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Analysis of land cover changes in the past and the future as contribution to landslide risk scenarios

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A B S T R A C T

Various factors influence the spatial and temporal pattern of landslide risk. Land cover change is one of the crucial factors influencing not only the natural process "landslide" and thus the hazard, but also the spatial distribution of elements at risk. Therefore the assessment of past and future landslide risk at regional scales implies the analysis of past and future land cover development. In this study, the first step in the analysis of landslide risk development over time is approached by analysing past land cover, as well as modelling potential future scenarios. The applied methods include analysis of orthophotographs and landcover scenario modelling with the Dyna-CLUE model. The timespan of the analysis covers 138 years from 1962 to 2100. The study area is located in Waidhofen/Ybbs (Austria) in the alpine foreland. A high number of landslides are recorded in the district. The predominant land cover types are grassland and forest. Buildings and residential areas are located in the valley bottoms and scattered on the hilltops. The results show clear changes in the land cover development of the past and in the future including spatial changes in the distribution of elements at risk. The trends show an increase in forest on the expense of grassland. The spatial evolution of the surfaces of arable land is rather high whereas the surfaces of residential zones increase steadily. The spatial analysis indicates also the development of new building areas and consequently potentially new landslide risk hotspots.

Introduction

The change in temporal and spatial patterns of landslide risk is attributed to several factors of global change. The changing climate is not only influencing intensity and frequency of extreme weather events, but also their extent, duration and occurrence time (IPCC, 2012). Alternating land use and land cover respectively may act as predisposing factors of landslide occurrence (Glade, 2003; Beguería, 2006), but may also control the spatial distribution of landslide consequences. The fact that not only the natural processes but also the elements at risk change continuously, leads to the assumption that risk assessment cannot be a static process (van Westen, 2010). To address the spatio-temporal variability of landslide risk, one aspect is to analyse past land cover changes, as well as future development of the land use and land cover using scenario-based approaches.

According to Slaymaker, Spencer, and Embleton-Hamann (2009), human activity, especially as far as land use and land cover patterns are concerned, is the most rapid driver of global change. Rindfuss, Walsh, Turner, Fox, and Mishra (2004) refer to the interaction of human and natural subsystems that lead to alterations in land use and land cover. New land cover patterns may occur not only due to natural factors but also as a result of a number of anthropogenic activities such as economic developments, population growth or land abandonment. The scenario based analysis serves as a tool to determine *what could happen* assuming different pre-conditions (Verburg, Eickhout, & Meijl, 2008). These pre-conditions mostly imply the interaction of factors of the subsystems as mentioned above (e.g. demographic or climate change). Modelling these scenarios and their uncertainties is an explorative analysis that helps to delineate the margins of the possible and conceivable (Verburg et al., 2008). Moreover, the analysis of the past and future land cover is significant to thoroughly investigate two of the major research questions dealing with land cover processes: 1) understanding in which locations land cover change occurs, and 2) assessing the rates of change (Lambin, 1997). The spatially explicit analysis enables to

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understand and delineate better the interactions of the two subsystems (Rindfuss et al., 2004).

The analysis of the possible future land cover development is especially important due to the fact that decision-makers are interested not only in the future hazard potential but also in the information on potential loss as input to a range of decisions (e.g. hazard mitigation plans; Downton & Pielke, 2005; Frazier, Walker, Kumari, & Thompson, 2013). Modelling and monitoring of land cover development on a regional scale has been conducted in many different regions around the world (Rembold, Carnicelli, Nori, & Ferrari, 2000; Ruelland, Levavasseur, & Tribotté, 2010; Teferi, Bewket, Uhlenbrook, & Wenninger, 2013). Many authors focus on ecosystems or more specific on deforestation (Etter, Mc Alpine, Wilson, Phinn & Possingham, 2006; Lambin, 1997). Regarding landslides and land cover change there are numerous studies available e.g. Alcántara-Ayala, Esteban-Chávez, & Parrot, 2006; Beguería, 2006; Glade, 2003 or Van Beek and Van Ash, 2004. Moreover, land cover change and consequent changes in the impact of natural hazards is an emerging topic within the research community e.g. Wood (2009) studying tsunami exposure, Alcántara-Ayala et al. (2006) assessing the distribution of landsliding in the context of vegetation fragmentation or Papathoma-Köhle and Glade (2012) also dealing with vegetation cover and landslide hazard and risk. In this study we apply a land cover analysis for the past, as well as, approximating future land cover in order to allow a first attempt towards the potential evolution of landslide risk.

The analysis of the spatio-temporal patterns of land cover will be the base for investigating the development of potential landslide risk. The focus of the paper is on the location explicit temporal analysis and the non-location specific quantitative analysis of land cover changes, based on implemented scenarios. First, the methodology used for the spatio-temporal land cover analysis is explained. Second, a short description of the study area detailed in order to demonstrate the relevance of the study's objectives on a regional scale. Finally, the results are discussed and some perspectives for further analysis are proposed.

Method

The approach for land cover analysis as a basis for the subsequent risk assessment requires the combination of different sets of methods. To analyse the land cover change, the applied methodology contains four steps:

1. setting the time scale of analysis,
2. analysing the spatial land cover changes,
3. adapting and modelling future land cover scenarios,
4. performing a quantitative and qualitative (spatially explicit) analysis.

Hereby, spatially explicit refers to a location based analysis of the different land cover types. Regarding the future land cover development, scenarios are envisaged in order to run the model for scenario-based approximation of possible future developments.

Time scale of the analysis

There are two considerations related to setting the time span of the land cover change analysis: a) which mapping documents are available for the past and b) what time span is reasonable concerning future scenarios.

In order to compare results, the time periods should be chosen in accordance to existing future scenarios regarding development plans or climate change models (Hiess et al., 2009; ÖROK, 2011; Schoener, Boehm, & Haslinger, 2011; Smiatek, Kunstmann, Knoche, & Marx, 2009). For this reason three future time steps are used in this analysis: 2030, 2050, and 2100. The year 2030 is selected due to the horizon of the spatial development plans and scenarios. 2100 is the horizon of various climate models and 2050 seemed reasonable in order to have periods with an adequate number of years for land cover analysis.

Spatial analysis of land cover changes

Analysis of past land cover changes

Available aerial photographs of past spatial land cover patterns are mapped in order to be used for the analysis of the land cover change over time. This is achieved by ortho-rectifying the available aerial photographs. To ensure reasonable results, certain rules and restrictions (Promper & Glade, 2012) were set for carrying out the visual interpretation in a GIS environment. If the data quality did not allow visual interpretation, a comparison with other orthophotographs was required.

Future land cover scenarios

Scenarios can be considered as alternative images on how the future might unfold (Nakićenović et al., 2000). Regarding land cover, this implies not only climate-driven changes but also direct anthropogenic impacts. Spatial and regional development scenarios available by authorities or previous projects may serve as a basis for land cover modelling. To serve as spatially explicit analysis, input parameters have to be defined. Further the assumptions need to be stated clearly in order to ensure transparency within the analysis.

The model Dyna-CLUE 2.0 (Verburg & Overmars, 2009) was selected to simulate the land use scenarios because it includes a spatial and a non-spatial module (Verburg et al., 2002). The model combines statistical analyses and decision rules that determine the sequence of land cover types (Schaldach & Priess, 2008). For the spatial analysis, the relationships between the different land cover classes and the main driving factors are evaluated by stepwise logistic regression (Verburg et al., 2002). Moreover, location specific restrictions (e.g. natural reserves) need to be included. The demand represents the non-spatial model input and is based on the scenarios used. These values are implemented in the model as a top-down factor. By an interactive process, the model tries to implement all these changes for one year before it proceeds to the next. This ensures that, for example in the map of 2030, all changes from 2005 onwards are already included.

The basis for the spatial distribution of the different land cover classes in the scenarios depends mainly on topographic factors like slope and aspect. However, some general spatial planning assumptions are also incorporated to limit certain factors (e.g. development in completely remote areas). Applying assumptions in scenario building enables implementation of possible societal and economic developments in order to simulate what might happen in the future (Rounsevell, Ewert, Reginster, Leemans, & Carter, 2005). The assumptions applied are explained in more detail in the following paragraph.

On one hand, an assumption that the demand for the years 2005–2030 will not change until 2100 had to be made, meaning that this was extrapolated, adopting at the same time some general trends in spatial planning. On the other hand, the second assumption is that no new building area outside a 100 m buffer of existing building area/street area is allowed. Further, a minimum distance (200 m) between farms is applied. Finally, street areas do not develop for the reason that Dyna-CLUE 2.0 does not integrate options for linear development. Another assumption was the fact that water surfaces do not change within the modelling process.

Additionally, the past development of land cover is not yet implemented into the future modelling. The hypothesis supporting