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Economic valuation of landslide damage in hilly regions: A case study from Flanders, Belgium

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HIGHLIGHTS

- ► Methodology to estimate damage caused by landslides in low-relief areas
- ► Assessment of societal benefits of a possible increase in biodiversity
- ► Quantitative input data for the estimation of future risks is provided.
- ► Landsliding is a continuously operating process with considerable economic damage.
- ► High damage due to construction of (railway) roads and houses in landslide areas

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ABSTRACT

Several regions around the globe are at risk of incurring damage from landslides, but only few studies have concentrated on a quantitative estimate of the overall damage caused by landslides at a regional scale. This study therefore starts with a quantitative economic assessment of the direct and indirect damage caused by landslides in a 2910 km^2 study area located west of Brussels, a low-relief region susceptible to landslides. Based on focus interviews as well as on semi-structured interviews with homeowners, civil servants and the owners and providers of lifelines such as electricity and sewage, a quantitative damage assessment is provided. For private properties (houses, forest and pasture land) we estimate the real estate and production value losses for different damage scenarios, while for public infrastructure the costs of measures to repair and prevent landslide induced damage are estimated. In addition, the increase in amenity value of forests and grasslands due to the occurrence of landslides is also calculated. The study illustrates that a minority of land (only 2.3%) within the study area is used for dwellings, roads and railway lines, but that these land use types are responsible for the vast majority of the economic damage due to the occurrence of landslides. The annual cost of direct damage due to landsliding amounts to 688,148€/year out of which 550,740€/year for direct damage to houses, while the annual indirect damage augments to 3,020,049€/year out of which 2,007,375 €/year for indirect damage to real estate. Next, the study illustrates that the increase of the amenity value of forests and grasslands outweighs the production value loss. As such the study does not only provide quantitative input data for the estimation of future risks, but also important information for government officials as it clearly informs about the costs associated with certain land use types in landslide areas.

1. Introduction

Natural disasters as well as technological accidents, pollution, terrorism, armed conflicts, food and energy security, and increasingly scarce resources, are thought to result in serious damage to at-risk populations and their environment (EOS, 2009; OECD, 2003). In Europe, thanks to a relatively high level of anticipation and precautions and moderate threats of natural origin, losses to human beings have remained limited during the past decades (EWCII, ONU, ISDR, 2003; OECD, 2003). However, economic losses linked to natural risks have increased considerably in Europe and are expected to increase even more in the future (EWCII, ONU, ISDR, 2003; Mendelsohn and Saher, 2010; World Bank and United Nations, 2010). In Belgium, storms, floods, forest, heathland or bush fires, landslides, and the repercussions of volcanic eruptions in nearby countries, have demonstrated the need for a systematic, interdisciplinary and cross-sectoral approach to assess and manage these risks (United Nations, 2005).

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In Belgium, one particular natural hazard that affects several hilly regions relates to landslides (Demoulin and Glade, 2004; Dewitte et al., 2006; Van Den Eeckhaut et al., 2005, 2011). These landslides cause severe structural and functional damage to properties and facilities and the losses are expected to further increase due to pressures of population expanding towards unstable hillside areas (Poelmans and Van Rompaey, 2010; Van Den Eeckhaut et al., 2010) and climatic changes (Baguis et al., 2010).

Many studies investigated how natural factors and human activities control landslides at various spatial scales (Crozier, 1986; Van Den Eeckhaut et al., 2010). These studies typically produced susceptibility maps depicting the spatial distribution of landslides (Carrara et al., 1995; Guzzetti et al., 1999; Li et al., 2012; Rossi et al., 2010; Vanacker et al., 2003; Van Den Eeckhaut et al., 2006, 2007a, 2007b). Also hazard studies in which not only information related to the spatial distribution of potential landslides is taken into account but also their temporal occurrence and their intensity are becoming more common (Cardinali et al., 2002; Ghosh et al., 2012; Gibson et al., forthcoming; Glade, 1998; Glade and Crozier, 2005; van Westen et al., 2006).

However, few studies have concentrated on quantitatively analysing socio-economic consequences of mass movements. Available studies focus on a qualitative or semi-quantitative damage assessment (Petrucci and Gulla, 2010; Puissant et al., forthcoming), or on damage assessments taking only one type of damage – typically direct damage – into account (Papathoma and Dominey-Howes, 2003; Papathoma-Köhle et al., 2007; Petrucci et al., 2008; Zêzere et al., 2008). The type of elements at risk and their vulnerability to landslides are very diverse, and a vulnerability and consequences analysis which aims at predicting future damage is an essential part of any risk analysis which in turn forms the basis for risk reduction efforts and preparedness planning (Holcombe et al., 2012; Lee and Jones, 2004; van Westen et al., 2006). However, a true economic valuation of the damage already caused by landslides and of the costs related to prevention and remediation is often lacking and, to our knowledge, most available economic valuations are relatively old and for North-American study areas (Schuster, 1995, 1996; Schuster and Fleming, 1986).

Therefore, this study aims at developing a methodology to estimate the overall direct and indirect damage already caused by landslides in low-relief areas in Belgium for which a landslide inventory is available (Van Den Eeckhaut and Poesen, 2009; Van Den Eeckhaut et al., 2011). Direct damage includes all of those physical impacts that lead to either the destruction or to deformations that reduce the functionality of an element (damage to property or facility) or that lead to damage to people who might be either killed or injured. Hence, costs of replacement, repair, or maintenance due to damage of property or facilities within the boundaries of a landslide can all be considered as direct costs. Indirect damage includes reduced real estate values, loss of productivity, lost revenue and loss of opportunity through the disruption of public services and interruption of business continuity, and the cost of measures to prevent or mitigate future mass movement damage (Middelmann, 2007; Petrucci and Gulla, 2010; Schuster and Fleming, 1986). In particular, we combine two economic valuation methods. On the one hand we estimate the decrease in the real estate value of houses and production value of forests and pastures, due to their location in areas with a high landslide susceptibility. On the other hand we estimate the costs to restore and prevent damage to private buildings and public infrastructure which is caused by the occurrence of landslides. This methodology provides us a lower bound of the economic value of the damage caused by landslides. The study aims to provide a complete picture of all damage to public infrastructure due to landslide occurrence in the region, while costs to repair damage to private properties are illustrated for a few case studies using the data collected in the semi-structured interviews.

Landslides will not only cause damage, but they might also create some societal benefits. They will change the forest and pasture landscape and disturb the hillslopes. A bumpy topography with ponds might emerge in reverse slopes and different soil types will be present since different soil parent materials will be exposed. Consequently, a micro-ecosystem might emerge in which more rare plant and animal species occur. All this will change the forest and pasture ecosystem services in general and the recreational attractiveness of the area in particular. As such landsliding might create some benefits to society (thus a negative cost). We estimate the increased recreational and experience value due to the occurrence of a landslide using '*nature value explorer*', an online benefit transfer tool which is developed for the economic valuation of ecosystem services in Flanders (Liekens et al., 2010).

This paper shows that landsliding in low-relief regions susceptible to landslides is not spectacular, but a slow, continuously operating process with considerable economic damage, and offers quantitative input data for the estimation of future risks. Next, the study illustrates that the increase of the amenity value of forests and grasslands outweighs their production value loss. As such the study does not only provide quantitative input data for the estimation of future risks, but also important information for government officials as it clearly informs about the costs associated with certain land use types in landslide areas.

2. Study area

This study focuses on 27 municipalities affected by landslides located in a region west of Brussels (Belgium) (Fig. 1). The study area is a hilly region characterised by altitudes ranging from 10 m to 150 m a.s.l. and hillslope gradients are generally less than 15%. In this study area, previous studies identified 291 areas where landslides occurred in the past (Fig. 2) (Van Den Eeckhaut et al., 2005, 2007a, 2011). Out of the 291 observed landslides, 73.6% ($n=214$) are deep-seated landslides, i.e. the shear surface was estimated to be deeper than 3 m and the area affected was larger than 1 ha. The deep-seated landslides are all earth slides and the majority are rotational slides. Among the 214 deep-seated landslides, there are 36 possible landslides with an unclear main sharp. The majority (ca. 75%) of the deep-seated landslides are completely or partly forested and ca. 20% of the deep-seated landslides are located under forests. The remaining 5% is located under gardens or orchards (Van Den Eeckhaut et al., 2010). Although the precise activation date is not known, they are assumed to be older than 100 years. Due to the absence of historical documents describing the initiation or reactivation of the landslides, the deep-seated landslides are often considered as dormant. However, using dendrochronological analysis, recent studies have shown that they are less dormant than assumed according to historical documents and that local reactivations are likely to occur (Van Turnhout et al., 2012). This is also confirmed by the observation that many of the forested landslides have a fresh, bumpy topography on which tilted trees are growing (Van Den Eeckhaut et al., 2009). 26.4% of all observed landslides are shallow complex landslides which occupy an area of less than 1 ha. These shallow landslides typically start as rotational earth slides, but their foot has flow characteristics. They can typically be found within the accumulation zones of deep-seated landslides and on hill slopes with significant human activities (expansion of the built environment). Most identified shallow landslides were initiated during the last 30 years (Van Den Eeckhaut et al., 2006, 2010).

In the study area, the (re-)activation of landslides has never led to physical injuries to human beings, nevertheless there was physical and functional damage to both public and private infrastructure such as houses, administrative, industrial and commercial buildings, electricity grid, roads, railways and underground cables (Van Den Eeckhaut et al., 2007b). The majority of areas within the landslide