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HEURISTIC APPROACH BY GEOTECHNICAL HAZARD EVALUATION OF THE MEDVEDNICA NATURE PARK

HEURISTIČKI PRISTUP GEOTEHNIČKOG HAZARDA U PARKU PRIRODE MEDVEDNICA

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Key words: preliminary landslide hazard zonation, causative factors, surface and ground water conditions, erosion, Medvednica Nature Park

Ključne riječi: preliminarno zoniranje po hazardu od klizanja, uzročni faktori, utjecaj površinske i podzemne vode, erozija, Park Prirode Medvednica

Abstract

In making the article, several thematic maps with scale 1:25000 were used. It is the lithological map with outlined engineering geological units, the inclination map with four categories and the landslide map with the areas with increased erosion and generally unstable areas are shown, structural-geomorphological map, surface and groundwater condition map and hydrogeological map. The last one was used with the aim to evaluate the influence of hydrogeological relationship on the synthetic hazard map. The integration of facts from all the maps and engineering evaluation lead to new quality that was presented in the last - synthetic, qualitative map of prognostic meaning. They have been adopted as the factor maps and with their overlapping the map with new contents was made. The Preliminary qualitative map of sliding hazard, including the erosion, was made by heuristic approach, as a predecessor to the hazard map. Such maps proved to be very useful as bases for spatial and development planning on the regional level as well as for evaluation of the site suitability for building.

Sažetak

Za izradu članka korišteno je više tematskih karata u mjerilu 1:25 000. To su : litološka karta s inženjerskogeološkim sadržajem, karta nagiba s podjelom na četiri kategorije, karta gustoće klizišta s područjima pojačane erozije, strukturno-geomorfološka karta i hidrogeološka karta. Potonja sa svrhom procjene utjecaja hidrogeoloških odnosa na sintetsku kartu hazarda. Preklapanjem nabrojenih karata dobivena je karta s novim sadržajem. Uzimajući u obzir sadržaj svake od njih, a napose hidrogeološke karte, nastojalo se procijeniti uzročne faktore za pojavu nestabilnosti padina. Tako su navedene karte usvojene kao faktorske karte za Preliminarnu kvalitativnu kartu hazarda od klizanja, izrađenu heurističkim pristupom. Takve su se karte pokazale vrlo korisnim podlogama za prostorno i razvojno planiranje na regionalnoj razini i za razmatranja pogodnosti terena za izgradnju.

Introduction

The investigation area is represented by Medvednica mountain, with the surrounding area (Fig. 1). The total surface of investigated area - Medvednica Nature Park, is around 225 km^2 (Miklin and Dolić, 2003; Miklin et al., 2003). The mountain belongs to the southwest mountain cores of Pannonian basin.

Geology and other nature based conditions predestined the individual terrain parts for the different types of instability. Their distribution is reflected on the space usability and the state of the inhibited areas (Jurak et al., 1998). Under the term “Geotechnical hazard” it is presumed here firstly the sliding hazard, including the erosion.

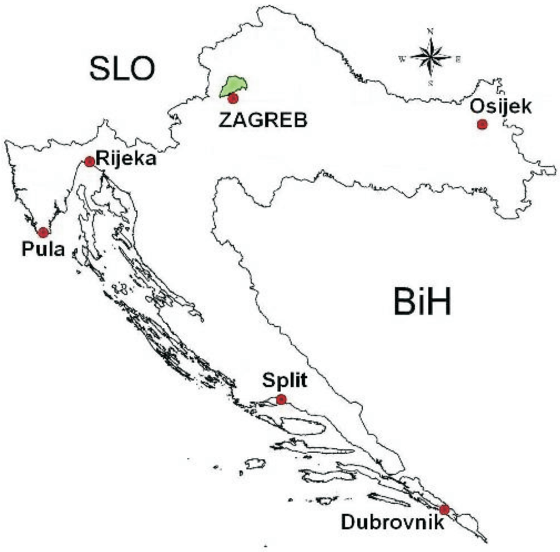

Figure 1 Location map of the study area
Slika 1. *Položajna skica*

The analysis of the causative factors

Preparatory and triggering factors

The evolution of recent landslides is under the influence of some material characteristics (ground conditions), geomorphological processes, physical processes of seasonal character (prolonged high precipitation) and especially significant permanently present human activities (man made processes, land use). They all are the preparatory factors. The extreme hydrological phenomena - torrent floods of the mountain streams of Medvednica Mt., as the triggering factors, can cause the mass occurrence of the landslide. Such phenomena could be initiated by intense precipitation of thousand-year return period. Due to known epicenter region near Kašina, the strong earthquakes should be counted as the initiation causes (Popesscu, 1994). For example, the strong mountain torrents occurred in summer of 1989 and they had all the characteristics of natural disaster (Gajić-Čapka, 1990).

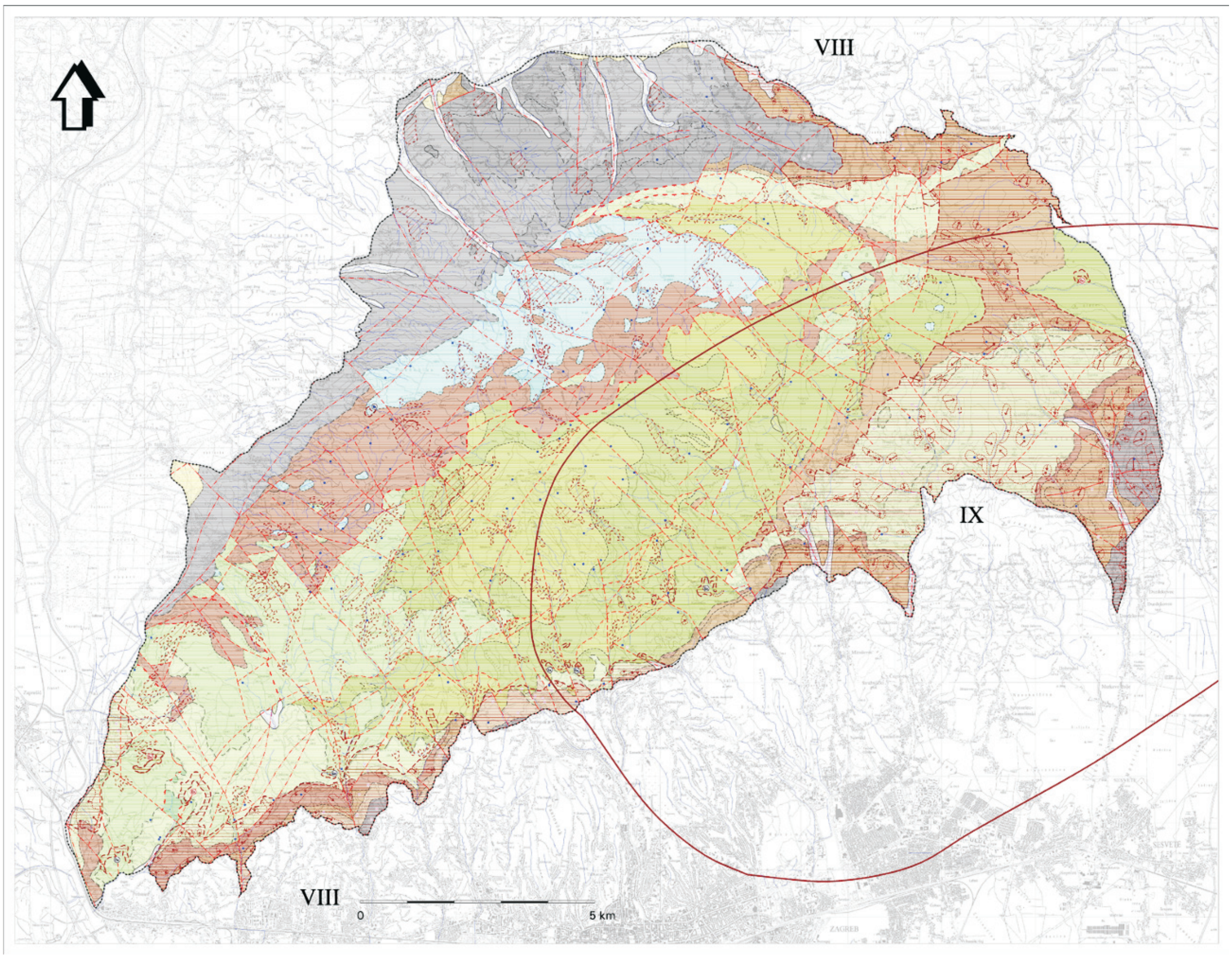

Figure 2 Lithological map
Slika 2. *Litološka karta*

LEGEND:

TUMAČ OZNAKA:

Pl,Q	Stratigrafski simbol
G,S,C	Litološka oznaka
	Geološka granica
	Geološka granica, pretpostavljena
	Erozijsko diskordantna granica
	Terasni odsjek
	Normalan rasjed
	Normalan rasjed, pretpostavljen
	Reversni rasjed
	Navlaka, pretpostavljena
Ex	Aktivni kamenolom
Ex	Napušteni kamenolom
•	Izvor
	Granica Parka prirode Medvednica

	Oznaka	Strat. pr.	IG oznaka	Litološki sastav	IG svojstva
ČVRSTE MAGMATOGENETSKE STIJENE					
Efuzivne stijene		K	ν	gabro	σc=250MPa, RQD=80-100%, GSI>80
Efuzivne stijene		K	$\beta\beta$	dijabazi, spiliti	σc=100-250MPa,RQD=60-90%,GSI=60-80
Metamorfne stijene		Pz	Mb	masivni mramori	σc=100-250MPa, RQD=80-100%, GSI>80
Metamorfne stijene		D,C	As,ν,$\beta\beta$	zeleni škriljavci, met. gabri, dijabazi	σc=70-120MPa, RQD=60-90%, GSI=60-80
Metamorfne stijene		D,C	ν,$\beta\beta$	metamorfozirani gabri i dijabazi	σc=20-70MPa, RQD=20-70%, GSI=40-60
Metamorfne stijene		P_1	Mb	mramori, mramorni škriljci	σc=20-70MPa, RQD=20-70%, GSI=40-60
ČVRSTE SEDIMENTNE STIJENE					
Čvrste sedimentne karbonatne stijene		T_2	Dl, Ls, Ms	dolomiti, vapnenci, podr.lapori	σc=20-70MPa, RQD=20-70%, GSI=40-60
Čvrste sedimentne karbonatne stijene		T_3	Dl, Ls, Sh	dolomiti, podr.vap., šeili	σc=20-70MPa, RQD=20-70%, GSI=40-60
Čvrste sedimentne karbonatne stijene		${}_{3,4}K_2^3$	Br,Cg,Ls,Ms	breče, konglomerati, vap., lap.	σc=20-70MPa, RQD=20-70%, GSI=40-60
Čvrste sedimentne karbonatne stijene		T,J	Ls	vapnenci i dolomitični vapnenci	σc=20-70MPa, RQD=20-70%, GSI=40-60
Čvrste sedimentne karbonatne stijene		${}_1M_2^2$	Ms,Ss,Ls	vap.lapori, pješčenjaci, biokl.vap.	σc=1-50MPa, RQD=0-30%, GSI=20-40
Čvrste sedimentne karbonatne stijene		${}_2M_2^2$	Ls,Ss,Br,Ms	org.vap., pješč., breče, lapori	σc=1-50MPa, RQD=0-30%, GSI=20-40

	Oznaka	Strat. pr.	IG oznaka	Litološki sastav	IG svojstva
ČVRSTE SEDIMENTNE STIJENE					
Čvrste sedimentne klastične stijene		T_1	Ss,Ms,Ls,Dl	pješč., laporci, lapori, vapnenci,dol.	σc=100-250MPa, RQD=80-100%, GSI>80
Čvrste sedimentne klastične stijene		K_1^2	Ss,Sh,Ls,Ms,Ch	pješčenjaci, šeili, vap.,lap.rožnjaci	σc=100-250MPa, RQD=80-100%, GSI>80
Čvrste sedimentne klastične stijene		Pc	Br,Cg,Ss,Ms,Ls	breče, kg.,pješč., lap., vap.	σc=100-250MPa, RQD=80-100%, GSI>80
Čvrste sedimentne klastične stijene		${}_1M_3^1$	Ms,Ls,Ss	vap.lapori, lap.vapnenci i pš.	σc=100-250MPa, RQD=80-100%, GSI>80
Čvrste sedimentne klastične stijene		${}_1M_2^1$	Cg,G,S,C	konglomerati, šljunci, pijesci, gline,	σc=70-120MPa, RQD=60-90%, GSI=60-80
Čvrste sedimentne klastične stijene		${}_2M_3^2$	Ms,Ss	lapori, pješčenjaci	σc=70-120MPa, RQD=60-90%, GSI=60-80
Čvrste sedimentne klastične stijene		$M_3^{1,2}$	Ms,S,Ss,Cg,Br	vap.lapori., pijes., pš,kg,br.	σc=20-70MPa, RQD=20-70%, GSI=40-60
Čvrste sedimentne klastične stijene		$M_3^{1,3}$	Ms,S,Ss,G,Cg	vap.lap., pijes., pš,šljun.,kg	σc=20-70MPa, RQD=20-70%, GSI=40-60
TLO					
Koherentno		l	M,C,S	glinoviti siltovi, glinoviti pijesci	qu100-200kPa,Ic=0,75-1,25 SPP 8-15
Nevezane i slabo vezane stijene		Pl_1^1	Ms,C,S	lapor, gline, pijesci	izuzetno dobro zb.>85% SPP >50
Nevezane i slabo vezane stijene		Pl_1^2	S,Ms,C	pijesci, lapor,gline	izuzetno dobro zb.>85% SPP >50
Nevezane i slabo vezane stijene		dpr	G,S,C	šljunci, pijesci, gline	izuzetno dobro zb.>85% SPP >50
Nevezane i slabo vezane stijene		Pl,Q	G,S,C	šljunci, pijesci, gline	dobro zbijeno 70-85%, SPP 30-50
Nevezane i slabo vezane stijene		a	G,S,M,C	šljunci, pijesci, siltovi, gline	vrlo rahlo tlo <20%, SPP <4

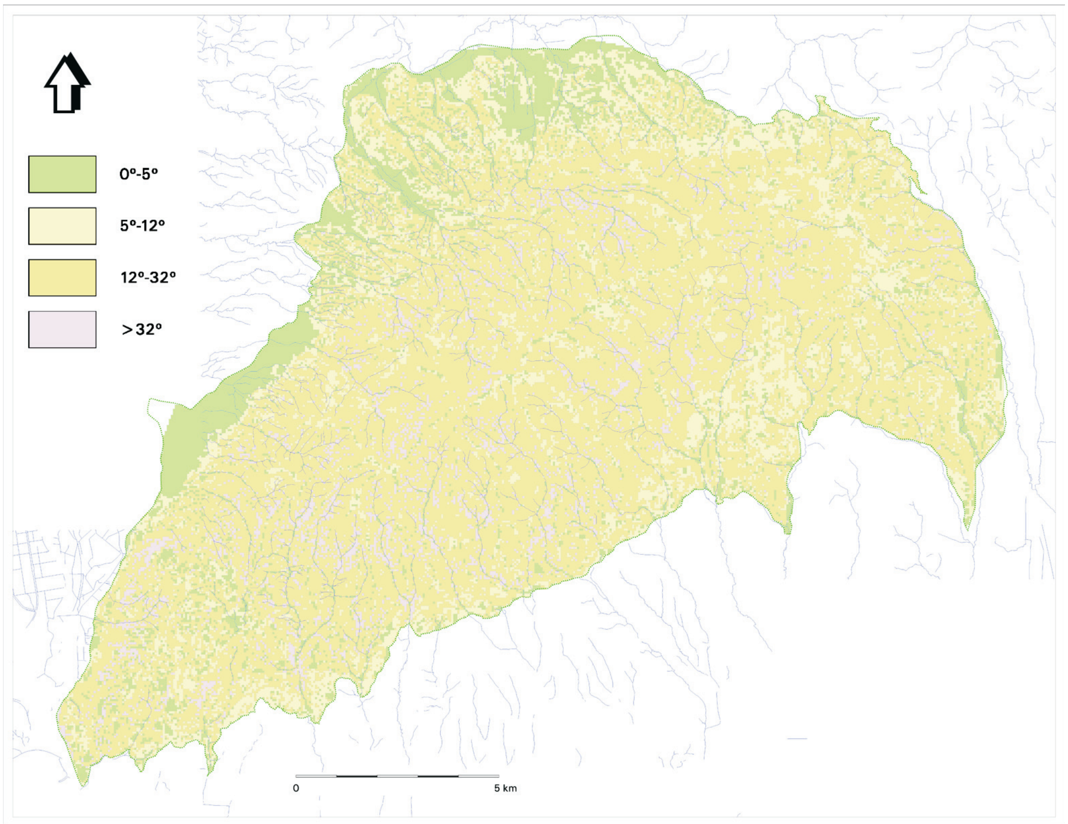

Figure 3 Inclination map, with four categories (0-5°, 5-12°, 12-32° and >32°)
Slika 3. *Karta nagiba s četiri kategorije nagiba padine (0-5°, 5-12°, 12-32° i >32°)*

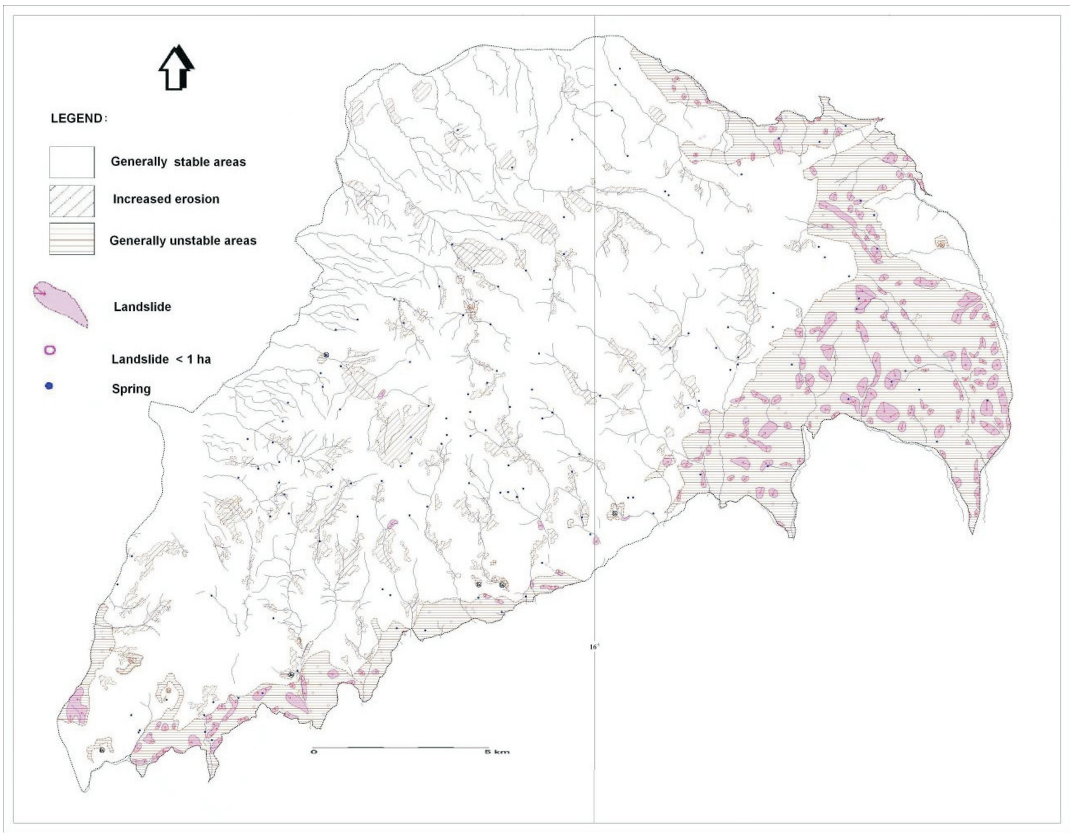

Figure 4 Landslide map, with increased erosion and generally unstable areas.
Slika 4. *Karta klizišta sa područjima pojačane erozije i općenito nestabilna područja.*

The lithological map (Fig. 2). with outlined engineering geological units and complexes, the inclination maps (Fig. 3). with four categories (0-5°, 5-12°, 12-32° and >32°) and the landslide map (Fig. 4). were made. On the latest map, the areas with increased erosion and generally unstable areas are shown (Table 1). Structural - geomorphological map (Fig. 5). (Hećimović, 2000) shows the main characteristics of recent structures.

Table 1 The presentation of stability categories and slope inclination.
Tablica 1. *Kategorije stabilnosti, nagibi padina i njihove površine.*

STABILITY CATEGORIES	TOTAL AREA (km^2)	AREAS WITH SLOPE INCLINATION (km^2)			
		0-5^0	5-12^0	12-32^0	>32^0
Stable terrains	161,31	25,02	26,00	103,89	6,40
Conditionally stable terrains	12,45	0,54	0,71	6,0	5,20
Conditionally unstable terrains	46	6,28	15,00	24,00	0,72
174 landslides greater than 1ha	5,44	0,44	1,8	3,1	0,10
69 landslides smaller than 1ha	0,04	0,0056	0,0216	0,0088	0,004
Totally - N.P. Medvednica	**225,24**	**32,2856**	**43,5316**	**136,9988**	**12,424**

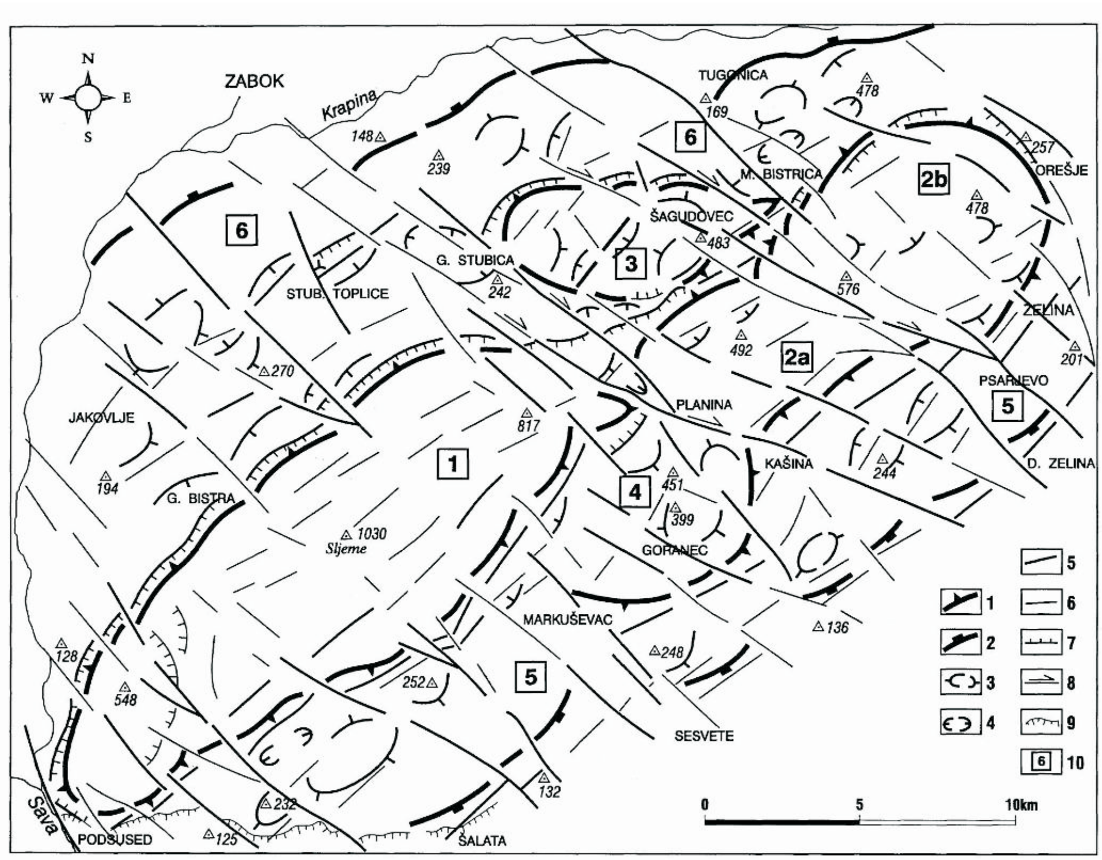

Figure 5 Structural - geomorphological map.
Slika 5. *Strukturno – geomorfološka karta.*

Legend:

1) morphostructures uplifted in Pliocene and Quaternary; 2) morphostructures uplifted in Qaternary; 3) local uplifted morphostructures; 4) local subsided morphostructures; 5) fault distinctly marked in the relief; 6) fault well marked in the relief; 7) reverse fault; 8) dextral strike-slip fault; 9) terrace cliff; 10) marc of morphostructure (Hećimović, 2000).

Hydrogeological map (Fig. 6). was considered tightly with geomorphological map. In that way, the map with new contents was produced - surface and groundwater condition map (Fig. 7). That enabled the evaluation of dominant triggering factor for activation the new landslides. The integration of facts from all the maps and engineering geological evaluation lead to new quality that was presented in the last - synthetic, qualitative map of prognostic meaning (Fig. 8).

Hydrogeological properties of Medvednica Mt. and Brim

Hydrogeological properties of Medvednica Mt. are differentiated according to two main morphohydrographic unities: mountain massif and low Neogene hills, enclosing the massif. The rocks are divided into two main categories: permeable and impermeable (Brkić and Čakarun, 1998; Slišković and Šarin, 1999) (Fig. 6).

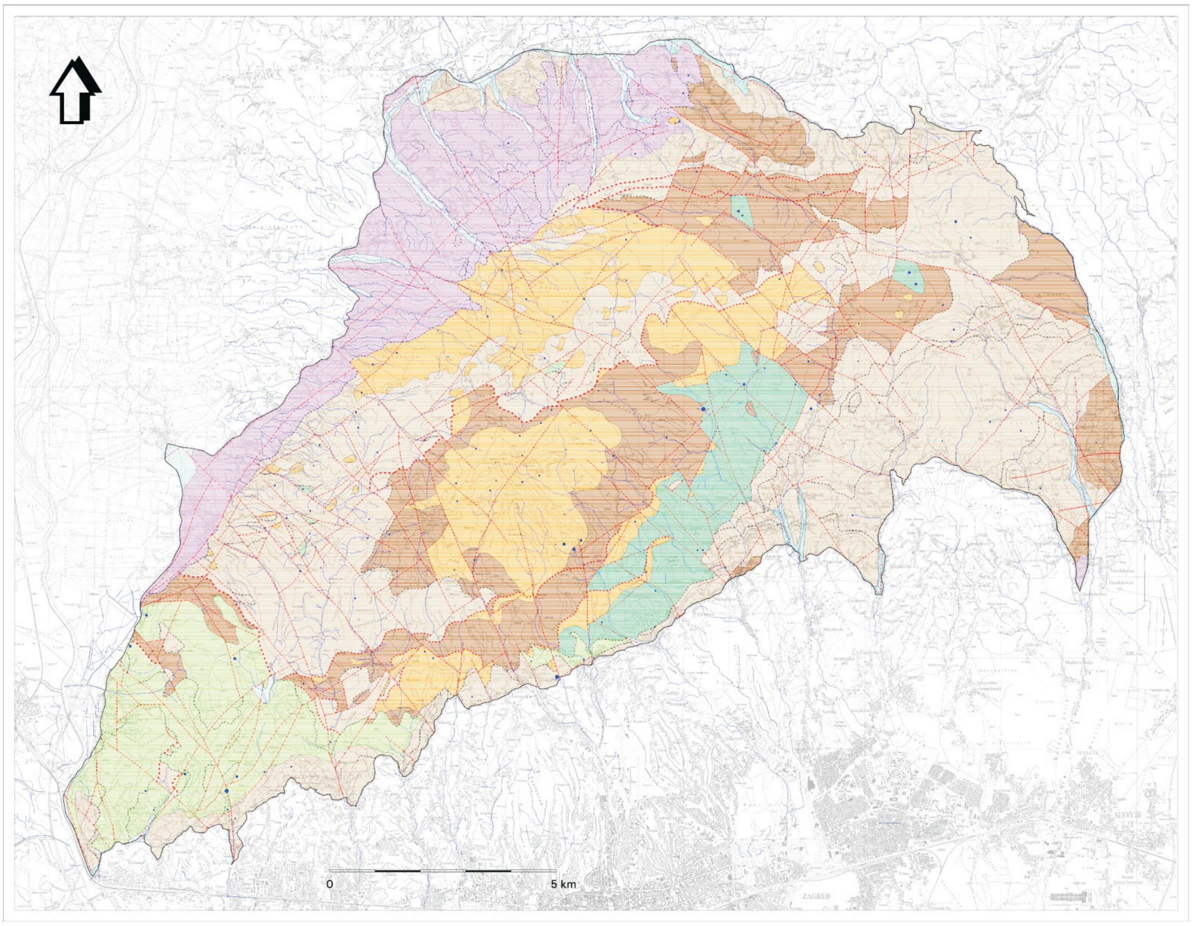

Figure 6 Hydrogeological map.
Slika 6. *Hidrogeološka karta*

Legend:

a Quaternary gravel and sand with clay - Intergranular porosity.

PlQ Plio -Quaternary clay and gravel – Low porosity.

$\mathbf{Pl_1^1;{}_1M_3^2;{}_1M_3^1;{}_2M_2^2;{}_1M_1^2;Pc;K_2^3;\ {}_{3,4}K_2^3;K_1^2}$ Clastic rock – Practically impermeable permeability and very low permeability.

TJ; $\mathbf{T_2;T_3}$ Carbonate rock – Medium permeability.

ββ;β;ν;γ;χ Eruptive rock and shale – Very low permeability.

P?;DC Marble limestone – Low permeability.

$\mathbf{T_1}$**;DC** Shale and clastic rock – Practically impermeable.

The permeable rocks are divided into the subclasses with good and poor permeability and the impermeable rocks are divided into the subclasses with low permeability and impermeable rocks. The horizontal and vertical lithological exchange leads to different permeability degree of such deposit complex.

Low metamorphic rocks of Paleozoic age and the clastic rocks of lower Triassic age are mainly impermeable. These are various sandstones, siltstones, marls, conglomerates and various schists and marbled schistic limestones. The shallow groundwater circulation takes place in marbled deposits. Effusive rocks also build the impermeable complex. The outflow takes place along the concentrated surface flows and the infiltration goes through weathering zone and along the discontinuities of limited persistence.

The south-west part of Medvednica Mt. is built mainly of Triassic dolomites and litotamnium limestones with morphological features and shapes typical for karst regions. The concentrated outflow is dominant.

Neogene hills include the brim of Paleozoic Medvednica massif. The south-east foothill is partially built of Miocene carbonate deposits. They are outlined as specific, because the water sinks in them and the groundflows are dominant. The water emerges in erosion cuttings or at the contacts with impermeable deposits of Pannonian age at the spread spring zones without significant water distributary.

The characteristic of Miocene deposits is frequent exchange of low permeable and impermeable units. The limited aquifers are connected to intrusions and lenses of sandstones, breccias, conglomerates, sands and limestones. The deposits of upper Pontian age include significant sand interbeds. Due to variable granulometric composition, from coarse over fine grained sands to silt and clay the value of hydraulic conductivity is very small. Rhomboidea-deposits towards the east change into deposits of lower Pontian, built of marls, clays and sands. The occurrence of permanent springs is rare, and periodic springs are very frequent.

The noncohesive and low cohesive deposits of upper Pliocene and Plio-Quaternary age are of intergranular porosity and have low permeability. They spread along the north-west foothill of Medvednica Mt., and consist of clay-sand-gravel mixture, with the gravel lenses.

The gravely-sand deposits along the torrent flows in the areas with smaller inclination have significant permeability.

Surface and ground water conditions

The region of Nature park Medvednica is divided into six terrain types according to following criteria: lithology, spring types, outflow types (surface and underground), watercondition and erosion, category of slope inclination and drainage possibility, including tectonic disturbance of rock masses and taking into account the secondary products (weathering products and slope deposits).

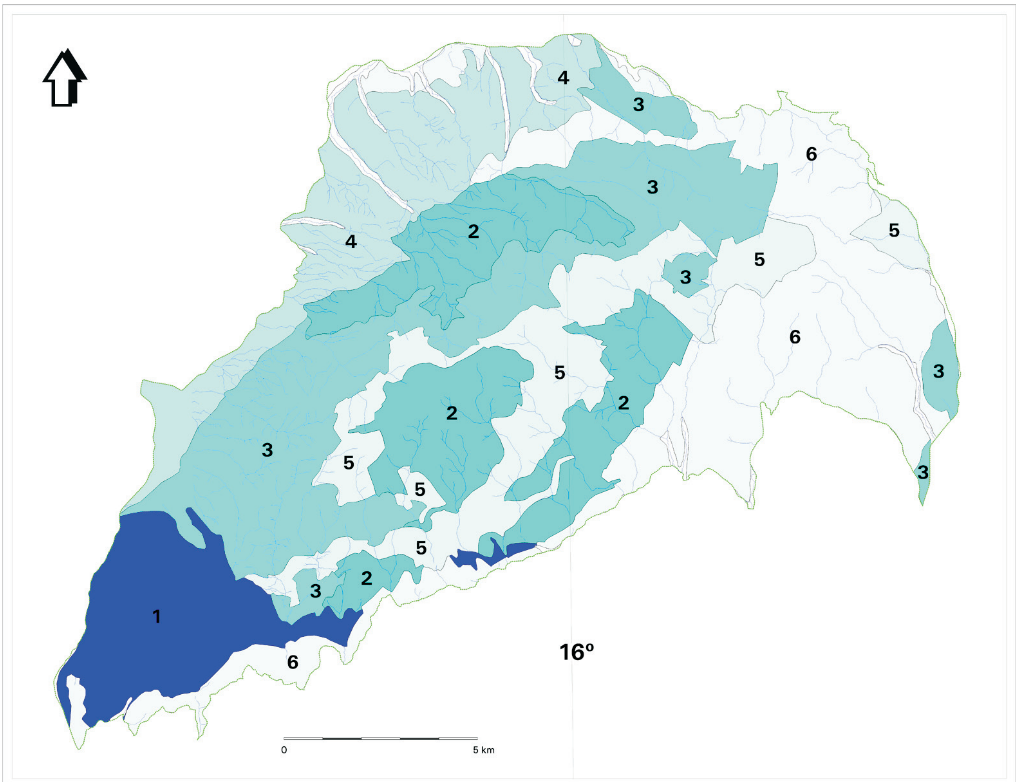

Figure 7 Groundwater condition map
Slika 7. *Karta utjecaja površinske i podzemne vode*

Table 2 Legend for the figure 7.
Tablica 2. *Legenda za kartu 7.*

TYPE	LITHOLOGY	TYPE OF SPRINGS	FLOW TYPE	WATER CONDITION AND EROSION	INCLINATION. CATEGORYS	DRANAGE
1	Carbonate deposits of Mesozoic and Upper Tortonian age	Pemament springs high yield	Concentrated groundflow	Dry, sporadically intensive deep erosion without permanent surface flows	0-5^0 5-12^0	VERY GOOD DRAINAGE
2	Green schists with several lithotypes, effusive rocks and marbles	Pemament springs low yield	Surface concentrated flow and shallow groundflow in take place		12-32^0 >32^0	
3	Variable lithology, pelite or carbonate component prevailing in the Cretaceous flysch	Many permanent springs of low yield		Water retention in the catchment area for longer time	5-12^0 12-32^0	LOW AND GOOD DRAINAGE
4	Plio-quaternary deposits.Gravel, sands, clay	Distinguished by spread spring zones	The fast infiltration	Dense drainage network. Water is not retaind on the surface, surface erosion	0-5^0	GOOD DRAINAGE
5	Low metamorphic rocks of Paleozoic age and clastic rocks of Triassic age	Scurce springs of diffuse drivage	Slow water outflow	The water retains in the deposits with predominantly clayey composition and in the weathering zone which drainages slowly	5-12^0 12-32^0	PORE DRAINAGE
6	Rock of mixed clastic composition	Dissipate intermittent springs	The water is saturat.,weathering zone and the clay deposits almost during the whole year	The appearence of slope instability landslides, deep and surface erosion water logged terrain saturation of secondary forms	12-32^0	

The first terrain category is represented with carbonate deposits of Mesozoic and upper Tortonian age. The concentrated groundflow and very good drainage is dominant.

The second category includes green schists with several lithotypes, effusive rocks and marbles, where surface concentrated flow and shallow groundflow take place.

The third category is made of terrains with variable lithology, which causes the water to retain in the catchment area for longer time. It was taken into account if the pelite or carbonate component is prevailing in the Cretaceous flysch.

Plio-quaternary deposits of north-west slopes of Medvednica Mt. represent the fourth terrain category distinguished by spread spring zones. The outflow takes place within the thick drainage net. Because the sand component prevails, the infiltration is quick and the drainage is good.

In the low metamorphic rocks of Paleozoic age and clastic rocks of Triassic age the water outflow is slow. The water retains in the deposits with predominantly clayey composition and in the weathering zone which drainages slowly. The terrains with these deposits are low drained.

In the last category with mixed clastic composition and with thick weathering zone, the slow surface outflow takes place with the emergence of flat erosion. The terrains are low drained. The water is saturating the weathering zone and the clay deposits almost during the whole year, creating numerous unstable slopes and landslides.

The land sliding intensity is increased by numerous periodical springs and diffuse outflow of groundwater, if the waters saturate unconsolidated deposit and degraded part of parent rock. The mountain torrent streams, after the long lasting precipitation, erode the side parts of the riverbeds and cause the creation of new landslides. Some tent retentions and accumulations were designed for the terrain protection from torrents and some of them have been constructed.

Conclusions - Preliminary qualitative map of sliding and erosion hazard

The heuristic approach was used for the design of synthetic map (Mihalić, 1998) that was elaborated in the paper by Anbalagan (1992a, 1992b) and book by Singh and Goel (1999) respectively. But, it has been applied in the simplest version, without the division of the surface into elementary topographic units. Such map should be used as the initial information about the terrain quality. In the future the process should continue with sophisticated GIS technology recommended by Carrara et al. (1995) and Chacon et al. (2006). The display with map of landslide and erosion hazard zoning in this case represents the engineering expectations.

The zoning according to landslide hazard, including erosion, mostly inherits the present morphostructure fabric of Medvednica Mt. and its brim.

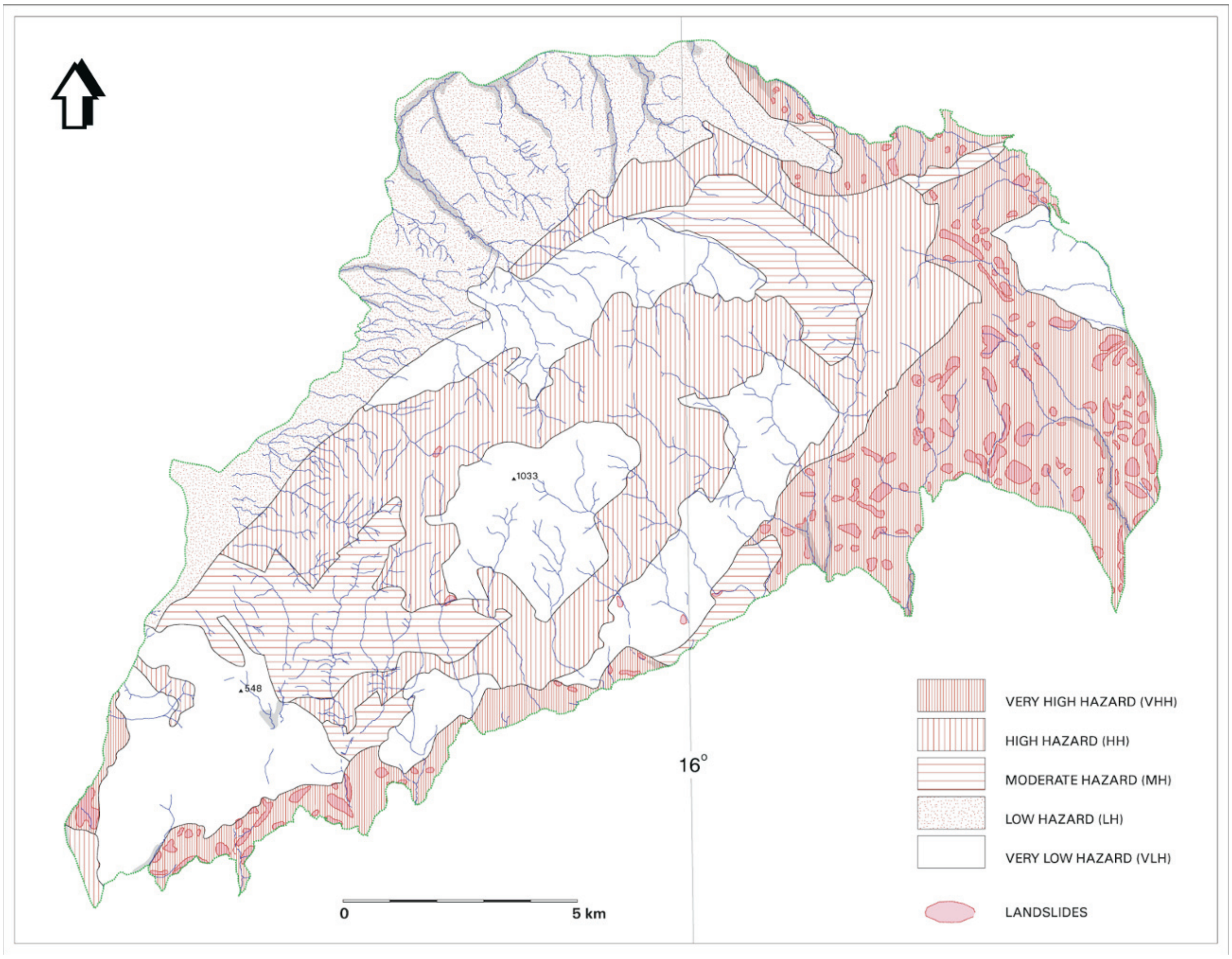

Figure 8.Preliminary qualitative map of sliding and erosion hazard
Slika 8. *Preliminarna kvalitativna karta hazarda od klizanja i erozije*

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