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A GIS-based approach for mapping hazardous areas due to geological slope processes: case study for Jesenice municipality in Slovenia.

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ABSTRACT: As the human population and the developed areas are increasing, rural areas are getting more and more populated. Development of rural areas creates problems especially in mountainous regions and areas that are highly susceptible to geological slope processes as people often tend to build houses and reside in such areas. Therefore, a need for classification and identification of hazardous zones is present so that precautions can be made in order to lessen the effects of geologically conditioned risks. In order to create a map of hazardous areas, identification of risk present for a specific site has to be made, as different geological processes dominate in specific areas. A case study is presented for a municipality of Jesenice where a steep mountainous region with a large energy potential and precipitation area are one of the main factors of geologically conditioned risks. The purpose of this study was to construct a hazard map classified in several classes according to susceptibility for geological risk and to prepare a set of measures to lessen the damaging effects and allow safe construction of different objects in affected areas. For that, identification of present geological processes in the area was made in order to create a hazard map for each of the prevailing processes. In our work landslides, debris flows and rock fall was identified as a present and prevailing slope processes in the area. According to different types of slope processes we made threat specific maps for each process in order to identify which risk is dominating in specific area. Determination of which process is dominating in specific area was crucial as the protection and countermeasures are completely different for each of the processes. After that we combined individual maps to get a final map of geologically conditioned hazardous areas. Due to a large area of interest Geographical Information System (GIS) based models were used – a different model for each process. Different input data were used for each of the model as the dynamics of each process is different. Data used in models included slope gradient, concavity of slopes, geology, vegetation and precipitation. For modeling rock fall we used a RockyFor3D developed by Luuk K.A. Dorren. Individual models were calibrated and verified on numerous observed locations. Final result of our model produced a hazard map divided in four classes according to degree of risk. For every class a chart was made with a list of conditions that must be met in order to ensure safe building in affected areas and prescribed necessary and relevant geological investigations. Models used in our study turned out to be a good tool for fast rating of geologically induced threats on a regional level, but they can easily be modified for use on a more site specific problems.

Keywords: GIS, landslides, rock fall, debris flow, geotechnics

1 INTRODUCTION

As the human population and the developed areas are increasing, rural areas are getting more and more populated. Development of rural areas creates problems especially in mountainous regions and areas that are highly susceptible to geological slope processes as people often tend to build houses and reside in such areas. Therefore, a need for classification and identification of hazardous zones is present so that precautions can be made in order to lessen the effects of geologically conditioned risks. A case study is presented for a municipality of Jesenice in the northern part of Slovenija, where a steep mountainous region with a large energy potential, precipitation area and the diversity of lithological units are one of the main factors of geologically conditioned risks.

The purpose of this study was to construct a hazard map classified in several classes according to susceptibility for geological risk and to prepare a set of measures to lessen the damaging effects and allow safe construction of different objects in affected areas. For that, identification of present geological processes was made in order to create a hazard map for each of the prevailing process. During this study several geologically conditioned slope processes were researched and modeled:

- landslides
- debris flows
- rock fall

Based on the type of slope process threat specific maps were constructed for each in order to identify which risk is dominating in specific area. In the last part partial hazard maps as a result of landslides, rock falls and debris flows were combined in order to get a general hazard map of the area.

Different input data were used for each of the model as the dynamics of each process is different. Data used in models included slope gradient, concavity of slopes, geology, vegetation and precipitation.

Final result of our model produced a hazard map divided in four classes according to degree of risk. For every class a chart was made with a list of conditions that must be met in order to ensure safe building in affected areas and prescribed necessary and relevant geological investigations. Models used in our study turned out to be a good tool for fast rating of geologically induced threats on a regional level, but they can easily be modified for use on a more site specific problems.

2 DESCRIPTION

The municipality of Jesenice is situated in the north western part of Slovenia. The city of Jesenice lies in the vales of river Sava, bordered with Karavanke Mountains on the northern part and Julian Alps on the southern part.

Municipality of Jesenice is one of the most versatile areas in Slovenia in geological sense, with the range of geological formations from Paleozoic era to Quaternary sediments. Populated areas in the municipality range in elevations from the main city center at elevation around 700 meters above sea level to remote villages at almost 2000 meters above sea level. Picture below gives the main overview of the municipality.

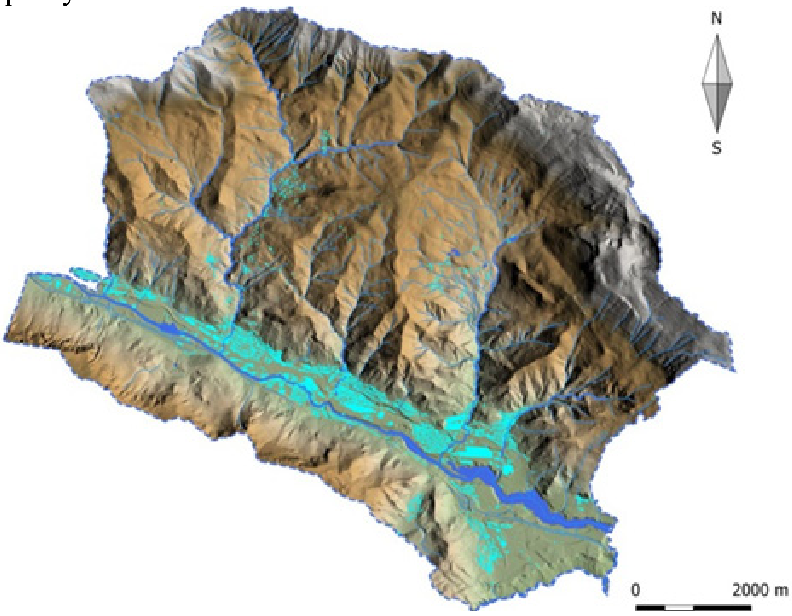

Figure 1. DEM of municipality of Jesenice (populated areas are in cyan color).

Geology and morphology of the terrain play a major role in problems related with catastrophic events. In last years number of catastrophic events is increasing in Slovenia causing major economic damage and loss of human life. Because of that municipality of Jesenice decided to conduct a study, based on which, landscape use will be made.

Landslides, debris flows and rock falls were identified as geologically related slope processes that are most likely to cause damage in the area. A map was created for each of the process in order to identify areas in which each risk is prevailing. The main cause for that was that the measures for increasing safety in given area are highly related to type of hazards. Diagram below shows the concept used in creating a hazard map.

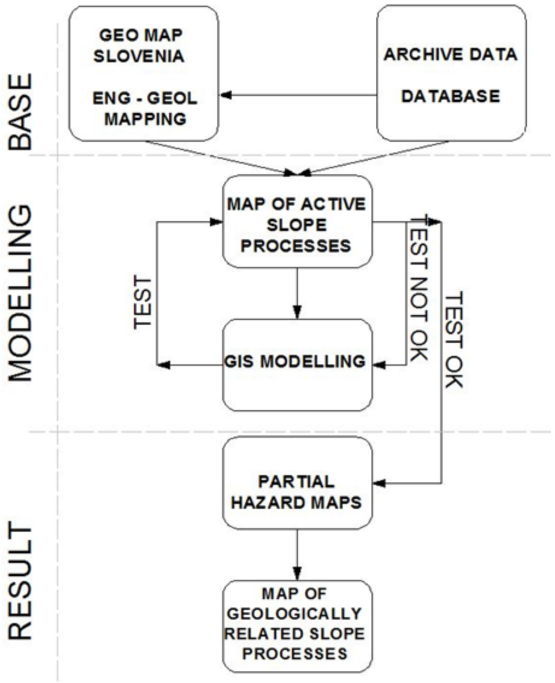

Figure 2. Concept used in creating a hazard map.

In creating of hazard map a base geological map of Slovenia (1:100000) was used as a foundation for engineering - geological mapping. Urban areas and areas with geotechnically worse lithology were mapped in bigger detail that other part of municipality.

GIS system was used as a base tool for spatial analysis and raster creation. Each of the slope process had different input, based on the mechanism that drives the process. Below diagram shows layers used in modeling each process.

	slope process	LANDSLIDE	DEBRIS FLOW	ROCK FALL
FACTORS	TERRAIN	LITHOLOGY SLOPE THICKNESS OF SOIL MORPHOLOGY	LITHOLOGY SLOPE POTENTIAL ELEVATION MORPHOLOGY	LITHOLOGY SLOPE MORPHOLOGY SURFACE ROUGHNESS ROCK DENSITY ROCK SHAPE
	INITIAL	CONCAVE/CONVEX PERCEPITATION	DISTANCE TO SURFACE FLOW ENERGY POTENTIAL OF WATERFLOWS CONCAVE/CONVEX PERCEPITATION	SOURCE POINTS

Figure 3. Factors included in modeling of slope processes.

All factors were normalized to values between 0 and 1 in order to provide equivalence when summing the raster together. This factor is called factor of contribution.

3 METHODOLOGY

Different methodology was used for each slope process. Engineering - geological map was created during mapping of urban and problematic areas. This map was later additionally modified and factor of contribution was dedicated. Factor of contribution was dedicated in accordance to geotechnical characteristics of rocks and sediments that dominate each process. Bellow table shows factors of contribution for given type of lithology used in modeling landslides and debris flows.

Table 1. Factor of contribution for given process

lithology	LANSLIDES	DEBRIS FLOWS
lithified sea sediments	1	0.5
marlstone	0.75	0.67
siltstones and silt	0.75	0.5
claystone	0.75	0.67
deluvial sediments	0.75	0.83
marl limestone	0.5	0.67
alternation of sand stones and siltstones	0.5	0.5
deluvial fans	0.5	0.83
claytones and clay	0.25	0.17
sandstones	0.25	0.5
alluvial sediments and river terraces	0.25	0.33
carbonate rocks	0	0.33
plain alluvial sediment	0	0

Same process was used in most input data raters. Models for landslides and debris flows are in general iteration models, based on trial and error. Data that we collected during geological mapping was saved in a database that was used in model calibration, according to figure 2. Raster was calculated (summed) where different weight was given to each layer until final map coincided with field observations. Bellow landslide risk map is presented.

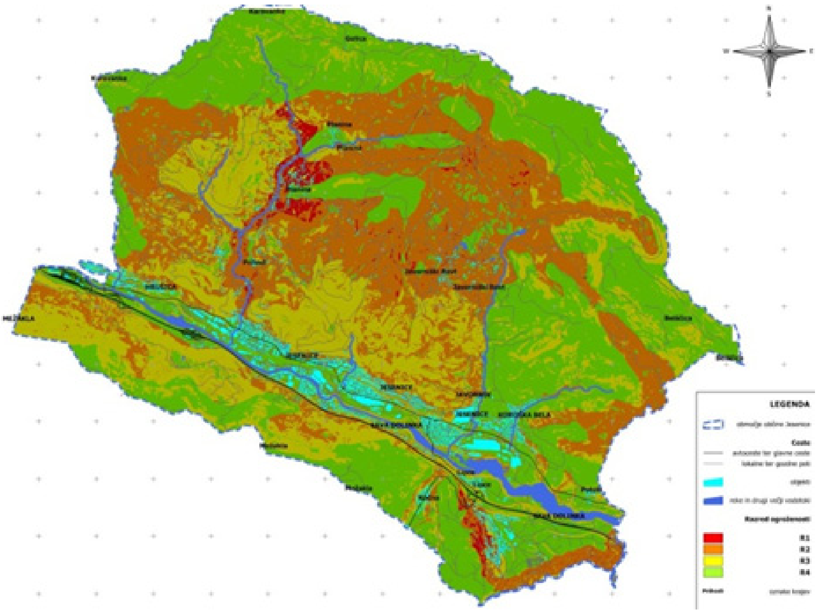

Figure 4. Landslide risk map

End maps were divided in 4 different classes using natural breaks method (“jenks”), where class 1 (red on figures 4 to 7) represents the most highly susceptible map and class 4 (green on figures 4 to 7) represents an area least likely to be hit by disaster.

Model for landslide and debris flows are not numerical model, but analytical. Because of that an additional mapping of run out zones for debris flow was conducted where areas historically stroked with debris flow were estimated. These areas were later accounted in summing the rasters which generated debris flow map. Figure 5 shows debris flow map generated with described methodology.

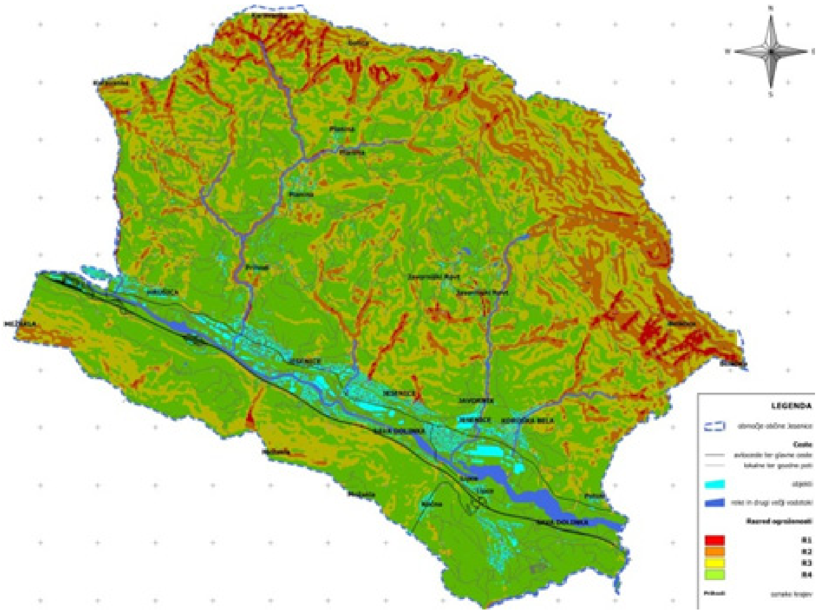

Figure 5. Debris flow map of Jesenice municipality

Methodology for rock fall forecast is different. For rock fall predicting a numerical model was used, developed from Luuk K. A. Dorren. RockyFor3D, a Matlab based model, was used to determine rock fall runout zones and energy created in falling rock. The result analysis was a raster map with quantified energies and trajectories of rocks. First initial zones were determined with the use of spatial analysis and GIS, which served as a base for numerical calculation. Different layers of input data was used, such as:

- lithology type
- rock shape
- falling rock dimensions
- DEM
- density of rock

Hazard map was created and divided in four classes (such as for landslides and debris flows) based on the amount of energy needed to damage certain structure. Bellow table show the logic we used in generating classes of risk from rock fall damage.

Table 2. Classification of rock fall risk classes

risk class	energy [kJ]	description
R4	0 - 200	no risk
R3	0 < E < 200	energy retained reinforced concrete
R2	200 < E < 2000	energy retained by strong containment fence
R1	> 2000	destructive energy

Map of rock fall risk classes is shown below, according to above table.

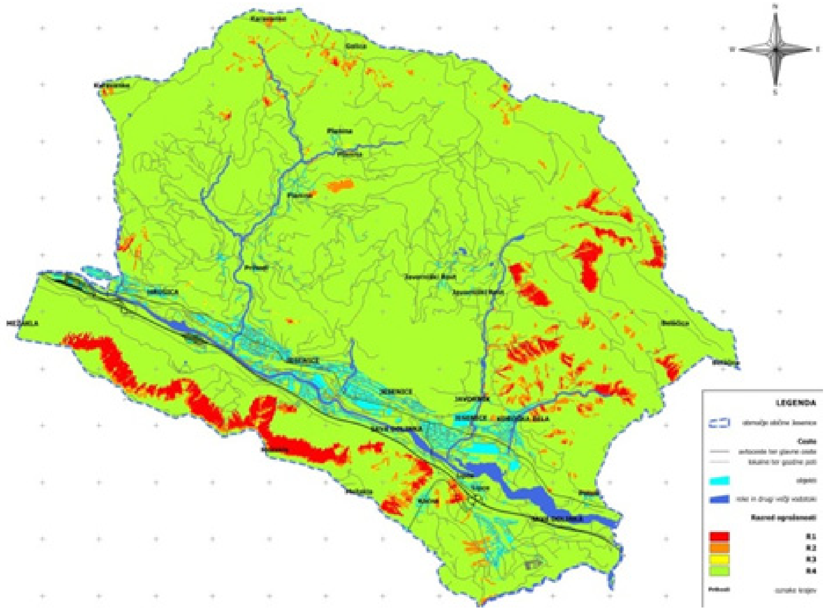

Figure 6. Rock fall risk map.

Final risk map contains all of modeled processes. Maps were joined together, where maximum value of class was determined, according to equation bellow:

Risk class = max([value RockFall], max([value Landslide],[value DF]))

Figure 7 shows final map of geologically conditioned risk as a result of slope processes, combined with the above equation.

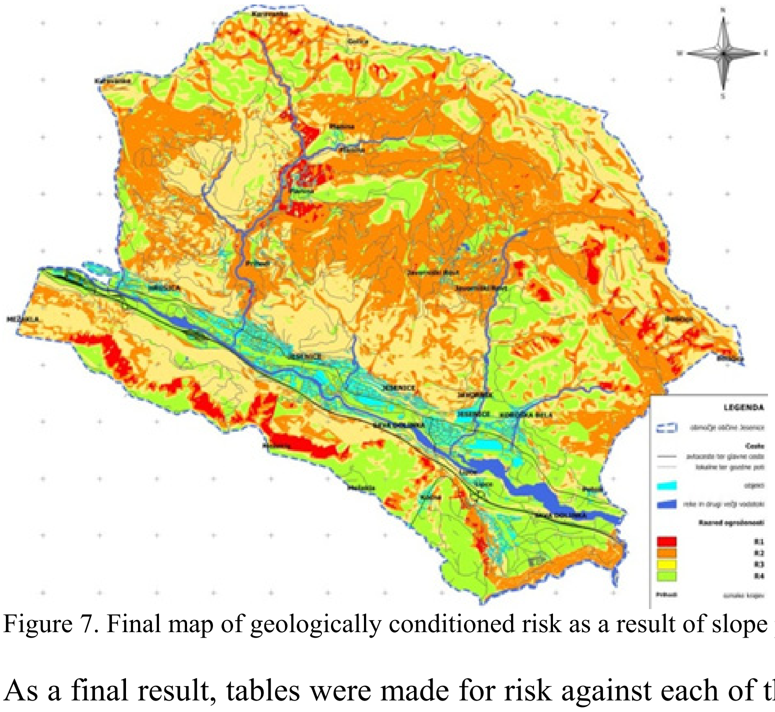

Figure 7. Final map of geologically conditioned risk as a result of slope processes for the municipality of Jesenice.

As a final result, tables were made for risk against each of the modeled slope process, with necessary and proposed geological investigations, that need to be conducted in order to assure safe building and living in endangered areas. Table 3 shows such table, where R1, R2, R3 and R4 represents risk class.

Table 3. Table of necessary site investigation created for landslides risk map. a - j are geological investigations, ranging from geomechanical boring to different types of analysis.

LANDSLIDES	**R1**	**R2**	**R3**	**R4**
complex objetcs	a,c,d,e,f,g,h,i,j	a,b or c,d,e,g,i,j	a,b,e,i	a,i
less complex objects	a, b or c, e, g, i, j	a,b,i	a, i	a
Non-complex and simple objects	a,i	a	-	-

Tables were made in accordance to current building and spatial laws in Slovenia and European standards for soil and rock investigations (Eurocode standards). Necessary and proposed site investigations are therefore prescribed for a given complexity of objects and the risk class obtained with GIS model.

4 CONCLUSION

GIS based survey made for the municipality of Jesenice showed good results and is serving as a good foundation for further landscape planning. Although the scale of created maps is fairly small (1:25.000) for an exact urban plan, it shows problematic areas which need to be analyzed in greater detail. Main advantage of this study was the wide range of the processes modeled, taking in account landslides, debris flows and rock falls. Mapping or modeling of each of slope processes allowed creation of rules and site investigation for a given risk. As a result of modeling each process independently, tables were created, which are serving municipality officials as a foundation on which they can propose the type of site investigation needed to assure higher safety of objects.

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