82 Climate Change Impact for Spatial Landslide Susceptibility

Christine Gassner, Catrin Promper, Santiago Beguería and Thomas Glade

Abstract

Climate change is influencing future precipitation patterns. Especially the short intense rainfalls are expected to increase. Intense precipitation is regarded as one of the main landslide triggering factors. In order to investigate the likely impacts of precipitation change on spatial and temporal patterns of landslide susceptibility it is important to distinguish which type of rainfall has a major influence. Therefore, this study analyses the influence of precipitation maxima and antecedent rainfall conditions on landslide susceptibility. Other dynamic factors such as land cover change are excluded from the analysis. Logistic regression was applied to derive landslide susceptibility maps based on different climate change scenarios. Independent variables were several precipitation indices, current land cover maps and DTM derivatives (e.g. the slope gradient, aspect and curvature). The dependent variable was an inventory of shallow landslides for the period 1962–2007. The extrapolation of landslide susceptibility to the future was performed by applying the coefficients determined from past precipitation indices to those computed from future climate scenarios. The assumption herein is that conditions of the future that are similar to the past result in the same consequences. The study area Waidhofen/Ybbs is located in the alpine foreland in the province of Lower Austria. The predominant lithology is composed of calcareous rocks and Flysch. The land cover is mainly grassland and forest. The results show distinct changes in landslide susceptibility for some regions of the study area. Altered precipitation patterns intensify landslide susceptibility as well as enlarge susceptible areas.

Keywords

Climate change • Susceptibility • Landslides • Statistical modelling

82.1 Introduction

Landslides cause tremendous economic and human loss worldwide. Landslide susceptibility maps as powerful instruments have been established in many communities, as well as a base for hazard analysis. Main triggers of landslides are extreme precipitation, snowmelt and seismic activity (e.g. Tatard et al. 2010; Wieczorek and Glade 2005). Usually susceptibility maps are elaborated based on data from past events, serving as key to the future (Carrara et al. 1991). It is assumed that the same conditions of the past (regarding land use, climate, etc.) will prevail in the future. Therefore developing landslide susceptibility maps

C. Gassner (✉) · C. Promper · T. Glade
University of Vienna, 1010, Wien, Austria
e-mail: christine.gassner@univie.ac.at

C. Promper
e-mail: catrin.promper@univie.ac.at

S. Beguería
Consejo Superior de Investigaciones Científicas,
50059 Zaragoza, Spain

G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 1*,
DOI: 10.1007/978-3-319-09300-0_82,

for different climate change scenarios is a challenging task. For this purpose precipitation is taken as an important proxy (Tatard et al. 2010), since heavy rainfall events have been recognized as a major triggering factor in the study area (Remaître et al. 2013; Schwenk 1992). Also damage reports in the building ground register (BGR) of the Geological Survey of Lower Austria refer to rainfall as a predominant triggering factor in that region (Petschko et al. 2010). The main objective of this study is to assess how landslide susceptibility may change as a consequence of changes in precipitation rates.

82.2 Study Area

The study area is located in the alpine foreland in Lower Austria. The district of Waidhofen/Ybbs covers an area of 130 km^2. Due to data availability the study area itself is approx. 112 km^2. The main land cover classes are grassland in the northern part and forest in the southern part. The building area is concentrated in the valley bottoms as well as dispersed farm houses and small settlements on the hilltops. The lithology is mainly comprised of Flysch and calcareous rocks. The smooth hills underlayed by the Flysch in the northern part are prone to slides. However, landslides also occur on the steep slopes in the southern part. The total distribution of different types of landslides in Waidhofen/Ybbs is described in Petschko et al. (2010).

Regarding the climate in Waidhofen/Ybbs, temperature as well as precipitation changes will be expected within the next hundred years. For this region Loibl et al. (2007) mentioned generally, that the change of the mean annual air temperature in the scenarios applied is around +2.2 °C. A stronger warming in autumn is expected while the warming in winter is estimated to be weaker. Precipitation is projected to decrease in summer and autumn for wide areas. In winter the region shows a more or less strong increase. The overall reduction of precipitation amount of around −11 %, the decreasing number of precipitation events with less than 10 mm/day, as well as the constant number of events exceeding 20, 30, 40 and 50 mm/day, indicates that the mean intensity is increasing while the frequency is decreasing. Consequently heavy rainfall conditions can be expected in the future (Loibl et al. 2007).

82.3 Data

Several datasets are considered in this research. Since the focus of this study is mainly on precipitation data and the landslide inventory, these will be explored in more detail.

82.3.1 Precipitation Data

The climate simulations for Europe were conducted with the Climate Local Model (CLM) based on the local model (LM) developed by the German Meteorological Service (DWD). The grid size is 18 km and rotating spherical coordinates are used. The model was driven in time steps of 75 s and the input from ECHAM/MPIOM was induced every 6 h. The timeframe is 1950–2100. Observed greenhouse gases were used until 2000 and then the SREX scenarios A1B and B1 were applied. For modelling at regional scale the grid size was downscaled to 1 km. The signal of the CLM and the LM were combined with dynamic, as well as with statistical methods (Loibl et al. 2007). The output of this meteorological model, the daily precipitation sum from 1.1.1948 to 31.12.2100 was integrated in our susceptibility model.

82.3.2 Landslide Inventory

The inventory was compiled by mapping landslides on orthophotos. The inventory is based on the years 1962, 1979, 1988 and a combination of 2005 and 2007. A total number of 133 events were mapped as polygons. As described in Petschko et al. (2010) there are several landslide inventories available for the study area. To get an approximate overview about the landslide occurrence in time, the inventory mentioned above was chosen. However this incorporates also clear limitations, as not all landslides can be seen due to e.g. land cover (forest).

82.4 Methods

The susceptibility modelling is based on a statistical logistic regression analysis (Atkinson and Massari 1998; Bell 2007; Van Den Eeckhaut et al. 2006). First the current susceptibility was investigated. Afterwards the computed model parameters were transferred to the parameters of future and past time periods.

82.4.1 Data Preparation

Particularly the climate data had to be prepared as model input. Originally the precipitation is based on precipitation sums in mm per day. In the study area most landslides are triggered by heavy rainfall events. In rare instances the triggering conditions relate also to high snow melt rates in spring or thunderstorms during summer (Schwenk 1992).

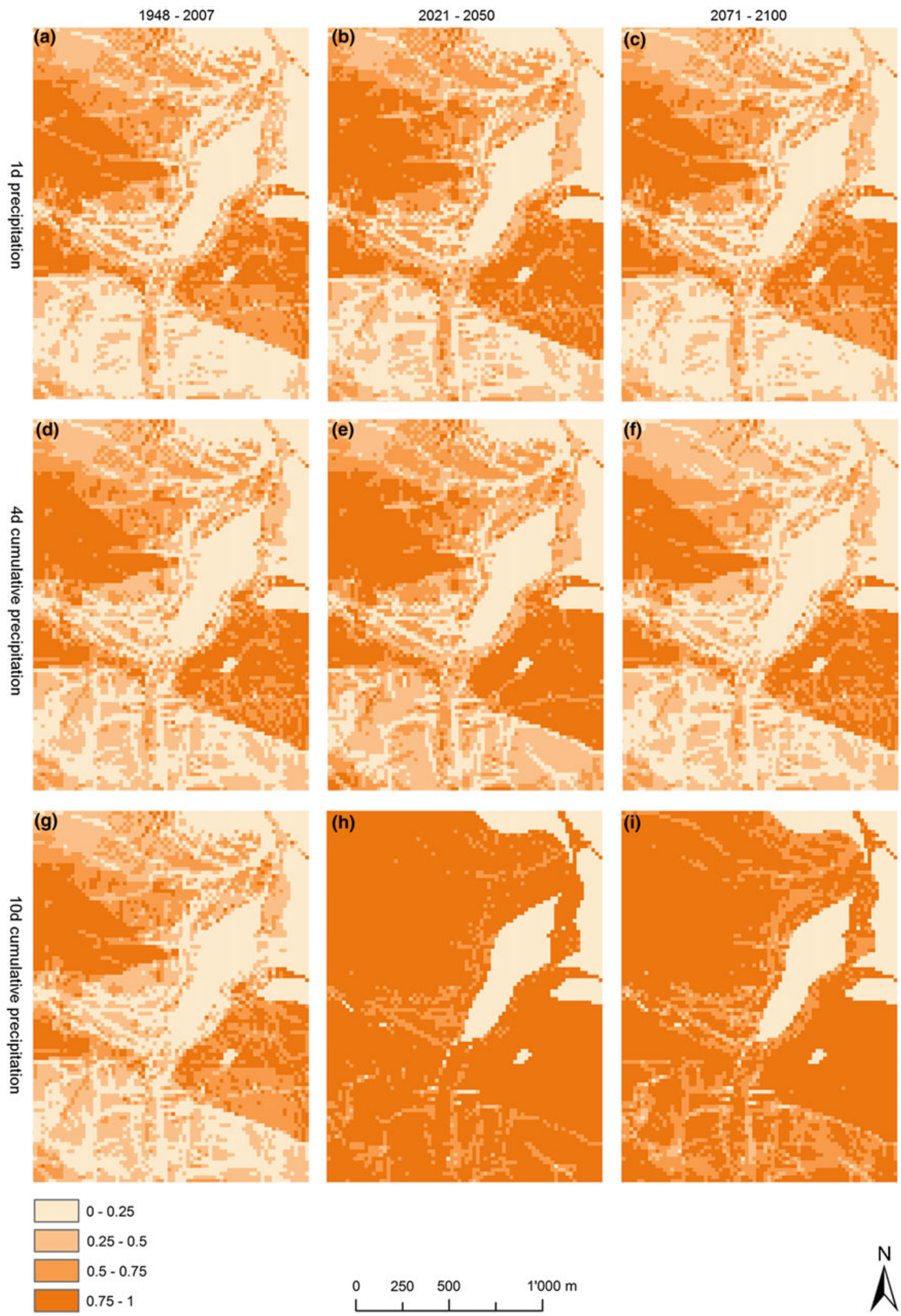

Fig. 82.1 Matrix with susceptibility maps at a small scale for modelled scenarios

Based on this and complemented by the analysis of Remaître et al. (2013) the focus of this study is on summer precipitation (June to August). For the current (1948–2007) and future (2021–2050 and 2071–2100) climate data the 90th percentile of the n-days summer precipitation is taken, where “n” defines a range between 1 and 10 days cumulative rainfall. All databases were aggregated to the land cover grid size of 20 m. Finally the input datasets for the models are the derivates of the DEM: slope gradient, aspect and plan curvature. Further the DEM, lithology, topographic wetness index, land cover (2005/2007) and the cumulative precipitation value (1, 4 and 10 days) were taken as explanatory variables. The landslides from the inventory of Riedler (unpublished project report 2013) represent the dependent variables.

82.4.2 Regression Modelling

For the modelling in R, a random sample is taken (n = 606). The sampling of slides and non-slides is equally distributed. The statistical modelling of present input parameters was conducted by stepwise backward variable selection in R, based on the Akaike’s Information Criterion (Akaike 1974). The Area Under ROC curve is provided as validation criterion which will be calculated by a training and test dataset (Beguería 2006; Brenning 2005). The extrapolation of the landslide susceptibility to the future was performed by applying the regression coefficients for precipitation (time period 1988–2005) to the future scenarios. The static parameters (i.e. lithology, slope, etc.) remain the same. Precipitation data are replaced for each time step. For visualization and comparison the values in the susceptibility maps were divided into quartiles. A second validation marked the true positives of each scenario of the classified maps.

82.5 Results and Discussion

The output of the stepwise variable selection calculated for the best fitted models has always the same variable setting (lithology, land cover, plan curvature, wetness index, slope angle and precipitation data). The 7-, 8- and 9-day cumulative precipitation models have no precipitation data in their output setting. Further these models have smaller AUROC values. However the AUROC values of the test data differs slightly at a high level from 0.80 to 0.82. The extrapolation of landslide susceptibility to the future was performed by applying the regression coefficients to synthetic datasets with the original precipitation values replaced with those obtained from future climate scenarios. Figure 82.1 shows a matrix of the resulting susceptibility maps at a small scale. The maps aligned horizontally represent a precipitation scenario (1, 4 and 10 days cumulative precipitation). In vertical direction the maps show the time period (1948–2007, 2021–2050, 2071–2100). Generally the maps of the period 2021–2050 show the highest susceptibility whereas the period 2071–2100 are closer to the past period (1948–2007). The highest susceptibility classes rise in the second period significantly. Despite a small change in the pixel distribution, there is a significant increase in the landslide susceptibility. In the 10 day scenario (Fig. 82.1g–i) a surpassing susceptibility rise can be seen especially in the two highest classes. The interpretation of this increase in susceptible areas is dichotomous. Either the data set is biased or the extrapolation thresholds take effect on the visualisation or it indicate a tendency of high susceptibility for long term precipitation periods, such as 10 day cumulative precipitation periods. This and the 4 day scenario are the statistically best fitted models.

82.6 Conclusion

This study focuses on summer precipitation. It can be seen that the long term precipitation data show significantly different results. Hence the next step of analysis is to test the models for winter and spring respectively, to measure the influence of snowmelt processes on landslide susceptibility. Climate change driven changes in precipitation do influence landslide susceptibility. However more proxy data e.g. and cover, land cover change or other anthropogenic proxy indices can contribute to improve the significance of susceptibility models.

References

Akaike H (1974) A new look at the statistical model identification. IEEE T Automat Contr 19:716–723

Atkinson PM, Massari R (1998) Generalized Linear Modelling of susceptibility to landsliding in the Central Apennines, Italy. Comput Geosci 24:373–385

Beguería S (2006) Validation and evaluation of predictive models in hazard assessment and risk management. Nat Hazards 37:315–329

Bell R (2007) Lokale und regionale Gefahren- und Risikoanalyse gravitativer Massenbewegungen an der Schwäbischen Alb (Dissertation). Universität Bonn

Brenning A (2005) Spatial prediction models for landslide hazards: review, comparison and evaluation. Nat Hazards Earth Syst Sci 5:853–862

Carrara A, Cardinali M, Detti R, Guzzetti F, Pasqui V, Reichenbach P (1991) GIS techniques and statistical models in evaluating landslide hazard. Earth Surf Proc Land 16:427–445

Loibl W, Beck A, Dorninger H, Formayer H, Gobiet A, Schöner W (2007) Kwiss-Programm reclip: more research for climate protection: model run evaluation. Final report

Petschko H, Glade T, Bell R, Schweigl J, Pomaroli G (2010) Landslide inventories for regional early warning systems. In: Malet

JP, Glade T, Casagli N (eds) International conference 'Mountain Risks: Bringing Science to Society', 2010, Strasbourg, CERG Editions

Remaitre A, Wallner S, Promper C, Glade T, Malet JP (2013) Rainfall characteristics associated to the triggering of fast- and slow-moving landslides—a comparison between the South French Alps and Lower Austria. In: European Geoscience Union General Assembly, 2013, Vienna

Schwenk H (1992) Massenbewegungen in Niederösterreich 1953–1990. Jahrbuch der Geologischen Bundesanstalt 135:597–660

Tatard L, Grasso JR, Helmstetter A, Garambois S (2010) Characterization and comparison of landslide triggering in different tectonic and climatic settings. J Geophys Res: Earth Surf 115:F04040

Van Den Eeckhaut M, Vanwalleghem T, Poesen J, Govers G, Verstraeten G, Vandekerckhove L (2006) Prediction of landslide susceptibility using rare events logistic regression: a case-study in the Flemish Ardennes (Belgium). Geomorphology 76:392–410

Wieczorek G, Glade T (2005) Climatic factors influencing triggering of debris flows. In: Jakob M, Hungr O (eds) Debris flow hazards and related phenomena. Springer, Heidelberg