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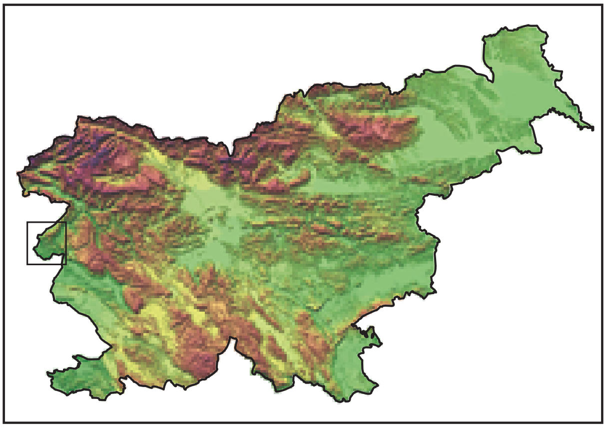
PROBABILITY MODELLING OF LANDSLIDE HAZARD

PROBABILISTIČNO MODELIRANJE PLAZOVITOSTI

Matija Zorn, Blaž Komac

The Goriška brda hills are one of the most cultivated Slovene regions.
Goriška brda so ena od najintenzivnejše obdelanih slovenskih pokrajin.



Probability modelling of landslide hazard

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ABSTRACT: In this journal, the authors (Zorn, Komac 2004) previously described the use of two deterministic methods for establishing the possibility of landsliding. This time, they take a step forward and using the example of the flysch Goriška Brda hills present the probability modelling of landslide hazard. In probability methods, the intensity and distribution of the processes are established by comparing indirectly determined landscape elements and the actual situation, while in deterministic methods, subjective decisions have an impact on the result. Authors have elaborated a probability map for landslides with a fixed return period using the Dempster-Shafer method on the basis of the data on 800 landslides that occurred with intensive precipitation in the fall of 1998.

KEYWORDS: geomorphology, natural disasters, landslides, risk maps, Dempster-Shafer algorithm, Goriška brda hills, Slovenia

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Contents

1 Introduction

Goriška Brda is a range of hilly ridges spreading like fingers in western Slovenia that covers 140 km^2 between the valleys of the Idrija river region to the east and the Soča River to the west with altitudes from 300 to 800 meters. The ridges are mostly sedimentary flysch rocks composed of layers of sandstone, marlstone, slate claystone, and limestone or calcarenite ranging from a few centimeters up to half a meter thick. The flysch rocks in Goriška Brda is divided into the Early Paleocene Kožbana layers with several carbonate elements dominant in the north and the younger Lower Eocene Medana layers with a higher content of clay elements found more frequently in the south (Pavlovec 1974, 146). The border between these types of flysch runs west to east from Bela past Krasno and Vrhovlje toward Podsenica and Podsabatin.

The two types of flysch rocks differ distinctly. The Kožbana layers originated from the sediments of large undersea landslides. Since the material was deposited quickly on the sea floor, the rocks are irregularly mixed and distributed. The flysch also contains rocks that the landslide scooped and tore from the slopes so conglomerate and breccia, for example, appear frequently. The Medana layers originated in a calmer sea sediment environment with the help of muddy turbidit currents. Layers of sandstone and marlstone alternate in the rock (Arčon 2004, 17–31).

That landslides are to be expected on the flysch rock of Goriška Brda can be surmised from the origin of the word »flysch«, since the original German word (*fliessen*) denotes a rock that »flows« (Pavlovec 1977, 213). The composition of this rock is the basic reason for the dissected relief and the vulnerability to landslides of this area. Flysch is poorly resistant to weathering, decomposing into fine weathered debris that can become mobile if certain other conditions are met.

Flysch also presents a landslide hazard due to its permeability and ability to retain moisture. A second, equally important cause of landsliding is the hilly relief with steep slopes.

The most important cause for landsliding is abundant or intensive precipitation that causes the groundwater to rise and burden the slope. Here too, the relief or the formation of the earth's surface plays a large role since the majority of landslides are triggered on steep concave slopes where water flows combine. Human activities play an important role as well: landslides and landslips frequently occur on intensely cultivated surfaces such as vineyards and along roads.

2 Intensive precipitation and landslides

With intensive precipitation, landsliding occurs due to strong fluctuation of the pore pressure and its increase in the surface layers of weathered debris. Increased pore pressure decreases intergranular forces along the existing landsliding plane, which increases the possibility of landsliding. The occurrence of landslides is therefore not necessarily directly related to the level of the water table. The initial water content in the ground plays an important triggering role because it lowers the necessary marginal quantity limit of precipitation (Govi, Sorzana 1980, 52; Komac 2005a, 264, 275). Komac (2005, 276) hypothesizes that the average annual precipitation does not directly influence landsliding, or only in combination with intensive short-term precipitation. Govi and Sorzana (1980, 59) observe, however, that on the same lithology with similar relief, the thresholds for the triggering of landslides change primarily due to the annual precipitation. Still, even the same precipitation in different areas with the same lithology and relief causes different instabilities.

A general curve for determining the limit value of precipitation or the threshold where landsliding occurs due to intensive precipitation is described by Caine's equation (1980, 23).

The border amount of precipitation that affects landslides in Slovenia is 100–150 mm in 24 hours or 130–180 mm in 48 hours (Komac 2005a, 275–276). The size class, i. e. the intensity of precipitation about 150 mm/24 hours, corresponds with the data from elsewhere. Limit values differ relative to lithostratigraphic units (Komac 2005a, 264, 277).

In Slovenia, we have often witnessed the triggering of numerous landslides during intense precipitation, most recently in August 2005 and in the spring of 2006 in eastern or southeastern Slovenia. The border quantity amounts of precipitation were 130–180 mm in 48 hours while the existing moisture in the ground lowered the triggering quantity of precipitation (Komac 2005a, 275).

The landslips or minor landslides that occurred during intensive precipitation in the summer of 1989 in the Haloze hills (Natek 1990; Natek 1996) and in the Lahomnica and Kozarica valleys east of Laško

(Gabrovec 1990; Gabrovec, Brečko 1990; Fazarinc, Pintar 1991; Fazarinc, Mikoš 1992) were studied in more detail. Both areas are interesting for comparison with Goriška Brda because both the Lahomnica and Kozarica valleys and the Haloze region have predominantly marl bedrock.

On August 19, 1989, on the approximately 20 km^2 area covering the watersheds of the Lahomnica and the Kozarica rivers, about 130–140 mm of precipitation fell in about two hours, in certain places even more than 400 mm. The intensity exceeded the centennial return period (Fazarinc, Pintar 1991, 12; Fazarinc, Mikoš 1992, 378, 381). Landslips were triggered even during the thunderstorm and their density was similar to that in the Haloze region after the July 1989 thunderstorm, but the affected area was smaller (Gabrovec 1990, 181; Gabrovec, Brečko 1990, 16). In the valley of the Loški potok stream in the Lahomnica watershed, the density was 36 landslips per km^2 (Gabrovec 1990, 184).

In the Haloze region, 150–200 mm of precipitation fell in 24 hours between July 3 and 4, 1989. In Žetale, 106 mm of precipitation was measured, just under three quarters of the monthly average. Such precipitation events have an approximately 25-year return period. On 106 km^2, about 5,000 landslips were triggered, an average of 47 landslips per km^2. Considering farmland only, the density was 120 landslips per km^2 (Natek 1990, 11; Natek 1996, 142). Tortonian marlstone/marl dominates in the area, and marly sandstone occurs to a lesser degree (Natek 1990).

In the Lahomnica watershed, the linkages between landslips and individual landscape elements were studied using geographic information systems in the early 1990's. In the Lahomnica watershed, landslips occurred only on three of the 16 lithostratigraphic units. This indicates a link with the lithology, particularly since larger inclinations frequently occur on the other types of rock as well. The most landslips were triggered on the so-called »Laško« marlstone/marl that covers 7% of the area, which is interesting for studying Goriška Brda given the similarity of its lithology. Landslips also occurred on 2% of the surface area with »Govec layers« (sand, sandstone with marl), named after a settlement west of Laško, as well as in the narrow belt of lithothamnian limestone (Gabrovec 1990, 181–182; Gabrovec, Brečko 1990, 16).

In the Lahomnica watershed, the linkage between landslips and inclination (we considered only inclinations on the affected rock) »… *is obvious but not very strong* …« Landsliding is clearly influenced by other relief elements in addition to inclination (Hrvatin, Perko 2002). We therefore included horizontal surface curvature in the landslide model for Goriška Brda. Most landslips in the Lahomnica watershed were triggered in small gable valleys and at the lower edges of cultivated fields. Most landslips were triggered at inclinations of 10°–14°, 15°–19°, and 20°–24° and occurred on about one quarter of the area in these inclination classes. One tenth of the area with an inclination of 25°–29° and a good 7% of the area with an inclination of 5°–9° (Gabrovec 1990, 182; Gabrovec, Brečko 1990, 17) were affected. In the Haloze region, almost 90% of the landslips were triggered at inclinations of 19–36°: 9.3% of the landslips were triggered at an inclination of 19–24°, 36% at an inclination of 25–30°, and 44.3% at an inclination of 31–36° (Natek 1990, 12). A good 9% of the landslips occurred at inclinations greater than 36°. Altogether, almost 99% of the landslips occurred at inclinations larger than 25°. Only 1.1% of the landslips occurred in the 13°–18° inclination class. Relative to relief forms, as much as 43.8% of the landslips occurred on the middle steepest parts of slopes, 0.7% on the upper convex parts the slopes, 7.8% on the lower concave parts of slopes, 29.1% at gable valley ends, and 1.3% on the upper part of ravines (Natek 1990, 12; Natek 1996, 144, 147–148).

In the valley of the Loški potok stream in the Lahomnica watershed, the average inclination at the upper edge of the landslips was 35°. The upper edge was usually located just below a bend in the slope where the inclination was substantially greater than the average inclination of the slope. On the lower edge of the landslip, the inclination was at least 10° to 15° lower. In the analysis, a relatively coarse 100 × 100-meter digital elevation model was used in which the inclination was calculated for entire hectare cells (10,000 m^2), so the calculated inclinations were even lower. The average inclination of the cells where landslips occurred was therefore barely 18° (Gabrovec 1990, 185). For southern Goriška Brda, we used a 12.5 × 12.5-meter digital elevation model (cell size 156.25 m^2).

In the Lahomnica River watershed, most landslips were triggered in orchards and on meadows. Natek (1990, 13) found a similar situation for the 1989 thunderstorm in the Haloze region where some 70.5% of the landslips were triggered on meadows and pastures and in orchards. In the Lahomnica River watersheds and in the Haloze region, the landslip density was also large on cultivated fields, mostly at their lower edges (Natek 1990, 14). There were substantially fewer landslips in the forest of the Lahomnica watershed, and they occurred at higher inclinations (average inclination of 23°) than the landslips on cultivated surfaces (14° on fields, 18° in orchards) (Gabrovec 1990, 183; Gabrovec, Brečko 1990, 19; Fazarinc, Mikoš 1992, 384–385).

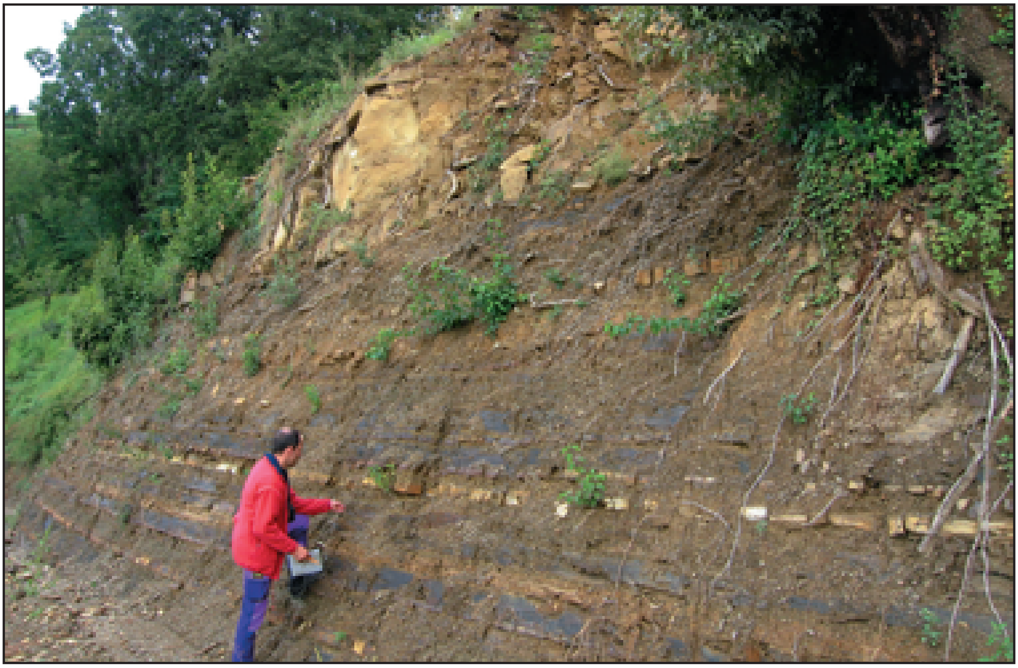

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Figure 1: Flysch in southern Goriška Brda.

In the Haloze region, just under 16% of the landslips were triggered in vineyards and just under 5% each on cultivated fields and in orchards. Some 5.6% of the landslips occurred in forests, and 5.2% on terraced vineyards, although the author notes that in terraced vineyards, »*… relative to the small coverage, very many landslips were triggered …*«, most of which were small (Natek 1990, 13).

In the municipalities of Pesnica, Slovenska Bistrica, and Ptuj, more than two hundred landslides were triggered during intensive precipitation between November 14 and 25, 1991. In Maribor, 162.3 mm fell, which greatly exceeds the November average of 92.8 mm. On farm land, most landslides occurred on meadows and in vineyards. In half of the local communities of the Pesnica municipality, the proportion of landslides in vineyards relative to all agricultural surface areas exceeded 50%, while in the Slovenska Bistrica municipality, the same proportion applied for the entire municipality. The primary reason for landsliding in vineyards was the overly steep banks of terraces and lower edges of the vineyards (Žiberna 1992, 12–13).

3 Landsliding in Goriška Brda

Landslides cause major damage to property in Goriška Brda. In vineyards on steep slopes, farmers must constantly repair their terraces, and in places the repairs take several weeks every year. Farmers often prevent the landsliding by draining and diverting the water to lower sites through pipes or channels (Komac, Zorn 2006a, 57; Komac, Zorn 2007).

It is characteristic that »*… smaller landslides actually occur throughout Brda, especially in the middle part where there are marls and steep embankments …*«, and that in the southwestern part »*… it is mostly just the shallow weathered debris that slides … Deep landslides most frequently occur near the bottoms of valleys where they are not so dangerous to agriculture. There are a few landslides in almost every larger valley. The envisaged irrigation dikes may also trigger landslides on the slopes due to the fluctuation of water … Unfavourable positions of layers of marly clays and clayey marls on all southwestern slopes are also a substantial cause for landslides, if they contain seeps or springs of water …*« (Grimšičar 1962, 8–9).

The latest geological sources also identify the landslide hazard to slopes in Goriška Brda. Ocepek (2002) observed that the flysch under the vineyard south-southeast of Dobrovo Castle is covered by

Figure 2: Bulging stone walls lining road cuts due to landsliding.

Figure 3: Stone walls require constant maintenance due to landsliding.

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Figure 4: Stone walls collapse when they can no longer hold back the landsliding.

a 1–2.5 meter thick layer of weathered debris that on the lower part of the slope reaches 3.5 meters deep and shows signs of sliding. Sliding is most visible on the »embankment,« which is »bulging in places«. The bulging of the stone embankments lining road cuts can be seen throughout Goriška Brda (Figure 2 and 3).

Landslide or »… *slide of regolith on the marly surface* …« occurs when water table rises for few centimetres if the regolith depth is more than 4 m and it occurs when water table rises for 30 cm if regolith depth is 1 m (Petkovšek, Klopčič, Maček 2007, 18).

3.1 Landslides in the fall of 1998

In the fall of 1998, precipitation in Goriška Brda was abundant. On September 6, as much as 114 mm of precipitation fell, and on September 13, 100 mm. Both precipitation events reached the five-year return period level. On October 6 of the same year, as much as 175 mm of precipitation fell in a 24-hour period. This means that the precipitation reached the fifty-year return period level. In the period between September 28 and October 13, 433 mm of precipitation fell, an average of 31 mm per day.

On the previously saturated bedrock, the intensive precipitation at the beginning of October triggered numerous landslides that occurred frequently in southern Goriška Brda especially. Due to the spatially limited data on landslides and the fact that northern and southern Goriška Brda differ relative to geological composition, we were only able to elaborate a landslide hazard probability map for southern Goriška Brda. There were more than 800 landslides alone that affected farming land and caused property damage in southern Goriška Brda. In this 41.32 km^2 area, landslides covered 1.7% of the surface.

Vineyards were the most affected, and forests and meadows to a lesser degree. Cultivated fields, which are mostly located on flat areas, were the least affected. The majority of landslides occurred in vineyards, which cover about 40% of the surface area of Goriška Brda and more than 60% of the slide areas. This is linked to the fact that the vineyards are often located on steep terraced slopes. About 10% of the landslides

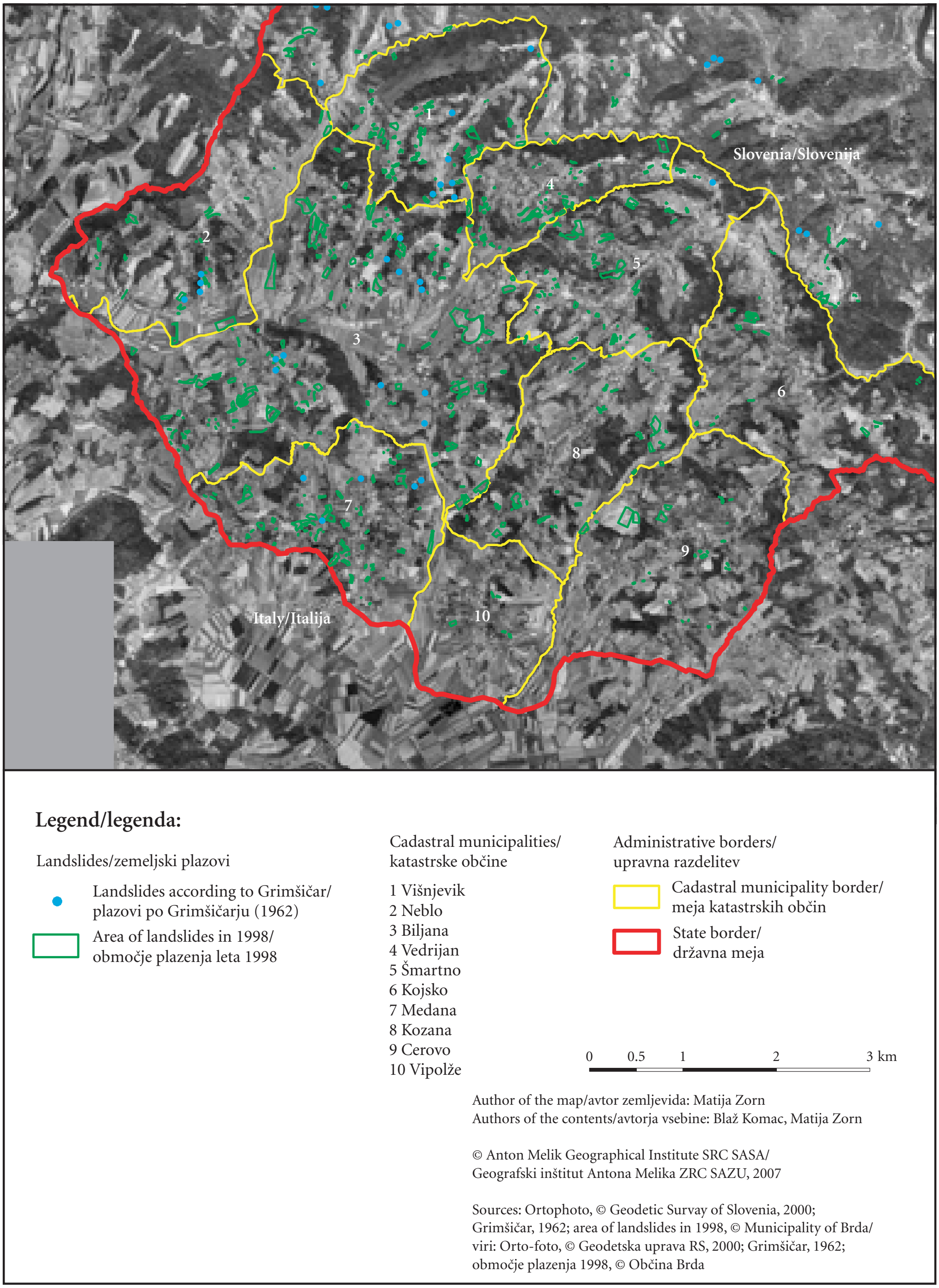

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Figure 5: October 1998 landslide area and landslides according to Grimšičar (1962).

occurred in the forests that cover a third of the Goriška Brda area. Less than 10% of landslide hazard areas are covered by meadows, and about 20% each by cultivated fields and orchards. Landslides occurred on about 3% of the built-up areas, which include infrastructure such as roads.

4 Methodology of landslide hazard map elaboration

Maps of geomorphic processes are one of the preventive measures in the fight against natural disasters.

We elaborated a landslide hazard map for the Goriška Brda hills using the Dempster-Shafer algorithm (Dempster 1968; Shafer 1990) similar to the work of Binaghi et al. (1998), or Gorsevski, Jankowski, and Gessler (2005) and Damm and Varga (2006). The work involves comparing the significance of individual landslide factors based on field work data. We elaborate a partial map for each factor showing where there is a larger or smaller probability of landsliding in the studied area.

Among the preconditions (Zorn, Komac 2002, 11–12) that influence landsliding, we considered eight factors in the model used to calculate the landslide hazard: lithological composition, surface inclination, horizontal curvature of the surface, dip of strata, a stream power index, an index of soil saturation, maximum 24-hour precipitation, and land use. The data on the landslides that occurred in 1998 was provided by the Municipality of Brda. The calculations were performed using Idrisi 3.2 and TAS 2.0.7 (Lindsay 2002) software.

The algorithm compares the factors in every hierarchically possible way and calculates the values in landslide hazard areas for each factor considered. These values are adopted as a criterion and considered as areas where there is a greater possibility for the occurrence of landslides. We must then establish the limit values where landsliding occurs for each factor and enter them into the computer. Thus, for example, in establishing the limit value for inclination, we discovered that landsliding does not occur below a certain value (6°) or above a certain value (20°).

The analysis works according to the Dempster-Shafer algorithm, described by the following rule:

$$\mathrm{m(Z)} = \frac{\sum m_1(X)\cdot m_2(Y); X\cap Y = Z}{1-\sum m_1(X)\cdot m_2(Y); X\cap Y = 0},$$ where m(Z) is the basic assigned probability or the sum of support for the hypothesis (Z). If the dividend is equal to $\sum m_1(X)\cdot m_2(Y); X\cap Y = 0$, then the equation reads: $\mathrm{m(Z)} = \sum m_1(X)\cdot m_2(Y); X\cap Y = 0$.

Finally, the algorithm compares the entire study area with the established criterion and establishes similarities or differences between individual areas, the cells of the digital elevation model. The final result is a map that shows the probability of landslide occurrence from the viewpoint of the used bases according to the conditions that existed when the entered landslides occurred.

Areas ultimately defined as landslide hazard areas are those that relative to the highest possible number of considered parameters most resemble areas where landslides have already occurred so the quality of the data entered on actual landslides is very important.

The landsliding probability is presented with values between 0 and 1. A value of 1 means that landsliding can occur at places where the precipitation has an approximately fifty-year return period. The landsliding probability is actually lower because it is also influenced by other factors than just intensive precipitation of short duration that can be the cause of landsliding (Zorn, Komac 2002, 11). In the interpretation of the map, all such factors must be considered. The map indicates that certain areas have larger or smaller probabilities for landsliding to occur in given conditions (e. g., precipitation with a fifty-year return period level).

A landslide hazard map is an assessment of the actual situation acquired by modelling. Its reliability depends on the quality of the applied cartographical foundation and of the method employed. To a certain extent, the assessment is also a probability measure that tells us that the probability exists for the occurrence of an event in a certain area. An accurate understanding of the natural processes enables the identification of threatened areas in the landscape and the direction of settlement and human activities to safer areas (Komac, Zorn 2002a).

The advantages of such a map or the method used to elaborate it include:

- being based on a sufficiently large number of concrete data (N = 800) on natural phenomena or landslips and landslides that have occurred along with known external circumstances (quantity of precipitation),
- being based on a relatively large amount of other entered data such as data on the lithology and relief,

- the considered landscape elements that influence landsliding are not weighted, which reduces subjectivity,
- the map is a suitable basis for further detailed field mapping.

Disadvantages of the method used include the following:

- the map is a model, and a model can only partially simulate natural processes,
- the map was elaborated using only one (time) set of data on landslips and landslides from the past,
- the data on landslips and landslides was provided to the Municipality of Brda by the farmers at the request of the municipality because they were entitled to government aid depending on the amount of damage, and therefore the source material must be treated critically (the consequence, for example, can be more frequent landsliding on cultivated land, vineyards in particular, than should normally be expected).

We excluded flat areas with inclinations below 6° from the presentation, where geomorphic processes by definition are either insignificant in the formation of the surface by landslides or are not sufficiently intensive.

4.1 Landslide hazard map

On the map, landslide hazard is presented in fourteen classes with a colour scale ranging from blue (the lowest landslide hazard) through green to yellow and red (the highest landslide hazard). We defined the classes by arranging the frequency distribution of the digital landslide hazard map with the values between 0 and 1 according to the arithmetic mean. The classes include a standard deviation of 0.1 and there are 13 classes; class 14 presents the 1998 landslides. About a seventh of the phenomena in class 7 are around the mean value, a quarter are below it, and a good half of the phenomena are above it. The median class encompasses values in the 0.2 standard deviation range ($\sigma \pm 0.1$). The frequency distribution corresponds to the exponential equation $y = 8.1 \cdot 10^{-8} \cdot e^{1.61x}$.

About half of the territory in southern Goriška Brda has a landslide hazard in classes 9–14, and a third in classes 11–14. A quarter of the territory has a landslide hazard lower than class 6, and about 18% of the territory has no landslide hazard.

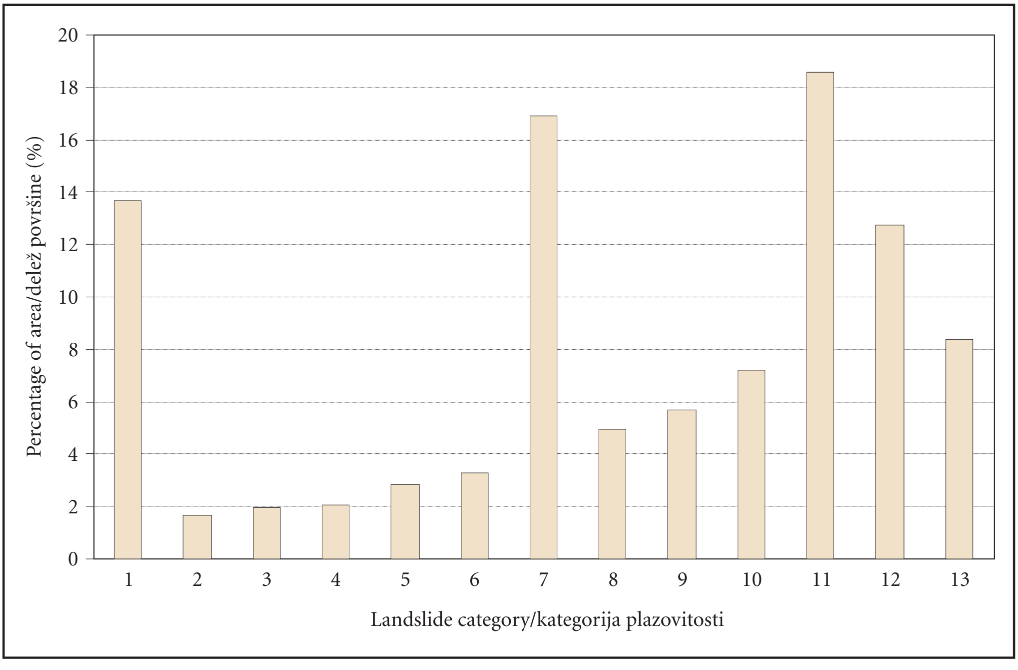

Figure 6: Frequency distribution of the landslide areas (abscise) relative to the landslide hazard (ordinate).

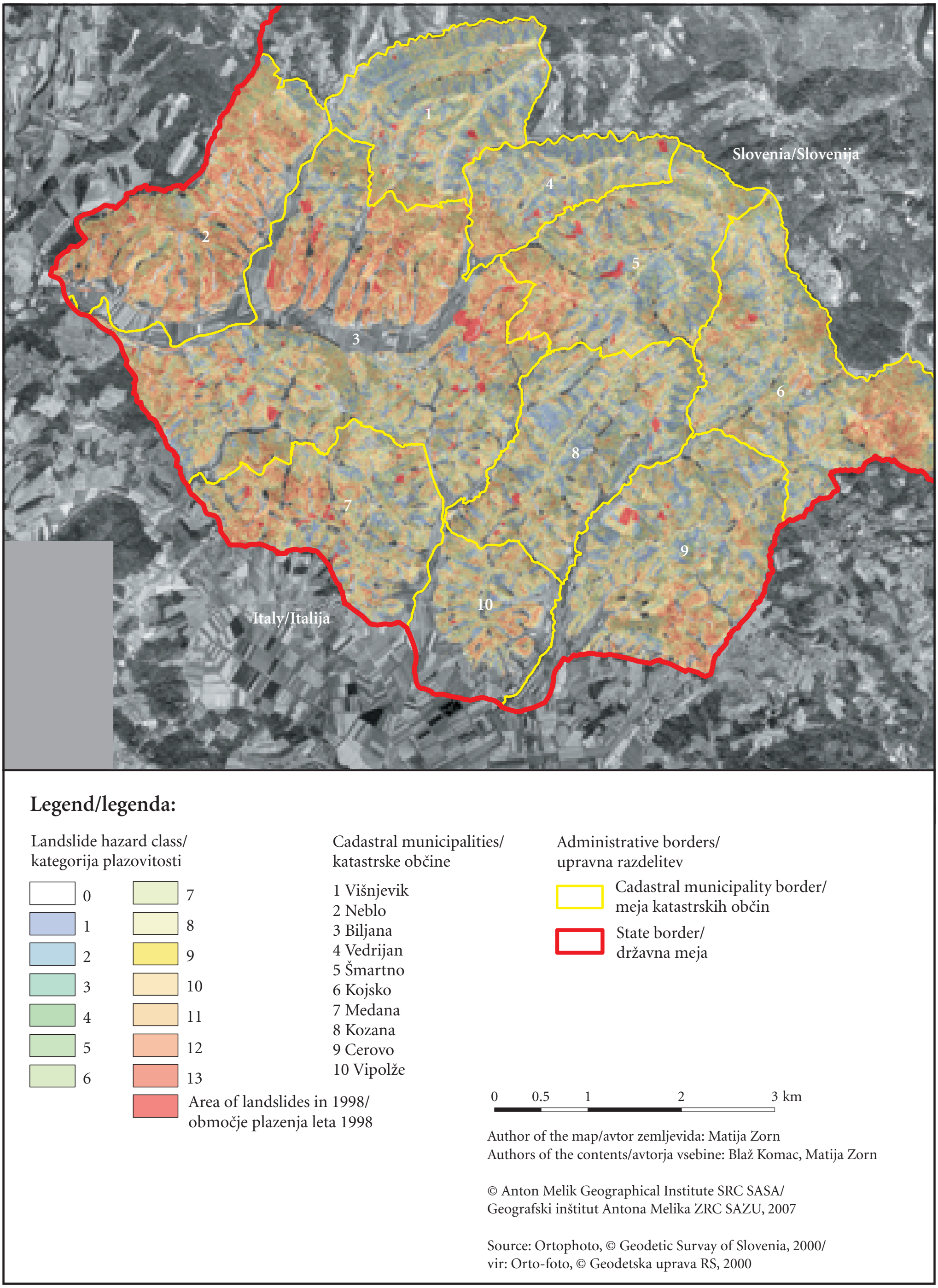

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Figure 7: Landslide hazard map of southern Goriška Brda.

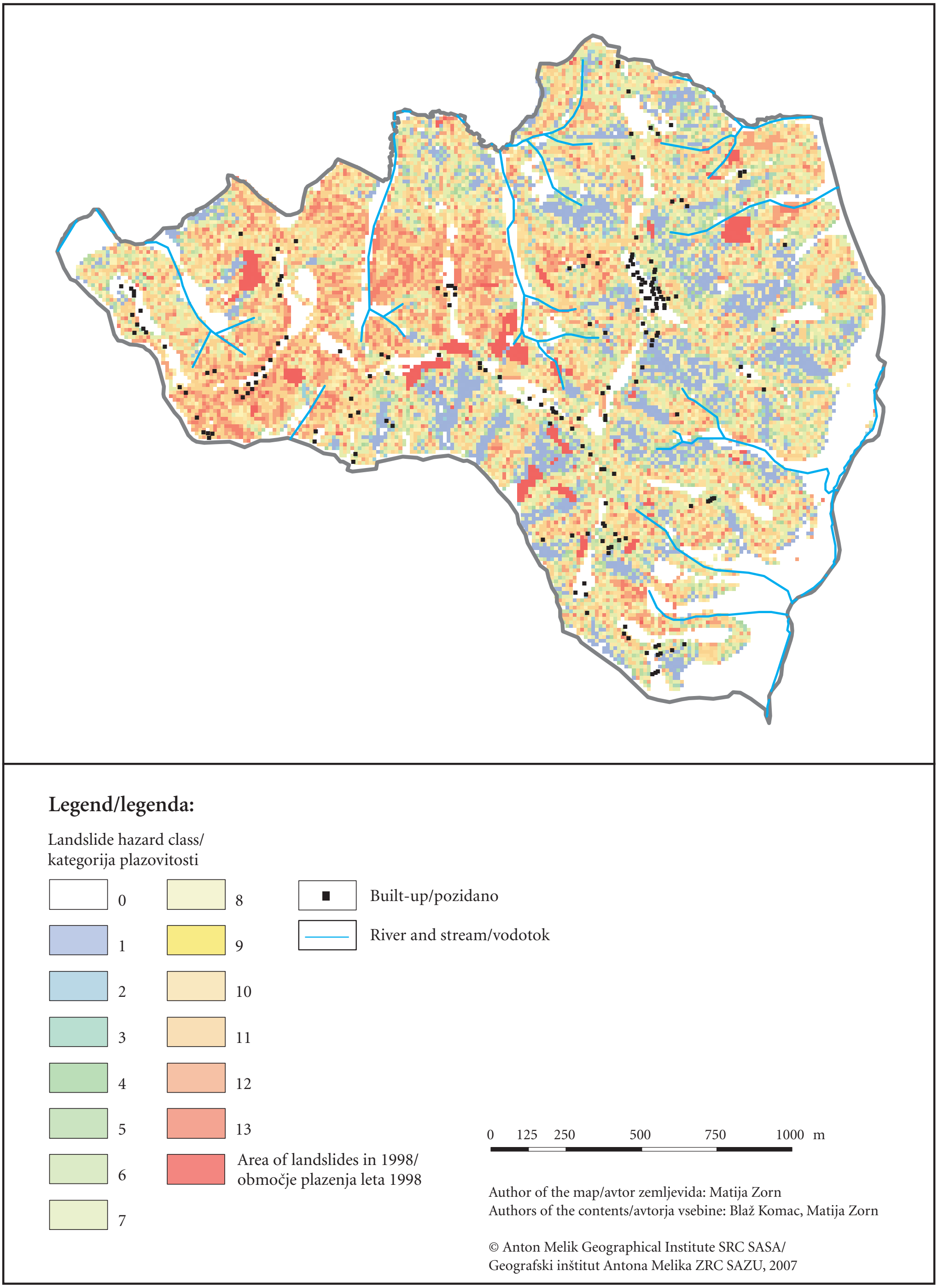

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Figure 8: Landslide hazard map of the Medana cadastral municipality. Settlement or buildings are located mostly on relatively safe ridges several dozen meters wide.

Comparing the proportion of the surface area of different types of land use in the landslide hazard areas with their proportion over the entire southern Goriška Brda, we determined that landslides occur more frequently in intensely cultivated plantations, particularly in vineyards but also in olive tree plantations and other permanent plantations. Because the proportion of vineyard areas relative to all the landslide hazard areas is larger than that for the entire southern Goriška Brda, landslides occur in vineyards more frequently than might be expected. This, of course, is the consequence of human activities and to a certain degree of natural factors as well.

In contrast, more landslides and landslips are statistically expected to occur in forests (relative to surface area) than the number of landslides that actually occurred in 1998. Similarly, more landslips and landslides are statistically expected in built-up areas (including infrastructure) and in areas with mixed land use (farm land and forest).

Table 1: Surface area and proportions of area in southern Goriška Brda (expected values) and in landslide hazard areas in southern Goriška Brda (actual values) according to land use.

Land use	Southern Goriška Brda		Landslide hazard areas in southern Goriška Brda	
	ha	%	ha	%
cultivated fields, gardens	121.67	2.94	1.84	2.63
vineyards	1,702.08	41.20	49.09	70.01
intensive orchards	218.17	5.28	3.02	4.30
extensive orchards	123.77	3.00	1.64	2.34
olive tree plantations	1.719	0.04	0.19	0.27
other plantations	0.05	0.00	0.00	0.00
extensive meadows	328.06	7.94	5.30	7.55
overgrown	57.33	1.39	0.75	1.07
mixed use	82.11	1.99	0.56	0.80
forest	1,248.38	30.22	6.88	9.80
built-up	242.36	5.87	0.86	1.23
barren	0.25	0.01	0.00	0.00
water courses	5.59	0.14	0.00	0.00

The most landslides occur in areas where the rock layers are oriented northeast, followed by southwest and northwest orientations. To identify the orientation of the rock layers, we used the 1 : 25,000-scale Strukturna karta Brd (Structural Map of Goriška Brda) elaborated by Gospodarič (1962, supplement 15).

The majority (48%) of the landslides were triggered at inclination from 12° to 20°, almost a quarter (22%) at inclinations from 6° to 12°, about a sixth (17.7%) at inclinations from 20° to 32°, and a ninth (11.6%) at inclinations below 6°. Almost by definition, landslides do not occur above 32° because the dominant geomorphic process here is falling rather than landsliding. On such steep slopes most loose material is constantly falling to lower positions, and therefore only a small number of landslides have occurred here, encompassing 0.1% of the surface of all the landslide hazard areas. The frequency distributions of inclinations in southern Goriška Brda and of the landslide hazard areas in southern Goriška Brda have a statistically significant positive connection (numerus (N) = 35, Pearson's correlation coefficient (r) = 0.99, t test = 34.6).

A quarter of the landslides and landslips occurred at inclinations below 10°, a half at inclinations below 14°, and three quarters at inclinations below 17.5°. The landslides were most frequently triggered at inclinations between 11° and 15°. Almost a tenth (9%) of the phenomena occurred at 15°, and slightly fewer at 11° and 13°. In the landslide hazard areas, inclinations of 10° to 17° are more frequent than elsewhere in southern Goriška Brda. The frequency distributions of inclinations for the landslide hazard areas and for southern Goriška Brda are very similar (correlation coefficient is 0.96, hi square is 7.6 at N = 46).

Four tenths of the landslide hazard areas are located on convex sites, 35% on linear sites (curvature equals 0), and a quarter on concave sites (Figure 10). The majority of the landslips and landslides occurred on the upper convex parts of slopes or just below them. Here, the slopes are steep enough and far enough from the ridges. Landslips and landslides increase the inclination of the slopes and also change the dominant curvature. Convex slopes are transformed into linear slopes, which prolongs the concave lower part of the slopes. The final result of this transformation is ridges with steep linear slopes that end at the floors of larger valleys or plains or continue in extensive, long, and gentle concave slopes. In Goriška Brda, there

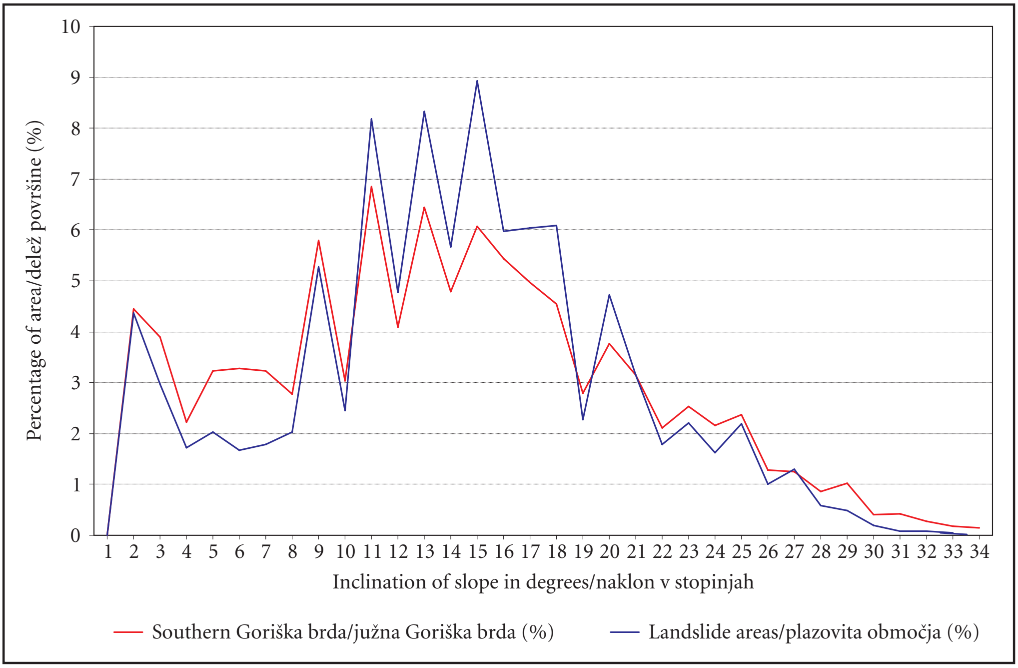

Figure 9: Landslide hazard areas in southern Goriška Brda (blue) and area of entire southern Goriška Brda (orange) expressed in percentages (ordinate) according to inclination in degrees (abscise).

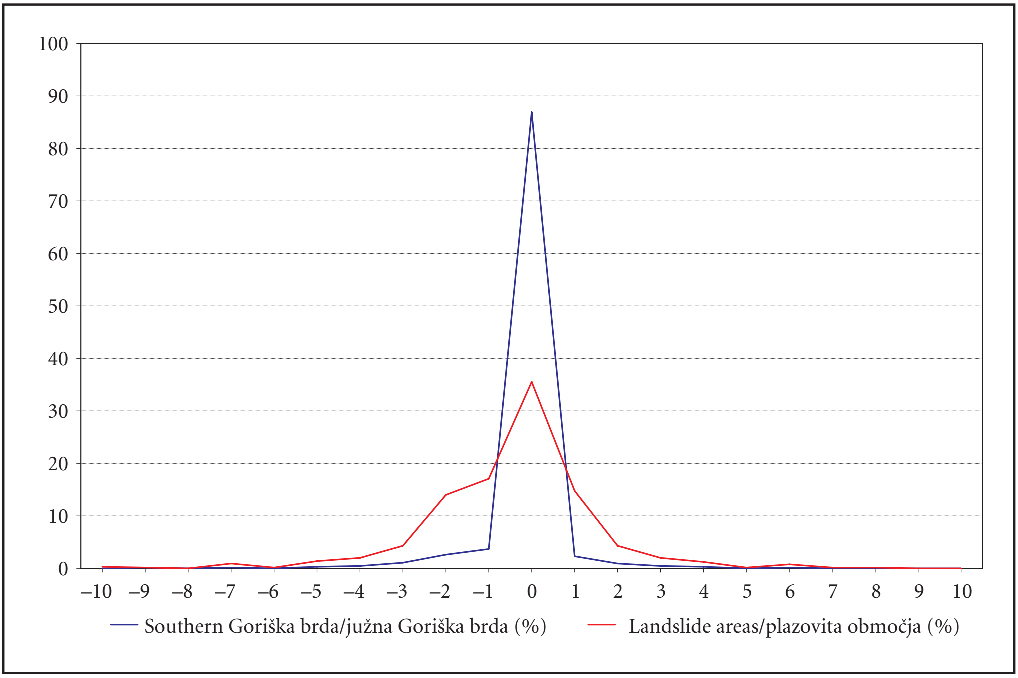

Figure 10: The surface area of landslide hazard areas in southern Goriška Brda expressed in percentages (ordinate) according to surface curvature (abscise). Negative values denote convex areas and positive values denote concave areas.

Figure 11: Water is one of the primary causes for the occurrence of landslides in Goriška Brda.

are fewer linear slopes outside of landslide hazard areas. The landslips and landsides are therefore an important factor in the formation of valleys. In this way, valleys with wide flat bottoms, the result of initial erosion of the surface, are formed high in the watersheds.

That the majority of landslips and landslides in Goriška Brda in 1998 occurred at a distance of about seventy meters below the ridges is consistent with the above observations. It appears that with such precipitation, a flow of water forms on the surface and in the weathered debris at a distance of several dozen meters below a ridge that is strong enough to saturate the ground and move the material to lower positions. Throughout southern Goriška Brda, the parts of the slopes with a large landslide hazard are most frequently located at distances of forty to one hundred meters below the ridges. In southern Goriška Brda, there are relatively few major landslides (only a few dozen), and the majority of earth movements are small landslides or landslips during which only the upper layer of the weathered debris slides. A quarter of the landslide hazard slopes in Goriška Brda are therefore shorter than twenty meters, and half of them are shorter than fifty meters. Only a quarter of landslide hazard slopes are longer than 100 meters.

A comparable indicator is the distance from watercourses. In southern Goriška Brda, landslips and landslides occurred at an average distance of approximately 130 meters from watercourses. A tenth are located at a distance less than 30 meters, a quarter at a distance less than 60 meters, and a half at a distance less than 115 meters. A quarter of the landslips and landslides are located more than 180 meters from watercourses.

4.2 Determining the landslide risk relative to specific landscape elements

We compared the landslide hazard map with several natural geographical and principal sociogeographical landscape elements to try and establish the landslide risk to them.

Vineyard terraces play an important role in the lives of a large number of people in Goriška Brda (Ažman Momirski et al. 2007), so we therefore calculated the correlation between the terraced areas and the landslide hazard classes. In southern Goriška Brda, terraces cover about 2,000 hectares. Most of the terraces are situated on slopes with inclinations below 23°, and half are on slopes with inclinations less that 13°.

Only a quarter of the terraces are located on slopes with inclinations above 17°, and barely a tenth on slopes with inclinations above 20°. Just over a tenth of the terraces are located on slopes with inclinations below 6°. About three hectares or 0.1% of the surface area of all vineyard terraces in southern Goriška Brda are located on slopes above 32°.

Although sloping surfaces are suitable for cultivating grape vines, the data that as many as half of the winegrowing terraces are situated in areas where a relatively high probability of landsliding (landslide hazard classes 9–14) exists is significant. A quarter of the vineyard terraces are situated on areas with low landslide hazard (classes 1–5).

Comparing the distribution of terraces in southern Goriška Brda relative to inclination and hazard, we can see that for inclination, the frequency distribution is close to normal while for hazard it shifts to the right of the distribution. For inclinations in classes, the center of the frequency distribution (modus) is close to a third of the distribution (with 13° of the total 39°), and for hazard is approximately two thirds of the distribution (through class 9 of the total 14 class). We can conclude that complex natural processes reflected in the landslide hazard have greater impact on the location of vineyard terraces than just the surface inclination.

From the socio-economic viewpoint, particularly relative to the accessibility of buildings, settlements, and production facilities, the landslide hazard to the road network is very important. We studied the correlation between the landslide hazard classes and the road network in southern Goriška Brda (Ažman Momirski et al. 2007). We divided the roads into three classes according to their importance: major roads, local roads, and wagon roads.

One fifth of the major roads run on areas with inclinations below 2° and half run on areas with inclinations below 7°. A quarter of the roads run on areas with inclinations above 12°, and a tenth on areas with inclinations above 16°. Landslides can occur on a third of the major roads while 56.6 km of these roads are not at risk. One tenth or 9.8 km of the major roads run on areas with the highest landslide hazard (classes 11–14), and a quarter or 21.1 km on areas where the landslide hazard classes are higher than 7. Three quarters of the major roads run on areas with landslide hazard classes 0–6.

One third of the local roads run on areas with inclinations below 6°, and a half on areas with inclinations smaller than 8.5°. A quarter run on areas with inclinations above 12°, and one tenth on areas with inclinations above 16°. Landslides present a serious risk to about a quarter or 24.1 km of the local roads (landslide hazard classes 9–14). More than a half or 54 km of the local roads are not directly at risk by landslides.

Table 2: Length of roads according to landslide hazard classes in southern Goriška Brda.

Landslide hazard class	Wagon roads		Local roads		Major roads	
	Length in km	Proportion (%)	Length in km	Proportion (%)	Length in km	Proportion (%)
0	216.48	34.39	53.97	55.50	56.57	67.39
1	58.09	9.23	3.47	3.57	2.72	3.24
2	6.72	1.07	0.69	0.71	0.48	0.58
3	7.90	1.26	0.70	0.72	0.59	0.70
4	9.04	1.44	0.85	0.88	0.57	0.68
5	12.20	1.94	1.26	1.30	0.94	1.12
6	14.52	2.31	1.70	1.75	0.99	1.18
7	76.09	12.09	8.27	8.50	5.52	6.58
8	22.08	3.51	2.20	2.26	1.29	1.53
9	25.77	4.09	2.65	2.73	1.67	1.99
10	33.53	5.33	3.21	3.30	2.74	3.26
11	76.47	12.15	9.58	9.85	5.24	6.25
12	45.17	7.17	5.99	6.16	3.28	3.91
13	17.48	2.78	2.30	2.37	1.13	1.35
14/Area of landslides in 1998	7.94	1.26	0.41	0.42	0.20	0.24
Total	629.48	34.39	97.25	55.50	83.95	67.39

One tenth of wagon roads run on areas with inclinations below 2°, and a fifth on areas with inclinations below 6°. As many as half of the wagon roads run on areas with inclinations above 12°, and a quarter on areas with inclinations above 17°. One tenth or 62.9 km of the wagon roads run on very steep areas

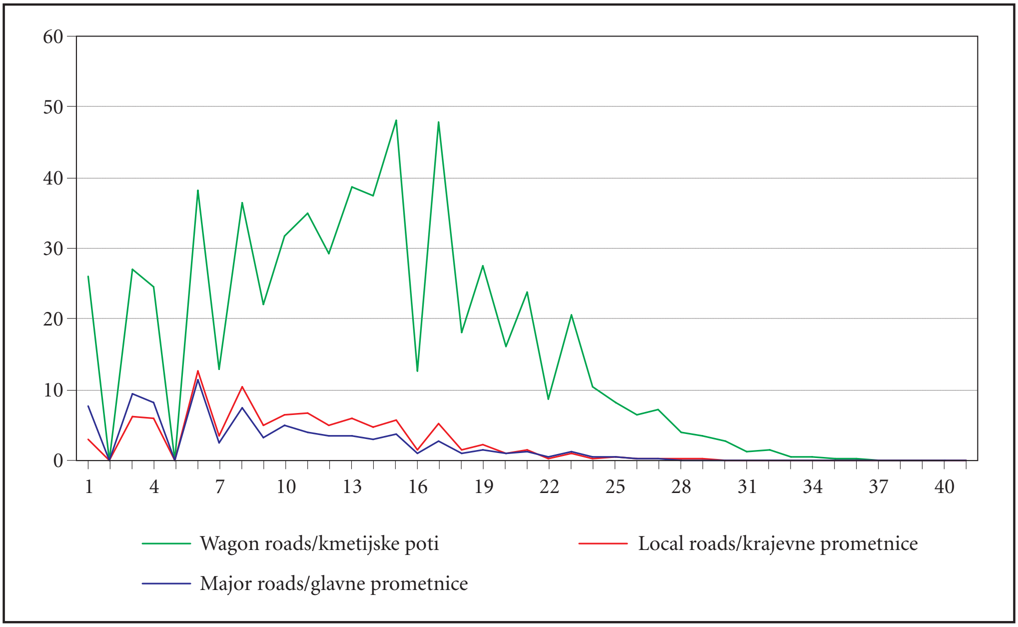

Figure 12: Distribution of road network in southern Goriška Brda (ordinate, in km) according to surface inclination (abscise, in degrees).

with inclinations above 22°. More than two thirds of the 629.48 km of wagon roads run on landslide hazard areas. A quarter of the wagon roads are located on areas in landslide hazard classes 10 to 14, and on a half of the wagon roads, the landslide hazard is higher than class 6. About a quarter of the wagon roads are not at risk by landslides since 110 km of these roads run on areas where the landslide hazard is lower than classes 7.

Table 3: Landslide hazard of settled areas in southern Goriška Brda.

Landslide hazard class	Number of buildings*	Percentage of buildings (%)
0	2,079	–
1	66	5.97
2	15	1.36
3	35	3.16
4	31	2.80
5	45	4.07
6	47	4.25
7	236	21.34
8	57	5.15
9	83	7.50
10	100	9.04
11	234	21.16
12	121	10.94
13	34	3.07
14/Area of landslides in 1998	2	0.18
Total	3,185	100.00

*The number of buildings is not completely accurate because the calculation was elaborated using data from a digital elevation model with a grid cell size of 12.5 × 12.5 meters.

From the viewpoint of spatial planning – in Slovenia the responsibility of municipalities – the comparison between landslides areas and settlement areas in southern Goriška Brda is very important. Over the entire area of southern Goriška Brda, settlement areas occupy about 50 hectares of land.

As many as a third of the buildings in southern Goriška Brda are located in landslide hazard areas. Half are located in areas with a large landslide occurrence probability (classes 9–14), and a quarter of the buildings are not significantly at risk because they are located in areas with a landslide hazard class below 6.

5 Conclusion

Goriška Brda is one of Slovenia's regions where natural conditions allow intensive agricultural production while numerous factors also make human activities impossible or difficult in some areas. Landslides present a constant problem in Goriška Brda (Grimšičar 1962; Vrišer 1954; 1956).

The landslide hazard map described in this article was entirely elaborated using the probability method, employing the Dempster-Shafer algorithm for the first time in Slovenia. Previously, we generally used deterministic methods (Natek et al. 2003; Zorn, Komac 2004; Komac, Zorn 2005a; Komac, Zorn 2005b; Zorn, Komac 2005) and only rarely probability methods (Komac 2005b; Komac, Zorn 2006; Komac, Zorn 2007). Based on the new landslide hazard map of Goriška Brda, we can state that the probability method is a distinct improvement.

The map is useful for spatial planning up to the settlement level and is a good foundation for detailed geomorphological mapping of landslide hazard areas. To correctly interpret the map, it is necessary to be familiar with the method used to produce it and with the positive and negative aspects or limitations of the (digital) data employed such as the digital elevation model with 12.5 × 12.5 meter grid cells, land use maps, vineyard terrace maps, and similar sources of data.

Although the map was elaborated on the basis of absolute data (landslides that occurred under known conditions in the past), it cannot be interpreted as absolutely accurate. The landslide hazard class scale used is a relative criterion of a larger or smaller probability for the occurrence of landslides. The highest landslide hazard classes present areas where landslips or landslides could occur following precipitation with a relatively high return period level (e. g., a fifty-year return period) and with other factors such as land use unchanged. For the lower landslide hazard classes we can only say that the landslide hazard there is smaller.

Landslides in Slovenia cause about 10% of the damage due to natural disasters, which totaled between 1.25 and 23.8 million euros annually in the 1995–2003 period. In 2002, the funds for rehabilitation covered almost 80% of the value of damage caused by landslides, and in 2003, the funds required were almost four times higher. On average, damage related to natural disasters in Slovenia annually amounts to two or three percent of the GDP, but it can be much higher in the event of individual major phenomena (Komac, Zorn 2005a). In 1993, landslides alone caused damage to property costing 4.8% of the annual GDP (Fajfar et al. 2005). Any thoughtful preventive measures taken – possibly on the basis of probability maps – would very likely lower the costs of rehabilitation.

From the viewpoint of agricultural management, the finding that a landslide hazard exists over the greater part (80%) of the studied area of southern Goriška Brda is a matter of some concern. Given the landslide hazard, it is necessary in the long run that agricultural activities that with the construction of vineyard terraces cause slope instability and the rehabilitation costs (in both time and money) connected with it be directed into areas with a smaller landslide hazard, largely located in the eastern part of Goriška Brda. In the construction of terraces, it is necessary to consider the frequency of landslides at certain inclinations, and another very important factor is the dip of the rock strata or their orientation relative to the course of the slope.

Landslide hazard must also be seriously taken into consideration in the construction of new roads and buildings, the determination of new settlement areas, and the expansion of settlement areas that to a great extent already respect the natural conditions since they have a long history of existence.

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Probabilistično modeliranje plazovitosti

UDK: 911.2:551.435.6(497.473)
COBISS: 1.01

IZVLEČEK: V reviji sta avtorja (Zorn, Komac 2004) opisala uporabo dveh determinističnih metod za ugotavljanje plazovitosti. Tokrat gresta korak naprej in na primeru flišnih Goriških brd predstavljata probabilistično metodo za ugotavljanje plazovitosti. Pri probabilističnih metodah intenzivnost in razširjenost procesov ugotavljamo s primerjavo posredno določenih pokrajinskih prvin in dejanskega stanja, medtem ko pri determinističnih na rezultat vplivajo tudi subjektivne odločitve. Probabilistični zemljevid plazovitosti z določeno povratno dobo je bil izdelan z Dempster-Shaferjevo metodo na podlagi podatkov o 800 zemeljskih plazovih, ki so nastali ob intenzivnih padavinah jeseni 1998.

KLJUČNE BESEDE: geomorfologija, naravne nesreče, zemeljski plazovi, zemljevidi ogroženosti, Dempster-Shaferjev algoritem, Goriška brda, Slovenija

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Kazalo

1 Uvod

Goriška brda so niz prstasto razporejenih gričevnatih hrbtov na zahodu Slovenije velikosti 140 km^2, ki se razprostirajo med dolinama Idrije na vzhodu in Soče na zahodu v višinah 300–800 m. Povečini jih sestavljajo sedimentne flišne kamnine, ki jih sestavljajo od nekaj centimetrov do pol metra debele plasti peščenjaka, laporovca, skrilavega glinavca in apnenca ali kalkarenita. Flišne kamnine v Goriških brdih delimo na zgornjepaleocenske kožbanske plasti z več karbonatnimi sestavinami, ki prevladujejo na severu, in mlajše, spodnjeeocenske medanske plasti z večjo vsebnostjo glinenih sestavin, ki so pogostejše na jugu (Pavlovec 1974, 146). Meja med omenjenima tipoma fliša poteka od zahoda proti vzhodu, to je od Bele mimo Krasnega in Vrhovelj proti Podsenici in Podsabotinu.

Zaporedji flišnih kamnin se razlikujeta. Kožbanske plasti so nastale iz usedlin velikih podmorskih plazov. Ker se je gradivo hitro usedalo na morsko dno, so kamnine premešane in razporejene neurejeno. Fliš vsebuje tudi kamnine, ki jih je plaz zajel in odtrgal na pobočjih, pogosta sta na primer konglomerat in breča. Medanske plasti so nastale v mirnejšem morskem sedimentacijskem okolju s pomočjo turbiditnih tokov. V kamnini se izmenjujejo plasti peščenjaka in laporovca (Arčon 2004, 17–31).

Na to, da lahko v flišnih kamninah Goriških brd pričakujemo zemeljske plazove, opozarja že izvor besede fliš, saj nemška beseda (*fliessen*) označuje kamnino, ki »teče« (Pavlovec 1977, 213. Kamninska sestava je temeljni vzrok za razčlenjenost reliefa in plazovitost tega območja. Fliš je namreč malo odporen na preperevanje, pri čemer razpada v drobno preperino, ki lahko postane mobilna, če so izpolnjeni še nekateri drugi pogoji.

Fliš je plazovit tudi zaradi slabe prepustnosti za vodo in zaradi zadrževanja vlage. Drugi, prav tako pomemben vzrok za plazenje je gričevnat relief s strmimi pobočji.

Najpomembnejši povod za plazenje so obilne oziroma intenzivne padavine, zaradi katerih pride do dviga talne vode in obremenjevanja pobočij. Tudi pri tem ima veliko vlogo relief oziroma oblikovanost zemeljskega površja. Večina zemeljskih plazov se namreč sproži na konkavnih strmih območjih, kjer se steka voda. Pomembno pa je tudi delovanje človeka: zemeljski plazovi in usadi so pogosti na intenzivno obdelanih površinah, na primer v vinogradih ter ob cestah.

2 Intenzivne padavine in plazenje

Ob intenzivnih padavinah pride do plazenja zaradi močnega nihanja pornega tlaka in njegovega povečanja v površinskih plasteh preperine. Povečan porni tlak zmanjša medzrnske sile vzdolž obstoječe drsne ploskve, kar poveča možnost zdrsa. Nastanek plazov tako ni nujno neposredno povezan z ravnijo podtalnice. Toda začetna vsebnost vode v tleh igra pomembno vlogo za sprožitev, saj zmanjša potrebno mejno količino padavin (Govi in Sorzana 1980, 52; Komac 2005a, 264, 275). Komac (2005, 276) domneva, da povprečna letna količina padavin ne vpliva neposredno na plazenje, oziroma le v kombinaciji z intenzivnimi kratkotrajnimi padavinami. Govi in Sorzana (1980, 59) pa ugotavljata, da se pragovi za sprožitev plazenja na isti litološki osnovi in podobnem reliefu spreminjajo predvsem zaradi količine letnih padavin. Toda tudi ista količina padavin na različnih območjih z isto kamninsko podlago in reliefom, povzroči različne nestabilnosti.

Mejna količina padavin, ki vpliva na plazenje v Sloveniji, je 100–150 mm v 24-ih urah oziroma 130–180 mm pri 48-urnih padavinah (Komac 2005a, 275–276). Velikostni razred, to je intenzivnost padavin približno 150 mm/24 ur, ustreza podatkom od drugod. Mejne vrednosti se razlikujejo glede na litostratigrafske enote (Komac 2005a, 264, 277).

V Sloveniji smo bili že večkrat priča proženju številnih zemeljskih plazov ob intenzivnih padavinah, nazadnje avgusta 2005 in spomladi 2006 v vzhodni in jugovzhodni Sloveniji. Mejne količine padavin so bile 130–180 mm v 48 urah, pri čemer je obstoječa vlaga v tleh znižala sprožilno količino padavin (Komac 2005a, 275).

Natančneje so bili obdelani usadi oziroma manjši zemeljski plazovi, ki so nastali ob intenzivnih padavinah poleti 1989 v Halozah (Natek 1990; Natek 1996) ter v dolinah Lahomnice in Kozarice vzhodno od Laškega (Gabrovec 1990; Gabrovec, Brečko 1990; Fazarinc, Pintar 1991; Fazarinc, Mikoš 1992). Obe območji sta zanimivi za primerjavo z Goriškimi brdi, saj imata tudi (Lahomnica in Kozarica) ali pa pretežno (Haloze) lapornato podlago.

Na okrog 20 km^2 velikem območju v porečjih Lahomnice in Kozarice je 19. avgusta 1989 v dobrih dveh urah padlo 130–140 mm padavin, na določenih mestih prek 400 mm. Intenziteta je presegla stoletne povratne dobe (Fazarinc, Pintar 1991, 12; Fazarinc, Mikoš 1992, 378, 381). Usadi so se prožili že med neurjem, njihova gostota pa je bila podobna kot po neurju julija 1989 v Halozah, le da je bilo prizadeto manjše območje (Gabrovec 1990, 181; Gabrovec, Brečko 1990, 16). V dolini Loškega potoka v porečju Lahomnice je bila gostota 36 usadov na km^2 (Gabrovec 1990, 184).

V Halozah je med 3. in 4. julijem 1989 v 24 urah padlo 150–200 mm padavin. V Žetalah so namerili 106 mm padavin, kar je slabe tri četrtine mesečnega povprečja. To so padavine s približno 25-letno povratno dobo. Na 106 km^2 se je sprožilo okrog 5000 usadov, povprečno 47 usadov na km^2. Če upoštevamo le kmetijska zemljišča je bila gostota 120 usadov na km^2 (Natek 1990, 11; Natek 1996, 142). Na območju prevladujejo tortonski laporovci, v manjši meri pa se pojavlja lapornati peščenjak (Natek 1990).

V porečju Lahomnice so že v začetku devetdesetih let dvajsetega stoletja s pomočjo geografskih informacijskih sistemov ugotavljali povezanost usadov z nekaterimi pokrajinskimi prvinami. Usadi so v porečju Lahomnice nastali le na treh od 16 litostratigrafskih enot. To kaže na povezanost z litološko osnovo, še posebej, ker so večji nakloni pogosti tudi v drugih kamninah. Največ usadov se je sprožilo na tako imenovanem laškem laporovcu, ki pokriva 7 % območja. To je zaradi podobnosti litološke osnove zanimivo za Goriška brda. Usadi so se pojavili še na 2 % površja z govškimi plastmi v podlagi (pesek, peščenjak z vložki peščenega laporovca), pa tudi v ozkem pasu litotamnijskega apnenca (Gabrovec 1990, 181–182; Gabrovec, Brečko 1990, 16).

V porečju Lahomnice je povezanost usadov in naklona (upoštevali so le naklone na prizadetih kamninah) »… *očitna, ni pa zelo močna* …« Na plazenje namreč poleg naklona vplivajo še reliefne oblike (Hrvatin, Perko 2002). Zato smo v model plazovitosti za Goriška brda vključili vodoravno ukrivljenost površja. Največ usadov se je v porečju Lahomnice sprožilo v zatrepih manjših dolinic in na omejkih, to je spodnjih robovih njiv. Največ usadov se je sprožilo na naklonih 10–14°, 15–19° in 20–24°. Usadi so se prožili na približno četrtini območja teh naklonskih razredov. Prizadeta je bila tudi desetina območja z naklonom 25–29° in dobrih 7 % območja z naklonom 5–9° (Gabrovec 1990, 182; Gabrovec, Brečko 1990, 17). V Halozah se je na naklonih 19–36° sprožilo skoraj 90 % usadov. Na naklonu 19–24° se je sprožilo 9,3 % usadov, 36 % na naklonu 25–30° in 44,3 % na naklonu na 31–36° (Natek 1990, 12). Dobrih 9 % usadov je nastalo na naklonih večjih od 36°. Skupaj je na naklonih večjih od 25° nastalo skoraj 90 % usadov. Le 1,1, % usadov je nastal v naklonskem razredu 13–18°. Glede na reliefne oblike je kar 43,8 % usadov nastalo na srednjih, najstrmejših delih pobočij, 0,7 % na zgornjih, konveksnih delih pobočij, 7,8 % na spodnjih, konkavnih delih pobočij, 29,1 % v dolinskih zatrepih in 1,3 v zgornjih delih grap (Natek 1990, 12; Natek 1996, 144, 147–148).

V dolini Loškega potoka v porečju Lahomnice je bil povprečen naklon na zgornjem robu usadov 35°. Zgornji rob je bil ponavadi tik pod pregibom pobočja, kjer je naklon bistveno večji od povprečnega naklona tistega pobočja. Na spodnjem robu usada je bil naklon vsaj 10–15° manjši. Pri analizi so uporabili dokaj grob digitalni model višin 100 krat 100 m, pri katerem se naklon računa za cele hektarske celice (10.000 m^2) in so bili zato izračunani nakloni še manjši. Povprečni naklon celic, kjer so se pojavljali usadi, je bil zato komaj 18° (Gabrovec 1990, 185). Za južna Goriška brda smo uporabili digitalni model višin 12,5 krat 12,5 m (velikost celice 156,25 m^2).

V porečju Lahomnice se je največ usadov sprožilo v sadovnjakih in na travnikih. Podobno ugotavlja Natek (1990, 13) za neurje v Halozah, kjer se je na travnikih, pašnikih in v sadovnjakih sprožilo skupaj dobrih 70,5 % usadov. V porečju Lahomnice in v Halozah je bila velika tudi gostota usadov na njivah, predvsem na omejkih (Natek 1990, 14). V gozdu je bilo v porečju Lahomnice usadov bistveno manj in so se pojavljali na večjih naklonih (povprečen naklon 23°) kot usadi na obdelovalnih površinah (na njivah 14°, v sadovnjakih 18°) (Gabrovec 1990, 183; Gabrovec, Brečko 1990, 19; Fazarinc, Mikoš 1992, 384–385).

V Halozah se je slabih 16 % usadov sprožilo v vinogradih, po slabih 5 % pa na njivah in v sadovnjakih. V gozdu je nastalo 5,6 % usadov. Na terasiranih vinogradih je nastalo 5,2 % usadov, vendar dodaja, da se je v terasiranih vinogradih »… *glede na razmeroma majhen obseg sprožilo zelo veliko usadov* …«, ki pa so bili večinoma majhni (Natek 1990, 13).

V občinah Pesnica, Slovenska Bistrica in Ptuj se je ob intenzivnih padavinah med 14. in 25. novembrom 1991 sprožilo prek 200 zemeljskih plazov. V Mariboru je padlo 162,3 mm padavin, kar močno presega novembrsko povprečje z 92,8 mm. Na kmetijskih površinah je bilo največ plazov na travnikih in v vinogradih. Delež plazov v vinogradih je v polovici krajevnih skupnosti v občini Pesnica, glede na vse kmetijske površine, presegal 50 %, v občini Slovenka Bistrica pa je enak delež veljal za celo občino. Vzrok za plazenje v vinogradih so bili predvsem prestrmi bregovi teras ali spodnjega roba vinograda (Žiberna 1992, 12–13).

Slika 1: Fliš v južnih Goriških brdih.
Glej angleški del prispevka.

3 Plazovitost Goriških brd

V Goriških brdih povzročajo zemeljski plazovi veliko gmotno škodo. V vinogradih na strmih pobočjih morajo kmetje nenehno popravljati terase, ponekod za to porabijo več tednov letno. Plazenje kmetje pogosto ustavijo z odvodnjavanjem in speljevanjem vode v nižje lege po ceveh ali kanalih (Komac, Zorn 2006a, 57; Komac, Zorn 2007).

Značilno je, da »*… se manjši plazovi pojavljajo dejansko po vseh Brdih, zlasti v srednjem delu, kjer so laporji in strme brežine …*«, ter da v jugozahodnem delu »*… plazijo večinoma le plitve preperine … Globokih plazov je največ pri dnu dolin, kjer niso tako nevarni za kmetijstvo. Skoraj v vsaki večji dolini jih je nekaj. Tudi predvidene zemeljske pregrade za namakanje bi lahko zaradi nihanja vode sprožile plazenje pobočij … Tudi neugodno ležeče plasti lapornih glin in glinastih laporjev na vseh jugozapadnih pobočjih so precejšen vzrok za plazove, če se v njih pojavljajo solzaji ali izviri vode …*« (Grimšičar 1962, 8–9).

Plazovitost pobočij v Goriških brdih ugotavljajo tudi novejši geološki viri. Ocepek (2002) za vinograd južno do jugovzhodno od gradu Dobrovo ugotavlja, da flišne plasti prekriva 1–2,5 m debel preperinski pokrov, ki na spodnjem delu pobočja sega 3,5 m v globino, in kaže znake plazenja. Plazenje je najbolj vidno na »brežini«, ki je »*… mestoma izbočena …*«. Izbočenost kamnitih zidov, ti so bili zgrajeni zaradi usekov cest, lahko opazujemo po vseh Goriških brdih (sliki 2 in 3).

Do plazenja oziroma »*… zdrsa preperine po lapornati podlagi …*« lahko pride, ko se podzemna voda dvigne le nekaj centimetrov nad njo (to velja za območja, kjer je debelina preperine ali preorane zemlje večja od 4 m). Pri debelini preperine oziroma preorane zemlje 1 m pa plazenje nastopi, če se podzemna voda dvigne 30 cm nad podlago (Petkovšek, Klopčič, Maček 2007, 18).

Sliki 2: Izbočeni kamniti zidovi nad useki cest zaradi plazenja.
Glej angleški del prispevka.

Slika 3: Kamnite zidove nad useki cest je treba stalno obnavljati.
Glej angleški del prispevka.

Slika 4: Kamniti zidovi se porušijo, ko ne morejo več zadrževati plazenja.
Glej angleški del prispevka.

3.1 Zemeljski plazovi jeseni leta 1998

Jeseni 1998 so bile v Goriških brdih obilne padavine. Šestega septembra je padlo 114 mm padavin in 13. septembra 100 mm padavin. Oba padavinska dogodka sta dosegla petletno povratno dobo. Šestega oktobra istega leta je v 24 urah padlo kar 175 mm padavin. To pomeni, da so padavine imele petdesetletno povratno dobo. V času od 28. septembra do 13. oktobra je padlo 433 mm padavin, ali povprečno 31 mm padavin dnevno.

Slika 5: Območja plazenja oktobra 1998 in plazovi po Grimšičarju (1962).
Glej angleški del prispevka.

Na predhodno namočeni podlagi so intenzivne padavine na začetku oktobra sprožile številne zemeljske plazove. Zemeljski plazovi so bili pogosti predvsem v južnih Goriških brdih. Zaradi prostorsko omejenih podatkov o plazenju in dejstva, da se severna in južna Goriška brda razlikujejo glede na geološko sestavo, smo lahko probabilistični zemljevid plazovitosti izdelali le za južna Goriška brda. Samo plazov, ki so prizadeli kmetijska zemljišča in povzročili gmotno škodo, je bilo v južnih Goriških brdih prek 800. Na 41,32 km^2 velikem območju so zemeljski plazovi obsegali 1,7 % površine.

4 Metodologija izdelave zemljevida plazovitosti

Zemljevidi geomorfnih procesov so eden od preventivnih ukrepov v boju proti naravnim nesrečam.

Med vzroki (Zorn, Komac 2002, 11–12), ki vplivajo na plazenje, smo v uporabljenem modelu za izračun plazovitosti upoštevali osem dejavnikov: litološko sestavo, naklon površja, vodoravno ukrivljenost površja, vpad skladov, indeks moči vodnega toka, indeks namočenosti tal, maksimalne 24-urne padavine in rabo tal. Podatke o zemeljskih plazovih, ki so se zgodili leta 1998, smo pridobili od Občine Brda. Izračuni so bili narejeni s programskima paketoma Idrisi 3.2 in TAS 2.0.7 (Linsday 2002).

Zemljevid plazovitosti smo izdelali s pomočjo Dempster-Shaferjevega algoritma (Dempster 1968; Shafer 1990), podobno kot na primer Binaghi in ostali (1998), Gorsevski, Jankowski in Gessler (2005) ter Damm in Varga (2006). Gre za primerjavo pomena posameznih dejavnikov za plazenje, ki temelji na podatkih s terena. Za vsak dejavnik izdelamo delni zemljevid, ki prikazuje, kje na obravnavanem območju obstaja večja, in kje manjša verjetnost za plazenje.

Program nato na vse hierarhično možne načine primerja dejavnike ter za vsak upoštevani dejavnik izračuna, kakšne so vrednosti na plazovitih območjih. Te vrednosti privzame kot merilo in jih upošteva kot območja, kjer je večja možnost za nastanek zemeljskih plazov. Za vsak dejavnik moramo nato ugotoviti in v program vpisati mejne vrednosti, pri katerih prihaja do plazenja. Tako na primer za naklon ugotovimo, da plazenja ni pod določeno vrednostjo (na primer 6°) ali nad določeno vrednostjo (na primer 20°).

Program deluje po Dempster-Shaferjevem algoritmu, ki ga opisuje naslednje pravilo:

$\mathrm{m(Z)} = \dfrac{\sum m_1(X)\cdot m_2(Y); X\cap Y = Z}{1-\sum m_1(X)\cdot m_2(Y); X\cap Y = 0}$, pri čemer je m(Z) temeljna pripisana verjetnost ali vsota podpore za hipotezo (Z). Če je $\sum m_1(X)\cdot m_2(Y); X\cap Y = 0$, potem se enačba glasi:

$\mathrm{m(Z)} = \sum m_1(X)\cdot m_2(Y); X\cap Y = 0$.

Program nazadnje celotno območje preučevanja primerja s tako postavljenim merilom in ugotavlja podobnosti oziroma razlike posameznih območij – celic digitalnega modela višin. Končni rezultat je zemljevid, ki prikazuje možnost nastanka zemeljskih plazov z vidika uporabljenih podlag ob takšnih razmerah, kot so bile takrat, ko so nastali vneseni zemeljski plazovi.

Kot plazovita območja so nazadnje določena tista, ki so glede na čim večje število upoštevanih parametrov najbolj podobna območjem, na katerih je že prišlo do plazenja. Prav zato je zelo pomembna kakovost vhodnih podatkov.

Možnost plazenja je prikazana z vrednostmi 0–1. Vrednost 1 pomeni, da lahko pride do plazenja na tistem mestu, ko imajo padavine približno petdesetletno povratno dobo. Verjetnost plazenja je v resnici manjša, saj nanj vplivajo tudi drugi dejavniki, ne le intenzivne kratkotrajne padavine, ki so lahko le povod za plazenje (Zorn, Komac 2002, 11). Zemljevid prikazuje, da je na določenem ozemlju večja ali manjša možnost, da pride ob danih razmerah (pri padavinah s petdesetletno povratno dobo) do plazenja.

Dobre strani takšnega zemljevida oziroma metode, po kateri je bil izdelan, so:

- temelji na dovolj velikem številu konkretnih podatkov (N = 800) o pojavih v naravi oziroma usadih in zemeljskih plazovih, ki so nastali ob znanih zunanjih okoliščinah (količina padavin),
- temelji na razmeroma velikem številu drugih vhodnih podatkov, kot so podatki o litološki sestavi in reliefu,
- upoštevane prvine pokrajine, ki vplivajo na plazenje, niso ponderirane, kar zmanjša subjektivnost,
- zemljevid je primerna podlaga za nadaljnje natančno terensko kartiranje.

Slabe strani uporabljene metode pa so naslednje:

- zemljevid je model, z modeli pa lahko le deloma simuliramo naravne procese,
- izdelan je le na enem (časovnem) nizu podatkov o usadih in zemeljskih plazovih iz preteklosti,
- podatke o usadih in zemeljskih plazovih so občini Brda posredovali kmetovalci na predlog občine, ker so bili zaradi višine škode upravičeni do državne pomoči, zato je vir potrebno obravnavati kritično (posledica je na primer pogostejše plazenje na obdelovalnih zemljiščih, zlasti vinogradih, kot bi pričakovali).

Iz prikaza smo izločili ravna območja z naklonom pod 6°, kjer geomorfni procesi po definiciji niso pomembni za oblikovanje površja z zemeljskimi plazovi oziroma niso dovolj intenzivni.

4.1 Zemljevid plazovitosti

Na zemljevidu je plazovitost prikazana v štirinajstih kategorijah z barvno lestvico, ki sega od modre (najnižja plazovitost) prek zelene do rumene in rdeče (najvišja plazovitost). Kategorije smo določili tako, da smo frekvenčno razporeditev digitalnega zemljevida plazovitosti z vrednostmi 0–1 razporedili glede na aritmetično sredino. Razredi obsegajo po 0,1 standardnega odklona in jih je skupaj 13, štirinajsti razred pa prikazuje plazove iz leta 1998. Blizu srednje vrednosti je v sedmem razredu približno sedmina pojavov, pod njo je četrtina, nad njo pa dobra polovica pojavov. Srednji razred obsega vrednosti v razponu 0,2 standardnega odklona ($\sigma \pm 0{,}1$). Frekvenčna razporeditev se ravna po eksponentni enačbi $y = 8{,}1 \cdot 10^{-8} \cdot e^{1{,}61x}$.

Približno polovica ozemlja ima plazovitost v 9–14 kategoriji, tretjina pa v 11–14 kategoriji. Četrtina ozemlja ima plazovitost nižjo od 6. kategorije. Približno 18 % površin v južnih Goriških brdih zemeljski plazovi ne ogrožajo.

Slika 6: Frekvenčna razporeditev plazovitih območij (abscisa) glede na plazovitost (ordinata).

Glej angleški del prispevka.

Slika 7: Zemljevid plazovitosti južnih Goriških brd.

Glej angleški del prispevka.

Slika 8: Zemljevid plazovitosti katastrske občine Medana. Naselja oziroma stavbe povečini stojijo na razmeroma varnih do nekaj deset metrov širokih slemenih.

Glej angleški del prispevka.

S primerjavo deleža površin različne rabe tal na plazovitih območjih in v celotnih južnih Goriških brdih ugotovimo, da so zemeljski plazovi pogostejši v intenzivno obdelanih nasadih, zlasti v vinogradih, pa tudi v oljčnih in drugih trajnih nasadih. Ker je delež vinogradniških površin večji glede na vsa plazovita območja kot glede na celotna južna Goriška brda, se v vinogradih zemeljski plazovi pojavljajo pogosteje, kot bi jih pričakovali. To je seveda posledica človekove dejavnosti, deloma pa tudi naravnih dejavnikov.

Obratno pa bi v gozdovih (po površini) statistično pričakovali več usadov in zemeljskih plazov, kot jih je dejansko nastalo leta 1998. Prav tako bi statistično pričakovali več usadov in zemeljskih plazov na pozidanih površinah (všteta je tudi infrastruktura) in na površinah z mešano rabo (kmetijska zemljišča in gozd).

Preglednica 1: Površina in delež površin v južnih Goriških brdih (pričakovane vrednosti) in na plazovitih območjih v južnih Goriških brdih (dejanske vrednosti) glede na rabo tal.

	južna Goriška brda		plazovita območja v južnih Goriških brdih	
	ha	%	ha	%
njive in vrtovi	121,67	2,94	1,84	2,63
vinogradi	1702,08	41,20	49,09	70,01
intenzivni sadovnjaki	218,17	5,28	3,02	4,30
ekstenzivni sadovnjaki	123,77	3,00	1,64	2,34
oljčni nasadi	1,719	0,04	0,19	0,27
ostali nasadi	0,05	0,00	0,00	0,00
ekstenzivni travniki	328,06	7,94	5,30	7,55
zaraščanje	57,33	1,39	0,75	1,07
mešana raba	82,11	1,99	0,56	0,80
gozd	1248,38	30,22	6,88	9,80
pozidano	242,36	5,87	0,86	1,23
neporaslo	0,25	0,01	0,00	0,00
vode	5,59	0,14	0,00	0,00

Največ zemeljskih plazov je na območjih, kjer so kamninske plasti usmerjene proti severovzhodu, sledita jugozahod in severozahod. Za usmerjenost kamninskih plasti smo uporabili Strukturno karto Brd v merilu 1 : 25.000, ki jo je izdelal Gospodarič (1962, priloga 15).

Večina, 48 % zemeljskih plazov se je sprožila pri naklonih 12–20°, skoraj četrtina (22 %) pri naklonih 6–12°, približno šestina (17,7 %) pri naklonih 20–32° in devetina (11,6 %) pri naklonih pod 6°. Nad 32°

po definiciji ne nastajajo zemeljski plazovi, saj je prevladujoči geomorfni proces padanje, ne pa plazenje. Na tako strmih pobočjih se večina gradiva sproti premakne v nižjo lego, zato je tam nastal le majhen del zemeljskih plazov, ki obsegajo 0,1 % površine plazovitih območij. Frekvenčni razporeditvi naklonov v južnih Goriških brdih in na plazovitih območjih v južnih Goriških brdih sta pozitivno statistično pomembno povezani (N = 35, Pearsonov korelacijski koeficient (r) = 0,99, t test = 34,6).

Četrtina zemeljskih plazov in usadov je nastala pri naklonih pod 10°, polovica pri naklonih pod 14° in tri četrtine pri naklonih pod 17,5°. Najpogosteje so se prožili pri naklonih 11–15°. Pri 15° je nastala skoraj desetina pojavov (9 %), nekaj manj pri 11° in 13°. Na plazovitih območjih so nakloni 10–17° pogostejši, kot so sicer v Goriških brdih. Frekvenčni razporeditvi naklonov na plazovitih območjih in v Goriških brdih sta si zelo podobni (koeficient korelacije znaša 0,96, hi kvadrat znaša 7,6 pri N = 46).

Štiri desetine plazovitih območij so v konveksnih legah, 35 % na premočrtnih legah (ukrivljenost je enaka 0), četrtina pa v konkavnih legah (slika 10). Večina usadov in zemeljskih plazov je nastala na zgornjih konveksnih delih pobočij oziroma tik pod njimi. Tam so pobočja dovolj strma in dovolj oddaljena od slemen. Z usadi in zemeljskimi plazovi se povečuje naklon pobočij, spreminja pa se tudi prevladujoča ukrivljenost. Iz konveksnih pobočij nastanejo premočrtna. S tem se podaljšuje konkavni spodnji del pobočij. Končni rezultat preoblikovanja so slemena, pod katerimi so strma premočrtna pobočja, ki se spodaj končajo v dnu večje doline ali ravnine ali pa se nadaljujejo v obsežnejše, dolgo in položno konkavno pobočje. Na neplazovitih območjih je v Goriških brdih manj premočrtnih pobočij. Usadi in zemeljski plazovi so zato pomemben dejavnik pri nastajanju dolin. Na ta način visoko v povirjih nastajajo doline s širokim, ploskim dnom, ki so rezultat začetnega razjedanja površja.

V skladu z omenjenim je tudi dejstvo, da je v Goriških brdih leta 1998 večina usadov in zemeljski plazov nastala na oddaljenosti približno 70 m pod slemeni. Kot kaže, ob takih padavinah na razdalji nekaj deset metrov na površju in v preperini nastane dovolj močan vodni tok, ki lahko prepoji gmoto in odnaša gradivo v nižje lege. V primerjavi s celotnimi Goriškimi brdi so plazoviti deli pobočij najpogostejši na oddaljenosti 40–100 m od slemen navzdol. V Goriških brdih je razmeroma malo velikih zemeljskih plazov (nekaj deset), pri večini premikov zemeljskih gmot pa gre za manjše zemeljske plazove ali usade, pri katerih zdrsne le zgornji del preperine. Zato je četrtina plazovitih pobočij v Goriških brdih krajših od 20 m, polovica pa krajših od 50 m. Le četrtina plazovitih pobočij je daljših od 100 m.

Primerljiv kazalnik je oddaljenost od vodotokov. Usadi in zemeljski plazovi so v Goriških brdih nastali na oddaljenosti povprečno 130 m od vodotokov. Desetina jih je na razdalji manjši od 30 metrov, četrtina na razdalji manjši od 60 metrov in polovica na razdalji manjši od 115 metrov. Četrtina usadov in zemeljskih plazov je od vodotokov oddaljenih več kot 180 metrov.

Slika 9: Površina plazovitih območij v južnih Goriških brdih (modro) in površina celotnih južnih Goriških brd (oranžno), izražena v odstotkih (ordinata) glede na naklon v stopinjah (abscisa).

Glej angleški del prispevka.

Slika 10: Površina plazovitih območij v Goriških brdih, izražena v odstotkih (ordinata) glede na ukrivljenost površja (abscisa). Negativne vrednosti pomenijo konveksna pobočja, pozitivne pa konkavna.

Glej angleški del prispevka.

Slika 11: Voda je eden od poglavitnih vzrokov za nastanek zemeljskih plazov v Goriških brdih.

Glej angleški del prispevka.

4.2 Ugotavljanje ogroženosti nekaterih prvin pokrajine

Zemljevid plazovitosti smo primerjali še z nekaterimi naravnogeografskimi in s poglavitnimi družbenogeografskimi prvinami pokrajine in na ta način ugotavljali njihovo ogroženost zaradi zemeljskih plazov.

Za življenje velikega števila ljudi v Goriških brdih so pomembne vinogradniške terase (Ažman Momirski in ostali 2007). Zato smo izračunali povezanost terasiranih območij in kategorij plazovitosti. Terase v južnih Goriških brdih pokrivajo približno 2000 ha površin. Večina teras je zgrajenih na pobočjih pod 23°, polovica pod naklonom 13°. Na pobočjih z naklonom več kot 17° je le četrtina teras, na pobočjih z naklonom več kot 20° pa komaj desetina. Nekaj več kot desetina teras je tudi na pobočjih z naklonom pod 6°. Na pobočjih z naklonom nad 32° je v južnih Goriških brdih približno 3 ha ali 0,1 % površine vseh vinogradniških teras.

Čeprav je nagnjeno površje primerno za pridelavo vinske trte, je pomenljiv podatek, da je kar polovica vinogradniških teras zgrajenih na območjih, kjer obstaja razmeroma velika možnost plazenja (9–14 kategorija plazovitosti). Četrtina vinogradniških teras je zgrajenih na območjih, kjer je plazovitost nizka (1–5 kategorija).

Če primerjamo razprostranjenost teras v južnih Goriških brdih glede na naklon in glede na ogroženost, lahko vidimo, da je pri naklonu frekvenčna razporeditev blizu normalne, pri ogroženosti pa je pomaknjena v desno. Sredina frekvenčne razporeditve (modus) je pri naklonih v razredih približno na tretjini razporeditve (pri 13° od skupaj 39°), pri ogroženosti pa približno pri dveh tretjinah razporeditve (v 9. kategoriji plazovitosti od skupaj 14. kategorij). Sklepamo lahko, da na lego vinogradniških teras bolj vplivajo kompleksni naravni procesi, ki se kažejo v plazovitosti, kot pa le naklon površja.

Z družbenogospodarskega vidika, zlasti z vidika dostopnosti stavb, naselij in proizvodnih obratov je zelo pomembna ogroženost cestnega omrežja zaradi plazovitosti. Preučili smo povezanost kategorij plazovitosti in cestnega omrežja v južnem delu Goriških brd (Ažman Momirski 2007). Ceste smo po pomenu razdelili v tri razrede: glavne prometnice, krajevne prometnice, kmetijske poti.

Petina glavnih prometnic je speljana po površinah z naklonom pod 2° in polovica jih teče po površinah z naklonom pod 7°. Četrtina jih poteka po površinah z naklonom večjim od 12°, desetina po površinah z naklonom nad 16°. Zemeljski plazovi lahko nastanejo na tretjini glavnih cest, neogroženih pa je 56,6 km glavnih cest. Desetina ali 9,8 km glavnih cest poteka po območjih najvišje plazovitosti (kategorije 11–14), četrtina ali 21,1 km pa po na območjih, kjer je kategorija plazovitosti višja od 7. Tri četrtine glavnih cest potekajo po območjih s kategorijo plazovitosti 0–6.

Tretjina krajevnih prometnic je speljana po površinah, ki imajo naklon manjši od 6°, polovica pa po površinah z naklonom manjšim od 8,5°. Četrtina jih poteka po površinah z naklonom nad 12°, desetina pa po površinah z naklonom nad 16°. Zemeljski plazovi močno ogrožajo približno četrtino ali 24,1 km krajevnih prometnic (9–14. kategorija plazovitosti). Več kot polovice ali 54 km krajevnih prometnic zemeljski plazovi ne ogrožajo neposredno.

Desetina kmetijskih poti je speljana po površinah z naklonom pod 2°, petina pa po površinah z naklonom, ki je manjši od 6°. Kar polovica kmetijski poti poteka po površinah, ki imajo naklon večji od 12°, četrtina pa po površinah, ki imajo naklon večji od 17°. Desetina ali 62,9 km kmetijskih poti poteka po zelo strmih površinah z naklonom nad 22°. Več kot dve tretjini od 629,48 km kmetijskih poti sta speljani po plazovitih območjih. Četrtina jih leži na območjih s kategorijo plazovitosti 10–14, na polovici kmetijskih poti pa je plazovitost višja od šeste kategorije. Približno četrtine kmetijskih poti plazovi ne ogrožajo, saj jih je približno 110 km na območjih, kjer je plazovitost nižja od 7. kategorije.

Preglednica 2: Površina cest glede na kategorije plazovitosti v južnih Goriških brdih.

kategorija plazovitosti	kmetijske poti		krajevne prometnice		glavne prometnice	
	dolžina v km	delež (%)	dolžina v km	delež (%)	ha	delež (%)
0	216,48	34,39	53,97	55,50	56,57	67,39
1	58,09	9,23	3,47	3,57	2,72	3,24
2	6,72	1,07	0,69	0,71	0,48	0,58
3	7,90	1,26	0,70	0,72	0,59	0,70
4	9,04	1,44	0,85	0,88	0,57	0,68
5	12,20	1,94	1,26	1,30	0,94	1,12
6	14,52	2,31	1,70	1,75	0,99	1,18
7	76,09	12,09	8,27	8,50	5,52	6,58
8	22,08	3,51	2,20	2,26	1,29	1,53
9	25,77	4,09	2,65	2,73	1,67	1,99
10	33,53	5,33	3,21	3,30	2,74	3,26
11	76,47	12,15	9,58	9,85	5,24	6,25
12	45,17	7,17	5,99	6,16	3,28	3,91
13	17,48	2,78	2,30	2,37	1,13	1,35
14/območje plazenja leta 1998	7,94	1,26	0,41	0,42	0,20	0,24
skupaj	629,48	34,39	97,25	55,50	83,95	67,39

Slika 12: Razprostranjenost cestnega omrežja v južnih Goriških brdih (ordinata, v km) glede na naklon površja (abscisa, v stopinjah).
Glej angleški del prispevka.

Z vidika urejanja prostora, ki je pri nas v pristojnosti občin, je pomembna primerjava območij plazovitosti z območji poselitve. Na celotnem območju južnih Goriških brd je poseljenih približno 50 ha površin.

Kar tretjina stavb v južnih Goriških brdih leži na plazovitih območjih. Od tega jih polovica leži na območjih z veliko možnostjo nastanka zemeljskih plazov (9–14. kategorija), četrtino stavb pa zemeljski plazovi malo ogrožajo, saj ležijo na območjih z manj kot 6. kategorijo plazovitosti.

Preglednica 3: Plazovitost poseljenih območij v južnih Goriških brdih.

kategorija plazovitosti	število stavb*	delež stavb (%)
0	2079	–
1	66	5,97
2	15	1,36
3	35	3,16
4	31	2,80
5	45	4,07
6	47	4,25
7	236	21,34
8	57	5,15
9	83	7,50
10	100	9,04
11	234	21,16
12	121	10,94
13	34	3,07
14/območje plazenja leta 1998	2	0,18
skupaj	3185	100,00

* Število stavb ni povsem točno, ker je izračun narejen na podlagi podatkov digitalnega modela višin s temeljno celico velikosti 12,5 krat 12,5 metrov.

5 Sklep

Goriška brda so ena od slovenskih pokrajin, kjer naravne razmere omogočajo intenzivno kmetijsko proizvodnjo, številni dejavniki pa človekovo dejavnost onemogočajo. Zemeljski plazovi so v Goriških brdih stalen problem (Grimšičar 1962; Vrišer 1954; 1956).

Opisani zemljevid plazovitosti je v celoti izdelan s probabilistično metodo. Prvič je bil v Sloveniji za izdelavo takšnega zemljevida uporabljen Dempster-Shaferjev algoritem. Do sedaj smo povečini uporabljali deterministične (Natek in ostali 2003; Zorn, Komac 2004a; Komac, Zorn 2005a; Komac, Zorn 2005b; Zorn, Komac 2005) in redkeje probabilistične metode (Komac 2005b; Komac, Zorn 2006; Komac, Zorn 2007). Na primeru zemljevida plazovitosti Goriških brd lahko ugotovimo, da je probabilistična metoda boljša.

Zemljevid je uporaben za načrtovanje rabe prostora do ravni naselja in je dobra podlaga za detajlno geomorfološko kartiranje plazovitih območij. Za pravilno interpretacijo zemljevida pa je treba poznati metodo, po kateri je bil izdelan ter dobre in slabe strani uporabljenih (digitalnih) podatkov, na primer digitalnega modela višin s temeljno celico 12,5 krat 12,5 metrov, zemljevida rabe tal, vinogradniških teras in podobno.

Čeprav je zemljevid izdelan na podlagi absolutnih podatkov (zemeljski plazovi, ki so nastali ob znanih razmerah v preteklosti), ga ne moremo intepretirati na ta način. Uporabljena lestvica kategorij plazovitosti je relativno merilo večje oziroma manjše možnosti za nastanek plazov. Najvišje kategorije plazovitosti prikazujejo območja, za katera moremo reči, da na njih ob nespremenjenih drugih dejavnikih (na primer raba tal) lahko nastanejo usadi ali zemeljski plazovi po padavinah s povratno dobo nekaj deset (približno petdeset) let. Za nižje kategorije plazovitosti lahko rečemo le to, da je plazovitost na njih manjša.

Zemeljski plazovi v Sloveniji povzročijo približno 10 % škode zaradi naravnih nesreč, ki je v obdobju 1995–2003 obsegala 1,25–23,8 milijona evrov. Leta 2002 so sredstva za sanacijo obsegala skoraj 80 %

vrednosti škode, leta 2003 pa so jo na primer za štirikrat presegala. Zaradi naravnih nesreč povprečno letno izgubimo dva do tri odstotke bruto družbenega proizvoda, ob velikih naravnih nesrečah pa še veliko več (Komac, Zorn 2005a). Leta 1993 so samo zemeljski plazovi povzročili škodo v višini 4,8 % bruto družbenega proizvoda (Fajfar in ostali 2005). Vsakršni razumni preventivni ukrepi – tudi na temelju zemljevidov plazovitosti – bi zelo verjetno močno znižali visoke stroške sanacij.

Z vidika kmetijskega gospodarjenja je do neke mere zaskrbljujoča ugotovitev, da je plazovit pretežni del (80 %) preučevanega območja oziroma južnih Goriških brd. Zato bi bilo potrebno z vidika plazovitosti zlasti kmetijsko dejavnost, ki z gradnjo vinogradniških teras povzroča nestabilnost pobočij in s tem povezane stroške sanacije (čas in denarna sredstva), dolgoročno usmeriti na območja z manjšo plazovitostjo, ki se povečini raztezajo v vzhodnem delu južnih Goriških brd. Pri gradnji teras je potrebno upoštevati pogostost zemeljskih plazov pri določenih naklonih, zelo pomemben dejavnik pa je vpad kamninskih plasti ali njihova usmerjenost glede na potek pobočja.

Na plazovitost bi morali biti posebej pozorni tudi pri gradnji novih prometnic in stavb oziroma pri določanju poselitvenih območij ali širjenju naselij, ki pa zaradi dolgotrajne poseljenosti območja v veliki meri že upoštevajo naravne razmere.

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6 Literatura

Glej angleški del prispevka.