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LANDSLIDES MAPPING IN ROZNOW LAKE VICINITY, POLAND USING AIRBORNE LASER SCANNING DATA

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ABSTRACT
Southern Poland, especially Polish Carpathians, is a region affected by strong mass-movements. The importance of mass-movements problems has been taken into consideration on the governmental level and Landslide Counteracting System (SOPO) program was launched in 2008. The main purpose of this program is to create inventory and map all active and inactive landslides and landslide prone areas in Poland.
However, in case of such gigantic work, the traditional mapping methods meet sometimes their limitations. In order to overcome some of efficiency problems the new technology, the application of airborne laser scanning was tested.
The main purpose of presented work is to test whether the LiDAR DTM is capable to support geological interpretation and landslide detection on steep and forested slopes for the purposes of landslide mapping within SOPO project. For this purpose the ALS dataset covering 40 km^2 of the area near Roznow Lake in Polish Carpathians have been acquired in April 2010. The average scanning resolution was 7 points/m^2 and LiteMapper 6800i system based on the full waveform, Riegl LMS-Q680i scanner have been used. Acquired point cloud was applied to generate DTM of 0.5 m resolution. For efficiency test purposes the detailed geological interpretation of constructed ALS DTM was focused on already well mapped large Zbyszyce landslide. The extents of the landslide and the zones of different level of activity have been mapped and then verified with field data. During the detailed analysis it was found that the level of the details of ALS DTM allows also performing morphometric analysis on landslides.

KEYWORDS: Airborne laser scanning, landslides, landslides mapping, Carpathians

1. INTRODUCTION

Airborne Laser Scanning (ALS), referred also as LiDAR (Light Detection and Ranging) has become in recent years the leading technique for obtaining information about the terrain surface topography, that is required for Digital Terrain Models (DTM) construction. In respect to the traditional data acquisition techniques, ALS removes a number of limitations that affects traditional methods. The main advantages are:

- Uses of an active sensor in the form of a narrow laser beam with high penetration capability allowing that the measurements are independent of weather conditions and time of a day;
- The high penetration rate of laser signal in densely vegetated (wooded) areas could be up to 70 % assure that many of reflections come from the terrain surface (Ackermann, 1999). In such areas all the traditional measurement techniques usually fail;
- Obtained data are characterized by the high density, even tens of points per square meter with high vertical precision from about 0.1 to 0.3 m.

ALS technologies develop very fast in terms of scanners efficiency and improvement of algorithms for ALS data processing. Moreover, due to increasing popularity it becomes more cost-effective and available for new applications. One of them is the landslides mapping and monitoring. The first attempt to apply ALS and also TLS (Terrestrial Laser Scanning) data for landslide research are in fact carried out since there technologies have become widely available (Carter et al., 2001; Haugerud et al., 2003). A good overview about recent achievements in this field has been given recently by Jaboyedoff et al. (2010).

The problem of mass movements occurs with particular intensity in the southern Poland. Over 95 % of landslides are located in Carpathian region (Poprawa and Rączkowski, 2003). The importance of landslide problem which directly affects local communities was recognized several years ago at the central level by creating "Landslide Counteracting System" (SOPO) (Grabowski, 2008). The main goal of this project is to create digital database of all active and inactive landslides and landslide prone areas. Most efforts within SOPO project is devoted to detailed field mapping of landslides and recognition of landslide-prone areas. Traditionally, the time-consuming field works are followed by the analysis of contour maps and aerial photos. Recently, similar analyses are supported also by interpretation of high resolution DTM (Wojciechowski, 2008) derived from aerial photogrammetry (Preuss and Kurczyński, 2002). Unfortunately both data sources: photogrammetric DTM and contour maps have limited resolution and details level in forested and steep slope areas which usually represents landslide prone areas. Therefore, application of such data may significantly decrease the number of detected landslides.

As it was mentioned above, the currently ongoing SOPO project is focused on landslides field mapping where cartographic base is the topographic map of scale 1:10 000 (Grabowski, 2008). Mapping geologist is obliged to determine a landslide limits and their main elements such as scarps, thresholds trenches, depressions, accumulation hills, tongues, cracks etc., and perform basic morphometric measurements (e.g. the landslide length and area, height and inclination of the main scarp and toe, etc.) of landslide and the slope on which the landslide is located. In addition, he has to determine the degree of its activity (Grabowski et al., 2008). Landslides are often not clearly noticeable in the slope morphology. This applies mainly to old landslides which are also difficult to interpret on topographical maps (often old and out of date) in the shape of contours. Interpretation problems are also encountered in the case of complex landslides with a number of progress stages, particularly in areas of difficult access or forested. Fragmentary observations adversely affect the proper time of whole landslide mapping.

The main purpose of presented work is to test whether the LiDAR DTM is capable to support geological interpretation and landslide detection on steep and forested slopes. As in case of traditional data, significant degradation of ALS-data accuracy can obviously be expected (Gołuch et. al., 2008). However for the purpose of geological mapping, the absolute accuracy of elevation is less important than information about local relief structures and relative height differences.

In a case of ALS data the error of relative height differences should be a few centimeters and therefore small scale terrain forms should be captured and in final DTM quit well mapped.

All analyses presented in this paper were designed to fulfill or to support the tasks required for landslide mapping performed within SOPO project. Many other analyses are available (Jaboyedoff et al., 2010). However they are beyond of the subject of current paper.

2. METHODS

In recent years the ALS is being increasingly used to landslides studies. In the paper of Schulz (2007) ALS-data with a resolution of about 2m were used for visual mapping of landslides, headscarps, and denuded slopes in Seattle, Washington but did not allow for detailed interpretations. Sekiguchi and Sato (2004) used airborne laser scanning for micro topography mapping and tested the capability of the ALS-data against contour map and aerial photos interpretation. In the paper of Baldo et al. (2009) a complex translational landslide was monitored using an experimental system based on terrestrial LiDAR and GPS. Chigira et al. (2004) used an airborne laser scanner to survey an area of the 1998 Fukushima disaster, where more than 1,000 shallow landslides occurred on slopes of vapor-phase crystallized ignimbrite overlain by permeable pyroclastics. The authors identified landslides that have occurred at the event and also detected previous landslides that were hidden by vegetation. In almost all mentioned studies, the ALS data were used as a supplementary data, to identify and visualize landslides range. However using new type of scanners with increased scanning resolution, the potential of ALS data seems to be widely greater in terms of landslide studies.

The authors propose the use of LiDAR data in landslide studies as illustrated in the diagram (Fig. 1).

The first stage is LiDAR date acquisition: airborne laser scanning was carried out for project purposes at the south east edge of Roznow Lake (Fig. 2) prior to catastrophic landslide activity in 2010. The acquisition time (Table 1) – early spring just after snowmelt season was chosen to minimise the influence of vegetation.

The scanning campaign was performed before the period of vegetation, in April 2010, which assures high quality of the obtained DTM, with a nominal resolution of 4 points per square meter. Due to large

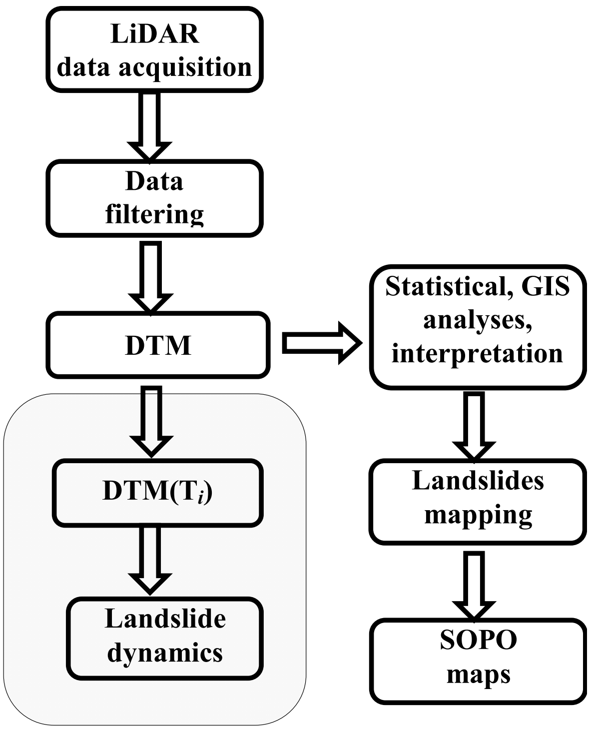

Fig. 1 Use of airborne laser scanning data for landslide monitoring. For explanations: see text.

Table 1 Metadata for the airborne lasers scanning in the study area.

Acquisition date	1.04.2010
Scanning system	Riegl, LiteMapper 6800i
Laser scanner	LMS-Q680i
Scanner type	Full waveform
Laser wavelength	Near infrared
Laser beam divergence	≤ 0.5 rad
Scanning mechanism	Rotating polygon mirror
Pulse repetition rate	400 kHz
Scanning speed	200 lines /sec
Range accuracy	20 mm
Field of view	60°
Intensity resolution	16 bit

overlapping of the neighbour strips (of about 50 %) the resulted point clouds has the average point density about 7 points/m^2. The density varies from 4 points near the border of the study area to 9 points within the area, reaching the maximum of about 11 points in crossing strips (see Fig. 2) The georeference was afforded by RTK GPS measurements with corrections from the permanent stations of ASG-EUPOS system. The basic technical data of applied ALS system were summarised in Table 1. The absolute height accuracy of georeferenced points cloud was evaluated by 10 cm. Simultaneously to ALS campaign, the digital aerial images with terrain resolution of 10 cm were acquired. An example of such image from Zbyszyce landslide is presented in Figure 3. Despite the high-resolution and despite the fact that the deciduous forest dominates the area, the image is not useful for mapping landslides and terrain forms are hidden under the crowns of trees. About 10 % of the study area is covered by forest. Moreover, about 59 % of the area of analysed Zbyszyce landslide is forested. There are mixed and deciduous forests, but the last one dominates significantly.

The second most important stage after scanning is proper data filtering. The filtering stage is very important because the resulted point cloud contains reflections that came not only from the bare ground but also from the land cover objects such as, e.g. buildings, trees. In forested areas, most reflections come from trees and low vegetation. For the landslide study purposes all of these points have to be removed. According to author's experience, the most effective filtering was obtained using the method of active surfaces model (Borkowski, 2004). This model is based on the assumption that the active surface is attributed to internal and external "energy". For the modelling we use the explicit representation of the surface, $z = z(x, y)$. The internal energy describes the geometrical properties of surface:

$$E_{\text{int}} = \frac{\alpha}{2}(z_x^2 + z_y^2) + \frac{\beta}{2}(z_{xx}^2 + 2z_{xy}^2 + z_{yy}^2)$$

where $z_x = \frac{\partial z}{\partial x}$, $z_{xx} = \frac{\partial^2 z}{\partial x^2}$, etc. The weighting parameters α and β are chosen freely depending on implementation and geometrical properties (smoothness) of modeled surface. The external energy E_{ext} depends on the deviation between measured height z_d and height approximated z_t at the same points. The optimal approximation surface $z(x, y)$ will be found if:

$$E_{tot} = E_{\text{int}} + E_{ext} \to \min .$$

Numerical solution of this variational problem is found iteratively (Borkowski, 2004; Borkowski and Jóźków, 2008). We have implemented active surface method in Matlab environment. If optimal terrain surface approximation is obtained, LiDAR points that do not lie on the model surface are removed from the points cloud. Other interesting ALS data filtering techniques for landslides mapping under a dense forest canopy were presented by Razak, et. al. (2011).

The method outlined above was used to filter the points cloud acquired in the first stage. It has been removed up to 45 % of points in forest areas, but still up to 6 points /m^2 are remaining on the terrain surface. In agricultural land about 20% of points have been removed. The remaining point's density was about 7 points /m^2. A fragment of the LiDAR data set from Zbyszyce landslide region before and after filtering is shown in Figure 4. Comparison in Figures 3 and 4 highlights advantages of LiDAR technique to capture height data over the forested terrain.

Based on ALS data filtered DTM GRID model with a resolution of 0.5 m was interpolated using linear interpolation. The obtained DTM (Fig. 5) was then subjected to a detailed expert-based analysis for the landslide areas identification.

Within the next step the landslide LiDAR DTM analysis was carried out by applying the traditional approach of visual interpretation by experience geologists. Using various methods of DTM visualization, the landslide extent and its major elements were determined (Figs. 7, 8). Variable

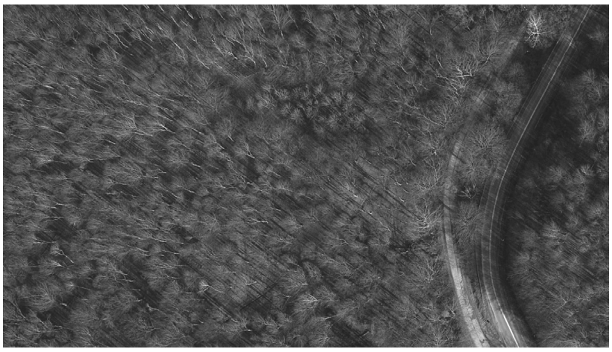

Fig. 3 Example aerial photography of the study area.

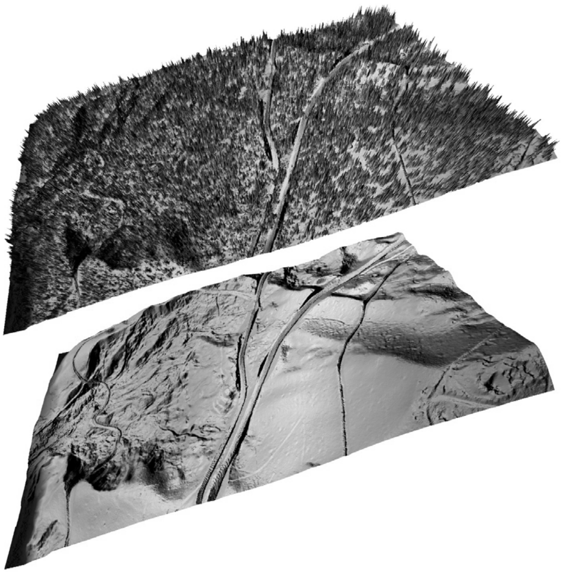

Fig. 4 Example of LiDAR data before (above) and after filtering (below), both gridded with 0.5 m resolution .

viewing direction of LiDAR DTM as 3D model support significantly a complete interpretation of the landslide by complementing and detailing vector drawing in GIS environment (mainly with Global Mapper software). Selection of the most appropriate visualization method depends on the geometry of landslide form. Landslide extent was determined using a method of variable illumination (shaded relief), and based on the simulated stereoscopic model of the terrain which was visualized as anaglyph. Both techniques are described by Nita et al. (2007) and Wojciechowski (2008).

The another aspect of LiDAR data use (shaded part in Fig. 1) is monitoring of landslides dynamics. Acquisitions of airborne laser scanning at specified time intervals T_i, with the same scanning parameters and the same georeference allows to build differential models, which should illustrate the dynamics of surface changes occurring on a landslide (Fig. 1). However, this aspect of the research will be the subject of further publications. In current research we focus on the static aspect only i.e. on the landslides mapping.

3. GENERAL SETTINGS OF THE STUDY AREA

The study area with dimensions 11x3.5 km is located in the central part of the Outer West Carpathians within the Ciezkowice Foothills (Starkel, 1972), along the eastern bank of Roznow Lake (Figs. 2, 5). This area is characterized by relative height differences of even 315 m and variable land cover: meadows, arable lands, forests and sparse urbanization represented by individual farms and small houses. The study area is characterized by high landslide susceptibility. Their activity is primarily attributable to the high variability of the hydrogeological conditions, controlled by fluctuation of water level in the Roznow Lake and a complex geology of the flysh type rocks. In the northern part there are fragments of the Silesian Nappe which consists of a series of sandstone, sandstone-shale and shale from the Upper Cretaceous to Oligocene. In these deposits rock series belonging to the Dukla Nappe and Magura Nappe are overthrusted. They consist of Krosno beds, Cergowa Sandstone, Inoceramus beds and Variegated Shales (Burtan et al., 1992). Rock series are strongly tectonically disturbed by many overthrusts and the transverse faults, that influencing the location of landslide prone areas. According to PGI's archivements, in the study area more than 70 landslides are known, most of which increased the activity in 2010. Many of landslides cause damages of big economic importance. Almost periodically for decades, part of roads and buildings are being damaged and destroyed, especially during periods of snowmelt and intense rainfall. The particular increase of activity was observed in late spring and early summer of 2010 after heavy rains occurred in April and June. Residents together with local authorities reported damages caused on over 30 landslides in the area of research. Most of these landslides are very active (i.e. causing damages and contain visible deformations, cracks etc.) but their sizes are diverse. There are both small, translational landslides and large, complex, rock and shallow landslides covering the entire slopes.

An example of LiDAR data interpretation were developed for landslide in Zbyszyce, which is the largest (138 ha) in the study area (Fig. 5). Moreover, Zbyszyce landslide has been studied by the authors since 2004 and due to many in-situ data from the instruments (piezometers, inclinometers, rain gauges) appears to be the perfect proving ground to test the LiDAR data. Zbyszyce landslide has diversified activity, a very varied morphology, and very large number of inner elements. The land cover of landslide area is variable, containing agricultural and forestry areas with scattered urbanization.

Landslide in Zbyszyce (Fig. 5) is classified as a complex type with many progress stages. Its depth reaches at least 30 m. The landslide area has a variable slope of the ground surface fluctuating in range 8° - 40°. Slopes steeper than 15° are typical for about 60 % of the landslide area (Wojciechowski, 2007).

Maximum height of the landslide is 295 m and it covers almost entire northern slope of Dabrowska Hill (581 m a.s.l). The activity of the landslide is manifested by damage to the buildings and road infrastructure. In 2006 about 65 buildings were damaged and 30 roads with a total length of 1200 m were destroyed. In 2010, further damages were reported. Figure 6 shows a fragment of the landslide near the petrol station. The dynamics of landslides shown in Figure 6 is causing a direct hazard to the petrol station infrastructure.

4. RESULTS

Using method described in chapter 2 comprehensive analyses, evaluation and interpretation of the terrain forms on LiDAR DTM were performed. As first extend of Zbyszyce landslide was determined (Fig. 7). As it was mentioned above the work has been done by visual interpretation of various views of DTM data including anaglyph, shaded relief, and slope and aspect maps. The landslide extent was digitized as the vector polygon by tracing such elements like the main scarp, side scarps and toe. The mentioned methods allowed determining also the minor scarps, and transverse ridges of the landslide and areas of very hilly, undulate surface, suspected as the areas of increased sliding activity (Fig. 8). Moreover, such forms were easily detectable even in wooded areas of LiDAR DTM and therefore the precise determination of their extents was possible.

The Zbyszyce landslide extent line is very complex. The upper limit of the landslide is composed by number of retrogressive main scarps of individual slides. The colluviums of these slides in the lower part are joined into one large landslide toe. The upper limit of the landslide is running close to the crest of northern part of Dabrowska Hill. The scarps are currently developed very close and in the southern part above the main road no. 975. In southern part of the landslide the road no. 975 is frequently damaged causing traffic problems for citizens. The Zbyszyce landslide toe limit is located below the water level of Roznow lake. In the coastal part of the lake the colluviums are partially buried and/or overlapped with alluvial sediments. Many secondary minor scarps are developed there due to water erosion causing slope instabilities.

Comparison of landslide range determined from the ALS DTM with a sketch map obtained from field mapping (Fig. 7) shows that in both cases the mapped landslide extents are very similar. The small differences are mainly caused by landslide activity, which causes landslide boundary expansion in its upper parts since field mapping was completed in 2004.

Zones of detached rocky material which is deposited as the active landslide tongue, are very clearly visible on the ALS DTM (Fig. 7). High numbers of small-scale hilly forms present on the surface of tongues proof its activity. As the result of this observation is seems to be possible to accurately determine fresh slides together with transport direction of colluvium sediment. This is of particular importance in inaccessible areas and overgrown with vegetation, which often masks the surface deformations. Figure 8 shows a fragment of landslide along the provincial road No. 975. In the central part there is a square with the petrol station (Figs. 6, 8). Every year the main scarp advances towards the road and petrol station installations. ALS data presents situation of April 2010 which document presence of an active landslide zone directly below the station. Fresh deformations of colluvium surface are clearly visible (Fig. 8). Here it should be noted that the lower part of this area is in the forest. The determination of this zone in the field would be probably less accurate and certainly more difficult.

According to SOPO instruction (Grabowski et al 2008) the mapping geologist is obligated not only to map the outlines of the landslide with its internal structure and activity but also to perform basic morphological measurements (morphometry). The measurements are later stored in a record of digital database related to the landslide. Morphometric measurements can be easily performed directly on high resolution ALS DEM (Fig. 9).

5. DISCUSSION

ALS DTM is commonly used for landslide detection, mapping of landslide extent and its main elements (see Jaboyedoff et al., 2010). However, in our case of very high resolution data it was possible to observe landslide morphology in much greater detail (Fig. 8). The Zbyszyce landslide main scarp has been mapped significantly more detailed (Figs. 3 and 4) than it was available during field mapping. However, it should be highlighted that the quality of the mapping depends directly on quality of LiDAR data and data filtering.

According to obtained results we confirmed that landslide mapping based on ALS DTM meets the requirements of SOPO instruction in a case of mapping and also morphometry. However the field verification is necessary to properly classify landslide morphology and discriminate them from processing errors and man-made structures. It should be highlighted that despite of absolute accuracy of ALS data, the relative precision and accuracy are extremely high and allow to detect even few centimeter structures. Based on author's experience the landslide forms up to 50 cm diameter should be mapped. Smaller forms does not have any practical importance and are usually masked or mixed with vegetation. ASL DTM does not allow to determine geological setting of the landslide, type of material, tectonics and hydrology of the landslide. Moreover, not all damages to the infrastructure are detectable. Such data must be collected in the field anyway however, the time spent in the field could be reduced significantly.

The costs of ALS data acquisition are extremely high at the moment. However this technique becomes more popular and more areas are acquired on governmental level. The costs of field work for landslide mapping is also very high and for complex areas it could be comparable with ALS data acquisition, processing and interpretation and the time required to complete the maps is considerably shorter.

6. CONCLUSIONS AND FUTURE WORK

Preliminary results presented in this work show the first stage of an ongoing research carried out on landslides in Roznow Lake vicinity. In this first stage LiDAR data were acquired using modern laser scanning system. Then, acquired point cloud was filtered using the active surfaces model method to obtain detailed and precise DTM. The resulted DTM proved to be a reliable and valuable product for landslides mapping and interpretation. Particularly, the detailed interpretation of such precise DTM allows for:

- landslides extent identification, especially in difficult areas e.g. forestry areas,
- identification of internal landslides forms,
- determination of landslide activity,
- measurement of basic morphometric parameters.

Finally it can be concluded that the LiDAR DTM appears to be a significant support for geological interpretation and landslide detection especially on steep and forested slopes. It can be recommended to use it for the purposes of landslide mapping within SOPO project.

Further studies will be focused on potentials of using the ALS technique for the landslides dynamics monitoring. To perform that, the second ALS data acquisition campaign is planned.

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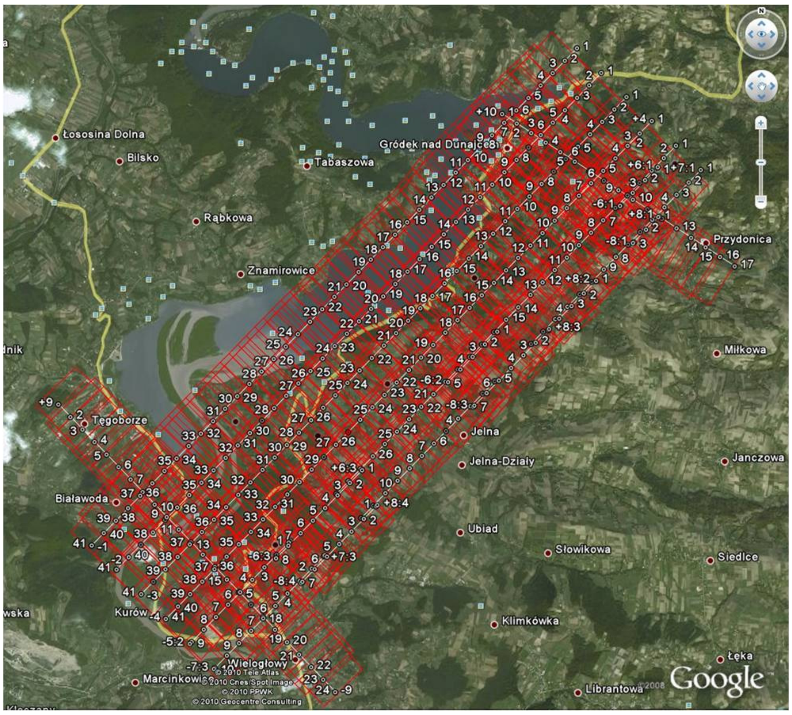

Fig. 2 Study area with the plan of aerial photography (red lines) mission and scanning strips (white lines).

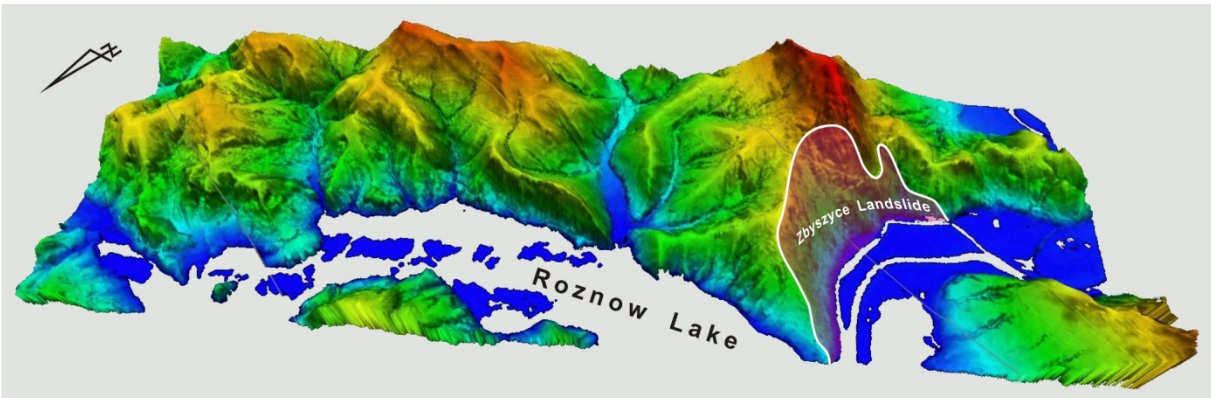

Fig. 5 DTM of the study area calculated from ALS data filtered with the active surfaces model

Fig. 6 Zbyszyce landslide in the direct neighborhood of the petrol station (Fig. 8).

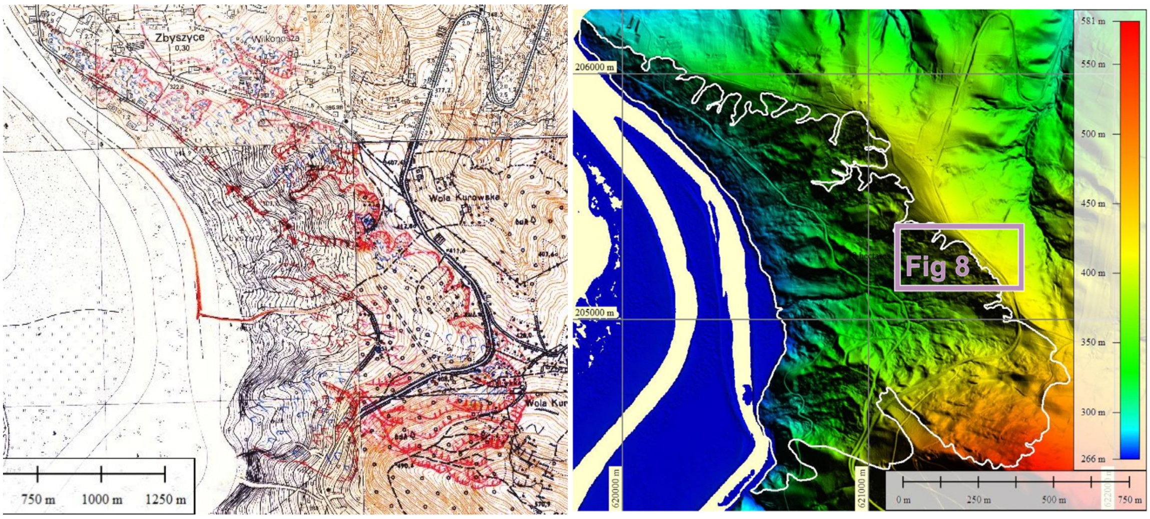

Fig. 7 Extension of the landslide in Zbyszyce. Field mapping in 2004 (left) and mapping on the 0.5m LiDAR-DTM (right).

Fig. 8 Landslide activity determined using LiDAR-DTM.

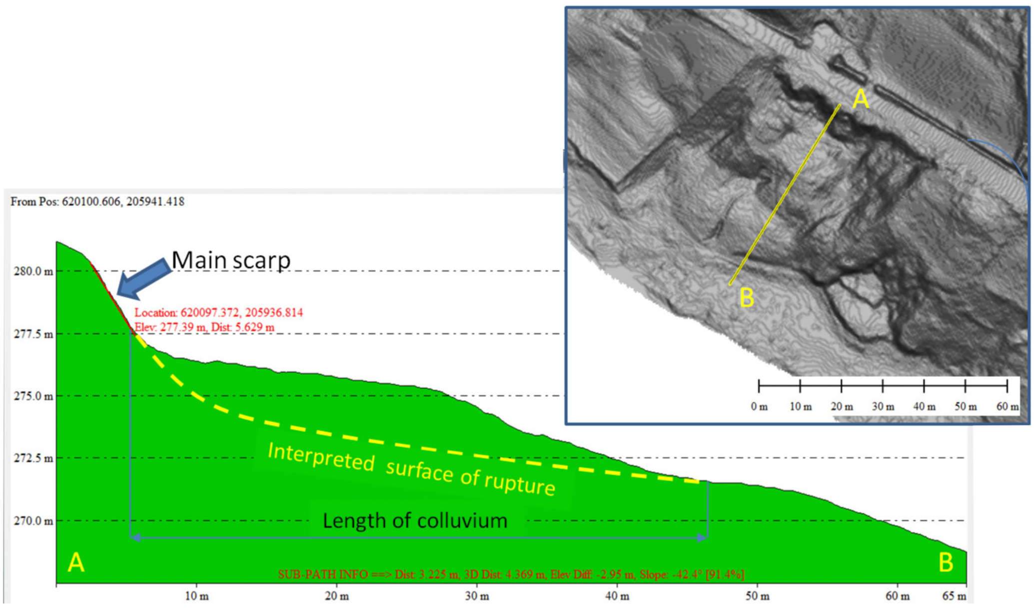

Fig. 9 Example of basic morphometric measurements performed on the profile of local slide within Zbyszyce landslide. Global Mapper profile tool allow interactively measure length, elevation difference and slope angle of selected element.