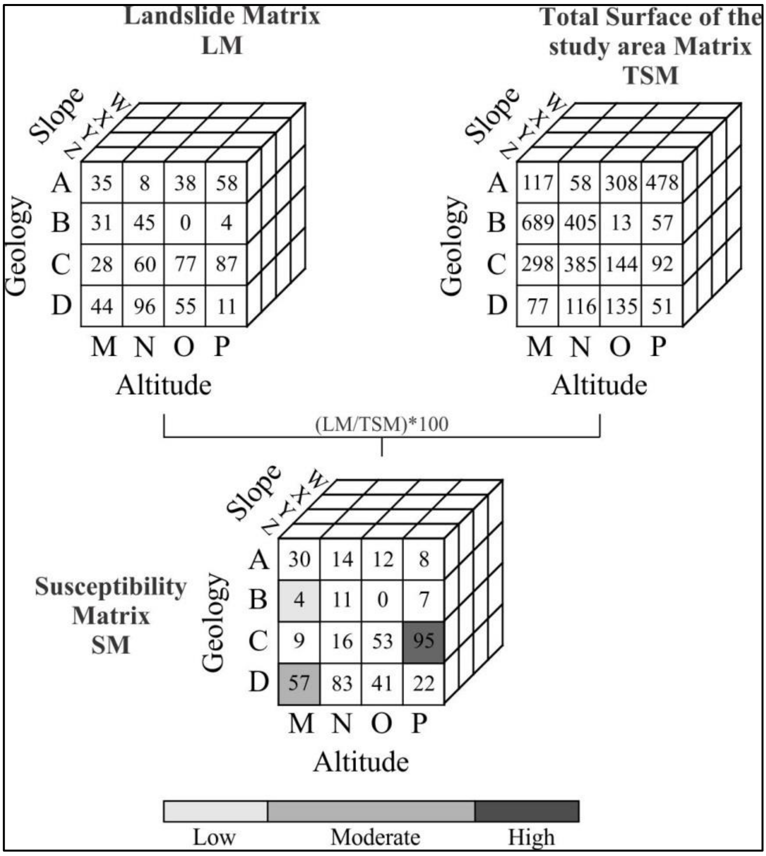

Fig. 3. Illustration of the determination of landslide susceptibility by the GIS matrix method

In this study, landslide susceptibility maps were validated using a 'degree of fit' method. The degree of fit (DF) is defined as follows:

$$DF_i = \frac{\frac{m_i}{t_i}}{\sum \frac{m_i}{t_i}}$$

where m_i is the area occupied by the source areas of the landslides at each susceptibility level i, and t_i is the total area covered by the susceptibility level. The degree of fit for each susceptibility level represents the percentage of mobilized area located in each susceptibility class. This method assesses the relationship between landslides and the developed susceptibility model. The quality of the model was estimated using spatial autocorrelation technique and measuring the degree of fit between the validation data set and the resulting susceptibility model. The ultimate goal was to assess the quality of the susceptibility model, as a predictive resource used to explain the spatial distribution of landslide in the project area (Irigaray et al., 1999; Fernandez et al., 2003; Jimanez-Peralvarez et al., 2009, 2011).

Results

The landslide inventory used for the landslide susceptibility zonation was generated in 2012 by terrain survey together with the interpretation of digital orthophotos. In the study area, 5.2% of the surface area was affected by landslide (Fig. 4). Most of landslides were shallow landslides (between 1 – 10 m depths) and occurred in terrain built from Neogene sediments and flysch. After intensive rainfalls in May and in August 2014, the data on the occurrence of landslides were collected in the same area of research. A total occurrence of 126 new landslides has been identified, with a total area of 0.20 km^2. Landslides are predominantly of translational type and belong to a group of the shallow landslide (Tab. 1).

Tab. 1. Landslide inventory and dimensions

Affected area (m^2)	Landslide inventory from 2012 year (landslide for susceptibility zonation)	Landslide inventory from 2014 year (landslide for validation)
Count	216	126
Minimum	228	87
Maximum	223400	19441
Sum	2917881	204134
Mean	13509	1620
Standard Deviation	22875	2756
Total area	55758886	55758886

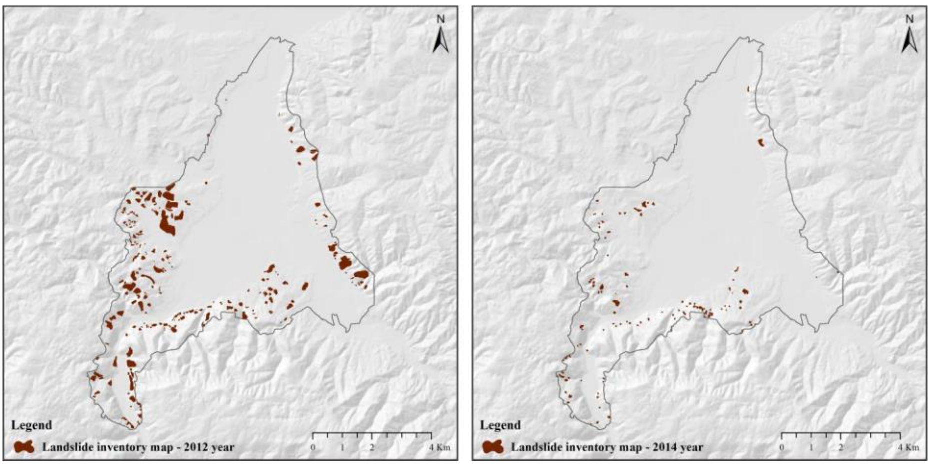

Fig. 4. Landslide inventory map (left from 2012 and right from 2014 year)

With the analysis of spatial distribution of these landslides, it is possible to distinguish several locations in the study area where landslides occur in group, and some locations where landslides occur as isolated events (Fig. 4). Particularly interesting is the fact that the largest number of landslides appeared on surface areas built from flysch and which have large declines.

For the analysis and definition of susceptibility zones, the aforementioned influencing factors and landslide inventory were used, and also a few different methods - Index based method (IBM), Statistical index method (SIM), Landslide susceptibility analysis (LSA), and GIS matrix method (GMM). After the spatial analysis using GIS tools, i.e. using IBM, SIM, LSA and GMM method, the areas in the urban area of the Municipality of Banja Luka were identified and delineated according to the landslide susceptibility category (Tab. 2, and Fig. 5).

Tab. 2. Landslide susceptibility zones by different methods (IBM, SIM, LSA, GMM)

Landslide susceptibility zones	(km^2)	%
IBM (Index-Based Method)		
Very Low	16.39	29.41
Low	13.00	23.33
Moderate	12.62	22.64
High	12.27	22.02
Very High	1.45	2.61
SIM (Statistical Index Method)		
Very Low	15.14	27.15
Low	12.81	22.98
Moderate	7.27	13.05
High	8.25	14.80
Very High	12.27	22.02
LSA (Landslide Susceptibility Analysis)		
Very Low	22.67	40.67
Low	9.10	16.33
Moderate	8.23	14.76
High	10.47	18.78
Very High	5.27	9.46
GMM (GIS matrix method)		
Very Low	44.98	80.68
Low	5.01	9.00
Moderate	3.38	6.08
High	1.85	3.33
Very High	0.50	0.91

Analysis of surfaces covered by the landslide susceptibility zones in the study area showed significant differences in the results obtained using the above mentioned methods of landslide susceptibility zoning. The highest values of high and very high susceptibility zone of 36.82%, and 24.63% are present in the landslide susceptibility maps performed with the Statistical index method (SIM) and Landslide susceptibility analysis (LSA) method (Tab. 2). The results of landslide susceptibility zonation using GIS matrix method (GMM) show low values of high and very high (4.24%) category of landslide susceptibility. When comparing these results with results found by other applying susceptibility analysis methods (IBM, SIM and LSA), we found that the GIS matrix method (GMM) has the strictest criteria in landslide susceptibility zonation (Tab. 2, Fig. 5).

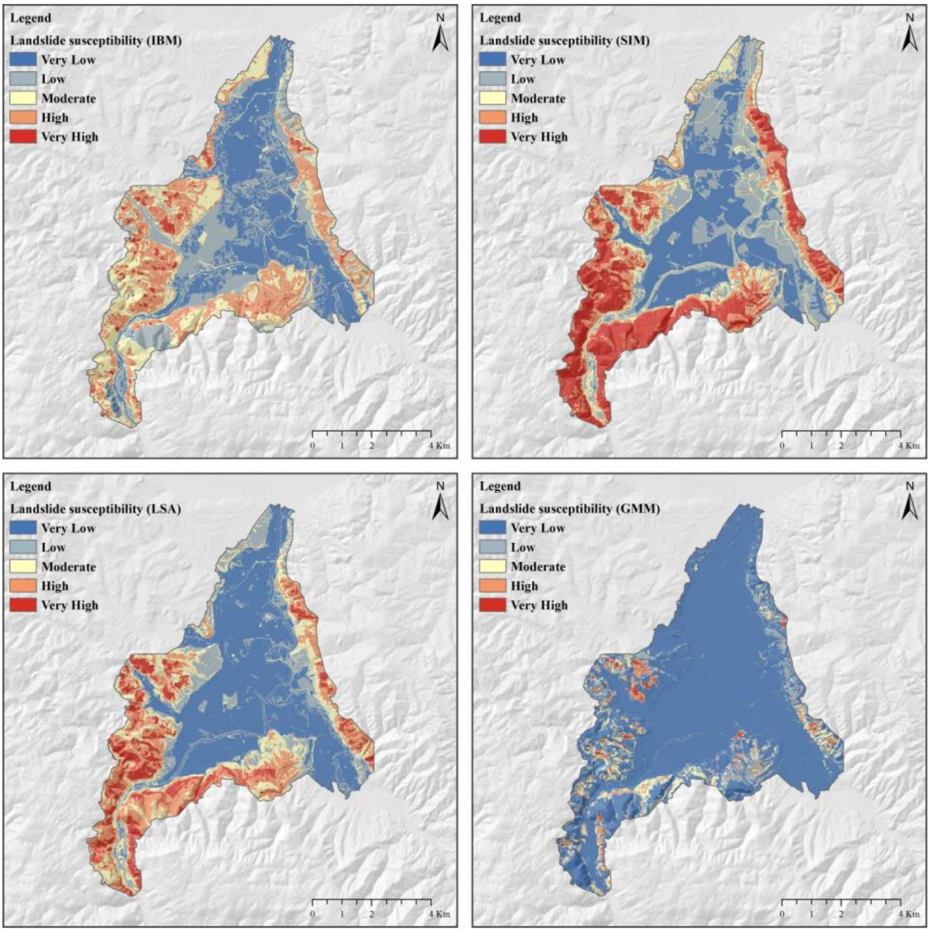

Fig. 5. Landslide susceptibility zonation maps based on Index based method (IBM), Statistical index method (SIM), Landslide susceptibility analysis (LSA) and GIS matrix method (GMM)

After the susceptibility maps were elaborated, the landslide susceptibility maps were validated by means of landslide inventory to the period of heavy rainfall that took place in period from May to August 2014. Landslide inventory for validation landslide susceptibility maps is independent landslide inventory data with 126 new landslides that was not used for the landslide susceptibility assessment.

After maps with tendency for landslides were made and data about new occurrences of landslides were collected during 2014, validation was performed using the matching degree in order to assess the quality of the created model maps with tendency for landslides.

The degree of fit for each susceptibility level represents the percentage of mobilized area located in each susceptibility category. A lower level of compatibility in very low and low category of susceptibility, and a higher percentage in high and very high category of susceptibility indicates a more reliable landslide susceptibility map and the method used for its elaboration.

Tab. 3. Validation indicators of the landslide susceptibility methods - degree of fit (%)

Category	Methods			
	IBM	SIM	LSA	GMM
Very Low	0.01	0.07	0.02	1.30
Low	0.52	0.70	0.98	9.02
Moderate	16.12	4.50	8.73	29.63
High	33.94	27.99	26.13	30.54
Very High	49.42	66.75	64.14	29.50

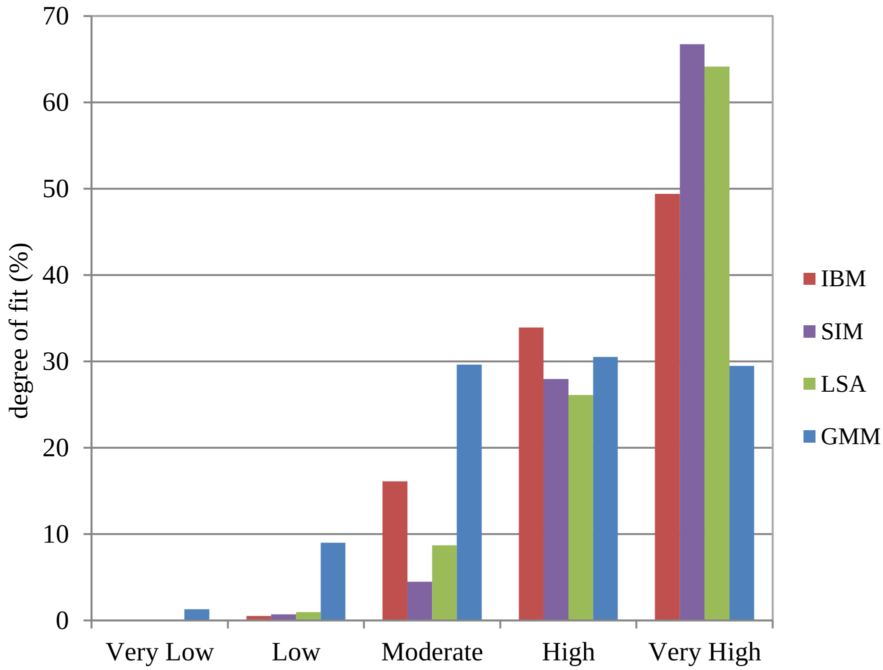

Fig. 6. Degree of fit between the sources areas of the landslides and each landslide susceptibility category in percent (%) (IBM, SIM, LSA and GMM methods)

The results of research evidence the good correspondence between the landslide susceptibility maps and landslide occurring in high and very high category of landslide susceptibility. The values of the degree of fit in high and very high category in all used methods are over 80%, except for GIS matrix method, where the percentage is 60% (Tab. 3, Fig. 6). The validation of our landslide susceptibility maps suggests that the applications of the above mentioned methods provide a good basis for elaboration of landslide susceptibility maps. Certainly, the best results are recorded with the landslide susceptibility map created by applying SIM methods, because high and very high categories have the largest distribution, while the weakest results are recorded with the landslide susceptibility map created by using GIS matrix method.

The reason for these differences in results lies in the methodological process of elaboration of the landslide susceptibility map by using various statistical techniques. The quality of the final landslide susceptibility maps obtained, apart from the quality of the statistical method applied, will depend on the inventory of landslide and on the influencing factors used in landslide susceptibility analysis. For this reason, it is necessary to update landslide inventory with the new occurrences of landslides, and continuously work on validation of the new landslide susceptibility maps for the purpose of allocation of the most reliable methodological method for elaboration of maps of landslide susceptibility for some study area - in this case that is the urban area of the Municipality of Banja Luka.

Discussion and conclusions

Landslides are the results of the interaction of complex influencing factors, therefore the spatial prediction of landslide susceptibility is a difficult task. In general, it can be stated that the methods used in this study proposed effectively explain the spatial distribution of landslide that took place after the elaboration of landslide susceptibility maps of study area in 2012. One approach in creating landslide susceptibility maps uses statistics techniques (quantitative) to compute the weighting values based on relationship of the influencing factors with existing landslides. The other approach in this study is the qualitative, and represents combination of maps where relative weighing values are assigned to the influencing factors and their classes on the basis of field knowledge and experience. The validity of landslide susceptibility maps obtained from the two approaches shows that the statistical approach gives the best results in landslide susceptibility assessment. An important role in this is the application of the Geographic information systems (GIS) as a powerful set of tools for collecting, storing, retrieving at will, displaying and transforming spatial data. The quantitative approach involves the use of statistics to express relationship between the existing landslide distribution and categories of influencing factors. Hence, it can be considered that quantitative approach is more objective than qualitative approach due to the fact that data-dependent character and much less experience is needed. However, success of all approaches is highly affected by the quantity, quality and reliability of spatial data.

The number of actual landslide events in urban territory of the Municipality of Banja Luka shows that this area is relatively prone to landslides. Since currently there is no official landslides database (landslide inventory) of the territory of the Municipality of Banja Luka, which is necessary for any land-use planning purposes, landslide susceptibility zonation in this area urgently requires determination of the landslide prone areas. Landslide susceptibility assessment and susceptibility zoning are actually just one part of disaster management. As a preventive medium to minimize landslides risk in the threatened area, these processes could be continued by other steps such as landslide risk mapping and its integration with land use planning. The susceptibility assessment in the urban area of the Municipality of Banja Luka using qualitative and quantitative methods concludes some points as below:

1. The used methods are applicable. Using ten influencing factors: lithology, land use, slope, aspect, relative relief, distance from faults, distance from stream, curvature (profile curvature), elevation and seismic zone, each method applies specific way to assign weight and build the susceptibility map.
2. The study area was mapped into five landslide susceptibility classes: very low, low, moderate, high and very high class. According to the results the largest area of high and very high susceptibility class is obtained by Statistical Index Method (SIM).
3. Degree of fit analysis showed that SIM method displays the best results high and very high categories have the largest distribution, while the lowest degree of corresponding is in the landslide susceptibility map created by using GIS matrix method.
4. Each method has its own characteristics, eminences and limitations. In short, Index based method has more flexibility concerning free requirement of landslide inventory dataset, but also has limitation in its subjectivity. Statistical index Method (SIM), Landslide susceptibility analysis (LSA) and GIS matrix method (GMM) are more robust in their analysis, but at the same time require more preliminary statistical treatments for the variables.

Landslide susceptibility maps obtained in this study provide valuable data on how prone land units are to landslides, they also represent a quick and simple assessment of the most appropriate terrains for building projects or areas where more detailed studies would be necessary.

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REFERENCES

Aleotti, P. & Chowdhury, R. (1999). Landslide hazard assessment: summary review and new perspectives. *Bulletin of Engineering Geology and the Environment*, 58(1), 21-44.

Burlica, Č. & Vukorep, I. (1980). Pedološka karta SR Bosne i Hercegovine. U Stefanović, V. i sar. (Ur.) *Ekološko-vegetacijska rejonizacija Bosne i Hercevgovine, Posebna izdanja* br. 17. Sarajevo: Šumarski fakultet.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V. & Reichenbach, P. (1991). GIS techniques and statistical models in evaluating landslide hazard. *Earth Surface Processes and Landforms*, 16(5), 427-445.

Cascini, L. (2005). Risk assessment of fast landslide-from theory to practice, *Proc 9th International Symposium on Landslides*. Landslides: Evaluation and Stabilization, Napoli.

Cascini, L. (2008). Applicability of landslide susceptibility and hazard zoning at different scales. *Engineering Geology*, 102(3), 164-177.

Crozier, M.J. & Glade, T. (2005). Landslide Hazard and risk: Issues, concepts, and approach. In Glade, T., Anderson, M., & Crozier, M.J. (Eds), *Landslide hazard and risk* (p. 1-40). Chichester: John Wiley & Sons.

Crozier, M.J. (1986). *Landslides: causes, consequences and environment*. London: Croom Helm.

Cruden, D.M. & Varnes, D.J. (1996). Landslide types and processes. In Turner, A.K. & Schuster, R.L. (Eds): *Landslides: investigation and mitigation, special report 247*, Transportation Research Board, 36-75. Washington. National Academy of Sciences.

Dahal, R.K, Hasegawa, S., Nonomura, A., Yamanaka, M., Masuda, T. & Nishino, K. (2008). GIS-based weights-of-evidencemodelling of rainfall-induced landslides in small catch-ments for landslide susceptibility mapping. *Engineering Geology*, 54(2), 314-324.

Dietrich, W.E., Reiss, R., Hsu, M.L. & Montgomery, D.R. (1995). A process-based model for colluvial soil depth and shallow landsliding using digital elevation data. *Hydrological Process*, 9(3-4) 383–400.

Dikau, R., Brunsden, D., Schrott, L. & Ibsen, M.L. (1996). *Landslide Recognition: Identification, Movement and Causes*. Chichester: John Wiley & Sons.

Dragićević, S., Novković, I. & Prica, M. (2009). The risk of slope processes on the territory of Ub municipality. *Bulletin of Serbian Geographical Society*, 88(3), 37-44.

Dragićević, S., Carević, I., Kostadinov, S., Novković, I., Abolmasov, B., Milojković, B. & Simić, D. (2012). Landslide susceptibility zonation in the Kolubara river basin (western Serbia) – Analysis of input data. *Carpathian Journal of Earth and Environmental Sciences*, 7(2), 37-47.

Dragićević, S., Milevski I., Novković, I. & Milojković, B. (2010): The natural conditions as a limiting factor for the development of Serbian-Macedonian border area. *The Bulletin of Serbian Geographical Society*, 90(4), 29-44.

Fernandez, T., Irigaray, C., El Hamdouni, R. & Chacon, J. (2003). Methodology for landslide susceptibility mapping by means of a GIS. Application to the Contraviesa area (Granada, Spain). *Natural Hazards*, 30(3), 297-308.

Foumelis, M., Lekkas, E. & Parcharidis, I. (2004). Landslide susceptibility mapping by GIS-based qualitative weighting procedure in Corinth area, *Bulletin of 10th International Congress of the Geological Society*, Thessalloniki.

Guzzetti, F., Carrara, A., Cardinali, M. & Reichenbach, P. (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. *Geomorphology*, 3(1-4), 181-216.

Highland, L.M., & Bobrowsky, P. (2008). *The landslide handbook - A guide to understanding landslides: Reston*. U.S: Geological Survey .

Hutchinson, J.N. & Chandler, M.P. (1991). A preliminary landslide hazard zonation of the Undercliff of the Isle of Wight. In Chandler, R.J. (Ed), *Slope stability engineering, development and applications,* 197-204. London: Institution of Civil Engineers.

Hutchinson, J.N. (1995). Landslide hazard assessment, Landslides, *Proceeding of VI International Symposium On Landslides*, Rotterdam.

Irigaray, C., Fernandez, T., El Hamdouni, R & Chacon, J. (2007). Evaluation and validation of landslide-susceptibility maps obtained by a GIS matrix method: examples from the Betic Cordillera (southern Spain). *Natural Hazards*, 41(1), 61-79.

Irigaray, C., Lamas, F., El Hamdouni, R., Fernandez, T. & Chacon, J. (2000). The importance of the precipitation and the susceptibility of the slopes for the triggering of landslides along the roads. *Natural Hazards*, 21(1), 65-81.

Irigaray. C., Fernandez, T., El Hamdouni, R. & Chacon, J. (1999). Verification of landslide susceptibility mapping. A case study. *Earth Surface Processes and Landforms*, 24(6), 537-544.

Jimenez-Peralvarez, J.D., Irigaray, C., El Hamdouni, R. & Chacon, J. (2009). Building models for automatic landslide-susceptibility analysis, mapping and validation in ArcGIS. *Natural Hazards,* 50(3), 571-590.

Jimenez-Peralvarez, J.D., Irigaray, C., El Hamdouni, R. & Chacon, J. (2011). Landslide-susceptibility mapping in a semi-arid mountain environment: an example from the southern slopes of Sierra Nevada (Granada, Spain). *Bulletin of Engineering Geology and the Environment*, 70(2), 265-277.

Luzi, L. & Pergalani, F. (1999). Slope Instability in Static and Dynamic Conditions for Urban Planning: the 'Oltre Po Pavese' Case History (Regione Lombardia – Italy). *Natural Hazards*, 20(1), 57-82.

Mojićević, M., Vilovski, S., Tomić, B. & Pamić, J. (1976). *Geološka karta Banja Luke, 1:10,000*. Beograd: Savezni geološki zavod.

Remondo, J., Gonzalez, A., Dıaz de Teran, J.R., Cendrero, A., Fabbri, A. & Cheng, C.F. (2003). Validation of landslide susceptibility maps: examples and applications from a case study in Northern Spain. *Natural Hazards* 30(3), 437-449.

Soeters, R. & Van Westen, C.J. (1996). Slope instability recognition analysis and zonation. Landslide types and processes. In Turner, A.K. & Schuster, R.L. (Eds): *Landslides: investigation and mitigation, special report* 247, Transportation Research Board, 129-177. Washington. National Academy of Sciences.

Tošić, R., Dragićević, S. & Lovrić, N. (2012). Assessment of soil erosion and sediment yield changes using erosion potential method - Case study: Republic of Srpska-BiH. *Carpathian Journal of Earth and Environmental Sciences*, 7(4), 147-154.

Tošić, R., Dragićević, S., Zorn, M. & Lovrić. N. (2014). Landslide susceptibility zonation: A case study from Banja Luka Municipality (Bosnia and Herzegovina). *Acta geographica Slovenica*, 54(1), 189-202.

Trkulja, D. (1998). *Zemljotresi Banjalučkog regiona*. Banja Luka: GrafoMark.

Van Westen, C.J. (1993). *Application of Geographic Information System to landslide hazard zonation (Thesis)*. Enschede: International Institute for Aerospace Survey and Earth Sciences.

Van Westen, C.J. (1997). Statistical Landslide Hazard Analysis. In: *Application Guide, ILWIS 2.1 for Windows*. Enschede: International Institute for Aerospace Survey and Earth Sciences.

Varnes, D.J. (1984). *Landslide hazard zonation: a review of principles and practice*. Paris: UNESCO.

Zorn, M. & Komac, B. (2009). The Importance of Landsliding in a Flysch Geomorphic System: The Example of the Goriska brda Hills (W Slovenia). *Zeitschrift für Geomorphologie*, 53(2), 57-78.

Zorn, M. & Komac, B. (2011). Damage caused by natural disasters in Slovenia and globally between 1995 and 2010. *Acta geographica Slovenica*, 51(1), 7-41.

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ВАЛИДАЦИЈА КАРАТА ПОДЛОЖНОСТИ КЛИЗИШТИМА: (СТУДИЈА СЛУЧАЈА: УРБАНО ПОДРУЧЈЕ ОПШТИНЕ БАЊА ЛУКА, БиХ)

Резиме: Клизишта представљају један од значајнијих гео-хазарда, како у Босни и Херцеговини тако и у многим другим дијеловима свијета. У претходном истраживању појава клизишта у урбаном подручју града Бања Лука коришћене су три методе засноване на географском информационом систему (IBM, SIM и LSA), како би се помоћу њих процијенила осјетљивост појединих простора на појаву клизишта. У оквиру тих истраживања валидација добијених модела извршена је поређењем постојећих података о клизиштима из 2012. године са добијеним моделима осјетљивости на појаву клизишта. У овом истраживању, карте осјетљивости на појаву клизишта, допуњене су картом осјетљивости на ову појаву која се заснивала на ГИС матричној методи. Дакле, расподјела површина и процената одређених класа осјетљивости на појаву клизишта у оквиру истраживаног простору резултат је коришћења четири различите методе. Као посљедица обилних киша, у периоду од маја до августа 2014. године, активирано је нових 126 клизишта на посматраном подручју. Како су се догодила у различитом временском периоду, у односу на претходна, она су представљала добру основу како би се њиме потврдили претходно добијени модели осјетљивости на појаву клизишта истраживаног простора. Провјера свих модела осјетљивости на појаву клизишта извршена је коришћењем метода "степена подударања". Вредновање добијених модела осјетљивости на појаву клизишта указују да све коришћене методе пружају добру основу за стварање карата потенцијалне осјетљивости на појаву и развој процеса клижења.

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