

Landslide susceptibility mapping of SE Serbia using GIS

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Key words:

*Landslide, susceptibility, AHP,
lithology, slope.*

Abstract. Landslides represent a great problem in Serbia. According to current estimates 30–35 % of Serbia is affected by landslides. In this paper a landslide susceptibility analysis is done for SE Serbia. Study area covers 1507 km². Relief is hilly or mountainous and characterized by high altitude differences. Analysis is done by geographic information system (GIS) and evaluation by analytic hierarchy process (AHP). For susceptibility assessment are used four factors: lithology, slope angle, distance to rivers and distance to faults. The most landslides are formed on slope steepness less than 30°. There is four classes of susceptibility in study area. Zone of very high susceptibility make 63.9 % of the study area. Zone of high susceptibility covers 15.7 % of the study area. The moderate class occupies 37.4% and zone classified as having low susceptibility accounts for 10 % of study area. Final landslide susceptibility map of SE Serbia is satisfactory.

Апстракт. Клизишта представљају велики проблем у Србији. Према тренутним подацима 30–35% територије Србије је захваћено клизиштима. У овом раду је урађена анализа осетљивости на клижење за југоисточни део Србије. Област истраживања је површине 1507 km². Рељеф ове области је претежно брдско-планински са великим висинским разликама. Анализа је урађена помоћу географског информационог система (ГИС), а вредновање помоћу Аналитичког хијерархијског поступка (АХП). За процену осетљивости разматрана су четири фактора: литологија, нагиб падина, удаљеност од река и удаљеност од раседа. Највећи број клизишта је регистрован на падинама нагиба до 30°. Према осетљивости на клижење издвојене су четири класе осетљивости. Зона веома велике осетљивости захвата 63,9% укупне површине. Зона велике осетљивости на клижење захвата 15,7% укупне површине. Зона средње осетљивости на клижење обухвата 37,4% истраживане области и зона мале осетљивости на клижење обухвата 10% области. Коначна карта осетљивости на клижење у југоисточној Србији је задовољавајућег квалитета.

Кључне речи:

*Клизишта, осетљивост,
АХП, литологија, нагиб
падина.*

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Introduction

Landslides represent a great problem in the countries all over the world. Landslides are common in Japan (YOSHIMATSU & ABE, 2006), China (DAI & LEE, 2001a), Korea (LEE & MIN, 2001), Malaysia (LEE & PRADHAM, 2007), Iran (POURGHASEMI et al., 2012; MANSOURI DANESHVAR, 2014), Tukey (AKGUN & BULUT 2007), USA (WACHAL & HUDAK, 2000), Italy (GUZZETY et al., 2008; PELLICANI et al., 2014), Austria (ZIEHER et al. 2016) and many others. Landslides endanger human lives, facilities, roads, forests and agricultural land. In the framework of the European Soil Thematic Strategy European Union recognized landslides as a soil threat requiring specific strategies for priority area identification, spatial hazard assessment and management (GUNTHER et al., 2013). The Strategy considers landslides as one of eight soil threats in Europe. So it is very important to identify areas where landslides can occur in the future (GUNTHER et al., 2013).

In order to reduce damage we need to define which areas are susceptible to landslides. Sites that are prone to landslides should therefore be identified in advance to avoid such damage (DAI et al., 2001b). Susceptibility maps show where landslides may occur (CHACON et al., 2006). Landslide susceptibility maps contain information on the type of landslides that might occur and on their spatial likelihood of occurrence (COROMINAS et al., 2014). For landslide susceptibility analyses detection of the location of landslides is very important (LEE et al., 2001). Lack of data prevents the quantitative determination of the probability of slope failure (COROMINAS et al., 2014). The susceptibility term is a function of potential landslide occurrence and landslide related factors (LEE et al., 2001). FELL et al. (2008) give definition of landslide susceptibility as a quantitative or qualitative assessment of the classification, volume, area and spatial distribution of landslides which exist or potentially may occur in an area. According to these authors the aim of susceptibility mapping is to include the maximum number of landslides in the highest susceptibility classes.

There is numerous methods for landslide susceptibility analysis such as fuzzy logic (SABOYA et al.,

2006), analytic hierarchy process (AHP), analytic network process (YALCIN, 2008), weighted linear combination (AYALEW et al., 2004), logistic regression (AKGUN & BULUT, 2007) and multivariate statistical approach (VAN WESTEN et al., 1997). Many researches use AHP for comparing the factors (KARLSSON et al., 2017; MANSOURI DANESHVAR, 2014; AYALEW et al., 2005; PELLICANI et al., 2014; MA et al., 2013; POURGHASEMI et al., 2012) because it is simple decision making method. In Serbia there are a few examples of use AHP for susceptibility (MARIJANOVIĆ et al., 2013) and for landfill site selection (DJOKANOVIĆ et al., 2016).

About 70% of Serbia is hilly or mountainous. In Serbia, many landslides are triggered by rainfall. According to current estimates 30–35 % of Serbia are affected by landslides (ĐOKANOVIĆ & TRBOJEVIĆ, 2018). DJOKANOVIĆ (2015), ĐOKANOVIĆ (2016a, 2016b) and JEVREMOVIĆ et al. (2015) report a landslides triggered by intense rainfall during 2014 in western and eastern parts of Serbia.

In this paper is considered the landslide susceptibility in southeast Serbia. For landslides susceptibility is used the regional scale map 1:100 000. Factors considered for analysis are lithology, slope angle, distance to rivers and distance to faults. Landslides susceptibility analysis is done using geographic information systems (GIS) and AHP. For AHP evaluation is used the extension from Marinoni. Landslides data used in this paper are taken from basic engineering geological map (sheet Bela Palanka) done by Geological survey of Serbia (GZS). Landslides data are collected by field study.

Materials and methods

GIS and AHP are used to map and evaluate landslide susceptibility in SE Serbia. AHP is multi-criteria method whose author is SAATY (1980). AHP enables a comparison of factors and determine the weight of each factors using a matrix in which all elements are compared with each other. The comparison values strongly depend on expert judgement and experience. Description of compared factors is shown in Table 1. To reduce the influence of subjectivity and possibility of inconsistencies,

SAATY (1980) defined the consistency ratio (CR) as follows:

$$CR = CI/RI$$

CI-consistency index, RI-average resulting consistency index, depends on matrix order.

If $CR < 0.1$ the judgments are seemed trustworthy. A $CR \geq 0.1$ requires revision of the judgments in the matrix, identifies reasons for inconsistencies and repeats the process of comparing.

Table 1. Scale of comparison (SAATY, 1980)

Description	Intensity of importance
Equal importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Extreme importance	9
Intermediate values	2,4,6,8

Four factors are used in analysis lithology, slope angle, distance to rivers and distance to faults. Each factor is then assigned a number from Saaty scale to gain a weight. Weights of factor mean their relative importance to slope instability in the study area. Then all factors are reclassified into four classes. Classified map is then overlain and we create final map of susceptibility in the study area. Susceptibility map overlay with landslide inventory map in the verification process.

Study area

Study area is located in southeast Serbia and covers an area of 1507 km² (Fig. 1). Geomorphologic features are conditioned by lithology and tectonic structure. Lithology influenced the morphometric characteristic (slope angle) and tectonic setting to the existence of larger morphostructures. Relief is characterized by high altitude differences (over 1000 m). Gentle relief have Neogene basins Zaplanje (254 m), Bela Palanka (283 m), Koritnik–Babušnica (350 m) and parts of Niš (204 m), Leskovac (219 m)

and Pirot (414 m) basins. These represent tectonic troughs bounded by faults. In central part of the study area dominates Suva Planina mountain that extends some 40 km NW and SE from Niška Banja to Lužnica River. The highest peaks are Trem (1810 m), Sokolov kamen (1523 m) and Golaš (1389 m). Valožje limestone plateau is about 1500 m average high. Suva Planina is most prominent positive morphologic unit in the area (MENKOVIĆ, 2011).

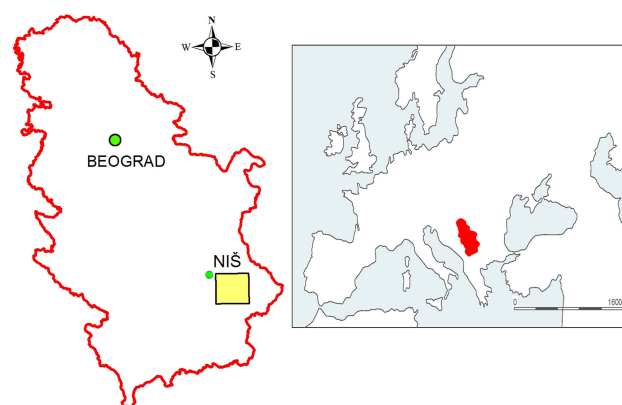


Fig. 1. Location of study area (yellow square).

In the base of the mountains rivers formed valleys with elevation 200–500 m. The major rivers are Južna Morava, Nišava, Lužnica, Koritnička and Kutinska. Nišava river composite valley is cut in rocks with distinguish resistance to erosion. The highest width is in Bela Palanka basin and the smallest width is in Sićevo Gorge. The gorge parts of the canyon have very steep walls up to 500 m high (MENKOVIĆ, 2011). All rivers drain study area into the Južna Morava. Climate of study area is moderate continental with element of mountains climate in the highest part. Summers are hot with little rainfall and winters are cold with lots of snow. Autumns are warmer than springs.

About 20 000 inhabitants lives mostly in rural areas. Among the larger settlements are Niška Banja, Bela Palanka, Babušnica, Gadžin Han and Donji Dušnik.

The main infrastructure is highway E-80 Niš–Pirot (corridor A10) with route Prosek–Crvena Reka–Bela Palanka–Crvenčevo in study area. There are also

roads Bela Palanka–Babušnica, Niš–Bonjince and Bonjince–Babušnica, Railway Niš–Piroć follow the valley of Nišava and Sićevo gorge.

Geology

The oldest rocks in the study area are crystalline schists. These are upper Proterozoic, Proterozoic–Cambrian and Cambrian age (VUJISIĆ et al., 1980). These rocks are mostly albite-chlorite-muscovite schists with lenses of albite, actinolite and chlorite-epidote schists and muscovite quartzite. Quartz conglomerate and quartzite are Cambrian age. Other Paleozoic rocks are Silurian, Devonian, Carboniferous and Permian age. The upper Silurian is preserved in small area in the core of Suva Planina (VUJISIĆ et al., 1980). Schist and meta sandstone of Modra Stena are supposed to be Silurian age. Devonian (lower, middle and upper) consists of flysch. Carboniferous rocks unconformably overlain Devonian and pass upward into Permian red sandstone. The study area mostly consist of Mesozoic formations (Triassic, Jurassic and Cretaceous). Triassic rocks are transgressive over Permian sandstone while Jurassic rocks unconformably overlain Permian sandstone or Triassic rocks (VUJISIĆ et al., 1980). The Jurassic is composed of calcareous rocks, clastic rocks and flysch. Lower cretaceous is the most widely spreaded Mesozoic formations. The upper cretaceous is predominantly developed in NE part of study area. It consists of sedimentary, calcareous and sedimentary-volcanogenic formation. The Tertiary rocks are Paleogene and Neogene age. The Paleogene is preserved in NE of study area. These rocks lie transgressively over Maastrichtian formations (VUJISIĆ et al., 1980). The Koritnik–Babušnica basin is represented by Oligocene rocks. These lie transgressively over Cretaceous formations. The Neogene rocks are deposited in basins which are formed under the influence of longitudinal dislocations (Zaplanje, Bela Palanka, Babušnica, Piroć, Niš, and Leskovac basin). Tertiary volcanic rocks consist of andesite and andesite tuff and dacite. The Quaternary rocks are developed mainly in Nišava, Južna Morava, Koritnička, Kutinska and Lužnica valley. Study area mostly belongs to Carpato-Balkanides

and the smaller part belongs to Serbian-Macedonian massif.

Digital elevation model

The digital elevation model (DEM) was created by digitizing of contours on the topographic map at scale 1:100 000. Equidistant between contours is 100 m. DEM was created in Arc Map 10.1 by interpolation. DEM was done with 100 × 100 mand standard deviation 2.5 m (Fig. 2). The slope angle map was derived from DEM.

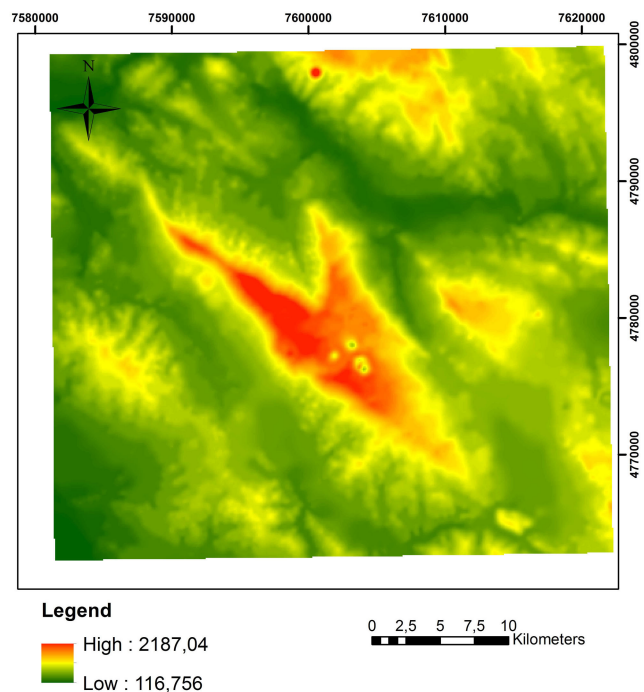


Fig. 2. Digital elevation model of study area.

Landslides susceptibility factors

The relationship between susceptibility to landslides and the factors is complicated and depends heavily on the specific conditions (MA et al., 2013). Data for landslide susceptibility analysis are obtained from geological, engineering-geological and topographical maps. Geological and topographical maps need to be digitized first. All maps are digitized in AutoCAD Map 2014 and then export to GIS software ArcMap 10.1. AHP extension from Marinoni is used

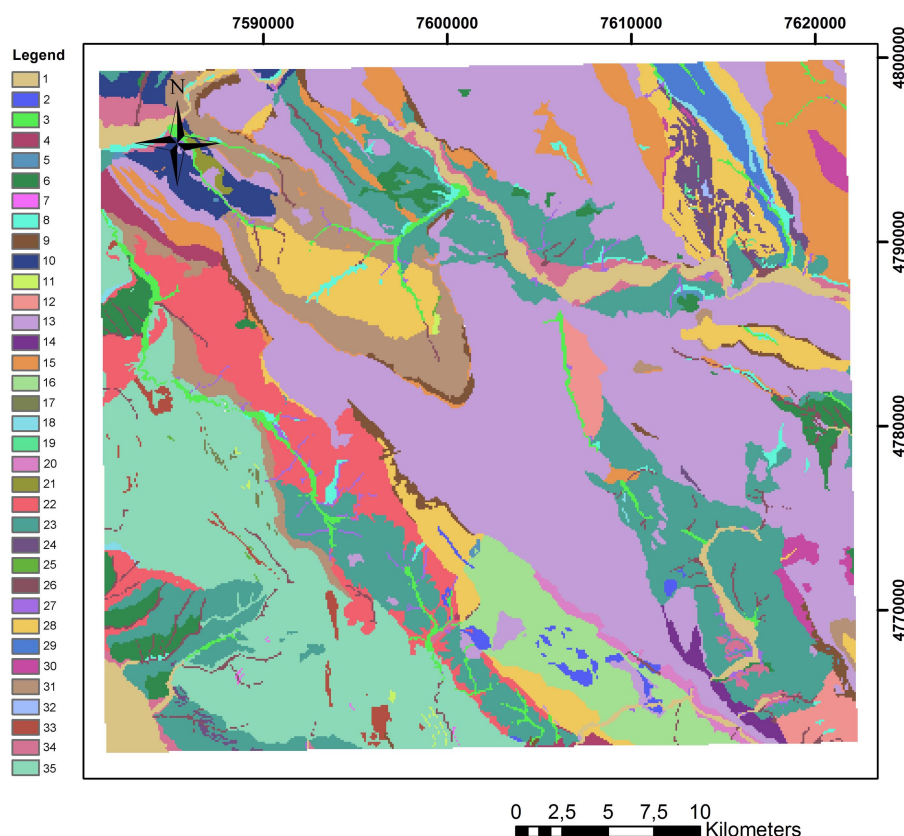


Fig. 3. Lithology map of study area; 1. alluvium, 2. andesite, 3. alluvium-proluvium, 4. argilloschist, sandstone, 5. spring deposit, 6. deluvium, 7. diabase, 8. deluvium-proluvium, 9. talus, 10. clay, sand, gravel, 11. gabbro, 12. shale, marlstone, siltstone, 13. limestone, dolomite, 14. limestone, marlstone, 15. limestone, sandstone, 16. limestone, sandstone, shale, 17. keratophyre, 18. conglomerate, sandstone, 19. latite, 20. marlstone, shale, 21. marlstone, limestone, 22. sand, sandstone, 23. sand, gravel, clay, 24. pyroclastic, 25. plagiogranite, 26. proluvium (larger flows), 27. proluvium (smaller flows), 28. sandstone, shale, 29. sandstone, shale, limestone, 30. sandstone, conglomerate, 31. sandstone, conglomerate, siltstone, 32. sandstone, shale, 33. quartzite, 34. terrace, 35. schist.

for evaluation (<http://www.arcgis.com/home/item.html?id=bb3521d775c94b28b69a10cd184b7c1f>).

Different authors use different factors for susceptibility analysis. MANSOURI DANESHAVAR (2014) use nine factors: elevation, slope, aspect, geology, land use, temperature, precipitation, faults, channels. WACHAL & HUDAK (2000) use four factors: slope, angle, geology, vegetation and distance to faults. DAI & LEE (2001a) use six factors: lithology, slope gradient, slope aspect, elevation, land cover and distance to drainage line. For landslides susceptibility for Europe the authors use slope angle, lithology and land cover (GUNTER et al., 2013). YOSHIMATSU

& ABE (2006) use five factors: definition of scarp, condition of landslide surface, occurrence position on large landslides, position and condition of crack and step ground and condition of landslide toe. PELLICANI et al. (2014) use slope angle, lithology, land use, aspect and two triggering factors rainfall and seismicity.

In this paper for landslide susceptibility is used four factors: slope, lithology, distance to faults and distance to rivers. For each factor is done map with different classes..

Lithology

Lithology is very important factor for landslide susceptibility analysis. Lithology includes the composition, fabric, texture or other attributes that influence the physical behavior of rocks and engineering soil (VARNES, 1984). Type of material is one of the most important factors influencing the behavior of landslides (HUNGR et al., 2014). Lithology experts a fundamental control on the

geomorphology of a landscape (DAI et al., 2001b). Different lithologic units have different landslide susceptibility values (POURGHASEMI et al., 2012). Lithology data are obtained from engineering-geological map (Fig. 3). Geological map is not appropriate because it gives stratigraphic view of lithology.

Study area consists of a large number (35) of lithological units. Three lithological units are the most represent: limestone and dolomites; sand, gravel and clay and schists. Limestone and dolomite make 29.81 % of study area. Lacustrine sand, gravel and clay cover 14.54% until schists cover 12.51 %. With 3–6 % are represented gravel and sand,

alluvium; limestone and sandstone; limestone, sandstone and shale; sand and sandstone; sandstone and shale; sandstone, conglomerate and siltstone. Other lithological units are represent by 1–3 %.

Lithological units are classified into four classes (Fig. 4) according to engineering geological properties and frequency of landslides (Fig. 5). Class 1 includes gravel and sand (terrace, alluvium, alluvium-proluvium and proluvium). Class 2 includes spring deposits, limestone, dolomite and magmatic rocks (latite, gabbro, diabase, andesite, keratophyre). Class 3 includes sandstone, conglomerate, shale, siltstone and pyroclastic. Class 4 includes gravel, sand and clay (deluvium, deluvium-proluvium and proluvium, lacustrine clay, marl, sand and gravel) and class 5 includes schists.

Slope

Slope angle is important factor for stability. Slope angle is an essential component of slope stability analysis (DAI et al., 2001b). The steeper the slope, the greater the landslide probability. But, not always and not necessary. In lacustrine rocks landslides are formed in slope with angle <15°. Different authors use different values for this factor so there are no unique values for slope angle. TEMESGEN (2001) use intervals of 10 degrees and distinguishes 7 classes. MARJANOVIĆ et al. (2013) use <5°, 5–10°, 10–15° and >15°. Slope map is obtained from DEM with resolution 100 × 100 m. For study area four classes of slope angle are classified (Fig. 6) less than 5° (class 1), 5–15° (class 2), 15–30° (class 3) and more than 30° (class 4).

Distance to rivers

Rivers and streams are important factor for soil stability (POURGHASEMI et al., 2012). Landslides may occur as a result of undercutting toe of the slope due to erosion. It happens often in Serbia. Streams are also important because they can cause gully erosion. DAI & LEE (2001a) suggest that the buffer zone should be 50 m and the maximum distance is over 300 m. TEMESGEN (2001) use 500 m as a buffer zo-

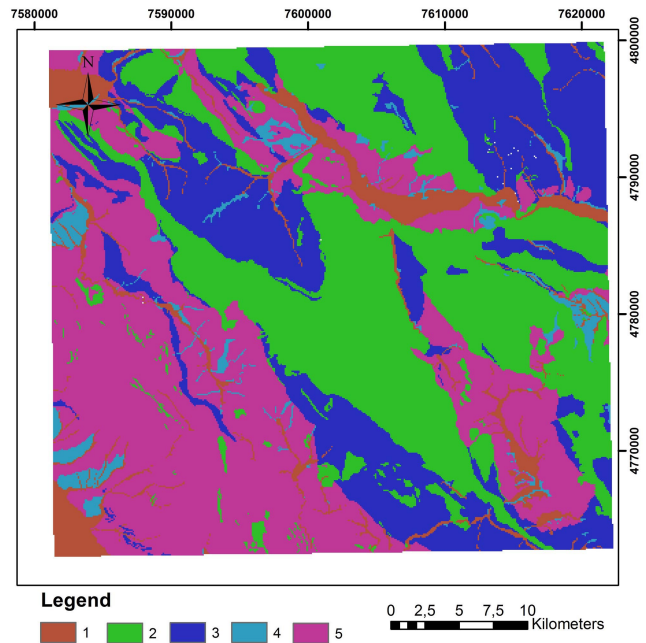


Fig. 4. Lithological classes; 1. gravel and sand (terrace, alluvium, alluvium-proluvium and proluvium); 2. spring deposits, limestone and dolomite, latite, gabbro, andesite, diabase and keratophyre; 3. sandstone, conglomerate, shale, siltstone pyroclastic; 4. gravel, sand and clay (deluvium, deluvium-proluvium and proluvium) and lacustrine clay, marl, sand and gravel; 5. schists.

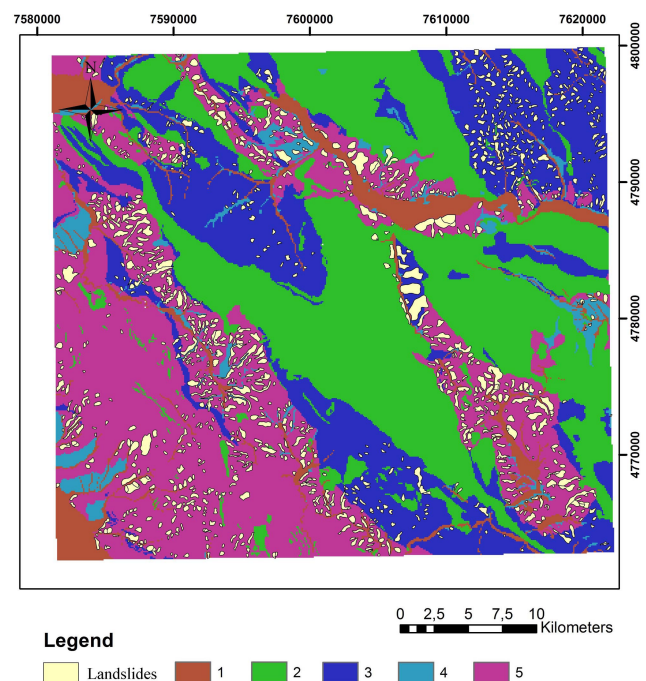


Fig. 5. Lithological classes and landslides.

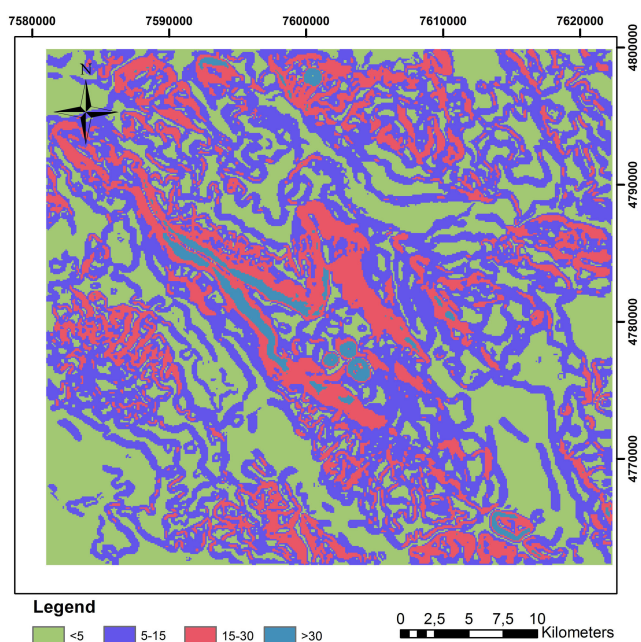


Fig. 6. Slope map.

ne. WEN et al. (2017) use 100 m as a buffer zone. For study area is much better buffer zone of 100 m. According to distance from rivers and streams four classes are classified (Fig. 7) less than 100 m (class 4), 100–200 (class 3), 200–300 (class 2) and more than 300 m (class 1).

Distance to faults

Faults are important factor for slope instability. Faults are important because the rock in this zone is cracked and weakened. Fault represents predisposed direction where landslides can occur. Fault information is also used frequently as one of the factors in a statistical assessment (VAN WESTEN et al., 2008). Faults data are taken from engineering-geological map. Determined and presumed faults are taken into account while photogeological are not considered. In study area there is no active faults. VAN WESTEN et al. (2003) suggest buffer zone of 50 m on each side of faults. WACHAL & HUDAK (2000) use buffer zone to 500 m and maximum distance is over 1500 m. POURGHASEMI et al. (2012) use buffer zone of 100 m. TEMESGEN (2001) suggests 500 m as a buffer. LEE & PRADHAM (2007) distinguished se-

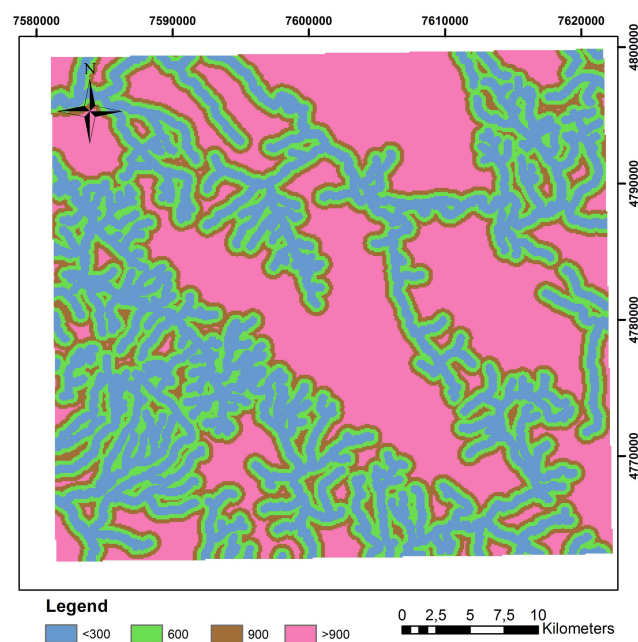


Fig. 7. Distance to rivers.

veral classes with buffer zone of 600 m. Considering the specificities of area in this paper is taken a buffer zone of 100 m as an appropriate. For study area four classes are classified (Fig. 8) less than 100 m (class 4), 100–200 (class 3), 200–300 (class 2) and more than 300 m (class 1).

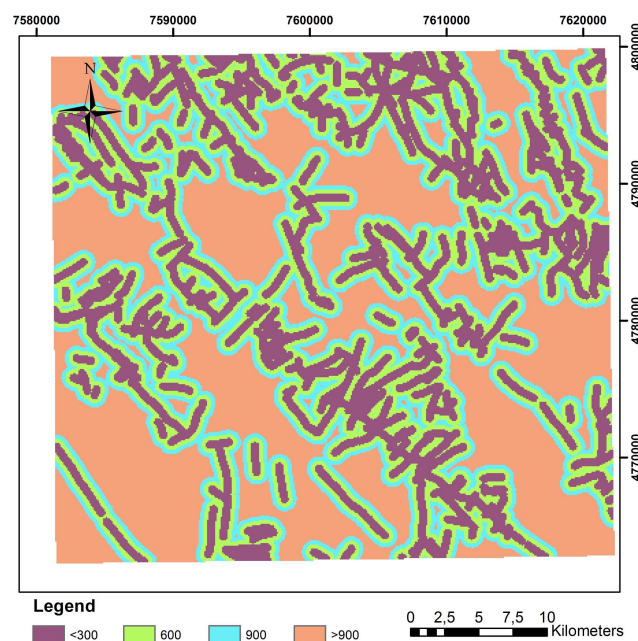


Fig. 8. Distance to faults.

Landslide data

The knowledge of the landslides in a particular area is expressed by a landslide inventory map which shows the locations and outlines of landslides (CHACION et al., 2006). Landslide inventory is an inventory of location, classification, volume, activity and date of occurrence of landsliding (FELL et al., 2008). Landslide map is obtained from the latest engineering-geological map. In the engineering-geological map landslides are classified as active or dormant. Landslide map of the study area is shown in Fig. 9. Landslides mapping is made by using topographical maps at scale 1:25 000. Landslides are then modified for scale 1:100 000.

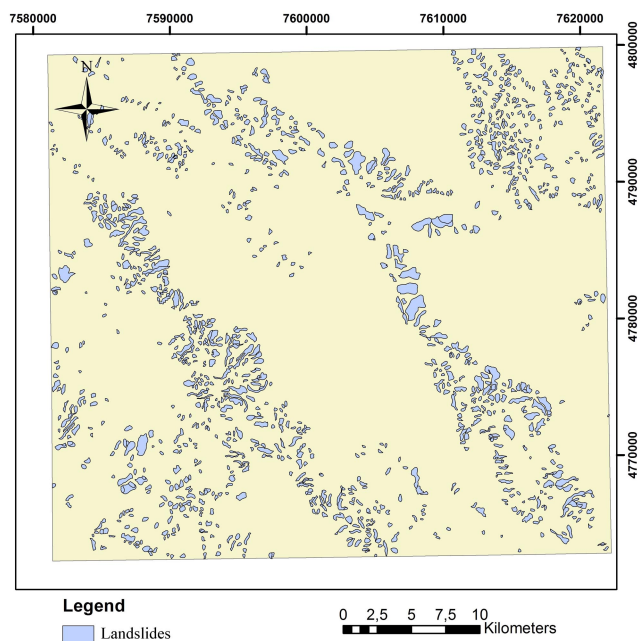


Fig. 9. Landslide map of study area.

Results and discussion

For landslides susceptibility analysis seven maps are done (DEM, landslides, lithology, slope, rivers and faults). Maps are created by AutoCAD Map 2014 and exported to the ArcMap 10.1. The landslide map shows 1297 landslides, 139 active and 1158 dormant with average density of 0.9 landslides per km². The total landslide area is 114 km² which makes 7.5% of the study area.

The lithological map shows that class 5 (units defined as the most sensitive) covers 34 %, class 4 makes 3.3%, class 3 makes 24%, class 2 occupies 32% and class 1 (the least sensitive) makes 6.7% of the study area. The largest part of study area almost equally consists of lithological classes 5 and 4, class 2 is in the middle, while classes 1 and 4 are represented less than 10%.

Slope map shows that the most part of area takes slope with angle 0–15°. Slope with angle <5° make 34.9% and from 5–15° cover 45%. A less are represented slopes with angle 15–30° (18.4%) and the least slopes with angle >30° (1.7%).

In order to compare maps the pairwise comparison matrix is created (Table 2). As a result of comparing the weights of each map are gained. Obtained CR=0.025 means that judgement is consistent. The greatest significance is given to lithology (56.929) and slope (26.427). The least significance is given to distance to rivers (10.552) and distance to faults (6.092).

Table 2. Pairwise comparison matrix and weight.

	Litology	Slope	Distance to rivers	Distance to faults	Weights
Litology	1	3	5	7	56.929
Slope		1	3	5	28.427
Distance to rivers			1	2	10.552
Distance to faults				1	6.092

After pairwise comparison the landslide susceptibility map of SE Serbia is created. This map is then reclassified and four classes of susceptibility are created (Fig. 10) very high (class 1), high (class 2), moderate (class 3) and low (class 4). Zone of the very high susceptibility represents 36.9% of the study area. Zone of the high susceptibility covers 15.7% of the study area. In this zone the chance for landslide development is high. The lithology of zone is diverse and slopes are of variable steepness. The moderate class occupies 37.4% of the study area and zone classified as having low susceptibility accounts for 10% of study area.

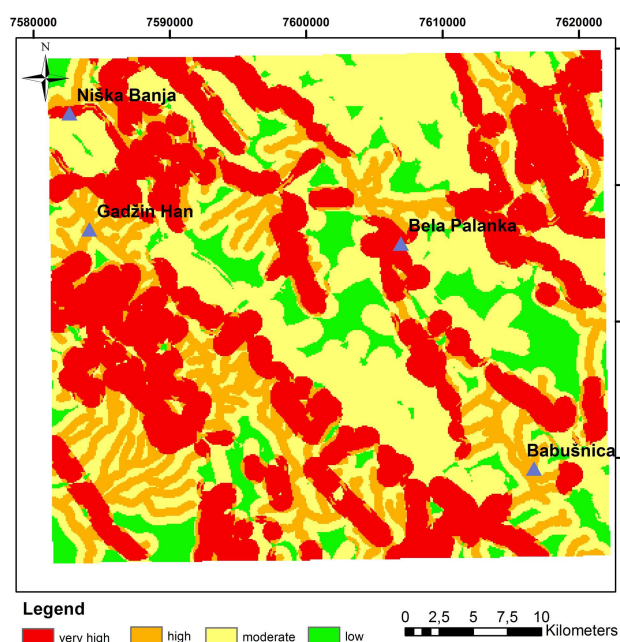


Fig. 10. Landslide susceptibility map of study area.

Landslide susceptibility map of SE Serbia is generally satisfactory. Steep slopes are favorable to the development of landslides but in study area, these slope are made of strong limestone with no landslide. Because of that in this case slope angle has small influence to the development of landslides.

Verification of susceptibility map is done by overlapping with existing landslides (Fig. 11). Total area of existing landslides is 114 km². About 8.37% of landslides are in class of very high susceptibility, 11.73% of landslides are in high susceptibility, 5.43% of landslides are in moderate class and 5.2% are in low susceptibility class. From here we can conclude that the landslide susceptibility map for study area is satisfying.

Conclusion

Landslide susceptibility map for SE Serbia shown in this paper is a result of selected factors relevant for susceptibility. This is the first time that landslide susceptibility mapping is done for this area of Serbia. The quality of final map depends on the quality and quantity of data we have. Geological map

is not suitable for determining lithological composition because it shows stratigraphic approach. For this reason, in this paper, the engineering-geological map was used. The final susceptibility map of study area is satisfying.

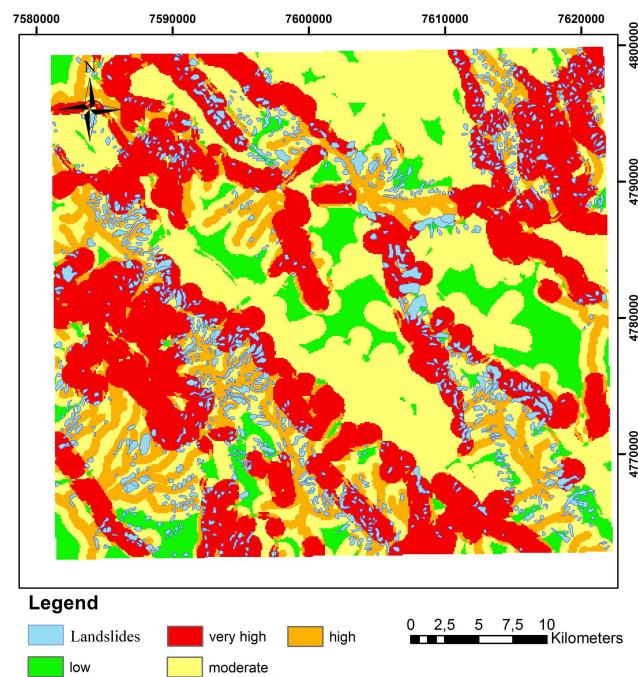


Fig. 11. Landslide susceptibility map with existing landslides of study area

GIS is a very powerful tool which allows susceptibility analysis easily and quickly to be performed. Problem is reported due to analysis as a result of used AHP extension. AHP extension from Marinoni does not provide possibility of forming a complex tree of comparison with several factors and subfactors. There is also no possibility to compare and evaluate classes within the same factor.

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Резиме

Утврђивање осетљивости на клижење у ЈИ Србији помоћу географског информационог система

Клизишта представљају велики проблем у Србији. Скоро 70 % територије Србије припада брдско-планинским пределима. Клизишта у оваквим теренима често настају као последица падавина. Према тренутним подацима око 30–35 % територије Србије је захваћено клизиштима. Предмет овог рада је простор југоисточне Србије површине око 1507 km². У складу са размером карте а узимајући у обзир специфичности области, за оцену осетљивости коришћени су следећи фактори: литологија, нагиб падина, удаљеност од река и удаљеност од раседа. За сваки фактор је урађена посебна карта на којој су издвојене одговарајуће класе. Укупно је регистровано 1297 клизишта. Просечно је регистровано 0,9 клизишта на km². Упоређивањем и вредновањем фактора добијена је карта осетљивости на истражном подручју. На овој карти издвојене су класе веома велике, велике, средње и мале осетљивости на клижење. Класа веома велике осетљивости захвата 36,9 % површине. Класа велике осетљивости на клижење захвата 15,7 %. Она представља зону у којој је вероватноћа настанка клизишта велика а обухвата подручја изграђена од различитих литолошких чланова и терене променљивог нагиба. Класа средње осетљивости на

клижење обухвата 37,4 % истраживане области. Класа ниске осетљивости на клижење обухвата 10 % истраживане области. Ова карта је потом верификована упоређивањем са картом клизишта. На основу ових података можемо рећи да је

добијена карта осетљивости на клижење задовољавајућег квалитета.

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