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Future land change scenarios for risk assessment: Linking participatory modelling and geosimulation

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INTRODUCTION

Land use changes can have significant consequences in mountain areas exposed to hydro-meteorological hazards such as floods and landslides (Fuchs et al. 2013). They can increase the risk by affecting the hazard pattern due to increased surface runoff after deforestation or expansion of impervious surfaces (Glade and Crozier, 2005). Furthermore, urban expansion can result in an increase and changes to the spatial distribution of elements at risk (Bronstert et al. 2002). The relationship between land use change and its impact on mountain communities has recently led to increased attention of decision makers in studying the possible futures of such changes (Schneeberger et al. 2007). Research of future land use change has so been proposed when studying changes to hydro-meteorological risk (Tollan, 2002).
Simulating future land use changes however remains a difficult task, due to uncontrollable and highly uncertain driving forces of change (Peterson et al. 2003). An adequate tool to address these limitations is scenario development. Scenarios offer exploring possible futures and the corresponding environmental consequences, and enable the analysis of possible decisions (Kriegler et al. 2012). Indeed, there is increased interest of decision makers and researchers to apply scenarios when studying future land changes (Rounsevell et al. 2006).
The uncertainty related to modelling future land change scenarios is among others defined by difficulties in obtaining data and its accuracy, quantification of intangible driving forces, and relating possible future changes to a spatial pattern. To address the issue of data and intangible driving forces, several studies have applied participatory techniques to develop future scenarios. Involving stakeholders leads to incorporating a broader spectrum of professional values and experience. Moreover, stakeholders can provide missing data, improve detail, uncover mistakes, and offer alternatives (Beierle and Cayford, 2002). Through participation the scenarios can be considered as more reliable and relevant (von Korff et al. 2010). Finally, participatory modelling promotes learning for and from all involved stakeholders, and can also be considered as a communication tool (Mendoza and Prabhu, 2006). Participatory scenario development has been applied to study a variety of issues in environmental sciences (Bayfield et al. 2008; Kok, 2009; Odada et al. 2009; Wollenberg et al. 2000). Still, participatory approaches are rarely spatially explicit, making them difficult to apply when analysing changes to hydro-meteorological risk.
Spatial explicitness is needed to identify critical areas of land change, leading to locations where the risk might increase (Verburg et al. 1999). In order to allocate land change

scenarios developed together with stakeholders, we combined participatory modelling with geosimulation in a multi-step scenario generation framework. We propose to present a framework that is able to develop scenarios that are plausible, can overcome data inaccessibility, address intangible and external driving forces of land change, and is transferable to other case study areas with different land change processes and consequences. The methodology was developed and applied in a regional scale case study in the Italian Alps, where the uncertainties regarding future urban expansion are high (Malek et al. 2014a). Later, we transferred it to a study area in the Romanian Carpathians, where the prevailing process of land change is deforestation. Both areas are subject to hydro-meteorological risk, posing a need for the analysis of the possible future spatial pattern and locations of land change. To achieve this, we linked qualitative methods, such as interviews and cognitive mapping, with geospatial techniques like GIS and environmental simulation. By working in a spatially explicit environment, we pointed at identifying hot spots of land change, serving as a possible input for a risk assessment.

STUDY AREAS

The study areas are situated in two major European mountain areas: The Alps and the Carpathians. More precisely, the Alpine study area lies in Friuli-Venezia-Giulia in North-eastern Italy, whereas the Carpathian lies in Buzau County in the South-east of Romania (Figure 1). The two regional scale study areas were selected due to their representativeness in terms of biophysical and socio-economic characteristics for the Alps and Carpathians respectively. For both study areas, there is a lack of research investigating the link between socio-economic changes and possible future changes to the land use. Moreover, the consequences of these changes in form of potential changes to future hydro-meteorological risk is as yet understudied as well.

Both areas experienced significant socio-economic changes in the last 30 years. The Alpine study area encompasses the mountain community of Gemona, Canal del Ferro and Val Canale, that borders Austria and Slovenia. In the last 30 years it witnessed a collapse of local commercial and customs zones, as well as one of the highest depopulation rates in the Alps. This was mostly due to the loss of its competitive border location after the enlargement of the European Union and the Schengen regime (Malek et al. 2014a). The focus of the regional economy therefore shifted towards tourism, with increasing investments in tourism and recreational infrastructural. The increase in possible new tourism related areas poses a need for studying the spatial pattern of future land changes, as the area is subject to numerous hydro-meteorological hazards, among them flash floods and debris flows are most frequent. The Romanian study area, the Buzau Subcarpathians experienced a collapse of local industry and collective agricultural organisations, as well as difficulties in forest management. This resulted in an increase of forest disturbances in the form of deforestation, a trend likely to continue in the future (Malek et al. 2014a). The area has a dense network of landslides, therefore continuing deforestation could affect the risk to landslide significantly. Studying the spatial pattern of potential future changes to the forest cover is therefore essential.

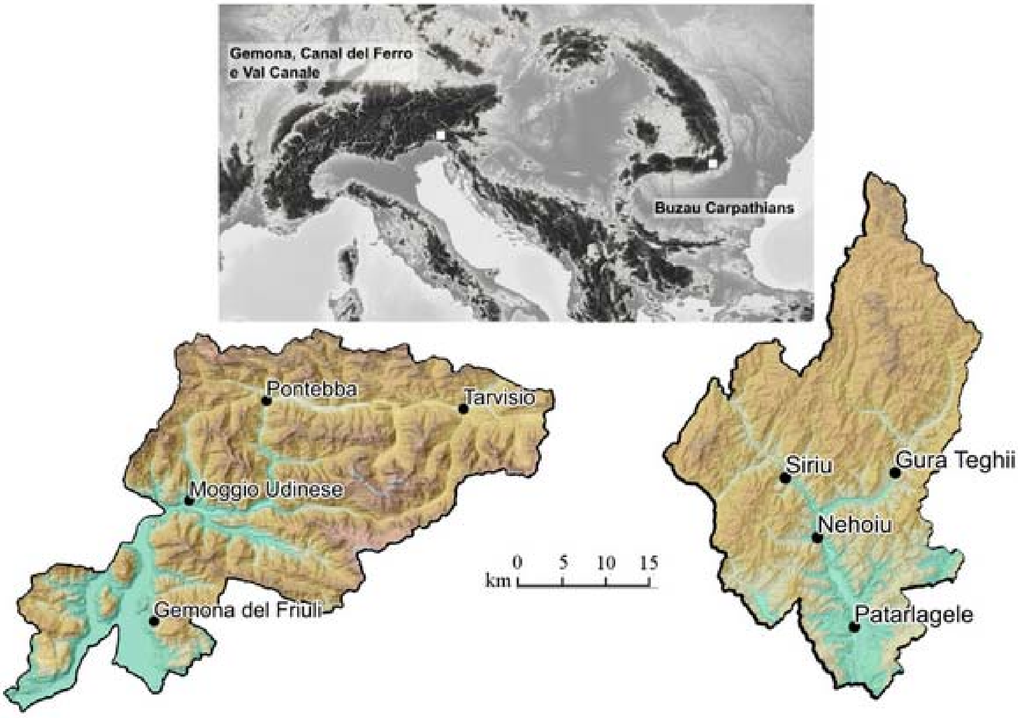

Figure 1. Location of study areas. Modified from Malek et al. (2014a).

METHODS

Participatory modelling

Due to lack of data and difficulties to identify external driving forces of land use change, we developed the scenarios in a participatory way. The aim was to investigate and model the expert knowledge on land use changes of local stakeholders. This model was purely qualitative and served as a conceptual model for a later development of a spatially explicit land use change model.

In both study areas, interviews and group discussions were performed with experts and decision makers from the field of spatial planning, risk management, forestry, agriculture and development. To map the expert knowledge, we used the method of Cognitive Mapping (CM). It is a qualitative methodology, where numerous concepts on a particular issue (in this case land use changes) are connected to each other in a form of a graph (Axelrod 1976). By expert involvement otherwise unknown knowledge about the issue can be investigated, therefore improving the difficulties of inaccessible data or external driving forces (Eden 1992). First, concepts on causes and consequences of land use changes were identified, followed by identifying the relationships between these concepts.

The CM method is useful for describing land use changes, however it cannot be used to explain or project future changes. In order to do this, the developed CM needed to be structured in a cause-response framework. Thus, the Driving Forces – Pressure – State – Impact – Response (DPSIR) framework was applied (EEA, 1999). This enabled the development of a conceptual model and the derivation of indicators and future development options, which was necessary in order to develop future scenarios.

Then, the statistical relationship between the different parts of the DPSIR model was investigated. Here, accessible data on the identified socio-economic driving forces was used. In the Italian study area, this meant investigating the relationship between tourism accommodation trends and the demand for tourism related built up areas. The proxy for tourism accommodation was used, as associating future tourism development to urban areas was to abstract for the stakeholders. In the Romanian area, the relationship between the demand for forest cover change and allowed amount of forest harvesting was investigated.

Here, the spatial demand for forests was more comprehensible to the stakeholders, however it was still difficult to relate it only to deforestation without considering other forest management options. In both study areas, two future scenarios based on different development options were developed. This way, the scenarios were based on different logic, instead of only being described by different growth/decrease rates (Ogilvy and Schwartz, 2004).

Geosimulation model

Based on the conceptual DPSIR model and developed indicators, a spatially explicit land use allocation model was developed. The model was developed in Dinamica EGO, a raster based environmental modelling software (Soares-Filho et al. 2002). The scenarios developed through participatory were allocated using a weights of evidence land use change potential map, and a cellular automata (CA) model.

In both study areas, I calibrated the model with past remote sensing observation on land use change, and spatial data (elevation, slope, aspect, distance to roads and settlements, protected areas…depending on the study area). To relate past observations with the spatial data, I applied the weights of evidence method, a Bayesian probability method to investigate the significance of spatial data on land changes using historic observations of these changes (Bonham-Carter, 1994; Hosseinali and Alesheikh, 2008). The result was a land use change potential map, defining the areas where future land use changes are more likely to occur.

To allocate the scenarios, a 30 m resolution CA model was used. CA are bottom-up models, where cells in a grid based landscape are subject to change in every time step (Engelen et al. 1995). The cells change according to transition rules (influenced by the potential map) and cell neighbourhood (Mitsova et al. 2011). Not all cells were considered in the simulation – protected areas and areas where it is legally excluded to build or harvest forest (such as areas on steep slopes) were excluded from the simulation. The shape and size of new areas subject to change (e.g. new urban patches, or patches of deforestation), were trained with past remote sensing data on land use changes.

Impact assessment

Due to data inconsistency between the two study areas, the methodology for evaluating the potential future impact of land use changes differed slightly for each study area. In both areas, a Geographic Information System (GIS) based assessment was performed. Future scenarios were thus combined with accessible data on hydro-meteorological risk.

In the Italian area, the data enabled measuring the extent of future urban expansion on areas with high risk. Geological risk and floods were taken into account by overlaying future scenarios with risk maps. As areas with highest risk were already excluded in the modelling due to legal exclusion of settlement expansion on these areas, only areas with moderate risk that area subject to future changes were measured. In the Romanian area, data on risk and hazard were not accessible. Therefore, a landslide susceptibility map developed by Hussin et al. (2013) was applied in the GIS based risk assessment. This way, I measured the extent of deforestation on areas with high landslide susceptibility was identified.

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RESULTS

Conceptual participatory models

The developed cognitive maps can be considered as expert based belief systems (Kosko, 1986). Still, they cannot be used for quantitative simulation and cannot operate on a temporal scale (Kok, 2009). Thus, the developed cognitive maps served only as a step in developing the conceptual models for land use change in the selected study areas. An example of a developed cognitive map for the Romanian study area is described in Figure 2. As it can be observed on the image, the CM enabled the identification of relationships between different concepts relating to land use change. Still, the CM is unstructured and cannot serve as a final model.

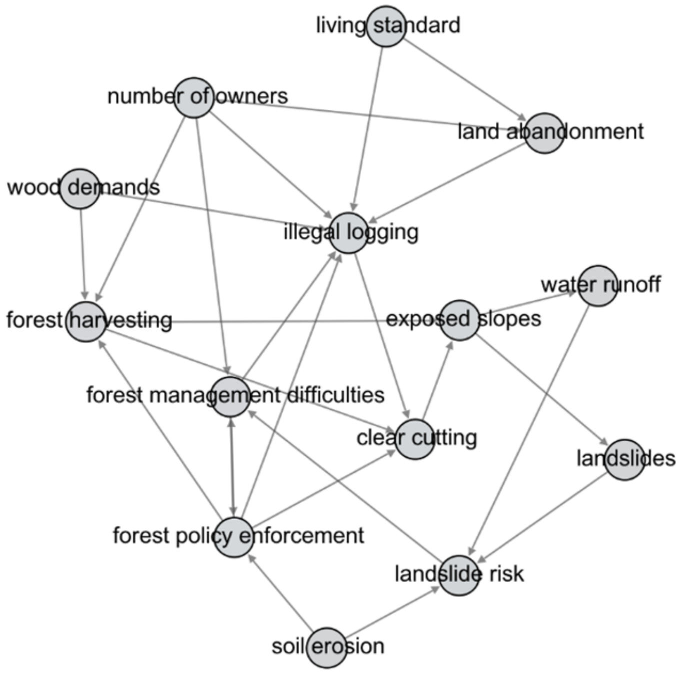

Figure 2. Example of a Cognitive Map for the Buzau Subcarpathians study area

The DPSIR model is an upgrade of the qualitative CM expert model and enables the identification of driving forces and consequences of land use change. A DPSIR based on cognitive maps developed in the Romanian area can be observed in Figure 3. Following the developed DPSIR model, different scenarios for each study area were developed. The DPSIR model enabled the development of scenarios, where scenarios are not just different growth/decrease rates, but are based on changes or different parts of the DPSIR model (new policy, development option). The scenarios in the Italian study area so focused on a potential increase of built up areas due to future tourism development. Two scenarios describing two different development pathways (large scale and a traditional) were developed. The large-scale scenario promoted the development of more large-scale tourism resorts, where tourism related built up areas are concentrated. The traditional scenario followed a less centralized spatial preference pattern, where smaller tourism objects were scattered around the landscape. In the Romanian study area, scenarios were based on possible future changes to the forest exploitation policy and subsequent deforestation. A business as usual (BAU) and forest harvesting increase scenario were thus developed. Whereas the BAU scenario followed the current forest harvesting policy, the increase scenario resulted in both higher quantity of harvested forest, as well as larger patches of deforestation.

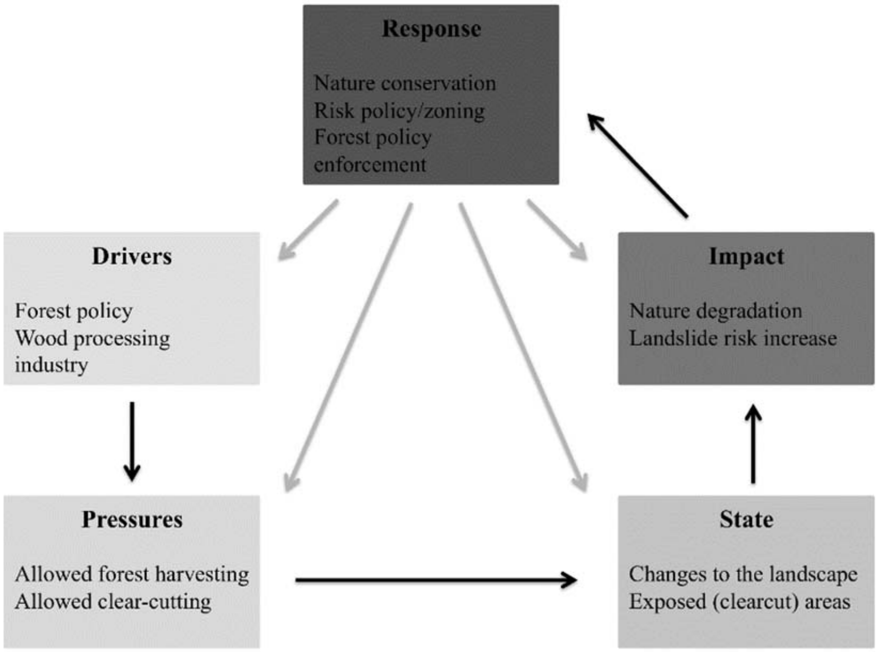

Figure 3. Conceptual DPSIR model as a participatory conceptual model of land use change. Modified from Malek et al. (2014b)

Spatially explicit scenarios

In both study areas, first land use change probability maps were generated, with probability ranging from 0 (low) to 1 (high). These spatially explicit maps provide information on areas where particular land use changes are more likely. They are based on spatial drivers described in the methodology section, so they present the likelihood of land use changes in a particular location (cell) under the assumption of considered spatial factors. In both study areas, the areas most susceptible to possible future land use change are shown in Figure 4. In the Italian study area, the map shows the probability of future expansion of built up areas. Areas on the valley floor and southern gentle slopes have the highest likelihood, whereas areas on higher altitudes and steep slopes with a big distance to existing settlements and roads have the lowest likelihood for potential future land use change. In the Romanian study area, the probability map shows the likelihood of future deforestation. Forests near forest roads and on gentle slopes are most likely to experience deforestation, whereas forests with a bigger distance to roads and steeper slopes have the lowest likelihood for deforestation.
The scenarios developed and discussed in previous sections were allocated around the landscape based on the probability maps. Depending on the study area, the amounts for urban expansion, deforestation… were allocated on areas with highest probabilities for land use change. The results were scenarios of built up area expansion in the Italian, and scenarios of deforestation in the Romanian study area. On Figure 5, examples of deforestation scenarios can be seen.

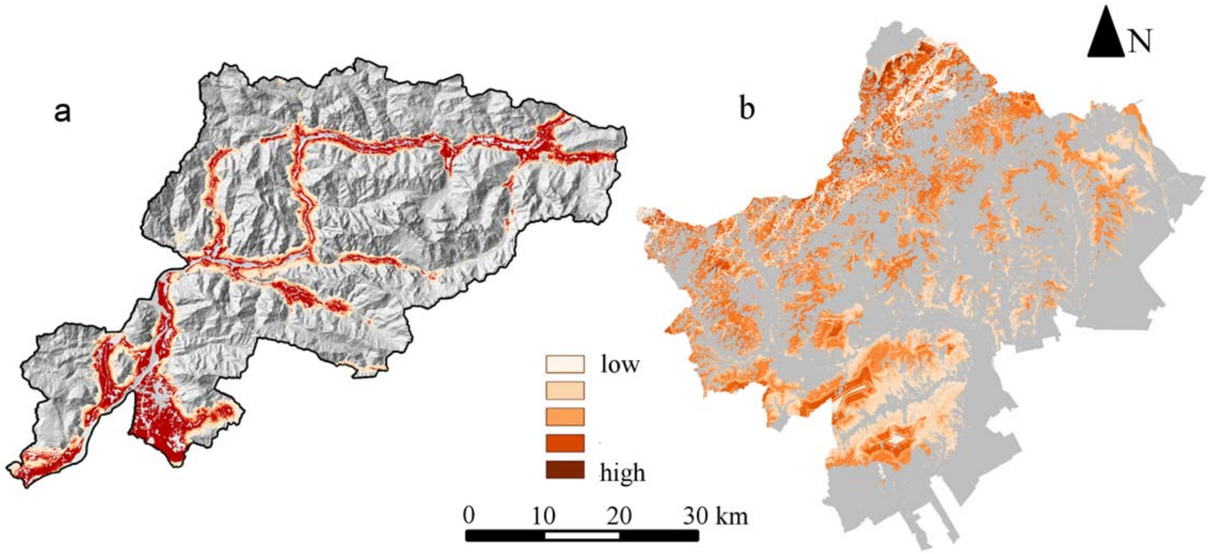

Figure 4. Land use change probability maps for the (a) Italian and (b) Romanian study area.

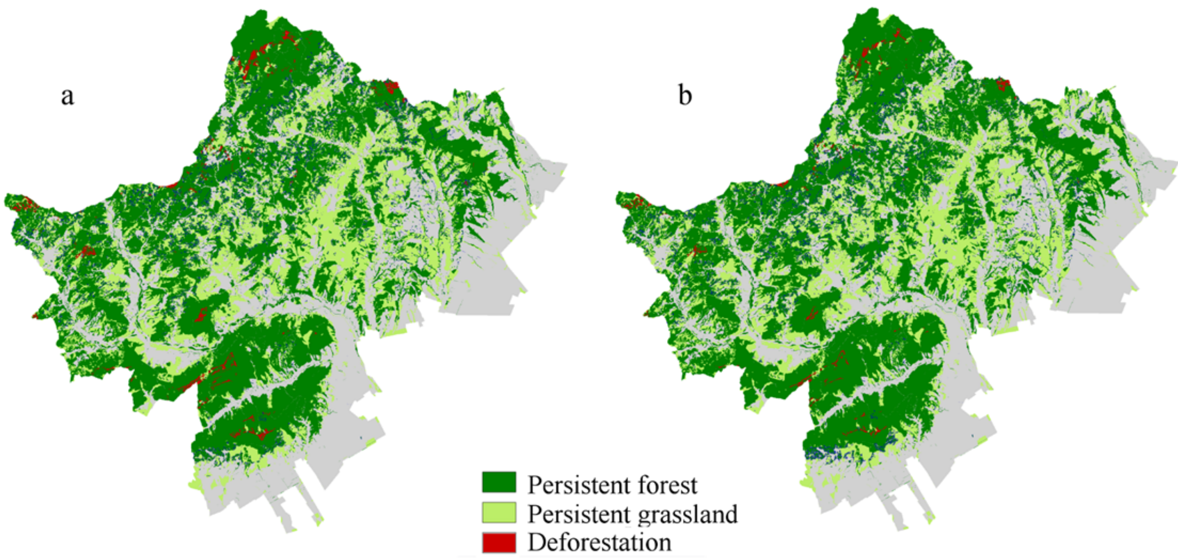

Figure 5. (a) Forest harvesting increase and (b) Business as usual scenario for the Romanian study area.

GIS based impact of scenarios

In both study areas, GIS based impact assessment was performed. Scenarios were overlaid with accessible risk related data, resulting in spatially explicit impact maps. Figure 6 shows the potential impact of future deforestation and forest expansion in the Romanian study area in terms of landslide risk. The map is based on analysing the gains and losses in landslide susceptibility. This last step of the proposed methodology, supports the application value of future land use change scenarios for analysing changes to risk. Other examples of potential analysis of impacts of future land use changes are changes to biodiversity, landscape image, and forest harvesting potential. Due to its simplicity, the approach is suitable for data poor areas. Nevertheless, for a more detailed identification of potential changes to risk, additional runs of flood or landslide related models should be performed. Moreover, this approach does not take into account climate change and other changes such as increase in value of elements at risk. Therefore, it should be used as a complementary method. Still, when evaluating different scenarios, it is useful as it enables a fast, transparent and straightforward approach to identify which scenario has more impact on risk.

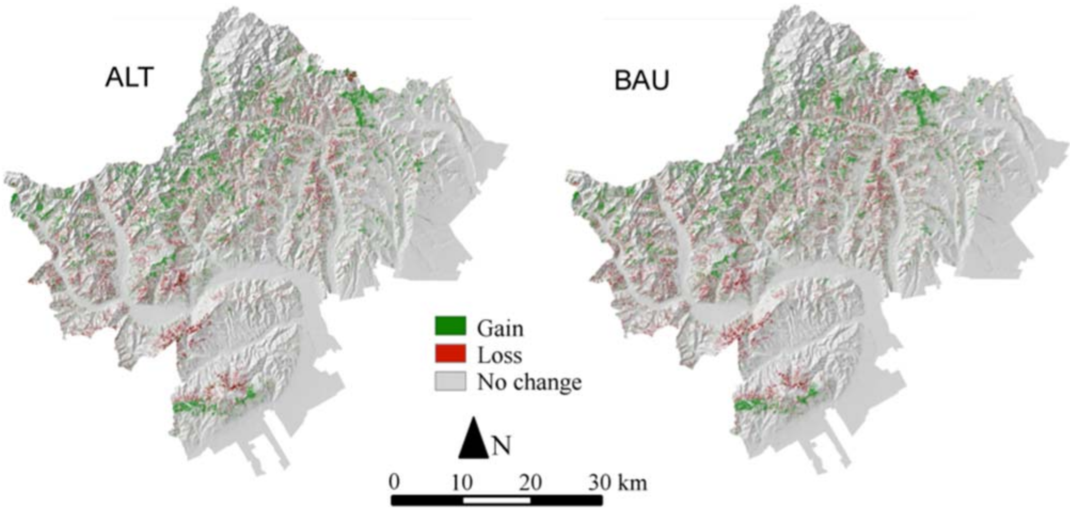

Figure 6. Potential impacts of future forest cover changes in the Romanian study area in terms of changes to landslide risk. Changes to landslide risk are defined as gains (less risk) or losses (more risk) due to changes to landslide susceptibility.

CONCLUSIONS

This contribution presents a methodology for developing land use change scenarios. It combines participatory modelling such as Cognitive Mapping with GIS and geosimulation. The approach is able to develop scenarios in a data scarce environment, or in areas where predominant driving forces are external and difficult to quantify. Moreover, it is transferrable to other study areas, as it was shown on two study areas in this contribution. Involving stakeholders leads to a more plausible (likely) scenarios, that are also more relevant and of interest to involved stakeholders. The quantitative, spatial part of the approach on the other side leads to a higher applicability of the methodology, especially in terms of its spatial explicitness.

The approach has its limitations. First of all is, that all the methodologies combined have their own uncertainties, which are aggregated. They are also combined with the uncertainties of the used data, which are usually higher in areas with scarce data. This poses questions on the reliability of the spatially explicit results. Nevertheless, the presented methodology was not meant for future prediction, but for scenario evaluation. Comparing different scenarios, through analysing the consequences of different driving forces or policies can thus lead to more informed decisions when planning the future land use. Moreover, by providing information on possible future locations of land use change, it can help in prioritising areas where land management emphasis or risk reduction measures should be considered.

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