EARLY LANDSLIDE PREDICTION IN NON-ALPINE AREAS

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In Centra Europe damages caused by landslides have increased drastically in the last years. Current research concentrates on soil creep in the province of Burgenland, Austria, where little is known about the distribution of these hazards and their triggering factors. During the project, 72 landslides were surveyed and characterized using mobile GIS. The landslide events together with factors like geology, land use, and topography shall help to predict endangered areas. Weights of Evidence modeling is utilized to calculate the probability for future landslides based on known hazards and geological and landscape factors. The resulting landslide susceptibility map is designed for use in urban and regional planning. For better understanding, it is reclassified into three levels of endangerment. Validation shows that 98 percent of landslides in a control group are correctly predicted. In the future, the study area will be extended and in-depth investigations will be carried out in the identified high-vulnerable regions.

1 INTRODUCTION

In the last years and increasing number of damages caused by land slides has been registered Burgenland, the most Eastern Province in Austria. Especially infrastructure and buildings in the Southern part of the province are most affected. Beneath changes in regional climate bringing heavy rain storms, the geological structure of the region can be made responsible for the increased landslide susceptibility. Together with population growth and changes in land use policy, the potential for damages has remarkably increased as more people set up there houses in potentially endangered zones, unaware of the inherent risk. Still there is no general information on the distribution of landslides available for Burgenland, neither in the form of overview maps nor as in depth analyses of endangered sites.

Therefore, the main objective of this project is the systematic collection of data on historic and recent land slide activities, as well as a comprehensive cause analysis. This means the survey of each landslide, characterization of its geological and geomorphological characteristics and determining triggering factors. The study area for this research comprises the Southern districts of Burgenland, extending to the North in future projects.

After data collection supported by mobile GIS during field campaigns in summer 2005, data are transferreed to ArcGIS for a first visual impression of the spatial extent of landslides and the generation of a land slides susceptibility map. Based on known land slides and the triggering factors, the probability for future events is calculated with spatial statistical methods over the extent of the study area. The purpose of the resulting hazard map is the delineation of landslide risk zones to support decision makers in local and regional land use planning.

2 STUDY AREA AND DATA

The study area covers an area of 738km^2 in the two most Southern Districts of Burgenland, namely Güssing und Jennersdorf. The area is bounded by the wide flat valleys of the rivers Pinka in the West and Lafnitz in the East. A typical hilly landscape with elevations between 150 m and 540 m above sea level and average slopes of 15 %, spans between those valleys. Figure 1 shows the characteristical landscape by an example taken from the village Kukmirn, where pomiculture is the dominating land use.

Figure 1: Location of the Study Area in the Southern Part of the Austria Province Burgenland

2.1 GEOMORPHOLOGICAL AND GEOLOGICAL OVERVIEW

Geomorphology and Geology are the most relevant factors for the occurrence of landslides. Figures 2 and 3 provide on overview of the study area using a shaded relief representation and a geological overview map.

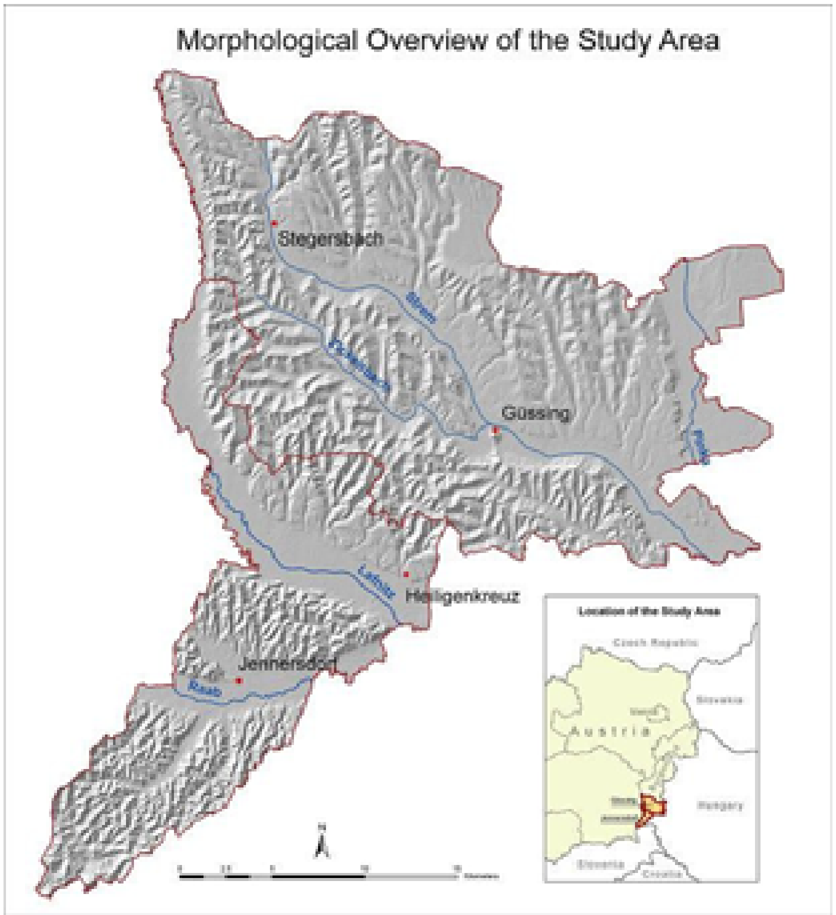

Figure 2: Morphology and Location of the Study Area in the Southern Part of the Province Burgenland

- **Geomorphology:** the shaded relief clearly shows the large flat valleys along the rivers Strem, Lafnitz, Pinka and Raab as well as the rugged hilly landscape in between. Interestingly, the roughness increases from North to South, whereas towards the East and the Pannonian Basin, the landscape flattens out. From these first observations a rough estimation on the distribution of landslides could be gathered. Accordingly, landslides are most likely to occur in the Southern and Central parts of the study area, where landscape is most structured and steeper slopes are found, but none are to be expected in the flat valleys and the flatter hills Northeast of Güssing.
- **Geology:** Pannonian klastic sediments, such as Clay, Silt, Sand and Fine Gravel are the dominating geological unit in the region. This formation is known to get instable in cases of heavy rains and most of the known landslides are located in their extent. In the Southern part these Pannonian Sediments are overlaid by layers of middle to coarse gravel, which are suspected to stabilize the slopes. In the larger valleys, alluvial sediments are found accompanied by gravel terraces along the banks.

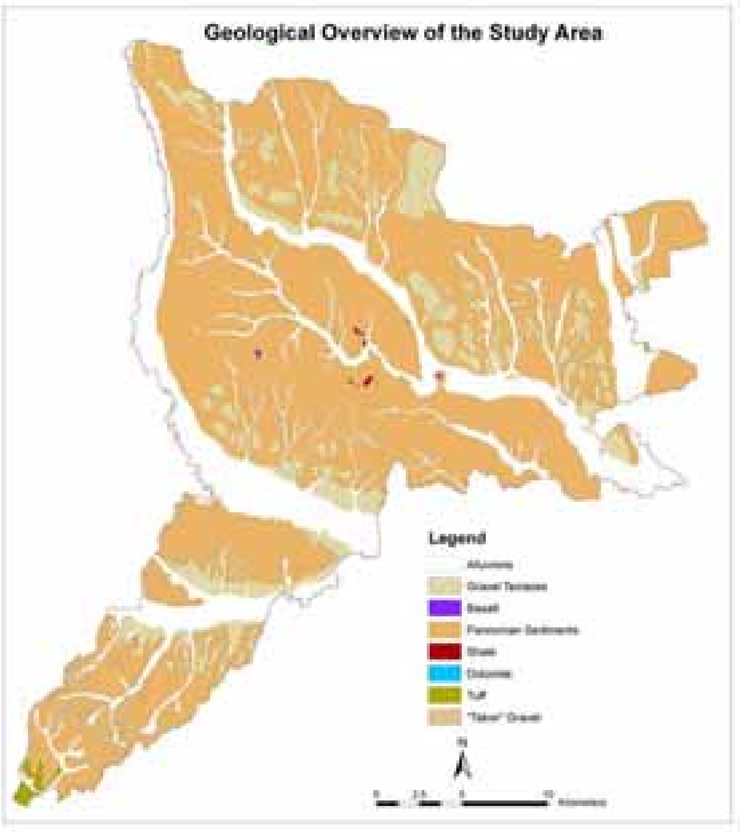

Figure 3: Overview of the dominating geological units in the districts of Güssing and Jennersdorf

2.2 AVAILABLE DATASETS

A set of digital and analogue data sets served the base for the research project. Most of the digital data were provided by the federal government of Burgenland:

- **Digital Elevation Model** with a horizontal resolution of 10 m
- **Color Orthophotos** with a horizontal resolution 0.25 m
- **Topographical vector data** (e.g. rivers, roads)
- **Topopgraphical raster map** 1:50,000

Geological maps from the Geological Survey Austria, covering the whole area at scales of 1:200,000 were complemented by a more detailed map at a scale of 1:50,000, which was only available for the Northern parts of the study area. Data on **landuse** stem from a European Corine Landcover dataset and were provided by the Austrian Environmental Agency. Talks to local authorities, land use managers and geologists as well as additional literature on geology and morphological characteristics proved to be very useful to understand the regional geology and get to known about accumulations of land slides before collecting further data during field surveying campaigns.

3 SURVEYING AND CHARACTERITZING LAND SLIDES AND DAMAGES

In July and August 2005, extensive field campaigns were started to get a comprehensive overview on landslides, their characteristics and spatial extent as well as damages on buildings and infrastructure. On site geographic and attribute data were recorded with a mobile GIS device and photos were taken of all remarkable features.

3.1 FIELD DATA COLLECTION

By the aid a GPS receiver with ArcPad software, the extent of landslides could be digitally recorded on site and with attribute data like the presence of specific morphological characteristics and vegetation or temporal information. Back in the office, a data base on landslides was set up in ArcGIS from the collected data which were complemented by with additional remarks from field notes. Using the color orthophotos in the background the delineated features were validated on screen. Figure 4 shows the distribution of landslides in the study area.

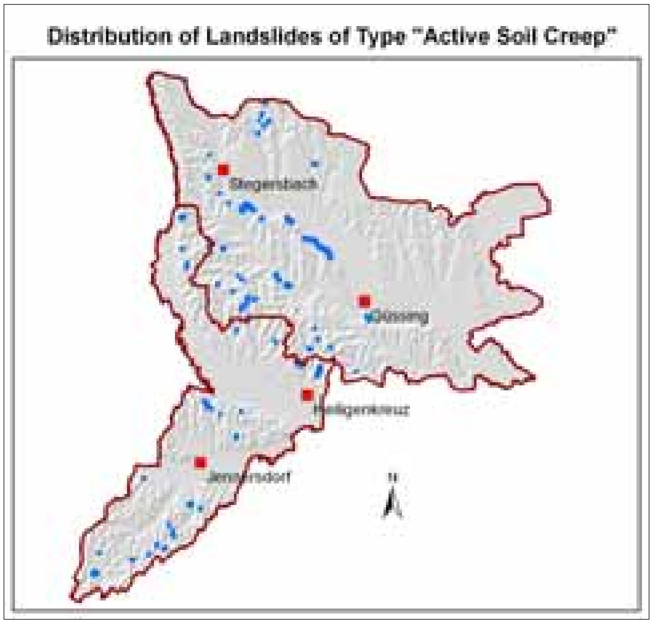

Figure 4: Distribution of landslides in the study area

3.2 ANALYSING MORPHOLOGICAL CHARACTERISTICS AND TRIGGERING FACTORS

Landslides were systematically characterized using a set of morphological features. It was for example recorded, if slopes are unnormally steep, subsidences or so called neck-valleys are present or if soil moisture is increased. Additionally, typical symptoms of trees were searched, as bent trees are mostly a clear indication, that they are growing on a moving ground. Figrue 5 exemplifies some of the characteristic features of a landslide, which in this case threatens a building.

Figure 5: Typical landslide morphology with subsidence (1), very steep slope (2) and a bent tree (3)

3.3 DAMAGES CAUSED BY LANDSLIDES

Besides the morphological characteristics, damages on infrastructure and buildings were recorded, where a correlation with landslides was most probable. Figure 6 provides an example for one of the more serious destructions of houses, which has become unhabitable. Generally it could be observed that larger damages are seldom. Most of the landslide areas have been stabilised and where necessary, houses and roads are permanently renovated.

Abb. 6: Damage to a building, caused by active soilcreep

4 PREDICTING LANDSLIDE SUSCEPTIBILITY

For the prediction of landslide susceptibility, based on morphological and geological, the method „Weights of Evidence" (WofE) (Bonham-Carter et al, 1989) was chosen. This probabilistic method has originally been developed for mineral and ore exploration, but is now increasingly used for the statistical assessment of landslide susceptibility (e.g. Neuhäuser, 2005). It is assumed, that future slides are triggered or influenced by the same or similar controlling factors as already registered landslides of the same type.

4.1 WEIGHTS OF EVIDENCE MODELING

Weights of evidence (WofE) methodology uses a Bayesian approach to combine spatial data from diverse sources for describing and analyzing interactions in order to model and predict the occurrence of events (Raines et al, 2000). In the present project the events to predict are landslides that depend more or less on different factors like geology, land use or terrain parameters (evidence themes).

WofE first estimates the prior probability, which describes the chance that an event occurs in particular area unit without any influence. Posterior probability is then calculated for each evidence theme based on prior probability and the presence or absence of this evidence in correlation with the events. Accordingly, the evidence layers are weighted based on their correlation with the landslides. A positive weight for a particular evidential-theme value indicates that more landslides occur on that theme than would occur due to chance, whereas the converse is true for negative weights. Figure 7 provides an example of these weights for different slope classes.

By combining the weights of predictor variables (e.g. slope classes) from the evidential themes, the probability that a unit cell (in our case a raster cell of a map) will contain an event (landslide) is determined. More information about the theory behind WofE can be found in Bonham-Carter et al (1989). Weights of Evidence Modeling is available with the free extension Arc-SDM 3 (Spatial Data Modeler) for ArcGIS 9.x (Sawatzky et al, 2004) and Spatial Analyst, together with other useful statistical methods.

4.2 GENERATING EVIDENCE LAYERS

The input data for WofE modeling like geology, DEM or landuse stem from the sources mentioned in section 2.2. Before investigating the correlation of these factors with the landslide locations, the evidence layers had to be digitally processed, including digitizing analogue geological maps and deriving topographic attributes from the DEM. The following list summarizes the involved data layers and their relevance:

- **Landslides:** During field surveys 72 landslides have been registered by their spatial extent and characterized as described before. As ArcSDM requires a points as input for the event layer, the landslide areas were represented by their centroids and randomly distributed points, which are needed to cover larger areas. Ultimately 97 control points with additional points fort he later validaton were available.

Evidence layers:

- **Geology:** Geology is one of the main factors responsible for the occurrence of landslides. To describe the geology for the whole study area, different geological maps were combined. Layers of gravel that might indicate more stable slopes were integrated.

- **Land Use:** Land use is mostly a good indicator for the usability of the Earth’s surface, e.g. for extensive agriculture. In field, it could be observed, that landslide areas involved are often no longer managed and lie idle. By the aid of the Corine Landcover data on level 2, such areas can be identified and incorporated in the further analyses.

Following parameters are derived from the DEM with a cell size of 10m, using Spatial Analyst as well as an additional extension in ArcGis:

- **Slope:** This factor is strongly correlated to slope stability. At low slopes, the triggering factor for soil creep is missing. Only above a slope of 15% areas are potentially endangered On the other hand stepper slopes indicate, that soil is better stabilized and the probability for a landslide decreases. For modelling, Slope in % was calculated and divided into 10 classes with a range of 5% for each class.

- **Aspect:** The direction of slope shows a certain degree of correlation with the occurrence of landslides in the study area. One possible reason is the accumulation of wind-eroded material in a specific direction, which is prone to cause landslides. Furthermore, local climate influenced by sun exposure is likely to affect the vegetation and hence the slope stabilisation. For further investigations, Aspect was calculated from the DEM in classified in steps of 45 ° (0-15°, 15-45°, ... , 315-360°)

- **Terrain Roughness (Surface Area Ratio):** This measure describes the ratio between surface area and horizontal area and gives indication of the terrain roughness. It was calculated from the DEM using the ArcView extension „Surface Areas and Ratios from Elevation Grid“ (Jenness, 2002).

All of the above mentioned evidence layers can be used in both vector and raster format in ArcSDM. However, performance is better with raster data.

4.3 COMPUTING LANDSLIDE SUSCEPTABILITY MAP

Following the approach outlined in section 4.2, for each of the evidence layers the probability that at landslide would occur if an evidence is present or absent, is calculated. To give an example, figure 7 shows the weighting of slope classes according to their relevance for the occurrence of landslides. W+ is an indicator for the probability that if a (slope-) class is present, a landslides may occur (W+ = positive) or may not occure (W+ = negative). W- describes the same relation, for the case that a class is absent.

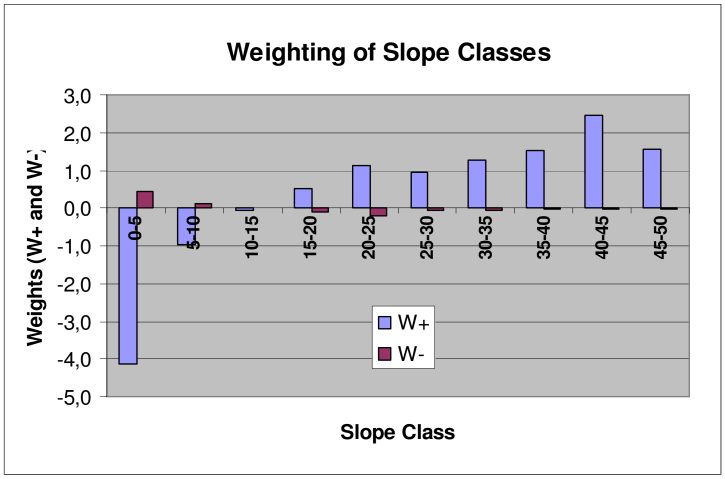

Fig. 7: Slopes between 20 and 50 % are significant indicators for landslides, while slopes lower than 15 % are a secure indication for the absence of landslides.

Accordingly the weights are calculated for all the evidence layers, to determine, which factors are strongly correlated with landslides. Those evidences with the highest positive spatial correlation (high W+ value) are summarized in Table 1. The normalised Contrast sC (Contrast divided by its standard deviation) describes the significance of the correlation. Looking at the overall contrast (including all classes of an evidence) in the second column of the table, slope has the highest value, meaning that it's the best indication for the presence or absence of landslides.

Table 1: Overview of evidence classes, which have been identified as good indicators for landslides by their positive spatial correlation.

Steuerungsfaktor/ Evidenz	Overall Contrast	Evidenz class	W^+	sC
Geological Unit	5,95	Pannonian Sediments – Miozän	0,34	4,75
Land Use / Land Cover	6,85	23: Grassland	1,05	5,54
		24:	0,43	2,42
Slope	10,62	20 – 25 %	1,02	4,71
		25 – 30 %	1,41	5,72
		30 – 35 %	1,32	3,67
		35 – 40 %	1,79	4,22
		40 – 45 %	2,47	5,11
		45 – 50 %	2,12	3,48
Terrain Roughness (Surface Area Ratio)	6,53	1,0085 – 1,0168	1,48	9,32
Aspect	1,73	0 – 45 °	0,91	4,37
		45 – 90 °	0,35	1,70

After calculating the weights for all evidence classes, they are combined for each cell of the final probability map to be able to predict the occurrence of future landslides for the entire study area. The probability values range between 0 and 0.99. This range might be interesting for statistical reasons or experts, for a practical use in decision support a reclassification is required. Following the Swiss suggestions to integrate landslide hazards in regional planning (Latelin, 1997) three hazard classes with color coding have been defined:

Hazard	🟧
Hazard cannot be excluded	🟦
No Hazard	🟨

5 RESULTS

The result from this reclassification is shown as three-dimensional representation in Figure 8. The overlay with the shaded relief intensifies the visual impact und makes the relations between terrain characteristics and the potential for landslides. Analysing the area distribution of the hazard zones, about 50 % of the region are not endangered, in one third of the region, landslides may occur and one sixth of the area is definitely endangered.

Fig. 8: Three-dimensional overview of the study area with the hazard map overlaid.

5.1 VALIDATION

As the hazard map shall form the basis for deeper investigations and an extension of the model area is planned, a validation of the map and its hazard zone is required. We have performed a two way approach:

- **Visual Interpretation by Experts:** By comparing the surveyed landslides overlaid on the hazard map with the experience and impressions gained from several field trips, the authors could approve the prediction of the map. Especially the overserved accumulations of landlsides on site correlated well with the Hotspots in the hazard map. Especially the Southern region and the surroundings of the Villages Kukmirn and Stegersbach can be pointed out (see Figure 9).

- **Determining the Prediction Rate:** Statistically, the model was validated by control points that have not yet been integrated in the model. For these points that have been randomly distributed over the landslide areas, it is checked if they lie within the zones “Hazard” or “Hazard cannot be excluded” and hence were predicted correctly. In Figure 9, the cumulated random points (y-axis) are drawn against the area percentage of each hazard zone (x-axis), ordered by the landslide susceptibility. The diagram illustrates that 98 % of the control points were correctly predicted to lie in one of the fully or partly endangered zones. The 2% of points that lie outside the hazard zones can be explained with a possible fuzziness of the input data.

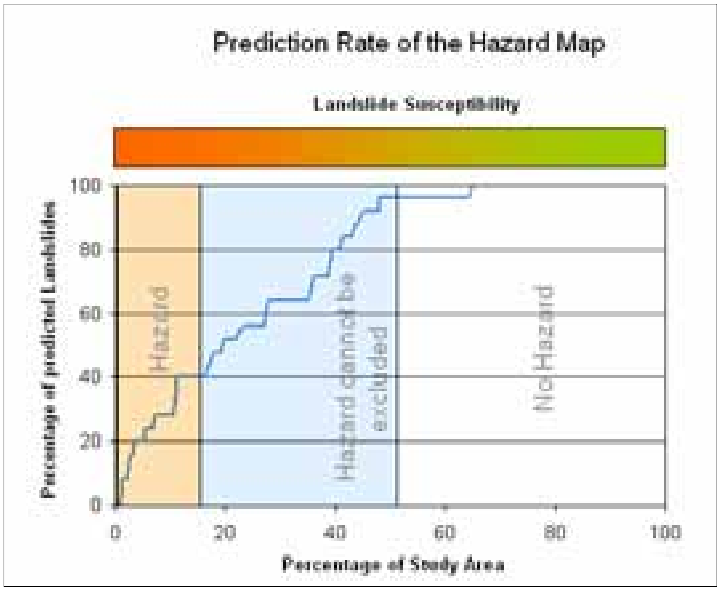

Fig. 9. 44: Prediction rate for landslides, based on random control points within known events that have not been considered in the model.

- **Comparison with very recent landslides:** In spring 2006, a mass movement was triggered by heavy rain near Loipersdorf. After comparing the location of the landslide event with the hazard map, the chief geologist expert from the Burgenland government could certify the correct prediction of the landslide by the map: the landslide was located in the orange “hazard” zone.

6 DISCUSSION

After presenting the hazard map to authorities at the Burgenland government, the authors got a very good feedback for their work. Such an area-wide mapping of landslide susceptibility had not existed before in the province and is now up to become a very useful tool for regional planning. Although local governments on municipal level are sometimes aware of endangered zones, a comprehensive overview of hazard zones on district level can help to consider landslides more strongly in planning processes of the federal government.

The methodology that has been used in the project turned out to be useful not only in mineral exploration but also for landslide predication. The quality of the results is more than satisfying, so WofE approached will be used intensively in future projects with the same or a similar framework.

7 OUTLOOK

Due to the good feedback from experts of the Federal Government of Burgenland, a Follow-up project could already be started in the district Oberwart, which is the neighbouring district North of Güssing. In this project we will basically use the same method and data as geology and morphology in most parts is identical, but we will also look more into detail at endangered zones. As part of proposed future research projects the incorporation of new methods for data acquisition as well as alternative modelling tools will be investigated.

8 ACKNOWLEDGEMENTS

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