LANDSLIDE SUSCEPTIBILITY MAPS FOR LOWER AUSTRIA

METHODS AND CHALLENGES

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ABSTRACT

Landslides occur frequently and widespread in many regions of the world. Consequently, approaches and methods on how to assess the spatial dimension of landslide occurrence is an important field of research. Of greatest interest is hereby to identify locations, where landslides might occur in the future. The spatial probability of landslide occurrence at a given location can be deduced from susceptibility maps. Besides a pure scientific interest, such information is of greatest value for numerous institutions which have to deal with or are responsible for a specific region and might have been affected by landslides. Such institutions include local and regional governments, geological surveys, insurance companies or spatial planning agencies, to name a few only. It is evident, that by introducing such maps into an official planning procedure, one has to ensure the highest possible reliability. Consequently landslide susceptibility maps should only be used if they are based on real landslide data. Commonly such spatial landslide data is difficult to obtain. Existing landslide registries have initially often not been developed for a statistical analysis of landslide distributions. Therefore, the registered information is regularly focusing on damaging events only and is thus neither complete nor representative. In addition, even the existing entries are frequently not referenced to the correct location. Therefore it is suggested to modify and extend existing landslide inventories by the usage of a high resolution airborne laser scanning DTM to get a sufficiently complete coverage of landslide occurrences or initiation areas (rock fall) in the past. To model landslide susceptibility for slide and rock fall processes different algorithms and methods have been applied and compared. The evaluation of the quality of the resulting maps was assessed by field checks (rock fall) or by statistical methods (slides). This gives an indication of the accuracy of the landslide susceptibility maps which is of high importance for their proper further application. The resulting information on the probability of landslide occurrence in a given region is of highest value for the affected institutions and their use coherently with the official guidelines and procedures of spatial planning will be further explored.

Keywords: Spatial landslide inventories, user-optimized landslide susceptibility mapping (rock fall and soil/debris slide), validation, spatial planning, Lower Austria

BACKGROUND

Recent landslide events such as the event in the Italian province Massa (Tuscany) at end of October 2010 or events in Styria, Austria (Feldbach June 2009, Gasen/Haslau August 2005) demonstrate that landslides can cause fatalities as well as high economic losses. Often, these events are not only of scientific interest. Moreover responsible institutions recognise that the focus on remedial work is not

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sufficient, rather some information for preparedness in terms of spatial planning is beneficial as decision support for future developments. This has also been recognised in Austria by the state of Lower Austria. Within the area of their responsibility, approximate 2,000 entries in the "building ground register" (BGR) of the Geological Survey of Lower Austria indicate that about fifty percent of the municipalities are affected by landslides. Hereby, landslide types range from rock fall to shallow translational and deep seated rotational slides. Both the number of events and afflicted municipalities emphasise the need of prevention measures on a regional scale in order to minimize the landslide hazards for inhabitants and their living environment. Powerful tools for enhancing spatial preparedness are landslide susceptibility maps, which can be implemented in spatial planning processes such as the "area zoning plans" *("Flächenwidmungsplan")* which are provided by the municipalities in Austria.

Methods for landslide susceptibility modelling form a comprehensive research field which mainly covers the development of proper modelling methods (e.g. Atkinson et al., 1998; Bell, 2007; Bozzano et al., 2010; Van Den Eeckhaut et al., 2006), datasets (e.g. Bathurst et al., 2010; Guthrie, 2002; Hoechstetter et al., 2008; van Westen et al., 2008) and validation techniques (e.g. Beguería, 2006; Brenning, 2005; Rossi et al., 2010; Sterlacchini et al., 2011) in order to obtain reliable landslide susceptibility maps. However the implementation of the resulting maps in regional or local spatial planning is often missing because both modelling processes on regional scale and implementation of these maps into practice are challenging tasks for geoscientists as well as for the responsible spatial planners. Additionally the limited availability of appropriate spatial and temporal data on landslide events and explanatory parameters is a major restricting factor when performing modelling on regional scales.

The research project MoNOE (Method development for landslide susceptibility modelling in Lower Austria) has been designed to fill this gap and to develop proper methods of modelling and map-design. One major focus is to produce landslide susceptibility maps which are end-user optimized, user-friendly and arranged to be ready for implementation in spatial planning.

OBJECTIVE

The main objective of this project is to develop best suited methods for the generation of spatial landslide susceptibility maps. With regard to landslide types the analyses focus on rock fall and soil and debris slides (as defined by Cruden and Varnes, 1996). These maps will be finally implemented in spatial planning strategies on a federal state and municipality level. To achieve this main objective, further aims have been identified. In particular datasets of explanatory factors are to be assembled, prepared and homogenised. Additionally, the given data will be integrated and checked by detailed field mapping. The compilation of a landslide inventory that is sufficiently complete to meet the requirements of statistical modelling is of major importance and determines the quality of the resulting maps. Considerable effort will also be taken on different validation techniques in order to estimate the quality of the derived landslide susceptibility maps. Finally, analysis of human impact on landslide occurrence and the possible representation in the final maps will also be carried out. Several ways of implementation of such human interference in the statistical model will be tested.

DATA AND METHODS

The study region "Lower Austria" covers an area of approx. 15,850km² and is located in the east of Austria. The workflow chart in Figure 1 presents the different working steps of the methodology. The different topics will be explained in more detail in the following paragraphs.

The preparation of high quality spatial datasets giving information on topographic characteristics of the study area but also on the landslides is a fundamental prerequisite. The compilation of data on landslide events and on explanatory parameters is a time consuming task and simultaneously decisive for the quality of modelling results later on. Therefore a comprehensive collection and comparison of existing and mapped landslide inventories (for soil and debris slides) with special focus on their usage for statistical modelling is performed (Petschko et al., 2010). The analysed existing landslide data collected from different Austrian institutions is summarized in Tab. 1.

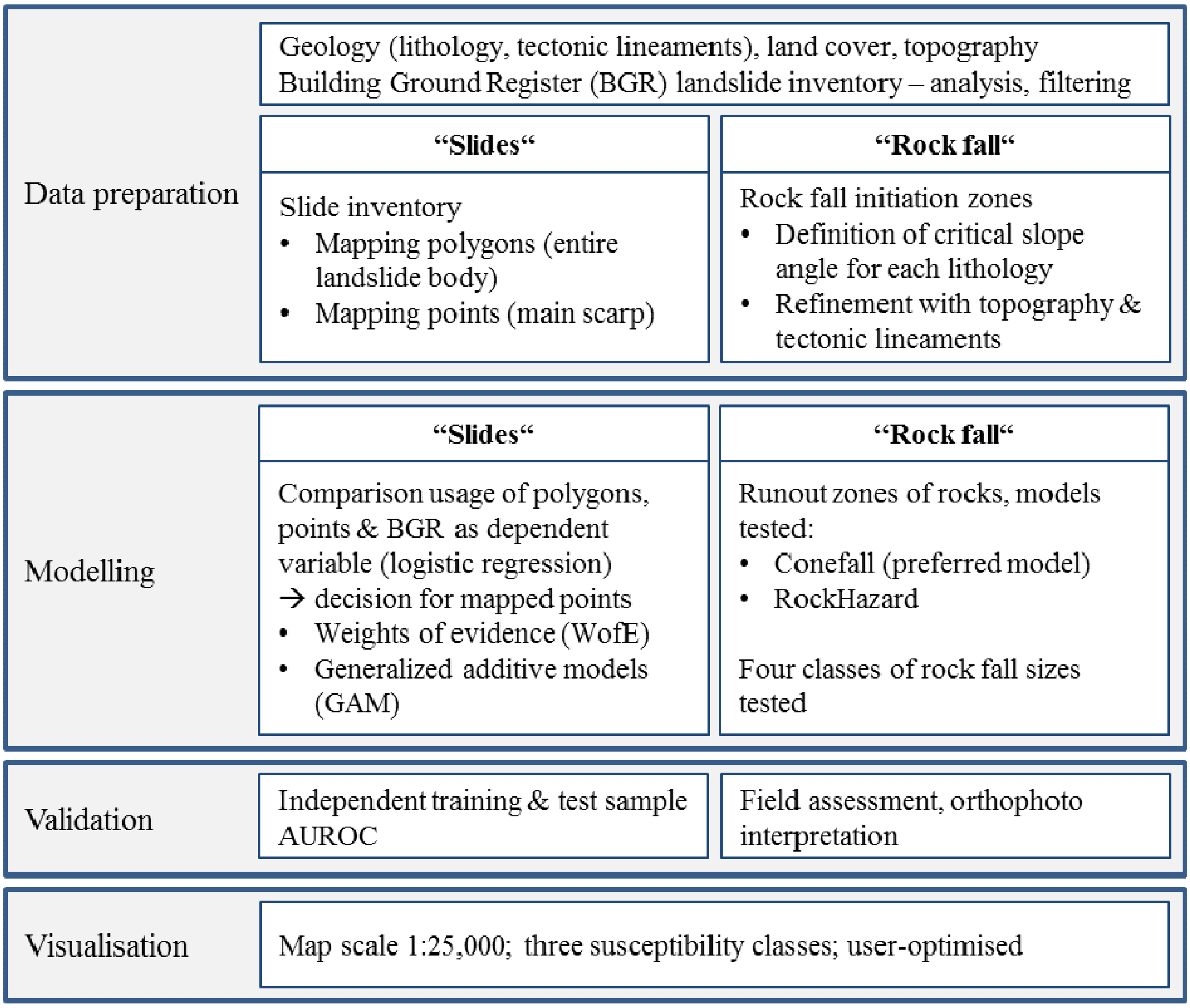


Fig. 1 The workflow chart outlines the stepwise analysis procedure from the data preparation to the final visualisation of susceptibility maps for “Slides” and “Rock falls” in Lower Austria. The details of the methods are given in this chapter.

Tab. 1 Available landslide data.

Typ	Source	Scale / resolution
Building ground register	Geological Survey Lower Austria	1:50,000 (points)
Hazard maps	Austrian Service for Torrent and Avalanche Control, provincial headquarter Vienna, Lower Austria and Burgenland	1:50,000, 1:2,000
Inventories of landslides and rock falls	Austrian Service for Torrent and Avalanche Control regional office Burgenland and southern Lower Austria	1:50,000
GEORIOS data	Geological Survey of Austria	1:50,000 (polygones, lines)
Map of loose sediments	Geological Survey of Austria	1:50,000

Geospatial data available for this study include information on geology, tectonic lineaments, regolith, vegetation and topographic indicators (e.g. slope angle, height, aspect, slope position, etc.) calculated from an resampled ALS DTM (originally 1m x 1m) with a spatial resolution of 10m x 10m. The complete available geospatial data is summarized in Table 2. The high resolution DTM is of major advantage because the ALS DTM gives detailed information on the terrain height, even under forest cover. This represents the terrain height very well, even when resampling the data to a spatial resolution of 10m.

Tab. 2 The different geospatial data available within the study (Note: GBA = Geological Survey Lower Austria; NÖGIS = Geographical Information System of Lower Austria; BMLFUW = Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management).

Typ	**Source**	**Scale / resolution**
Geological map, GK200	GBA	1:200,000
Geological map, GK50	GBA	1:50,000 (only partially available)
Map of sedimentary deposits	GBA	1:50,000
Land cover	Joanneum Research	10m resolution, classified from satellite imagery
Diverse geospatial data (roads, rivers, railway, settlements, agricultural regions, etc.)	NÖGIS	1:50,000, 1:10,000, 1:1,000
Rainfall distributions, rainfall estimates for hydrology	Hydrology / BMLFUW	6 km resolution
Orthophotos	NÖGIS	Resolution: 12.5 cm and 25 cm
Digital terrain model – DTM Digital surface model – DSM	NÖGIS	1m resolution from Airborne Laserscan (ALS) imagery

Furthermore the analysis and visual interpretation of the available high resolution ALS DTM and its derivatives proved to be of highest potential to check the quality of existing landslide inventories and to map a new landslide inventory with higher accuracy in location of the landslides (Petschko et al., 2010). Additionally to the visual comparison of existing landslide inventories with the mapped inventory further tests have been performed to analyse the applicability of the different inventories for the development of a spatial landslide susceptibility map.

Using logistic regression the effects of different landslide inventories on the final landslide susceptibility maps are investigated. The focus was on comparing results applying two different input data sets. One input data set contains point data taken from the building ground register. The second one refers to point data derived from the landslide mapping. This comparison has been carried out in the district Waidhofen/Ybbs and Amstetten in Lower Austria. The explanatory variables such as aspect, flow accumulation, slope angle, slope length, land cover, geology, landform classification and the topographic wetness index have been kept constant for all three test runs. Further details on the research strategy are given in Petschko et al. (2012). It was concluded, that each inventory has its advantages and disadvantages concerning information on landslide age and size, date of occurrence and accuracy of the location of the points. However, with respect to spatial landslide susceptibility modelling it was decided to create a new spatial landslide inventory by mapping landslides on the basis of the ALS DTM derivatives.

For the rock fall modelling, the knowledge on initiation zones is crucial for the further analysis in order to know where potential rock falls could start. The ALS DTM is again a very good data basis for the delineation of potential initiation zones. These were derived by applying different thresholds of slope angles in different lithological units according to literature values (e.g. Melzner et al. 2012) combined with findings made during field work. Input parameters include lithology, topography and tectonic lineaments. Firstly, a critical slope angle for the rockfall source area was defined. Secondly, the potential detachment regions have been exported from the ALS imagery and thirdly, the previously defined critical slope angle has been refined based on topography and tectonic lineaments. The final critical slope angles have been validated by field data and from orthophoto interpretation.

The landslide susceptibility was modelled with different methods for the processes slide (soil and debris) and rock fall. Both approaches are shortly described in the following, starting with the modelling of landslide susceptibility.

Based on the input data described above, spatial landslide susceptibility analysis for the process of slides has been performed by two statistical modelling methods to analyse the benefits and drawbacks of the one or the other method and to develop a method which results in reliable susceptibility maps. The modelling was performed with the WofE (Weight of Evidence, Bonham-Carter & Agterberg

1989) method by the Austrian Institute of Technology and with logistic regression and GAM (General Additive Models, Hastie & Tibshirani 1990) by the University of Vienna. Hereby, GAM is a further development of the logistic regression. The main advantage of GAM is the combination of linear and non-linear relations between dependent and independent variables. The full potential is explained in detail by Brenning (2008) and Goetz et al. (2011).

The respective landslide susceptibility maps have been checked for their accuracy by determining the area under the receiver operation curve (AUROC) value (Hosmer & Lemeshow 2000). The AUROC validation technique has been applied to landslide studies by Brenning (2005) and Begueria (2006) and has been applied in this study. This value is derived by splitting the data set randomly into independent training and test samples. The model is then trained with the training sample and transferred to the test sample and evaluated with the information on “slides” and “no slides” given by the test sample. This comparison shows how many slides are correctly classified with a high susceptibility. According to that the AUROC, which varies between values of 0-1, shows with values from 0.5–1 that the model was successful to discriminate between slide and no slide points (Brenning, 2005).

The rockfall runout zones were calculated by applying the CONEFALL (Jaboyedoff 2003) software package. Four classes of rock fall sizes have been defined as class 1 with > 125,000 cm^3, class 2 with 8,001 – 125,000 cm^3, class 3 with 1,001 – 8,000 cm^3, and class 4 <1,001 cm^3 respectively. The final values are expressed as kinetic energy. These values have been classified in the three categories <30 kJ, 30-100 kJ, and >100 kJ and have been used for the final susceptibility classes.

The final landslide and rock fall susceptibility maps will be produced at the scale of 1:25,000 for selected areas in Lower Austria. The final products have not been calculated yet, thus only examples of the different methodological steps are presented in the following chapter.

RESULTS & DISCUSSION

As a basis for all landslide modelling, a comprehensive spatial landslide inventory is required. Spatial inventories may contain the landslide information as points or as polygons of total area, or differentiated by source, run-out and deposition area. Due to the limited resources and the large spatial extend, tests have been performed to identify the most appropriate methods to map landslides with the highest precision in locality under consideration of the best time-efficiency during mapping. Petschko et al. (2012) has shown for landslide inventories of polygons in comparison to points in the landslide source region, that the differences of landslide susceptibility are only marginal. An excerpt of the results is presented in Figure 2 for a test area. Petschko et al. (2012) concluded that a randomly selected point in the source area of a landslide scar is sufficient for a reliable landslide susceptibility map. Therefore it was decided to map only points in the landslide scar for the further susceptibility analysis. Consequently, landslides in Lower Austria have been mapped from the ALS imagery. The spatial distribution of the total 13,162 landslide locations in Lower Austria are identified in Figure 3. The advantage of this new inventory towards the existing building ground register (BGR) of the Geological Survey in Lower Austria is given in Table 3 and demonstrates the increase of the quantity of landslide locations from the available BGR points to a sufficiently complete coverage in the region of Lower Austria.

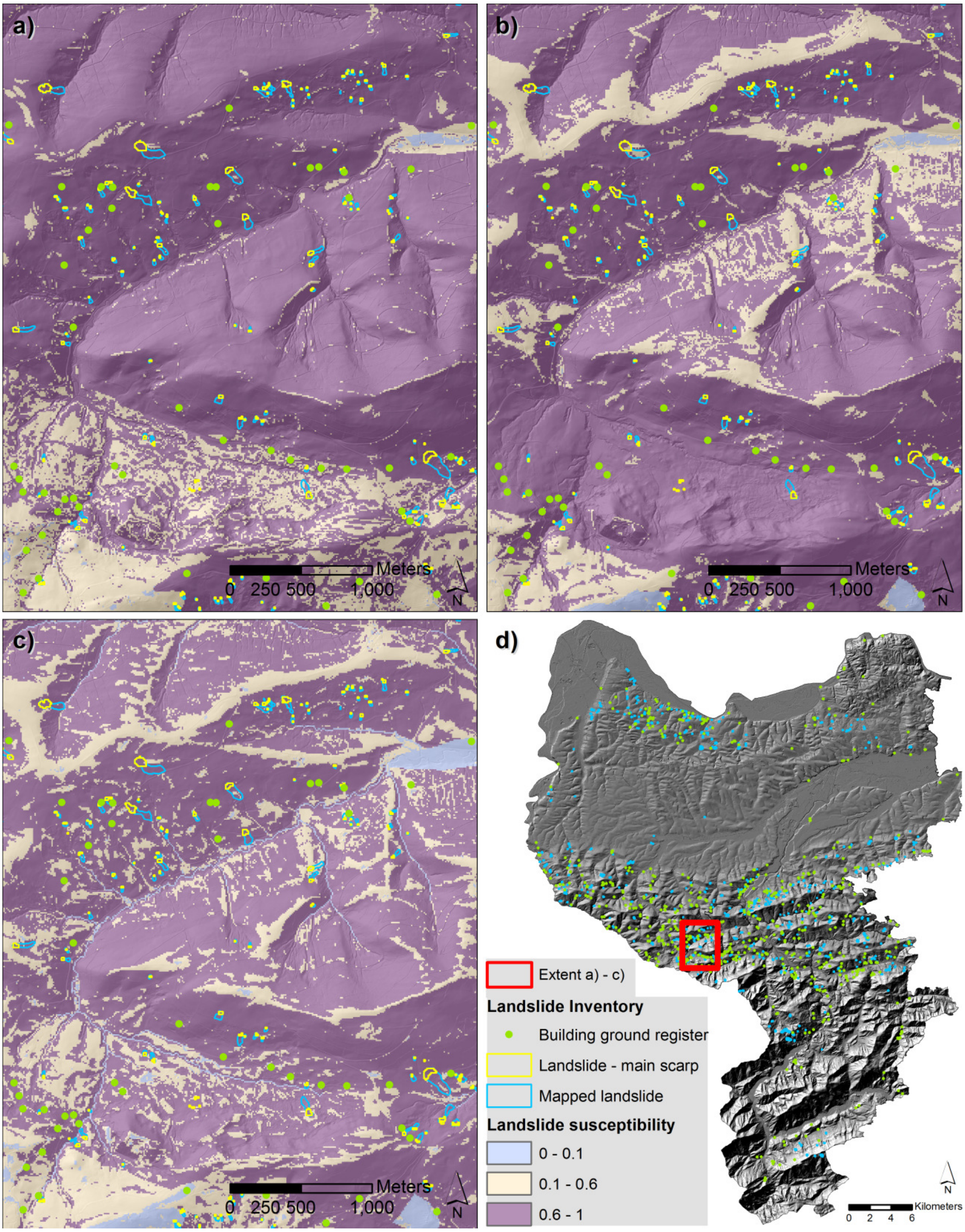


Fig. 2 The different landslide susceptibility maps using as landslide information a) randomly selected BGR points (green points), b) points that are randomly sampled in the entire landslide polygon (blue polygons), and c) points that are randomly sampled in the main scarp of the landslide (yellow polygons). The explanatory variables have been kept identical (refer to Petschko et al. (2012) for further details).

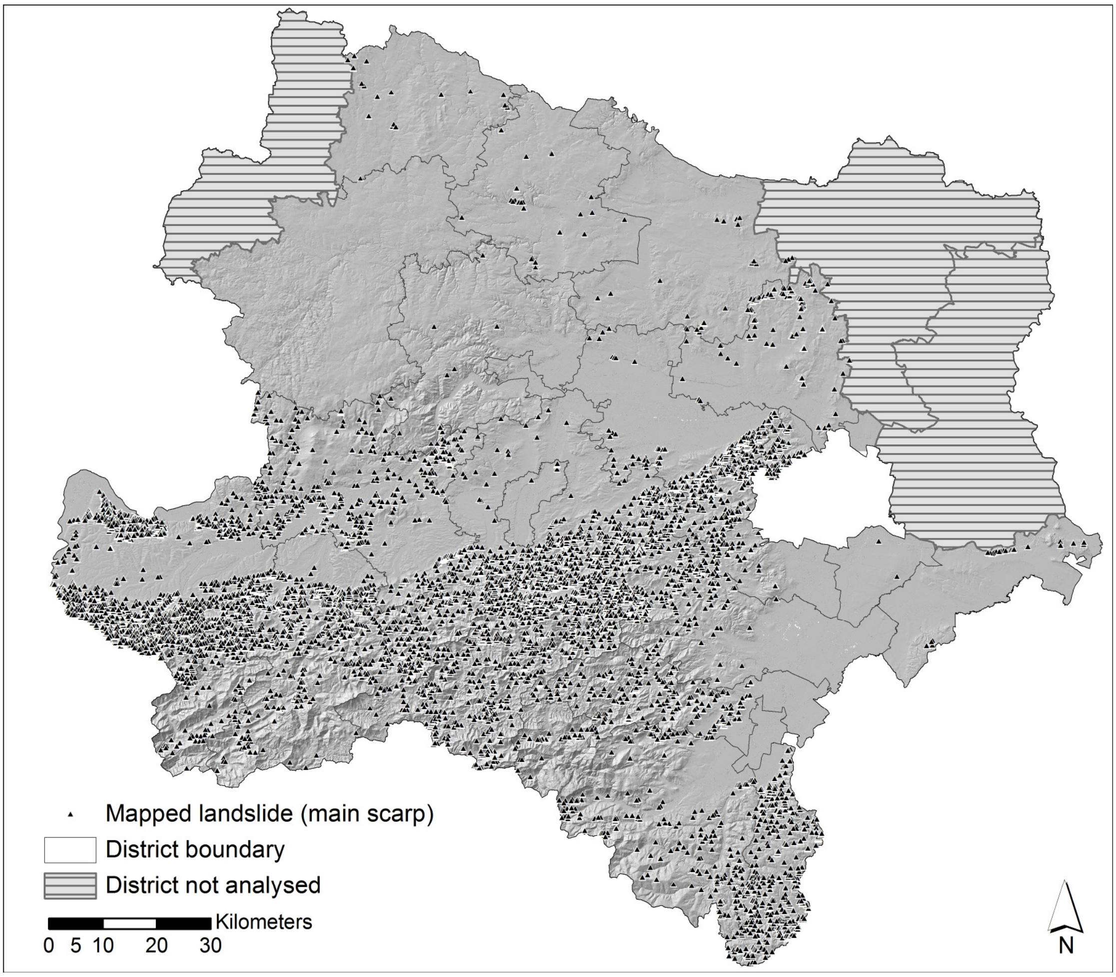


Fig. 3 Spatial distribution of mapped landslide locations in Lower Austria (refer also to Table 3).

Tab. 3 Comparison of mapped landslide locations from ALS and data available in the BGR (building ground registry) for the different provinces in Lower Austria (Landslide mapping was performed by Austrian Institute of Technology & University of Vienna).

Province	**No. of mapped landslides**	**No. of landslides in BGR**	**Difference (Mapped – BGR)**	**Area of the province in km²**
Amstetten	2,712	561	2,151	1,187.33
Baden	219	19	200	754.08
Bruck/Leitha	34	12	22	495.36
Hollabrunn	20	28	-8	1,011.05
Horn	42	12	30	783.04
Korneuburg	157	21	136	627.14
Krems (City & region)	8	77	-69	975.08
Lilienfeld	2,589	55	2,534	932.89
Melk	765	92	673	1,014.95
Mödling	118	18	100	277.68
Neunkirchen	334	89	245	1,151.00
Scheibbs	1,429	360	1069	1,024.60
St, Pölten (City & region)	1,369	191	1,178	1,231.77
Tulln	558	23	535	658.13
Waidhofen/Thaya	27	4	23	669.31
Waidhofen/Ybbs	1,063	177	886	131.31
Wien region	667	37	630	485.20
Wr, Neustadt (City & region)	1,051	44	1,007	1,033.93
Zwettl	0	0	0	1,399.92
TOTAL	***13,162***	***1,827***	***11,335***	***15,843.77***

These landslide points have been used for further statistical analysis using the two different methods WofE and GAM. Various combinations of parameters have been applied to test the model performance with respect to the minimum requirements on the landslide inventories. The resulting maps were classified in three classes respectively, named "Landslides not to be expected", "Landslides not to be excluded" and "Landslides to be expected" (Bell et al. 2012). Within WofE all mapped landslides have been combined with simplified geology, slope angle, slope aspect and land cover. The preliminary result for a test area around the city of Wieselburg, Lower Austria is presented in Figure 4.

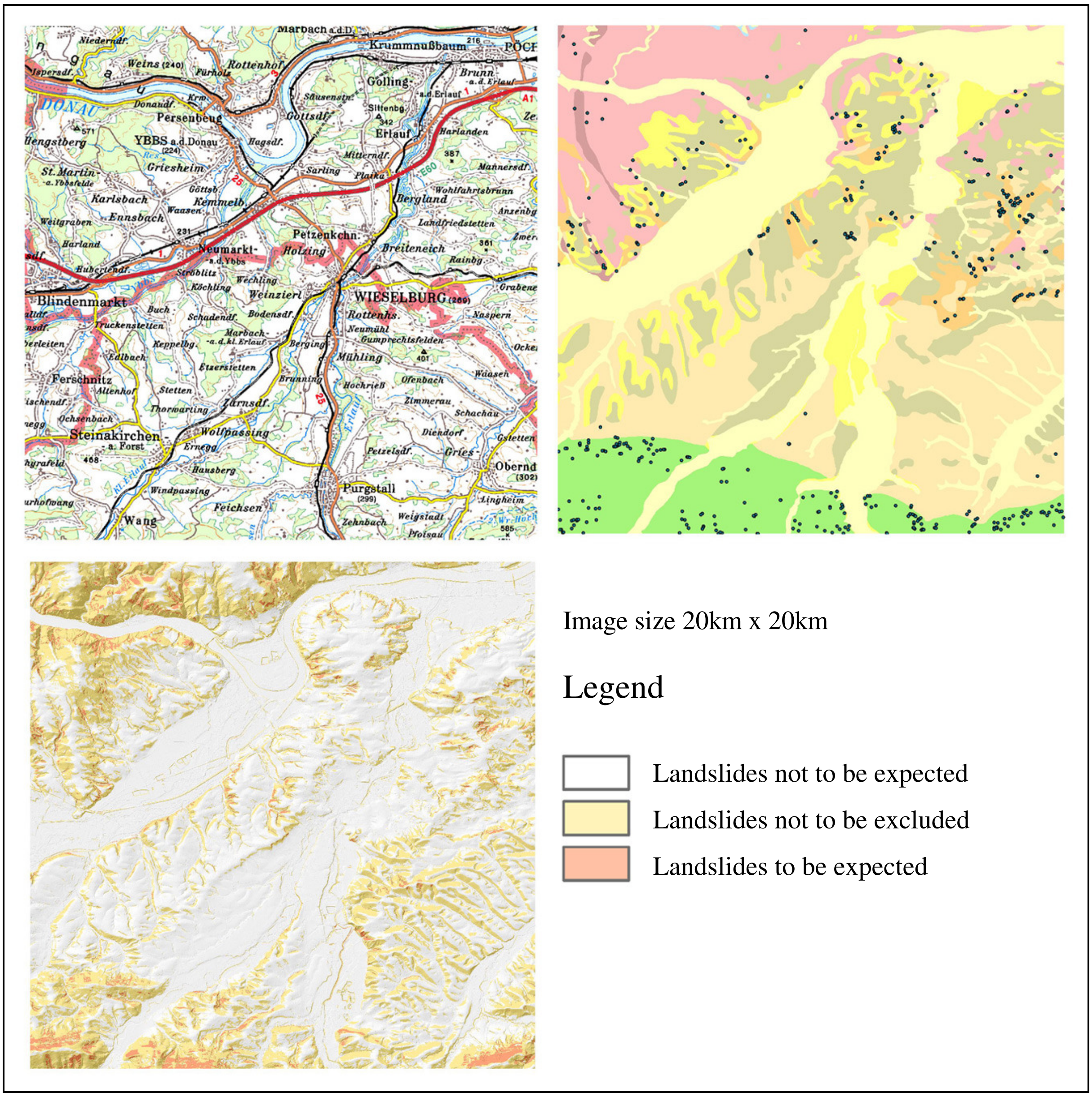
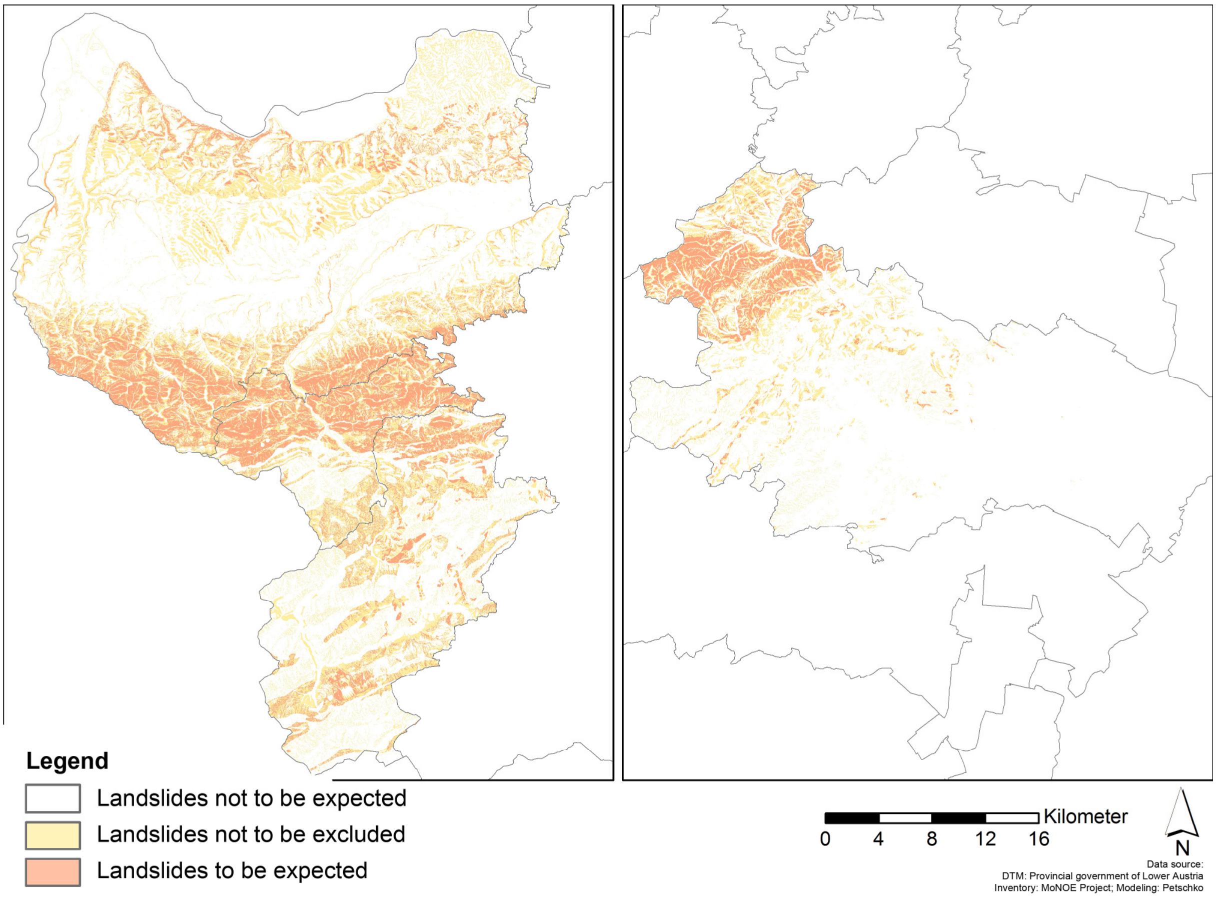


Fig. 4 A preliminary landslide susceptibility map calculated by the WofE method for a region 20 x 20km near Wieselburg, Lower Austria. The upper right graphic contains information of simplified geology and landslide locations (black dots). The lower left graphic is the preliminary landslide susceptibility map.

The GAM method has been applied to the region Amstetten, Baden and Waidhofen/Ybbs. Hereby, the landslide locations have been combined with aspect, flow accumulation, slope angle, slope length, curvature, geology and the topographic wetness index. The preliminary landslide susceptibility map is shown in Figure 5 for the exemplary region. Further tests are required for the quality control of this landslide susceptibility map. In particular, the previously described validation tests have to be performed in more detail and the respective information has to be associated with the final map.



Data source:
DTM: Provincial government of Lower Austria
Inventory: MoNOE Project; Modeling: Petschko

Fig. 5 A preliminary landslide susceptibility map calculated by the GAM method for the districts Amstetten, Waidhofen/Ybbs (left map) and Baden (right map).

In order to get also information on rockfall susceptibility in Lower Austria, a respective analysis has been carried out. As explained in the methodology chapter relevant areas have been delineated from the ALS imagery, from the lithology and tectonic lineaments and from the orthofotos. The final spatial distribution of kinetic energy has been classified into the preliminary three classes “rockfall susceptibility minor”, “rockfall susceptibility with low intensity”, and “rockfall susceptibility with high intensity”. An example of the resulting map is given in Figure 6.

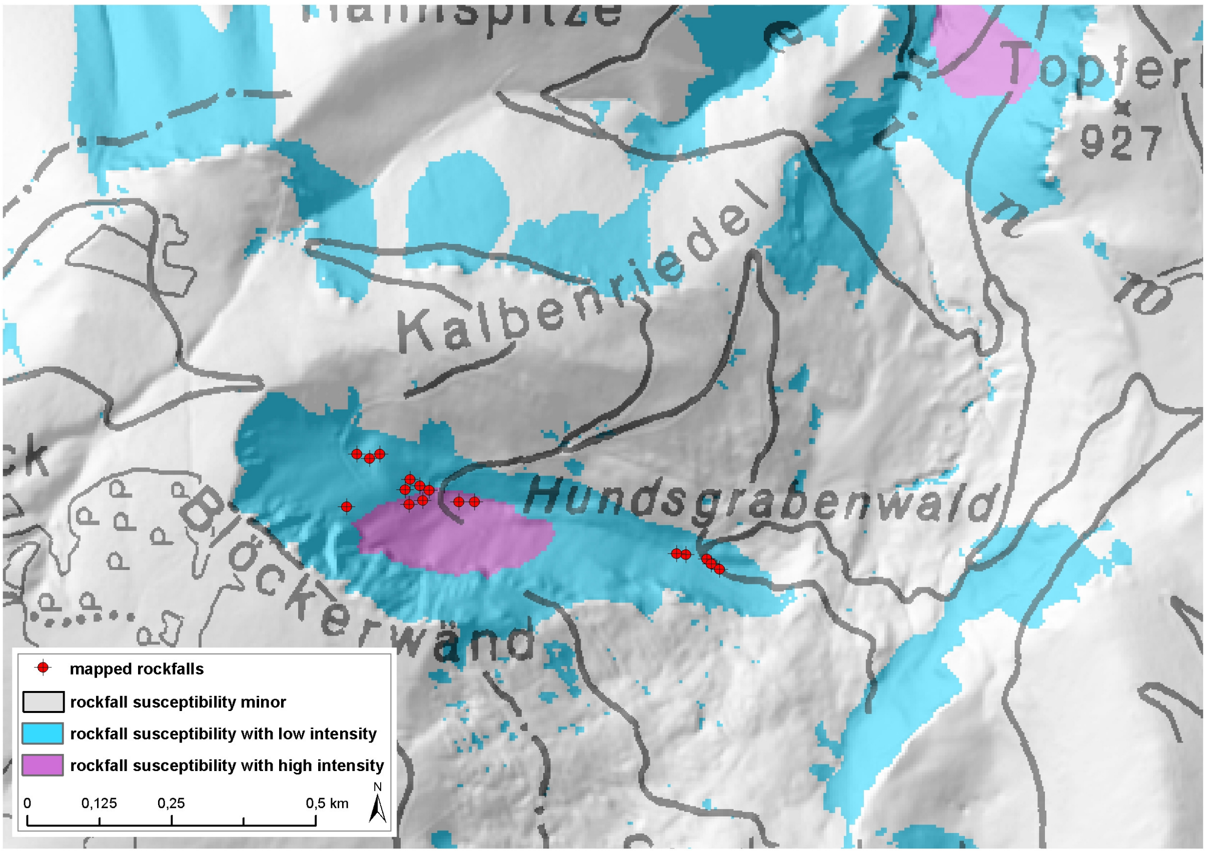


Fig. 6 A preliminary example of a final rockfall susceptibility map based on the three preliminary classes “minor”, “low intensity” and “high intensity”.

CONCLUSIONS

The suggested methods and tools for landslide and rock fall susceptibility modelling include weights of evidence, logistic regression, GAM and empirical approaches. The CONEFALL (Jaboyedoff 2003) software was used for the definition of rockfall runout zones. The combination of these is tested in various representative districts of Lower Austria in order to develop a convenient method for the entire study area. The presented regions include the locality near Wieselburg and the districts Waidhofen/Ybbs, Amstetten and Baden. The latter districts are analysed in a smaller scale. The lessons learned while analysing different methodologies in these districts provide important inputs for the design of a proper method for the entire study area.

Due to the size of the study area and the available data sets the project team had to face different challenges while generating the susceptibility maps. These challenges rose especially in terms of availability of sufficiently complete and accurate data sets but also concerning computing capacities. Therefore special adaptations of the applied methods were carried out to permit the modelling for the entire study area according to consistent standards.

Future research will indeed focus on the improvement of the quality of the resulting landslide and rockfall susceptibility maps. In addition a focus will be given on:

- the criteria to decide on the best susceptibility map (soil and debris slides)
- the criteria to class the values into the respective classes,
- the number of classes of each map,
- the choice of colours to differentiate the different susceptibility class,
- the terms to be used for the description of each class, and
- the implication of each class on spatial planning procedures.

The intended final results are landslide and rockfall susceptibility maps at the scale of 1:25,000 for each affected municipality. These maps will be well fitted to the needs of the end-users such as spatial planners and local authorities in order to provide a basis for a sound spatial assessment of landslide and rockfall susceptibility in a given region. Indeed, these maps can only provide an indication and should not be directly used for local planning in the sense of a detailed local investigation of the slope. Any site-specific project in a potentially endangered region requires a detailed geotechnical report with respect to the local conditions. However, the maps are an important basis for any future risk management strategy which has to be define how to rationally cope with the widespread occurrence of landslides.

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