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Geohazard Assessment in the Eastern Serbia

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Abstract

The territory of eastern Serbia is characterized by a variety of igneous, sedimentary and metamorphic rocks formed through different paleogeographic developments. As a result of varied natural conditions, the region is vulnerable to various geohazards, such as earthquake, landslide, excessive erosion, flood, rockfall, cave collapse and subsidence. The occurrence of any geohazard depends on the intensity of the process causing it. An assessment of each type of hazard or combination of all hazards is necessary for this region of Serbia which accommodates major power-generation, industrial and mining facilities and has rich mineral resources. Depopulation of eastern Serbia reduces the ability of local communities to invest in the hazard control works. This assessment of the geohazards begins with the reference to the available seismic maps and proceeds with the research in the landslide, potential flood and excessive erosion hazards, then rockfall and rock collapse. Research results suffice to prepare a generalized geohazard map of eastern Serbia showing areas vulnerable to particular natural hazards and to estimate a total area endangered by hazardous processes. The purpose of this work is to locate and classify areas of potential hazards on which future protective actions may be based.

Keywords: *geohazard assessment, vulnerable areas, natural conditions, eastern Serbia*

Rezumat. Evaluarea hazardelor geologice in Serbia de Est

Teritoriul din estul Serbiei este caracterizat de varietatea rocilor magmatice, sedimentare şi metamorfice formate în urma unor evoluţii paleogeografice diferite. Ca urmare a condiţiilor naturale variate, regiunea este vulnerabilă la diferite hazarde geologice, cum ar fi cutremure, alunecări de teren, eroziune excesivă, inundaţii, căderi de pietre, surupări de peşteri şi subsidenţă. Apariţia unui hazard geologic depinde de intensitatea procesului care l-a cauzat. O evaluare a fiecărui tip de hazard sau a tuturor hazardelor este necesară pentru această regiune din Serbia care deține mari generatoare de energie electrică, amenajări industriale şi miniere şi are resurse minerale bogate. Depopularea estului Serbiei reduce capacitatea comunităţilor locale de a investi în lucrări pentru controlul hazardelor. Această evaluare a hazardelor geologice începe cu referirea la hărţile seismice disponibile şi continuă cu cercetarea alunecării de teren, posibile inundaţii şi riscuri de eroziune excesivă, apoi căderi şi prăbuşiri de roci. Cercetarea este suficientă pentru a întocmi o harta a hazardelor geologice generalizate din estul Serbiei indicând zonele vulnerabile la anumite riscuri naturale şi pentru a estima o suprafaţă totală pusă în pericol de hazarde. Scopul acestei lucrări este de a localiza şi de a clasifica zonele cu potențial de risc pe baza cărora se pot implementa acțiuni viitoare de protecție.

Cuvinte-cheie: *evaluarea hazardelor geologice, zone vulnerabile, condiții naturale, Serbia de Es*t

INTRODUCTION

The growing intensity and frequency of natural disasters that endanger global population gave rise to international cooperation in this sphere that intensified from 1990 when UN General Assembly proclaimed 1990-2000 period a decade of natural hazard control. To reduce the consequences of the ever greater natural disasters, regional and international efforts were felt necessary. In result, the UN General Assembly passed two Resolutions in late 2003: (A/RES/58/214: International Strategy for Disaster Reduction) and (A/RES/58/214: Natural Disaster and Vulnerability).

Many countries in the region and the world signed the 2005 Hyogo Declaration (International Strategy for Disaster Reduction Program 2005-2015, www.unisdr.org), which inter alia promotes organization of agencies at regional, institutional and national levels for monitoring and acting to reduce the impacts of natural hazards on property and population. Control of natural hazards and disasters are given much consideration in the UN, with the result of numerous projects financed from EU funds (INTERREG III B CADSES NP PROJECT).

Natural hazards on the territory of Serbia are various and vulnerability to them is not uniform but depends on the type of hazard and potential damages. Natural conditions of eastern Serbia are varied and require a complex study of geohazards in the region. Hence, the objective of this paper is to individualize and research geohazard areas and to assess their vulnerability to hazards. Major potential geohazards are earthquake, landslide, rockfall, flood and torrent, excessive or high potential of erosion, cave collapse, all resulting from natural processes that directly or indirectly threaten people, property and terrain itself.

In addition to natural processes, geohazards may result from human activities related to exploitation of mineral resources. In the region of petrologic diversity, numerous surface and subsurface mines of eastern Serbia generate conditions for geohazards. This work will designate zones of human activities in which geohazards may be expected.

This contribution is important for presenting the distribution of geohazards in the selected region as the first step towards the control of natural disasters and prevention of their consequences. Given the conterminous position of the region with Romania and Bulgaria, the research exceeds the national and acquires regional and even international significance.

Geospatial characteristics

Eastern Serbia occupies an area of 17,060 square kilometres, or 17.3% of the Republic of Serbia territory (Table 1). It is bordered by the Danube on Romania in the north, Bulgaria in the east, by the rivers Velika Morava and Juzna Morava in the west, and the Nisava watershed in the south.

Table 1

General characteristics

Study area, P	17060.15 km^2
Perimeter, O	906.82 km
Maximum altitude	2169 m
Minimum altitude	28 m
Mean elevation, N_{mn}	455.5 m
Mean altitudinal difference, D	2141 m
Mean slope of area, J_{mn}	9.06º
Drainage intensity, G	1.3 km/km^2
Mean precipitation amount (1961-1990)	768 mm
Average air temperature (1961-1990)	8.86º C

The entire territory gravitates to the Danube, the lower base of erosion, and major rivers (Velika Morava, Nisava, Timok, Mlava, Pek) are either its primary or secondary tributaries.

METHODOLOGY

A proper assessment of the geohazard vulnerability of eastern Serbia, or of the limitations for land use, must be based on a comprehensive analysis of natural conditions which are the basic factor in producing geohazards on the territory. This was the approach to the work that resulted in the Potential Geohazard Map with designated geohazard zones. The map is particularly important for the fact that previous studies of natural hazards on the European and world scale were without relevant information about the territory of Serbia.

This work focuses on scientific knowledge and achievements in recognition and prediction of geohazards, preventive action and adequate protection of people, property and environment.

The description of geology is based on the Geological Map of the Carpatho-Balkanides region between Mehadia, Oravita, Niš and Sofia at the scale 1:300,000 (Kräutner and Krstić, 2003). The modifications and additions in the Map are based on the Geological Map of Serbia at scale 1:2,000,000 (Dimitrijević, 2002) and compilations from different publications. In order to facilitate the study of the influence of geology on the development of geohazards, geologic complexes are divided and considered from the aspect of the potential erosion. After a detailed study of geological and topographic maps (vertical variation of land configuration maps, land surface slope-angles maps), the territory is divided into the potential erosion areas. The assessment of vulnerabilities to potential cave collapses, landslides and other rock or soil mass movements is based on the knowledge of the engineering-geological and geomorphologic characters of the terrain, and the knowledge of the effects of external factors on the geological environment. Seismic hazards were assessed using the existing seismic maps (Vukašinović, 1987). Potential landslides, rockfalls and intensive erosion were assessed using respective methods (Guzzetti et al., 1999; Dragićević et al., 2007, 2009, 2010), reference maps: the Erosion Map of Serbia (Lazarević, 1983) and the Geomorphologic Map of Serbia (Menković et al., 2003).

Field research data (Manojlović and Dragićević, 2000; Manojlović et al., 2003; Dragićević et al., 2009) were used in establishing the intensity of recent geomorphological processes.

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The complex study of natural conditions in eastern Serbia produced the most important result of the research work – the Geohazard Vulnerability Map of its territory showing the geohazard vulnerability zones. The recent state of impact by natural hazards in Serbia, based on the mentioned maps, is combined into a unified map, which shows the areal distribution of different hazards believed to exert a limiting influence on the regional land use for development. Thus, the areas threatened by particular natural hazards are designated and their respective surface and proportion of the territory of Serbia are calculated.

Natural conditions as a factor of geohazards

The complex geologic nature of eastern Serbia is the main factor of the geohazard threat in the region. Mosaic geologic pattern and marked vertical diversity of the relief account for the varied climate and hydrogeology. Depending on the complexity of the given natural conditions, each region on the Earth surface is particular in character and tendency to some natural occurrences and processes, consequently to the threats by various natural hazards. The region of eastern Serbia has natural conditions complex enough to give rise to geohazards.

The facts that natural conditions are potential sources and that hazards are the limiting factor for a planned land development justify their consideration from different aspects. Analysis and quantification of natural conditions anywhere on the Earth are impossible without the proper knowledge and understanding of natural processes. This is because natural conditions result from both natural processes and human activities which directly cause and activate natural hazards in the area. Consequently, the knowledge of the distribution of natural conditions and of the process intensities is the first step to a proper control of geohazards and prevention of their consequences. A geohazard activity may in extreme events greatly endanger human life and property, in which case it is taken for a natural disaster.

An analysis of natural conditions is considered to include the recent state formed by different natural processes and human activities. A change in the intensity of any process may disturb the natural balance and is both the cause and the consequence in a point of time and an area.

Geological and geomorphological setting

The knowledge of regional geology is very important for planning and protection from natural hazards. The lithologic composition, age and structural pattern and the effect of other factors determine the possible manifestations of geodynamic processes and consequent geohazards. Dominant geomorphic processes are related to the geologic character (e.g. frequent landslides, heavy erosion, cave collapse are characteristic of carbonate rocks in the areas built of Neogene deposits). In order to establish the distribution of geohazards in eastern Serbia in relation to lithology, we grouped lithologic units into lithologic complexes, because their behaviour to exodynamic processes is different (in intensity of weathering, washout, etc.).

Eight major lithologic complexes are recognized, then each complex is studied for the types of geohazard threat (landslide, rockfall, cave collapse, etc.). In addition, structural features are studied for an assessment of the seismic hazard.

The tectonic setting of eastern Serbia is complex, composed of structures that belong to the east-Serbian segment of the Alpine system and to Romania. The units are from west to east the following: Serbian-Macedonian, Supragethic, Lower and Upper Danubian (Krstić et al., 1996; Dimitrijević, 2002; Kräutner and Krstić, 2003) (Fig. 1a).

Geological framework is deliberately simplified to show only major petrologic complexes, some of which have played dominant role in the source and distribution of geohazards (Fig. 1). These are:

- Precambrian and Lower Paleozoic metamorphic rocks, mostly complexes of crystalline schist, amphibolite, gneiss, mica schist and quartzite, susceptible to thermal disintegration and consequent formation of thick deposits of debris by sliding, rockfalling, rapid gully and slope-washing.
- Precambrian ultrabasic rock massifs (dunite and hartzburgite) and serpentinite.
- Igneous rocks: older Upper Proterozoic/ Cambrian gabbro, Caledonian and Variscan granitic rocks, and younger Upper Cretaceous/Paleocene plutonic complexes of granodiorite, diorite, andesite and dacite.
- Upper Paleozoic and Mesozoic sandy carbonate flysch. The complex of flysch deposits, highly varied in lithology and facies, has properties unsusceptible to geohazards. Weathering products of these rocks form blankets that may start a sliding process. Occurrences, additional to slides, are rill and other forms of erosion, even by torrents.

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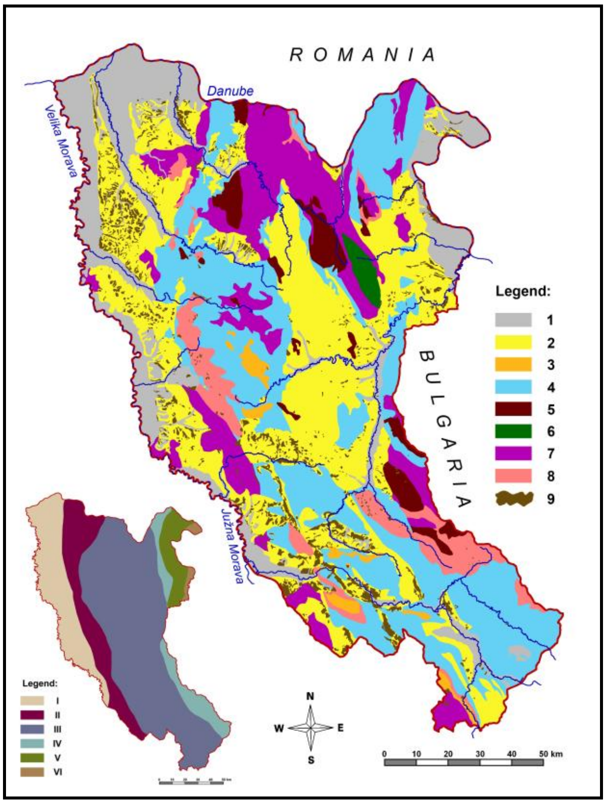

Fig. 1. Lithology as a factor of landslide distribution Simplified geologic outline of eastern Serbia (1) and schematic map of tectonic units (1a). In (1): 1. Quaternary cover; 2. Neogene deposits; 3. Mesozoic complex of carbonate rocks; 4. Upper Paleozoic and Mesozoic clastics; 5. Flysch; 6. Igneous rocks; 7. Precambrian ultrabasic rock massifs and serpentinites; 8. Precambrian and Lower Paleozoic metamorphic formations; 9. Landslides areas. In (1a): I. Serbian-Macedonian unit; II. Supragethic unit; III. Gethic unit; IV. Upper Danubian; V. Lower Danubian; and VI. Moesian plate.

- Upper Paleozoic sandstone, conglomerate, arkose and accessory Jurassic coal shale are clastic deposits (Table 2).
- Thick Mesozoic carbonate rocks (limestone and dolomite) are susceptible to chemical decomposition, corrosion, detachment and fall. Corrosion wears outer and inner parts of calcareous rocks forming surface and subsurface karst features prone to collapse. Limestone is in the group of rocks highly susceptible to temperature disintegration. Rockfalls are common where limestone is dominant.
- Neogene conglomerate, sandstone, breccia, marl, shale post-tectonic deposits readily disintegrated and producing thick loose covers. Owing to a clay constituent, most of landslides in Serbia occur in Neogene deposits. Surface and subsurface erosion evolves in places of dominantly coarse, slightly cemented sand constituent.
- Quaternary cover.

An analysis of recent relief characteristics as a source of geohazards is complex and requires designation of major and representative ones for the set target. The relief impacts have been considered in relation to the morphogenic, morphodynamic and morphometric parameters. This, with the aid of numerical analysis, is the basis for a proper assessment of the relief impact on the occurrence of geohazards.

Table 2
Areas of lithologic complexes

Geologic complex	Area (km^2)	Total percentage
Quaternary	2860.19	16.77
Tertiary	5585.84	32.74
Flysch	214.37	1.26
Mesozoic carbonate rocks	4510.13	26.44
Igneous rocks	586.21	3.44
Serpentinite	121.28	0.71
Metamorphic rocks	2244.44	13.16
Paleozoic and Mesozoic clastics	937.69	5.50
Total	**17060.15**	**100.00**

The relief parameters expressed in altitudes, vertical and horizontal slope diversity, are basic for consideration of the land configuration conditions and of their genetic and morphometric influence on the intensity of natural, particularly geomorphologic, processes and eventual occurrence of geohazards. A quantitative geomorphologic map has to be prepared before embarking on the selection of areas susceptible to erosion and deposition processes, or before establishing the erosion potential in an area (on the basis of "Erosion Potential Method" (EPM) (Gavrilovic, 1972).

Related to the regional geology and geomorphology, the territory of eastern Serbia may be divided into the areas of high, medium and low potential erosion. More than half the territory (66.41%) is in the group of low erodibility, and a smaller part (32.87%) is medium erodible.

Erodibility of landforms, however, should be correlated with other factors of physical geography. Designated areas of each natural factor overlap in the composite map of potential erosion.

Surface areas divided by altitude zones are divided into: 7.32% below 100 m, 13.65% from 100 m to 200 m, or 21% below 200 m, 42% from 200 m to 500 m, 31.72% from 500 m to 1000 m, and only 5.32% above 1000 m. The average altitude of the

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terrain is 455.5 m. The topographic map was the data base in the research of lands threatened by slope erosion, which is widespread in the region.

It is well known that certain relief characteristics represent one of the major conditions for the appearance of slope processes. Also, it is essential to carry out hypsometric analysis, as well as the analysis of "energy" and inclination of topographic surface, which at the same time present the core of the quantitative geomorphologic analysis. The hypsometric map presents the starting point in the analysis of terrain potentially at risk of slope processes, especially since the fact that the upper limit of neogenic sediments in Serbia is 420-450 m (Dragićević et al., 2009).

According to the relief characteristics of eastern Serbia (63% or 10740.5 square kilometers to 500 m), and the fact that Neogenic sediments include the surface of 5585.84 square kilometers (32.74% of the total area), slope processes as dominant geomorphologic processes on this territory are established.

Land surface inclination is one of the basic factors for geohazards. Surface areas divided by the slope angle are the following: 10907.3 km^2 (63.93%) to 10º, 4781.28 km^2 (28.03%) from 10º to 20º, and 1371.59 km^2 (8.02%) higher than 20º. The dominant area susceptible to landslide processes in eastern Serbia is on the slope angle from 5º to 15º, 73.8 %, which is according with the distribution of Neogene deposits (Table 3).

Table 3
Lithology and Potentially landslide areas

Rocks	**Area (km^2)**	**Percent proportion**
Quaternary deposits	57.42	7.98
Tertiary deposits	609.70	84.78
Flysch	1.72	0.24
Mesozoic carbonate rocks	9.55	1.33
Igneous rocks	1.65	0.23
Serpentinite	0.44	0.06
Metamorphic rocks	20.15	2.80
Paleozoic and Mesozoic clastics	18.49	2.57
Total	**719.12**	**100.00**

Climate conditions

While varied in many geographic aspects, eastern Serbia is not much heterogeneous in climate. Difference in the values of climate elements is more local than resulting from circulation processes in the atmosphere. The Karpatho-Balkan mountain range, the largest morphostructure of eastern Serbia, acts as a barrier between cold air masses from the north of Europe, especially from the Valachian depression, and warm humid masses from the west of Europe and the Mediterranean. The barrier effect is reduced, however, by infrequent coincidence of the air masses and the discontinuous height of the mountain range (only 5.32% above 1000 m), so that the exposure to either side is comparatively equal.

Major climate elements that directly or indirectly form hazards are precipitation and temperature. Divided by Živković (2005-a), roughly a third of eastern Serbia is between isohyets 600-700 mm and 700-800 mm, a fifth between isohyets 800-900 mm, and the rest (2340 km^2 or 13.4%) receives more than 900 mm or less that 600 mm precipitation. The area with more than 1000 mm occupies 737 km^2 or 4% of the territory. Average precipitation depth in the area is 768 mm for period1961-1990. Converted into the volume of atmospheric precipitations, eastern Serbia annually receives 13.4 km^3 of water.

The precipitation depth, on average, is the lowest (560-590mm) in SW, in the Niš-Aleksinac depression, and the highest (about 1500 mm) on Stara Planina peaks (Živković and Anđelković, 2004). The half-period 1991-2005 is characterized by much lower precipitation depths, when the area below the 600 mm isohyet was notably larger (500 mm in Niš and Negotin) (Anđelković, 2009). The pluviometric range had two maximum and two minimum mean amounts of rainfall: one maximum in late spring/early summer (May-June) and the other in late autumn (November); one minimum in early autumn (September) and the other in late winter/early spring (February/March). Snow discharges occur from November to mid-March at low altitudes, and from October to mid-April on mountains. Average depth of fallen snow recorded in meteorological stations ranges from 8 cm in Niš to 35 cm on Crni Vrh (highest zones in the region are believed to receive 50 cm of snow). Mean maximum snow cover is 20-30 cm in Timočka Krajina, 70-110 cm on Kučaj, and 110-150 cm on Stara Planina (Dukić, 1975).

Precipitations, extreme in intensity or duration, or lacking, which influence geomorphologic processes and consequently the physiognomy of the land surface or configuration, are important for the occurrence of hazards. Daily maximum is an important indication of the actual danger e.g. from flood, torrent, landslide, etc. The research data for central Serbia indicate that precipitations of only 25 mm and 50 mm respectively cause overflow of streams and large-scale floods. The threshold of intensive precipitation, an alert of serious danger in eastern Serbia is 40 mm in the south and 50 mm in the north (Anđelković, 2009), in western Serbia is

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30 mm (Dragićević, 2007); at that, it may occur any time of the year, though rarely in the end of winter or early spring. The absolute maximum values are recorded in Veliko Gradište (116 mm) and on Crni Vrh (136 mm). It should be said that vulnerability of the region depends on the interaction of all natural factors, not on the precipitation alone.

Hail falls any time of the year, commonly in May and June. In depressions it may fall once or twice a year, and more often in mountains (to four times on Crni Vrh). The number of hail fall days in the period 1991-2005 was 5 in V. Gradiste, 8 in Niš and Ćuprija, 14 in Dimitrovgrad, 15 in Negotin and 24 on Crni Vrh.

Unlike precipitation, air temperature has an indirect influence on geohazards, which is expressed in soil saturation in winter and drying in summer. An abrupt rise in air temperature in winter causes rapid melting of snow, torrents and floods in the former event, and rainless summer heat dries up soil in the latter. Both processes are well at work in eastern Serbia. The trend of the mean annual temperature rise is registered in Serbia from 1980, with highest rise in the eastern region. Annual rise for the period 1951-2005 was 1.8ºC/100 year in Negotinska Krajina and even 5ºC/100 year since 1990 (Popović, 2007). Floods from melting snow are more frequent in the last twenty years due to the alternating cold and warm intervals during winter and spring. Then, with the snow cover still on, temperature rises much above normal for the season and holds for 2-4 days or longer. The latest example was the Beli Timok flood in the town of Zaječar. First discharge occurred in December 2009, another in the end of February and successively continued into spring 2010. Similar events occur almost every year, mainly in the drainage basins of Timok, Mlava, Pek, and Resava. On the other hand, Timočka Krajina is exposed to long draughts in the rainless and hot summers. This area is rapidly expanding under the impact of draught, with the obvious continuous reduction of crop yields (Živkovic et al., 2005).

Hydrological conditions

The distinctive hydrologic features of the region are related to the position, orography, lithologic and pedologic character, vegetation and climate, each particular in itself. What is most important is the influence of calcareous rocks on both surface and subsurface waters. Karst of the Carpatho-Balkanides in eastern Serbia occupies somewhat more than 4510 km^2 or 26.44% of the territory. Karst aquifers are abundant and each major river runs from a strong resurgence or is fed from its downstream. There are more than 70 springs of the minimum flow rate over 10 l/s, including 16 resurges of over 100 l/s. This is why the central mountainous area has a continuous runoff, unlike the rest of Serbian territory of similar physiognomy and many periodical streams. Eastern Serbia also has few intermittent streams in the low Neogene areas surrounded by higher limestone massifs. Sinking streams, another feature of karst, are many (about 70) but they are short (1-3 km), the longest being Busovata (8.8 km), Nekudovska (8.5 km) and Blato (8.3 km) (Gavrilović, 1992).

All streams have the hydrologic rain/snow regimen, but the Danube, the northern border of the region, has combined flow characteristics. Stream flows are high in late summer, September and August. The stream catchments receive annually 600-800 mm precipitation, of which much more water evaporates than runs off. The runoff coefficients for the streams fed less or more by groundwater are between 20% and 30%, and up to 50% (Zlot River), respectively. The runoff proportions in relation to the altitude are similar: one fifth from low drainage basins and two thirds from small basins at the altitudes above 800 m, respectively. In any case, the difference is great, related to slopes, vegetation and soil properties in addition to the mentioned factors. The bordering rivers have the highest discharges: Danube 565 m^3s^{-1}, Velika Morava 230 m^3s^{-1}, Južna Morava 100 m^3s^{-1}, Nišava 30 m^3s^{-1}, and Veliki Timok 30 m^3s^{-1}. The tributaries discharge up to 10 m^3s^{-1} which is drained by the rivers into the Danube.

Man's impact on hydrology in eastern Serbia is mostly manifested in the artificial lakes formed by dams. The two largest lakes, among the largest in Europe, are on the Danube: Đerdap I and Đerdap II. The former is more than 120 km long and has a volume of 1.28 milliard cubic metres, and the latter, downstream lake has a volume of 716 million cubic metres. Both lakes are formed primarily for the purpose of power generation. Other storage lakes, Bor and Grliš Lakes (12 mil. m^3 each), Bovan and Zavoj Lakes (170 mil. m^3), are small, used for water supply and for sediment control.

A common characteristic of all streams in eastern Serbia, excluding the Danube, is very high variation of medium and extreme flows. Mean monthly maximum/minimum discharge ratios are 2.1 for the Danube, 5 for the Velika Morava, 12.5 for Grliška, and as high as 28 for the Sikolska (March-September). An even better indication is the ratio of high (1% probability of occurrence) and low (95% probability) flows. These parameters are 9 for the Danube, 70 Velika Morava, 186 Južna Morava,

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707 Crni Timok, 790 Trgoviški Timok, 909 Pek, and as high as 1055 the Beli Timok in Zaječar, which indicate the torrential character of the streams and low retentive capacity of the drainage basins after intensive rainfalls. Moreover, seasonal runoff is not constant as indicated by the variation coefficients for monthly discharges. These coefficients are less than 0.5 for steady flows (e.g. the Danube by Veliko Gradište has least steady flows of 0.35 in October and 0.37 in November), and much higher for minor rivers. This parameter is slightly below 0.5 only in March and April at two gauge-sections in the Nišava drainage basin. The variation coefficient values are higher than unit, especially in October, for most streams (Sikolska 2.63, Grliška 3.64). The inadequate forest cover and erosion processes are also factors contributing to frequent stream overflows and often to torrents and floods. Flood plains occupy 7.7% of the region, the largest plains located in the valleys of major rivers (Velika Morava alluvium, Niš-Aleksinac depression of the Južna Morava and Zaječar depression of the Timok, Negotin field, etc.). In the Timok valley alone, high water of the hundred-year probability endangers 7700 hectares of land, and an almost double larger area in the immediate catchment of the Velika Morava. There is no doubt that the flood protection and river regulation system is passive at present consisting essentially of embankments and channel regulation works, whereas active measures with beneficial effects such as artificial lakes are secondary. A general impression is that little has been done in eastern Serbia for protection from floods. Voluminous works completed were the regulation of the Velika Morava (after 1950) that included cutting off sixteen meanders to reduce a fifth of the river length. The mouths of the tributaries and their channels in the alluvial plain through towns also were regulated. Some ten kilometers of levees in the Timok basin were built to protect major towns (Knjaževac, Zaječar). The Mlava and its tributaries also were regulated in a total length of 30 km.

The case example of Zavoj Lake well indicates how serious the threat of hazards may be. The lake formed during two days in 1963 after a mass landslide dammed the Visočica valley. The slide was 1.3 km long, about 200 m wide and moved at the rate of 7 m per hour. About two million cubic metres of rock and soil formed a dam 530 m wide at the base and 140 m at the crest, and 30 m high above the river. With the surface of 3 km^2 it was one of the largest natural lakes (later the dam was developed for the power generation purpose). The landslide caused an ecologic disaster; among other effects it flooded two villages with 150 inhabitants. This is not the only case example in Serbia. A much smaller landslide (28000 m^3) formed the Alušontu Lake in 1883 (Stanković, 2007).

Human activities as a factor of geohazard

A change in land configuration exerted by human activities may result from mining (coal, copper, gold) or groundwater pumping. The two mentioned activities leave caverns in the lithosphere subsurface that may easily collapse and modify the land surface producing a geohazard.

Geological and petrological diversity or abundant mineral resources are related to the paleogeography of the region. A large number of surface and subsurface mines have created conditions for the occurrence of geohazards in many areas. The Crna Reka andesite-dacite bodies is a rich resource of copper (Bor), gold, zinc, lead, iron, wolfram, etc. Coal is exploited in many locations of eastern Serbia, to mention Zaječar, Knjaževac, Niš, Sokobanja, Pirot. The joint contributions of man and nature in creating a hazard are best illustrated by the case example of the Bor Mineral Basin. The Borska stream has been for decades a collector of wastewater from the many mine workings. It is now probably the cleanest river in the world devoid of any life, without a single bacterium. A tributary of the Timok~~, it~~ transforms this river of eastern Serbia into a dead stream over a length of 50 metres, to its confluence with the Danube. The scenery of the Timok alluvial plain, thickly covered by pyrite gangue, looks more like ~~e~~ a picture from another planet. Groundwater and air are polluted, and even rainwater indicates that it contained radionuclide like after the Chernobyl disaster. Many conscious persons keep warning of the serious health problems and of grave diseases in the Timok basin, but the warnings are long and successfully covered up because economic development is priceless.

RESULTS AND DISCUSSION

A geohazard vulnerability map is prepared based on a study of natural conditions in eastern Serbia, which has national importance, and is useful on a larger, regional or European scale. The map delineates zones of geohazard vulnerability, which for the lack of data were omitted in most of researches of natural hazards in Europe or over the world (Berz et al., 2001; Grimm et al., 2002; Peduzzi, 2005; Barredo, 2007; Gaume et al., 2009). As there can be seen on the Map, the seismic hazard is greatest along the Morava fault, western area of

  DOI: 10.5775/fg.2067-4635.2011.003.i

the east-Serbian region. Broken by the earthquake intensity, 79.24% of the territory may expect earthquakes of VII to VIII MCS-64, 19.71% earthquakes of VIII to IX, and only 1.05% is in the intensity zone of IX to X MCS-64.

The Map of potential erosion (Fig. 2) shows that 16.67% of the territory is highly erodible. The erosion hazard is particularly great in Neogene deposits at steep slopes. Excessive erosion occur on 0.72% (Table 4).

Table 4
Areas of potential erosion

Erosion potential	Area (km^2)	Total percentage (%)
Very high	122.68	0.72
High	2843.80	16.67
Medium	2764.29	16.20
Low	11329.38	66.41
Total	**17060.15**	**100.00**

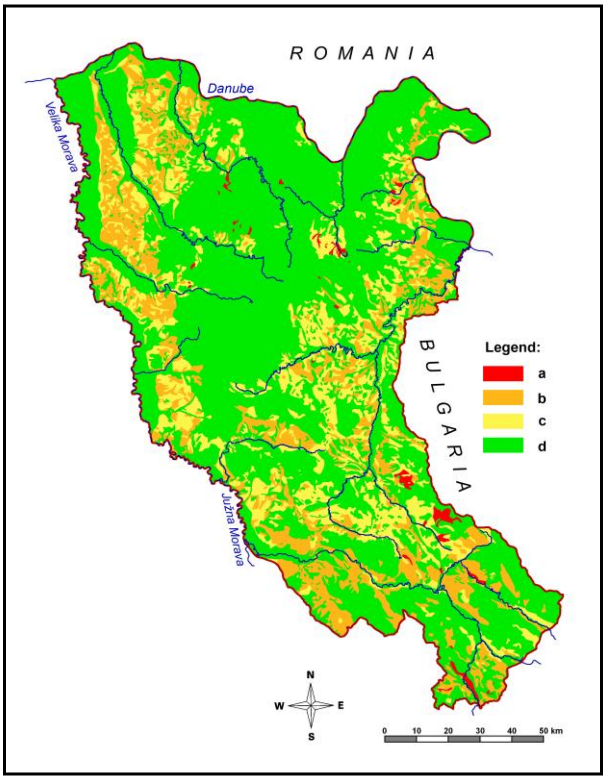

Fig. 2. Map of potential erosion
a) Very high; b) High; c) Medium;
d) Low potential erosion

As to the potential landslides (4.2%), their distribution is related to the lithology and ground slope. The relation to altitudinal distribution of Neogene deposits in Serbia, 83.20% of landslide hazard zones are below the altitude of 500 m, and 96.51% on slopes lower than 15º.

Rockfalls occur in many locations (less than 1% of the east-Serbian territory); mostly carbonate rocks at the sides of canyons and gorges.

Potential cave collapses zones are numerous in places where the lithosphere surface is cavernous either from natural processes or human activities. Large or extensive caves or caverns, numerous crevices and cave passages have formed by erosion in carbonate rocks. Natural and artificial factors may lead to break down of surface layers and their collapse into subsurface caverns. A cave collapses of excessively thinned surface layers may be triggered by earthquake, thunder, or rockfall. The average annual total mineralization of Carpatho-Balkanian mountains in Serbia, coressponding to the average annual discharge is to be found within span of 100-413 mgl^{-1}. The intensity of chemical erosion is in range of 10-167 tkm^{-2}yr^{-1} (Manojlović and Dragićević, 2000).

Carbonate rocks, limestone and dolomite, cover 26.44% of the east-Serbian territory. In the mosaic distribution of limestones, karst features are found all over eastern Serbia. A plausible estimate of the number of caves is between 1500 and 2000 (Djurović, 2005).

Potentially flood plains constitute 7.69% of the total research area.

It results from the above stated that 6479.19 km^2, or 38.17%, are endangered by geohazards. Let it be noted that the accuracy of surface areas should be taken with due caution, because the considered region is large and the generalization degree of the reference maps is fairly high. Nevertheless, the Geohazard Vulnerability Map of eastern Serbia is very useful as a data base for land use planning. For any specific conclusion, a geohazard cadastre at the local level will be needed.

CONCLUSION

Geohazards are an important segment of the land use and town plans, especially in the hazard vulnerable areas. This work is important for presenting the acquired geohazard data that can be used to select appropriate methods for the land use planning, development and utilization in relation to the vulnerability to their manifestations. Natural geohazards are a limiting factor in the land use planning, which needs a model to be developed for the proper control of natural conditions.

This approach allows in all subsequent stages of planning to determine an acceptable level of natural hazards in eastern Serbia and to develop a system of preventive, organizational and other measures and instruments for intervention against the occurrence

DOI: 10.5775/fg.2067-4635.2011.003.i

or for mitigation of hazard consequences to a tolerable level.

Land use planning with reference to The Hazard Vulnerability Map of Eastern Serbia (Fig. 3) has a long future in the prevention of geohazards and in minimizing damages they may inflict (Table 5).

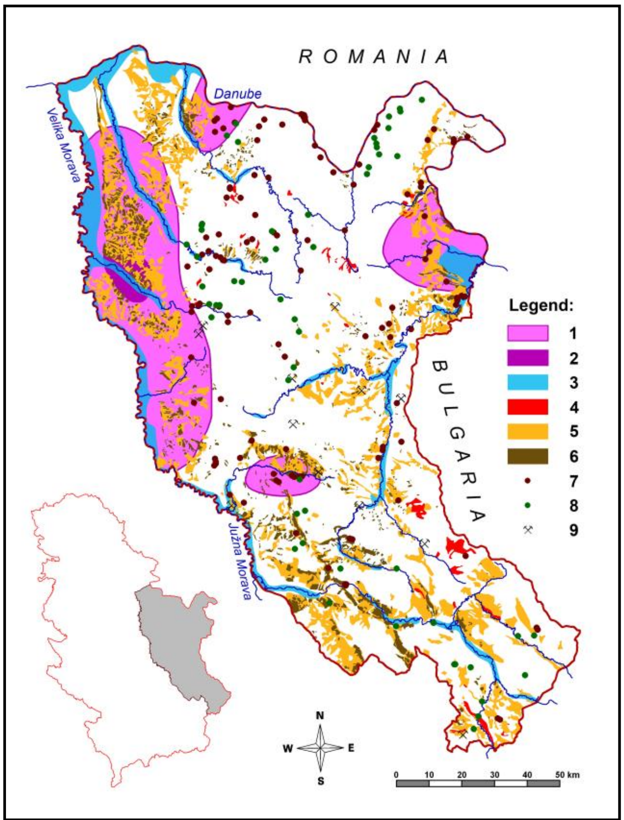

Fig. 3. Composite map of geohazard vulnerability of eastern Serbia
1. Seismic hazard VIII to IX MCS; 2. Seismic hazard IX to X MCS; 3. Potential floodable areas; 4. Excessive erosion areas; 5. Strong potential erosion; 6. Landslide hazard areas; 7. Rockfalls; 8. Potential cave collapses; 9. Subsurface mines.

Table 5
Geohazard areas in eastern Serbia

Geohazard type	Area (km^2)	Percent proportion
VIII to IX MCS	3361.75	19.71
IX to X MCS	179.82	1.05
Potential floodable areas	1311.61	7.69
Excessive erosion areas	122.68	0.72
Strong potential erosion	2843.80	16.67
Landslide hazard areas	719.12	4.22
Rockfalls	19.76	0.12
Total endangered	**6479.19**	**38.17**

The research results may be contained in a model of the geohazard control, as the key component of an integral plan of protection against natural hazards. The risk of natural hazards remaining after the implementation of relevant geohazard control measures must not be greater than what a local community may be allowed to suffer.

The composite geohazard vulnerability map of eastern Serbia has a wider than national importance because natural hazards strike irrespective of administration borders. Hence, it may be a base for cross-border cooperation and for a geohazard vulnerability map of all countries within the Danube lower basin.

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