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Landslide susceptibility maps for spatial planning in Lower Austria

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Abstract Landslides threaten most parts of the provincial state of Lower Austria and cause damage to agricultural land, forests, infrastructure, settlements and people. Thus, the project "MoNOE" (Method development for landslide susceptibility modelling in Lower Austria) was initiated by the provincial government to tackle these problems and to reduce further damage by landslides. The main aim is to prepare landslide susceptibility maps for slides and rock falls and to implement these maps into the spatial planning strategies of the provincial state. Landslide susceptibility maps are either prepared by statistical (for slides) or empirical or process-based (for rock falls) approaches. Final maps are combined to a single landslide susceptibility map and optimised for the end-users (spatial planners and local authorities). It shows that a difference exists between the best scientific maps and the best maps for spatial planning purposes. This involves questions about the best number of susceptibility classes, its thresholds and ideal colours.

Keywords landslide inventory, landslide susceptibility, spatial planning, LiDAR DTM, Lower Austria

Introduction

Landslides occur frequently in Lower Austria - a federal province of Austria (e.g. Schwenk 1992). Since 1953 more than 1500 landslides have been studied by the Geological Survey of Lower Austria and stored in the Building Ground Register (BGR). These landslides mainly have caused damage to agricultural land, forests and infrastructure, but also threaten settlements and people. Therefore, the project "MoNOE" (Method development for landslide susceptibility modelling in Lower Austria) is funded by the provincial government. The main objectives of this project are:

1) Design of a method for landslide susceptibility modelling for a large study area (about 10,200 km^2)
2) Production of landslide susceptibility maps (for rock falls and slides)
3) Implementation of the susceptibility maps into the spatial planning strategies of the provincial state of Lower Austria

Together with the heterogeneous geology and the aim to implement the landslide susceptibility maps in spatial planning strategies of the state this poses huge challenges towards the development of new and suitable methods for modelling landslide susceptibility. Limitations are given by restricted (digital) data availability for such large areas, e.g. geology is only available at a scale 1:200,000 for the entire study area. Since reliable landslide inventories are an essential prerequisite for high quality susceptibility maps, all available digital landslide information was gathered and evaluated. Furthermore, basic geodata had to be prepared and homogenized.

Subsequently, susceptibility modelling for slides and rock falls was carried out independently. However, since the final landslide susceptibility map shall comprise both processes in one map, approaches for combining single process susceptibility maps have to be developed. Due to the need to optimise final landslide susceptibility maps for spatial planners and local authorities, the maximum number of susceptibility classes and respective thresholds and colours for each class has to be defined. Consequently, the difference between the best scientific landslide susceptibility map and the best map for spatial planning purposes is analysed. Beside all this, human impact on landslides is analysed, mainly at local scale. However, depending on the results it will be tested

whether parameters can be derived that can be integrated into regional scale landslide susceptibility modelling.

Study Area

The study area Lower Austria covers an area of approx. 10,200 km², which is about 2/3 of the provincial state of Lower Austria. It is located in the northeast of Austria (Fig. 1). Only districts which are prone to landslides and where landslides have been recorded by the Geological Survey of Lower Austria are investigated.

The main geological units of Lower Austria comprise the Northern Calcareous Alps, the Flysch Zone, the Molasse Zone and related units (Vienna basin and Waschbergzone), the Eastalpine Crystalline (Paragneiss and Quarzphyllite), the Bohemian Massif (Granite and Gneiss) and quaternary sediments (fluvial terraces and alluvial deposits) (Fig. 1). Deatails on the geology can be found in Wessely (2006). Based on the BGR inventory most of the registered landslides occurred in the Flysch Zone, followed by the Molasse Zone and the Northern Calcareous Alps (Schwenk 1992, see also Fig 1).

The pattern of total rainfall distribution in the study area follows mainly the topography and shows its maximum in the high mountain area of the Northern Calcerous Alps in the southwest with approx. 1700 mm and dropping down to the northeast to approx. 500 mm (www.noe.gv.at).

Detailed information on spatial planning laws in Lower Austria is given in Pomaroli et al. (2011).

Materials/Data

To model landslide susceptibility, essential digital information on landslides and basic geodata must be gathered. Various landslide inventories were available (Table 1). Their spatial representation is shown in Fig. 1. Furthermore, numerous basic geodata was collected, which is listed in table 2.

Table 1 Available landslide inventories in Lower Austria (Note: N.T. = No information on time of mapping / of the events available)

Type	Source	Scale
Building ground register (BGR)	Geological Survey of Lower Austria	1:50,000; Lower Austria; Points; since 1953
Hazard maps and Hazard zoning maps	Austrian Service for Torrent and Avalanche Control - WLV	1:50,000, 1:2,000; Lower Austria – areas surrounding settlements; Polygons (in Tiff); N.T.
Localisation of Slides and Falls	Austrian Service for Torrent and Avalanche Control - WLV	1:50,000; Lower Austria, Points; N.T.
Geomorphological maps (Mapping, archive data)	BUWELA Project WLV, southeast of Lower Austria	ca. 1:50,000, "Bucklige Welt", Points; N.T.
GEORIOS Database	Geological Survey of Austria	1:50,000; Lower Austria, Points, Lines, Polygons; N.T.
Map of unconsolidated rocks	Geological Survey of Austria	1:50,000; Lower Austria, Points, Polygons; N.T.

Table 2 Available basic geodata in Lower Austria (Note: NÖGIS = webgis of the provincial state of Lower Austria, BMLFUW = Federal Ministry for Agriculture, Forestry, Environment and Water Management)

Type	Source	Scale
Geological Map, GK200	Geological Survey of Austria	1:200,000
Geological Map, GK50	Geological Survey of Austria	1:50,000, Parts of Lower Austria
Map of unconsolidated rocks	Geological Survey of Austria	1:50,000
Land cover	Joanneum Research	10m resolution, derived from satellite data
Various Geodata (Roads, Rivers, Train, Settlements, etc.	NÖGIS	1:50,000; 1:10.000; 1:1,000
Precipitation and designed rainfall	Hydrology / BMLFUW	Station records, 6 km resolution
Orthophotos	NÖGIS	12,5 cm & 25 cm resolution
Digital Terrain Model	NÖGIS	1m resolution, Airborne LiDAR

Methods

Various methods are applied for the different tasks of the project.

In a first step all available data on landslide inventories were gathered and their potential regarding the applicability for susceptibility modelling was analysed in detail. Furthermore, basic geodata were collected, prepared and homogenised. A new land cover classification was created by deriving it from satellite images.

Whereas slide susceptibility is modelled using statistical approaches (Weights of Evidence and Logistic regression), rock fall susceptibility is modelled based on two steps. First, rock fall release areas are determined by empirical slope thresholds depending on geology (lithology as well as tectonics), followed by modelling the run-out using empirical and process-based run out models. Both susceptibility maps are verified in the field. Furthermore, slide susceptibility maps are validated using common validation criteria like AUROC, success and prediction rate curves.

Final slide and rock fall susceptibility maps are combined and optimised for end-user needs. This is jointly developed with the spatial planners and geologists of the provincial government.

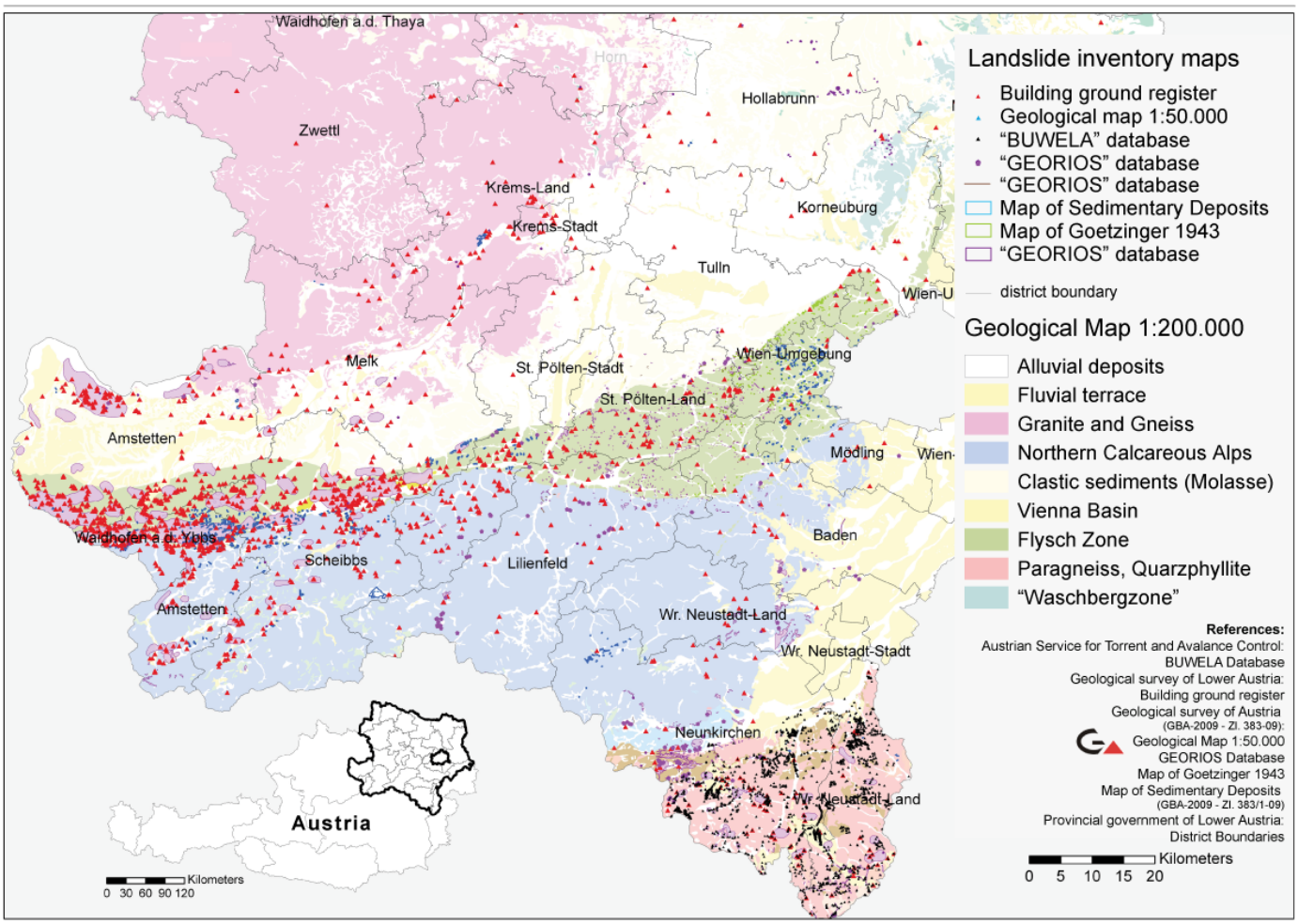

Figure 1 Location, geology and available landslide inventories of the study area Lower Austria

Results

Analysing all available landslide inventories, it turned out that only the landslide inventory based on the Building Ground Register of the Provincial Geological Survey could be used to some extent for slide susceptibility modelling. Furthermore, the need for preparing a new and homogenized landslide inventory based on LiDAR DTM interpretation became evident. Detailed results on the landslide inventories and minimum requirements for susceptibility modelling are presented in Petschko et al. (in this volume).

Regarding the preparation of the basic geodata, it turned out that the geological map at a scale of 1:200,000 showed some major errors in representing alluvial areas. These areas reach up to 200m upslope in many cases. This aspect was corrected within this project. Furthermore, there was the need to simplify the geological map to lithological relevant parameters.

So far, susceptibility modelling was carried out in three test districts (Waidhofen/Ybbs, Amstetten, and Baden) to develop methods to be applied subsequently in the whole study area. Whereas for Waidhofen/Ybbs and Amstetten the BGR landslide inventory shows sufficient landslide information, the district Baden shows only seven entries, but was chosen to test and develope methods in a district with insufficient landslide information.

First results of the comparison of slide susceptibility maps based on Weights of Evidence and Logistic regression show to a great extent quite similar results. However, some differences are significant and must be further analysed. Detailed information on this comparison is given in Leopold et al. (in this volume). Proske et al. (in this volume) concludes that applying first an empirical run-out model for rock fall susceptibility and subsequently a process-based run-out model in hot spot areas of the empirical model provide a reasonable solution for modelling rock fall susceptibility for such large areas. For details it is referred to the respective paper.

This contribution is focussed on the combination of the rock fall and slide susceptibility maps and the end-user optimisation.

Intensive discussions with the representatives of the provincial government resulted first in the decision that the common traffic light colours (green, yellow, red, or

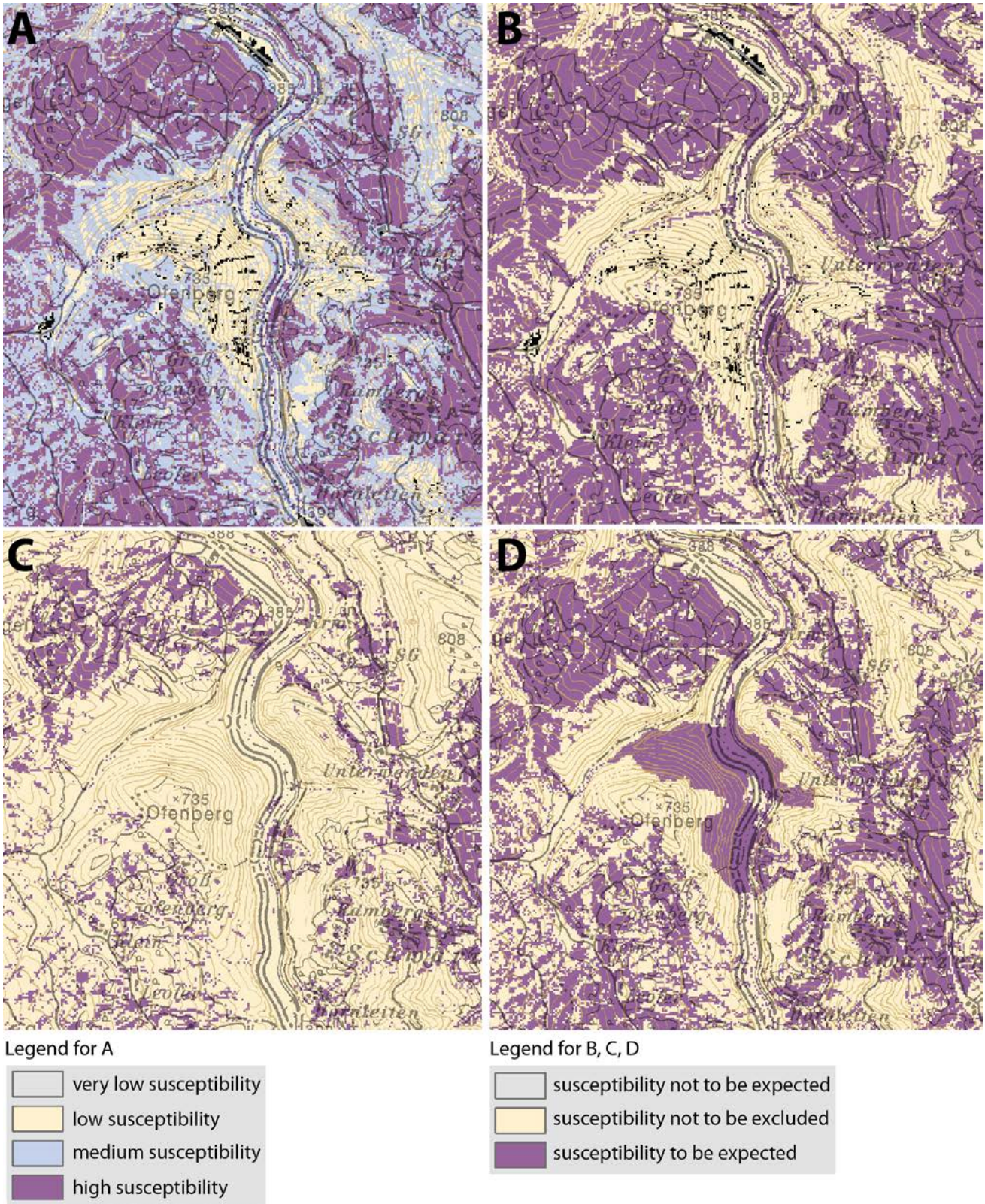

Figure 2 Different landslide susceptibility maps. A = slide susceptibility map, example of a preferred scientific map with 4 classes; B = slide susceptibility map, example preferred for implementation into spatial planning strategies, class thresholds: lowest class = 1% of landslide pixels - 40% of the study area, highest class = 80% of landslide pixels – 21% of the study area; C = slide susceptibility map, like B but class thresholds: lowest class = 0.1% of landslide pixels – 26% of the study area, highest class = 50% of landslide pixels – 8% of study area; D = combined slide and rock fall susceptibility map, preferred for implementation into spatial planning strategies

dark green, light green, yellow, orange, red) should not be used for the final landslide susceptibility classes ranging from low to high or very low to very high, although these colours are the most intuitive ones, enabling an easy way to read and understand the maps. The reason for this is that the colours yellow and red are used within the hazard zoning maps of the Austrian Service for Torrent and Avalanche Control. Whereas there are strict regulations including e.g. the prohibition of new building activities connected with the different hazard zones, the final landslide susceptibility map will have only a status of indication. To prevent misunderstandings and misinterpretations especially at the local authorities it was decided not to use these colours. Several alternative colour schemes were tested which resulted so far in the usage of the colours beige and purple, in addition to transparent for "susceptibility not to be expected" (Fig. 2 B-D).

Parallel to the discussion of the colours the final number of different susceptibility classes had to be decided. The scientists preferred four to five classes to more exactly differentiate within areas susceptible to landslides (Fig. 2 A). However, this was finally rejected because of the difficulties to define specific options for actions for each class, which would make sense for the end-users. Thus, it was decided to take three classes (susceptibility not to be expected, susceptibility not to be excluded, susceptibility to be expected) for the final maps (Fig. 2 B-D).

A third question to be answered is the value of the susceptibility class thresholds. In Fig. 2 B (conservative) and 2 C (progressive) different options are shown based on the percentage of landslide pixels from the landslide inventory used in modelling. The final decision is still being discussed between the scientists and the provincial state government. Fig. 2 D presents the first result of a combined rock fall and slide susceptibility map. The high susceptible rock fall areas in the center of the map where slide susceptibility is minor (see Fig. 2 B or C) can easily be seen.

Discussion and Conclusions

Analysing all available landslide inventories showed that only the BGR inventory is of some use for landslide susceptibility modelling. It clearly turned out that a new inventory must be prepared. With regard to the available data and especially the large size of the whole study area we decided to prepare such a new landslide inventory based on interpretation of the LiDAR DTM. Historical landslide information (e.g. the BGR) was not directly integrated in the newly mapped inventory since the available information is not comprehensive for the entire study area and has limitations in the accuracy of the location. However, historical landslide information was used as orientation in analysing the LiDAR DTM. Details on the preparation of the LiDAR landslide inventory can be found in Petschko et al. (2010) and in Petschko et al. (in this volume).

First modelling results for rock fall susceptibility as well as slide susceptibility are very promising for the three test districts. However, some more analyses and validations have to be carried out before the developed approaches can be applied to the whole study area.

A major decision regarding the end-user optimisation has already been taken, i.e. the number of susceptibility classes. Final decisions for the ideal colours and the susceptibility class thresholds are shortly before reached.

The project has demonstrated so far that close cooperation between scientists and representatives of the provincial state government is essential to prepare high quality and end-user optimised landslide susceptibility maps. Although the results show that there is a difference between the best scientific map and the best map for implementation in spatial planning strategies, this way it is ensured that only landslide susceptibility maps are produced which will have clear options for action for each susceptibility class and therefore will be more easily accepted by responsible spatial planners and local authorities.

Acknowledgments

The authors thank several institutions and individuals for their support: the colleagues from the Geological Survey of Austria and from the Austrian Service for Torrent and Avalanche Control for providing inventory data; the Provincial Government of Lower Austria in particular the colleagues from the Geological Survey and the Department of Spatial Planning and Regional Policy for inventory data. Thanks to them for supporting the MoNOE-project and for numerous fruitful discussions. Thanks also to the Department for Hydrology and Geoinformation for providing LiDAR and orthophoto data.

Finally, the authors are grateful for financial support of the Provincial Government of Lower Austria.

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