# Landslide inventory in the Abava spillway valley, Latvia

Kārlis Kukemilks

Department of Geology, University of Trier, Behringstraße 21, D-54296 Trier, Germany; Kukemilks.karlis@inbox.lv

Received 14 August 2017, accepted 8 March 2018, available online 10 May 2018

**Abstract.** This study discusses the compilation of landslide inventories and their possible application in landslide research and risk assessment. A case study was conducted in the Abava River valley (western Latvia) between the towns of Sabile and Kandava to determine the most effective methods of landslide mapping and to demonstrate the possible applications of landslide inventories there.

Landslide inventories are necessary for landslide risk zoning and landslide hazard prevention. An efficient landslide mapping is one of the first steps for creating a landslide inventory. The effectiveness of different landslide mapping approaches was compared in the real-world study area of the Abava River valley. Hillshade maps and stereoscopic aerial photographs were used to map landslides. To evaluate the accuracy of the applied landslide mapping methods, field surveys were conducted in the study area. During the field surveys, the slopes of the Abava River valley were inspected for the occurrence of landslides. During the field surveys, landslides were also classified according to their morphological expression. By comparing the results of landslide mapping through stereoscopic aerial photographs and hillshade maps with the field surveys, the most appropriate methodology for landslide identification was determined. The information containing the spatial location of landslides and their morphological characteristics reveals factors controlling landslide formation in the study area and delivers information for landslide research and risk assessment.

**Key words:** landslides, landslide inventories, aerial photographs, hillshade maps, Abava spillway valley.

## INTRODUCTION

In Latvia, landslides are common on the slopes of river valleys. Landslide processes have been studied in the Daugava River valley (Soms 2006) and in the Gauja River valley (Venska 1982; Mūrnieks 2002; Āboltiņš et al. 2011; Kukemilks & Saks 2013). Landslides are also common in river valleys in Estonia (Kohv et al. 2009). In 2002, landslides came to be the focus of increased media attention in Latvia because a dangerous landslide occurred on the southwestern slope of the Turaida castle mound (Āboltiņš et al. 2011). The Turaida Museum Reserve and medieval castle in the vicinity of Sigulda are popular tourist destinations in Latvia. That year two landslides endangered the historical building and blocked the motorway from Turaida to Sigulda. The Turaida landslide was investigated in detail and slope stabilization measures were carried out (Āboltiņš et al. 2011). A recent landslide threatens regional motorways in the Abava spillway valley, between the towns of Kandava and Sabile (Latvijas Valsts ceļi 2014).

When discussing the main triggers of landslides in the Gauja River valley, the slope angle and elevation have been estimated as the most important landslide-related factors (Kukemilks & Saks 2013). Landslide-cirque gullies are often present in the Daugava spillway valley, in the span between Krāslava and Naujene (Soms 2006). Besides lithology, hydrogeological conditions are important causes of these landslides (Soms 2006). Hydrogeological conditions have been discussed as a relevant trigger mechanism of the Turaida landslide as well (Āboltiņš et al. 2011). In western Estonia, lithology is one of the most important triggers of landslides as they occur mostly in glaciolacustrine varved clay (Kohv et al. 2009). The influence of the slope angle is not pronounced because landslides can also occur on relatively flat slopes (critical slope gradient for clay is ≥10°) (Kohv et al. 2009).

This literature review shows that previous studies consider individual landslides (Āboltiņš et al. 2011) or landslide events in a specific region (Soms 2006; Kohv et al. 2009; Kukemilks & Saks 2013). However, a regional or national landslide inventory would put single landslide events into a wider perspective and provide information for landslide risk research and mitigation.

Landslide inventories are a necessary source of information for land use planning, engineering decisions and palaeoclimate research (Booth et al. 2009). Landslide inventory maps are a crucial source of information for both scientists and other experts including decision-makers, planners and civil defense managers (Galli et al. 2008). It is assumed that landslides often happen under similar climatic, morphological and lithological settings. Thus the most important function of landslide inventories is to deliver information about these climatic, morphological and geological triggers of the past landslides helping to predict landslide hazards in the future. Moreover, data about the existing landslide population are also needed to calibrate models of landslide risk zoning (McKean & Roering 2004).

When inventorying landslides, it is important to document the extent of landslide phenomena in a region and to investigate the distribution, types, patterns, recurrences and statistics of slope failures (Guzzetti et al. 2012). The landslide inventory can deliver information about the landslide location, type, dates of occurrence, frequency of occurrence, state of activity, magnitude or size, failure mechanisms, triggering factors and the damage caused (Van Den Eeckhaut & Hervás 2012). To collect the information about landslide processes in the whole country or in a specific region, many European countries have created or are creating national and/or regional landslide inventories (Van Den Eeckhaut & Hervás 2012). Nonetheless, not all European countries have landslide inventories. Out of 37 states 22 have national and six have regional landslide inventories. Six countries have no landslide inventories at all, and there was no information obtained from Latvia, Luxemburg and Lithuania (Van Den Eeckhaut & Hervás 2012).

Effective landslide mapping is one of the most important steps for the compilation of a landslide inventory. Numerous techniques are used for landslide mapping, in order to compile landslide inventories (McKean & Roering 2004; Van Den Eeckhaut et al. 2005, 2011; Booth et al. 2009; Fiorucci et al. 2011; Stumpf & Kerle 2011). The conventional approach for landslide mapping uses visual interpretation of stereoscopic aerial photography together with field surveys. However, this approach is considered time-consuming and resource intensive (Guzzetti et al. 2012). Topographic maps often lack the resolution required to map small or topographically unexpressive landslides, while forest vegetation often hides morphologic features indicative of landslides in aerial photographs. Consequently, old slides with weak topographic expression cannot be identified in aerial photographs (Van Den Eeckhaut et al. 2005). Detailed field mapping is one of the most reliable methods of landslide identification. But, on the other hand, it is more time-consuming and difficult to carry out, especially in forested terrain (Booth et al. 2009). Moreover, landslide inventories of the same area, compiled by different experts, can vary significantly (Van Den Eeckhaut et al. 2005).

Nowadays, innovative satellite, airborne and terrestrial remote sensing technologies are delivering exact data for landslide mapping (Guzzetti et al. 2012). Advances in object-oriented image analysis and machine learning algorithms allow us to identify topographic signatures of landslides from high-resolution digital elevation models (Booth et al. 2009; Stumpf & Kerle 2011). Multi-temporal Light Detection and Ranging (LiDAR) data can be helpful in identifying recent slope deformations (Hövel et al. 2015). However, high-resolution terrain models are not available for the Abava spillway valley. Only a topographic map 1 : 10 000 (TOPO 10K PSRS) and aerial photographs in a scale of 1 : 25 000 are available. Therefore the aim of this study is to determine which of the data sources – aerial photographs or hillshade maps are more appropriate for landslide mapping in the Abava spillway valley. The results were validated through field surveys to determine which data source allows more effective identification of landslides in the study area. Subsequently using information about the landslide population extracted from different mapping sources, landslide-related factors were determined and possible applications of landslide inventories were discussed.

## STUDY AREA

The study area is located in western Latvia (Fig. 1), within the area glaciated by the Scandinavian ice sheets during the last Ice Age (Zelčs et al. 2011), between the Eastern Kursa and Northern Kursa uplands.

Pleistocene glaciations, especially the last Weichselian event, significantly shaped the present-day topography of the study area (Zelčs & Markots 2004). Glacial meltwaters discharged into ice-dammed lakes along the retreating ice margin. Drainage of ice-dammed lakes caused rapid incision of deep proglacial spillways in watershed areas (Zelčs & Markots 2004).

The Abava–Slocene spillway is among the most complex systems of glacial meltwater drainage valleys in Latvia (Veinbergs 1975). This valley stretches from east to west, forming a natural border between the Eastern Kursa and Northern Kursa uplands (see Fig. 1). The Abava–Slocene spillway runs from the town of Tukums to the village of Renda. It is more than 60 km long and between 0.7 and 2.5 km wide. The valley reaches a depth of 52 m at Sabile and 47 m at Kandava. Erosional terraces are mainly present on the slopes of the river valley (Veinbergs 1975).

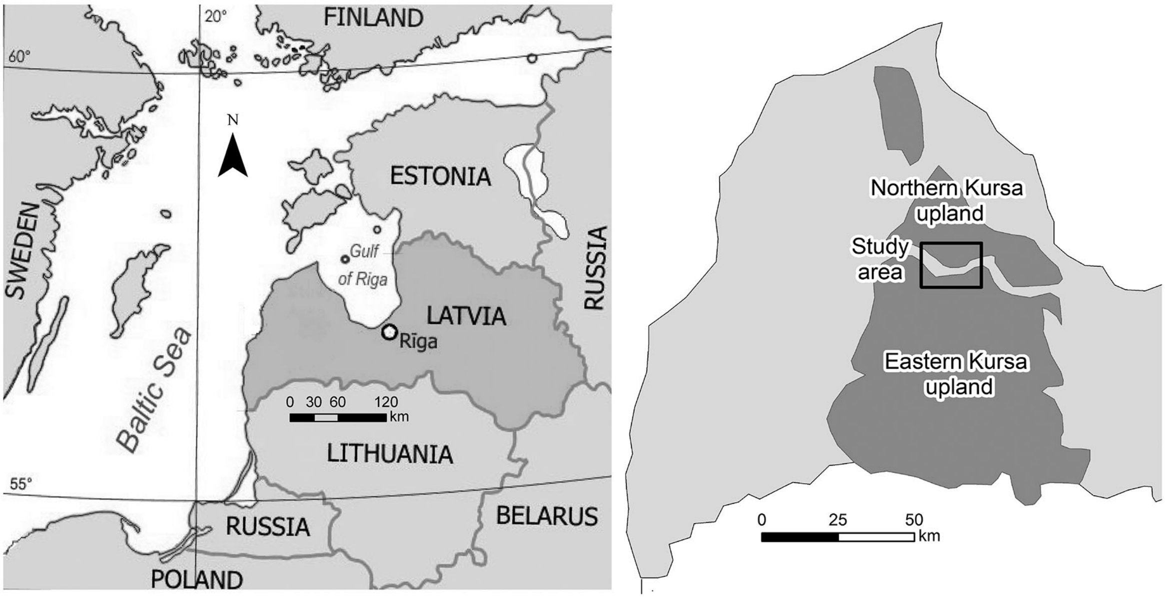


**Fig. 1.** Location of Latvia in the Baltic region (left). Study site in western Latvia between the Northern and Eastern Kursa uplands (right).

The study area is located in the Abava spillway which is the most remarkable section of the Abava–Slocene ancient valley system. The Abava spillway valley is deeply incised (up to 52 m) in the Quaternary and Upper Devonian bedrock deposits. In the study area, Quaternary deposits represented mainly by glacial till, glaciofluvial sand and gravel cover the bedrocks (Veinbergs 1975). On the slopes of the valley, Upper Devonian sandstones, clays, dolomites and marls are outcropping (Fig. 2).

In the section between the towns of Kandava and Sabile, the slopes of the valley are commonly dissected by gullies and valleys of tributaries. The tributary valleys of the Amula and Imula rivers are the deepest. Landslide processes occur on the steepest slopes of the valley, especially in the vicinity of the town of Kandava (Veinbergs 1975). The landslides in the Abava spillway valley possibly developed during the Late-glacial period as a result of paraglacial adjustment. Landslide processes may have activated during the Holocene due to heavy rainstorms, large snow storage and high snowmelt runoff, forest clearing and agricultural land use. River bank erosion and slope undercutting also may have decreased slope stability. The recent landslide event of Greiļu kalns (Latvijas Valsts ceļi 2014) approximately 5 km SE from the town of Sabile is related to anthropogenic activity. Mass movement was initiated by material removal from the foot of a landslide susceptible slope during the reconstruction of a regional motorway (Skels & Bondars 2015).

## METHODS

The span of the Abava spillway valley between Kandava and Sabile was chosen for field research due to its high landslide susceptibility (high and steep slopes) and landslide occurrence in the past (Veinbergs 1975). First the landslides were identified by visual interpretation of stereoscopic aerial photographs and are shown on the digital elevation model (Fig. 3). Greyscale aerial photographs at a scale of 1 : 25 000 (year of origin: 1994, provider: Faculty of Geography and Earth Sciences, University of Latvia) and stereoscope were used. Landslides were recognized from opposing and irregular contours (Booth et al. 2009) accompanied by a well-defined main scarp, an abrupt change in the slope angle and morphology (Van Den Eeckhaut et al. 2005). Nonetheless, landslides were often not clearly and easily detectable. Another problem associated with the mapping of landslides from aerial photographs is the ineffectiveness of this method for areas under a tree canopy (Van Den Eeckhaut et al. 2005). However, there is no tree cover in 64% of the study area. Therefore, mapping from stereoscopic images could be applied there.

A second landslide map was based on visual interpretation of hillshade maps of a digital elevation model derived from the 1 : 10 000 scale topographic map. The hillshade maps were extracted from a digital elevation model. For these purposes, a digital elevation model was generated from a 1 : 10 000 scale topographic map (TOPO 10K PSRS 1979–1980, measurements

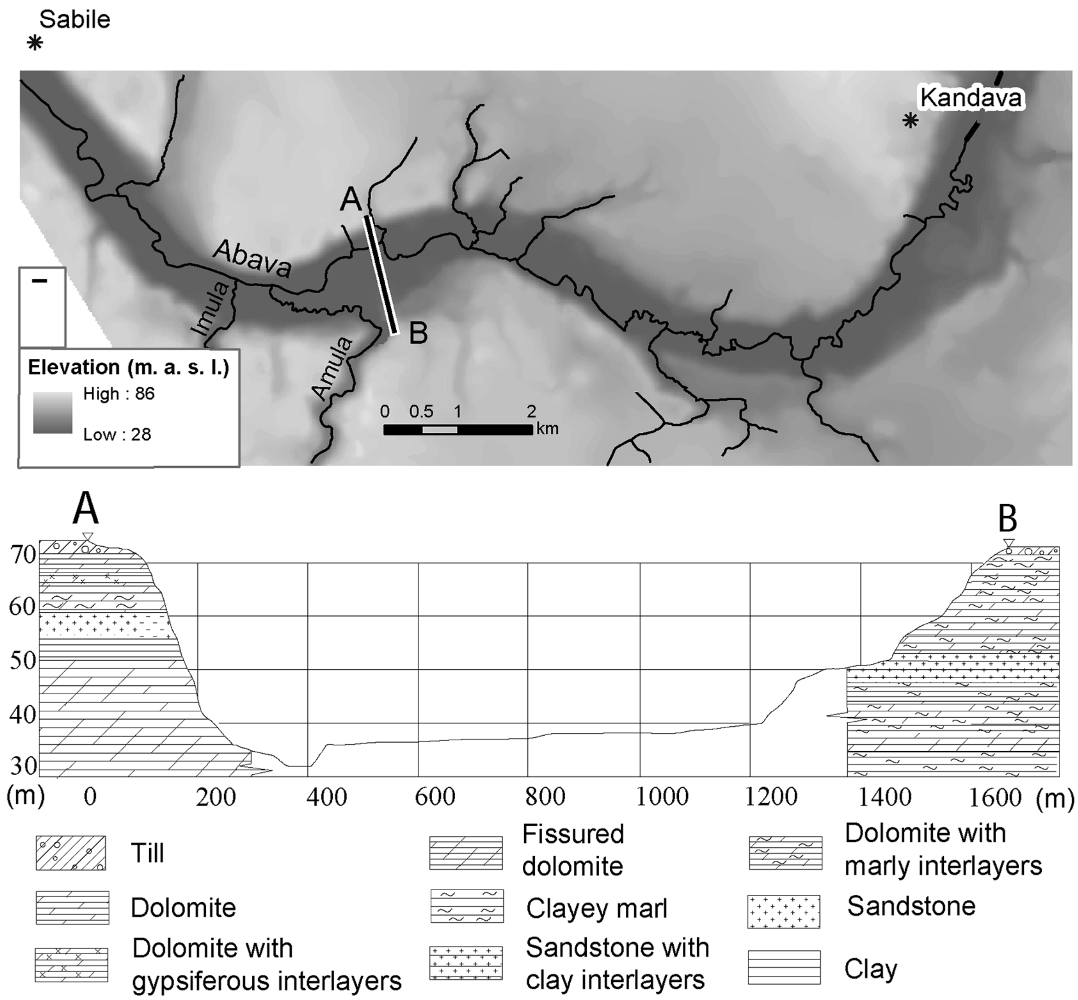


**Fig. 2.** Geological cross section A–B of the Abava River valley (compiled by the author after Jarvis et al. 2008; Takčidi 1999).

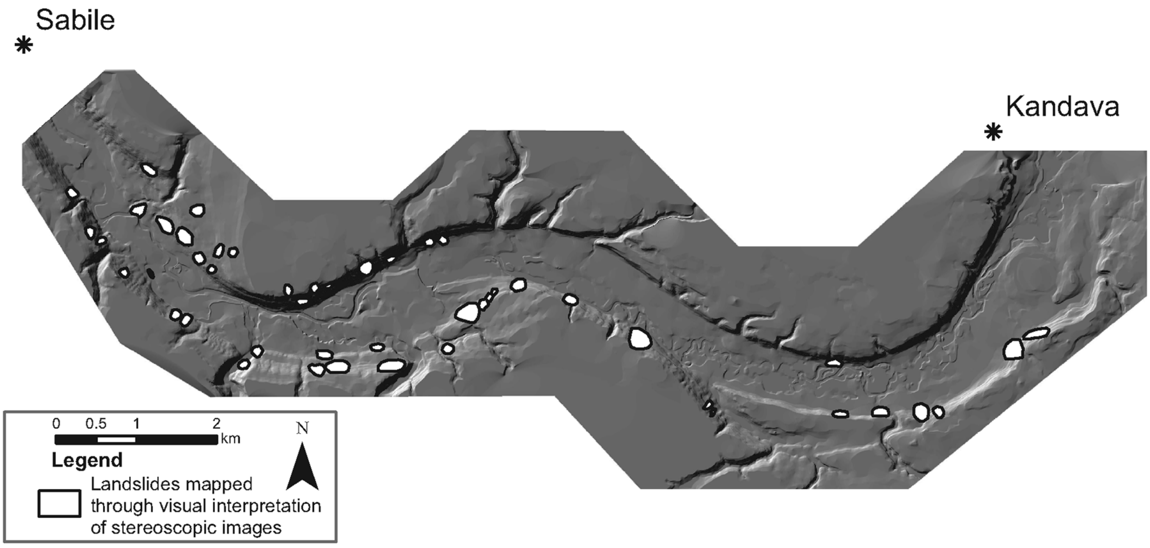


**Fig. 3.** Landslides mapped through visual interpretation of stereoscopic images (shown on the digital elevation model, sun azimuth angle 315°, sun elevation angle 25°, vertical exaggeration 3) (compiled by the author using TOPO 10K PSRS 1979–1980).

conducted in 1975–1976) in the ESRI ArcGIS 10 environment. All contour lines with a vertical interval of 2 m were digitized and a digital elevation model with a cell size of 1 m equal to half of the contour lines interval (Li et al. 2005) was created. Four different hillshade maps were compiled, with a sun azimuth angle of 315°, 225°, 135° and 45°, an equal sun elevation angle of 25° and a vertical exaggeration of 3. In the hillshade maps, the slopes of the river valley were illuminated from four different directions because some landslides were visible only under specific lighting conditions. The best lighting conditions for landslide identification in a hillshade map are those with a low sun elevation angle with the light falling nearly parallel to the slope. Under such conditions, hummocky topography can be interpreted well in the hillshade map including typical morphological characteristics of landslides – a landslide tongue and a main scarp. The sun azimuth angles of 315°, 225°, 135° and 45° were chosen because the Abava spillway valley in the research area mainly runs from southwest to northeast or from northwest to southeast and the light should fall in roughly the same direction. Landslides from the hillshade maps were digitized (Fig. 4) in the ESRI ArcGIS 10 environment and saved as a separate layer.

During the field surveys, the entire study area was inspected for the occurrence of landslides. The field surveys were carried out in order to verify the accuracy of the landslide maps derived from both the visual interpretation of stereoscopic aerial photographs and hillshade maps. They were conducted in four days along both banks of the Abava spillway valley. The minimal dimensions of a landform to be counted as landslide was a 1.5 m wide main scarp and 3 m extension downhill. In some locations fences and livestock blocked access to the potential landslides. However, the areas were inspected visually to try and determine the presence of landslides there. The landslides were mapped with GPS as single points. Mapping as single points is appropriate, because the aim was to determine whether landslides mapped through hillshade maps/aerial photographs were indeed present in the landscape. The GPS device Germin GPSmap 62 with 6 m horizontal accuracy was used. Afterwards a 20 m buffer was applied to the mapped landslide points, to compensate for any inaccuracies caused by the GPS measuring and georeferencing of the cartographic material. This procedure was necessary if the landslide point mapped in the field did not lie within the polygon of the landslide identified through aerial photographs or topographic maps due to the above-mentioned inaccuracies. A landslide was accepted as correctly identified if a landslide point from field surveys was measured at a distance of 20 m or closer from the landslide polygon's outline.

All landslides were described directly on site and classified according to their morphological expression and sliding mechanism. Depending on how well preserved their typical landslide morphology was, the landslides were subdivided into high, moderate and low morphological expression. Typical characteristics of high morphological expression are a clearly visible main scarp and tongue of the landslide without a permanent vegetation cover. Landslide morphology is very well preserved with few or no traces of recent erosion at all. Landslides with a permanent vegetation cover are

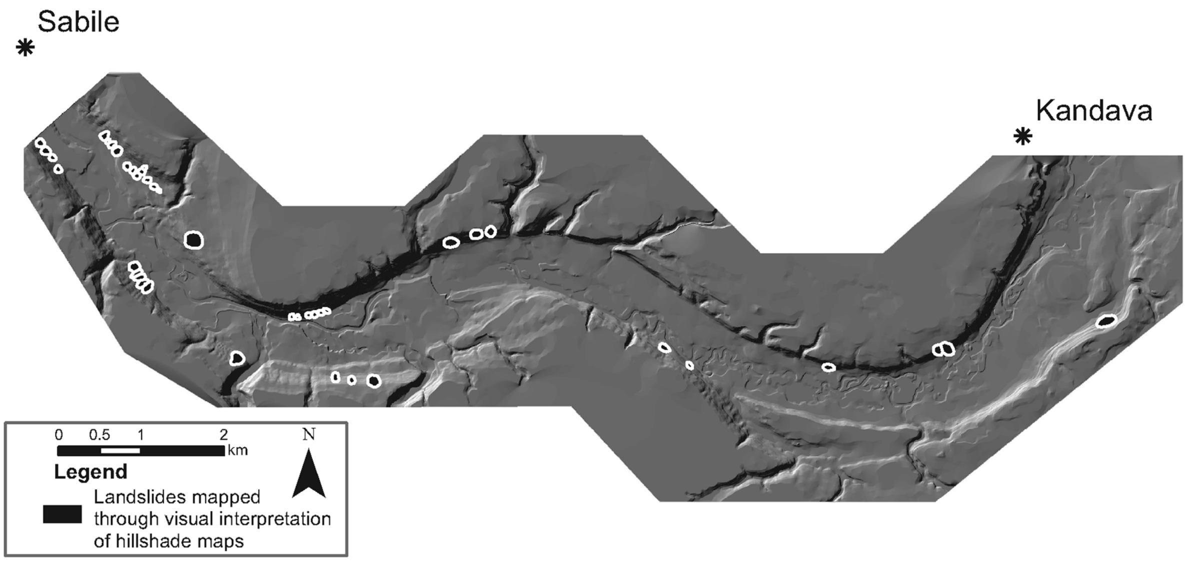


**Fig. 4.** Landslides mapped through visual interpretation of hillshade maps (shown on the digital elevation model, sun azimuth angle 315°, sun elevation angle 25°, vertical exaggeration 3) (compiled by the author using TOPO 10K PSRS 1979–1980).

classified as having moderate or low morphological expression because a permanent vegetation cover indicates that the landslide has been exposed to erosion processes for certain time. Moderate morphological expression is accompanied by tilted trees and high topographic expression. Typically, the landslide morphology is well preserved without significant traces of erosion. In the case of low morphological expression a stable vegetation cover without tilted trees is accompanied by a poorly preserved landslide morphology. No recent traces of deformation such as tension cracks or tilted trees can be observed. The landslide body and toe are largely affected by erosion. Hummocky topography is typical for old landslide areas. Light depression in the zone of depletion and a small hill in the zone of accumulation can be observed. However, these landslides can be easily overlooked because they are not expressive in the landscape. When classifying the landslides according to their sliding mechanisms, three main types were observed in the study area: translational slides, rotational slides (Hutchinson 1988) and earthflows (Easterbrook 1999). Translational slides move along a rough planar surface with little rotation or backward tilting as a single unit of a relatively coherent mass (Hutchinson 1988). A rotational slip is a landslide in which the surface of rupture is curved concavely (Hutchinson 1988). One characteristic of rotational landslides is reverse slopes which are responsible for the presence of an elongated pool (Van Den Eeckhaut et al. 2005). Earthflows have a distinctive 'hourglass' shape. The slope material liquefies and runs out, forming a bowl or depression at the head (Easterbrook 1999).

To define the accuracy of the landslide mapping method, the number of landslides validated through field surveys can be related to the number of all landslides mapped with this method (Eq. 1):

$$r_m = N_v / N_m \, , \qquad (1)$$

where $N_v$ is the number of landslides identified by the considered method which are validated through field surveys; $N_m$ is the total number of landslides identified by the considered method; the index $r_m$ denotes the accuracy of the method applied by relating the landslides verified in the field to the total number of landslides identified by the considered method.

The number of landslides observed in the field, but not identified by the considered method is also relevant as it shows how applicable the stereoscopic aerial photographs and hillshade maps are to landslide identification in general. Moreover, the spatial distribution of not identified landslides indicates areas where aerial photographs and hillshade maps have lower effectiveness, e.g. depending on the land cover.

## RESULTS

Attempts were made to characterize landslides directly in the study site according to their sliding mechanism. However, field research has shown that the morphological form can be misleading. A well-eroded rotational slide, for instance, can be similar in appearance to an earthflow. The identification of the sliding mechanism was especially complicated when the landslides were already older and eroded, therefore the sliding mechanisms were not applied in further analysis.

Figure 5 illustrates the distribution of landslides determined during the field surveys in the study area. Comparing the results of mapping with Figs 3 and 4, one can notice that many landslides have been overseen in the stereoscopic images and hillshade maps.

The clustering of landslides was often observed in the field survey data. It can be explained with local-scale landslide triggers like slope undercutting by a river which will be discussed later. The Greiļu kalns slide also occurred in a landslide-susceptible area where recent landslides have been observed.

Table 1 shows that, in total, 48 landslides were identified through stereoscopic images and 41 through hillshade maps. Three times fewer landslides (12 vs 36) were mapped through stereoscopic images in the territories with forest cover than in those without a tree canopy. Twenty-five landslides mapped through hillshade maps are found in the areas without tree cover.

The landslides determined through field surveys were classified according to the preservation of their morphology (morphological expression). Sixteen landslides were identified with high morphological expression, 22 with medium and 13 with low morphological characteristics. Table 2 shows how many landslides identified through hillshade maps and aerial photographs are really present in the landscape. The table illustrates that hillshade maps were not an appropriate source for the identification of landslides. Only five out of 41 landslides, determined from hillshade maps, were validated during the field surveys which leads to very low values of the index $r_m$ (12%). Stereoscopic images were more effective ($r_m$ = 25%) but still only 12 out of 48 identified landslides could be found during the field work. It should be added that the effectiveness of aerial photographs was higher in deforested areas. More than half (37 out of 51) of the landslides from the field surveys were found under forest cover, but the majority of the correctly identified landslides from stereoscopic images are located in the areas without tree cover (8 out of 12).

Table 2 also reveals that only one third of all landslides mapped in the field were determined from aerial photographs and hillshade maps. Only landslides with medium and high morphological expression were

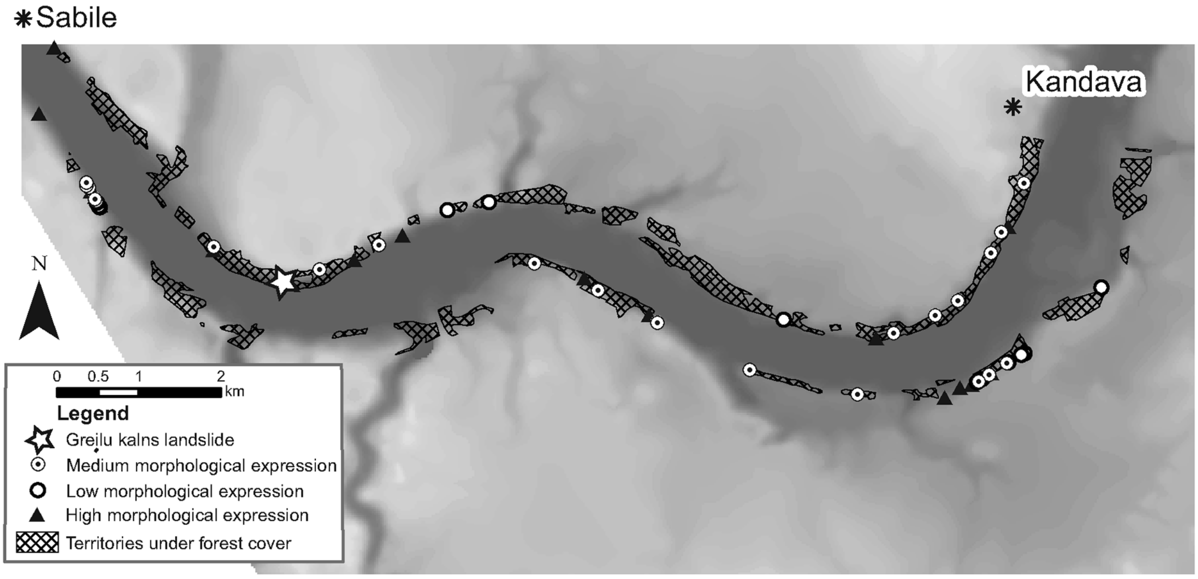


**Fig. 5.** Landslides mapped through field surveys and their morphological expression (compiled by the author after Jarvis et al. 2008).

**Table 1.** The distribution of landslides according to their source of mapping in dependence of the land cover

| Source of mapping | Under tree cover | Without tree cover | Total |
|---|---|---|---|
| Stereoscopic images | 12 | 36 | 48 |
| Hillshade maps | 16 | 25 | 41 |

mapped through stereoscopic images. No landslides of low morphological expression were identified. Conversely, with the hillshade maps, three landslides found during the field surveys were of low morphological expression and only one had high and medium morphological expression.

## DISCUSSION

The results of the mapping were validated during the field surveys. The field work shows that the hillshade maps derived from the topographic map 1 : 10 000 (TOPO 10K PSRS) are not a reliable source for landslide mapping. Only a few of the landslides identified from the hillshade maps were found in the field and these findings may be well attributed to pure coincidence. Possibly, the generalization of the topographic map does not allow including separated landslide morphology in the map. In addition, the compilation of hillshade maps required multiple stages of data processing (such as geodetic measurements in the field, the drawing of the topographic map, the digitizing of the map and

**Table 2.** The number of landslides validated during the field surveys depending on their source of mapping and total number of landslides found through field surveys

| Landslides | Validated through surveys (stereoscopic images)/index $r_m$ (%) | Validated through surveys (hillshade maps)/index $r_m$ (%) | Total number found through field surveys |
|---|---|---|---|
| Under tree cover | 4/33% | 2/13% | 37 |
| Without tree cover | 8/22% | 3/12% | 14 |
| High morphological expression | 6 | 1 | 16 |
| Medium morphological expression | 6 | 1 | 22 |
| Low morphological expression | 0 | 3 | 13 |

creation of the hillshade model). Many landslide-like morphological forms can be found on hillshade maps (see Fig. 6) but they rarely prove to be genuine landslides in field surveys. Consequently, hillshade maps can be conducive to getting a better overview of the terrain with different lighting conditions, but they are not able to deliver information which is not included in the source data. In contrast, aerial photographs are more appropriate, since landslides are directly identified in photographs.

Contrary to the hillshade map derived from topographic maps, aerial photographs contain information about some of the landslides found in the study area despite their relatively small scale. About 25% of all landslides identified in 1 : 25 000 scale aerial photographs can indeed be found in the field. This indicates the relatively low reliability of the data source for landslide identification. However, it is also possible that all landslides determined from aerial photographs were not found in the field. Large areas can be overlooked in aerial photographs, but the ability to carry out mapping along slopes is significantly limited during field surveys. Possibly, not all landslides could be validated during field work since very dense vegetation, fences and livestock prevented access to the landslides in some areas as well.

The effectiveness of aerial photographs considerably depends on the land cover. The effectiveness was more than 50% in deforested areas (8 out of 14 landslides found in deforested areas during the field surveys were also identified in the aerial photographs), but significantly reduced under forest cover (4 out of a total of 37 landslides under the tree cover were identified in the aerial photographs). However, in comparison with the Gauja River valley, where about 90% of the slopes are covered with forest (Kukemilks & Saks 2013), aerial photos are more applicable in the Abava spillway valley.

Consequently, the advantage of aerial photographs over hillshade maps is that the necessary information can be accessed directly, while the creation of hillshade maps requires several processing steps during which important information may be lost. Another possible reason for the higher effectiveness of aerial photographs may be the fact they were taken relatively recently (footage shot in 1994). Perhaps some of the landslides were not present yet when the topographic maps were compiled (year of the origin 1975–1976).

The high number of landslides under forest cover discovered during field studies may be due to the steepness of the slopes under this land cover. Because of their steepness, these slopes are not suitable for agricultural use. Another probable explanation may be agricultural activities which increase soil erosion rates. This in turn causes the erosion of morphological characteristics of landslides and reduces thus the traces of landslides in agricultural land. Aerial photographs proved to be unsuitable for the mapping of landslides with low morphological expression. It was problematic to discern

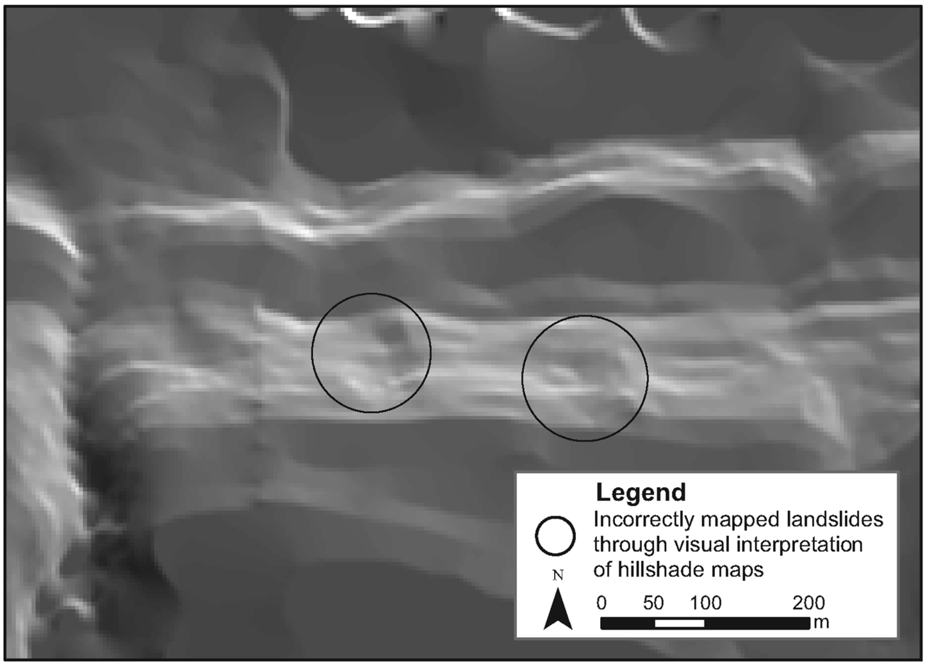


**Fig. 6.** Landslide-like morphological forms on the hillshade map (compiled by the author using TOPO 10K PSRS 1979–1980).

different slope processes and their states of preservation during the field studies. Visual distinction of poorly preserved landslides from earthflows is often not possible due to their similar morphological features. Consequently, the large number of landslides mapped through the field survey (and not seen in stereoscopic aerial photographs and hillshade maps at all) shows the necessity of direct geomorphological field mapping.

The landslide density in the Abava River valley is lower than in the Gauja River valley (Kukemilks & Saks 2013). An obvious reason is that the slopes in the Abava River valley consist of resistant dolomite, marl and sandstone rocks, while in the Gauja River valley loose sandstone and clay deposits are present (Kukemilks & Saks 2013). In the Abava spillway valley, a common cause of slope instability is slope undercutting by the river. Figure 7 shows several landslides caused by slope undercutting. These slides were not identified on the hillshade maps and aerial photographs (probably due to a dense forest cover), which shows that field surveys are necessary for landslide inventories in the study area.

Sites of possible landslide risks were also examined during the field surveys in the Abava spillway valley. Some sections of the motorway Kandava–Sabile may be affected by landslides, as intense surface deformations and active landslides were observed in the vicinity. Also the recent landsliding event of Greiļu kalns shows that anthropogenic influences, such as reconstruction of the motorway, in a landslide-susceptible area can result in mass movements. In the town of Kandava recent landslides were found directly in the residential area where an additional landslide risk assessment could be necessary.

This study illustrates that landslide inventories are a necessary tool for land-use planning and landslide research. The first contribution of the landslide inventories would be identifying the territories most affected by landslides. A landslide risk zoning is needed in the areas where landslides threaten built-up environments or human lives. For this purpose high-resolution digital elevation models (DEMs) are indispensable. At present, no DEMs are available for the whole territory of Latvia (http://lidojumi.metrum.lv/gmap/FIS.phtml). Additional airborne LiDAR surveys have been and are currently carried out for several territories, and the whole of the country may be covered in the future. However, field surveys will still be necessary for the validation of landslides identified using LiDAR techniques. Further, a detailed hydrogeological and slope stability modelling might be necessary to evaluate the safety of separate buildings and infrastructure objects in the areas affected by landslides. Moreover, detailed slope stability and hydrogeological analyses of landslides would be a useful tool for understanding the trigger mechanisms of landslides in the area.

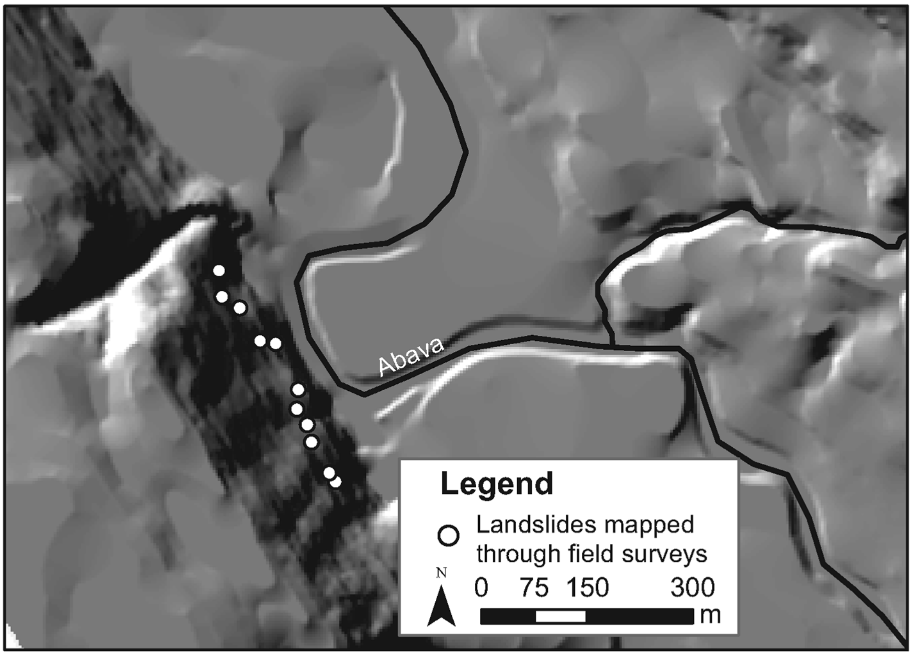


**Fig. 7.** Intensive landsliding caused by slope undercutting on an exterior river bank of the Abava River (compiled by the author using TOPO 10K PSRS 1979–1980).

## CONCLUSIONS

Landslide inventories are a common source for landslide research, risk management and decision-making. Thus, many European countries already have national or regional-scale landslide inventories (Van Den Eeckhaut & Hervás 2012), which in Latvia as well could be an appropriate tool for decision-making and risk prevention in areas subjected to landslide processes. A case study in the Abava River valley between the towns of Kandava and Sabile was conducted to determine appropriate landslide mapping approaches and possible application of landslide inventories. Topographic maps derived from hillshade maps and stereoscopic aerial photographs were used to identify possible landslides in the study site. Field research was conducted to validate landslides from hillshade maps and stereoscopic photographs. Hillshade maps derived from topographic maps were found to be an unsuitable source for landslide mapping. Aerial photographs can be applied in deforested areas, however, a significant part of landslides is not identified correctly by this method. Moreover, aerial photographs are unfit for the mapping of landslides with low morphological expression and under dense forest cover. For this reason field surveys are crucial.

Recent landslides detected during the field mapping show that landslide risk still exists in the Abava River valley. In this valley, landslide inventories would be necessary to determine which areas are threatened by landslides and how their hazards can be prevented. During the landslide mapping, locations with intense landslide concentration were observed. Also the recent sliding event of Greiļu kalns occurred in an area where several recent landslides have been recorded during the landslide mapping. This could have been considered as an additional indication of landslide risk during the construction works.

One of the landslide causes in the study area is slope undercutting by the river or anthropogenic activity, however, there are additional lithological and hydrogeological factors present. Therefore a more detailed investigation of landslide-related factors through monitoring and slope stability modelling would be highly beneficial for understanding the landslide causes.

**Acknowledgements.** I would like to thank Dr Tomas Saks, who helped me by designing this study, Kārlis Livkišs, who accompanied me during the field research and Justin M. Hartman and Tammy Ganster for linguistic corrections to the manuscript. I am grateful to the referee Birgitta Kausch and the anonymous referee for the constructive reviews of the article. The publication costs of this article were covered by the Estonian Academy of Sciences.

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## Läti Abava jõe maalihete inventuur

Kārlis Kukemilks

On käsitletud Läti Abava jõe oru näitel maalihete inventuuri koostamise põhimõtteid ja nende võimalikku rakendamist maalihete riskide hindamisel. Efektiivne maalihete kaardistamine on üks riskide maandamise sammudest. Maalihete kaardistamiseks kasutati topokaarte ja stereo-aerofotosid ning kontrolliti välitööde käigus maalihete esinemist Abava jõe oru nõlvadel ja määrati maalihete identifitseerimiseks sobivaim metoodika. Maalihkeohtlike alade asukoht ja morfoloogilised andmed näitavad uuringus maalihete moodustumist reguleerivaid tegureid ning annavad soovitusi riskihindamise kohta.