Analysis of land use in landslide affected areas along the Łososina Dolna Commune, the Outer Carpathians, Poland

Paweł Kroh
Institute of Geography, Pedagogical University of Krakow, Krakow, Poland

ABSTRACT
Land use of landslides is still a poorly investigated problem. Landslides cannot be regarded as areas unsuitable for use since they occupy a significantly large surface. The Łososina Dolna municipality in the Outer Carpathians is characterized by a very large number of landslides (16% of the total area, about 500 landslides). Land-cover analysis of this agricultural and forest municipality showed a relatively similar structure of land-cover types on areas affected and unaffected by landslides. Six categories of land cover: forest, woodland, agricultural fields, meadows, orchards and built-up areas occupy in total 98% of landslides and 89% of the municipality. On landslides forests had an 11% higher and agricultural fields a 3% lower share in land cover compared to the whole municipality area. The shares of other types of land cover, such as built-up areas, orchards, and shrubs, were very similar, with not more than a 1% difference. This indicates that despite the occurrence of landslides, these areas can still be used for economic purposes, and on sites under extensive management (e.g. meadows and pastures) landslides may cause no land-use changes.

1. Introduction
The relationships between the occurrence of landslides and human activity are numerous and mutual. The impact of landslides in Polish Carpathians on the infrastructure (e.g. Mrozek et al. 2004; Rączkowski 2007; Kaczmarczyk et al. 2012) and environment (Alexandrowicz & Margielewski 2010; Alexandrowicz et al. 2003; Żaburski et al. 2009; Gorczyca 2010) is the subject of many publications. The effects of land-use changes on the occurrence of landslides have also been repeatedly investigated (Leventhal & Kotze 2008; Turkelboom et al. 2008; Mugagga et al. 2012; Tasser et al. 2003; Promper et al. 2014). Alimohammadlou et al. (2013) proposed a classification method for damage caused by landslides, and pointed out the large scale of this problem. It should be noted, however, that because of the very high number of landslides it is impossible to abandon land affected by mass movements from use, and analyses focusing on the contemporary use of landslides are still relatively scarce.

The occurrence of landslides in the Carpathians, especially in their flysch part, is quite common. As part of the SOPO Project, approximately 60,000 objects have been inventoried in the Polish part of the mountains. The geological structure causes the landslides to be likely enough that they often occupy over 50% of slope surface (Alexandrowicz et al. 2003). In some regions over 70% of area could be susceptible for landsliding (Sandric et al. 2011). Systematic studies of landslides in the Western Carpathians have been conducted since the 1920s (Ondrášik 2002). The high risk of
landslides, the relatively good degree of their identification and the development of GIS technology are the reasons why a number of susceptibility studies are conducted within this area. The use of various models proved their high effectiveness in predicting landslides, amounting to 79% in the Low Beskid Mountains in Poland (Mrozek et al. 2004) or 87.1% in the Czech Republic (Klimeš & Novotný 2011). The lack of proper land-use planning may result in as many as 90% of buildings in urban areas being located within high and medium susceptibility zones (Mihai et al. 2014, Chitu et al 2015). The damage caused by landslides in Poland during June–July 2010 is estimated at 2.9 billion euro (Mrozek & Laskowicz 2014).

The landslide risk reduction strategy focuses on two objectives – recovery and mitigation (Mrozek & Laskowicz 2014). The susceptibility study is an inseparable part of the 'mitigation' aspect. On the other hand, the recovery programmes are naturally focused on the infrastructure being in danger of landslides. Identifying the effects of the presence of landslides on agricultural economy or other forms of spatial management may be as significant for land-use planning as local actions aimed at the protection of infrastructure.

The investigation of the problems of developing landslide areas, among which are almost the entire Outer Western Carpathians, should focus on two aspects. One of them is the mapping of landslides, the determination of risk or susceptibility to their occurrence, or generally speaking – an attempt at avoiding the risk of landslides. Another direction of research is answering the question: 'how to develop areas where contemporary landslides are already present?' The introduction to solving that problem is an analysis of the land cover of landslides occurring today.

Differences between the use of landslides and other municipal areas have therefore become an interesting research problem. The aim of our study was to identify the structure of the land cover of landslides in the municipality, and to compare it to the land-cover types in the whole municipality. The results of such an analysis may show how landslides affect the use of land. Another important aspect of the study was conducting a methodological attempt at analysing the land cover of landslides based on the data belonging to the state, publicly available for all levels of administration responsible for spatial planning.

2. Study area

Landslides are a common process in the Flysch Carpathians. Because of the dominant geological structure facilitating mass movements, the problem of landslides affects most municipalities located in the Polish Carpathians. More than 50,000 landslides have been recorded in the Polish Carpathians, of which 13% included in their area elements of infrastructure (buildings, roads, transmission lines) (Marciniec & Zimmel 2015).

The Łososina Dolna municipality is located in the Outer Carpathians (Figure 1). The terrain of the Beskidy part mainly has features of low- and medium-high mountains and medium-high foothills (Starkel 1972). Predominant slope gradients are in the range of 10°–35°, and the relative elevations are from 300 to 340 m in the montane part, and from 140 to 180 m in the sub-montane part (Gorczyca et al. 2013). Most of the municipality area is occupied by agricultural land (42%), while forests account for 34% of the total area (Kroh et al. 2014). The landslide density ratio (the number of landslides in the given area to land area) is eight landslides per km². The highest incidence of landslides has been reported for the area adjacent to Rożnów Lake (Gorczyca & Wrońska-Wałach 2011). Field mapping during SOPO Landslide Counteraction Framework Project has shown 572 landslides. This included 298 fully active landslides, 69 partially active landslides and 205 inactive landslides. More than half of documented landslides were small in area – 325 had an area less than 1 ha, 185 had an area of 1-5 ha, 33 had an area of 5-10 ha and 29 had an area more than 10 ha. Large inactive landslides were usually found in Beskid Wyspowy part of commune: in woodland areas, on upper slope segments and in cones of depression. The area most prone to landslide activity is directly adjacent to Rożnów Lake. The mean size of analyzed landslides is 2.3 ha, and the maximum size is 45 ha (Gorczyca et al. 2013).
Following Varnes classification after an update (Hungr et al. 2014) all landslides have slide type of movement in the montane part (Beskid Wyspowy Mts); they are in type no. 6 – rock rotational slide. On the Wielickie Foothills landslides are on types 11, 12 and 14 – clay/silt rotational, planar and compound slides.

3. Methods

The general flowchart presenting the used methodology is shown in Figure 2. Airborne laser scanning and DEMs generated based on point clouds or aerial photos have been used many times before. Particular progress in these techniques has been made in the last decade (Ardizzone et al. 2007; Van den Eeckhaut et al. 2007; Fell et al. 2008; Scandic & Chitu 2011; Bell et al. 2012; Jaboyedoff et al. 2012; Razak et al. 2013; Sailer et al. 2014; Tarolli 2014; Ciampalini et al. 2016), and they have become one of the basic tools for large-scale landslide investigations. Because of the high susceptibility to landslides and the diversity of land forms the vicinity of the study area has become a Polish testing ground for the use of LIDAR in mapping landslides (Wojciechowski et al. 2012; Borkowski et al. 2011; Perski et al. 2014; and others).

The study was carried out using two sources of data. The first source was the Topographic Objects Database (Baza danych obiektów topograficznych, BDOT10k), from which information on the land cover was acquired. The second source was vector data-sets on landslides occurring in the municipality (Figure 2). The *.shp layer with the boundaries of landslides was created by the vector transformation of digital elevation model (DEM). The surface model was created from a LIDAR point cloud, density of 4 points/m² (Table 1) and verified by independent body (Wężyk 2014). The point cloud from laser scanning was acquired from the Central Documentation Centre of Geodesy and Cartography, from a data-set prepared under the ISOK project (http://www.isok.gov.pl/en/). The point cloud for the ‘ground’ category was used to generate a DEM, with a spatial resolution of 0.5 m using the ArcGIS LasTools toolbox (Esri). Shaded relief images were generated in four light direction variants (light angle 45°, 135°, 225° and 315°) to improve the clarity of the surface model. Landslide areas were charted and analysed using ArcGIS 10.2.1 software. Landslides were surveyed by focusing on relief features such as outstanding concave and convex landforms, both increases and decreases in slope gradient, shape of slope meso-forms, fractures, and other non-anthropogenic linear elements. Based on DEM 489 landslides have been mapped (Figure 1). Field verification of landslide mapping was conducted for the whole studied area. A comparison of the results of mapping performed in the field and based on the terrain model performed for the whole area of the municipality indicated high effectiveness of mapping which is based on numerical terrain model,
resulting in surface conformity with field mapping amounting to 86% (Kroh et al. 2014). The considerable difference in the number of landslides resulted primarily from the different approach to larger objects, which were divided into smaller landslides by field surveyors, while the surveyor working with the terrain model merged them into larger objects. An analysis of the effectiveness of landslide mapping based on the model was conducted for the whole area; nonetheless, it is a very complex issue which requires a separate paper (Kroh et al. 2016).

Information on land cover was acquired from the Topographic Objects Database (BDOT10K). This database is a public official database of topographic objects with a level of detail corresponding to standard topographic maps on a scale of 1:10,000. The BDOT10k database is created based on a vectorized digital orthophotomap, direct measurements, historic data and other registers kept by public institutions. The database was prepared in 2012–2013 following technical guidance laid down in the regulation of the Minister of Internal Affairs and Administration of 17 November 2011. Regulation requirements appoint geometrical accuracy of coordinates under 1 cm, and angle

![Figure 2. Research data sources and method phases.](image)

| Table 1. Parameters of airborne laser scanning in ISOK project (Wężyk 2014). |
|---------------------------------|------------------|--------------------------|--------------------------|-----------------------------|-----------------------------|
| Laser points density | Transversal scan angle | Laser points elevation accuracy after the alignment | Laser points situation accuracy after the alignment | Registration of multiple reflections | Date of scanner raids |
| 4 point.m⁻² | ≤ ±25° | ≤0.15 m | ≤0.50 m | Minimum 4 echos | From mid-October to late April |
For ‘land-cover’ class minimum area of one object is 1000 m² (Regulation 2011). The BDOT10k database consists of the following layers: (1) network of watercourses, (2) network of roads and railways, (3) network of public utility lines, (4) land cover, (5) buildings and installations, (6) land-use complexes, (7) protected areas, (8) administrative units, (9) other objects. The ‘land-cover’ category was used for the presented analysis (Figure 3).

Definitions of all 19 codes of land cover found in the study area are presented in Table 2. Objects in the BDOT10k public database are organized in a three-level coding system. The first level of classification has a two-letter designation corresponding to an abbreviated name of the category of objects. The second level has a four-letter designation that combines the abbreviation of the first category and the abbreviation of the category of object classes. This level of database in our paper is specified as a type of land cover. The third level has a four- and two-digit designation indicating the category of individual objects. Because in this article we used data only from one layer designated as PT (in Polish Pokrycie Terenu), this abbreviation was omitted in codes. For example, LZ01 for forest and TR02 for agricultural field used in the paper correspond to codes PTLZ02 and PTTR02 in the BDOT10k database. Codes being abbreviations from the Polish language were retained in the paper to enable readers to make a comparison to the whole BDOT10k database. Detailed definitions of individual codes (Table 3) were presented for the six most frequently found categories, which occupy in total 98% of the landslide area and 89% of the municipality area.

Figure 3. Three fragments of commune with landslides and land-cover classes.
The land cover of the municipality and the land cover of landslides were analysed in a two-stage process. ArcMap 10.2.1 software was used in the first stage. Analyses for the whole municipality area and landslides were performed in parallel. To obtain information on the land cover of landslides, a separate .shp layer was created by extracting a common part for the landslide layer and ‘land-cover’ layer using the intersect function. Next, the calculate geometry function was used to quantify the area of individual polygons in the municipality and landslide layers. Areas obtained in this process and the whole table of attributes was exported to an MS Excel spreadsheet. Database sorting and filtering, as well as summing records having individual codes were used to analyse the share of individual classes of land cover.

4. Results

4.1. Land cover of the municipality area

The structure of land use for the municipality area and landslides located in the municipality were similar. Table 4 and Figure 4 present areas of individual types of land use for landslides and the municipality. In Table 5 there are specific categories presented. The largest area in the municipality was occupied by agricultural fields (TR, 41%), where meadows and pastures (TR01) covered about...
25% of the municipality area, and agricultural fields (TR02) 17%. Other major types of land use were forested and wooded areas (LZ), which occupied over 33% (forests LZ01 32%, woodland/bush 1%), and permanent crops (UT, orchards UT03), which occupied 9%. Built-up areas (ZB) occupied 6.4% of the municipality, where single-family houses (ZB02) had a significant 5% share. The Lososina

| Land-cover types | Area | | | | | | |
|------------------|------|------|------|------|------|------|------|
|                  | Landslides (m²) | Commune (m²) | Landslides (%) | Commune (%) | Landslides (%) | Commune (%) | Landslides (%) | Commune (%) |
| LZ               | 6,017,783 | 28,475,952 | 44.84 | 33.63 | 44.86 | 36.41 |
| TR               | 5,158,635 | 35,168,390 | 38.44 | 41.54 | 38.46 | 44.97 |
| UT               | 1,355,178 | 7,720,273 | 10.10 | 9.12 | 10.10 | 9.87 |
| ZB               | 795,680 | 5,419,134 | 5.93 | 6.40 | 5.93 | 6.93 |
| RK               | 64,165 | 968,127 | 0.48 | 1.14 | 0.48 | 1.24 |
| KM               | 14,755 | 171,404 | 0.11 | 0.20 | 0.11 | 0.22 |
| WP               | 5620 | 6,463,540 | 0.04 | 7.63 | 0.04 | 0.27 |
| PL               | 5190 | 207,926 | 0.04 | 0.25 | 0.04 | 0.07 |
| NZ               | 2274 | 57,217 | 0.02 | 0.07 | 0.02 | 0.07 |
| GN               | 14,755 | 171,404 | 0.11 | 0.20 | 0.11 | 0.22 |
| Σ                | 13,419,281 | 84,667,615 | 100 | 100 | 100 | 100 |

Figure 4. Comparison of land-cover types in areas affected and unaffected by landslide in Lososina Dolna Commune. Inside ring represents landslides and outside ring represents areas unaffected by landslides.
Dolna municipality is located by a reservoir (Roźnów Lake, Jezioro Roźnowskie), and therefore surface water (WP) also represents a significant part of its area, i.e. more than 7%. Other types of land use accounted for a small percentage of the municipality.

4.2. Land cover of landslides

Three types of land cover accounted for 93% of landslides: forested areas (45%), agricultural fields (38%) and permanent crops (10%). Another 6% was made up by all categories of built-up land.

The analysis of the individual categories of land cover demonstrated the clear dominance of forests (LZ01), which occupied 43% of the landslide area (LZ02 – 2%, LZ03 – 0.02%). Meadows and pastures (TR01) occupied 30% and orchards (UT03) 10% of landslides. Other important categories of the land cover of landslides were agricultural fields (TR02 – 9%) and single-family houses (ZB02 – 5%).

4.3. Land cover of landslides vs. land cover of the municipality

The largest difference between the land cover of landslides and the land cover of the municipality was found in the share of forested areas. On landslides, the LZ type of land cover (including forests, woodlands and trees) occupied over 11% more area compared to the municipality. Forests (LZ01) alone, without trees and woodlands, occupied 10% more landslides than on the municipality area. Agricultural fields occupied 3% more of the municipality area compared to landslides. The shares of other types of land cover differed by no more than 1%.

Sandy or gravelly areas (GN03) classified under wasteland were not found on landslides, but occupied 0.02% of the municipality. No multi-family buildings were found on landslides, but this type of land cover accounted for 0.02% of the municipality.

The nature of the data results in a limited range of the statistical analysis which can be performed. Table 5 presents the cardinalities of the individual categories of objects. The presented figures indicate the numbers of polygons which are assigned to the specified categories of land use present within the area of the municipality and the area of the landslides. The statistical analysis involved

| Land-cover categories | Area | Land cover | Land cover without ‘WP03’ category | No. of objects (polygons) |
|-----------------------|------|------------|-----------------------------------|--------------------------|
|                       | Landslides (m²) | Commune (m²) | Landslides (%) | Commune (%) | Landslides (%) | Commune (%) | No. of Landslides | No. of comm. |
| LZ01                  | 5,748,606 | 27,336,191 | 42.84 | 32.29 | 42.86 | 34.61 | 638 | 397 |
| TR01                  | 4,001,289 | 21,006,755 | 29.82 | 24.81 | 29.83 | 26.59 | 645 | 951 |
| UT03                  | 1,354,103 | 7,677,703 | 10.09 | 9.07 | 10.09 | 9.72 | 238 | 375 |
| TR02                  | 1,157,346 | 14,161,635 | 8.62 | 16.73 | 8.63 | 17.93 | 415 | 1013 |
| ZB02                  | 658,518 | 4,642,938 | 4.91 | 5.48 | 4.91 | 5.88 | 510 | 1726 |
| LZ02                  | 266,961 | 915,211 | 1.99 | 1.08 | 1.99 | 1.16 | 95 | 143 |
| ZB05                  | 133,796 | 583,641 | 1.00 | 0.69 | 1.00 | 0.74 | 82 | 272 |
| RK02                  | 64,165 | 968,127 | 0.48 | 1.14 | 0.48 | 1.23 | 30 | 57 |
| KM01                  | 14,755 | 171,404 | 0.11 | 0.20 | 0.11 | 0.22 | 6 | 3 |
| WP03                  | 5,505 | 5,678,435 | 0.04 | 6.71 | 0.04 | 0.26 | 7 | 86 |
| PL01                  | 5190 | 207,926 | 0.04 | 0.25 | 0.04 | 0.26 | 3 | 34 |
| ZB03                  | 2280 | 107,053 | 0.02 | 0.13 | 0.02 | 0.14 | 2 | 22 |
| NZ01                  | 2274 | 57,217 | 0.02 | 0.07 | 0.02 | 0.07 | 2 | 12 |
| LZ03                  | 2216 | 224,550 | 0.02 | 0.27 | 0.02 | 0.28 | 1 | 7 |
| ZB04                  | 1086 | 68,512 | 0.01 | 0.08 | 0.01 | 0.09 | 2 | 8 |
| UT02                  | 1075 | 42,570 | 0.01 | 0.05 | 0.01 | 0.05 | 1 | 7 |
| WP02                  | 115 | 785,105 | 0.00 | 0.93 | 0.00 | 0.99 | 2 | 8 |
| GN03                  | 15,652 | 0.00 | 0.02 | 0.00 | 0.02 | 0 | 3 |
| ZB01                  | 16,990 | 0.00 | 0.02 | 0.00 | 0.02 | 0 | 4 |
| Σ                      | 13,419,280 | 84,667,615 | 100 | 100 | 100 | 100 | 870 |
only those categories of land use whose cardinality was greater than or equal to 30. There were eight such categories (LZ01, LZ02, TR01, TR02, UT03, ZB02, ZB05, RK02). The basic statistical indicators (the mean, the median, the maximum and minimum values, the standard deviation) are presented in Table 6.

The chi-squared test of independence is a standard statistical test used to examine the relationship between two nominal variables. Therefore, it was used to examine the dependence of land cover on the occurrence of landslides. Surface values were analysed for individual land-use categories present within the landslides (X) and outside of them (Y). The tested null hypothesis stated that ‘the X and Y variables are interdependent’; the alternative hypothesis stated that ‘the X and Y variables are independent’. This means that the statistical relationship between land cover within the landslides and in the municipality indicates that the presence of landslides does not cause any changes in land use.

The actual and theoretical values were calculated for eight land-use categories. Based on an analysis of the chi-squared test, a structural conformity test was conducted along with a dependence test. In both tests the statistical value amounted to 0. According to the chi-squared distribution table, the critical value indicating the dependence of the individual sets with 7 degrees of freedom amounts to 18.475 for a significance level of 0.01. Both tests thus indicate that the null hypothesis should be adopted. It stated that the sets of land cover in the municipality and land cover within the landslides are interdependent. This means that they are independent of the occurrence of landslides. Therefore, the result indicated that land use is not statistically dependent upon the presence of landslides in the municipality of Łososina Dolna.

5. Discussion

The study revealed a high concordance of land-use types between landslides and the whole municipality. This may be attributed to three factors. The first one is a very high landslide ratio in Łososina Dolna municipality. Because of the presence of nearly 500 landslides in the municipality (Figure 1) and the high geological susceptibility of most of its area to this type of mass movement, landslides can be considered random events. Therefore, landslides randomly affect different types of used land in the same proportion as in the whole municipality area.

The second factor is the ownership structure. Most of the land in the municipality is owned by private individuals and used for economic purposes. Owners, even if a landslide has occurred, will be determined to continue the use of their land. The occurrence of landslides, in many cases, does not prevent the use of land for agricultural purposes or for permanent crops, such as orchards.

The third factor hindering the interpretation of results is the age of the source materials. Layers of the land use used in this study were updated in mid-2013. Some of the analysed landslides were formed during a landslide disaster in July 2010. Because of the relatively short time elapsing between the formation of some landslides and the generation of the land-use data layer, the type of land use could change on some sites, but it was not recorded on the orthophotomaps used as a benchmark for the creation of the BDOT database. One possible example of this is an abandoned meadow,
which in three years had not overgrown enough to be classified as woodland, although it is no longer used as a meadow. In a few-year perspective, the update of the BDOT database could reveal interesting facts about the land-cover changes resulting from landslides, but at this point such new data are unavailable.

A greater share of forested areas on landslides can have two reasons. First, historical deforestation to create new agricultural land was done on slopes with lower inclinations, while steeper slopes covered by forests were unaffected due to their lower suitability for cultivation. The rockslide hazard, on the other hand, is higher in areas with greater inclinations because of the higher potential energy of the slope. The second reason for the greater share of forested areas on landslides is also associated with the history of land use. The active landslides (formed before 2010) after the creation of niches and the transformation of land relief could have become useless for agriculture. Therefore, cultivation on these sites was abandoned, and forests developed instead.

A clear difference in land use between landslides and the area of the municipality is seen with respect to the category of ‘surface water’, which occupies 6.7% of the municipality area, as a part of Rożnów Lake is located there. For obvious reasons, landslides will not occur in this region of the municipality. However, some landslide areas are under land cover classified as ‘surface water’. This is due to the fact that Lake Rożnów is an artificial reservoir, with a fluctuating water level. During

Figure 5. Comparison of land-cover types in areas affected and unaffected by landslide in Łososina Dolna commune without ‘water’ (WP) land-cover type. Inside ring represents landslides and outside ring represents areas unaffected by landslides.
airborne LIDAR scanning based on which DEM was prepared, the water level was probably below its highest possible level. Therefore, the point cloud and DEM for the area of the municipality also include fragments of land classified under the ‘surface water’ category (WP03).

The comparison of landslides and the municipality in terms of land use, and with consideration of surface water does not reflect the actual relationship. This is because landslides (even those under the water level) are not expected to occur in the area of the reservoir. Thus, the category of surface water should not be considered when comparing land-cover types. For this reason, the WP type of land cover and WP02 category were omitted in the comparison (Table 4). This had a minor effect on the land cover of landslides because surface water occupied only 0.04% of their area. Nevertheless, statistics of land cover changed for the municipality, i.e. the share of forested areas increased by 3%, and that of agricultural fields by 3%. Shares of other types of land cover increased by 1%.

Land cover defined as ‘built-up areas’ (ZB) and its specific categories (ZB02, ZB03, ZB05) are noteworthy here. Built-up areas occupy about 5% of both landslides and the municipality (Tables 4, 5 and Figures 3–5). Of note is that the category of built-up areas does not refer to the actual surface under buildings but the whole area of building plots (Table 3). The scale on which the landslides negatively affect built-up areas in the municipality is also important. 14% of all built-up areas are located on landslides, which accounts for 6% of the total municipality area. The vast majority of buildings are still in use. However, buildings damaged by landslides or abandoned are still under the ZB class of use. In the database a derelict building is still classified as a building. Because of this the database is not a useful source of information for the analysis of changes in built-up areas.

The development of regional and national databases for landslides (Mrozek et al. 2014; Jäger et al. forthcoming; Damm & Klosse 2015; Komac & Hribernik 2015) and digital topographic databases open great possibilities for research and land-use planning. The analysis of potential uses for landslide areas is a chance for developing relevant planning recommendations that would enable their optimal utilization in economic and environmental terms.

6. Conclusions

Land-use planning should eliminate landslides from their use for development. Not all types of landslides necessitate changes in land-use types. Landslides present within the research area, meaning rock/clay/silt rotational, planar or compound slides, eliminate the areas from possible development, but they do not inflict changes in the character of agricultural or silvicultural management within these areas. Therefore, it can be concluded that landslides does not necessarily disrupt the economic activities of a municipality that relies on agriculture and forestry, or cause significant damage and costs for local people. Even mass movements reaching the scale of a landslide disaster, may not have a significant impact on the structure of land use in a specific area.

The presented study shows that areas where landslides have occurred do not have to be lost to the local community. In many cases, despite the occurrence of landslides, the affected areas can still be used for economic purposes, and on sites under extensive management (e.g. meadows and pastures) landslides may cause no land-use changes.

Acknowledgments

I would like to thank two anonymous reviewers for their work and attention given on this paper. I have got many deep and critical comments that helped in getting this article much better and will help me also in next research. I would like to thank also Dr. L. Pawlik and Dr. S. Dorocki for help with statistical interpretation.

Disclosure statement

No potential conflict of interest was reported by the author.
References

Alexandrowicz Z, Margielewski W. 2010. Impact of mass movements on geo- and biodiversity in the Polish Outer Flysch Carpathians Geomorphol. 123:290–304. doi: 10.1016/j.geomorph.2010.07.020

Alexandrowicz Z, Margielewski W, Perzanowska J. 2003. European Ecological network Natura 2000 in relation to landslide areas diversity: a case study in the Polish Carpathians. Ekologia (Bratislava). 22:404–422.

Allmohammadlou Y, Najafi A, Yalcin A. 2013. Landslide process and impacts: A proposed classification method. Catena. 104:219–232. Available from: http://dx.doi.org/10.1016/j.catena.2012.11.013

Ardizzone F, Cardinali M, Galli M, Guzzetti F, Reichenbach P. 2007. Identification and mapping of recent rainfall-induced landslides using elevation data collected by airborne Lidar. Nat Hazards Earth Syst Sci. 7:637–650.

Bell R, Petchko H, Röhrs M, Dix A. 2012. Assessment of landslide age, persistence and human impact using airborne laser scanning digital terrain models. Geograﬁska Annaler: A, Phys Geography. 94:135–156. doi: 10.1111/j.1468-0459.2012.00454.x

Borkowski A, Perski Z, Wojciechowski T, Józêków G, Wójcik A. 2011. Landslides mapping in Rožnów Lake vicinity, Poland, using airborne laser scanning data. Acta Geodyn Geomater. 8:325–333

Chiţu Z, Istrate A, Adler MJ, Sandric I, Olario B, Mihai B. 2015. Comparative study of the methods for assessing landslide susceptibility in Ialomiţa Subcarpathians, Romania. Eng Geol Soc Territory. 2:1205–1209.

Ciampilini A, Rasperi F, Frodella W, Bardi F, Bianchini S, Moretti S. 2016. The effectiveness of high-resolution LiDAR data combined with PSInSAR data in landslide study. Landslides. 13(2):399–410. doi: 10.1007/s10346-010-0663-5

Damm B, Kloese M. 2015. The landslide database for Germany: closing the gap at national level. Geomorphology. 249:82–93. Available from: http://dx.doi.org/10.1016/j.geomorph.2015.03.021

Esri. ArcGIS for Desktop Basic 10.2.1. License for Institute of Geography. Pedagogical University of Cracow.

Fell R, Corominas J, Bonnard C, Cascini L, Leroi E, Savage WZ, on behalf of the JTC-1 Joint Technical Committee on Landslides and Engineered Slopes. 2008. Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning. Eng Geol. 102:99–111. doi: 10.1016/j.enggeo.2008.03.014

Gorczyca E. 2010. Slope relaxation following landslides in the Lososina River Basin, Beskid Wyspowy Mts. Poland Landform Anal. 14:3–11

Gorczyca E, Wrońska-Wałach D. 2011. Explanatory notes on maps of landslides and areas at risk of mass movements. Warszawa: Municipality of Lososina Dolna, Polish Geological Institute, 1–47. Polish.

Gorczyca E, Wrońska-Wałach D, Długosz M. 2013. Landslide hazards in the Polish Flysch Carpathians. Example of Lososina Dolna Commune. In: Loczy D, editor. Geomorphological impacts of extreme weather. Springer Geograﬁ. Netherlands: Springer; p. 237–250.

Hunger O, Leroueil S, Picarelli L. 2014. The Varnes classiﬁcation of landslides types, an update. Landslides. 11:167–194. doi: 10.10007/s10346-013-0436-y; [cited 2016 Jan 15] Available from: http://www.isok.gov.pl/en/.

Jaboyedoff M, Oppikofer T, A, Derron M-H, Loeve A, Metzger R, Pedrazzini A. 2012. Use of LIDAR in landslide investigations: a review. Nat Hazards. 61:5–28. doi: 10.1007/s11069-010-9634-2

Jäger D, Kreuzer T, Wilde M, Bemn S, Terhorst B. forthcoming. A spatial database for landslides in northern Bavaria: a methodological approach. Geomorphology. Available from: http://dx.doi.org/10.1016/j.geomorph.2015.10.008

Kaczmarczyk R, Tchórzewska S, Woźniak H. 2012. Charakterystyka wybranych osuwisk z terenu Polski południowej uaktywnionych po okresie intensywnych opadów w 2010 r [Characteristic of selected landslides in south Poland reactivated after heavy rainfall period in 2010]. Nowoczesne Budownictwo Inżynieryjne Lipiec – Sierpień. 2012:74–77.

Klímes J, Novotný R. 2011. Landslide susceptibility assessment in urbanized areas: example from flysch Carpathians, Czech Republic. Acta Geodyn Geomater. 8:443–452.

Komac M, Hribernik K. 2015. Slovenian national landslide database as a basis for statistical assessment of landslide phenomena in Slovenia. Geomorphology. 249:94–102. Available from: http://dx.doi.org/10.1016/j.geomorph.2015.02.005

Kroh P, Struś P, Gorczyca E, Wrońska-Wałach D, Długosz M. 2014. Identiﬁcation of landslides in Lososina Dolna Commune based on spatial data from airborne laser scanning. Prob Landscape Ecol, T. XXXVIII: 54–63. Polish.

Kroh P, Struś P, Wronska-Wałach D, Gorczyca E, Długosz M. 2016. Identiﬁcation of landslides on the commune scale based on spatial data from airborne laser scanning, Lososina Dolna Commune. Polish flysch Carpathians. in review.

Leventhal AR, Kotze GP. 2008. Landslide susceptibility and hazard mapping in Australia for land-use planning – with reference to challenges in metropolitan suburbia. Eng Geol. 102:238–250. doi: 10.1016/j.enggeo.2008.03.021

Marciniec P, Zimmel Z. 2015. Map of landslides and areas at risk of mass movements (MOTZ) and landslide inventory forms (KRO) as a source of information on landslides. In: OISWISKO Polish Conference, 19–22 May 2015, Wieliczka, Warszawa: Polish Geological Institute, p. 47–48. Polish.

Mihai, B, Săvulescu, I, Sandric, I, Chiţu, Z. 2014. Integration of landslide susceptibility assessment in urban development: a case study in Predeal town, Romanian Carpathians. Area. 46:377–388. doi: 10.1111/area.12123.

Mrozek T, Kulak M, Grabowski D, Wójcik A. 2014. Landslide counteracting system (SOPO): inventory database of landslides in Poland. In: Sassa K, Canuti P, Yin Y, editors. Landslide science for a safer geoenvironment. Springer International Publishing; p. 815–820. doi: 10.1007/978-3-319-05050-8_126
Mrozek T, Laskowicz I. 2014. Landslide risk reduction in Poland: from landslide inventory to improved mitigation and land use practice in endangered areas. In: Sassa K et al., editors. Landslide science for a safer geoenvironment, Vol. 2. Switzerland: Springer International Publishing; p. 765–771, doi: 10.1007/978-3-319-05050-8_118

Mrozek T, Poli S, Sterlacchini S, Zabuski L. 2004. Landslide susceptibility assessment: a case study from Beskid Niski Mts., Carpathians, Poland. Proceedings of the Conference "Risks caused by the geodynamic phenomena in Europe". Polish Geol Inst Special Papers; 15:13–18.

Mugagga F, Kakembo V, Buyinza M. 2012. Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. Catena. 90:39–46, doi: 10.1016/j.catena.2011.11.004

Ondrašik R. 2002. Landslides in West Carpathians. In: Stemberk Rybár, Wagner, Landslides. Lisse: Swets & Zeitlinger; p. 45–57.

Perski Z, Wojciechowski T, Wójcik A, Borkowski A. 2014. Monitoring of landslide dynamics with LIDAR, SAR interferometry and photogrammetry. Case study of Kłodne landslide. Southern Poland. Proceedings of World Landslide Forum 3, 2–6 June 2014, Beijing.

Promper C, Puisant A, Malet J-P, Glade T. 2014. Analysis of land cover changes in the past and the future as contribution to landslide risk scenarios. Appl Geography. 53:11–19. Available from: http://dx.doi.org/10.1016/j.apgeog.2014.05.020

Razak KA, Santangelo M, Van Westen CJ, Santangelo M, Van Westen CJ, Straatsma MW, de Jong SM. 2013. Generating an optimal DTM from airborne laser scanning data for landslide mapping in a tropical forest environment. Geomorphology. 190:112–125. Available from: http://dx.doi.org/10.1016/j.geomorph.2013.02.021

Rączkowski W. 2007. Landslide hazard in the Polish Flysch Carpathians. Studia Geomorphol Carpatho-Balcanica. XLI (2007):61–75.

Regulation of the Minister of Internal Affairs and Administration of 17 November 2011. On the topographic objects database and database of geographic objects as well as standard cartographic studies. Dz. U. 279, item 1642. [cited 20.12.2016]. Available from: http://www.dziennikustaw.gov.pl/DU/2011/1642/1

Sailer R, Rutzinger M, Lorenzo R, Wichmann V. 2014. Digital elevation models derived from airborne laser scanning point clouds: appropriate spatial resolutions for multi-temporal characterization and quantification of geomorphological processes. Earth Surf Process Landforms. 39:272–284. doi: 10.1002/esp.3490

Sandric I, Chiștiu Z. 2011. Landslide inventory for the administrative area of Breaza town, Curvature Subcarpathians. Romania J Maps. 5(1):75–86. doi: 10.4113/jom.2009.1051.

Sandric I, Chiștiu Z, Mihai B, Săvulescu I. 2011. Landslide Susceptibility for the Administrative Area of Breaza, Prahova County, Curvature Subcarpathians. România J Maps. 7:552–563. Available from: http://dx.doi.org/10.4113/jom.2011.1168

Starkel L. 1972. Characterisation of land relief in the Polish Carpathians. and its role in human economic activity. Prob Zapospodarowania Ziem Górskich. 10:57–150. Polish.

Tarolli P. 2014. High-resolution topography for understanding Earth surface processes: opportunities and challenges. Geophys J R Astron Soc. 216:295–312, doi: 10.1061/j.geomorph.2014.03.008

Tasser E, Mader M, Tappeiner U. 2003. Effects of land use in alpine grasslands on the probability of landslides. Basic Appl Ecol. 4:271–280.

Turkelboom F, Poesen J, Trébuil G. 2008. The multiple land degradation effects caused by land-use intensification in tropical steeplands: A catchment study from northern Thailand. Catena. 75:102–116. doi: 10.1016/j.catena.2008.04.012

Van den Eeckhaut M, Poesen J, Verstraeten G, Vanacker V, Nyssen J, Moeyersons J, van Beek PH, Vandekerckhove L. 2007. Use of LiDAR-derived images for mapping old landslides under forest. Earth Surf Process Landforms. 32:754–769 doi: 10.1002/esp.1417

Wężyk P. 2014. Podręcznik dla uczestników szkoleń z wykorzystania produktów LiDAR [Manual for the participants of training from LiDAR products]. Warszawa: Główny Urząd Geodezji i Kartografii.

Wojciechowski T, Borkowski A, Perski Z, Wójcik A. 2012. Data from airborne laser scanning in research on landslides – a case of landslide in Zbyszyce. Outer Carpathians. Przegląd Geol. 60:95–102. Polish.

Zabuski L, Wójcik A, Gil E, Mrozek T, Raczkowski W. 2009. Landslide processes in a flysch massif – case study of the Kawiory landslide, Beskid Niski Mts. (Carpathians, Poland). Geol Quart. 53(3):317–332.