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Mapping the economic value of landslide regulation by forests

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ABSTRACT

The role of forests in regulating landslide risks is well established but estimates of the economic value of this ecosystem service are limited. In order to incorporate the role of forests for landslide risk mitigation in spatial planning and other decision-making contexts, there is a need for spatially explicit information regarding the value of this service. We develop a methodological framework to combine bio-physical modelling of natural hazard risk and socio-economic exposure in a predictive model to estimate and map of the economic value of forest regulation of landslides. This method is applied in a case study of Adjara Autonomous Republic of Georgia to examine alternative scenarios for forest management and associated land cover change. The approach produces credible spatially explicit results to inform policy decisions regarding investment in forest management; and has the potential for replication in other data scarce regions.

1. Introduction

It is expected that damages from landslides will increase steadily over the coming years (Dai et al., 2002). Underlying this trend is an increase in human activity in landslide prone areas, which increases risk through two channels: development generally involves deforestation, which increases the probability of landslides occurring; and more human activity generally means more assets that are exposed to damage (Nadim et al., 2006). An additional factor that will drive increasing landslide damage is that climate change is predicted to cause increased precipitation in many areas already prone to landslides and may result in additional areas facing the risk of slope erosion and landslides (Dale et al., 2001; Ciabatta et al., 2016; Crozier 2010).

The role of forests in regulating landslide risks is well established (Endo and Tsuruta, 1969; Megahan et al., 1978; Wu and Swanston, 1980; Preston and Crozier, 1999; Jakob, 2000). The economic value of this regulating service has, however, received limited attention in the economic valuation and ecosystem services literature (Chiabai et al., 2011; de Groot et al., 2012; Häyhä et al., 2015). Existing research has tended to focus on the value of forests for timber (Phan et al., 2014; Pohjanmies et al., 2017), non-timber forest products (Schaafsma et al., 2014; Mutoko et al., 2015), water supply (Ojea et al., 2012; Wang et al., 2017), recreation (Zandersen and Tol, 2009) and carbon storage (Triviño et al., 2015). The relatively limited number of studies that do estimate the economic value of landslide regulation by forests tend to be for small-scale study sites (e.g. Olschewski et al., 2012; Dominati et al., 2014).

Information on the economic value of forests in regulating landslides is useful for informing forest management decisions (Langner et al., 2017). Quantification of the damage costs of deforestation (or avoided damage costs resulting from reforestation) provides input for the appraisal of investments in conservation and restoration. Mapping ecosystem service values delivers additional information to support decision making, particularly for land use policy development, spatial planning and resource allocation (Schägner et al., 2013; Nahuelhual et al., 2015). In order to incorporate the role of forests for landslide risk mitigation in spatial planning and other decision-making contexts, spatially explicit information related to the value of forest landslide regulation needs to be developed.

Many regional governments, especially in the developing world, do not have the resources to create and gather such data in usable forms, in the absence of which, policy attention is not paid to investments in forests as a landslide mitigation measure. While reliable techniques for assessing landslide hazard often require detailed geotechnical information on existing conditions, the high cost of which means they are available only where high risk is already anticipated, more exploratory

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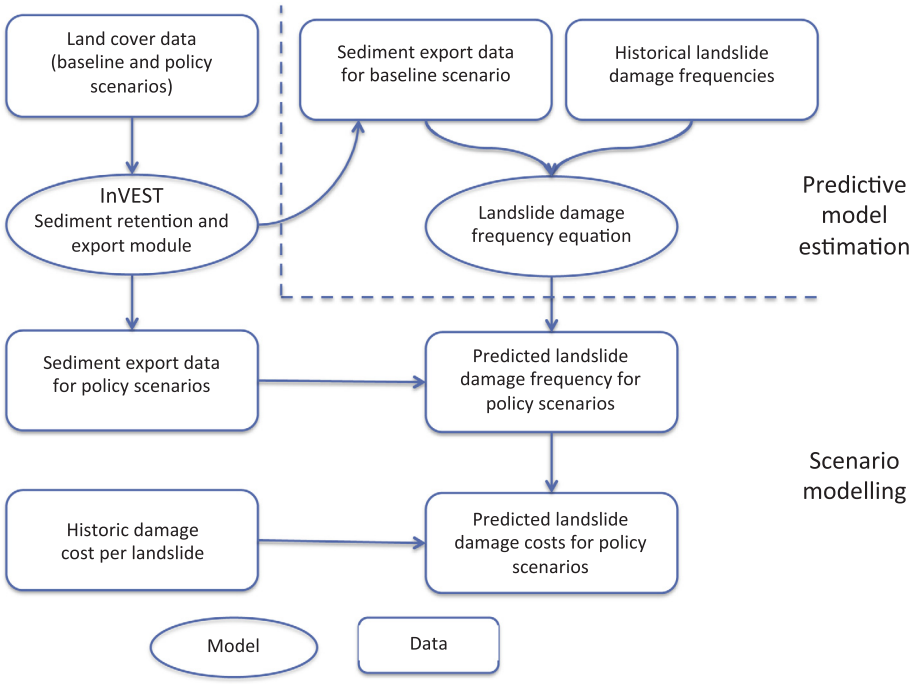

Fig. 1. Methodological framework for the valuation of landslide damages.

techniques of hazard and risk can provide frameworks for development planning and environmental protection measures (Gaprindashvili and Van Westen, 2016).

This paper contributes to the literature on ecosystem service assessment and forest management by developing a methodology to estimate spatially explicit values for the regulation of landslides by forests using widely available data and relatively simple models that can be applied at broad geographic scales. We apply this methodology at a regional scale to the Adjara Autonomous Republic in Georgia. Like the rest of Georgia, Adjara is mostly mountainous and its steep slopes are prone to landslides. By mapping the value of landslide regulation by forests in Adjara, we aim to deliver information to support political and administrative decision-making regarding long term forestry management.

The structure of the paper is as follows: Section 2 describes the methodological framework that is developed to map the value of forests in regulating landslide damage; Section 3 provides a description of the case study area on which the method is tested; Section 4 describes and maps alternative future land use scenarios for the case study area (spatially defined deforestation or restoration pathways for the period 2015–2035); Section 5 presents the empirical estimation of a predictive model for landslide damage; Section 6 combines the estimated landslide damage model with future scenario data to predict spatially explicit changes in landslide damage occurrence and costs; Section 7 draws conclusions regarding the application of the analysis to inform decision making and the scope for replication in other landscapes.

2. Methodological framework

The literature on natural hazards describes four broad methodological approaches that have been developed for studying landslide risks (Remondo et al., 2008). The first approach—inventorying—is based on mapping the locations of past landslides. The landslide inventory allows the estimation of landslide probabilities and forms the basis of susceptibility mapping techniques. A second approach—heuristics—is also based on historic information about landslides and involves eliciting expert opinions to estimate landslide potential from data on preparatory variables. The third approach is statistical and involves building multivariate statistical models to determine the risk of landslides based on an analysis of the variables that have in the past led to landslide occurrences. Finally, there are deterministic approaches, which are based on modelling the stability of the slope of the area under investigation. The most commonly used deterministic model sets the relative hazard level of a landslide as a function of the slope of the site, its lithological composition, the moisture conditions of the soil at the site, and the precipitation and seismic conditions at the site (Nadim et al., 2006, Mora and Vahrson, 1994).

Building on models that determine the probability of landslide events occurring, vulnerability models calculate the risks of the potential damage or degree of loss for a given asset subject to a landslide of a given intensity. Assessing vulnerability therefore requires calculating the risk of a landslide and also understanding the interaction between a landslide and the impacted assets (de Ruiter et al., 2017). Physical vulnerability indicators include infrastructures (such as in the transport, utilities and health sectors) and buildings, while social vulnerability indicators include demographic variables such as the size, structure and distribution of population and economic variables related to wealth and livelihoods.

In this paper we develop an approach to modelling the economic value of forests in regulating landslide damage that draws on elements of statistical, deterministic and vulnerability modelling. We estimate a multivariate statistical model using data on past landslide events, population and deterministically modelled rates of sediment export, combined with data on human settlements and damage compensation payments. Output data are spatially referenced to enable the results to be mapped. The general methodological framework for quantifying the economic value of landslide regulation as an ecosystem service provided by forests follows those of Balmford et al. (2011), Bateman et al. (2011) and Brander et al. (2012). In particular it incorporates several critical insights from the environmental economics literature by comparing future scenarios that are driven by alternative policy interventions and modelling spatially explicit variation in the delivery and value of ecosystem services. The general methodological framework is represented in Fig. 1.

The approach involves first developing land cover maps for a baseline scenario and alternative policy scenarios. Spatial data on land