Results of Recent Monitoring Activities on Landslide Umka, Belgrade, Serbia —IPL 181

Biljana Abolmasov, Uroš Đurić, Jovan Popović, Marko Pejić, Mileva Samardžić Petrović, Nenad Brodić

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Results of Recent Monitoring Activities on Landslide Umka, Belgrade, Serbia—IPL 181

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Abstract

Results of recent monitoring activities conducted from 2014 to 2019 are presented in the paper as a part of IPL 181 Project progress report. Recent monitoring activities are concentrated on several landslide monitoring techniques—automated GNSS monitoring system measurements, geodetic benchmark survey monitoring, UAV imaging, processing and analysis, and PSInSAR data processing and analysis. Results of all monitoring activities were analysed and used for cross-correlation and for verification of monitoring results obtained from different techniques. Displacement rates from GNSS measurements indicate that object point UmkaGNSS2 has moved 0.30 m towards the North and 0.50 m towards the West, while the vertical displacement was approximately −0.15 m for the 2014–2018 time span. Similar range of GNSS displacement rates were found in previously published results from monitoring activities realized from 2010–2014. PSInSAR data analysis also showed good correlation between nearest PS points and GNSS point for the same period of monitoring. Results from UAV and geodetic benchmarks survey showed very good correlation in displacement vectors' direction. According to the analyzed data it could be concluded that all monitoring results are in compliance with previous research results and confirm that the Umka is slow to very slow moving landslide with cyclic acceleration and deceleration phases.

Keywords

Landslide • Monitoring • GNSS • Geodetic survey benchmarks • UAV images • PSInSAR

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Introduction

The IPL project No 181 titled "Study of slow moving landslide Umka near Belgrade" started in November 2012. Basic objective of the Project is to enable the analysis, correlation and synthesis of data obtained from various phases of investigation conducted on the Umka landslide after a few decades of research. Results received from geotechnical monitoring conducted during certain phases of research are compared with data from automated GNSS monitoring of last ten years and recent monitoring activities conducted in the last four years. Synthesis of research results help us define the mechanism and dynamics of this large, active, and slow landslide, with the final objective to propose adequate remedial measures. Project results would also help in better understanding of other landslides found on the right bank of the Sava river. More details about the project mission, objectives and goals can be found at Abolmasov et al. (2014, 2017).

Comprehensive analysis and results of previous geotechnical investigations and monitoring activities on Umka landslide from 2005–2014, were presented in Abolmasov et al. (2015). Recent monitoring activities are concentrated on several landslide monitoring techniques introduced after 2014—geodetic benchmark survey

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monitoring, UAV imaging, processing and analysis, and PSInSAR data processing and analysis, additionally to the existing GNNS monitoring system. The objective of this paper is to present the results of recent monitoring activities conducted from 2014 to 2019 as a part of IPL 181 Project report.

Study Area

The study area is located on the right bank of the Sava river, 25 km South-west of Belgrade, the capital of Serbia. Extensive geotechnical investigations and monitoring activities were conducted during several field campaigns in wider area during 1970–2006 (Vujanić et al. 1995; Mitrović and Jelisavac 2006). Most of the geotechnical investigations were performed for the Preliminary and Main Design for the Belgrade-Obrenovac Highway (E-763), and for the Umka urban plans and regulations. A summary of the geotechnical investigations results until 1995 can be found in Ćorić et al. (1996), while the summary of investigations and monitoring results until 2005 can be found in Mitrović and Jelisavac (2006).

Geometry, geological settings, mechanism and material properties of Umka landslide were well defined by previous geotechnical investigations. This landslide is fan-shaped, with the length along the slope of 900, 1650 m wide in the toe, reaching maximum depth of sliding surface at 26 m, and average slope gradient of 9°. Previous geotechnical research has shown that Umka landslide can be described as complex landslide within the stiff fissured Miocene (M_3^2) clayey marls. Landslide is active, with various phases of deceleration and acceleration, which are mostly in correlation with the Sava river level rise/drawdown, respectively, whereas landslide velocity is characterized as slow to very slow (Abolmasov et al. 2012, 2015).

The Umka landslide area is urbanized and populated with more than 490 inhabitants who are still living on the body of an active landslide. The state road IB 26 (from Belgrade to the state border with Bosnia and Herzegovina), is crossing landslide body and it is also constantly affected by slow displacement.

Previous Monitoring Activities (2010–2014)

Automated GNSS Monitoring

One of widely used system which is proven to be an effective and reliable tool for landslide monitoring is Global Navigation Satellite System (GNSS). Gili et al. (2000) give a general overview of the basic principles and discuss its applicability to landslide monitoring on Vallcebre landslide, in Spain. Since then, many published research papers presented successful landslide monitoring by GNSS and its integration with other observations (gained by other geodetic instruments such as automated total stations) across the world. GNSS landslide monitoring has proved its applicability especially for measuring surface deformations on large and slow-moving landslides (Mansour et al. 2011).

The first automated GNSS monitoring system in Serbia was established in March 2010, on Umka landslide (Abolmasov et al. 2012). The GNSS monitoring system consists of GNSS network and supporting software solution. The network is consisted of reference and object (monitoring) points on which GNSS stations (sensors) are mounted. Highly precise, multi-channel, multi-frequency systems (receivers and antennas) are used on all network points. Reference points are the integral part of the Active Geodetic Reference Network of Serbia (AGROS network), which is a permanent GNSS service of accurate satellite positioning over the Republic of Serbia.

The system is using two Leica Geosystems software solutions: GNSS Spider and GeoMoS (Geodetic Monitoring System). All observed GNSS measurements, with observation rate of 30 s, are collected by GNSS Spider and further forwarded, in a form of RINEX files, to GeoMoS Monitor and GeoMoS Analyzer on processing and further analysis, respectively.

The Umka landslide is represented by one object point (GNSS), which is located in the landslide body on the roof of a house (Abolmasov et al. 2012) (Fig. 1). This ten-years long project represents the longest continuous landslide monitoring in Serbia, and probably, one of the longest in the Balkan region. During these ten years of permanent monitoring, the GNSS network has changed one time due to the technical reasons, but the concept remained the same. The main change occurred due to the relocation of the Umka object point station (GNSS1), 25 m to Southwest—from one house to neighboring house in 2014 (Fig. 1). This change caused loss of more than 9 months of permanent monitoring, from the end of December 2013 until the September 2014 and the establishing new Umka monitoring point (GNSS2)(Fig. 1), already disscused and reported in Abolmasov et al. (2018).

During the first 45 months (March 2010–December 2013) the monitoring point Umka (GNSS1) has moved 0.46 m towards the North (Δx), and 0.70 m towards the West (Δy). Based on those results it can be concluded that the total 2D surface displacement was 0.84 m towards the Northwest, i.e. towards the Sava River. Furthermore, during the same period, the vertical displacement (Δz) of Umka GNSS1 sensor was nearly −0.30 m (Abolmasov et al. 2015).

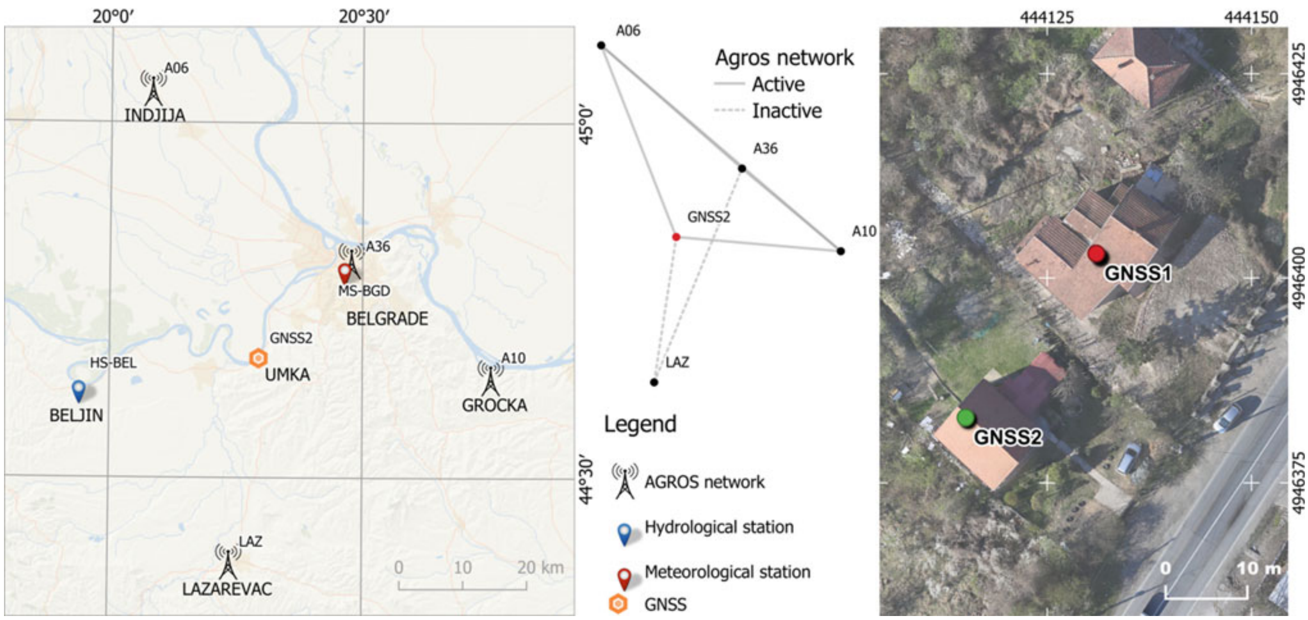


Fig. 1 Locations of Umka landslide area, GNSS stations, AGROS network stations, Belgrade Main meteorological station, and Beljin Sava river water level (hydrological) station

Recent Monitoring Activities (2014–2019)

In the past few years many authors integrated monitoring data from different sources to reduce uncertainities (Mateos et al. 2017, Casagli et al. 2017). In addition to the existing GNSS monitoring system on the Umka landslide, recent monitoring activities are composed of several newly introduced techniques for landslide monitoring: geodetic benchmark survey monitoring, UAV imaging with photogrammetric processing and analysis, and PSInSAR data processing and analysis. The main goals for introducing new monitoring techniques were: (1) to increase the number of surface monitoring points, (2) to test accuracy of existing and newly introduced monitoring techniques and (3) to compare monitoring data obtained from different techniques within same time span. Common to all implemented monitoring techniques is to measure displacement of the observed points (*dx*, *dy*, *dz*) on the landslide surface. Results of all monitoring data were analysed according to the measurments period and accuracy of monitoring techniques.

Data of climatological parameters and Sava River level are colected on daily basis from Hydrometerological Servise of Serbia from the begining of the monitoring project (2010), but correlation with monitoring results are not disscused and presented in this IPL181 Project report.

Geodetic Benchmarks Survey

In order to increse the number of surface monitoring points and to assess the reliability of photogrammetrically assessed displacements, conventional geodetic monitoring network was established during March 2018. The network initially consisted of 62 (1–62) object points, which were stabilized inside the landslide body and measured by RTK GNSS rover, as well as the four baseline points outside the landslide body in the stable ground. The high accuracy of the geodetic measurements in the research (positional <0.01 m and elevation accuracy <0.02 m), provides an accurate assessment of the displacements of object points. The location and distribution of the object points as well as baseline stable points are shown in Fig. 2. After processing, 59/62 points obtained from initial measurement were validated and they were used as “zero” measurement for further analysis. Two additional sequences of object points survey were conducted—in November 2018 and in March 2019. The main idea was to reconstruct surface displacement vectors from multiple sequences, as a represent of displacement within the landslide body. Displacement results were used for comparative analysis against photogrametric data obtained from UAV imaging covering the same period (2018–2019). Similar approach could be found in Peternel et al. (2017).

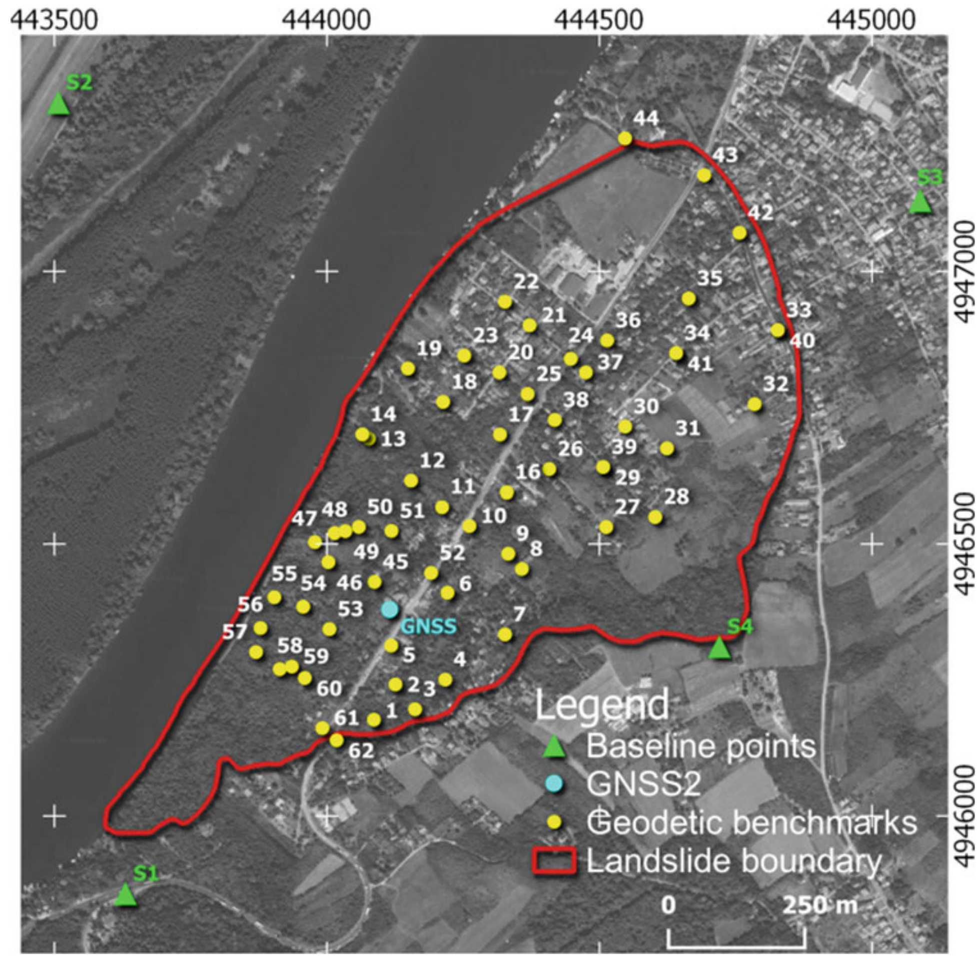


Fig. 2 Position of geodetic points and baseline points within Umka landslide area

UAV Imaging and Mapping

Using of small Unmanned Aerial Vechiles (UAV) systems and its implementation in Structure from Motion (SfM) photogrammetry is found very practical for landslide surface modeling and monitoring. Many advantages of UAV-based remote sensing for landslide characterization and monitoring were disccusesed in Colomina and Molina (2014), Balek and Blahut (2017), Peternel et al. (2017), Rossi et al. (2018). SfM method can provide accurate multitemporal and spatial surface products for landslide monitoring, primarily Digital Elevation Models (DEMs). Assuming the same procedure and same data quality, DEMs can be collected sequentially and compared. Change detection is used to reveal differences of the resulting DEMs, which are primarily caused by ground displacement.

Two aerial photogrammetric surveys were performed using aircraft DJI MATRICE 600 PRO industrial hexacopter with mounted DSLR camera Canon EOS 6D, resolution of 20.2 megapixels and focal length of 24 mm. More than 2000 images were taken by UAV during March 2018, and after manually removing blurred and oblique imagery, 1982 images were left for further processing. Forward image overlap was at least 90% and overlap between flight path rows was around 60%. UAV was flying at height of 80 m above take-off station achieving average pixel size of 2.2 cm. Seven flights were performed in order to cover the entire landslide area (Fig. 3).

"Zero" high resolution orthophoto and Digital Elevation Model (DEM) were principal SfM products from each sequence, as the same procedure was repeated in March 2019 and both obtained DEMs were analyzed and compared (DEM2018 vs DEM2019). These two sets of UAV aerial images (2018 and 2019) of the Umka landslide were used for generating the orthophotos, which were subsequently processed and analysed. Automated measurement and extraction of ground surface movements rate from these high resolution orthopohotos was conducted in Cosi-Corr software (https://www.tectonics.caltech.edu), with Statistical Correlator and kernel size 64 pix. Using Cosi-Corr software

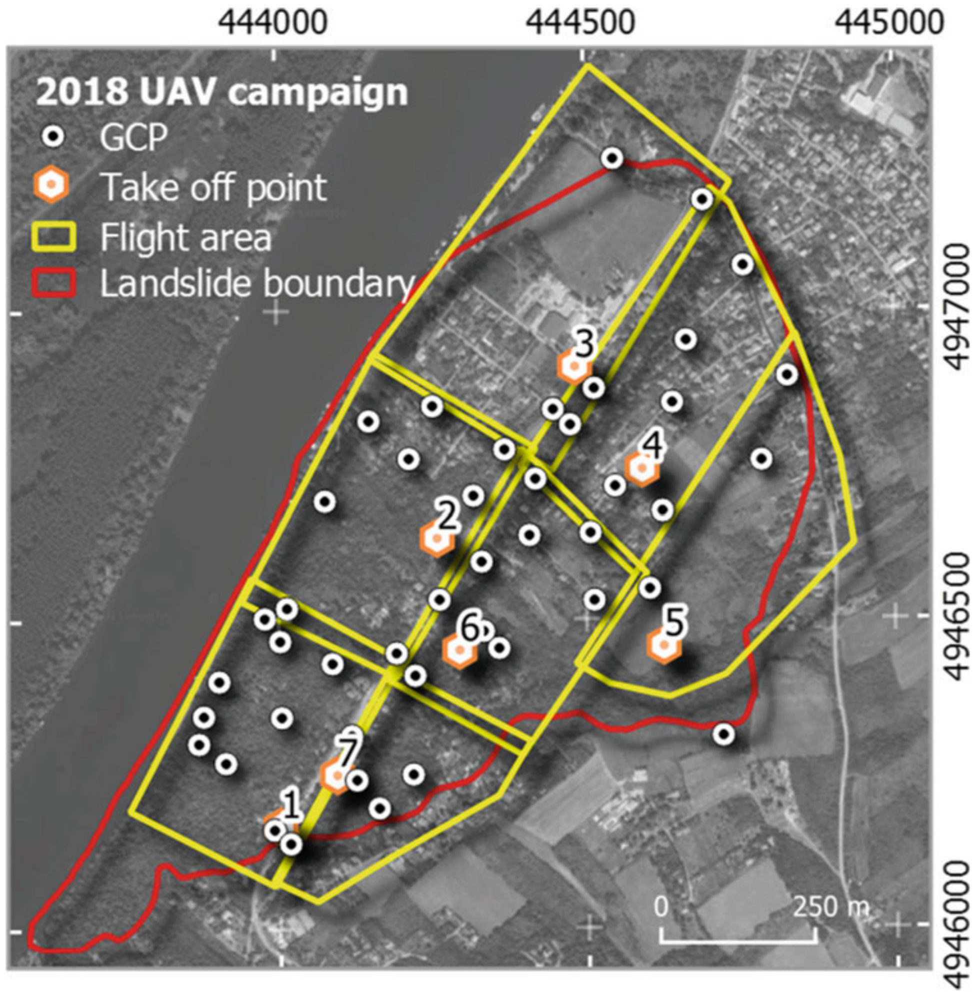


Fig. 3 UAV flight area (2018)

more than 25 k points were generated, and for each point 2D (x, y) vector and h (z) were calculated. According to the pixel size of processed images (2.2 cm) those generated points were filtered from noise, and only points with a higher displacement rate than 3 cm were selected and considered for further analysis and comparison. Those data were used for 2D points vector azimuth analysis and for comparison of points elevation (h) differences.

PSInSAR Data Analysis

Interferometric techniques named Persistent Scatter Interferometric Synthetic Aperture Radar (PSInSAR) have been developed and designed to generate time-series of ground deformations of individual coherent radar targets-Permanent Scatterers (PS). PSInSAR signal analysis allows estimating displacement of PS, acquisitions by acquisition. In the field of landslide monitoring the basic principles and possibility of using multi-temporal PSInSAR data were discussed in Tofani et al. (2013), Mateos et al. (2017), Casagli et al. (2017), Solari et al. (2019), Raspini et al. (2019).

In this research PSInSAR technique was used to analyze radar satellite images for displacement measurement from 2016 to 2018. ASF Earth Data search engine (https://vertex.daac.asf.alaska.edu) was used to select and download more than 140 radar images from ESA Sentinel 1a satellite mission over Umka landslide wider area (74 images from ascending and 69 images from descending acquisition mode) (Table 1).

PC compiled SarPROZ (Perissin 2016) software was used (https://www.sarproz.com) for the preliminary PSInSAR analysis. Standard procedure was applied for the extraction of master and slave images, co-registration, sparse point selection, APS estimation and Multi-temporal analysis of both radar datasets. After preliminary analysis, 4429 sparse

Table 1 PSInSAR images and their characteristics used in analysis

Sentinel 1a pass mode		
	Ascending	Descending
No of images	74	69
Level of processing	SLC	SLC
Acquisition level	IW	IW
Polarization	VV + VH	VV + VH
Subswath	2	2
Acquisition period	03.05.2016–31.12.2018	02.05.2016–30.12.2018
Heading angle	350°	190°
LOS	80°	280°
Swath	250 km	250 km
Spatial resolution	5 × 20 m	5 × 20 m
Incident angle	39,2°–40,3°	39.1°–39,5°
Track	175	153
Line	142	440–445

points were generated from ascending and 5465 sparse points from descending datasets. Fine tuning and filtering by location and coherence quality were also performed. The total of 71 stable radar targets from ascending and 84 radar targets from descending dataset were selected for detailed analysis. Finally, only 29 points from ascending and 15 points from descending dataset were found inside the active Umka landslide body, and only one from both datasets in vicinity of GNSS2. These two PS points were selected for correlation and validation versus GNSS2 permanent ground station data.

Results and Discussion

The analyzed results from recent GNSS measurements indicate that object point UmkaGNSS2 has moved 300 mm towards the North and 500 mm towards the West, i.e. the total cumulative 2D displacement was 650 mm towards the NW, while the vertical displacement was approximately 150 mm for the period September 2014–September 2018. Furthermore, it can be concluded that landslide displacement velocity of the target monitoring point GNSS2 varied during the observed time period (2014–2018) (Fig. 4).

The analyzed average annual 2D displacement was approximately 160 mm/year for analyzed time span (September 2014–December 2018), except in the period September 2014–March 2015 (Fig. 4), which was characterized by intensive fluctuation of the Sava River level (drawdown effect), which started dropping from high level for several meters in a short period. Fluctuation of the river level in 2014–2015 was followed by highest river discharge during floods in May 2014, particularly enhanced by discharge of the Djerdap lake accumulation downstream. This prominent level drop caused drawdown effect and quick redistribution of pore pressures. Similar correlation and the conclusion that followed from 2010–2014 monitoring data were reported in Abolmasov et al. (2015). According to the average annual displacement Umka landslide velocity can be classified as slow to very slow during measurements period of 50 months.

The 2D displacement vectors analysis was done for 59 stabilized geodetic survey points, i.e., dx, dy and dz were obtained from geodetic survey measurements. Zero measurements (March 2018) were compared with first sequence (November 2018). Directions and amount of superficial displacement were plotted for all points and spatial distribution of displacement vectors are presented on Fig. 5. Maximal displacement rates were recorded in central and SW part of the landslide body (95.8–139.1 mm) close to local secondary scarps. Taking into account time span between two survey sequences (eight months), displacement vectors rates were in line with obtained GNSS2 object point monitoring results for the same period.

UAV photogrammetric survey analysis from two series of imaging (2018 and 2019) was used for 2D displacement vector analysis and correlation with geodetic benchmarks survey data for the same period. Very good correlation was established between displacement vectors azimuth obtained from geodetic points survey and displacement vectors

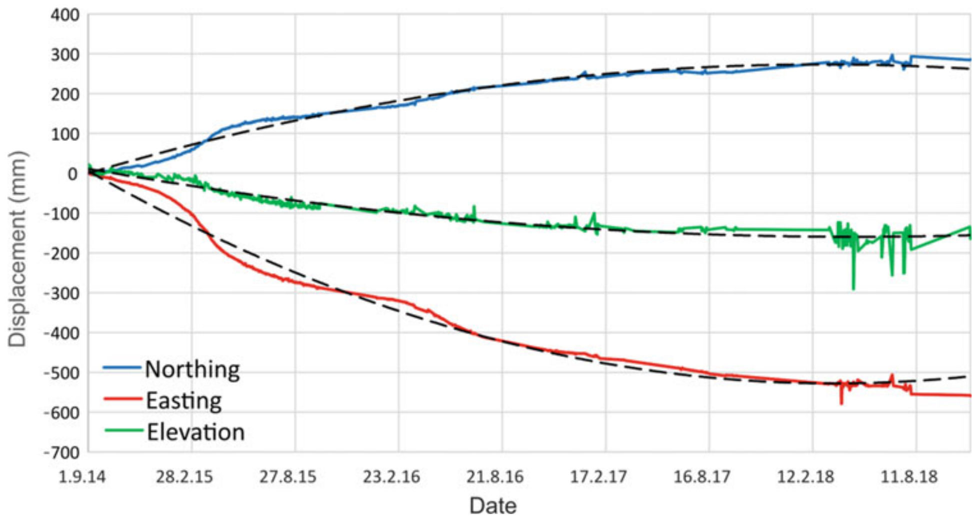


Fig. 4 Displacement of GNSS point from 2014 to 2018

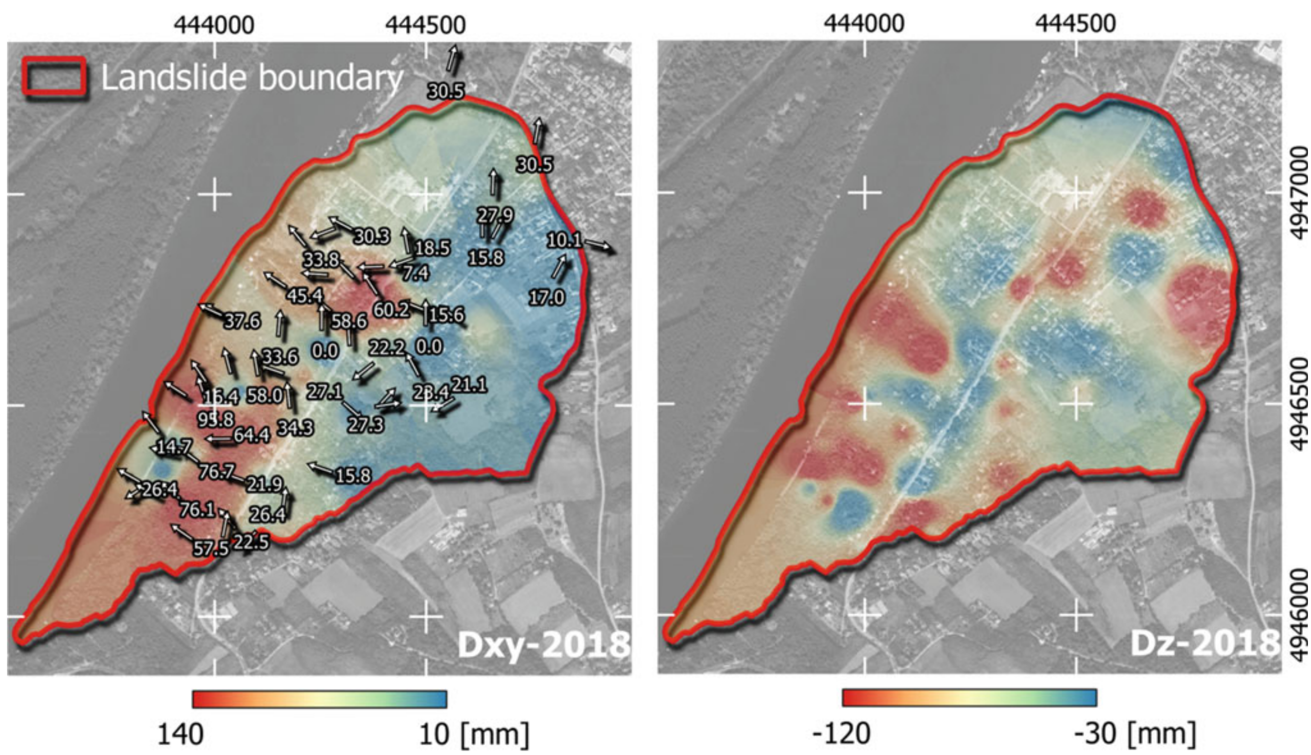


Fig. 5 Results of geodetic benchmarks survey; displacement vectors analysis; "zero" measurements (March 2018) versus November 2018 measurements

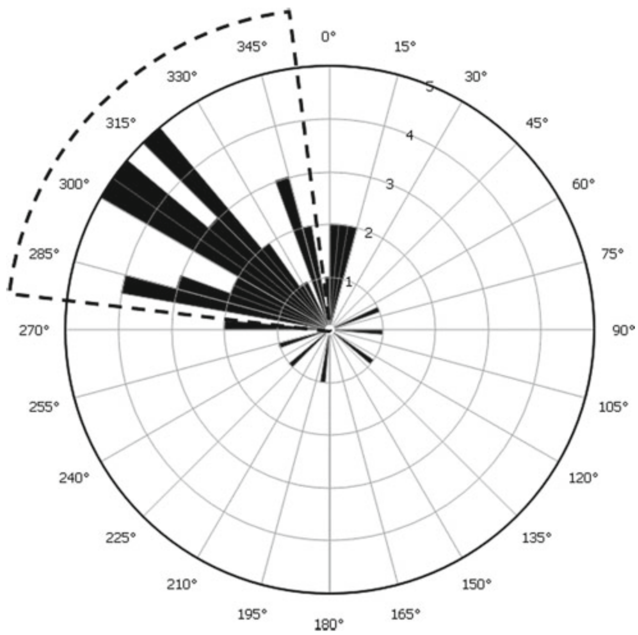


Fig. 6 Displacement vectors azimuth obtained from geodetic benchmarks survey campaigns 2018–2019

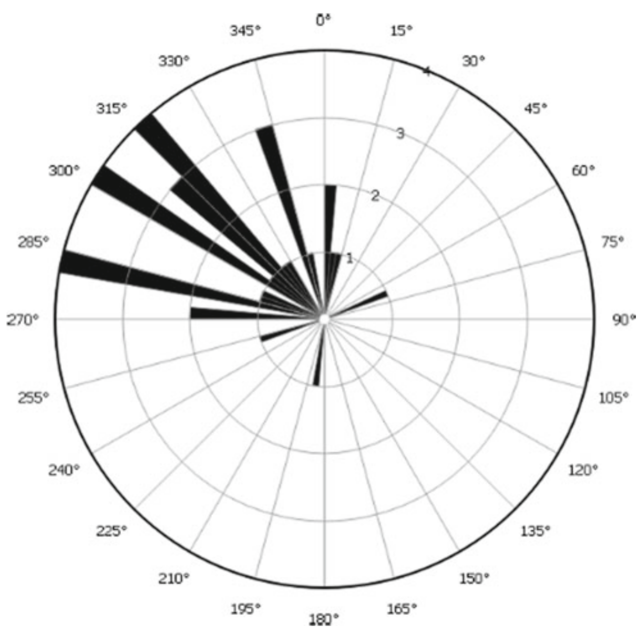


Fig. 7 Displacement vectors obtained from UAV imaging after 2018 and 2019 campaigns

obtained from UAV imaging after 2018 and 2019 campaigns (Figs. 6 and 7). Displacement vectors from both statistical analyses were within expected range of 285°–315°, which is also confirmed by Umka GNSS2 monitoring point.

The results of PSInSAR image analysis were correlated with GNSS2 object point monitoring. The analysis indicates that the selected point LOS displacements have a clear correlation and similar rates as *dz* GNSS2 permanent monitoring point (Figs. 4, 8),. Cumulative displacement for both GNSS2 and PS764/PS3954 were between 5 and 10 mm for the analyzed period of monitoring (March 2016–December 2018).

Spatial distribution and analysis of displacement rate of sparse points over the whole landslide body unfortunately are not evenly distributed due to small number of finally selected PS points. This is probably due to a fact that most of the landslide area is covered by vegetation.

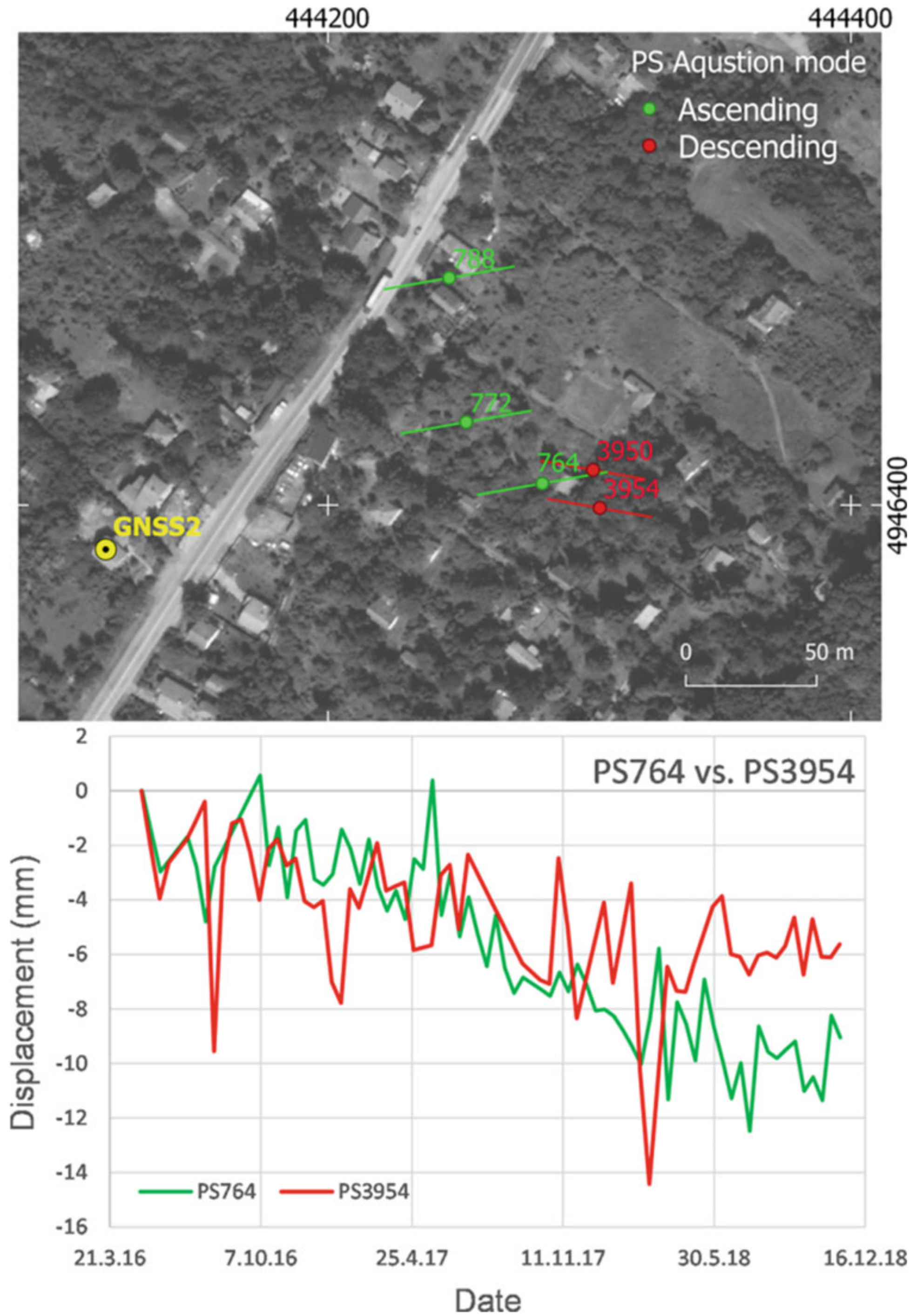
Conclusion

Recent monitoring activities on the Umka landslide included several landslide monitoring techniques realized from 2014 to 2019. Results of all monitoring activities were analysed according to the longest common survey period and then used for cross-correlation and for verification of monitoring results obtained using different techniques.

Displacement rates from GNSS indicate that object point Umka GNSS2 has moved 0.30 m towards the North and 0.50 m towards the West, while the vertical displacement was approximately −0.15 m for the 2014–2018 time span. Similar range of GNSS displacement rates were found in previously published results from monitoring activities realized from 2010–2014. PSInSAR data analysis showed very good correlation between nearest PS points and GNSS point for the same period of monitoring (2016–2018). Results from geodetic survey benchmarks showed displacement rates in accordance to average displacement rates of GNSS2 object point. Results from UAV and geodetic benchmarks survey data analysis showed also very good correlation in vectors azimuth (for the period 2018–2019). According to the presented data it could be concluded that all monitoring results are in compliance with previous published research and monitoring results, and confirm that the Umka is a slow to very slow moving landslide.

Further research within IPL181 Project will be focused on continued monitoring and analysing: (1) spatial patterns and relationships between landslide and element at risk, (2) proposing quantitative risk model and (3) landslide risk management, according to the Project goals. Those research objectives will be also part of IPL248 joint Project research between Univeristy of Belgrade and Univeristy of Salerno.

Fig. 8 Results of cumulative displacements of PS 764 (ascending mode-green) and PS3954 (descending mode-red) and their position within landslide Umka area; position of GNSS2 (2014–2019) (yellow)



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