GROUND DISPLACEMENTS DETECTION IN TRIFON ZAREZAN LANDSLIDE BASED ON GNSS AND SAR DATA

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UDC: 551.311.24:[528.8:629.783(497.2)

ABSTRACT

The Trifon Zarezan landslide is one of the well-studied areas north of Varna. It has been registered in 1998 and monitored since then, but due to expansion of construction activities and lack of sewerage facilities in 2005 it exhibited strong activation seriously damaging the panoramic coastal road remaining closed up to nowadays. One important issue in mitigating the effect of this phenomenon is its continuous monitoring and one promising solution of this problem is the usage of differential Synthetic Aperture Radar interferometry In the framework of this study two sources of data have been used – three geodetic surveys and SAR data from C-SAR instrument onboard Sentinel-1. The main research objective was to combine the advantages offered by both data sources in order to produce regularly updated information about the whole site. The GNSS data are precise, but does not originate from dense geodetic network, while SAR data cover the whole area, but they lack of high spatial resolution which is disadvantage in case of exploring small areas such as this one. Based on the results achieved it can be concluded that both sources of data provide complementary information confirming the overall behavior of the studied phenomena for the time period analyzed.

Key words: landslide, GPS data, DInSAR

1. INTRODUCTION

The Trifon Zarezan landslide is one of the well-studied natural occurrences located north of Varna city with initially recorded area of 3ha, but has grown to 6ha and continues to increase. This is one of the 88 objects prone to natural

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hazards in the area of the region. First movements of the landmasses has been registered in 1998 and monitored since then by the competent national authorities (MRRB, 2017). Due to expansion of the construction activities in its vicinity and lack of sewerage facilities in 2005 it exhibited strong activation seriously damaging the panoramic coastal road remaining closed up to nowadays. The monitoring of this landslide revealed the following facts – direction of movement is eastward, total horizontal displacement for almost 20 years to be 11m and on some places of the landslide the subsidence was found to be more than one meter.

2. MOTIVATION

From the geology surveys carried out in mentioned region it resulted that the geology settings are highly favorable for landslides formation and in addition it was established that the abrasion process is the most important factor for triggering of such phenomena. All those negative geodynamic processes and phenomena have been studied since 60-ties of the last century especially along the road Varna – Golden Sands resort. For this reason the region has been included in list of Europe's towns prone to ground instability geohazard (Pangeo'2017).

Figure 1: Cracks and subsidence in the area of Trifon Zarezan landslide.

As pointed out above the human activities, more specifically construction ones, have intensified during the last decades contributing to natural factors. The consequences resulted in serious damages to the private properties, roads, water mains, power lines and other facilities.

The reasons stated above motivated the authors to initiate this research for monitoring the landslide movement by SAR data complemented by GNSS measurements. The focus was set on this single object located 20km north of the town of Varna since it affects directly human lives. The slope of the terrain is between 18 and 24 degrees and the elevations vary from 0m to 37m ASL. The manifestation of the landslide started in 1998 by forming a circle affecting five plots, then in 2001 expanded again. In 2005 new activation was registered (see Fig.1) and the process continues up to nowadays evidenced even by satellite images available in Google Earth (Fig.2).

Figure 2: Landslides region of Google Earth 2018

3. METHOD AND DATA

One important issue in mitigating the effect of the landslide phenomenon is the regular monitoring of the area of the landslide and its surroundings at short intervals. One reliable source of information in resolving this task lies in using the satellite differential Synthetic Aperture Radar interferometry (DInSAR) – a widely adopted technique which is able to create map of ground surface deformations delivering sub-centimeter accuracy. Serious advantage of the proposed approach is the possibility to obtain data at six days intervals regardless of the weather conditions owing to the SAR data freely provided by ESAs' Sentinel-1 mission. The created interferometric maps can be complemented by conventional geodetic field surveys as well thus benefiting from the advantages offered by both methods in updating the existing landslide map.

3.1 DATA

In order to carry out the tasks foreseen in the framework of this research two sources of data have been used – GNSS measurements from three geodetic surveys in made in two consecutive years and SAR data from C-SAR instrument onboard Sentinel-1 constellation. To reach the main objective set it was essential to exploit at full scale the advantages offered by both sources in order to produce regularly updated information about the whole site. The GNSS data are precise, but because creation of dedicated geodetic network was a must and additional human effort for frequent measurements was required, information could be obtained for several points only. On the other hand the SAR data cover the large area, but they lack of high spatial resolution which is serious drawback when exploring small areas such as of this landslide.

a b

Figure 3: Picture of landslides region and GNNS network (a) and sampling network for SAR data (b).

3.1.1 GEODETIC SURVEYS

In case exploration of a landslide has to be done by GNSS measurements one must establish a network by fixing two types of points – ones on geologically stable terrain and others that are to be monitored inside the investigated area. The main advantage of such measurements is that no direct visibility between points is required, but for every point of the network it is essential to have the

GNSS receiver set for certain amount of time. For this specific study three cycles of GNSS measurements have been performed on a purposely built geodetic network. This network consists of 8 points representing all the typical features of the investigated terrain and their position is presented on Fig.3a. It needs to be emphasized that two landslides are located closely in the studied area and most probably both contribute to ongoing land deformation processes.

3.1.2 SAR DATA

The SAR data used in this research are acquired by SAR instrument onboard the Sentinel-1 mission which entered its operational phase in November 2014. Those data are freely provided by ESA and have been downloaded from its official repository (https://scihub.copernicus.eu/). In order to obtain reliable information about the ground displacements the authors set the following requirements:

1. The satellite orbit should be ascending – this is because the radar is right looking this way the foreshortening effect shall be minimized since most of the slopes are eastward facing;
2. Time of the SAR acquisitions – to be as close as possible to dates of field campaigns;
3. Minimum vegetation cover – due to lack of obvious persistent scatterers in the area we had to rely on constant properties of the ground objects to mitigate the temporal decorrelation;
4. Small perpendicular baseline (PB) – the images selected for processing to have as short PB as possible and high modelled coherence (MC).

For interferometric image creation selected were two SLC images satisfying the above criteria namely one from Nov 26th 2014 and the other from April 7th 2015. From them an interferometric pair (IfP) having PB=21.95m and MC=0.83 was formed. This IfP coincided with the period between in-situ GNSS measurement cycles 2 and 3. The final interferometric image representing the displacements was produced within SNAP software following the methodology implemented in (Veci, 2016). The DEM used during the processing was the SRTM with 1arcsec spatial resolution while for better overlaying the SAR pixels were multilooked thus obtaining square pixels. At next stage the phase of the processed complex SAR signal was unwrapped in order to convert it to metric units and finally the whole image was image geocoded as it has to be used as raster layer for visualization in Google Earth.

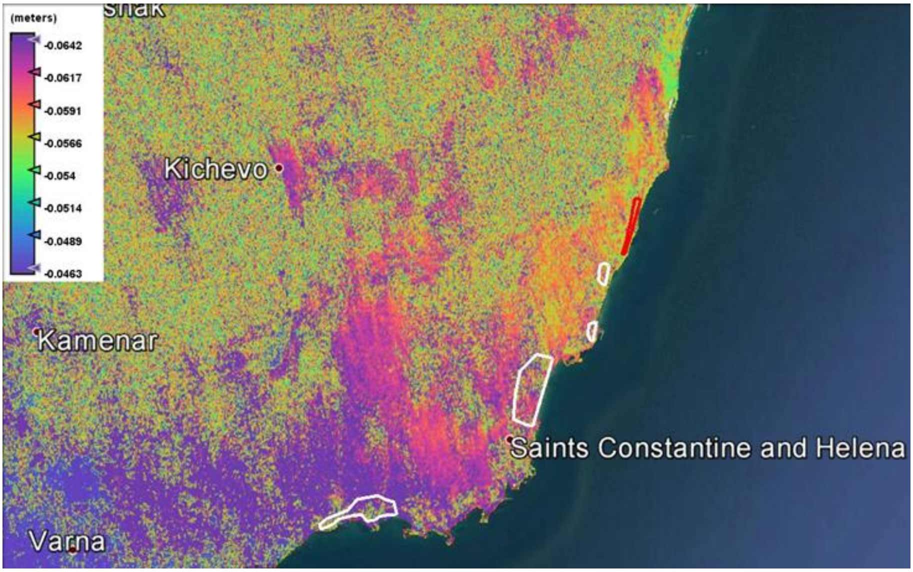

Figure 4: Excerpt from results from the DInSAR (from Nov 26th 2014 to April 7th 2015) over study area (white polygons are as reported to Pangeo Project).

In order to evidence the deformations after year 2015 one additional IfP was created covering the period 2015-2018, but unfortunately for this period some of the points of the geodetic network were already destroyed because of new activations of the landslide. For this reason here we report results based only on information from SAR data. This new IfP used for interferometric processing consisted of two SLC images covering the period from March 1st 2015 to February 25th 2018 from a descending track 36 of Sentinel-1A acquired in IW swath mode. Based on those images an IfP having PB=41.80m was created and processed the same manner as described in the previous paragraph.

4. RESULTS

The image on Figure 4 represents a part from the interferometric image which corresponds to the displacements for larger area including the site investigated (denoted by the red polygon). As it can be seen their magnitude is in the range from 4 to 6 centimeters subsidence.
In order to calculate the horizontal and vertical displacements for the points located inside the studied area of the landslide by direct geodetic measurements two stable points situated outside the zone of deformation were selected (see Fig. 3a points 101, 102) and all results reported are relative to

them. In Table 1 presented are the horizontal displacements in the two perpendicular directions X and Y (Nikolov,2016).

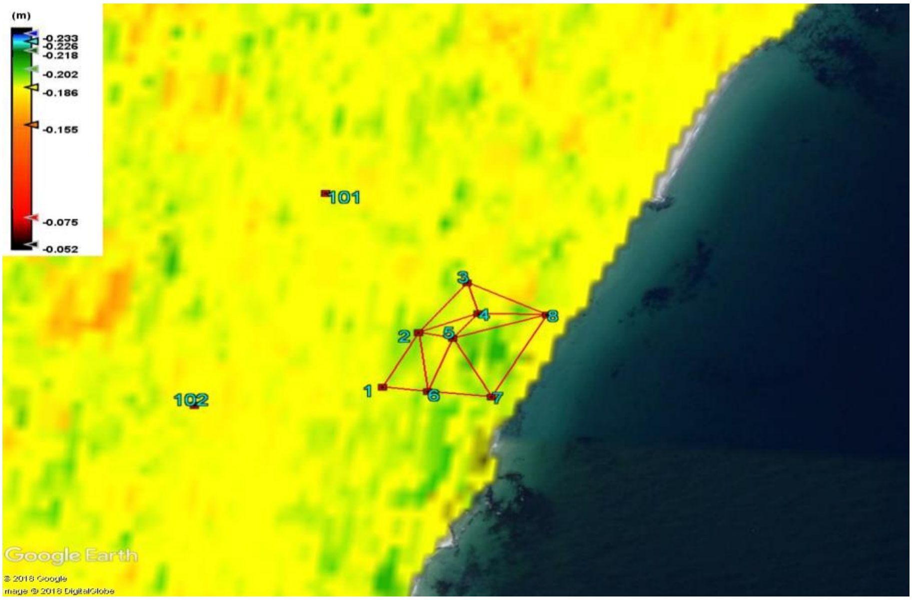

Figure 5: Excerpt from the interferometric image covering the study area (SAR images are dated March 1st 2015 and February 25th 2018).

On the other hand the vertical displacements reported in Table 1 are those displacements of the studied area in vertical plane for every point. This displacement can be subsidence or lifting relative to the height of the same point as measured during the previous cycle.

Table 1: Horizontal and vertical displacements as calculated from GNNS measurements.

	I-st - 10.08.2014 II-nd - 08.11.2014					II-nd - 08.11.2014 III-rd - 21.03.2015				
	∂X/m/	∂Y/m/	∂S/m/	α/g/	∂H/m/	∂X/m/	∂Y/m/	∂S/m/	α/g/	∂H/m/
1	-0.059	-0.028	0.065	228.2088	-0.003	0.053	0.069	0.087	58.3017	-0.017
2	-0.098	-0.053	0.111	231.5614	-0.016	0.098	0.094	0.136	48.6739	-0.01
3	-0.003	-0.06	0.06	296.8195	-0.014	0.001	0.092	0.092	99.308	-0.019
4	0	-0.093	0.093	300.00	-0.067	0.002	0.248	0.248	99.4866	-0.074
5	-0.046	-0.052	0.069	253.8928	-0.027	-0.009	0.225	0.225	102.5451	-0.156
6	-0.063	-0.032	0.071	229.9196	-0.07	0.033	0.279	0.281	92.5049	-0.172
7	-0.114	0.062	0.13	168.2889	0.015	0.068	0.266	0.275	84.0667	-0.045
8	-0.061	0.003	0.061	196.8716	-0.034	-0.011	0.259	0.259	102.7022	-0.037

101	0.002	-0.002	0.003	350	-0.007	0.002	-0.003	0.004	338.4359	-0.01
102	0.001	0.002	0.002	70.4833	0.002	0.003	0.005	0.006	65.5958	0.006

At the final stage of IfP processing obtained were the displacements for every pixel from the interferometric image located inside the polygon formed by the corner points of the GNSS network. The quality of these results was assessed by means of the coherence calculated for the same element. It was assumed that if its value is below 0.3 those data can't be considered reliable. This is why from the 235 points forming the point vector layer of the sampling grid (see Fig.3b) only 93 have been accepted as correctly reflecting the real ground movements. As final step from the interferometric raster images containing the computed displacements extracted in a new vector layer were only the mentioned 93 points and they were subsequently imported into GoogleEarth for visualization.

Table 2: Comparison between the vertical displacements calculated from GNSS and those obtained from SAR data.

	X	Y	∂H/m/	displ_VV 2014/2015	displ_VV 2015/2018
1	28.03604295	43.26730233	-0.0170	-0.0289	-0.17225
2	28.03639275	43.26803072	-0.0100	-0.0301	-0.18107
3	28.03690931	43.26871200	-0.0190	-0.0244	-0.17132
4	28.03711245	43.26833259	-0.0740	-0.0310	-0.16925
5	28.03683690	43.26799073	-0.1560	-0.0239	-0.16341
6	28.03662526	43.26728444	-0.1720	-0.0323	-0.17312
7	28.03746616	43.26726091	-0.0450	-0.0277	-0.16449
8	28.03802484	43.26838694	-0.0370	-0.0340	-0.16216

In Table 2 a comparison is made between values for the vertical movements as calculated from GNNS data and those derived from the interferometric images. The values presented in the last two columns in the same table are the calculated displacements based on the values of the unwrapped phase.

5. CONCLUSIONS

Based on the results reported above it can be concluded that both sources of data provide comparable results (being in the range of centimeters) confirming the overall behavior of the phenomenon studied. The differences between them could be contributed to large number of external factors affecting the SAR data used such as vegetation cover and temporal decorrelation. One more thing needs to be taken into account when comparing the results from GNSS measurements and those from the SAR data is that the values of the latter correspond to displacements of a much larger area (15m by 15m) than those retrieved from GNNS where the size of the point can be a centimeter. Nevertheless the results obtained encourage the authors to continue their research in improving this method for investigation landslides with SAR data since for most of them no data from GNSS surveys are present and this is only possibility to register their expansion.

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