Landslide susceptibility mapping using AHP and GIS weighted overlay method: a case study from Ljig, Serbia

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Abstract

Landslides are one of the natural hazards that occur frequently in Serbia, causing huge loss of property every year, especially after heavy rainfall events. Due to the geological condition, rapid development activities and other inherent natural conditions, the Ljig municipality has been exposed to landslide hazards. Therefore, the present study concentrates on landslide susceptibility (LS) analysis in this area using the analytical hierarchy process (AHP) and geographic information system (GIS) weighted overlay method. The causative factors considered for the study (slope, geology, pedology, distance from roads, distance from river network, land cover and rainfall) were graded and the result was a map showing areas divided into five classes based on the possibility of landslide occurrence (from very low to very high). According to the landslide susceptibility area map, about 42% of the study area falls into high and very high susceptibility zones and approximately 44% of the area has medium susceptibility for landslide events. The results of this study can be a valuable input for slope management, land use planning and disaster management planning by the responsible authorities.

1. Introduction

In geomorphology, a "landslide" is the movement of a mass of rock, debris or earth down a slope under the influence of gravity (Cruden and Varnes, 1996). In a broader sense, landslides are downward movements of rock, debris or earth masses, usually developed along predefined planar discontinuities. These are called slip-surfaces (simple planar or higher order complex surfaces), which propagate throughout the mass and separate intact bedrock material from the moved material above. Other elements of a landslide include crown and head, separated by a scarp; main body, channeled by flanks; foot, terminated by a toe; depletion zone capturing upper and accumulation zone capturing lower portions of a landslide. Landslides can drastically vary in size and area, as

well as in other characteristics. They can develop in natural or engineered/constructed slopes. A large number of active landslides today are caused by inappropriate construction works and land cultivation (Marjanović, 2013). Consequently, they have been studied in various scientific branches ranging from Geology and Geomorphology to Geological, Geotechnical and Civil Engineering (Lee and Jones, 2004; Bell, 2007). Relative to other natural disasters, the International Disaster Database (EM-DAT) suggests that landslides account for 4.9% of all natural disaster events and 1.3% of all natural hazard fatalities between 1990 and 2015 (Ali et al., 2019). However, the dedicated global landslide databases indicate that global multi-peril databases underestimate the impact of landslides on society. Landslide susceptibility stands for the spatial distribution and magnitude estimation

of landslides which exist or may potentially occur over an area. It could also be treated as a pure spatial probability of landslide occurrence (Fell et al., 2008). Landslide hazard stands for a probability of landslide occurrence over an area within a given time period (temporal probability). It could be regarded as a temporal extension of susceptibility. It is sometimes confused with susceptibility, but it is sufficient to notice its temporal dimension to make a distinction (Lee and Jones, 2004). Undeniably, landslide hazard awareness reached considerable quota in recent years. It involves not just the general population, but the academic circles and political officials, as well. Google's insight for search indicates a considerable average rise in interest for keywords such as landslide, debris flow, landslide hazard and susceptibility. The interest is particularly high right after the events that had caused considerable damage to society and that have been followed-up by media. Consequently, interest is the highest in the affected areas (Marjanović, 2013). The Republic of Serbia has suffered huge economic losses over the last decades due to natural disasters. In Serbia, 30-35% of the territory is landslide-prone (Milošević et al., 2006). The occurrence of landslide events has remarkably increased in this region due to climate variation, intense rainfalls and increased population pressure. External or internal factors, e.g. slope steepening, removal of support from slope, inherently weak material, etc. may trigger landslide events (Ali et al., 2019). The rainfall that triggered numerous landslides in 2006 and 2014 caused extensive damage to housing, infrastructure, agriculture, etc. According to Milošević et al. (2006), due to its geological structure and terrain morphology, central Serbia is susceptible to the formation of landslides with even small changes in geometry or burdening of unstable slopes. Registered landslide areas in the study area are small in size and are usually the consequence of human activities, most often following cuts for road routes. The territory of the Ljig municipality is in great part affected by landslide processes (Milošević et al., 2006). Van Westen et al. (2003) and Galli et al. (2008) considered and examined the relationship between geomorphological factors and the appearance of landslides. Awawdeh et al. (2018) developed a landslide susceptibility map (LSM) along the Jerash-Amman highway in Jordan using geographical information systems (GIS) and weighted overlay method. A few studies investigated landslides in the municipality of Ljig. Milošević et al. (2006) presented the locations of frequent occurrences of landslide processes, while Đorđević (2006) examined and evaluated natural environmental factors influencing the development of the Ljig municipality. Besides, GIS was used in

the spatial analysis of the landslide susceptibility of slopes and described thoroughly by Carrara et al. (1995).

The main objective of this study is the use of GIS and Remote Sensing to produce a landslide susceptibility map of the Ljig municipality. The increasing popularity of GIS has led to many studies, predominantly using indirect susceptibility mapping approaches. As a consequence, fewer investigations use GIS in combination with a heuristic approach, either geomorphological mapping or analytical hierarchic process (AHP). Accordingly, this study displays a landslide susceptibility assessment method based on GIS technology combined with an AHP-weighted information content method. This area is prone to landslides and has therefore been chosen as the subject of this study. The aim of this research is to give an analysis and to try to locate the potential future appearances of the landslides and with this kind of approach find possible solutions and affect minimizing the losses.

2. Study area, data and methods

2.1. Study area

The municipality of Ljig is located in the central part of Serbia (Fig.1). With an area of 278.84 km2 it is neighboring two entities, one belonging to Šumadija and the other to northwestern central Serbia (Spatial plan of the municipality of Ljig, 2008). The boundary between these two areas is the Ljig River, which flows through the western and northwestern areas of the municipality. The southern part of the municipality is situated on the main ridge of Suvobor mountain. The mountainous area covers the southern and eastern parts of the study area and flatlands (up to 200 m elevation) cover 23.1% of the total territory of the Ljig municipality. The analysis of the slope angles revealed that flatland (less than 3°) occupies 15% or 44 km2, and the difference of 8% refers to valley sides that are at lower elevations than 200 m, but they are at considerable slopes (over 3o and most often 5-8o), thus, they cannot be classified as plains. The area varies in elevation from about 121m near the settlement Latković in the northern part, to 848 m in the southern part (Radanović, 2010). The mean annual temperature within the study area for the last 30 years is about 11°C in the lowest parts and about 9°C in the mountainous parts. During the growing season, which lasts from late March to late October, the mean temperature ranges between 14°C at Rajac to 17-18°C in the lowest parts of the municipality. The average annual rainfall for this area is 810mm/year, but it varies from 650mm/year in the northern parts to 1000mm/year in the mountainous area. The highest rainfall is in the period May-July and the

lowest in January-March (Spatial plan of the municipality of Ljig, 2008).

According to the last Population Census (2011) the municipality had about 12,000 inhabitants. The population lives in 28 settlements, of which the only urban settlement is Ljig, which is also the largest settlement with 3226 inhabitants. The municipality is predominantly agricultural with a 45% share of cultivated land (Municipalities and regions of the Republic of Serbia 2018, 2019).

In addition to the national road M 22 and the regional road network, there is also a highway, "Miloš Veliki", which was completed in 2016, that also passes through the municipality.

2.2. Data

The starting point for performing a GIS-based landslide susceptibility analysis is the collection of the data considered to influence the occurrence of landslides. The selection of causal factors differs depending on the scale of analysis, the characteristics of the study area, the landslide type and the failure mechanisms (Van Westen et al. 2008). In this study, for assessing and mapping the landslide susceptibility in the Ljig municipality, the following predisposing factors were selected: lithology, land cover, hydrological factors and morphometric factors, i.e. slope angle and aspect. For each of these layers, the incidence of landslides in their classes was evaluated (Pellicani et al., 2017). The main data required for landslide susceptibility and risk assessment in this study were collected from various sources and are presented in Table 1.
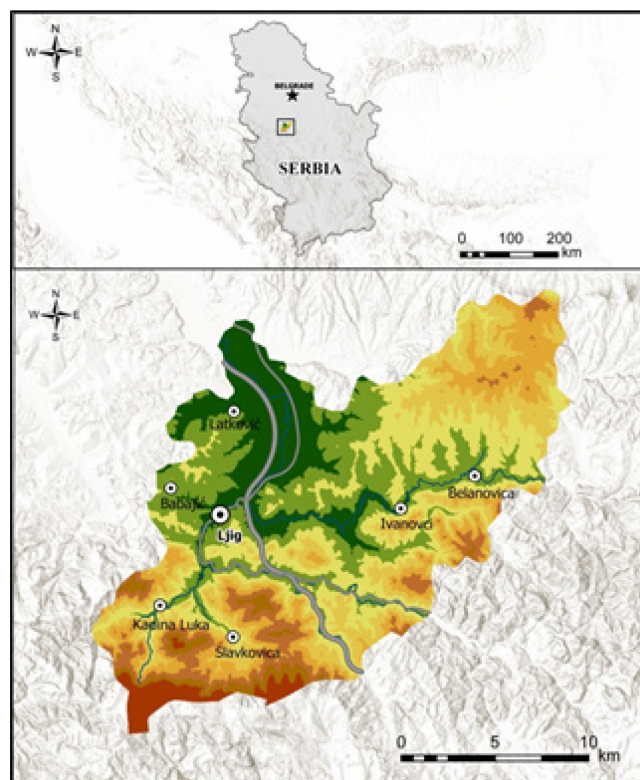

Figure 1. Location of the study area

The first step was the creation of the derivatives from the ASTER global digital elevation model (DEM, 30 m resolution). This included the calculation of the slope angle and the aspect in ArcGIS Pro 2.5 software. A digital relief model was used to generate the slope layer and slope expositions (Abrams, 2016). It is known that "as the slope increases, the shear stress on the slope increases, and the probability of landslide occurrence also increases" (He et al., 2019, p. 15).

Table 1. Sources of data used for the study

Data	Description	Source
Landsat 8 OLI	Downloaded	https://earthexplorer.usgs.gov
Sentinel-2	Downloaded	https://scihub.copernicus.eu/
Aster GDEM (Digital Elevation Model - DEM)	Downloaded	https://earthexplorer.usgs.gov
Rainfall	Downloaded	https://www.chc.ucsb.edu/data/chirps
Roads	Downloaded	http://download.geofabrik.de/
Land cover	Derived	from Sentinel-2
Slope angle	Derived	from ASTER DEM (30 m)
Aspect	Derived	from ASTER DEM (30 m)
River network	Derived	from ASTER DEM (30 m)
Lithology	Digitized from 1:100,000 geological map	Basic geological map of Serbia 1:100 000 (Gornji Milanovac sheet L 34-137)
Pedology	Digitized from 1:50,000 pedology map	Pedology map of Serbia 1:50 000 (Valjevo 4 sheet)
Landslide reference locations	Provided from authors	Previous studies (Milošević, 2006) and municipality reports

The aspect is related to sunlight, winds, and rainfall which may control the occurrence of landslides. Winds and rainfall increase landscape instability, while the sunlight increases evaporation which causes less vegetation and increases soil erosion (Suzen and Doyuran, 2004).

The thematic layers of distance to drainage network and roads were calculated by using the Euclidean distance tool of ArcGIS Pro 2.5. A Sentinel-2 image with 10 m spatial resolution acquired on 12/06/2019 was also used to generate the land cover map after radiometric and atmospheric corrections. The land cover map was produced by supervised Maximum Likelihood Classification of satellite data using ArcGIS 10.4 software and classified into 3 classes: forest, cultivated and built-up areas. This method was used since there is a need for larger-scale land cover mapping. The existing data such as CORINE land cover dataset at a scale of 1:100.000 is often not detailed enough for many national and regional applications.

Data limitations are related to the absence of a meteorological station in the Ljig municipality. Hence, the annual average rainfall was obtained from the inverse distance weight (IDW) interpolation of data from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). The CHIRPS is a high-resolution rainfall product with quasi-global coverage. Spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present, CHIRPS incorporates in-house climatology, CHPclim, 0.05° resolution satellite imagery, and in-situ station data to create gridded rainfall time series for a 35+year period (Saeidizand, et al., 2017). Dinku et al. (2018) evaluated CHIRPS rainfall data. The evaluations were done by comparing CHIRPS with reference rain-gauge data as well as with two similar satellite rainfall products (ARC2 and TAMSAT). The CHIRPS products performed significantly better than ARC2 and TAMSAT with lower random errors. While CHIRPS often under/overestimates daily precipitation and has limitations for local landslide-related studies, it is often the best available data for studies on a regional scale, if rain gauge data is not available (Hölbling et al., 2020). Therefore, the CHIRPS product has been the most suitable rainfall data alternative for the study area.

Generally, a full landslide inventory covering the study area is desirable which is by far the most basic requirement for landslide susceptibility mapping. Unfortunately, most places in the world, including Serbia, lack the historical database of landslide inventory. This includes some obvious limits due to the lack of some fundamental information such
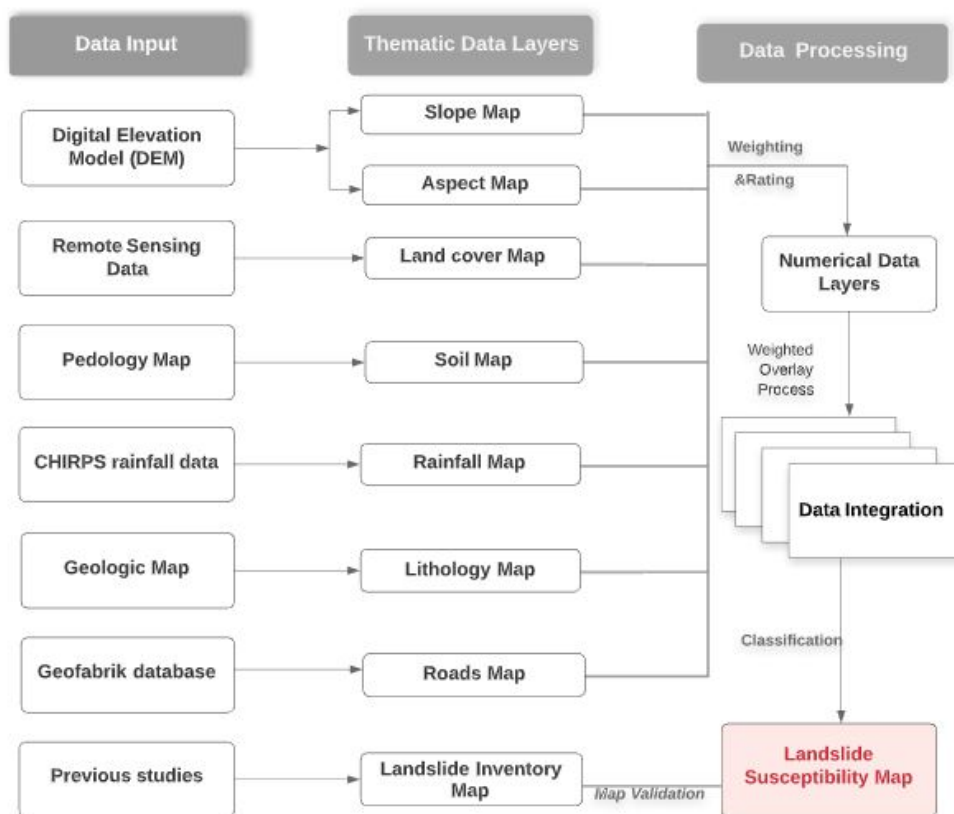

Figure 2. Visualization of GIS model methodology used for landslide susceptibility mapping

as the landslide occurrences for the whole study area. There-
fore, landslide inventory is collected from previous studies.
A qualitative heuristic approach is used in this study, which
is an optimal approach to map the landslide susceptibility,
especially in the absence of landslide inventory data.

2.3. Methods

A GIS method based on the collection and analysis of all the
factors related to landslides was used to develop a landslide
susceptibility map (LSM) of the Ljig municipality. This
method involves six steps: I) selecting the relevant factors,
II) database construction, III) data layers generation, IV) data
preparing, V) numerical ranking of each factor and VI) vali-
dation of the landslides model (Sarkar and Kanungo, 2004).
Eight conditioning factors affecting the occurrence of land-
slides were determined for LSM based on the literature re-
view and landslide inventory map of Serbia (GeoSrbija – Na-
tional Spatial Data Infrastructure). The methodology
adopted for this study is illustrated in Fig. 2. All the data were
collected or created in a digital raster data format and pro-
cessed to prepare the different thematic layers. The thematic
data were then processed and analyzed to derive the input
parameters for the AHP and the weighted overlay method.

The different classes of thematic layers were assigned rat-
ing values corresponding to their relative contribution to
landslide occurrence (Awawdeh et al., 2018). Previous stud-
ies provided important information for weighting and rating
the parameters. Rating values were derived through the AHP
method. AHP provides objective mathematics to process the
subjective and personal preferences of an individual or a
group in making a decision (Saaty, 2001). This method pro-
vides an opportunity to determine the importance of each
criterion (by calculating criteria weights and creating a hier-
archy), meaning that the weights will determine the effect of
particular criteria in the overall assessment (Božić et al.,
2018). The AHP method was used to find the relative weight
and priority of individual factors and sub-factors that foster
the occurrence of landslides in the Ljig municipality. The
multi-criteria assessment based AHP is a decision-making
tool to deal with complex and multi-attribute problems and
was first developed by Saaty (Gudiyangada Nachappa et al.,
2020). It helps decision-makers to discover the best suits of
their objective and their understanding of the problem
(Jazouli et al., 2019). In this study, the weight of the criteria
is based on the expert's opinion, literature and landslides oc-
currences in Serbia.

After the landslide susceptibility (LS) identification, the
accuracy of LS was evaluated by comparing the landslide lo-
cations and the LSM. Accordingly, the final LSM was vali-
dated by analyzing known landslides within each of the var-
ious categories of the landslide susceptibility map.

The landslides are complicated consequence of many ter-
rain characteristics in a particular area such as geological
structure, slopes, landforms, hydrology as well as meteoro-
logical conditions (He et al., 2019). The impact of lithology on
landslides appearance is reflected in the differential between
lithology and structure in an area and their highly impact on
the strength as well as other properties of rocks and soils
such as permeability, porosity, abrasive resistance, etc.
(Georgios Stavropolou and Lekkas, 2019; Champati Ray et al.,
2007). The topsoil cover on the downhill increases landslide
susceptibility, especially when the soil retains water (Wati,
2010). According to Rozos et al. (1988) in many cases heavy
rainfall triggers landslides. Thus, the landslide susceptibility
was assessed using eight affecting factors (i.e., lithology, dis-
tance from roads, distance from river network, slope, aspect,
land cover, annual rainfall and pedology). The weight of each
factor was determined using the AHP method. All thematic
layers were combined using the weight index overlay
method to derive the landslide susceptibility map.

The landslide susceptibility maps can be built using the
weighted overlay method (WOM), a method of modeling
suitability available with Spatial Analyst toolset in Arc GIS
(Shit et al., 2016; Intarawichian and Dasananda, 2010)

In this study an overlay of raster layers was done to pro-
duce a susceptibility map. According to Intarawichian and
Dasananda, 2010, reclassification of all raster layers was
made and weighted due to their AHP significance. For this
calculation, the following Equation (1) was used:

$$S = (\sum W_i S_{ij})/(\sum W_i) \tag{1}$$

where,
W_i – the weight of i-th factor map
S_{ij} – the i-th subclass weight of j-th factor map
S – the spatial unit value of the output map

As a result of the explained process, the landslide suscepti-
bility map was made. Raster calculations were accomplished
on the rasterized layers of the eight affecting factors to esti-
mate the overall landslide susceptibility. The results of the
application of each model are described in the following sec-
tion. For the application of the WOM, numerical values were
assigned to each of the five susceptibility classes per factor

as follows: Very low = 1, Low = 2, Moderate = 3, High = 4, Very High = 5 (Shit et al., 2016).

3. Results

In this study, AHP was used as a multicriteria evaluation approach to identify the potential landslide occurrences in the Ljig municipality. Eight landslide conditioning factors i.e. slope, aspect, pedology, lithology, land cover, rainfall, distance to river network and distance to roads, were employed for susceptibility analysis.

3.1. Geological factors

Lithology always has a fundamental role in landslide evolution and landslide occurrences (Sarkar and Kanungo, 2004). There are eighteen lithology groups in the study area (Fig. 3). The most dominant lithology classes are flysch, sands and alluvium and they cover 34.8%, 18% and 15% of the study area, respectively. Each formation was rated according to its influence in developing landslides. According to expert's opinion, three units are the most important for the landslide events: flysch, clay and conglomerates. Therefore, the highest rating values were assigned to these three lithology groups. The highest rating values (4 and 5) cover 71% of the study area. A majority of the recorded landslide events happened in the areas with high rating values.

Unbound sediments are most prevalent in the Ljig River valley and north of the Kacher River, in the form of gravels, sands and clays. In the conglomerate group, breccias, tuffs and sandstones are many different formations, which are not

especially territorially grouped ones, especially in the Kacher Valley. Flysch is a rock complex that is heavily represented in the municipality of Ljig. It extends west of the Bolshevik junction, in a wide band north and to the east of the Slavkovica volcano, and to the east of the Bolkovo Cave, the most widespread flysch is predominantly composed of sandstone. Compact magmatic rocks occur west of Slavkovica (Milivojević and Ćalić, 2006).

3.2. Slope

The slope represents the steepness of the terrain and has an influence on the occurrence of landslides and their development. The slopes of the area range from 0° to 56°, and were conveniently divided into seven classes (Fig. 4). The highest slopes are found close to the highway and in the southern part of the municipality. The largest area was characterized by the 0–5° (31.83%) and 10–15° (23.92%) slope classes. The slope between 15°-35° is most susceptible to landslide events (Gökceoglu and Aksoy, 1996). These classes are rated with the highest weight and cover 20.2% of the study area. More than 60% of landslide events occurred in class III (15–20°), whereas the least landslide events (8.3%) occurred in class I and class VII (0–15 and ≥35°).

3.3. Aspect

Exposition is an indirect factor that affects slope instability (Sarkar and Kanungo, 2004). In the study area the slopes are mostly positioned in the NE-SW direction (Fig. 5). By evaluating the statistical distribution of aspects in areas affected by landslides, the resulting map has revealed that slopes
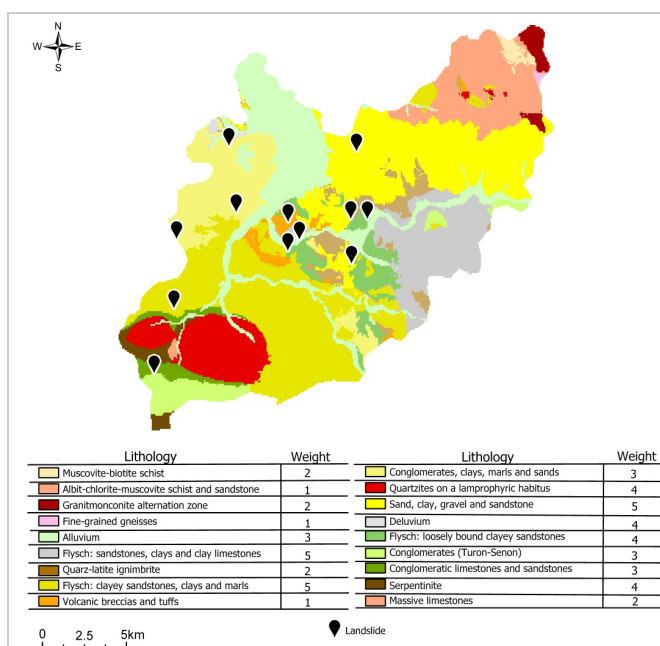

Lithology	Weight		Lithology	Weight
Muscovite-biotite schist	2		Conglomerates, clays, marls and sands	3
Albit-chlorite-muscovite schist and sandstone	1		Quartzites on a lamprophyric habitus	4
Granitmonconite alternation zone	2		Sand, clay, gravel and sandstone	5
Fine-grained gneisses	1		Deluvium	4
Alluvium	3		Flysch: loosely bound clayey sandstones	4
Flysch: sandstones, clays and clay limestones	5		Conglomerates (Turon-Senon)	3
Quarz-latite ignimbrite	2		Conglomeratic limestones and sandstones	3
Flysch: clayey sandstones, clays and marls	5		Serpentinite	4
Volcanic breccias and tuffs	1		Massive limestones	2

Figure 3. Lithology map

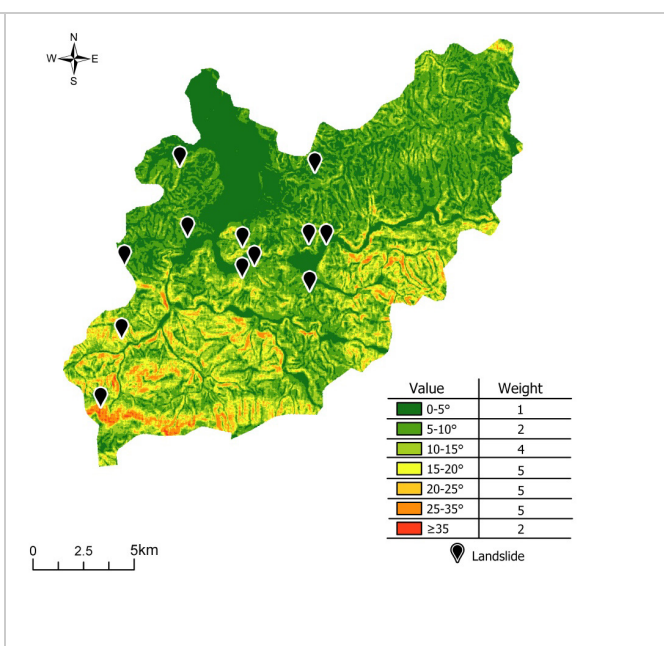| Value	Weight
0-5°	1
5-10°	2
10-15°	4
15-20°	5
20-25°	5
25-35°	5
≥35	2

Figure 4. Slope map

with N-NW direction, where the snow cover lasts longer, are more likely to be landslide-prone than slopes with the S orientation. This happens because slopes on south (on the northern hemisphere) have more sun thus there is less evaporation comparing to northern slopes. Therefore, the slopes with N-NW and NE direction are rated with a high rating value 4. The expositions with the high rating value occupy the maximum area (41.3%), whereas the lower values (3, 2, 1) occupy the following areas: 25.8%, 34.7% and 0.2%, respectively.

3.4. Pedological factors

The different soil textures were rated in terms of their potential contribution to landslide occurrence. The study area is dominated by two soil types: gray-brown acid soil on sandstone (40.4%) and skeletoidal black soil on serpentine rock (24.2%). The gray-brown acid soil on sandstone is found mostly in the northern and western parts of the area (Fig. 5). The remaining are skeletal soils on serpentine rocks (12%), gray-brown soil on limestone rocks (9.5%), gray-brown skeletoidal acid soil on granit rock (6%) and skeleton-stone fragments (5%). The majority of landslide events (40%) happened on the gray-brown soil on limestone and the shallow black soil. This is mainly due to the potential of such soil classes to retain water during precipitation leading to a reduction in shear strength.

3.5. Climatological factors

The most important triggering factor influencing slope stability is the rainfall. The heavy rainfall in the years 2006 and 2014 initiated landslides in the study area. Since then, landslides have become more frequent, especially during the rainy season. The highest rainfall values are observed in the southwestern part of the study area and the lowest values in the northern one (Fig. 7). The statistical analysis of the data showed that the frequency of landslide events increases with increased precipitation. Therefore, rainfall is an important factor in triggering landslides. As a result, the highest susceptibility levels were assigned to the areas of the highest annual height of rainfall. Areas with the highest annual rainfall cover 22% of the area.

3.6. Land Cover

It can be observed that the landslides occur in places with a pronounced anthropogenic factor, i.e. on arable land (Fig. 8). In the areas with dense vegetation, the roots are important for making the slope more stable and less prone to slipping (Nohani et al., 2018). The rating values ranged from 1 for forest to 5 for cultivated/planted areas. Forests, cultivated land and built-up areas cover 51%, 44% and 5% of the study area, respectively. The vast majority of landslides events (75%) are located in cultivated areas. This indicates that the modification of natural conditions by human activities such as forest harvesting could have a considerable effect on landslide activity in the study area.

3.7. Distance from roads

Nohani et al. (2019) under explanation about 'distance from road' as factor for landslide formation, are citing Tuan and Dan (2012) who confirmed the dependence of landslides on
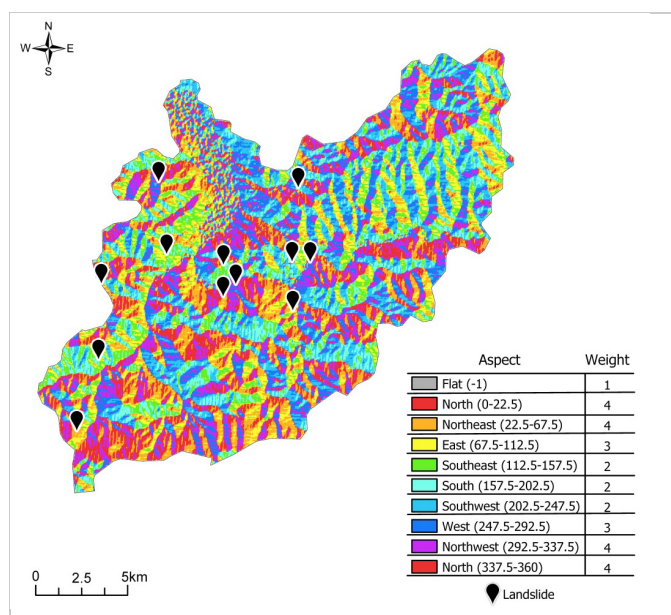

Aspect	Weight
Flat (-1)	1
North (0-22.5)	4
Northeast (22.5-67.5)	4
East (67.5-112.5)	3
Southeast (112.5-157.5)	2
South (157.5-202.5)	2
Southwest (202.5-247.5)	2
West (247.5-292.5)	3
Northwest (292.5-337.5)	4
North (337.5-360)	4

Landslide

0 2.5 5km

Figure 5. Aspect map

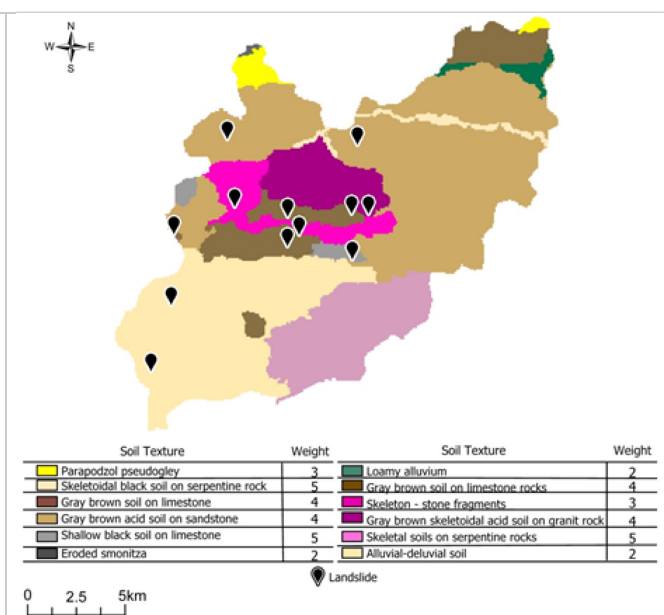| Soil Texture	Weight	Soil Texture	Weight
Parapodzol pseudogley	3	Loamy alluvium	2
Skeletoidal black soil on serpentine rock	5	Gray brown soil on limestone rocks	4
Gray brown soil on limestone	4	Skeleton - stone fragments	3
Gray brown acid soil on sandstone	4	Gray brown skeletoidal acid soil on granit rock	4
Shallow black soil on limestone	5	Skeletal soils on serpentine rocks	5
Eroded smonitza	2	Alluvial-deluvial soil	2

Landslide

0 2.5 5km

Figure 6. Pedology map

the proximity of roads. They said that "by cutting the slope hills for construction of roads in the slopes more than 10 degrees, discontinuity is made in the soil and rock. Accordingly, the area can be prone to landslides" (Nohani et al., 2019, p. 5). In the area under study the maximum number of landslide events (50%) occurred within a distance of approximately 0 to 100 m from any given road (Fig. 9). This may be because the road network can affect slope stability in negative way, eliminating "natural support for the upper part of the slope through undercutting the base of the slope during

its construction and by adding extra weight on them" (Skilodimou et al., 2018, p. 14). Further away the frequency of landslide occurrences gradually decreases. Accordingly, a medium susceptibility level was given to the buffer up to a distance of 200 m from the road network while the low susceptibility level was assigned to distances beyond 500 m.

3.8. Distance from rivers

The water of rivers is considered as one of the main sources of soil moisture. Pham et al. (2018) stated that 65% of landslides occurred close to rivers (0–50 m). According to this
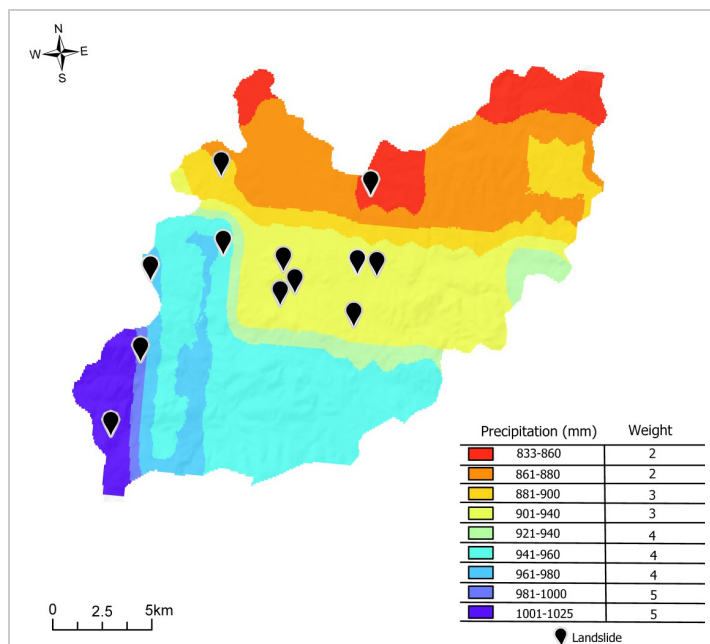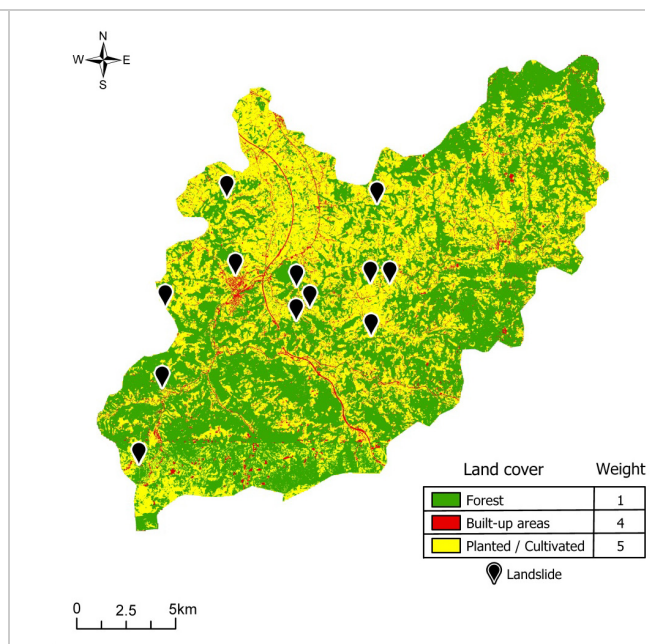

Figure 7. Rainfall map
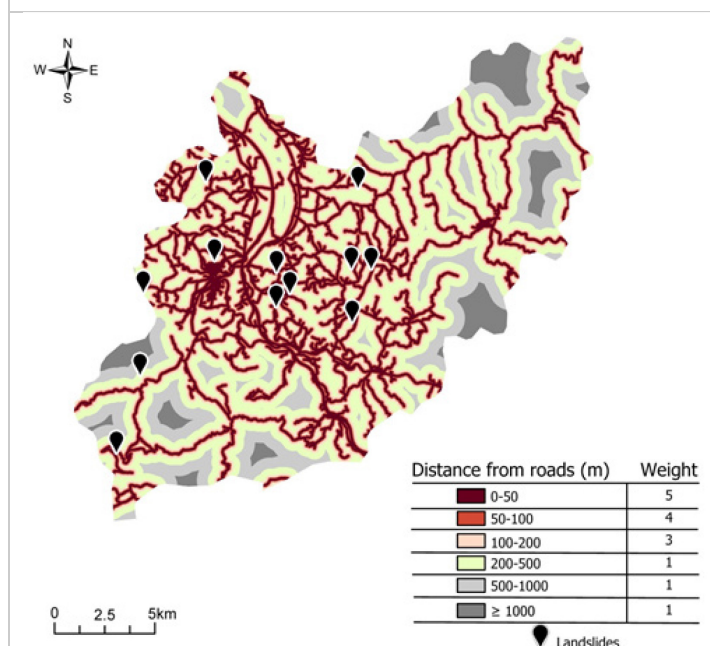

Figure 8. Land cover map
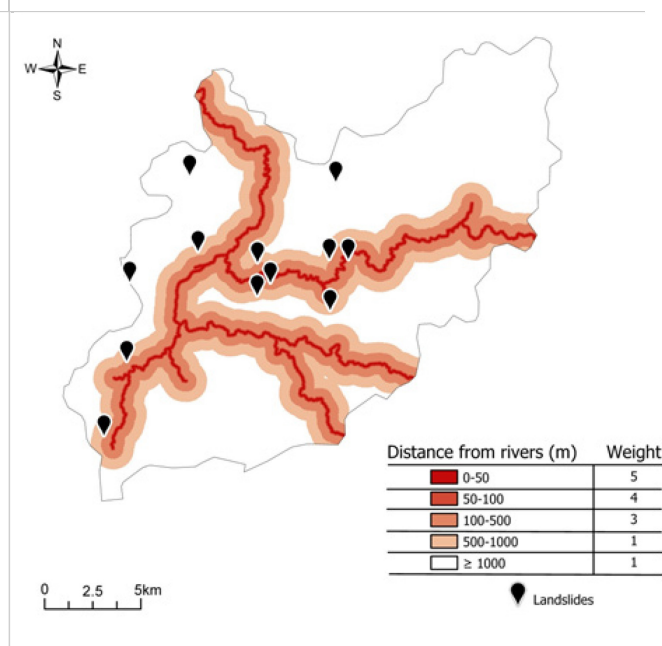

Figure 9. Distance from roads map

Figure 10. Distance from rivers map

statement, rivers represent very dominant factor in LSM. This factor was extracted through Euclidean Distance tool in ArcGIS Pro 2.0 software and classified into five classes as following (1) 0–50, (2) 50–100, (3) 100–500, (4) 500–1000, and (5) >3000 m (Fig. 10). He et al. (2019) determined characteristic factors for landslide formation and one of them is 'distance from rivers' where they revealed that "landslides are active in regions where scouring intensity is enhanced as a result of hydrostatic action or human disturbance" (p. 15). In the Ljig municipality in areas distanced 0-50 m from the river, there is a high potential of landslide occurence.

3.9. Land susceptibility map

After the assessment of all factors independently, weighted overlay analysis (WOA) was performed. For WOA, a five-step landslide susceptibility scale was used: very low, low, medium, high and very high susceptibility. AHP method was used to determine the weight for each factor (Table 2).

Table 2. Factors weight in WOA

Factor	Weight (%)
Geology	21
Pedology	10
Slope	15
Aspect	3
Rainfall	14
Land cover	17

Distance from roads	10
Distance from rivers	10

Geology with a weight of 21% stood out as the main factor for landslide risk assessment. The second most important factor is land cover, which has proven to be extremely important for landslide risk assessment in the field (existing landslides) and in the literature. It is worth mentioning that aspect is the least important factor at the locations of existing landslides, not only in the municipality of Ljig but also in other municipalities in Serbia. This is mainly because it is extremely variable, and thus, aspect cannot be considered as a key factor for risk assessment, although it is often mentioned in literature.

Based on the map of landslide susceptibility, areas with varying levels of risk were inventoried. It can be concluded that a total of 24% of the area is not susceptible (very low and low susceptibility) and 55.4% of the area is susceptible (high and very high susceptibility) to a landslide occurrence (Fig. 11). The remaining 20.6% of the area falls within the area of moderate susceptibility. The spatial distribution of these shares by susceptibility categories is primarily due to the geological structure of the area, and the morphometric terrain parameters. The areas of very high susceptibility are
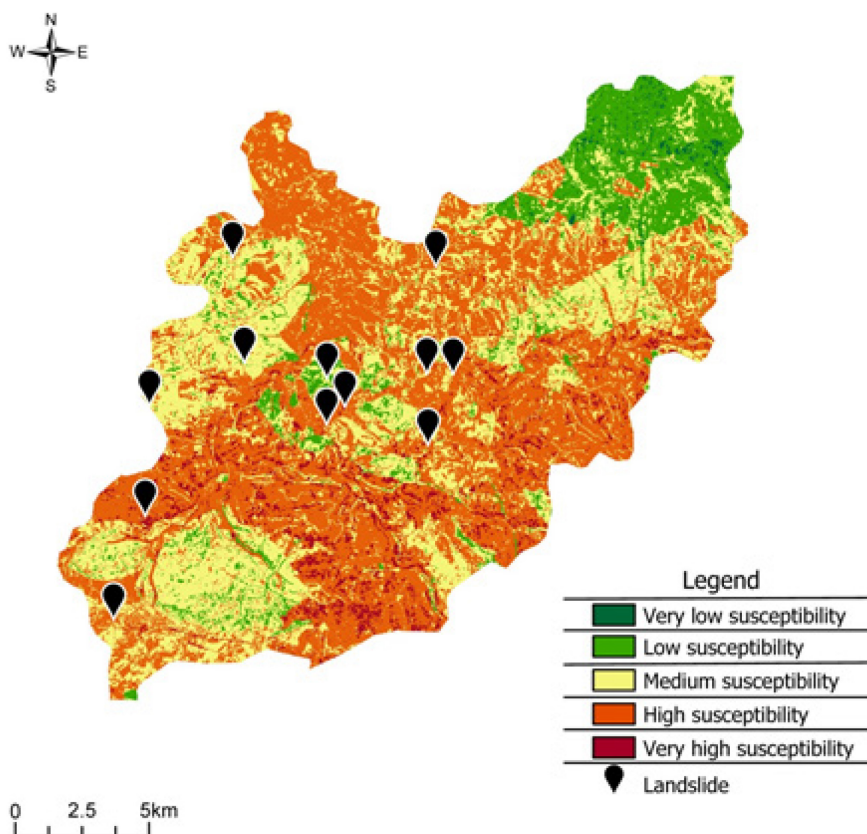
Figure 11. Landslide susceptibility map

mainly found in southern and central parts of the municipality. Very low and low susceptibility areas are located in northern parts of the municipality.

4. Discussion

The creation of LSM and information that it gives can contribute to the development of hazard strategies and beside that detect potential locations for landslide formation and in that way help in risk mitigation (Nohani et al., 2019). A landslide susceptibility map is a useful tool in natural and urban planning, especially for the definition of the land use zones and for the design of future construction projects. The AHP model is usually based on a rating system provided by expert opinion. Expert opinion is very convenient in resolving complex problems like landslides. However, to some extent, opinions may change for every individual expert, and thus may be subjected to cognitive limitations with uncertainty and subjectivity (Jazouli et al., 2019).

When speaking about landslides and man activity the mutual influence is obvious. The houses and buildings that are built on unstable terrains are very likely to have great consequences through infrastructure damage and destruction. Landslides can harm large areas of settlements as well as act locally which means that some part of the certain infrastructure is destroyed. This property also includes water reservoirs, electricity systems, roads, etc. The secondary affected sectors are tourism, industry, transport, and environment that can have long-term results. Since in Serbia there are no exact and clear land-use policies, this problem becomes bigger. Building permits for some objects can be questioned. The quality of the infrastructures should be examined because communities often are not able or prepared to act quickly and prevent damage. On the other hand, climate conditions are also one of the main factors when it comes to the landslide formation. The frequency and intensity of rainfall events can induce sudden landslides and contribute to greater destruction. For the reasons stated above, during the 2014 extreme rainfall, when landslides in the Republic of Serbia and the municipality of Ljig were triggered, traffic infrastructure and residential buildings were mostly affected. All existing landslides considered in this study have just been recorded because they endangered the infrastructure and suprastructure of the municipality.

The data obtained indicate that the central and southern parts of the study area are the most susceptible. The central and southern parts of the area include 15 settlements with 60% of the total population of the Ljig municipality. Adding the dense road network to this, it can be concluded that damage from the activation of landslides would be extensive.

The results show that as much as 44.7 km of the municipality's transport network is in the area of the highest risk of landslides and as much as 285.3 km is at high risk of landslides. It is also interesting that the highway itself is partly in the area of extremely high risk, but precisely because of the extremely risky terrain for the construction of infrastructure, the highway mostly goes underground (tunnel) through the high-risk area.

Due to the very high percentage of the threatened territory (54%), additional factors should be measured in the field to further increase the reliability of the results. Those factors should be implemented in future studies. Finally, the model would be complemented with in-situ terrain observations.

In addition to defining the criteria themselves, locations of existing landslides in the municipality of Ljig were used to validate the data. The assessment results show that almost 83% of landslides are distributed in the very high susceptibility (VHS) and high susceptibility (HS) zones, while 17% of landsides occurred in the moderate susceptibility (MS) zones. In low susceptibility (LS) and very low susceptibility (VLS) zones there are no recorded landslide events, therefore it can be concluded that this model provides reliable results.

This research may provide a basis for further improvement of the methodology. Ideally, planning and construction efforts, as well as the environmental policy within the territory of the municipality of Ljig, would consider landslide susceptibility zones as an important source for future regional planning and development efforts, as well as for risk management.

5. Conclusion

In the determined LS and MS zones, it is possible to plan and construct buildings along with any economic activity. Instead, in the HS and VHS zones, extra consideration should be given in planning for any activity, including building construction. Consequently, the more hazardous the zone is, the more specific the wariness on planning is needed. Human activities such as road cuts coupled with natural factors such as lithology and slope made most parts of the study area prone to landslides. Unfavorable rock strata such as flysch, loosely bound clayey sandstone and clays are considered the main contributing factors for landslides. The HS zone should be entirely avoided for settlement or other developmental purposes. If unavoidable circumstances compel the execution of road cutting and urban projects, caution should be

taken in consultation with geological experts. The MS zone comprises areas that have intense road cuts with low drainage density and relatively weak-to-moderately strong rocks. Although this zone involves areas that are stable in the present condition, future land use activity must be duly planned to maintain its current status. The low susceptibility zone is stable. In rare sites, some slope instability was observed in this zone due to the road cutting in moderately fractured rock. The VLS zone is very stable, and it generally comprises areas covered by dense forest and strong rock structure, mostly located far from human activity. The validation of the model verified that the selected causative factors are highly relevant and that the model performs properly. However, further data collection on landslides may change the results of model validation.

The final susceptibility map can be considered as a base map for landslide hazard evaluation when intending to avoid or reduce future hazard's impacts and improve decision-making prior to any development in this municipality. The result can be useful for explaining the conditioning factors for triggering landslides, thereby, supporting the efforts to mitigate future landslide hazards in the study area. As previously mentioned, a landslide is an underestimated, in turn, less studied subject in Serbia. This study may serve as an initiative and suggests that more efforts should be made to investigate the landslide hazard in other basins in central Serbia. Besides, landslide susceptibility mapping is an important step prior to landslide assessment planning, management and disaster mitigation. Identification and detailed assessment of this underestimated hazard are needed in effective landslide hazard reduction through disaster mitigation planning and development strategies.

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