INTEGRATION OF THE MEASUREMENT TECHNIQUES USED FOR MONITORING THE LAZE LANDSLIDE IN SLOVENIA

VKLJUČEVANJE MERILNIH TEHNIK, KI SE UPORABLJAJO ZA SPREMLJANJE PLAZU LAZE V SLOVENIJI

Aleš Lazar
Geoservis, d.o.o.
Litijska cesta 45, 1000 Ljubljana, Slovenia
E-mail: ales.lazar@geoservis.si

Tomaž Beguš
Geotrias, d.o.o.
Dimičeva ulica 14, 1000 Ljubljana, Slovenia
E-mail: t.begus@gmail.com

Milivoj Vulić
University of Ljubljana,
Faculty of Natural Sciences and Engineering
Aškerčeva cesta 12, 1000 Ljubljana, Slovenia
E-mail: milivoj.vulic@guest.arnes.si

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Ključne besede

monitoring, plaz, analiza premikov in deformacij, geotehnologija, varstvo okolja

Abstract

The slow movement of the terrain in the area of the village Laze in the municipality Gorenja vas-Poljane accelerated significantly after heavy rainfall in early 2014. Research was conducted to determine the volume of the landslide, the depth of the sliding plane and the displacement dynamics. During a study of the creep sliding dynamics we found the old orthophoto plans and a comparison of the cyclic aerial imagery very useful. The article describes the monitoring system that has been established and describes innovative procedures for using existing spatial data for a better interpretation of the movement dynamics. These comparative analyses of the absolute or relative shifts are useful for land-use planners and for risk analysis as a part of an environmental policy.

Izvleček

Počasno premikanje terena na območju vasi Laze v občini Gorenja vas-Poljane se je močno pospešilo po intenzivnih padavinah v začetku leta 2014. Raziskave so bile izvedene za določitev prostornine plazu, globine drseče ravnine in dinamike premika. Med študijo dinamike drsenja lezenja smo ugotovili stare ortofoto načrte in primerjavo cikličnih letalskih posnetkov za zelo koristne. Članek opisuje vzpostavljen sistem spremljanja in opisuje inovativne postopke za uporabo obstoječih prostorskih podatkov za boljšo interpretacijo dinamike gibanja. Te primerjalne analize absolutnih ali relativnih premikov so uporabne za načrtovalce rabe zemljišč in za analizo tveganja kot del okoljske politike.

1 INTRODUCTION

The landslide body is composed of rock, debris or soil. A slip occurs within the mass of this composition or at the contact with the ground [1]. One third of the Slovenian territory is defined by a high to a very high probability of landslides [2]. Landslides endanger people, housing and infrastructure [3,4,5]. In 2015, 7273 landslides were recorded on the Slovenian territory [6]. Smaller landslides, depressions and rockfalls are the most common [2,7,8,9].

A natural risk analysis is an essential part of any preventive action and a cornerstone of spatial planning assessments, programs and policies [10,11,12,13]. The first condition for successful prevention is to recognize and understand the properties of the slope's mass movements and the local factors that cause them [14]. The properties of these processes can be determined by establishing a monitoring system to perform periodic and systematic observations and obtain data on changes in time and space [15,16,17,18]. For this purpose, the results of the different measurement methods for observation are used [9,19,20,21,22,23,24,25].

1.1 The area of research

The Laze landslide represents a morphological form between the valley below the ridge of Blegoš in the north and the Kopačnica valley in the south, and generally falls at an angle of 10°. It winds in an S shape down the terrain (shown in Figure 1). The length of the morphological form is 3 km, its width is 0.4 km, and it narrows towards the valley so that at the bottom it is approx. 70 m wide. The area of the Laze landslide is estimated to be 105.5 ha. Traces of the movement of the terrain are visible throughout the area, either as a morphologically pronounced crease of the terrain or as an extremely thick cover or an active land movement. Considering the extremely active land movement within the area of the Laze landslide, we distinguish two parts:

- The **upper landslide** in the Slug valley is a mud stream 600 m long, 130 m wide and is characterized by scattered trees and clearly visible movement of the terrain. Sliding has been active for a long time (at least 20 years). The size of the area was estimated to be 4.8 ha and is several meters thick,
- The **landslide in Laze village** is 550 m long and 250 m wide and is characterized by marked cracks that extend in the direction of the slope, especially at the edges of the movement. They occurred in January and February 2014 as a result of intense rainfall [26]. The size of the area was estimated to be 10.5 ha and is several meters thick.

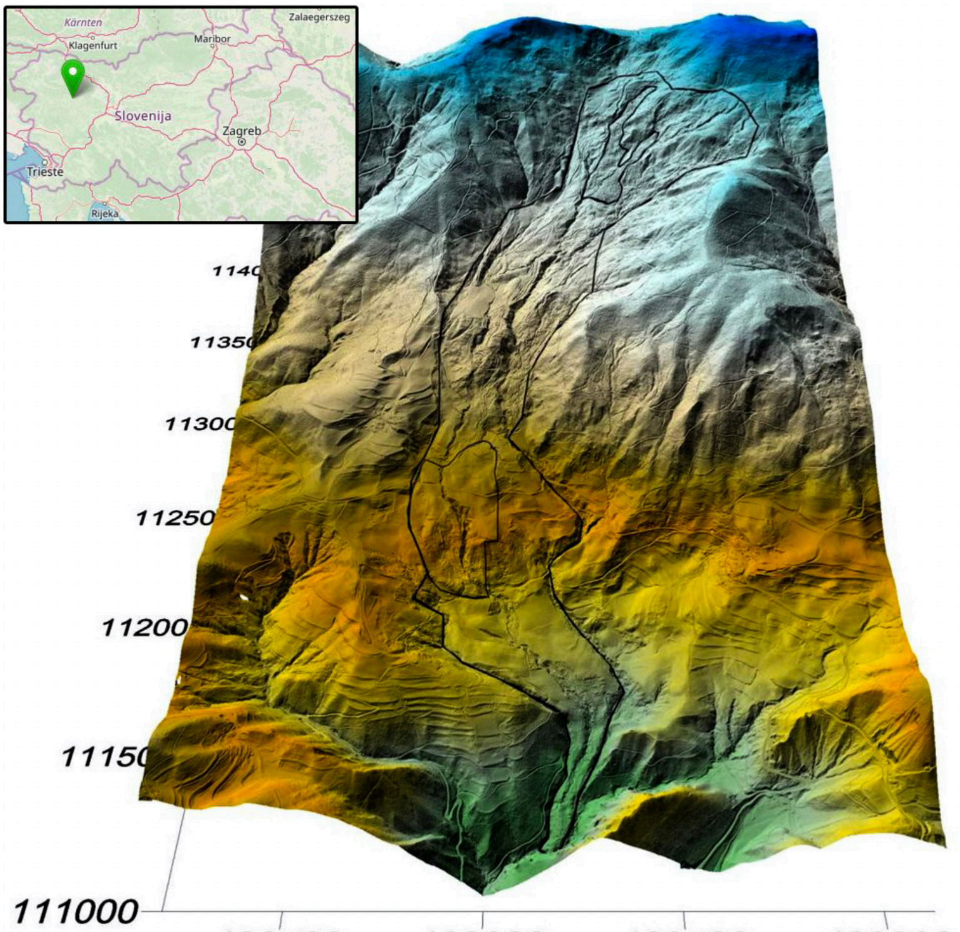

Figure 1. 3D view of the Laze landslide with two of the most active parts. Looking north.

The area of Blegoš, including the examined area, represents a complex tectonic contact between the outer and inner Dinarides, which manifests itself in the form of vertical breaks or fracture zones and thrusts (Figure 2). The thrusts occur in the northern part of the map (upper landslide) and break in the area of the village Laze. Tectonic elements certainly influence the sliding in terms of creating preferential waterways, water barriers and directed clay lots within rock packages.

Generally speaking, the entire area consists of Ladinian and Carnian rock - Pseudo-zilian beds. These are dark-gray graywacke, aleurolites and clay slate, tuff, tuffite, rhyolite and in some places dark gray limestone. These rocks are characterized by rapid weathering and high subjection to sliding, especially when in contact with water. At the end of the landslide the dolomite and rarely limestone of the Norian and Rhaetic ages appear in layers and belts. These layers represent a kind of barrier to the landslide material.

2 MATERIALS AND METHODS

Measurement networks and individual groups of monitoring parameters were focused on finding the volume of the landslide, the sliding dynamics, the depth of the landslide, determining the groundwater depth, and finding options to reduce the movement by lowering the groundwater levels. With these measures the image of the landslide was made and based on these appropriate measures were prescribed. Depending on the nature of the measurements, we divide them into monitoring networks. A graphical representation of the position of the networks is shown in Figure 3. Analytical shading of the digital terrain model is used for the background of the map [27].

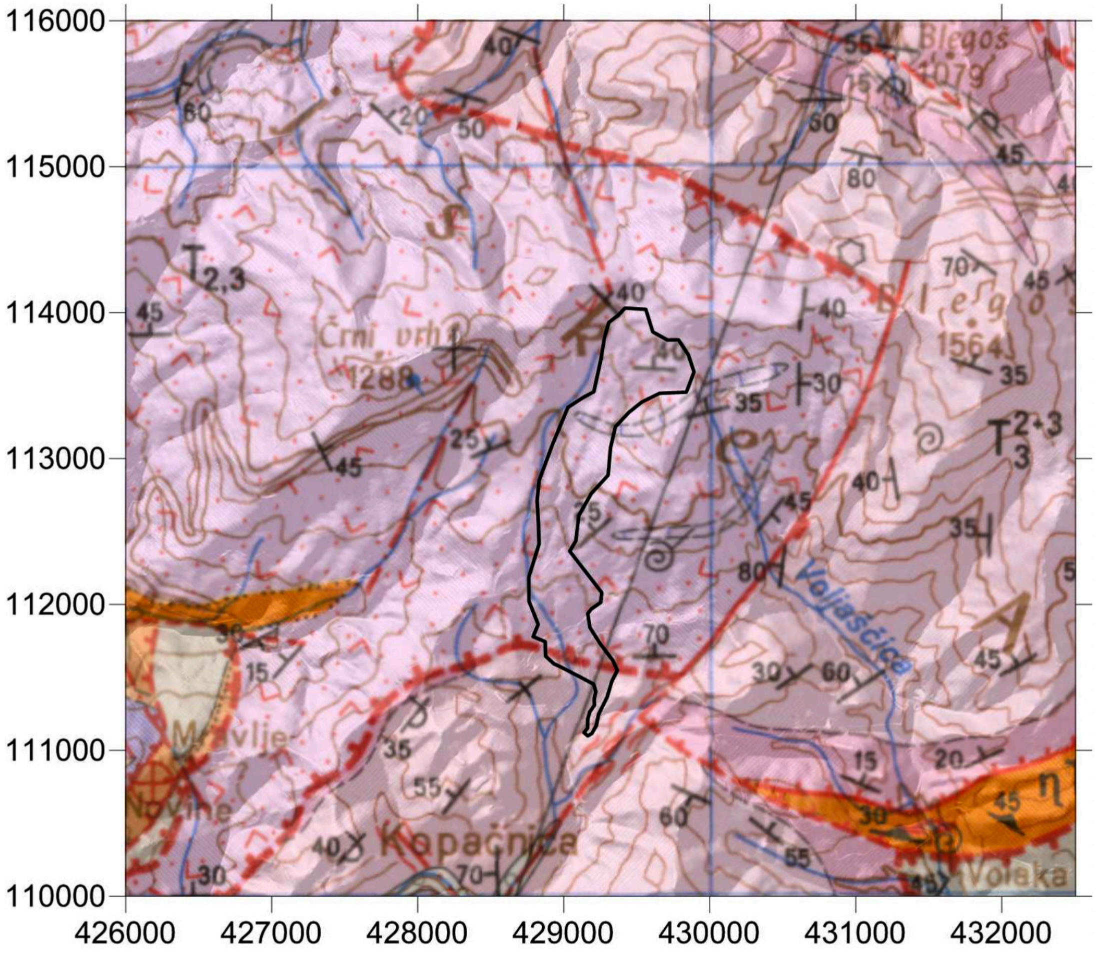

Figure 2. Position of the Laze landslide in the Basic geological map, sheet Kranj: The majority of the area consists of Pseudo Ziljan beds.

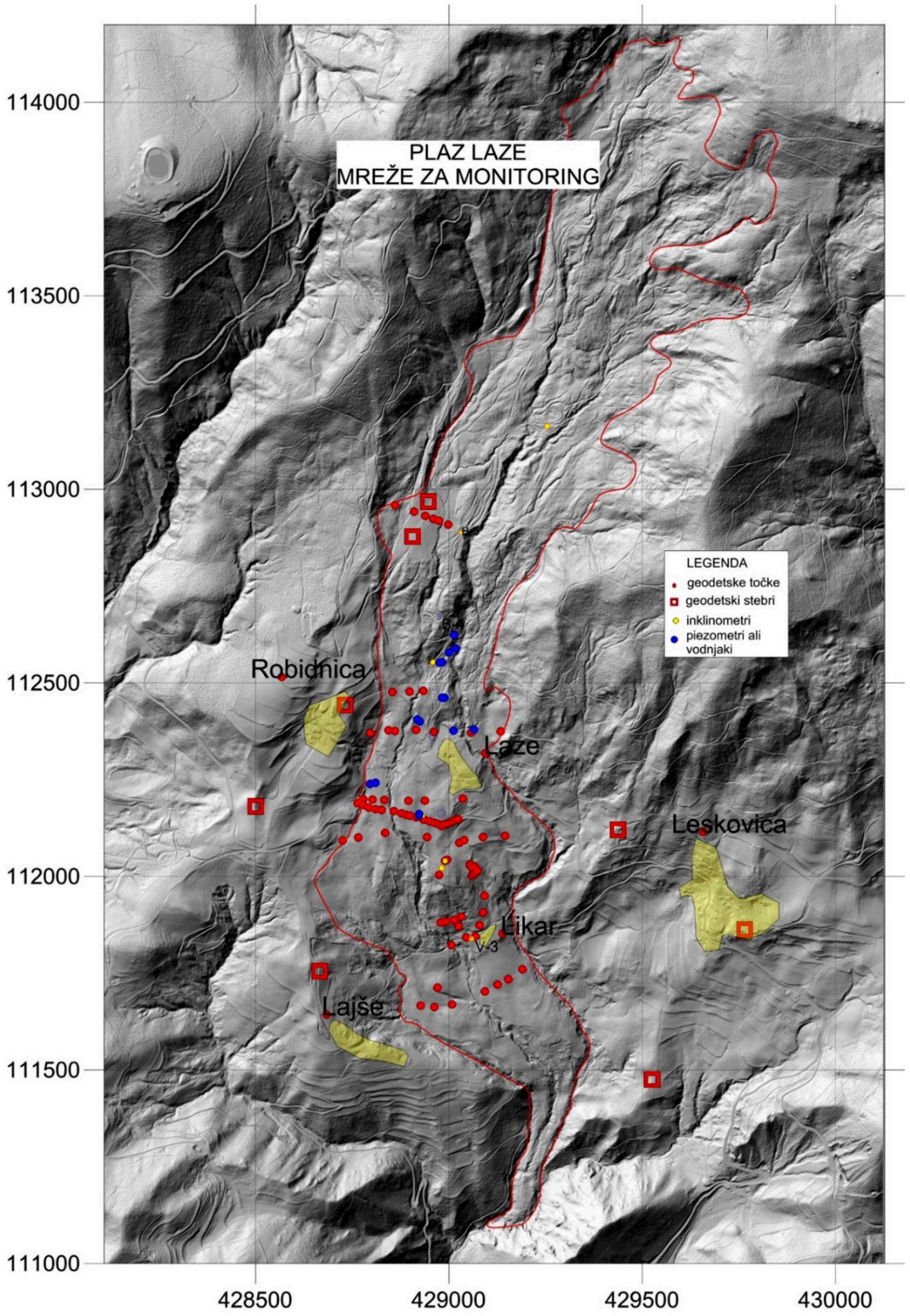

Figure 3. A system of Laze landslide monitoring networks.

Figure 4. Landslide in the Slug Valley. Laze in the background. Looking south.

2.1 Overview of the landslide area and the use of an unmanned aerial vehicle

The landslide was first thoroughly examined by visual inspection, especially the area where the morphological features indicated possible sliding. This information was supplemented with occasional flights using unmanned aircraft (Figure 4). These data were initially used to determine the extent of the sliding area; the main morphological characteristics to determine the dynamics of the sliding.

2.2 Inclination boreholes

In the Laze landslide area, eight boreholes were drilled between 2014 and 2016 to determine and monitor the depth of the sliding surface. Six boreholes were drilled to determine the depth of the sliding surface. An additional two boreholes were made to control the movement above the structure (house/homestead). Geomechanical laboratory tests were carried out on samples from some of the boreholes.

2.3 Wells for monitoring the water level and the pumping water

Boreholes for monitoring the groundwater levels and the pumping water that supplies the landslide were drilled in 2015 and 2016. Large boreholes (nominal 300 mm) called **wells** (marked VOD) were equipped with filters, and boreholes of smaller diameter called **piezometers** (code Pz) were drilled for monitoring the water level.

In 2015, three pairs of wells were drilled: wells for groundwater extraction (300 mm in diameter and 34 m in length) and adjacent wells, piezometers, smaller in diameter (100 mm) and about the same length. The groundwater levels were then determined in these wells. In two of the three wells, the soil is so impermeable that it is not possible to pump water. One of these three wells is suitable for intensive water pumping and the other two are for inclination measurements. The groundwater levels are systematically monitored in these wells. One of the wells along the side of the road has a groundwater level meter installed and in the event of a sudden rise an alarm is sounded.

2.4. Surveying and LIDAR terrain recording

Prior to conducting the research, LIDAR was recorded for the entire area where the sliding occurred.

The first movement-monitoring network was set up in 2015. At that time, 37 measurement points were set. The layout of the measuring points followed the most evident shifts in the lower landslide area and around the houses.

Figure 5. On the left, a measuring column on stable ground, in the background Leskovica, where a measuring prism is placed on the bell tower. Right, polygon point in the ground under a protective cover.

In 2016, the movement-monitoring network was systematized and extended to the entire area of the Laze landslide. The system is based on seven cross-sections on the landslide, which determine those parts of the landslide that are moving faster. There are 95 measuring points. The network is based on eight fixed geodetic points outside the landslide area, the position of which is determined by precise GNSS observation. The fixed points are the starting points for each observation. The obtained data are millimeter precision. The heights are absolute.

2.5 Measurement stations

Displacement sensors were initially set on the lateral portions of the landslide to monitor the movements in real time. In the event of major sudden movements, an alarm is triggered and the appropriate municipal emergency department is notified. The results did not show a clearly pronounced movement that could be registered. Therefore, a landslide displacement-measurement system was set up at the landslide, which is then transmitted to

Figure 6. On the left, searching for a movement detector location through a clearly pronounced lateral crack. Right, measuring station to monitor the movement in the borehole. Station MS1.

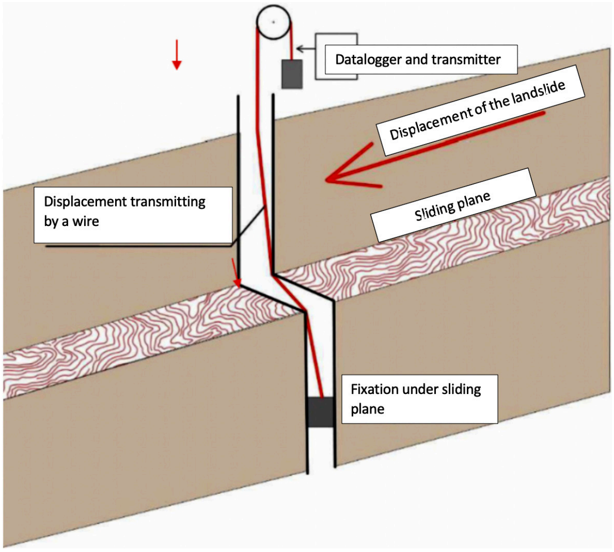

Figure 7. Schematic representation of a measurement at the measuring stations [28].

surface recorders with a system that enables immediate reporting to the appropriate services. Inclination boreholes are used in which an anchor is fixed under the sliding surface. The registers record the movements.

On the cracks in the apartment house of the Likar homestead, a measuring instrument is installed to measure the movements of the cracks. This part also has a rain station.

2.6 Review of old aerial photographs

Since 1985 Slovenia has been regularly aerial recording in the envisaged three-year cycles (Cyclical Aerial Survey - CAS). In 2003, part of the territory was first recorded in color. Since 1994, aerial photographs of Slovenia and their enlargements have been made publicly available. Aerial imagery is basically the source for making orthophoto plans [29].

As part of the analysis of landslide movement in the past, we have reviewed older and newer orthophoto plans. We performed a comparative analysis between them to determine the dynamics of the movements in different periods.

3. PROCEDURES AND RESULTS

3.1 Landslide area inspection and unmanned aerial vehicle inspections

The morphological forms that indicated sliding did not change in the post-2014 period to an extent to determine the dynamics. The most obvious are the shifts on the local municipal road, where the two lateral sections of the landslide are clearly showing shear cracks.

3.2 Results of the inclination measurements

Inclinations in individual boreholes were measured for the first time a few weeks after installation, as there was a fear that measurements could no longer be possible due to the displacements.

In three boreholes (I-1, I-2 and I-3; manufactured in 2014), a shift in boreholes was evident shortly after the installation. The boreholes I-1 and I-2 were already considerably displaced in 2015. For this reason, further measurements were no longer possible.

From the inclination measurements, the sliding surface of the Laze landslide was clearly determined. Movement dynamics can also be seen from the measurements. Impenetrable boreholes were used to continuously monitor the landslide movements.

Table 1. Results of the inclination measurements.

borehole	Feature - sliding surface at depth
I-1/2014	Sliding surface at depth 24–25 m
I-2/2014	Sliding surface at depth 31–32 m
I-3/2014	Sliding surface at depth 20 m and minor displacement at depth 6–7 m
I-4/2015	Sliding surface at depth 22–26 m
I-5/2015	Sliding surface position not clear, possibly at depth 56 m
I-6/2015	Sliding surface at depth 31 m
I-7/2016	Displacement at depth 25–26 m
I-8/2016	Displacement at depth 23–24 m

3.3 Results for monitoring the water level and pumping water

A water pumping test was performed at each well. In most boreholes, a probe was installed to automatically register the levels.

Samples for chemical analysis of the water were taken from some boreholes. The boreholes contain sodium calcium hydrocarbonate sulphate water and sodium calcium hydrocarbonate water.

In most boreholes, the groundwater level does not, or very poorly, fluctuate. Bores indicating a higher amplitude of oscillation are likely to be in the more fractured area (inclinometers).

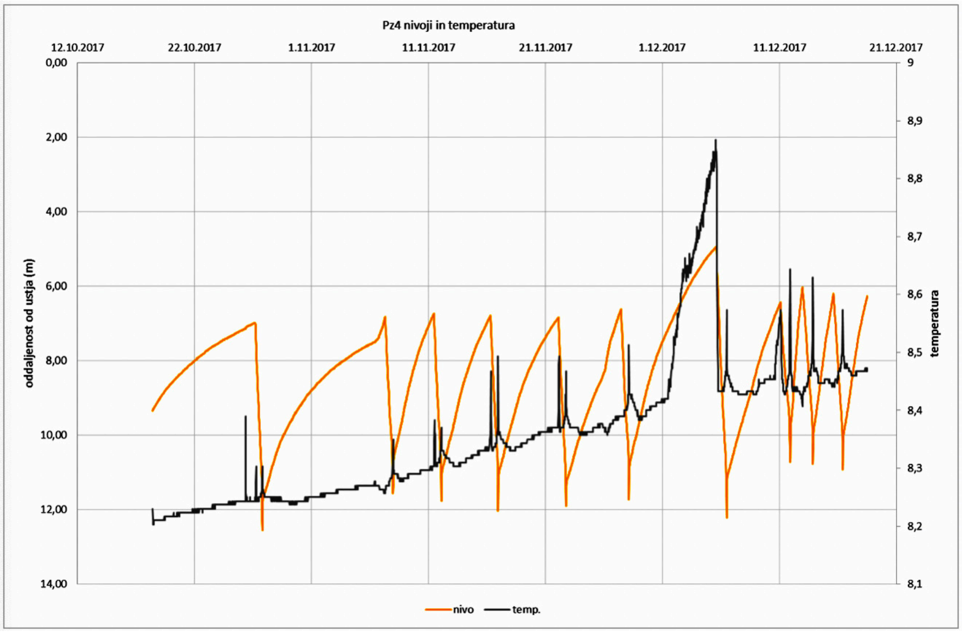

Figure 8. Influence of pumping water in well 4/16 on the level in the Pz4 piezometer.

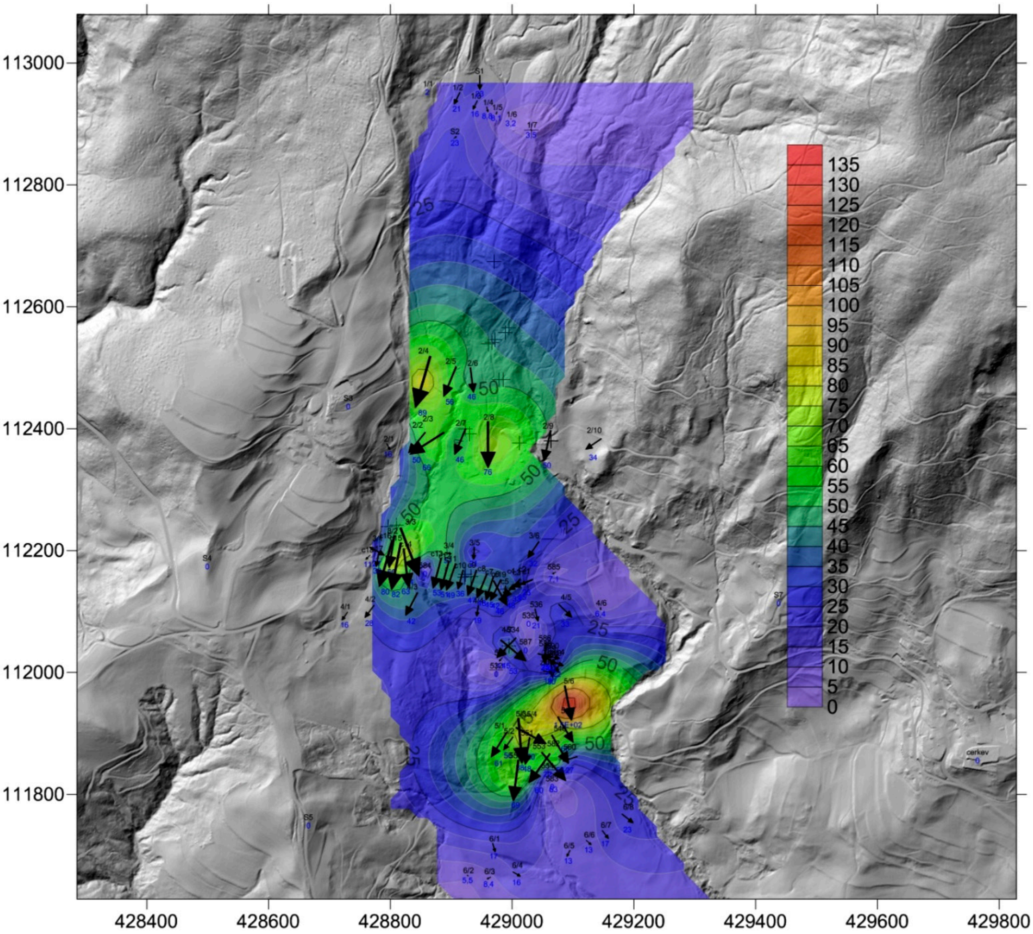

Figure 9. Isolines of the annual displacements of the Laze landslide.

The effect of the pumping water in Platoon 4/16 on the level in Pz4 is clearly visible.

3.4 Tracking movements and ground settlement

The results of two cyclical LIDAR recordings of the Laze landslide were available: from 2014 and 2015. Due to the short periods in between the two recordings, the movements could not be determined. It is also difficult to determine the translational movements of the landslide from the LIDAR recording if no markers are present in the field.

A review of the results of the measurements between 2015 and 2017 showed displacements throughout the measured area. They average 8 cm/year. We made isolines of the annual displacements (Figure 9).

3.5 Past displacements

We examined the spatially placed orthophoto plans of the Laze landslide area. The geometric resolution (pixel size on the ground) was not precise enough for our purposes. With the occurrence of coloured orthophotos, the usefulness of these products for the purposes of landslide monitoring has increased.

We performed a comparative analysis between the orthophotos from 2005 and 2014. We identified the same elements on both orthophotos. The older type of orthophotos do not have our own observation points, so we monitored objects and their position in space. As the most reliable object in nature, we recognized the power line in combination with its visible shadow. Although the power lines on the orthophotos are projected differently, their contact with the earth is well defined by the

Figure 10. The left image shows a 2004 photo where the position of the power line pole on the ground (arrow) is clearly visible. The right image shows a 2014 photo of the same pole marked with a cross. The displacement is obvious and is 2.1 m.

Figure 11. Graphical display of the displacements between 2005 and 2014.

Table 2. Displacements on the Laze landslide between 2005 and 2014.

Difference 2005 - 2014					
ID	dX (m)	dY (m)	dH (m)	movement dXY (m)	3D movement (m)
1	-0.037	-2.555	-0.291	2.56	2.57
2	-0.223	-1.502	0.004	1.52	1.52
3	0.027	-1.980	-0.349	1.98	2.01
4	-0.265	-2.249	-0.211	2.26	2.27
5	-0.172	-1.993	-0.189	2.00	2.01
6	0.000	-2.289	0.064	2.29	2.29
7	-0.049	-2.070	-1.258	2.07	2.42
8	0.062	-2.129	-0.249	2.13	2.14
9	0.062	-2.006	-0.418	2.01	2.05
10	-0.031	-1.267	0.211	1.27	1.28
11	0.062	-1.081	0.086	1.08	1.09
12	0.683	-1.850	-0.239	1.97	1.99
13	0.543	-1.772	-0.663	1.85	1.97
14	0.544	-1.983	-0.157	2.06	2.06
15	0.477	-1.981	-0.069	2.04	2.04
16	-0.200	-2.049	-0.482	2.06	2.11
17	-0.085	-2.088	-0.201	2.09	2.10
18	0.321	-0.921	-1.389	0.98	1.70
19	0.361	-1.482	-0.300	1.53	1.55
20	0.961	-1.235	-0.449	1.56	1.63
21	0.894	-2.179	0.052	2.35	2.36
22	-0.077	-0.384	-0.189	0.39	0.43
23	0.038	-0.133	-0.018	0.14	0.14
24	1.484	0.816	-0.018	1.69	1.69
25	0.742	-0.742	-0.251	1.05	1.08
26	0.646	-0.246	-0.004	0.69	0.69
27	0.039	-2.208	-0.360	2.21	2.24
28	0.237	-2.287	-0.231	2.30	2.31
29	-0.039	-2.405	-0.014	2.41	2.41
30	0.000	-2.366	0.317	2.37	2.39
31	0.237	-1.735	-0.144	1.75	1.76
32	-0.315	-2.484	-0.296	2.50	2.52
33	-0.473	-2.168	-0.022	2.22	2.22
34	-0.710	-1.853	-0.309	1.98	2.01
35	0.777	-0.915	-0.457	1.20	1.28
36	0.056	-0.224	-0.007	0.23	0.23
37	0.067	0.000	-0.007	0.07	0.07
38	0.000	-0.103	-0.006	0.10	0.10
39	-0.310	-0.155	-0.092	0.35	0.36
40	0.000	-0.144	-0.023	0.14	0.15
41	0.648	0.576	-0.023	0.87	0.87
42	0.000	-0.230	-0.092	0.23	0.25
43	-0.134	-0.269	-0.095	0.30	0.31
44	0.000	-0.134	-0.044	0.13	0.14
45	-0.044	-0.311	-0.048	0.31	0.32
46	0.622	-0.266	-0.198	0.68	0.70
47	-0.526	0.364	0.031	0.64	0.64
48	0.690	-1.610	-0.852	1.75	1.95
49	0.236	-1.892	-0.219	1.91	1.92
50	0.047	-2.081	-0.279	2.08	2.10
51	-0.636	-1.765	-0.164	1.88	1.88
			Max displacement:	2.56	2.57
			Average displacements:	1.46	1.50

onset of the shadow (example in Figure 10). The elevation data is related to the digital terrain model that was generated when creating the orthophotos.

During a period of 9 years (between 2005 and 2014) the landslide in the village Laze has moved approximately 1.5 to a maximum of 2.5 meters. The graphical representation of the movements during this period is illustrated in Figure 11, where the average displacement is emphasized (the graphical basis is DOF 2014).

4 DISCUSSION

Landslide monitoring is performed by physical inspections of the landslide, measurements and study of the obtained parameters. With physical inspection of the landslide, possible changes are determined. The study of the data obtained determines the extent of the displacements and the dynamics of the sliding.

A very rough projection of the volume of stored water in the landslide may be as follows. The water supply surroundings of the village Laze measure 1.045 km^2, a thickness of 30 m and a porosity of 5 %. The conclusion is that 1,568,358 m^3 (1,045,572 m^2 x 30 m * 0.05) of water can be stored in the landslide. If this water seizes ½ of the total landslide volume, we expect the volume of water to be 784,179 m^3.

Rainfall at the Leskovica rain station is 1742 mm/year. Subtracting evaporation (500 mm/year) from this quantity and the drainage coefficient at 0.3 gives the following values: Q = 1,045,572 m^2 x 1242 l/m^2 x 0.7 = 909,020 m^3 of stored water annually. By pumping, at least 10 % of this water could be removed.

The entire unstable region of Laze is subject to sliding, which is activated at different time periods. Different areas move as different episodes, and the movement covers the entire area. During the 2014–2016 survey phase, it was determined that the sliding plane was at least 20–30 m below the surface of village Laze, and that it slides approximately a decimetre per year. The largest displacement occurred in January 2014, before the measures to reduce the speed of the sliding had been taken. Between 2005 and 2014, the average displacement was 1.5 m.

Because of its constant movement, the dynamics of sliding was detected on the older orthophoto plan from 2005. In identifying the same objects on orthophotos from different periods, we used an innovative method where we determined the ground point of power-line poles. Vertical objects at the junction with their shadow define the point on the ground. On condition that it is sunny.

In Slovenia, a cyclic aerial survey is carried out approximately every 3 years. This permanently creates an orthophoto and digital terrain model for the whole territory of Slovenia. The survey shows that by comparing well-defined points on orthophotos from different periods, the dynamics of the movement of natural objects can be monitored. With new insights into determining landslide dynamics, we can model predictions of landslide movement. By analysing the stability of the slopes, the risk of landslides can be determined.

5 CONCLUSIONS

The Laze landslide is classified as a slow-moving landslide (summarized by [30,31,32]). Water is the main generator of the sliding. By pumping water from the wells, the water flow in the sliding area is reduced. Since 2014, when these measures were taken, the landslide in the observed area slides about 8 cm per year. Prior to the measures, its speed was estimated to be 16 cm per year, and therefore twice as fast.

Changes in time and space can also be determined for the period prior to the establishment of the systematic monitoring of the landslide if spatial data such as a cyclic aerial survey were periodically obtained in the area. In Slovenia, this system is well regulated, which is why we have a great potential for establishing a high-quality landslide-forecasting model. This would reduce the risk of natural disasters as part of environmental policy.

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