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Spatial analysis of geohazard on the Fruška Gora mountain

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1 Introduction

The significance of studying geomorphological processes shaping the surface of mountains and the associated vulnerability (geohazard mapping) has increased greatly in the last decades due to the trend of increase in occurring damages and casualties.

At the same time the mathematically based methods of geomorphometric digital elevation model analysis (DEM) revolutionized the modern geomorphological research in combination with new powerful geospatial tools of GIS based spatial analysis, remote sensing and novel observing, surveying and measuring methods, becoming thus increasingly successful in confronting the problems of fundamental geomorphological research, and also in meeting the demands of society for damage prevention and mitigation strategies more adequately.

Systematic research of geohazard in Serbia has not been conducted in the last two decades and the application of spatial analysis in this discipline is still a new field, with relatively few examples of local or regional studies. Although geohazard has been investigated with traditional means in many areas, the application of geospatial methods gives an opportunity of gaining new insight in natural processes that are causing very significant damages, and providing planners and decision makers with necessary informations about the spatial distribution of the most vulnerable areas.

The Fruška Gora mountain (in the Autonomous province of Vojvodina in Serbia) represents an excellent example of the variety of problems arising from the combination of geohazard and inadequate planning, and provides an interesting „natural laboratory" for testing novel approaches in geospatial analysis with its high spatial, topographic, geological, geomorphological heterogeneity in a relatively small area, and as such it has been selected for the study area for this dissertation. From the total 979.6 km2 nearly 40 % is in some way affected by one or more types of geohazard. Seismic and mass movements, intensive erosion, flash floods also threaten the protected natural and cultural values of the Fruška Gora National park, which occupies the central areas of the mountain (266.72 km2 or 27 %) (Dragicevic et al., 2013)

2 Objectives

One of the key problems of geohazard study on the Fruška Gora, and in Serbia in general is the lack of continuous data from environmental measurements (above all climatological and hydrological observations are incomplete) which are required for natural hazard and risk assessment. There was also no detailed geohazard inventory available for the purpose of this study, which is the most important, fundamental data input for any geohazard research.

The first goal was thus to build a database of available geohazard environmental factor measurements and maps and produce a geohazard inventory, particularly the landslide inventory for the Fruška Gora, which would serve as a basis for digital geomorphometric analysis. Beside this the aim was to establish a new landslide classification system for the Fruška Gora which would facilitate the process of analysis and identifying the factors behind the slope instability development. Since there was also no readily available digital elevation dataset, the construction of Digital elevation model (DEM) of the Fruška Gora was a necessary objective. As the problem of obtaining high quality basic topographic maps became apparent, another goal was introduced alongside the initially planned research objectives, which was to evaluate the usefulness and suitability of unconventional land surface data sources for geohazard analysis, such as the high resolution stereoscopic archive satellite images from the CORONA program, from the end of the 1960’s. During the search for information about past landslides on the Fruška Gora the question of the usability of historic topographic maps in reconstruction of landslide events emerged and became another important objective of the study. The primary aim of the research was to successfully identify and map areas susceptible to exodynamic geohazard on the Fruška Gora using novel digital geomorphometric and geospatial methods, and to highlight new aspects and correlations of land surface processes, which were perhaps not fully recognized in other studies based upon the traditional geomorphological approach. The intention was to make the obtained results suitable for serving as a basis of a future decision support, planning and monitoring system for more detailed hazard and risk analyses on the mountain and other similar terrains. This included the preparing of separate landslide susceptibility maps for shallow and deep seated landslides on the Fruška Gora. Finally one of the important goals of this thesis was also to assess the applicability and feasibility of geospatial analysis in mountainous areas where the availability of high-quality data is not adequate, by evaluating the quality of the obtained susceptibility modelling results.

3 Applied techniques

3.1 Landslide interpretation from high resolution aerial image in 3D GIS environment

The **landslide inventory** of the Fruška Gora mountain was prepared by compiling and re-interpreting landslide locations from various sources:
(1) geomorphological map of the Vojvodina province (1 : 200,000), (2) geological map of Serbia (1 : 100,000) (3) geotechnical studies for road, bridge, infrastructure construction and maintenance, (4) many more unpublished engineering documents (with scales ranging from 1 : 500 to 1 : 5000) and (5) my field observations and measurements.
The location of each landslide was evaluated and corrected by interpreting high resolution digital aerial and satellite photographs overplayed on hillshade DEM displayed with vertical exaggeration in 3D view (ArcGIS ArcScene), in combination with the representation of slope, curvature, geology and pedology, achieving thus adjustment between very heterogenous data sources of varying scale and avoiding inconsistencies.

3.2 Creation of the Digital land surface model of the Fruška Gora

I created two digital representations of the Fruška Gora land surface:

- The DEM based on digitized 1:25,000 topographic map was generated using ArcGIS TopoToRaster. Of all available and tested methods for DEM interpolation from contours, the ANUDEM 5.3 program implemented in ArcGIS10.1 TopoToRaster tool showed by far the most acceptable results, and was found to be the most flexible and adaptable approach for DEM generation. Particularly useful were the very detailed diagnostic tools included in the program, which facilitated greatly detection of errors from digitalization.
- I extracted the DSM from an archive stereographic satellite image from the CORONA program using ERDAS OrthoBase. Ground controll points measured with DGPS were used for external orientation of the image, with about 30 points recognizable from the image identified at crossings of paved roads, rails of bridges crossing the streams and canals, large monuments and other landmarks. The DSM was processed

in ArcGIS using TopoToRaster in order to smoothen the surface and enable calculation of DSM derivatives (slope, curvature).

- Another DEM of a smaller test area on the north-eastern part of the mountain known for a large landslide event in 1941 was constructed from a topographic map from the Third ordnance survey of the Austro-Hungarian empire from 1881 (1 : 25,000) also with the ArcGIS TopoToRaster tool with 10 m grid size.

3.3 Evaluation of landslide susceptibility on the Fruška Gora

Landslide susceptibility was analysed using two methods. Shallow landslide susceptibility of the Fruška Gora was evaluated using the **SINMAP deterministic model**, based on the infinite slope stability model and steady state hydrological model using 15 m grid size DEM in ArcGIS 9.1. Parameters for the stability index calculation (relative wetness, combined cohesive force of the root system, and soil cohesion, soil friction angle, and wet soil density) were obtained from various geotechnical studies. Four calibration regions with different parameters were designated based upon the soil type and vegetation cover (Figure 7).

For the deep seated landslide susceptibility evaluation the **Likelihood Ratio model** was used, based on Bayes' theorem of conditional probability. The susceptibility calculation was performed using 10 environmental factors related to landslide formation, each divided into categories: Elevation, slope, profile curvature, plan curvature, total curvature, aspect were derived from the DEM, the wetness index was calculated using SINMAP, geology, soil map were digitized from thematic maps and the information about land use was obtained from the improved version of the CORINE 2006 v16 dataset. Susceptibility was calculated for 5 landslide types from the inventory separately, in order to represent the different factors in more detail. The 5 different maps were summarized for the synthetic map of susceptibility (Figure 8).

4 Results

4.1 DEM and DSM of Fruška Gora

I created a DEM of Fruška Gora with 15 m grid size and also extracted the DSM (5 m grid size) of the central parts of Fruška Gora from a stereo pair of high resolution archive satellite image from the CORONA program (Figure 1) With a vertical accuracy between 10-25 and horizontal accuracy of 10 m I found it to be a usefull resource for geomorphometric investigation of geohazard in areas with no other high qualty topographic source (Figure 3). In comparison with the SRTM DEM the extracted DSM showed superior quality of derivatives (slope and curvature)(Figure 2).

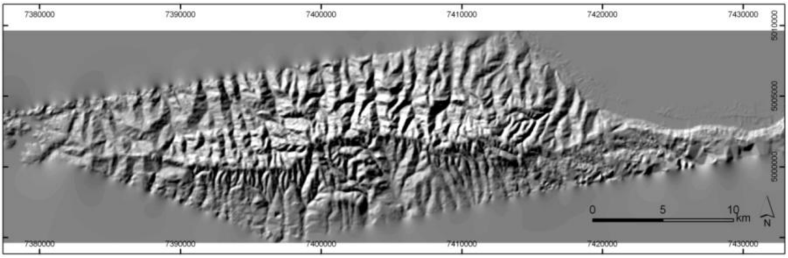

Figure 1. Shaded relief representation of the Fruška Gora DSM extracted from the CORONA program high resolution archive satellite images

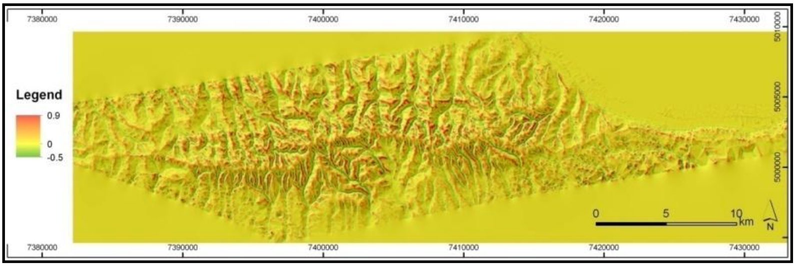

Figure 2. Surface curvature map Fruška Gora extracted from high resolution archive satellite image from the CORONA program

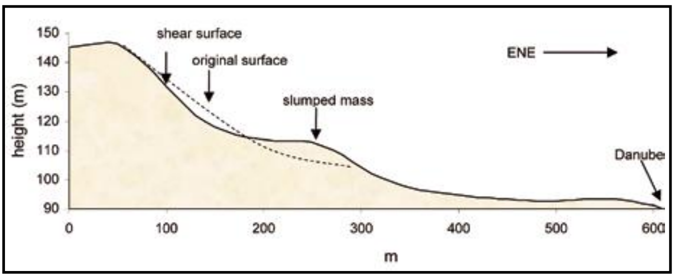

Figure 3. Profile obtained from the 2 m cell size CORONA DSM over a landslide area beside the Danube (Mesaros et al., 2007)

4.2 Reconstruction of an old landslide initiation zone from a historic topographic map

The most likely initiation zone (shown in red) of a landslide event from 1941 (Figure 4) was reconstructed from a topographic map from the Third ordnance survey of the Austro-Hungarian empire from 1881, and the method was demonstrated to be feasible for smaller areas. For larger areas a more precise alignment of the historic maps will have to be solved.

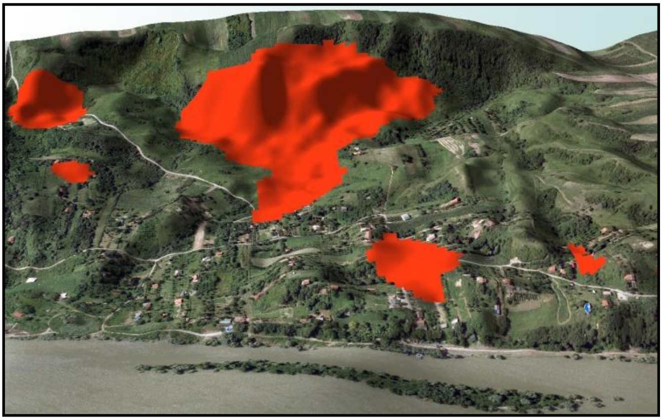

Figure 4. Areas shown in red represent differences between 47 and 20 meters in surface heights identified on digital elevation models based on maps from 1881 and 1977 (the image is shown with vertical exaggeration x4)

The landslide initiation area was very clearly identified on the comparative map of the two digital elevation models from 1881 and 1977 (Figure 5). Differences in heights were indicated mostly on locations where they could be explained by real surface changes. The histogram showing the distribution of height difference pixels suggest that the overall accuracy of source map matching is acceptable, with most of the terrain showing in effect no height changes

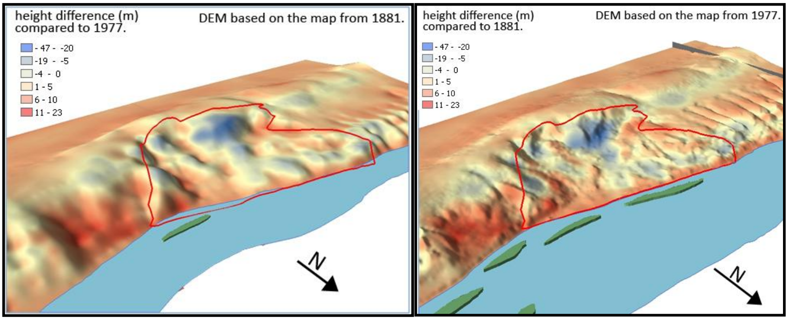

Figure 5. Height differences between the 1881 (right) and 1977 (left) digital elevation models (DEMs), clearly showing an above-average negative height difference (dark blue) in the central parts of the landslide initiation area.

4.3 Shallow landslide susceptible mapping using SINMAP

Shallow landslide susceptibility was assessed using a physically based deterministic SINMAP model, and potentially unstable slopes were identified (Figure 6 and Table 1).

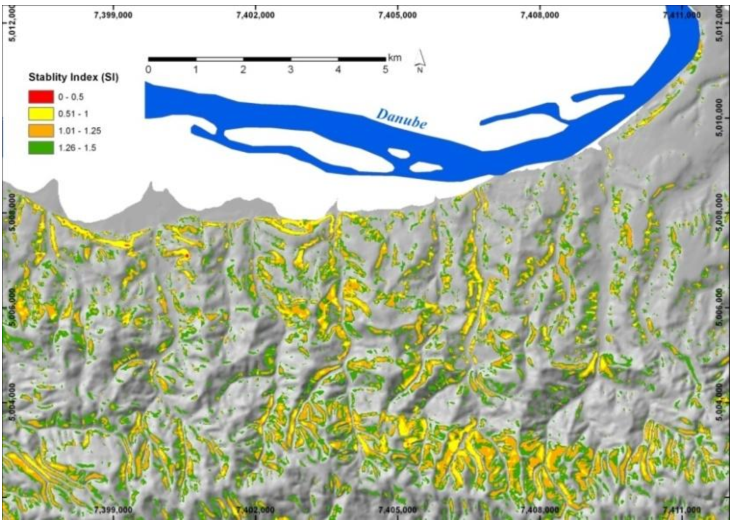

Figure 6. A section of the stability index map generated in SINMAP model

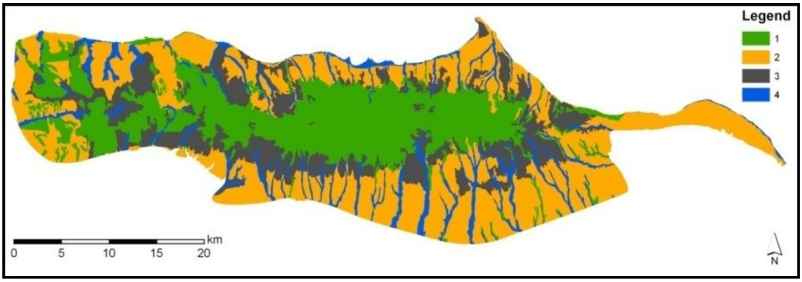

Figure 7. defined SINMAP calibration regions with different geomechanical parameters 1- forest, 2 – chernozem, 3 – loamy soils, 4 - alluvial soils

Legend: SI > 1.5 Stable slope zone; 1.5 > SI > 1.25 Moderately stable zone; 1.25 > SI > 1.0 Quasi-stable slope zone; 1.0 > SI > 0.5 Lower threshold slope zone; 0.5 > SI > 0.0; Upper threshold slope zone; 0.0 > SI Defended slope zone

	calibr.region	Stability index class						Total
		I	II	III	IV	V	VI	
Area(km^2)	1	261.8	24.1	11.9	1.6	0	0	299.4
% of Region	1	**87.4**	**8**	**4**	**0.5**	**0**	**0**	100
Area(km^2)	2	**376.1**	**15.9**	**9**	**2.7**	**0**	**0**	403.8
% of Region	2	**93.1**	**3.9**	**2.2**	**0.7**	**0**	**0**	100
Area(km^2)	3	**170.9**	**7.3**	**2.9**	**0.7**	**0**	**0**	181.8
% of Region	3	**94**	**4**	**1.6**	**0.4**	**0**	**0**	100
Area(km^2)	4	**72.7**	**5.8**	**3.7**	**1.6**	**0**	**0**	83.8
% of Region	4	**86.7**	**6.9**	**4.4**	**1.9**	**0**	**0**	100

Table 1. SINMAP statistics: I-Stable; II-Moderately Stable; III-Quasi-Stable; IV-Lower Threshold; V-Upper Threshold; VI-Defended

4.4 Landslide susceptibility map based on the Likelihood Ratio method

The landslide susceptibility map for deep seated mass movements was prepared using the statistical likelihood ratio model. The model proved robust and effective, as the necessary calculations can be performed entirely in GIS application, without the need for additional statistical software. The model achieved an acceptable level of performance with an overall agreement with the record of existing deep landslides of 76.3 % (Table 2 and Figure 9). After the revision of the landslide inventory trough additional field investigations, and excluding incorrectly marked unstable areas this proportion will certainly be higher. The low κ index of 0.149 can be interpreted more as an indicator of the inventory incompleteness, than poor model performance. The susceptibility likelihood ratio was calculated for every type of unstable slopes from the inventory (with the exception of two anthropogenic landslides), and the results merged in a map representing the total susceptibility for deep seated landslides. The map represents very well the zonality of environmental factors on the mountain, with the stable central parts and the much higher susceptibility on the northern slopes, which clearly shows the influence of the Danube on the surface processes on the entire northern mountainside (Figure 8).

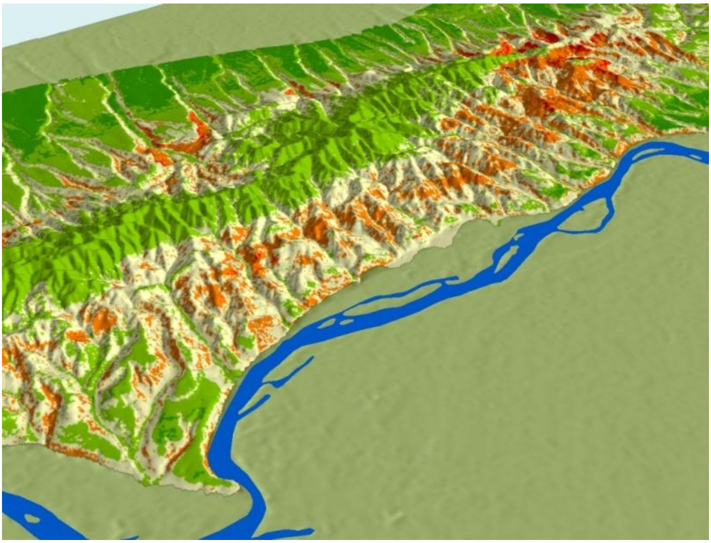

Figure 8. A 3D view from the northeast, with the Danube riverside (vertical exaggeration 2.7)
susceptibility map legend: green – low, yellow – medium, red - high

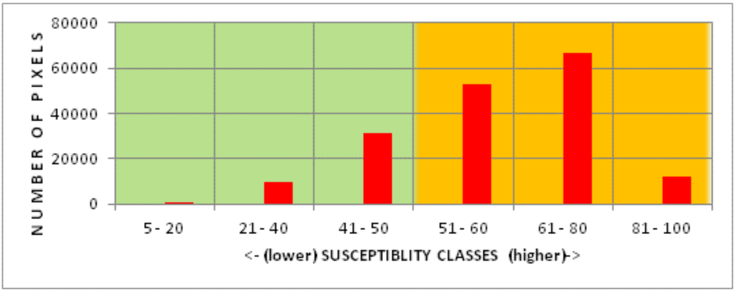

Figure 9. Distribution of unstable zones from the inventory in susceptibility classes

	Unstable (No of pixels)	% correct
Prediction - Type1	37355	72.1
Inventory - Type 1	51777	
Prediction Type2	56786	75.5
Inventory - Type 2	75241	
Prediction Type3	14695	86.1
Inventory - Type 3	17060	
Prediction Type4	16015	81.6
Inventory - Type 4	19619	
Prediction Type5	6871	77.1
Inventory - Type 5	8909	
TOTAL UNSTABLE – PREDICTED	131722	**76.3**
TOTAL UNSTABLE - INVENTORY	172606	

Table 2. Overall percentage of correctly classified pixels for different landslide types

I identified a smaller number of landslides with very low susceptibility, which are most likely erroneously delineated in the inventory, and will require additional reassessment by field investigation. Zones without informations about landslides in the inventory, but clearly marked as highly susceptible by the model are also worth re-examining in more detailed field mapping.

Susceptibility for the TYPE 1 deep, complex „Danube" landslides

This distinctive and characteristic landslide type has the most specific and complex set of determinants, that differ very sharply from other unstable slopes on Fruška Gora. The strongest correlation was found with the feature categories of elevation (lower than 100 m), slope (10-25 %), total curvature (between -1 and -0,25) plan curvature (-0.3 and -0.2) profile curvature larger than -0.75, northern aspect. The Pliocene clay, sand, coal, silt, and Miocene conglomerate geologic units of showed the strongest correlation.

Susceptibility for the TYPE 2 landslides on concave, convergent valley side slopes

These unstable slopes are most abundant between 150 and 300 meters, strongly related to the inclination of terrain between 10 and 35 percent, total curvature between - 0.5 and -0.25, eastern aspect and partially saturated aquifer. From the geologic units upper pontian sandstone, sand, marl, Miocene conglomerate, sandstone, clay, coal and also various tortonian formations represented by sandstones, marl and conglomerates showed the highest indexes.

Susceptibility for the TYPE 3 landslides on steep, convex or planar valley-side slopes

these landslides are mostly concentrated between 250 and 350 meters. It could be expected that they extend into higher elevations, as the central parts of the mountain have very steep valleys, but the geologic composition limits landslide formation only to small scale shallow displacements. These unstable areas are clearly clustered around the values of slope between 10-25 %., which is somewhat less than expected. The slopes are most often oriented toward east and southeast. Deluvial-proluvial sediments have the strongest correlation of all geologic formations with the unstable, steep valley side slopes. The prevalent land cover is partially cultivated landscape followed by mixed forests.

Susceptibility for the TYPE 4 landslides above the stream source area

This type is mostly found in the elevation zone of 250-350 m. The stream initiation zone where these landslides form should have even higher elevations, but the exposed metamorphic and igneous geologic units restrict the formation of unstable areas in the central parts of the mountain. Slope values are dispersed according to the expectation between 15 and 35 %. The upper pontian sandstone, sand, marl formations are related predominantly to the occurrence of landslides above the stream initiation zones.

Susceptibility for the TYPE 5 landslides beneath loess scarps

Landslides in loess are located most frequently in the narrow zone between 200 and 250 m, with slopes between 15 and 35 %, northern and north-eastern exposure. Redeposited loess is the most dominant geological unit, followed by loess and deluvial-proluvial sediments in a much smaller proportion. The slopes under this type of landslides have larger profile curvature values compared to other landslides (0.2 - 0.5)

The most susceptibility index values were within the expected ranges, which confirms the soundness of the model and the adopted landslide classification. The proposed landslide typology has been generally upheld by the results from the likelihood susceptibility model, with susceptibility indexes of environmental parameters within the expected ranges for most types of landslides.

4.5 Landslide inventory of the Fruška Gora mountain

I prepared the landslide inventory of Fruška gora, with the locations of 122 landslides covering a total of 40.6 km^2 (4.3 % of the total area of 976 km^2) and classified into 6 groups based on their relative topographic and geomorphologic position (Figure 10).

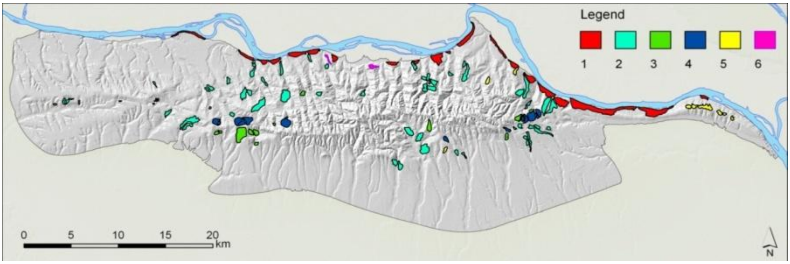

Figure 10. Landslide inventory of the Fruška Gora mountain legend: 1 - Deep, complex „Danube" type landslides above the Danube riverbank, 2- Landslides on concave, convergent valley side slopes, 3-Landslides on steep, convex or planar valley-side slopes 4-Landslides above the stream source area,5-Landslides beneath loess scarps, 6- Landslides under predominant anthropogenic influence

5 Conclusions

Based on the obtained results it can be concluded that from the very limited available resources and medium quality data an acceptable representation of the geohazard susceptibility of the Fruška Gora was achieved. The employed methods can be implemented in the future also with higher quality data which will hopefully become more available in the coming years. These results and proposed methods will be used as a part of the Geographic Information infrastructure in the National Park of Fruška Gora and the GIS of the Institute for Nature conservation of Serbia, and can be implemented in planning, damage mitigation, prevention and research purposes.

The obtained results constitute the part of my ongoing research of nautral conditions on Fruška Gora, which will be continued trough more detailled terrain investigations based on the landslide susceptiblity maps. The database of geohazards will be also analysed with other models and the results will be further improved.

This research has been supported by the Ministry of the Education, Science and Technological Development under the project „Biosensing technologies and global systems for continous research and integrated ecosystem management“ No III43002.

6 New research results

- The database of geohazard factors for the Fruška Gora was created;
- Digital elevation model of Fruška Gora was created, based on contours and elevation points from topographic maps in 1:25,000;
- Digital surface model (DSM) of Fruška Gora was extracted from a stereo pair of high resolution archive satellite image from the CORONA program;
- I showed the applicability of the DSM extracted from CORONA images in geomorphometric analysis, as a viable source of land surface features for larger areas where no detailed topographic data is available;
- I demonstrated the suitability of historical topographic maps from the Third ordnance survey of the Austro-Hungarian empire from 1881 (1 :

25,000) in analyzing past large landslide events in smaller areas by identifying the likely landslide initiation area;

- I prepared the landslide inventory of Fruška Gora, with 122 identified landslides classified in 6 types;
- I mapped shallow landslide susceptibility on the Fruška Gora using the SINMAP deterministic model, and identified areas most vulnerable to shallow slope movements;
- I created the susceptibility map for deep seated landslides on Fruška Gora and identified areas of various levels of vulnerability;
- I proposed a set of efficient and applicable methods for geohazard evaluation on the Fruška Gora and similar terrains that can be performed from very limited available resources and medium quality data;

List of publications concerning the topic of the dissertation

1. Dragićević S., **Mészáros M.,** Đurđić S., Pavić D., Novković I., Tošić R. (2013). Vulnerability of National Parks to Natural Hazards in the Serbian Danube Region, Polish Journal of Environmental Studies, Vol 22, No 4. (In press)
2. **Mészáros M.**, Szatmári J., Tobak Z., Mucsi L. (2008). Extraction of Digital Surface Models From CORONA Satellite Stereo Images, Journal of Environmental Geography, 2008, Vol. 1, No. 1-2, pp. 5-10
3. **Mészáros M.,** Pavić D., Seferović S. (2007). Monitoring Mass Movements and Natural Hazard in The Northern Parts of Srem Loess Plateau in Serbia, Geographica Pannonica, Vol. 11, pp. 9-13, UDK: 05:91(497.1)=20, ISSN 0354-8724.
4. **Mészáros M.**, Szatmári J., Tobak Z., Mucsi L. (2006). Digitális domborzatmodellek előállítása és alkalmazása sztereo CORONA űrfelvételek alapján, Geodézia és Kartográfia, 2006, No. 3, pp. 30-35, ISSN 0016-7118.
5. **Mesaroš M.,** Pavić D. (2006). Mogućnosti upotrebe GIS-a u geomorfološkim proučavanjima na primeru Fruške gore (Possiblities of GIS application in geomorphological research on the example of Fruška gora), Researches review of the Department of Geography, Tourism and Hotel management No 35., Faculty of Sciences and Mathematics, University of Novi Sad, pp. 238-245 (in Serbian)
6. **Mészáros M,** Marković S. B., Mijović D., Jovanović M. (2005) Physical geographic characteristics and geo-heritage of Fruška gora mountain (Vojvodina, Serbia), Acta Geographica Szegediensis Tomus XXXVIII, pp. 148-157