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LANDSLIDE SUSCEPTIBILITY ZONATION IN THE KOLUBARA RIVER BASIN (WESTERN SERBIA) – ANALYSIS OF INPUT DATA

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Abstract: According to estimates, 25% of the territory of the Republic of Serbia is affected by landslide processes. In the spring, when snowmelt is accompanied by the maximum amount of precipitation, a great number of landslides have been activated within the territory of Serbia. The year 2006 had a particularly large number of registered landslides accompanied by huge material damages. Because a landslide data base for the territory of Serbia does not exist, it is very difficult to carry out the regular assignment of land use and to make a spatial development strategy. This imposed a need for methodological development of landslide hazard zonation (LHZ) for the territory of Serbia. The Kolubara River Basin was selected as an area with a significant number of landslides occurence. The spatial distribution of landslides is a result of the interaction of many parameters. Landslide susceptibility zones in the Kolubara River basin were identified by heuristic analysis of landslide causal factors - local topography, morphological and geological setting, and the existing and past landslides identified the study area. Based on the results obtained in this study, it was found that 243.75 km^2 or 6.69% of the total area was prone to landsliding. The results can be implemented as a base for development of LHZ model for the overall territory of Serbia, and will represent the first step for compilation of a landslide data base.

Key words: Multi-parameter analysis, Landslide distribution, Neogene sediments, Landslide causal factors, Kolubara River.

1. INTRODUCTION

The goal of this paper is to determine and analyse the areas that are potentially at risk for landslides in the Kolubara River Basin of western Serbia. The intensity of deluvial-proluvial and coluvial slope processes is conditioned by a large number of physical-geographical factors, whose basic characteristics are spatial, and weather changeability (Kostadinov et al., 2006; Akgün & Türk, 2010). They are formed as a result of superposition often conditioned by additional anthropogenic pressures. This kind of analysis is an unavoidable part of the strategy for the spatial development of some territory. Separately, this approach presents a real base for the development of a contemporary method for managing natural disasters. This research can be useful for all land use management activities including land use planning, construction of residential and industrial objects, infra-structure and waterworks, making spatial development strategies, and assessing the influence on the environment (Lateltin et al., 2008; Dragićević et al., 2009a)

Landslides are a significant natural hazard within the territory of Serbia (Dragicevic et al., 2011). Because landslides cover a large area of the territory of Serbia, they demand complete analysis. Previous studies in the north part of the Kolubara River Basin (Gavrilović, 1990) identified and proclamated erosion zones (Kostadinov & Stefanović, 2005).

Numerous historical data have been collected on the activation of large landslides in the Kolubara

Basin (Lazarević, 2000). The frequency of landslide activation on the territory of Serbia, and thus in the Kolubara Basin, is especially high during the spring. This is because the soil is saturated with water from the thawing of snow cover, and the characteristics of the pluviometric regime are such that the maximal quantity of rainfall is also present in the spring (Dragićević, 2001). A large number of landslides on the territory of Serbia, particularly in the Kolubara Basin, were activated during the spring of 2006 (Milošević et al., 2006). The abundance of landslides initiated the creation of landslide occurrence maps and stimulated research studies focused on the protection from natural disasters (Dragićević et al., 2009b; Dragićević et al., 2010).

Because there is not currently a landslides data base of the territory of Serbia, which is necessary for any land use planning purpose, this paper attempts to determine the areas susceptible for landsliding. Determining potential areas susceptible to landsliding presents the first, the most economical and the most important phase in the struggle against eventual consequences and one of conditions for efective and efficient risk control of damage caused by natural hazards (Milojković & Mladjan 2010).

The multi-criteria analysis for determining the areas potentially at risk for landslide processes was not carried out by past studies. This paper presents the first assessment for the landslide susceptibility zonation in Kolubara river basin in Serbia. The relations between the geological and geomorphological characteristics of this area are particularly important and can serve as a model for compilation of a landslide cadastre for the territory of Serbia.

2. GEOSPATIAL CHARACTERISTICS OF THE KOLUBARA RIVER BASIN

The Kolubara River Basin encompasses the western part of Serbia and covers 4.12% of Serbia's surface area (Fig. 1). The basin has an irregular quadrangle shape, and the distance between the farthest western point ($19^{\circ}30'$ E) and the farthest eastern point ($20^{\circ}35'$ E) in a roughly west-east direction is 81.2 km. The distance between the farthest northern point ($44^{\circ}40'$ N) and the farthest southern point ($44^{\circ}05'$ N) in a north-south direction is 64 km. The highest point in the drainage basin is at 1,346 m, and the lowest has altitude of 78 m.

The Kolubara River is the last large tributary of the Sava River. It is formed from the joining of the Obnica and the Jablanica rivers at ~195 m altitude. The Kolubara River is classified as a middle-sized river in the territory of Serbia according to the flow length (86.4 km) and the basin surface (3,641 km^2).

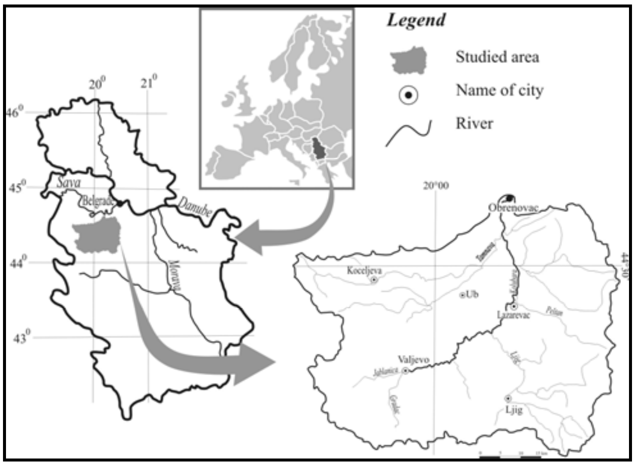

Figure 1. Location map of the studied area.

The Kolubara River covers a significant part of western Serbia and flows through the different parts of terrain. This diversity is reflected in geologic structure and age of some parts of the basin, as well as in the geotectonic complexity of the terrain through which the river flows. The drainage basin is built of Mesozoic and Cenozoic age igneous and sedimentary rocks and of Paleozoic metamorphic rocks.

Based on rainfall data from 27 rain-gauge stations in the Kolubara Drainage Basin, the maximum rainfall occurs in June at 25 stations; the maximum is in May for only two stations. The Kolubara Basin has a continental-pluviometric regime that is characterised by a maximum rainfall at the beginning of summer and a minimum rainfall in the winter. The average annual rainfall in the Kolubara River Basin from 1925 to 2000 was 722 mm.

3. GEOTECTONIC FRAMEWORK AND GEOLOGICAL SETTING

Until recently, this area has been geotectonically considered as part of Sumadija and Internal Dinarides structural-facial zones (Andjelković, 1978; Andjelković & Nikolić, 1980). Currently, it is adjoined to the Jadar Block terrain and the Vardar zone composite terrain (Karamata & Krstić, 1996) (Fig. 2a). The research area is in a complex geotectonic setting north of the large ophiolitic complex of Maljen and Suvobor in western Serbia. The underlying ophiolitic mélange was formed due to the closure of the oceanic area during the Late Jurassic to Early Cretaceous (Schmid et al., 2008). The eastern parts of the Vardar zone closed in the Late Juassic, but the western belt closed in the Late Cretaceous (Karamata & Krstić 1996). Recently published data for outcrops of inter-lava calcareous pelagic sediments from northern parts of the Vardar zone western belt indicate that oceanic crust still existed within this belt prior to final closure of the Tethys by the end the Cretaceous (Grubić et al., 2009). The Jadar Block is considered as an exotic body pushed into the Vardar Zone during the Late Cretaceous (Karamata et al., 1994).

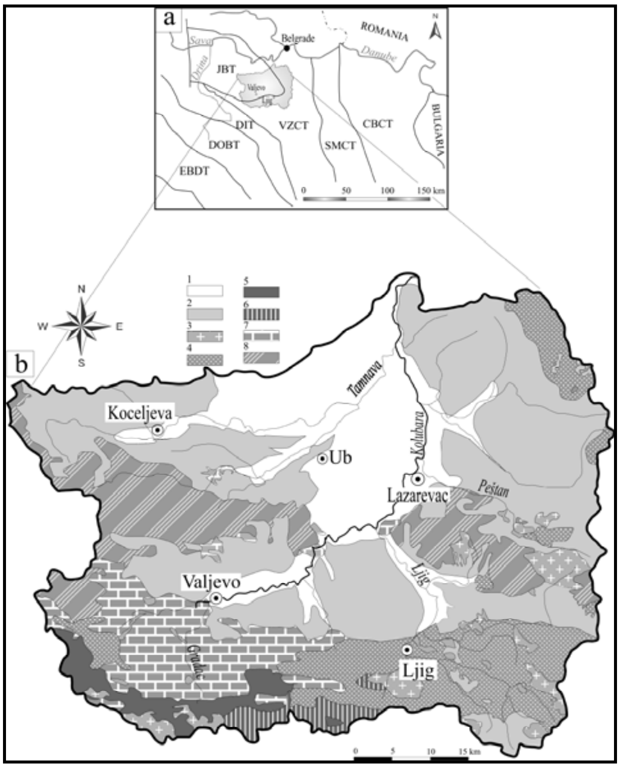

Figure 2. (a). Terranes of central and western Serbia as part of Balkan peninsula (Karamata & Krstić, 1996): CBCT-The composite terranes of Carpatho-Balkanides; SMCT-The Serbian-Macedonian composite terrane; VZCT-The Vardar zone composite terrane; JBT-The Jadar Block terrane; DIT-The Drina-Ivanjica terrane; DOBT-The Dinaric Ophiolite Belt terrane; EBDT-The East Bosnian-Durmitor terrane. b). Simplified and modified geological map of the researched area based on the Basic Geological Maps of Former Yugoslavia: sheet Obrenovac, 1:100 000 (Filipović et al., 1976), sheet Vladimirci, 1:100 000 (Filipović et al., 1967) and sheet Gornji Milanovac, 1:100 000 (Filipovic et al., 1971).1-Quaternary deposits; 2-Neogene sediments; 3-Cenozoic complex of various igneous rocks; 4-Cretaceous flysch and clastic sediments; 5-Jurassic diabase-chert formation; 6-Jurassic ophiolitic complex; 7-Triassic carbonate sediments; 8-Paleozoic metamorphic formation.

The oldest deposits within the Kolubara Basin are represented by a series of Paleozoic metamorphic rocks of psammitic-pelitic character (Fig. 2b). This formation is composed of arenites, siltstones and argillaceous schists (Filipović et al., 1994) with olistoliths of Devonian and Carboniferous limestone (Pesic, 1982; Filipovic & Pesic, 1988). The Mesozoic sedimentary cover is composed mainly of Triassic limestone and dolomite. The Jurassic consists of ultramafic massifs of Maljen and Suvobor and a diabase-chert formation (sandstone, chert, conglomerate, diabase, gabbro, serpentinite) exposed throughout the Vardar zone western belt. The ultramafic massifs of the Vardar zone western belt gradually change in composition northwards from depleted spinel lherzolites to depleted harzburgites (Robertson et al., 2009). These bodies probably originated in a back-arc spreading centre (Bazylev et al., 2009). The ophiolites are unconformably overlain by Late Cretaceous flysch precisely dated as Late Senonian-Paleogene (Ustaszewski et al., 2009). Additional components of the Kolubara basin are large bodies of granitoid rocks of different ages and settings. The first is dated at 20 to 17 Ma (Bukulja Mountain granitoids pluton) and is related to tectonomagmatic events controlled by the early extensional phases in the opening of the Pannonian basin (Cvetković et al., 2007). The second is dated at 18 to 15 Ma (Cer Mountain granitoids pluton) and is assumed to be post-collisional in origin (Knezević et al., 1994; Pamić et al., 2002). Prelević et al., (2005) recognised them as ultrapotassic rock groups of lamproites. Neogene sediments have a large distribution. They belong to the marine, brackish and lacustrine formations represented by clays, conglomerates, sandstones and marlstones. Quaternary beds have the largest extent within the major river courses, and they consist of loess, loessoid clay, gravel, and sand.

4. RESEARCH METHODOLOGY

A perfect assessment method for landslide susceptibility does not exist (Ercanoglu & Gokceoglu, 2002). Within the Kolubara River Basin, we define a "landslide susceptibility zone" (LSZ) as the area of possible or probable short-term evolution of an existing landslide or a group of landslides with similar characteristics (Reichenbach et al., 2005) identified from the topographical and geological maps or observed in the field. The proposed method complies with the existing and widely accepted definitions of landslide hazard (Varnes, 1984; Guzzetti et al., 1999a, 1999b). Landslide susceptibility zones were identified based on local topographic, morphological and geological settings, and data about the landslides presence that were identified in the study area. The heuristic method is empirical and subject to various levels of uncertainty but has proved to be a reliable and cost-effective method that allows for detailed and comparable assessments of landslide susceptibility. Quantitative geomorphological analysis of causal factors, including hypsometry, vertical dissection of relief, and slope angles of terrain, was also carried out.

The following three steps were followed to develop a landslide susceptibility map for the Kolubara River Basin:

1) The first step of the research was to create a landslide inventory map to obtain the basic data of recorded landslides. Analysis of the occurrence location, geological and geomorphological characteristics, and the morphometric characteristics was conducted for all the landslides. These analyses revealed a pattern in the landslide field location and the basic causal factors (geological setting, hypsometry, slope angle and vertical dissection of the relief).

2) A multi-parameter analysis was performed as the second step in the research. After detailed geological, topographical and quantitative geomorphological analysis (the maps of vertical dissection of the relief and terrain slope angle), overlapping the layers with correspondingly terrain characteristics, and application of the GIS software, some potentially endangered terrains were singled out (Kostadinov & Stefanović, 2005). All the surfaces that did not fulfil the conditions for the occurrence of the slope processes according to their lithological structure were excluded by the method of elimination (Lazarević, 2000; Milošević et al., 2006; Jelinek & Wagner, 2007; Dragicevic, 2007; Farrokhzad, 2011). If the relief dissection is expressed with the significant angles of terrain slope, and lithologic structure and land use are such that real conditions for the occurrence of landslides exist, then all the factors for landslide manifestation on topographic surfaces are realised (Cardinali et al., 2002; Clerici et al., 2002, 2006; Dragicevic et al., 2007; Kanungo et al., 2008; Dragićević et al., 2009a). Parallel analysis of the quantitative geomorphologic maps and selected lithologic components helped to define potential landslide areas (Akgün & Türk, 2010).

3) In the third step of the research, field mapping was conducted to confirm or reject former statements, and entry of this data on the surface maps was performed. The method of fitoindication was used in addition to the visual collection of data on the terrain morphology, and the support offered by methods and devices such as aerial photos, remote sensing images or GPS. Fitoindication has already been proved applicable for geomorphological landslide research. The application of technical factors for identifying landslides meant registering deformation and cracks on residential objects, roads, and supporting walls.

All the areas in the Kolubara Basin in which some active and suspended landslides exist according to the existing documentation, as well as the terrains which have all conditions for the occurrence of the landslides (the areas at risk of landslides) were mapped according to the aforementioned extensive preparations and field researches. Such prepared material was the base for singling out the analysis of spatial distribution of landslides depending on geological and geomorphological characteristics of the terrain.

5. THE RESULT ANALYSIS

Landslide occurrence is largely a function of the interaction of natural conditions such as unfavourable lithology, stratigraphic sequence, structural and geomorphological setting, earthquakes, and rainfall. The emphasis of this paper is on the influence of the geologic composition and geomorphologic characteristics of the landslides in the Kolubara Basin. The analysis in this study, therefore, only depends on the topographic attributes of the region such as elevation, vertical dissection, slope gradient and lithology (Ayalew et al., 2004). A discussion of these parameters with regard to their effect on the process of landslide is given below.

Certain characteristics of the relief represent one of the basic conditions for the occurrence of the slope sliding processes. The influence of the relief on the slope process is most powerful when the height difference is considerable and when the inclination of the surface is large. Therefore, it is very important to do a hypsometric analysis, as well as to analyse the vertical dissection and the inclination of the topographic surface. This presents the core of quantitative geomorphologic analysis. To assess the effect of altitude on landslide distribution, we classified the elevation map of the project site into 9 categories on a 100-m basis. Then, we calculated the area with landslide potentials for each elevation class.

A hypsometric map is the starting point for analysis of terrain that is potentially at risk of the slope processes, especially because the upper edge of Neogene sediments in Serbia is 420 to 450 m. If the largest number of landslides and the highest intensity of erosion on the territory of Serbia are present in the Neogene sediments, then making the hypsometric map is absolutely justifiable. The highest altitude of this geologic formation in the Kolubara Basin does not exceed 450 m. Terrain inclination and the slope processes are the causes for the occurrence of the landslides and high-intensity soil erosion. From the total surface at risk of the landslides (243.75 km^2) in the Kolubara Basin, 198 km^2 or 81, 4% is distributed at the height zone from 100 to 400 m (Fig. 3).

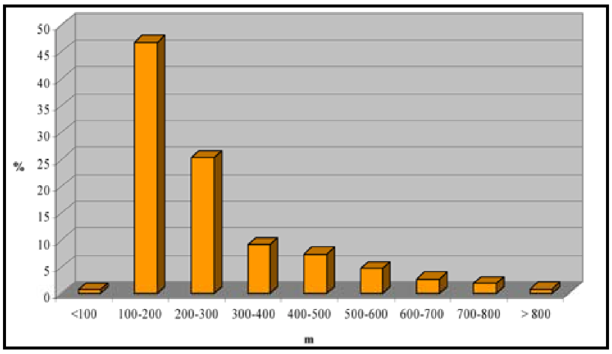

Figure 3. Histogram illustrating percentage of area at risk of slope processes and relation to height zones

Contrary to hypsometry, which presents an indirect indicator of the distribution of the areas at risk of landslides, vertical dissection and terrain inclination (relief fall) directly determine spatial distribution of the landslides and the erosion potential in the Kolubara Basin (Fig. 4).

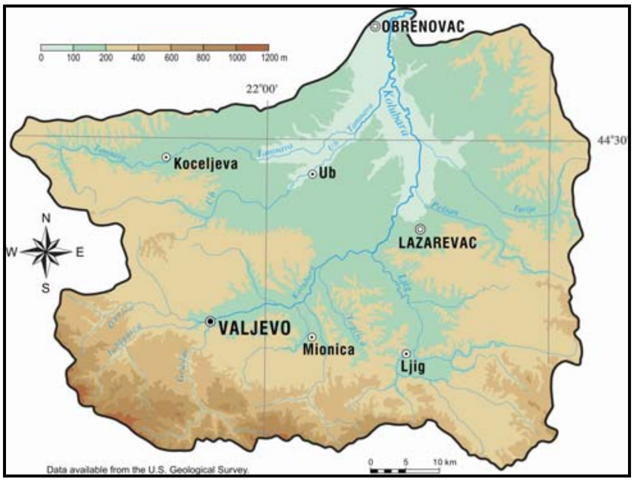

Figure 4. Hypsometric map of the Kolubara River Basin

Vertical dissection of the relief presents potential energy of certain parts of the topographic surface defined as the difference between the highest and the lowest points. There are different opinions about the name, significance and the influence of this relief parameter on the intensity of the recent process of landsliding. Vertical dissection of terrain can have only approximate significance as an indicator of predisposition of the terrain for the occurrence of the erosive and accumulative processes. The process of sliding is characteristic of wavy and stair-like types of slopes, and it is important to mention that its shape indicates the potential possibility for the occurrence of the landslides. It is clear that, with the analysis of the slope morphology and its angle of slope, some geomorphologic processes can be predicted and hazard occurrences can be avoided (Tab. 1).

Table 1. The slope angles in the Kolubara Basin

The terrain inclination [°]	The basin surface [%]
0-5	40.0
5-10	32.7
10-15	19.0
15-20	6.0
20-25	1.8
> 30	0.5

The effect of slope on landslides is widely documented by Lee & Min (2001) and Dai & Lee (2002). As far as gradient is concerned, six classes of slope angles were established, and the corresponding landslide densities were calculated. The slope angle of the topographic surface presents one of the basic factors for the occurrence of landslide.

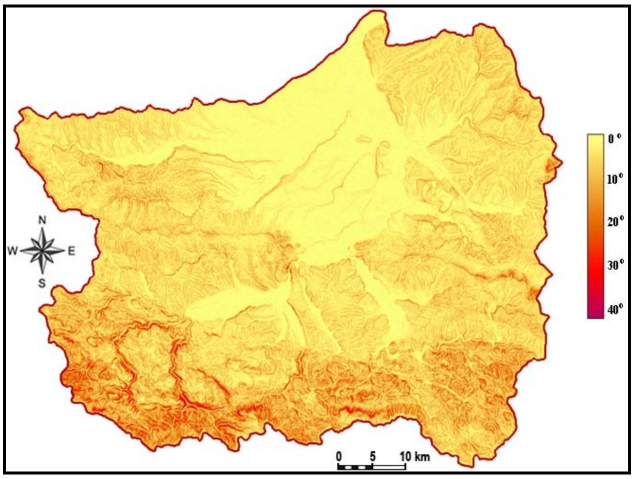

Figure 5. Slope angle map of the Kolubara River Basin

Research in the Kolubara Basin showed that landslides can occur on slopes less than 5°, but they are most frequent on slopes greater than 5°. For the formation of landslides on the lower slopes, the important role is the inner structure, i.e., the failure of layers and the size of the failure in the direction of the slope inclination. In the case of large inclination of the topographic surface (more than 20°), landslides can occur in the horizontal layers of rocks as well as on the inclined layers. This observation is opposite to the direction of the failure of the topographic surface (Fig. 5).

There is a general consensus that high probability of failure exists when at least one of the slope curvatures is concave because of the possibility for groundwater concentration in a deep soil stratum. Many researchers agree that landslides on convex topographic surfaces need a long time to develop because the slope geometry forces water to drain away from the site. It was observed that landslides occur both on convex and concave slopes in the study area. In fact, there was no difference in landslide densities between concave and convex profile curvatures, and a big influence on such condition is lithologic structure.

Asymmetric location of Lower Kolubara valley by the eastern side of the floor of the Lower Kolubara Basin is due to the location of the Kolubara scissor fault of Post Pontian and Quaternary age. The Kolubara continually undercuts the right valley side (slide plane), and a lot of landslides have been formed at that place.

To establish the distribution of the landslides in the Kolubara Basin depending on the lithologic composition, we joined some of the lithological components into lithological complexes. Eight main lithological complexes were identified, and then, the areas at risk for landslides were shown (Table 2).

6. DISCUSSION

From the table above, it can be seen that most of the areas susceptible to landslides are in the Neogene sediments. No such occurrences are found in the alluvium and the complex of ultramafics and serpentinites.

Although alluvium covers considerable area (840 km^2, which is 23% of the Kolubara Basin) there are no conditions for the occurrence of landslides in it, so in this lithologic unit, their occurrence was unexpected. However, contrary to the alluvium, serpentinites are very susceptible to the occurrence of this process, but it has not been registered in this lithologic component in the area of the Kolubara Basin. The main reason for this is the extremely small surface that they cover on the research area, although all other conditions for their occurrence are fulfilled (dissection of the relief, significant inclinations of topographic surface, enough water and pluviometric regime of the rainfall).

The Neogene sediments include 1303.16 km^2 (36% of total surface), where 191.66 km^2 is susceptible to the landslide processes, which presents 78.62% of the total surface endangered by landslides in the Kolubara Basin. The landslides are characteristic for this lithologic unit group, and they mostly occur on the sides of smaller river valleys that dissect hilly Neogene complexes. The zones of the Neogene sediments are clearly noticeable in Fig. 6, and they are easily recognisable by the large number of landslides.

There are numerous reasons for the occurrence of landslides on the Neogene terrains of the Kolubara Basin. The Neogene sediments have different degrees of consolidation. Marly clays and marls of Sarmathian, Pannonian and Pontian are mostly present. Sarmathian clays are characterised by a thin, stratified structure where clayey and also have well-consolidated carbonate masses.

Table 2. Landslide distribution in different lithological composition in the Kolubara Basin

Lithologic complex		The surface of complex [km^2]	The surface of complex at risk of landslides [km^2]	The share in the total surface at risk of landslides [%]
1.	Quaternary deposits	840.10	0.00	0.00
2.	Neogene sediments	1303.16	191.66	78.62
3.	Cenozoic complex of various igneous rocks	135.65	2.16	0.89
4.	Cretaceous flysch and clastic sediments	426.49	24.68	10.13
5.	Jurassic Diabase-chert formation	102.93	9.06	3.72
6.	Jurassic ophiolitic complex (ultramafics and serpentinites)	58.05	0.00	0.00
7.	Triassic carbonate sediments	343.57	0.97	0.40
8.	Paleozoic metamorphic formation	431.05	15.22	6.24
Total		**3641.00**	**243.75**	**100.00**

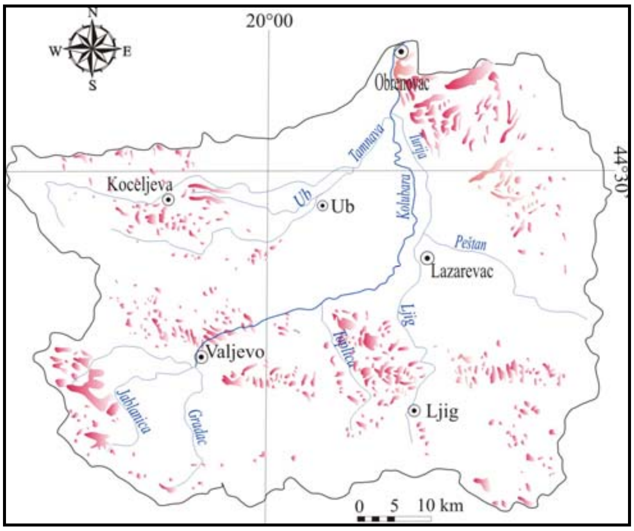

Figure 6. Map of landslide occurences in the Kolubara River Basin.

The aforementioned characteristics of the Neogene clays are the main cause of numerous occurrences of landslides, especially up to a depth of 10 to 15 m. Geologic construction of the slope in the hilly terrain of the Neogene basin was made using the detailed analysis of terrain and borings on the right bank of the Kolubara River at Mislodjin. Four to five-meter thick eluvial-deluvial formations lie over ten-meter thick layers of overconsolidated weathered clayey and clayey-marly sediments, and below them are compact marly clays and marls (Dragicevic, 2007). On the whole territory under the Neogene, the lithologic structure is such that the components with expressed functions of hydro-geologic collectors and isolators alternate, as well as water porous sediments. Potential possibilities have been realised for the occurrence of the sliding at the contact of these sediments.

There are numerous large and complex landslides on the right side of the Lower Kolubara. They cover entire slopes, and their depth often exceeds 10 m. Over 70% of this terrain is covered by landslides. The sliding process occurred within upper, modified parts of clay and marly clays as well as the deluvial sandy and sandy-silty clays that lie over them. In the basement of these loose and relatively porous deposits are compact and nearly impermeable marly clays and marls. Deep landslides are mostly formed above this surface.

In the Cretaceous flysch and consolidated clastic rocks, the process of sliding can be expected on 24.68 km^2, which presents 10.13% of the established surface at risk of this process. This complex in the Kolubara Basin covers a 426.49 km^2 area.

Because of its big discrepancy in the lithologic and facial terms and because of the effect of different exogenic factors, the complex of flysch sediments in the Kolubara Basin is characterised with significant cracks at different depths. Thick weathered zone (2-10 m) are formed with their disintegration, divided with the systems of cracks of different genesis, and form covers. From the hydrologic aspect, having the layers with the abilities of collectors, they can be initiators of the sliding process. The landslides are less frequent in this complex, but when they occur, they are very significant according to their scope and harmful consequences. They are developed in relatively thick and often moist superficial cover that moves over a waterproof surface. Such occurrences are connected to the northern slopes of Rajac Mountain and to the zones of the Ljig flysch (south and south-eastern parts of the Kolubara Basin). It was concluded based on the research of Dragicevic (2007) that oxidation and hydration processes are very important for the genesis of the landslides. Namely, it has been established that crystals of gypsum and anhydrite occur in the lower part of the marl's weathered zone, and they formed as a result of pyrite disintegration. As a result of the action of water and oxygen, the pyrite dissolves on the limonite and sulphur acid, and the sulphur acid causes the formation of anhydrite in reaction with calcite. In the process of hydration, anhydrite turns to gypsum. The gypsum presents a sliding plane over which weathered zone moves. Most landslides in the flysch terrains are connected to this contact zone.

Most surfaces under igneous rocks are not susceptible to the occurrence of landslides, but here in the complex mentioned above, granites, andesites, dacites, diabase, gabbro, volcanic breccia, agglomerates, tuff-breccia, and ignimbrates are included. Considering the fact that individual components of this complex (volcanic breccia and tuff) form the disintegration crust that can be caught by the sliding process, it is clear why the development of the surfaces mentioned that are prone to this process occur (2.16 km^2).

Based on the structural-texture characteristics, it is possible to divide igneous rocks according to the degree of resistance to the effect of erosion. Granites are more dominant in the eastern part of the Kolubara Basin (spring part of the Ljig and Pestan). The process of their disintegration is very slow and has little importance in the process of forming landslides. Granodiorites, basalts, and other compact magmatic rocks also have low amounts of disintegration. Dacite-andesite tuffs can be found in the eastern part of the Kolubara Basin. The basic characteristic of this rock type is that they form pedologically very poor ground with poor vegetation, with the result being the dominant effect of erosive processes.

Jurassic diabase-chert covers the utmost south-eastern part of the Kolubara Basin (the spring part of the rivers Jablanica, Gradac and Ribnica). It has very low water porosity, which contributes to the increased dynamic of this environment, i.e., gravitational movements. Because this rock formation occurs in areas of high potential energy of relief with steep slope angles, increased intensity of exogenic processes can be expected on this area. Owing to the basic structural-texture characteristics of this rock type, the processes of sliding are more expressed. The largest number of complex and large landslides connected to this geological environment occur surrounding Valjevo. They are mostly conditioned by the movement of superficial deposits (deluvial-eluvial) over the water-impermeable base rocks.

Jurassic serpentinites and ultramafics typically have lower resistance than the previously mentioned rocks and appear in the Kolubara Basin on several locations. They are susceptible to the temperature destruction that forms a thick clastic material. The thickness of the clastic material ranges from 0.5 m to 3 m, and it is mostly by the action of exogenic forces.

Triassic carbonate rocks do not possess the necessary conditions for the occurrence of landslides. However, such registered characteristics on them are conditioned by the existence of the deluvial deposits of various depths and at the point of contact with lithologic units that are susceptible to the analysed process.

The carbonate rocks in the Kolubara basin cover about 9.4% of its total surface. From the aspect of the development of the slope processes, they do not have great importance in the development of the landsliding except for the occurrence of rock creep and rockslide. However, at the contact of limestone and lithologic components with the expressed potential of sliding, a part of the moved material may catch and cover carbonate rocks as well, i.e., it may move carbonate clasts. Such occurrences have happened in the Kolubara Basin.

Approximately 6.48% of the total sliding surfaces in the Kolubara Basin (15.22% of the total surface of the complex) are in the complex of Paleozoic metamorphic rocks. This value in the diabase-chert formation is 3.72%, which comprises 9.06% of the surface of lithologic complex and is considerably higher than the previous case.

The landslides in the disintegrated schist can occur in the western and eastern parts of the Kolubara Basin. In the western part, Paleozoic schists cover the western and northern part of the Obnica Basin and the utmost western and south-western part of the Tamnava Basin (the whole spring section of the Ub River). In the eastern part of the Kolubara Basin, Paleozoic schists are affected by landslide processes. A disintegrated zone of various thicknesses was formed by disintegration of the schists (sandy and sandy-gravel structure). Disintegrated schist is very susceptible to sliding, and thus, landslides can form. The thickness of the eluvium is 2 to 3 m. Necessary conditions connected to the relief characteristics are also fulfilled in these regions. The presence of feldspar is 30% in metamorphic rocks, which emphasises the importance of the hydrolysis process on the chemical disintegration and the increasing intensity of landsliding.

7. CONCLUSIONS

According to previous studies (Lazic & Bozovic, 1995), 25% of the territory of the Republic of Serbia is potentially at risk for landslides and rock falls. On the integral vulnerability map of the natural hazards in the territory of Serbia (Dragicevic et al., 2011), landslide hazard zones are mostly developed on the slopes of Neogene basins made of heterogeneous sediment complexes, with frequent unfavourable interactions between the lithological compositions, complex hydrologic characteristics and unfavourable morphologic conditions. To verify the prior assumption, the Kolubara River Basin, which has a complex geological setting, was selected. It is extensively covered by Neogene deposits in various slope angles and also provides the landslide activities during the past period (during the spring of 2006, a large number of landslides was activated - see Fig. 7). The documented landslides are dominantly developed in the areas covered by Neogene deposits with slope angles from 4-20°.

The areas that are potentially at risk of landsliding and that have various geological settings and morphological characteristics are analysed in detailed using the applied methodology. A map of landslide risk in the Kolubara Basin was made to avoid these occurrences and to identify the terrains susceptible to such events. The results of the entire analyses and evaluation allowed us to divide the study area into five zones that are susceptible of landslides in western Serbia (the Kolubara River Basin). The zones are the following: 1) extremely low (Quaternary deposits, Jurassic ophiolitic complex, Triassic carbonate sediments, Cenozoic complex of various igneous rocks), 2) very low (Jurassic Diabase-chert formation), 3) low (Paleozoic metamorphic formation), 4) medium (Cretaceous flysch and clastic sediments), and 5) high (Neogene sediments).

Figure 7. The landslide in the Tamnava River basin

The results of previous investigations in the territory of the Ub district representing a small part of Kolubara River Basin (Dragićević et al., 2009a) and the observation of the entire basin have shown that the largest number of areas potentially at risk for landslide processes are distributed in Neogene deposits at slopes greater than 5º and at heights up to 450 m. Based on the results obtained in this study, it was found that 243.75 km^2 or 6.69% of the total area was prone to landsliding (Fig. 6). The Neogene sediments include 1303.16 km^2 (36% of total surface), where 191.66 km^2 is susceptible to the landslide processes, which presents 78.62% of the total surface endangered by landslides in the Kolubara Basin. If applied as a model for the entire territory of Serbia, the largest number of landslides is expected on 18.4% of the total surface of Serbia that is covered by Neogene deposits. In agreement with previous hypotheses, 83.20% of landslide hazard zones are below the altitude of 450 m, and 96.51% occur on slopes lower than 15º.

There is no landslide data base for the territory of Serbia. The results of this research are of great importance because they will speed up the compilation of landslide inventory map. Namely, singling out the areas potentially at risk gives priority to 17,1% of the total surface of Serbia up to 400 m altitude, at slopes from 5-15º, with a favourable geological setting (Neogene deposits) for landslides (Manojlović et al., 2004).

Because the majority of slope sliding processes are initiated by numerous influences, the methodology shown in this study of singling out areas potentially at risk enables a preventive way to avoid consequences. Determining landslide susceptibility zones is the first, most economic and most important phase in the struggle against the landslide processes and the beginning of the compilation of landslide hazard and risk management.

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