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Economic assessment of landslide risk for the Waidhofen a.d. Ybbs region, Alpine Foreland, Lower Austria

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ABSTRACT: Landslides are natural hazards typical for Alpine regions in Austria. They often lead to negative consequences for the society and environment and cause frequently high economic losses. Estimation of economic risks is a sound basis for landslide risk mitigation and prevention. This research aims to assess risk and estimate economic damage caused by landslides. The study area is located in the Ybbs valley, Lower Austria, a touristic region and a critical transport corridor. Methodology consists of GIS analysis and estimation of the monetary losses. Spatial analysis includes defining elements at risk located in the buffer zone of 100 m near landslides. The results include estimated losses caused by the destruction of immobility and transport, including costs for buildings demolition, restoration, roads rebuilding, debris transport, excavation and removal.

1 INTRODUCTION

Landslide risk assessment aims to provide an objective and justifiable measure of risk using selected criteria. It includes hazard analysis, i.e. analysis of the probability and characteristics of the landslides, identification of the elements at risk, assessment of their vulnerability and final calculation of the respective risk (Glade et al. 2005, Cruden & Fell 1997). According to different risk studies (e.g. Bell & Glade 2004, Glade et al. 2005, Lee & Jones 2004), the complete risk assessment includes risk analysis, risk evaluation and risk management. Herein the first implies estimation of the risk in a given environment, the second mostly concerns social aspects of risk perception and acceptance, and the latter is decision-oriented. Two approaches in landslides risk assessment are traditionally defined: a qualitative landslides risk assessment, which includes ranking method varying in detail and complexity (Hartlen & Vilberg 1998), and a quantitative risk assessment implying probabilistic stability analysis, object-oriented analysis as well as consequence analysis (Morgenstern 1997, Glade et al. 2005, Heinimann 1999). The final model choice is determined by the required accuracy, the data availability, scale of research and the specific character of the research area. This study focuses on the regional quantitative assessment of the monetary losses caused by landslides.

2 RESEARCH AREA

2.1 Geographic location

The research is carried out in the Ybbs valley (Fig.1) in the Alpine Foreland, Austria. The study region covers a total area of 131.3 km². The land cover at the Ybbs river valley is characterized by the dominated agricultural land, pasture and large forests. The region is of much attractiveness for the tourists due to its environmental and historical value. Therefore, the area is covered by the dense network of transport lines, power supply lines and water supply.

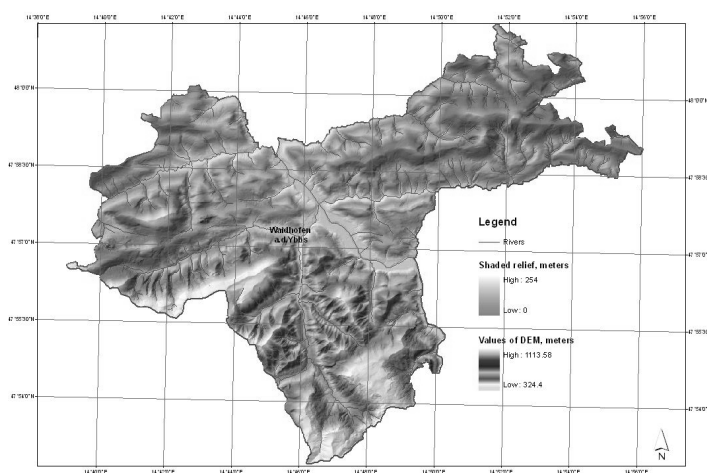


Figure 1. A shaded relief of the Ybbs valley in Lower Austria Scale: 1:410,000 (Source: Provincial Government of Lower Austria)

2.2 Environmental settings

Situated in mountainous Alpine Foreland, the research area is developed in the conditions of humid to continental climate. This is characterized by moderate temperatures in summer areas, usually reaching +17°C. The most humid months are in summer with the maximal amount of precipitation totaling to 144 mm (July), with an average of 84 mm. In spring and autumn the rainfall is also intensive with maximal values up to 99 mm (May) and 93 mm (September). In winter months snowfall level reaches a maximum of 84 mm in December (Zentralanstalt für Meteorologie und Geodynamik 2011). Therefore, the meteorological settings create favorable conditions for landslides.

A geological overview of the research area shows that the southern part of Alpine Foreland is composed by the Triassic carbonate rocks. Flysch sandstone can be found in its northern part, and marl of the Helvetic cover and loess layer of the Alpine Foreland (Bellos et al. 2006). Gravel, sand, marl, conglomerate, calcareous sandstone and clay are deposited in various sedimentation layers. The Ybbstal Alps are located in the Molasse and Neogene basin (Fig. 2). Within the sediments there are conglomerates, gravels and sands as well as sandy marl and clayey marls (Thenius 1974). The soils in this region are not rich of minerals, with the exception of loess soils; therefore, most of the region is used as pasture. Such loose or weak soil types are especially prone to landslides triggered by intense rainfall (Wieczorek 1996).

Vegetation is characterized by the presence of sub-alpine species as the area is located in the central European floral region. Rapid snowmelt and intense rainfalls, typical for the climate in Alpine Foreland, intensify erosion processes and largely contribute to the landslide movements.

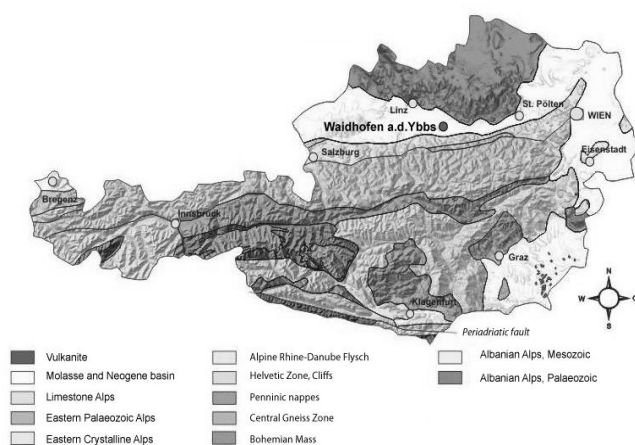


Figure 2. Geology of the Waidhofen a.d. Ybbs. Scale 1:6,740,000 (Source: Geologische Bundesanstalt (GBA), 1964, modified).

2.3 Socioeconomic settings

Socioeconomic characteristics of the region are dominated by rural and semi-rural areas with population mostly living in one-family houses distributed in the valley. The region is also being widely visited by tourists in winter for skiing. The area of Waidhofen a.d. Ybbs is equipped with a transport network, well-developed for a provincial scale. The transport system in the area consists of railway and roads, widely used by public transport means (buses) and private cars, and encompasses the city Waidhofen a.d. Ybbs and the surrounding area within the Ybbs valley. All farms on the slopes have well-developed road access. The accessibility, connectivity and efficiency of the transport network are an essential condition for the development of the urban area situated in the mountainous region.

Therefore, socioeconomic losses from the landslides can be very extensive in this area, distinct by high level of human development, and include much damage to immobility, transportation systems and utilities.

2.4 Landslides

Landslides are common geomorphological events occurring often in the mountainous areas with specific geological conditions. The main factors determining landslide occurrence are topographic conditions (e.g. slope angle, curvature, aspect, etc.), lithology, vegetation cover and covering material. Triggers include external meteorological (e.g. precipitation) and/or or tectonic factors (e.g. earthquakes), but also internal factors (e.g. decrease of strength by soil weathering).

The diversity of landslide occurrence is determined by various mechanisms and environmental local conditions, such as topography, lithology, geological structure, hydrogeology, climate and vegetation (Lee & Jones 2004). Cruden & Varnes (1996) proposed the following classification of landslide types: Rotational landslides, translational landslides, block slides, rockfalls, topples, debris flows, debris avalanches, earthflow, creeps and lateral spreads. All of those of various ages and different grade of activity can be found in the study region, however, the main landslide types include rock falls and shallow and deep seated translational and rotational slides. In the study region, various ages of these landslide types can be observed (Fig. 3).

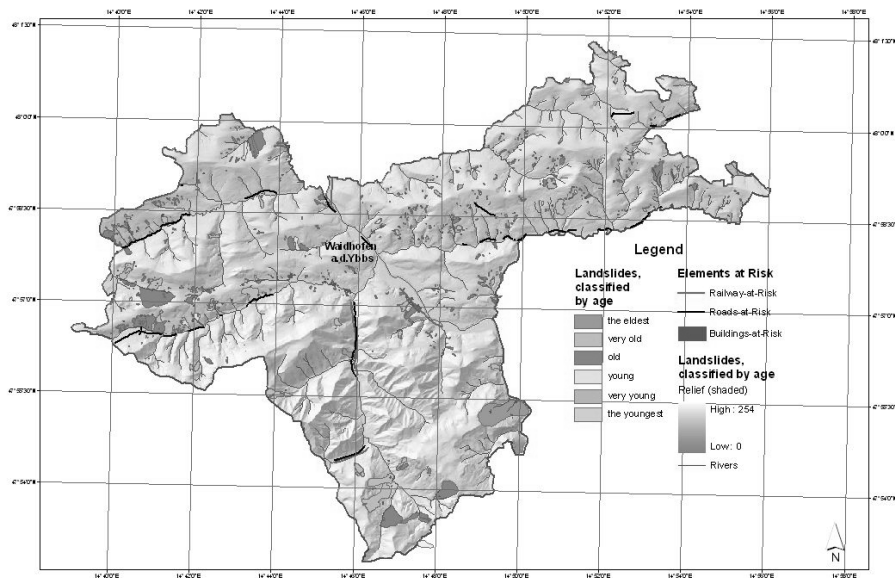


Figure 3. Landslides classified by age. Ybbs valley (Source: Petschko et al., 2011)

3 METHODOLOGY OVERVIEW

There are a wide range of various factors that need to be involved in landslide risk assessment. The assessment of landslides risk is traditionally estimated using the function $R = f(H, A, V)$, where $R =$ risk; $H =$ hazard as landslide probability of a given magnitude, i.e. temporal and spatial likelihood of their occurrence; $A =$ elements at risk; $V =$ vulnerability of the elements at risk towards a given event magnitude. Due to the lack of data, the vulnerability in this research of the identified elements at risk is approximated as “one” in case of landslide occurrence, and “zero” by no hazard. The probability of the landslides is suggested as one, because it is assumed that the landslides occur with certainty. Consequently the risk is based on the assumption that if an element at risk is affected, it is totally destroyed. This assumption had to be taken due to the missing vulnerability curves for the various landslide processes and magnitudes. Thus, this study mostly focuses on the estimation of the exposed elements at risk, their value and potential losses that landslide occurrence might cause.

The analysis of the potential monetary losses is commonly applied within the economic part of the risk assessment. There are two approaches defined in economic losses (Giacometti 2005): direct and indirect damages caused by the hazard. The direct damages include costs of recovery and reconstruction of the elements destroyed during the event. In contrast, indirect damages may involve various consequences that happened because of the interruption of economic activities and flows, e.g. as a result of damaged infrastructure such as energy, communications, tourism, transport network, jobs, etc. (Giacometti 2005). The spatial extent of indirect damages may go far beyond the place of landslide occurrence.

Nevertheless, this study is not addressing indirect monetary losses due to missing data, but approximates the direct costs. It calculates possible losses in real estate and transport routes.

4 DATA MANAGEMENT

The data for analyzing landslide risk and estimating economic losses have been organized in a digital database. The data include orthophoto imagery covering the area, thematic vector layers and maps provided by the Provincial Government of Lower Austria and modified by H. Petschko from the University of Vienna (i.e. geological maps of Low Austria, landslides location and respective classification of the Waidhofen region) as well as the analysis of spatial pattern of landslides.

Table 1. Data structure within this project.

Type of factors	Thematic layers
Anthropogenic	Roads (railway, highways) Areas of demolishing & dismantling Areas of construction work Settlements Natural Parks
Topographic	Orthophotos DEM (1m and 3m resolution), DTM Vector relief map
Environmental	Watershed areas Water catchment areas Landscape protected zones Areas of NATURA-2000 Geological vector map Natural protected zones Tectonic lines Forest areas

The data includes different types such as DEMs, vector layers of buildings, roads, railway lines, topographic maps, orthophoto maps, geological and geo-

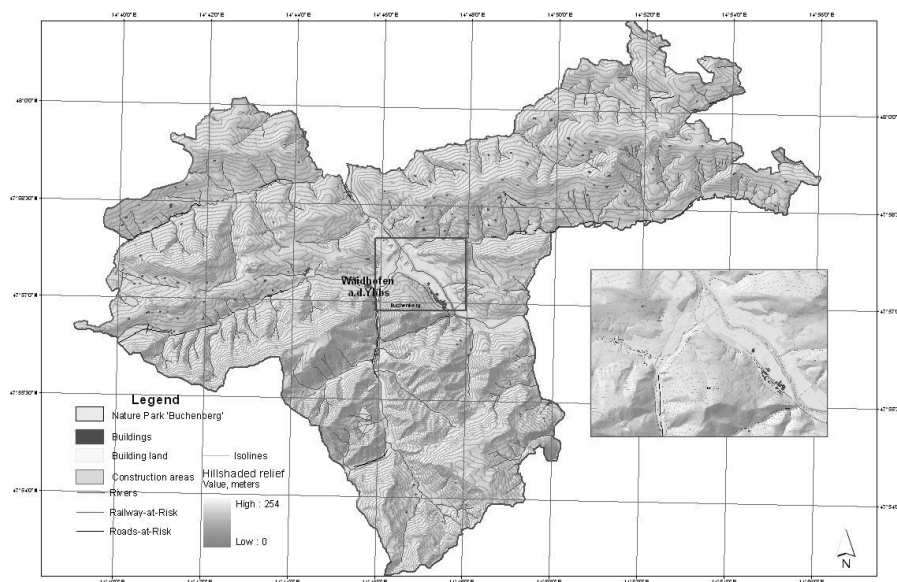


Figure 4. Elements at risk: Infrastructure of the Waidhofen a.d.Ybbs - Buildings, roads and railway lines. Enlarged: city centre (Data source: Provincial Government of Lower Austria).

morphological maps, basic geographic information, such as rivers, cadastral objects, polygon layers showing location of nature protected areas, infrastructure layers such as postal codes, provincial regions, areas of construction works, etc.. All data have been stored in the ArcGIS project using common geographic reference system of Transverse Mercator projection on Bessel 1841 ellipsoid, Austrian National grid Austria Bundesmeldenetz (BMN) M34.

5 METHODS

5.1 *Elements at risk*

In order to estimate the potential effect of future landsliding, a risk buffer zone has been defined. This zone is established as 100-meter buffer area surrounding all landslides downwards, because a landslide with volume of 1 km³ may reach 100 meters in its movement (Mishuev et al. 1993). This buffer zone has been chosen based on the assumption that new landslide will affect the area surrounding the existing landslide body. Therefore, in this work the objects located in the 100 meter distance near the landslides are regarded as exposed elements at risk.

Using Near function of the Proximity Analysis from the Analysis Tools of ArcGIS the 100 m distance from all landslides was calculated. Afterwards, the elements at risk located in the buffer zone were selected by location using the SQL Query Builder tool in Arc Toolbox. Namely, from the respective vector layer containing the featured objects (e.g. “buildings”) only those were selected which are located within the buffer zones. The elements at risk included buildings, roads and railway lines. The communication, power and water supply lines, suggested

initially, were not included to the list of analyzed objects, due to the lack of precise data.

The objects located in the 100-m zone were then added to the attribute table of the corresponding layer. Elements located far apart from the target (landslides) were given attribute “-1” while all others received positive values. Thus, the selection of the elements at risk from the total amount of the objects of the same class has been made using Selection by Attribute function in ArcMap.

5.2 *Estimation of the economic losses*

Applying the methodology proposed by Giacometti (2005) the estimations of the total losses caused by the landslide hazards in the Ybbs valley were calculated. Based on the real estate prices for the various aspects of houses renovation and rebuilding the economic losses have been assessed. Calculations have been done based on the average price for reconstruction and renovation of destroyed or partially damaged immobility and transport routes.

The potential damage in the affected area has been analyzed using quantitative economic assessment, which includes estimation of the area possibly damaged following a landslide failure (m²) as well as the monetary consequences expressed as damage (€), thus finally expressed as monetary risk in €/m².

The monetary losses were calculated using average real estate prices, costs of renovation, construction and restoration, as well as amount of the elements of risk or total area affected. The estimation of the economic losses caused by real estate and transport network damage in the Ybbs valley is based on Giacometti (2005). In the calculations, the average prices of the buildings construction and market prices for the transport network reconstruction, separately for roads and railways have been used.

6 RESULTS

6.1 Defining elements at risk

According to the accepted area of the landslide risk zone including the downward 100-meter buffer area surrounding all landslides, the elements at risk have been selected using spatial analysis. As a result of the proximity analysis, the length and number of the elements at risk (Fig. 4) located within the distance of 100 meters from the landslides totals to 20.9 km of railway lines, 13.5 km of roads and the 641 buildings located near the landslides.

6.2 Calculation the economic losses

The calculation of the real estate losses is computed from the calculation of five different types of costs: demolition, transport and disposal debris, restoration of inner walls, furniture restoration and house construction (Tab. 2). First, the demolition costs for the destroyed houses were estimated (Tab. 2) for the concrete house using demolition costs and costs of mechanical excavation.

Table 2. Real estate destruction losses, Ybbs valley, as for average market value (Source: Giacometti, 2005; 138-140).

Type of investment	Construction cost (€/year), one house	Total costs (€), for all houses (*)	
Demolition cost (concrete masonry), €/m ³ (a)	87		
Average volume to demolish, m ³ (b)	189.32		
Mechanical excavation costs, €/m ³ (c)	25.5		
Total (€) to demolish walls, concrete masonry = (a*b)+(c*b)	21,298	13,652,338	
Transport and disposal debris, €/m ² (**)	26	3,608,462	
Inner walls restoration costs (€/m ²)	7		
Average surface of inner walls (m ²)	607		
Average charge to restore inner walls (€)	4,252	2,725,852	
Average price to restore furniture, €/m ² (x)	600		
Average house base area, m ² , (y)	317		
Total average charge (€) to restore furniture (x*y)	190,500		
	122,110,500		
Average house base area (m ²)	317		
Average cost to build a house (€/m ³)	1,100		
Total average charge to build a house, €	349,250	223,869,250	
Total complete average charge (demolition + restoration), €	216,051	138,488,691	

(*) Number of houses at risk in Ybbs valley = 641

(**) Total area of buildings at risk, m² = 138

The average volume to demolish damaged buildings indicated the dimensions of the losses of approx. 13.65 M €. The landslide types often include intensive debris or mud flows. Debris flows in Ybbs area may lead to severe damage to exposed buildings and infrastructure. It may also cause injuries and human deaths. The exact volume of the masses flow may vary depending on the preparatory and triggering factors (Crozier 1989). However, in this study the calculation of the transport and disposal debris is based on the average costs to transport and

disposal debris in a dump. Thus, for the Ybbs valley the estimated price for the debris removal is approx. 3.6 M €, in case buildings at risk in the Ybbs valley are totally affected and covered.

The restoration of the inner walls within the buildings has been assessed using prices for two main components of the building restoration: average costs and approximate total surface of the inner walls. Thus, total estimate of the losses for the inner walls restoration is 2.73 M €. Furniture can often be damaged during the buildings destruction. It is rather difficult to estimate the furniture costs exactly, as it varies strongly in different households. However, using approximate prices of the furniture costs as estimated by Giacometti (2005) in a typical house as well as the total area of the house, the costs for furniture renovation is € 190,500.

Finally, a cost for construction of completely new house is computed according to the known real estate prices and an average house area in m² (Giacometti 2005), which sums up to € 349,250. Based on the given assumptions it is approximated, that a total of almost 140 M € would have to be invested for the complete renovation of the Ybbs valley in case of a landslide disaster. The economic losses of the transport routes (Tab. 3) are calculated also based on Giacometti (2005), and include costs to rebuild a road, a railway, and a restoration of the roads.

Table 3. Estimation of possible monetary losses for transport network caused by landslides.

Type of Investment	Construction cost (€)	Length (m)	Total losses (€)
Railway tracks, €/m restoration (*)	4,200	20,953	A = 88,005,204
Road rebuilding, €/m (**)	4,131	13,541	B = 55,948,749
Debris excavation (a)	17	13,541	
Debris removal (b)	25	13,541	
Transportation (c) & storage	26	13,541	
Roads restoration, €/m ² (***) a+b+c	68.0	13,541	C = 927,590
Total possible direct damages (A+B+C)			144,881,544

(*) Source: Zischg et al., 2005

(**) Source: Giacometti, 2005

(***) Source: Sterlacchini et al., 2007

The total roads restoration includes debris removal, excavation, transportation and storage of material (Tab. 3). Total length of the roads affected by the landslides is multiplied by the restoration and renovation costs. The final costs for the direct damages of the roads are € 144.88 M € for the whole transport routes (roads and railways), assuming that all roads and railways are totally affected by the landslides.

7 CONCLUSIONS

The current research focuses on the monetary estimation of the possible losses caused by landslides. Es-

timation of the economic damages is performed using existing simplified methodologies. Calculations were based on real estate and market price of the elements at risk. While assessing the potential damage during the hazardous events confusion often arises because of three factors. First, the temporal probability of the landslides occurrence is highly difficult to assess: it can only be estimated based on the reliable and obtainable data. This includes historical data continuously reporting the occurrence of the landslides. Secondly, difficulties arise by estimation of the indirect losses and partially damaged objects. The amount of the damages can be assessed based on elements vulnerability, which is very uncertain to estimate exactly. Thus, the vulnerability may differ depending on object location, individual characteristics and external factors. Third, we do not differentiate in the term “landslide” between debris flows and shallow or rotational landslides. This is an important source for uncertainty, because the movement characteristics of these landslides are different. Moreover, confusing over different methodological approaches in the landslide risk assessment may generate various results based on estimation of landslide hazards. This might differ in magnitude and occurrence of landslides, risk perception and assessing elements vulnerability. Therefore, overall estimation of the landslide risk should be based on complex investigations. The information about landslide probability should be gained from landslide monitoring programmes which are currently not in place. The elements at risk are defined based on spatial analysis and infrastructure inventory. The vulnerability estimation should include census data and social questionnaire. Finally, monetary losses are estimated using market prices and spatial GIS analysis.

8 PERSPECTIVES AND RECOMMENDATIONS

In view of the difficulties and uncertainties in the determination of landslide risk, the main recommendation is flexible combination of research approaches, landslide hazard modeling, and application of various methodologies to study area. Buffer zones have to be validated by fieldworks. Data from cadastral and statistical information sources could enable carrying out vulnerability assessment. The investigations of supporting guidelines would be of great assistance in research on landslide risk assessment. The obtained results can be empirically tested.

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