# Rockfall Susceptibility Maps in Styria considering the protective effect of forest

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## ABSTRACT

The study presents a GIS-based approach aiming at the identification of rockfall propagation areas considering the protective effects of forests in the Province of Styria, Austria. An empirical approach was selected to identify potential rockfall source zones. Based on a Digital Terrain Model derived from LiDAR data, threshold slope values for potential release areas were attributed to geotechnical units. The run-out distances were estimated by velocity calculation based on a one parameter friction model. The method was applied for the first time in such large study area. Friction coefficients were attributed to forestal units based on the detailed characterisation of relevant forest parameters derived from laserscanning data. Finally, two scenarios based on different friction coefficients were modelled: one considering the current forest cover and one assuming no forest cover. The results demonstrate the strong protective effect of the forest cover. Furthermore, an indicative hazard map was generated by classifying the transition frequencies and kinetic energies of blocks.

## KEYWORDS

Rockfall; Forest effects; GIS based modelling; Indicative hazard maps; Styria

## INTRODUCTION

Within the frame of the project "Indicative Natural Hazard Maps in the Province of Styria" the applicability of a GIS-based approach aiming at the identification of areas which are potentially endangered by rockfall has been analysed. Furthermore, the protective effect of forests was taken into account. This work was performed at JOANNEUM RESEARCH, Institute for Information and Communication Technologies (Remote Sensing and Geoinformation). The study area is the Province of Styria, located in the southeastern part of Austria and covering approx. 16.400 km² (Fig. 1). The area is part of the Eastern Alps with peaks reaching approx. 3.000 m asl.

Forests cannot stop the devastating effect of large magnitude rockfall events, but for low magnitude rockfall events, forests provide effective protection (Hétu and Gray, 2000). The maintenance of forest stands with a protection function is often more cost-effective and more sustainable than technical measures (Kienholz and Mani, 1994; Motta and Haudemand, 2000). However, in many mountainous regions it is not known whether active forest management ensures effective protection against rockfall. Therefore, the main aim was to

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assess the protective functions of the forest cover at a regional scale, as more than 60 % of the Province of Styria is covered by forests.
The results are visualized using the example of the Triebenstein region in Upper Styria (cf. Fig. 1).

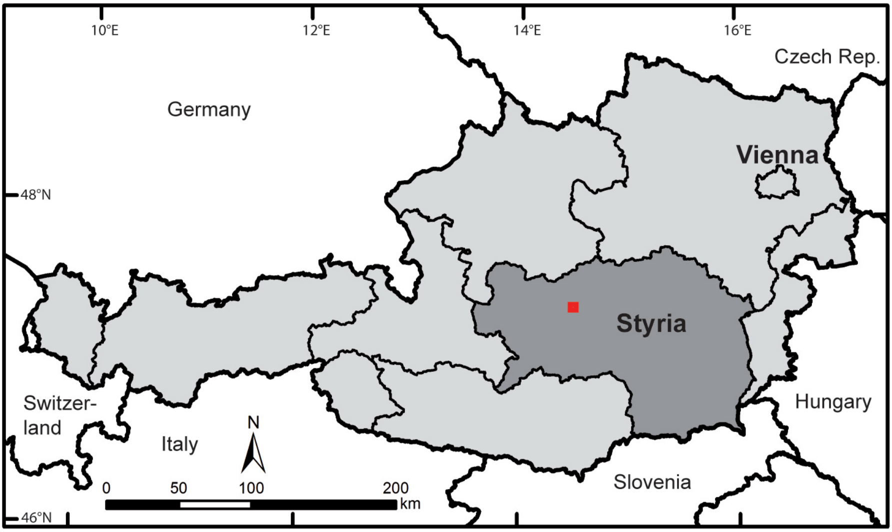


Figure 1: Study area. The red dot marks the location of the Triebenstein region from which results are shown in Figures 2, 3 and 4.

## METHODS

Two main aspects had to be taken into account: (a) the identification of potential source zones, and (b) the estimation of rockfall propagation zones.

### (a) Identification of potential rockfall source zones

An empirical approach was used for the identification of potential source areas. Due to the availability of a 1 m - Digital Terrain Model (DTM) based on Airborne Laserscanning (ALS) escarpments could be identified with high spatial resolution. With regard to data processing capacities, the spatial resolution was reduced to 2 m.

All lithological units in the study area were assigned to 16 geotechnical units (GTU) according to geotechnical properties (e.g. stability of escarpments, bedding and schistosity, weathering resistance). Threshold slope values for potential rockfall release areas were attributed to these geotechnical units based on field observations and inclinometer measurements as well as analysis of remote sensed data (Orthophotos, ALS-DTM). Morphometric parameters (e.g. profile curvature) and the tectonic situation (large faults and boundaries of nappes) were taken into account by introducing correction factors with a maximum value of 2°. The defined threshold slope angles cover values from 43° in tectonized carbonates up to 55° in massive granitic and gneissic rocks of the crystalline Central Alps.

For the simulation, the mean block volumes of each GTU were classified in three volume classes representing the most probable event, according to field observations: (1) ≤0,008 m³; (2) >0,008 – ≤0,125 m³; (3) >0,125 – 3,375 m³. As the rockfall propagation zones were modelled area-wide, one average value for rock density had to be defined and was fixed with 2,4 g/cm³ according to literature (e.g. Kobranova, 1989; Carmichael, 1984).

Figure 2 displays the GTU and potential rockfall source areas of the Triebenstein region. The geological situation is characterized by rocks belonging to the paleozoic greywacke zone (Fig. 2a). The main rockfall source areas (Fig. 2b) are situated within carbonatic rocks, building steep cliffs up to 200 m height (cf. Fig. 3). The forested slopes below the cliffs (Fig. 3c) are mainly built by phyllites where large areas are covered by talus material.

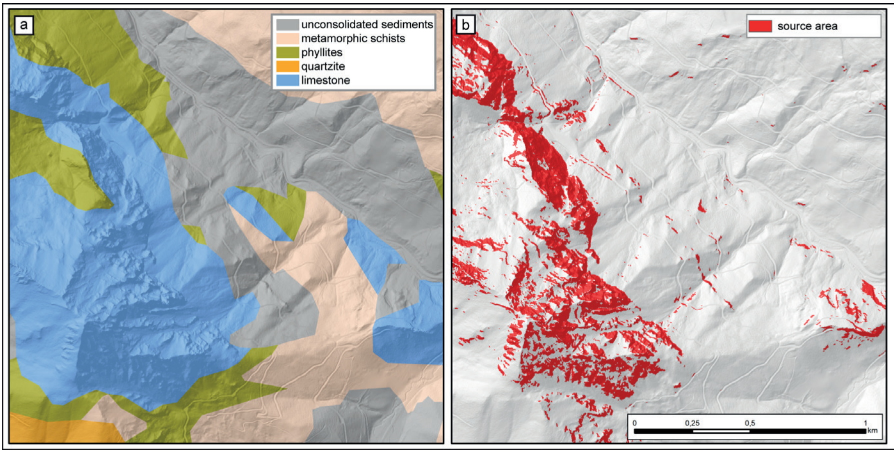


Figure 2: GTU (a) and modelled potential rockfall source areas (b) in the Triebenstein region.

### (b) Estimation of rockfall propagation zones

The runout distances were estimated by velocity calculation based on a one parameter friction model (Scheidegger, 1975). With this method, the velocity of a rock particle is calculated along a profile line that is divided into a number of triangles.

Depending on whether or not a rock breaks, 75–86% of the energy gained in the initial fall is lost in the first impact on the talus slope (Broilli, 1974; Dorren, 2003). The initial velocity on the talus slope is calculated by taking into account a factor K and in this way reducing the energy:

$$v_i = \sqrt{2.\, g.\, h_f.\, K}$$

Formula 1

where = initial velocity on talus slope [m/s]; = gravitational acceleration (9,81 m/s²); = height difference between start point and element I [m]; K = portion of energy which is reduced by impact.

The further propagation velocity is calculated on the basis of energy conservation of a mass that is considered to move over a slope surface as defined by Scheidegger (1975). In this energy conservation approach, a friction coefficient is responsible for energy loss. For each cell in the falltrack, the velocity of the falling rock is calculated as follows:

$$V_{out} = \sqrt{V_{in}^2 + 2g\,(h - \mu_f + X)}$$

Formula 2

where: = outgoing velocity [m/s]; = incoming velocity [m/s]; = fall height [m]; = friction coefficient [–]; and = horizontal fall distance [m]. This velocity is calculated for each cell within the falltrack, starting at the rockfall source cell or at the impact cell on the talus slope, respectively (Dorren and Seijmonsbergen, 2002).

Stopping occurs because energy is lost through friction forces and thus, velocity becomes zero. The value of the friction coefficient depends on the surface cover characteristics, including obstacles like vegetation and rocks.

Basic friction coefficient values were defined according to literature (e.g. Meißl, 1998; Dorren and Seijmonsbergen, 2002; Wichmann, 2006). Small rocks retard more easily than bigger rocks; mainly, because during a rockfall the total kinetic energy of small rocks is lower than that of bigger rocks (Dorren, 2003). This was taken into account by the definition of different friction coefficients for each volume class. Forest cover characteristics were taken into account for the refined estimation of the friction coefficient. This step was based on a detailed characterisation of forest parameters on basis of ALS-data and satellite data which was performed within the frame of the same project (Schardt et al., 2015). According to the derived tree heights and their homogeneity, an automatic segmentation to forestal units was performed resulting in a GIS database with a total of 6.9 million polygons. The following forest parameters were selected as being relevant indicators of the surface roughness: (a) treetop number per unit area (4 classes), (b) crown coverage (3 classes), (c) height of upper layer (3 classes) and (d) vertical forest structure (2 classes). This resulted in the definition of 24 forest types. The final refined friction coefficients are between 0,62 and 1,24 and were assigned to each of the forestal unit polygons. The friction coefficient values were calibrated by adjusting the modelled maximum runout distances to measured maximum runout distances in selected test sites (field measurements and analysis of remote sensed data). This was done for each volume class and each forest type in an iterative process. Subsequently for each volume class a friction coefficient file has been generated (cf. Fig. 3b).

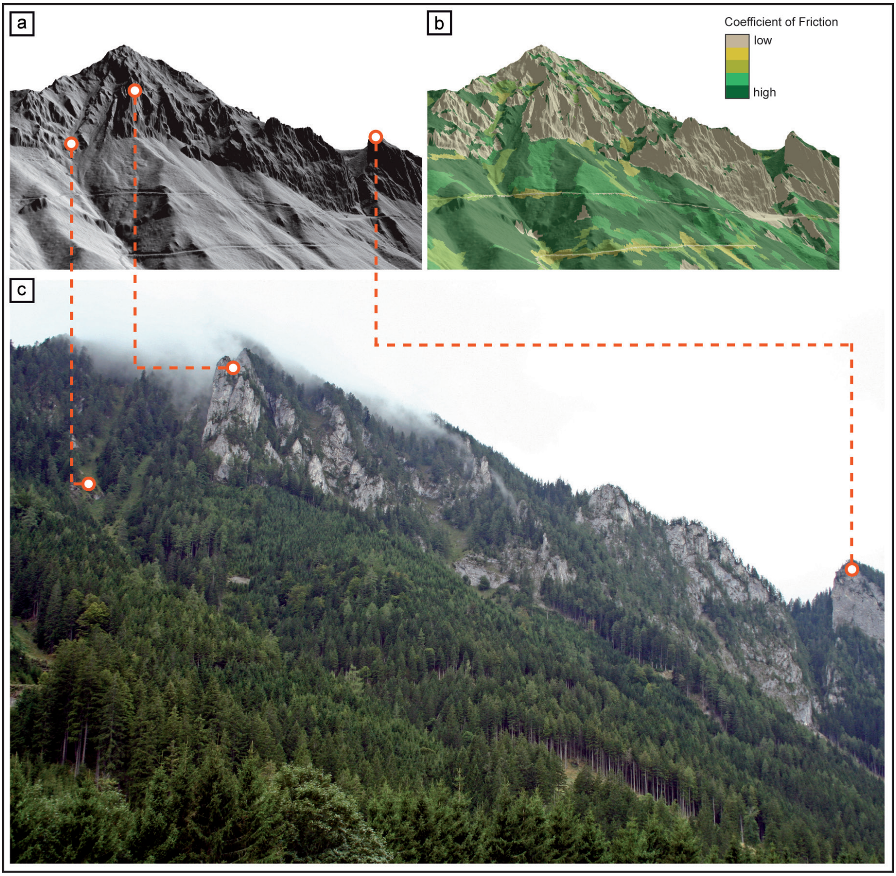


Figure 3: Detail of the Triebenstein region. (a) Hillshade visualization (b) Friction coefficients for Volume class 1 to forestal units (c) photograph of the most relevant rockfall area

Potential transition cells for velocity calculation are assigned by using a multiple flow direction algorithm, based on the work of Gamma (2000). This algorithm was adapted for rockfall and compiled in the SAGA module Rock HazardZone by Wichmann (2006), not provided free of charge.

The algorithm takes the local relief into account in order to calculate the magnitude of divergence yielding more realistic results. The method is implemented as a random walk in conjunction with a Monte Carlo approach. Modelled divergence is calibrated by three parameters: (1) a slope threshold, above which no divergence is modelled. (2) a parameter for the magnitude of divergence controlling whether a neighbouring cell exhibits a sufficiently high gradient to be selected as potential pathway and (3) a persistence factor that allows to increase the probability of that neighbouring cell, which features the same direction like the centre cell (Wichmann and Becht, 2006).

The number of iterations was fixed to 1000 after tests with a higher number of iterations had not resulted in significant improvements of the outcomes.

Modelling outputs consist of: (1) the number of transit frequencies. Due to high number of iterations (1000), the transition frequencies can be interpreted as transit probabilities of blocks approximatively. (2) The maximum velocities for each cell of the simulated blocks. Considering the three volume classes of blocks, approximate kinetic energies were calculated.

The process area was finally classified with three qualitative susceptibility categories (low, moderate, high) based on the transition frequency and the estimated kinetic energy (cf. Table 1). The Swiss codes are applied with regard to the limits of the kinetic energy (cf. Jaboyedoff, 2005).

Table 1: definition of susceptibility categories

| | | energies [kj] | | |
|---|---|---|---|---|
| | | > 0 ≤ 30 | > 30 ≤ 300 | > 300 |
| transition frequencies | 1-5000 | low | moderate | high |
| | > 5000 | moderate | high | high |

By choosing appropriate friction coefficients, two scenarios were modelled: (1) a “bare earth” scenario simulating a complete absence of forest and (2) taking into consideration the forest cover at the time of the ALS flight mission.

## RESULTS

The area wide modelling resulted in a total of approx. 603 km² of potential rockfall source areas (3,67 % of the study area), most of it situated in the Calcareous Alps and in crystalline rocks of the Niedere Tauern range. Based on field verifications in representative rockfall prone areas there is evidence that the used method rather over-estimates the extension of source areas.

In the bare earth scenario an overall of 2.171 km² is shown as endangered by rockfalls which is 13,2 % of the area of Styria. This number is composed of 1,3 % classified as low, 5,4 % classified as moderate, and 6,5 % classified as high susceptible.
Considering the forest scenario an overall of 1.541 km² is shown as endangered by rockfalls which is 9,4 % of the area of Styria. The portion of low susceptible areas rises to 1,7 %

whereas the percentage of moderate susceptible areas decreases to 3,0 % and that of high susceptible areas decreases to 4,7 %. Field verifications of maximum runout distances in selected regions indicated that the results provided a high degree of accuracy.
Due to different friction coefficients, the maximum runout distances between the bare earth scenario (low friction) and the forest scenario (higher friction) vary significantly. Especially multi-layered forest types with a high treetop density and with high (and therefore strong) trees reduce the propagation area. This can be interpreted as protective effect of forests (Fig. 4).

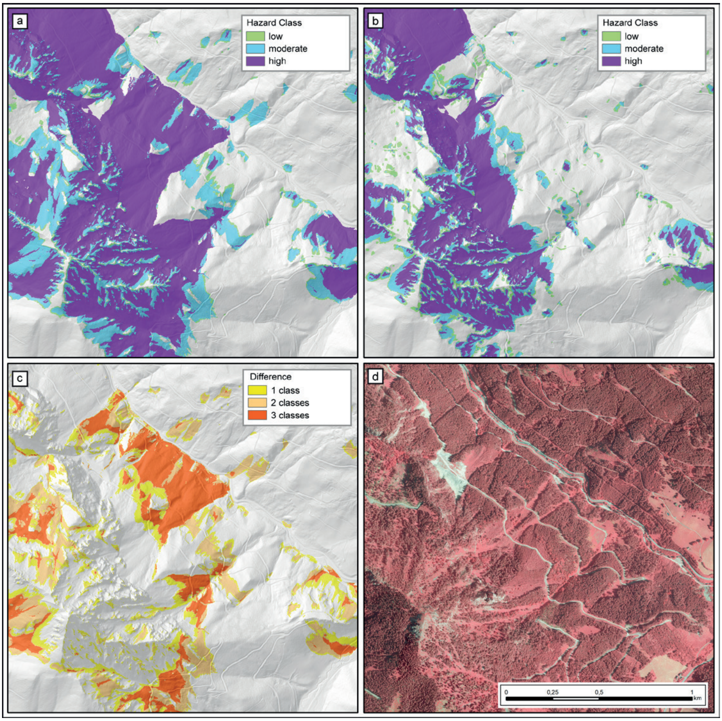


Figure 4: Results of the rockfall modelling in the Triebenstein region: (a) "bare earth"-scenario; (b) scenario considering forest cover; (c) difference map; (d) and CIR orthophoto showing current forest cover and infrastructure).

The protective effect of forests can be further visualized by calculating the difference of propagation areas between the forest scenario and the bare earth scenario (Fig. 4c). Thus the maximum reductions (three classes: from "high susceptible" to "not susceptible") mainly can be found in the lowest parts of the rockfall runout zones and hence, in areas which are often used for infrastructure and settlements.

## CONCLUSIONS

The presented method describes a generally applicable approach to model rockfall propagation areas. The approach is also suitable for large areas, which was done for the first time within the frame of the presented project. However, computing times up to several months have to be expected in large areas.

High importance has to be given to the detailed identification of potential rockfall source areas, as the whole propagation modelling procedure is based on the results of this work step. Input parameters have to be calibrated in the field taking into account representative geological conditions that can be transferred over a wide area. In this context, additional efforts have to be made with regard to the generation of more detailed and reliable geological base maps.

The modelling results of the presented method for the estimation of runout distances allow the classification into three susceptibility classes which can be used as indicative hazard map at a regional scale.

Furthermore, different scenarios with regard to forest cover (e.g. reduced or missing forest cover) can be calculated, thus demonstrating the protective functions of forests. It is however required to have detailed information about relevant forest parameters and its effects on coefficients of friction. Here, again, extensive fieldwork is a fundamental precondition for receiving plausible results.

## ACKNOWLEDGEMENTS

The project was funded by the European Agricultural Fund for Rural Development and supported by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, the Styrian Forestry Board and the Forest Association Styria.

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