Event-based rapid landslide mapping including estimation of potential human impacts on landslide occurrence: a case study in Lower Austria

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ABSTRACT

Within any landslide susceptibility, hazard and risk assessment, landslide inventories play a crucial part determining the quality of further analyses. The applied methodology describes a fast way of assessing landslides related to a heavy rainfall event in Lower Austria in May 2014. Based on reported damages and aerial photographs a first inventory was created. Information on the location, extent and human activities potentially influencing landslide occurrence were assessed. The resulting event-based landslide inventory showed that a quick landslide mapping can provide an overview of affected areas following a rainfall event. The extent of the landslides was assessed allowing a better estimation of potential hazards accompanying heavy precipitation in the study area. Analyzing the potential human impact on landslide occurrence showed that numerous indirect and direct influences, such as slope undercutting, forest roads or drainage, can serve as preparatory and predisposing factors for landslide occurrence. Although the direct human impact on landslide-triggering could not be determined, landslide mapping immediately after the event provided detailed documentation of human influences on landslide occurrence.

KEYWORDS

landslide mapping; landslide inventory; event documentation; human impact

INTRODUCTION AND BACKGROUND

Landslide investigations are important when assessing hazard and risk in any region. Especially in alpine areas with often highly varying lithological, morphological and environmental settings, landslides are relevant phenomena influencing the landscape (Schweigl & Hervás 2009). Landslide mapping, as an essential part of any landslide susceptibility, hazard and risk assessment, is a crucial element determining the outcome and applicability of any final product such as detailed slope stability information or any kind of inventory, susceptibility, hazard or risk maps (Glade et al. 2005). Especially in the context of specific triggering factors, the assessment of all associated landslides triggered by respective hydro-meteorological events is of particular interest. An inventory of event-related landslides, including debris slides and flows, translational or rotational slides or rock falls (according to Cruden & Varnes 1996), not only provides detailed information on the time of occurrence, but also on the

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specific landslide types triggered by the particular heavy rainfall event (Guzzetti et al. 2012). A landslide inventory in general represents the total number of landslides and their location in a certain area and can also include information on the type of movement and/or the time-scale of each event (Guzzetti et al. 2000). Often such inventories cannot be generated directly following a triggering event because of insufficient resources to perform the immediate investigations, which results in restricted data availability (Guzzetti et al. 2012). Several methods for creating landslide inventories can be applied, depending on the specific aim of the study and data availability (Hervás 2013). For example, creating an inventory based on remote sensing data has, in the past few years, become a very common method of generating new and extending existing inventories (Petschko et al. 2010). Although the interpretation of aerial photographs or landform models based on laserscanning is a rather quick way of generating a landslide inventory, there are often no such data available directly after a triggering rainfall event (Ghosh et al. 2012). Furthermore, remote sensing data do usually not include exact information on the time of occurrence for each landside, but only the date on which the photograph or laserscan data were taken, thus only showing all landslides that occurred in the period prior to that date.

Another method of creating landslide inventories is the interpretation of historical data from different archives (e. g. literature sources, chronicles, newspaper reports; Glade 2001, 2005) or expert knowledge (Guzzetti 2005). But certain issues of data availability and accuracy can also arise when analyzing different data sources (Petschko et al. 2014b). Compiling a landslide inventory can also be done by field-mapping. Even though field-mapping can be very time-consuming and often landslides cannot directly be identified in the field (due to e.g. vegetation, removal of dislocated material; Bardi et al. 2014), it also shows numerous advantages compared to other methods (Guzzetti et al. 2012). Field-mapping can be done directly after a certain triggering event, thus providing information on the time of occurrence and also the direct relation to the triggering event can be assessed.

Furthermore field-mapping allows for a detailed investigation of potential human impacts on predisposing factors of landslide occurrence, such as slope undercutting, deforestation, drainage etc. to determine the role of humans within in landslide assessment. During field-work it is possible to examine, and often quite clearly to determine, which kind of factors might have influenced each single landslide leading to the slope failure. Therefore the method applied here presents a rapid way to record landslide occurrences to better estimate and further analyze the underlying factors and consequent process dynamics. The presented study aims to apply a quick way of mapping specific landslides related to a certain triggering event in order to create a detailed landslide inventory. Furthermore this inventory also includes information on potential human impact on landslide occurrence, thus providing a first estimation of potential human influences on slope stability and the subsequent effects on the potentially related hazards and risks. A fast inventory of landslides related to certain triggering event, as presented within this study, can further serve as valuable input for future risk assessment and management (Guzzetti et al. 2012).

STUDY AREA

The study area is located in the western part of Lower Austria (Figure 1) within the districts of Amstetten, Waidhofen/Ybbs, Scheibbs, Lilienfeld and St. Pölten. The landscape is characterized by forests (mainly in the southern part) and farmland (Petschko et al. 2014a) with settlements situated predominantly in the valley bottoms. The area is based mainly within the lithological units of the Flyschzone and the Northern Calcerous Alps, in particular including Limestone and Dolomite (Figure 1).

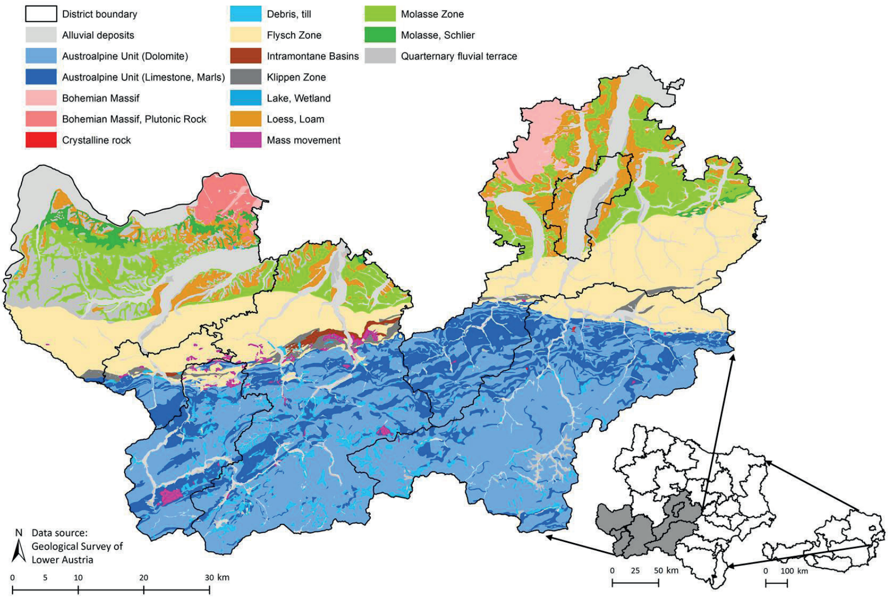

Figure 1: Lithological units and general location of the study area in Lower Austria, Austria.

The study area is situated in a transition zone between marine and continental climate (Petschko 2014), with an average annual precipitation of 1200-2000 mm including extreme single rainfall events (Hydrographic Service of Lower Austria 2014). Throughout the whole region the highest precipitation and temperature values are usually recorded during the late spring and summer months, from May to August (Figure 2). In 2014 a heavy rainfall event occurred during this generally wet season, with a maximum of total precipitation in May of 453 mm in Lunz/See (district Scheibbs) or 348 mm in Waidhofen/Ybbs (ZAMG 2014). This rainfall event represents an event with a 30-year recurrence interval (Hydrographic Service of Lower Austria 2014), and mainly occurred from 15th to 18th of May followed by further precipitation peaks from 23rd to 28th of May, leading to numerous floods and landslides. This event thus served as a basis for the mapping and development of the event-based landslide inventory presented in this study.

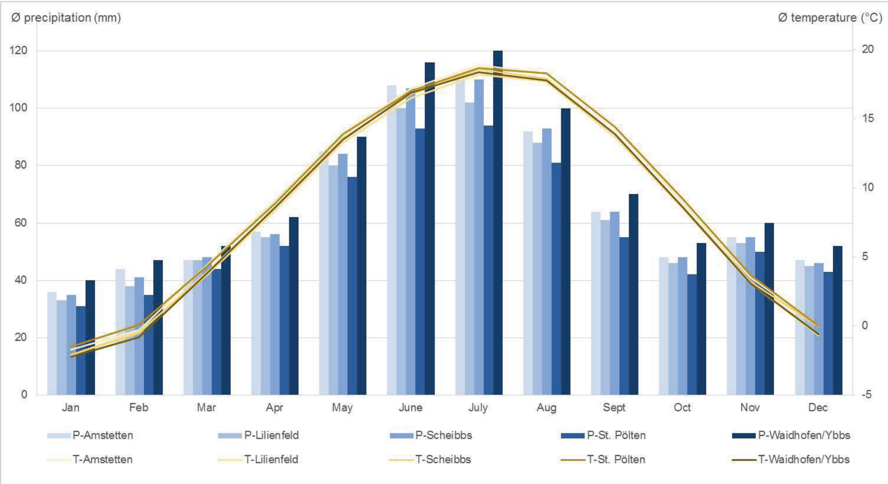

Figure 2: Average precipitation and temperature values in the districts of Amstetten, Lilienfeld, Scheibbs, St. Pölten and Waidhofen/Ybbs (modified after http://de.climate-data.org/index.html)

METHODS

Data acquisition

The database used for generating the landslide inventory consists of several datasets provided by the provincial government of Lower Austria and the Geological Survey of Austria (Table 1). 24 damage reports were included, that were already available shortly after the rainfall event. Furthermore aerial images of landslides, acquired during a helicopter flight carried out by the Geological Survey of Lower Austria, were used as a basis for the field investigations resulting in a total of 56 landslides. Each of these events were geographically located using

Table 1: Available data.

	Level	Year	Resolution
DGM & derivates	District	2006-2009	1 m
Orthophoto	Federal state	2002/2005/2007	25 cm
District boundaries	District	2004	1:50 000
Municipality boundaries	Municipality	2004	1:50 000
Rivers	Federal state	2001	1:10 000
Forest-cover	Federal state	1986	1:50 000
Road network	Federal state	a. n.	1:50 000
Lithology	Federal state	2011	1:200 000

GPS coordinates, thus resulting in a first inventory of landslides including the location and number of events related to the May 2014 heavy rainfall event.

Mapping

Using these datasets as a basis, a detailed mapping to create the landslide inventory was carried out (Figure 3). Several field surveys were performed between May and September 2014. Within the field surveys a specific mapping form was developed based on the work of Cruden and Varnes (1996) and Turner and Schuster (1996). This form includes information on the type of movement (rock fall, debris slide, debris flow or complex movements), geographical coordinates of landslide location, detailed extent and other relevant criteria such as land use, lithology, exposition and slope angle. Further parameters like the distance of the landslide to roads, buildings and watercourses as well as records of slope undercutting, deforestation or drainage were added in order to be able to estimate the potential human impact on landslide occurrence. In addition some information on planned and/or already performed mitigation measures were included to establish a highly detailed dataset for each landslide.

Using the already available information on landslides reported by the Geological Survey of Lower Austria, a first mapping route was defined (Figure 3). This route served as a basis for the field work and was expanded adding surrounding areas and additional landslides based on conversations with locals and visible slope movements in the field, which had not been reported prior. The extent of all landslides near this route was measured, slope-profiles of each landslide were generated and numerous photographs were taken as further accompanying information. A specific code was assigned to each landslide to allow a precise identification within the landslide inventory.

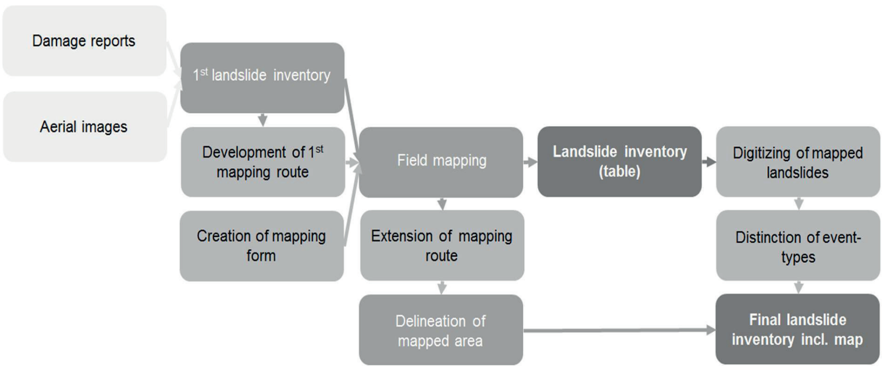

Figure 3: Flow-chart of the methodology for the mapping procedure.

Based on this mapping procedure, the landslide extent was digitized taking also into account the different types of movement. In case of combined processes and complex movements, e. g. a debris slide resulting in a debris flow further downslope, the different process-types were separately mapped, measured and digitized to allow a more precise analysis of the process distributions.

Delineation of mapped area

For potential further analyses the completely mapped area, i. e. the area where a completeness of the inventory can be assumed, had to be delineated (Figure 3). Since not all areas within the whole study region of western Lower Austria could be fully mapped due to resource restrictions, certain adjustments to confine the mapped area were needed. Due to missing digital imagery and satellite data in the period directly after the May 2014 event and because of the urgent need to rapidly assess the landslide information, it was decided to specifically include only the areas that were actually investigated during the field surveys. This limitation is especially important, since the inventory and the related data on landslides in May 2014 might serve as input for further studies, for example for landslide susceptibility

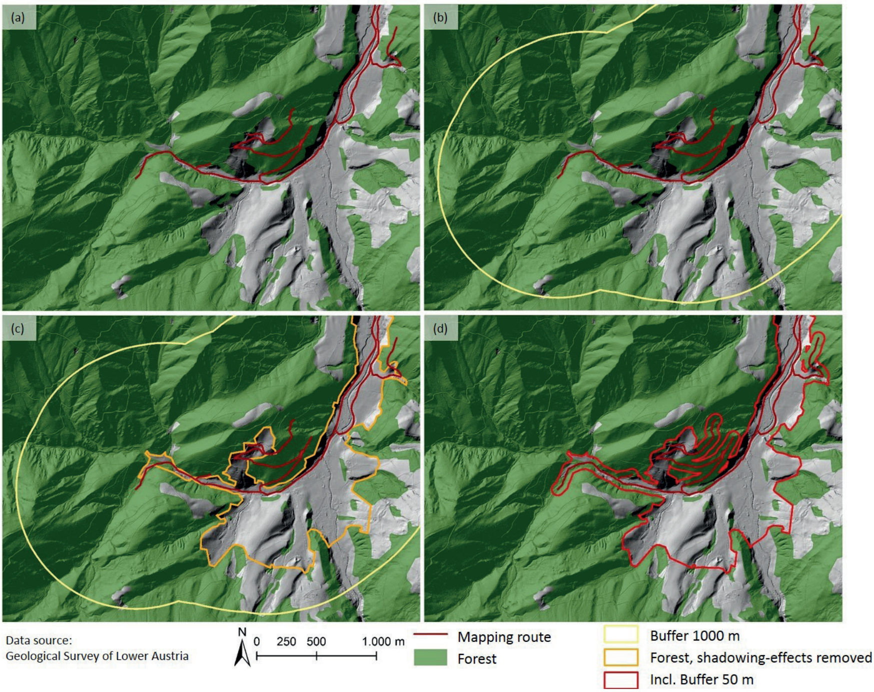

Figure 4: Detail of delineation of the mapped area, showing (a) the mapping route, (b) with a 1000 m radius representing maximum visibility, (c) with exclusion of forest areas and shadowing effects and (d) after including visibility of 50 m for forested areas representing the final mapped area.

and hazard modeling. In such a case it is of major importance to only include these landslides and surrounding areas in the modeling analysis, which were covered within the field survey in order to get valid and therefore reliable results.

Starting from the mapping route based on damage reports (Figure 4a) a maximum visibility of the landscape of 1000 m was assumed representing the average visible area taking into account a minimum landslide size of 100 m². This 1000 m buffer was added on all sides of the mapping route (Figure 4b). Additionally, densely forested parts were excluded due to reduced visibility. Within the mountainous area, shadowing effects of mountain ridges or valley corners were eliminated by reducing the total mapped area at the respective locations to the visible regions (Figure 4c). Finally within the remaining forest zones, a visibility of 50 m was assumed and implemented, representing the minimum visibility from the mapping route (Figure 4d). After these adjustments, the resulting study area represents the mapped area (Figure 5), where one can assume that all landslides that occurred during the May 2014 rainfall event have been recognized, investigated and mapped. Thus the final landslide inventory can be regarded as complete in this area.

RESULTS

The investigated road network extends to a total of 292.76 km. After the abovementioned restriction (as deduced in Figure 4) the total mapped area covers a region of 112.57 km² (Figure 5). From the preliminary inventory of 56 already known events, 18 of these needed to be excluded prior to or in course of the field work. This had to be done because not all landslides identified on the aerial photographs could be specifically related to the May 2014 rainfall event or because mapping in the field was not possible due to restricted access to the sites (e. g. non-accessible private properties). In some cases no landslide tracks could be found in the field, which also led to an elimination of these landslides from the inventory. In total 52 sites were visited, but as mentioned above, not all could be mapped and thus have not been included in the inventory.

With an addition of four landslides that were identified in the field but not formerly being recognized, a total of 42 landslides were investigated in detail. The landslide types included 28 debris slides, one distinct debris flow, two rock falls and eleven complex movements where earth and debris slides turned into debris flows (Table 2).

Table 2: Mapped landslides for each district distinguished by process types.

Process type	District			
	Amstetten	Lilienfeld	Scheibbs	St. Pölten
Debris slide	7	3	2	11
Debris flow	1	–	–	–
Rock fall	1	–	1	–
Complex movements	5	–	2	3
∑	14	3	5	14

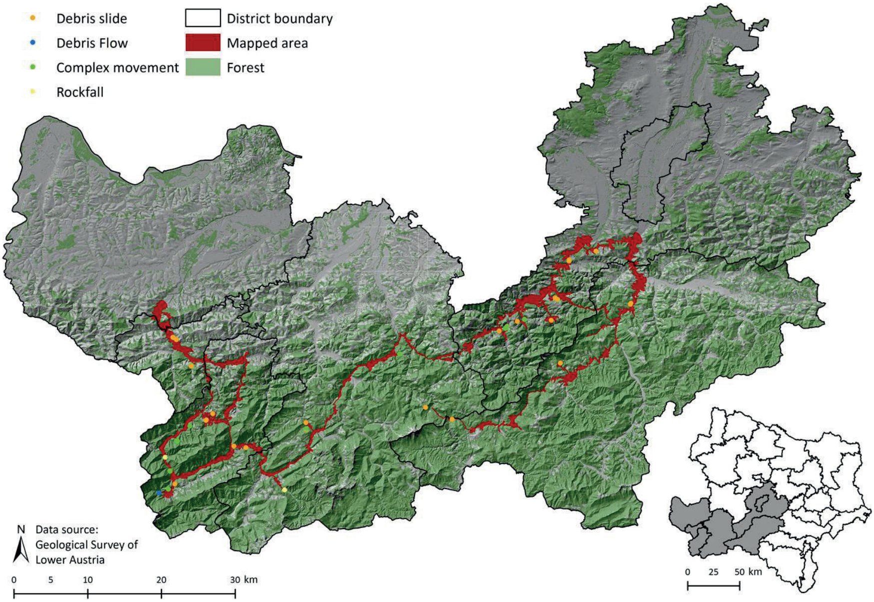

Figure 5: Mapped area during the field investigations and landslide inventory related to the May 2014 heavy rainfall event in the investigated study region.

The final landslide inventory (Figure 5) showed not only the dimensions and general geographic information for each landslide, but also the differences of landslide occurrence related to land use and the potential influences of human activities such as drainage, deforestation or road construction. Most of the landslides could be detected in forest areas (45 %), followed by grassland (24 %) as well as pasture (21 %). Especially the rather high abundance in forest areas indicates the importance to account for completeness of the inventory in forested zones thus only including areas that actually were mapped when delineating the study area for potential further analyses.

Regarding the analysis of potential human impact on landslide occurrence, especially the scarp and source as well as the surrounding area was investigated for each landslide. Within the complex movements, only the combination of earth and debris slides and flows have been examined. Rock falls show different triggering dynamics and therefore did not contribute to complex movements. The vicinity to drainages or wells seems to act as a preparatory factor influencing the hydrology of a slope thus potentially changing its stability. Forest roads and slope undercutting near the scarp area might also have a potential effect on stability as well as deforestation. For all landslides all these factors were recorded and also the multiple occurrence of different potentially influencing factors was registered. Table 34 shows the results of this investigation in relation to the land use. The total numbers indicate that within the investigated study area forest roads might be regarded as the main potential influence on slope stability. The highest number of landslides occurring directly on or in the vicinity of forest roads was found in forest areas where the roads directly cut through the tree-cover and change the topography through cuts in upslope and fills in downslope directions. This can be interpreted as a potential decrease of local slope stability leading to potential failures. But also drainage outlets could be identified as potential influences on slope stability in seven cases. These outlets were located above or, in some cases, directly within the landslide-mass, which is why the drainage influence on the movement at the specific sites cannot be fully excluded.

Table 3: Potential human influences on landslide occurrence for each land use type.

	Forest roads	Deforestation	Wells	Drainage	Slope undercutting
Forest	13	1	1	1	1
Grassland	4	–	2	2	3
Pasture	5	–	1	4	–
Garden	1	–	–	–	1
∑	23	1	4	7	5

CONCLUSIONS

To rapidly create a landslide inventory following a heavy rainfall event is often necessary to better implement response strategies and estimate the effects of such extreme precipitation. The methodology applied within this study gives the indication, that it is possible to implement a detailed inventory on the basis of damages reported directly after an event with rather limited resources (e.g. data and time restrictions). Nevertheless, this method has proven to provide valuable information, not only for direct reconstruction and subsequent mitigation measures, but also for a first approximation of the underlying process-dynamics and a preliminary overview of potential impacts of human activities on slope stability.

The delineation of the study area, i. e. the completely mapped area, carried out within this study has proven to be a necessary step towards creating a database for potential further analyses. It is crucial to explicitly define the investigated area within any susceptibility, hazard or risk mapping in order to provide useful information for further modeling or validation of existing models. The method for defining the mapped area applied here did not consider administrative boundaries or river catchments, as it is often the case in landslide analyses. On the contrary these boundaries were completely neglected to create an inventory related to the May 2014 rainfall event, which spread over several districts and river catchments but did not cover them all. Still the tight clipping of the study area alongside the mapping route shows the restrictions of the applied methodology with only a small area being completely mapped and large forested areas not being included in the inventory. The applied field mapping based on known events showed, that a fast way of creating an event-related landslide-database is to investigate these events first. As an immediate second step, this information has to be expanded by designing a mapping route and then extending the existing data base entries in order to receive a final detailed and most complete inventory.

It has to be mentioned that not all landslides that occurred during the May 2014 event could be mapped, because such wide-spread mapping would have required much more time. When mapping landslides it is often crucial to act quickly within the given resources, since remedial works along the transport corridors often have to be done immediately following the event. Therefore it is necessary to investigate the events directly after their initiation and not wait until sufficient data is available. Even though not all landslides in the area could be mapped, a detailed inventory within the defined study area was established. This inventory contains, besides the specific time of occurrence for each recorded landslide, also detailed information on single landslide locations and the human activities that have a potential impact on their occurrence.

The evaluation of the potential human impact showed that numerous activities including slope undercutting, drainage or deforestation have likely influenced slope stability. But still these relations are just field-based observations and have not been assessed in full detail. Indeed, a more profound analysis is required. Furthermore, to better understand the exact dynamics between the different processes leading to a landslide, further analyses are indispensable. The inventory established within this research only outlines the different potential impacts on slope stability within the study area and does not give a definite relation of human activities to landslide occurrence. However, it is a valuable source for practitioners and for further more detailed analysis.

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