Studying the of Landslide Processes at the "Dalgiya Yar" - a Lanslide Circus by joint use of GNSS and InSAR

Mila ATANASOVA, Hristo NKOLOV, Ivan GEORGIEV, Nikolay DIMITROV, Anton IVANOV, Bulgaria

Key words: Earth movements, GNSS, SAR, Landslide monitoring

SUMMARY

The main objective of this research is monitoring the ongoing landslide processes by complementary use of SAR and GNNS data. It will be achieved by means of proved methodology for continuous monitoring of landslide areas by integrating information from interferometric images and GNSS data from permanent and local geodetic networks. The study will give reliable data for ongoing risky geo-processes for the region of the Northeastern Bulgaria, known with several large active landslides.

These results are important for understanding the origin and dynamics of landslide processes as well as assessing the resulting hazards. Local archive with Sentinel-1A/B images for this region is created and interferograms are produced. Raster heat map based on displacement values from interferograms was made. The area of interest of this study is "Dalgiya yar" - a landslide circus in which concentration of ground deformations has been observed.

When geodynamic networks are used to study landslide processes several types of surveying points are used – ones fixed on geologically stable terrain, others located inside the landslide. For stable points located in the non-deformable zone of the landslide used were stations of permanent GNSS network NIGGG. New established network in and around the landslide area "Dalgiya yar" – “Fara” consists of a total of 30 stabilized points.

In the geodynamic network "Dalgiya yar" are included all old 6 points that were discovered on the ground from the network used to track deformations along the road. A preliminary study, based on data provided by Ministry of Regional Development and Public Works of the landslide processes in the road I-9. Analysis of horizontal and vertical deformations for the period 2013 - 2018 along the road I-9 the last cycle of June 2019yr.

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INTRODUCTION

The Black Sea coast of Bulgaria north of Varna is heavily affected by landslides (North landslide zone).The purpose of this study is to analyze the results of the studies conducted in 2018 and 2019 years by the authors for determination to the dynamics of landslides. Data from the annual reports of the "Geozashita" Ltd. Varna (2018), were also used for the preventive activities, carried out in 2017 and 2018, related to the registration and monitoring of landslides and areas with abrasion processes along the Black Sea coast (https://www.mrrb.bg/en). For this reason, it is necessary to identify areas with active landslide movements along the Northern Black Sea coast of Bulgaria for monitoring by combining data from Global Navigation Satellite Systems and interferometric images from Synthesized Aperture Radars.

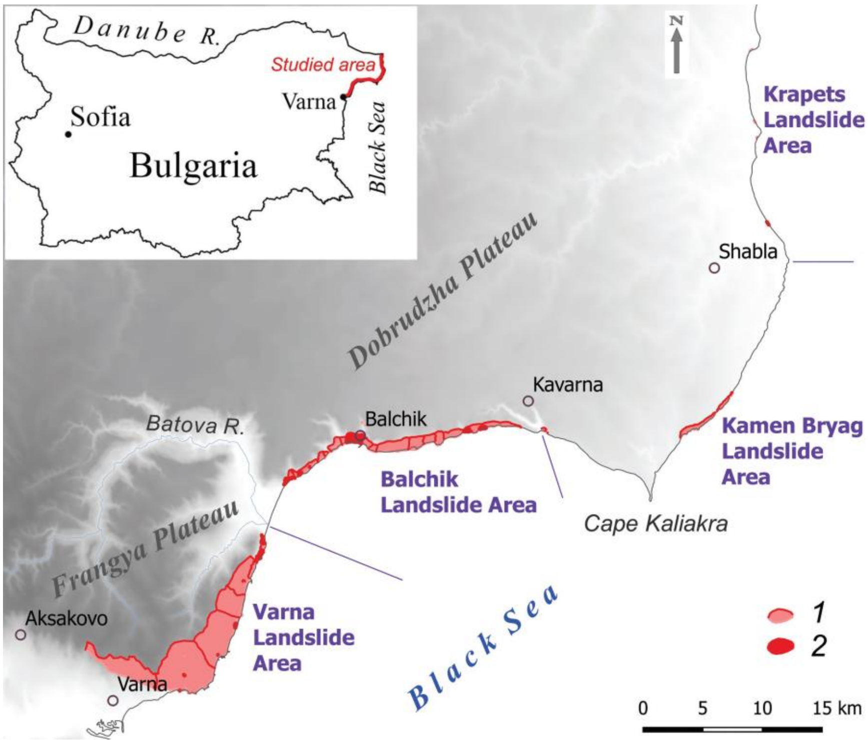


Figure 1. Landslides along the northern and northern Black Sea coast of Bulgaria 1 - landslide complex; 2 - active landslide (Nankin R. and Ivanov P. 2019)

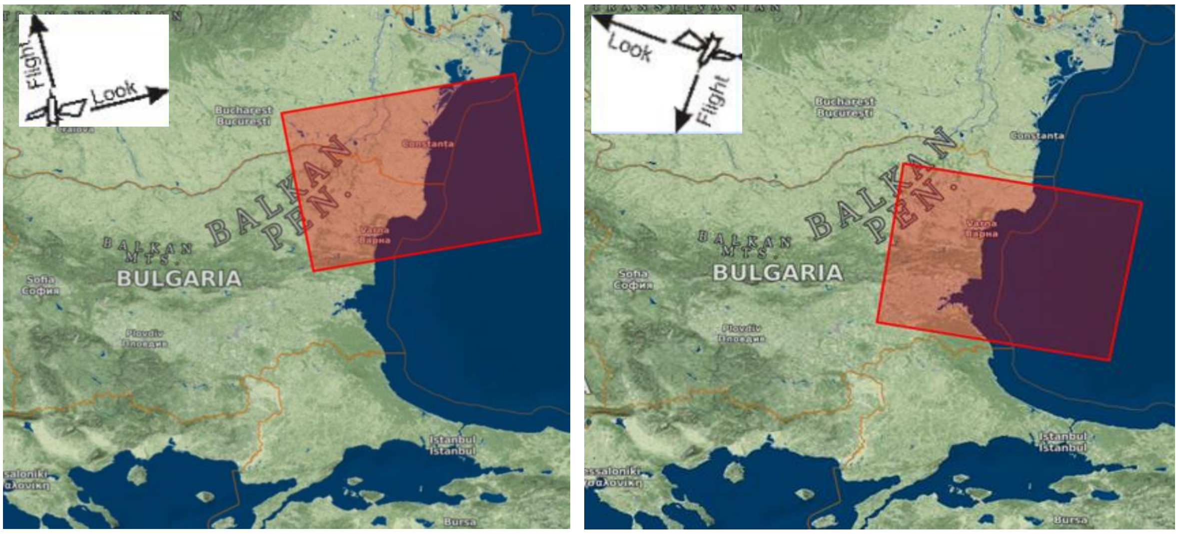
This area is characterized by plateau relief, sedimentary rocks of Paleogene and Neogene periods, whose layer are slightly inclined to almost horizontal (3–5° East). It includes the Frangenskoto plateau (Varna, Golden Sands, Kranevo) and the southern part of the Dobrudzha plateau (Albena, Balchik and Kavarna), a sector from the Dobrudzha plateau to the north and west of Kavarna, including Cape Kaliakra and north to the Bulgarian-Romanian border. The landslides are concentrated in four landslide areas (Figure 1). There are two types of landslides in the regions along the Varna and Balchik coasts - circular for the Varna landslide region and linear-stepped (bundled) landslides for the Balchik landslide and the landslide region Kamen Briag (Nankin R. and Ivanov P. 2019)..
The **Varna landslide region** includes the coast from the city of Varna to the valley of the Batova River, near the village of Kranevo. The formation of deep landslides in the area is mainly due to marine abrasion. These are large landslide complexes (circus type) manifested along the eastern slope of the Frangen Plateau - from the edge to the seashore. Against the background of these old (archaic), stabilized landslides, as a result of the complex impact of natural factors and technogenic activity, contemporary active local landslides occur (Bruchev I. at et. 2007, Evlogiev Y. and Evstatiev D. 2011, Berov at et. 2013, Nankin R. and Ivanov P. 2019).

1. METHOD

1.1 Synthetic Aperture Radar (SAR) Data and DInSAR Processing

A short description of the SAR data and the processing steps used to produce the interferometric images (IFIs) that were combined with the geodetic data in studying the landslides is presented in this section. The SAR data that have been processed are from a constellation comprised of two satellites (A and B) Sentinel-1 mission freely distributed by ESA and can be obtained from Scientific Data Hub (https://scihub.copernicus.eu/dhus/#/home). Every satellite has revisiting time of 12 days which means that one and the same area is imaged every 6 days by one of the satellites. The SAR instrument is a C-band radar (corresponding to a wavelength of 5.56cm) with right-looking line of sight (LOS) regardless of the orbit direction, and operates in four acquisition modes stripmap, interferometric wide swath (IW), extra-wide swath and wave mode. For interferometric processing single look complex (SLC) data obtained in IW mode are to be used since in it not only the amplitude of the backscattered signal is available, but its phase too. The phase signal is of crucial importance since after appropriate processing it delivers information about the changes in the distance to the objects on the Earth's surface between two satellite overpasses (Luis, 2016).
DInSAR (SAR Interferometry) is a method that uses SAR data to produce topographic and surface motion maps based on information about the deformations based on interferometric phase. It is based on the acquisition of complex-valued data over the same area at different time and uses the difference found in the phase signal to detect the horizontal/vertical changes caused by ground deformations. Since in the measured phase there are two components – one

corresponding to the distance of single object from the surface and next reflecting the phase change by the environment – a measure of quality is introduced, known as coherence, an estimate for the noise level in the phase signal. It is widely accepted that for the single pixel from the phase band of the IFI to be considered reliable the same pixel in the coherence band should have value above 0.3. Low values of this parameter are due to many external factors such as troposphere state at the time of acquisition, the position of the satellite in its "orbital tube" which defines perpendicular baseline, presence of vegetation in the area of study, etc.



A) Ascending orbit 058 B) Descending orbit 036

Figure.2 Shape of the SAR images from ascending (A) and descending orbits (B)

It needs to be underlined that the information provided by the phase signal is a relative with regard to the one of the SAR images, often called "master", and with regard to a point on the ground which is assumed to be stable. One more thing that needs to be addressed here is that all detected deformations are measured along the LOS of the SAR instrument and for this reason additional calculations are needed for properly combining GNNS and SAR data.
A drawback of the SAR data that needs mentioning is that they cannot detect ground changes along the track of the satellite which results in better registering movements in east-west direction then in north-south. This can be overcome by combining information derived from IFIs from both ascending and descending orbits (Figure 2). An advantage offered by the DInSAR method is the possibility to register ground changes over large or difficult-to-access areas thus delivering more information than by single in-situ acquisition. This does not mean that it can completely substitute terrain measurements, but rather to provide details on the surface movements for larger areas in the investigated region.
The processing of the SAR data to produce deformation map includes the following steps – precise co-registration of both images used in the IFI based on the orbital data, formation of the interferogram, filtering and speckle reduction, phase unwrapping, and geocoding. The most important step is the phase unwrapping since only after it the information contained in the phase signal is converted into ground displacements. At this step by integrating the phase

difference between neighboring pixels at every 2π the difference in altitude in LOS is generated after any integer number of altitudes of ambiguity has been deleted.

1.2 Geodetic surveying for Landslide Monitoring

In the past decades the North Eastern Black Sea coast of Bulgaria has been the subject of scientific research. In the mid of the 1990 a geodynamic network is built for monitoring the landslide processes around the town of Balchik (Tsenkov, T. 1993). Due to intensive construction activities at the coastal area in the last 20 years and the lack of funding for research and its maintenance some of the points of network (pillars for precision instrument positioning) were destroyed. Nevertheless an extensive and comprehensive methodology for geodetic investigations of landslides was developed (Milev, G. at et 1987). In it underlined is the significance of the following issues – type, size and form of the landslide; velocity of the displacements; availability of stable areas in vicinity of the studied object; the capability of the instruments to be used as required the desirable precision.
Geodynamic networks established for landslides monitoring consist generally of two types of points – reference or fixed points located on geologically stable terrain and survey points located within the landslide. In order to be accomplished the objectives of the present study, geodetic data from these two types of points are necessary. Data from the stable points situated in non-deformable zone are provided by the permanent GNSS network.
The new established points are located inside the specific landslide and will be measured in few cycles. The deformation analysis of the geodynamic networks will be done after the third measurement cycle by applying an appropriate approach.
The main advantage of GNSS measurements is the fact that no direct visibility is required between the points at which high precision receivers are placed and thus making this technology competitive to the classical geodetic measurements. Sometimes it is difficult to make measurements of the landslide processes at the GNSS points of the geodetic network due to technical reasons e.g. the presence high trees result in deterioration and lack of GNSS signal from the satellites; difficult terrain; the danger of semi-destroyed buildings and facilities; administrative obstacles - private ownership of the properties in the active part of the landslide.

2. RESULTS AND DISCUSSION

First step to achieve the main objective was to create a local archive with Sentinel-1A/B images for the region of Northeastern Bulgaria consisting of about 300 SLC images. For mapping the deformations in the region of interest interferometric images at intervals 4 and 8 months were produced.
The stated time intervals were used since one of the main factors affecting the quality of the IFIs is the vegetation and for this reason only autumn and spring scenes were processed. Also most of the landslides are active at those seasons. Another factor that should be accounted before producing IFI is the presence of snow – used data are from days with no snow coverage (https://www.stringmeteo.com/). In the figure 3 presented are the displacements found in an IFI produced from images dated 01Jan2015-21Dec2016, one of many processed. The color of the pixel represents the surface movement in metric unit for the investigated period ranging from dark blue to purpura. Particularly vulnerable areas are shown in purpura,

less vulnerable in yellow and green. Example for the landslide activity assessment resulting from this IFI shows Figure 3 that subsidence range from -48 mm to -69 mm.

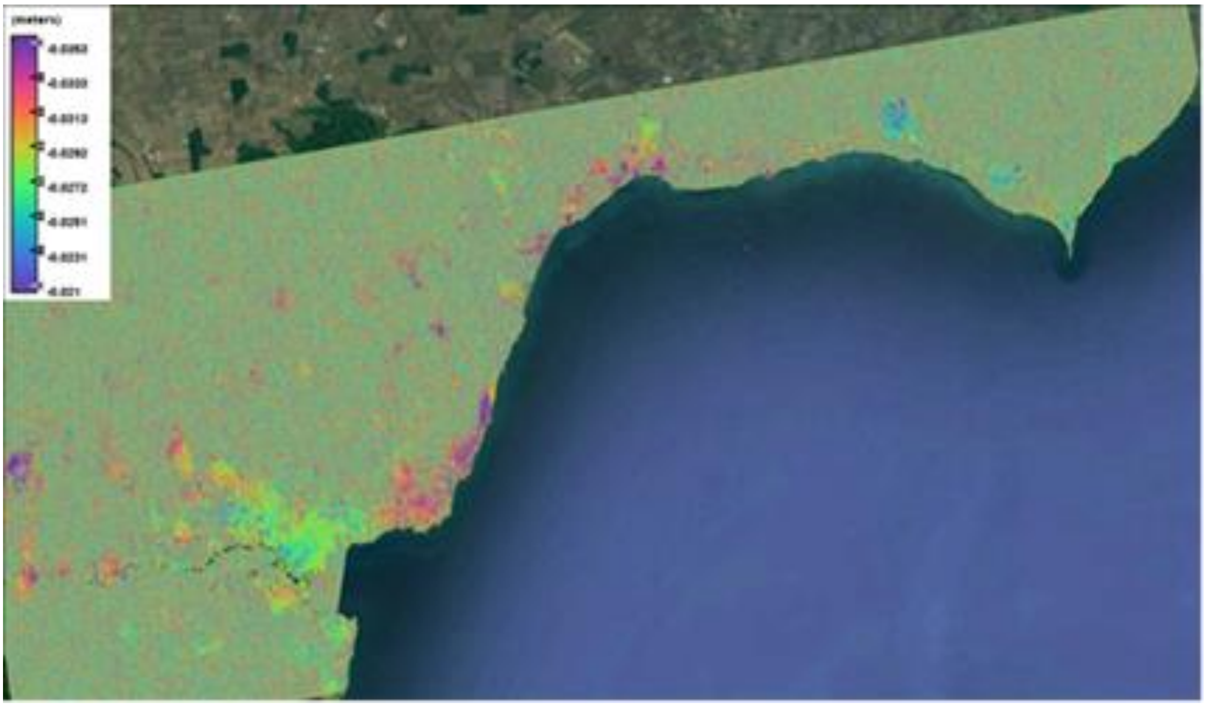


Figure.3 Displacements obtained from IFI 01Jan2015-21Dec2016

Figure.4 Raster heat map based on displacement values at the points of landslides registered

Raster heat map (Figure. 4), based on displacement values from interferograms was made. The area of interest of this study is the one marked by the shaded red quadrate in which concentration of ground deformations has been observed. This area is called "Dalgiya yar" - a landslide circus that covers several active landslides, whose boundaries overlap and for this reason difficult to differentiate. Even for some of the investigated landslides located in this area, a smaller landslide could be delineated inside them. This phenomenon can be seen in figure 5. In this figure the registration landslide codes are shown as they appear in the landslide register maintained by Ministry of Regional Development and Public Works (MRDPW) and the boundaries of the separate landslides are shown in different colours.

The landslide "Fara" located between the village of Kranevo and the touristic resort "Panorama" covers only the low stage of the circus (Evlogiev Y. and Evstatiev D., 2011). This landslide with assigned identification number VAR 02.54145-01-17 in the register of landslides in the Republic of Bulgaria activated on October 13th 2012 destroying the lighthouse and villas.

Figure.5 ID codes from MRDPW register and the boundaries of the investigated landslides.

The landslides and collapses in the activated area in 2013 are due to human activities that took place in the last 20 years mainly the illegal construction, as well as to the fact that the requirements for civil engineering were not respected. For example instead of building small bungalow houses two- and three - storey buildings were erected. In some of them swimming pools have been built whose waters flow down the slope of the landslide. Those flows had very serious impact, as the water from the said pools flows down the slope where there is no drainage. Water supply network accidents often occur there, because landslides tear the water mains slip and, in turn, water – regardless of its origin (from the water supply system, rains, or pools) leads to activation and development of landslide and collapse processes.

In this research the authors set their attention on a landslide located in the investigated area – "Dalgiya yar" – “Fara”. This specific object was selected since only for it old data from previous geodetic measurements and geological observations were made available. This fact made possible the comparison between in-situ data and data obtained from satellites. For landslide “Fara” two measurement cycles were carried out (2013, 2018) of a network consisting of 8 points located on the road I-9 above the landslide. The geodetic data of these points were obtained from Geozashtita Varna Ltd. according to the assignment by the MRDPW (see Figure 6).

Figure. 6 Geodetic network used for determination of displacements along the road (colored in blue)

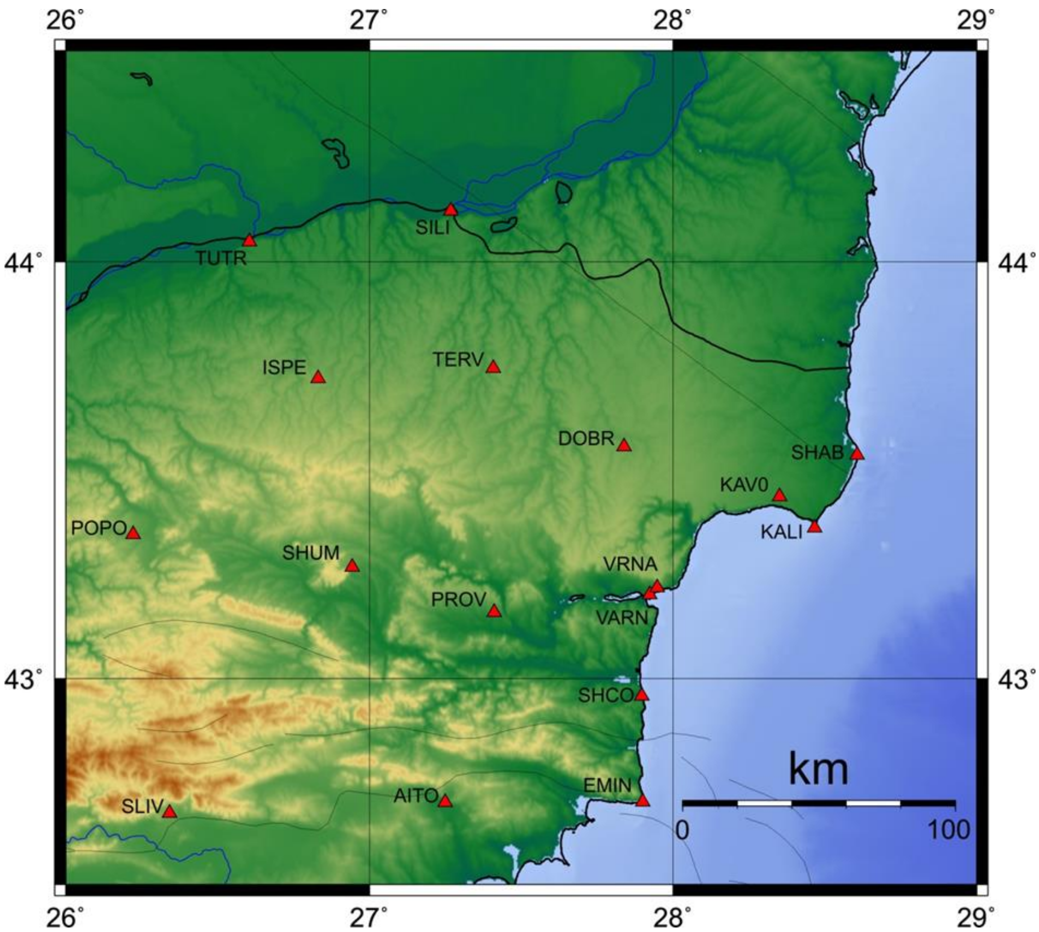


Figure. 7 Part of National Permanent GNSS Network in the region

For this study a control geodynamic network covering the landslide area "Dalgiya yar" – “Fara” (Figure 8) was established. It consists of a total 30 points, stabilized with metal pipes 35 cm long and metal bolts in the rock. The GNSS measurements were carried using 4 reference stations ant 2 rovers GNSS receivers. GNSS receivers are of type CHC i80 GNSS and P3E GNSS. Measurements of all points are carried out in static mode with interval 15 sec. and duration one hour. Reference stations duration measurements are about 8 hours. Reference frame is given from stations of the National Permanent GNSS network (Figure 7).
The newly established geodynamic network (Figure 8) located inside the landslide will be measured once a year. In the mentioned geodynamic network "Dalgia yar" all old five points that were found on the ground from the network used to monitor deformations along the road (blue colored in Figure 6 and Figure 8) are included. The first measurement cycle of the geodynamic network was carried out in June 19-23, 2019.

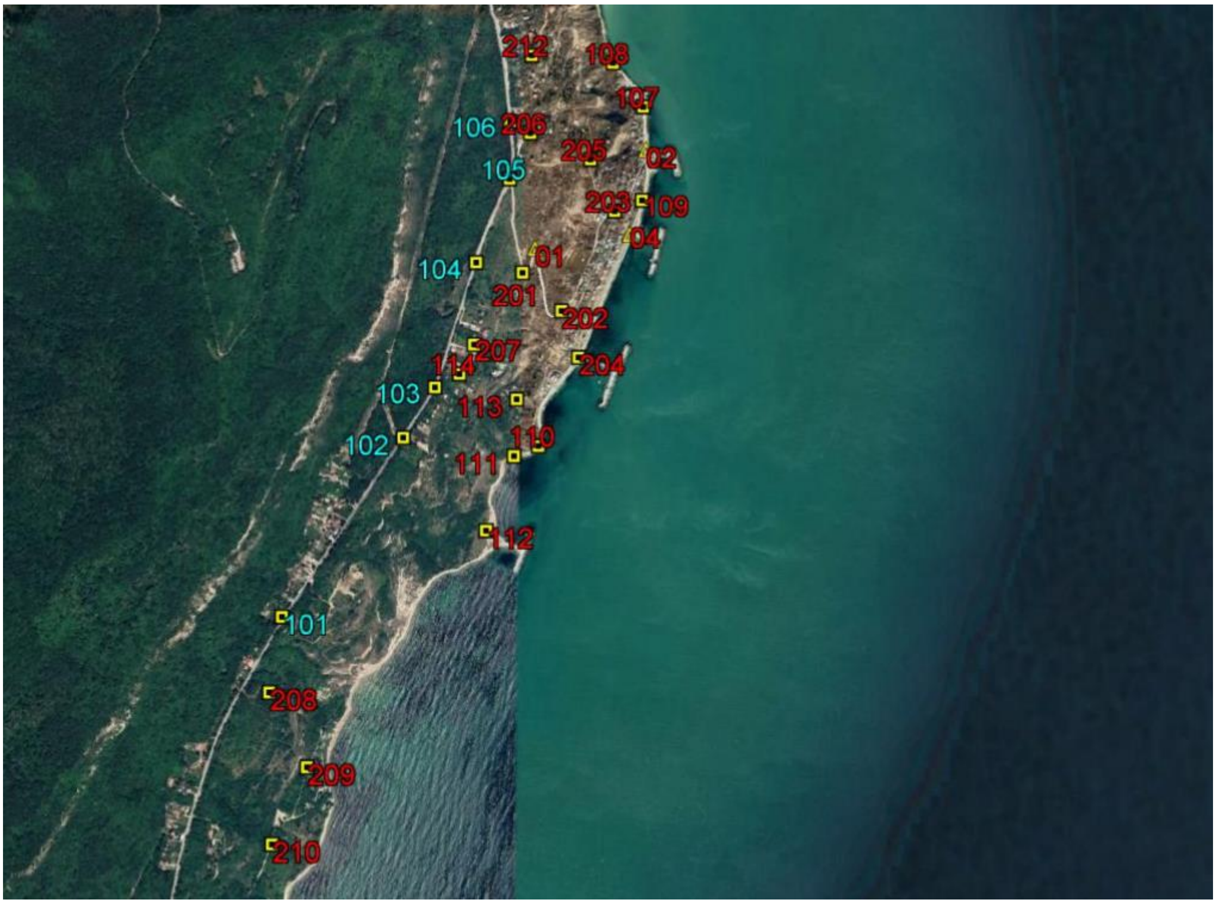


Figure.8 Points of the new geodynamic network in and around the landslide "Dalgiya yar"

The horizontal displacements were obtained from the results in 2013 and in 2018 (Table 1). The largest displacements for the area under consideration were found in the southwest part of the site.

Table 1 Horizontal (ΔD) and vertical (ΔH) displacements for the periods 2018 – 2013 and June 2019 - August 2018

old	***new***	***2018 - 2013***				***June 2019 - August 2018***			
point	**name**	**ΔX m**	**ΔY m**	**ΔD m**	**ΔH m**	**ΔX m**	**ΔY m**	**ΔD m**	**ΔH m**
2008	101	-0.325	0.513	0.607	-0.088	-0.033	0.079	0.085	-0.056
375	102	-0.265	1.00	1.034	-0.465	-0.068	0.066	0.094	-0.072
2002	103	-0.278	0.586	0.648	-0.375	-0.002	0.148	0.148	-0.054
1004	104	-0.161	0.181	0.242	-0.068	0.048	0.094	0.105	-0.074
2004	105					0.001	0.092	0.092	0.019
1005		-0.034	0.161	0.164	-0.038				
1003		0.035	0.155	0.159	0.017				
1001	106	0.039	0.134	0.139	0.054	0.053	0.069	0.087	-0.037

Horizontal and vertical deformations obtained for the period 2013 - 2018 along the road I-9 it range 0.61 - 1.04 m and vertical are in the range between -0.088 ÷ - 0.465m. It was established that the overall movement of the terrain lies in southwestern part of the area after one of the turns of the road I-9 (points 2002, 375, 2008). The maximum displacements are at the point 375 – horizontal 1.034 m and vertical –0.465 m. In the northern part of the road I-9 (points 1001, 1003, 1004) slight movements of the terrain were obtained in the range of 0.139-0.242 m in the horizontal plane and from 0.05 to -0.07 m in the height.
For II period (June 2019-August 2018, only 10 months), horizontal and vertical deformations are at lower values 0.08-0.10 m in the horizontal plane and vertical max.0.075 m.

3. CONCLUSION

The obtained first results of this study can be summarized as follows:

1. Extensive research was performed on the recent activations of landslides,
2. Old and new geodetic data about the deformations were selected as result of 1),
3. A local image archive of Sentinel-1 satellites was created for the region of Northeastern Bulgaria;
4. A set of interferometric images was created at fixed intervals - monthly, every 4 months, 8 months, an year;
5. Thematic interferometric images used in mapping deformations for the region of Northern Black Sea coast are generated,
6. The strong relationship between geodetic and satellite derived information concerning ongoing landslide processes is confirmed.

On the base of the obtained results it can be concluded that both data sources used lead to similar results (the displacements are in the range of centimeters) and they confirm the overall behavior of the study landslides. The differences between them could be explained with the large number of external factors affecting the SAR data such as vegetation and temporal decorrelation. When comparing the two methods it should be taken into account that the values of the IFIs elements correspond to much larger area (15m by 15m) while the GNSS concern point measurements.

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Since 1998, she has experience in involved in the processing and analysis of GNSS data, coordinate systems and transformations. In October 2013 she obtained a PhD degree on thesis “Transformations models in contemporary geodetic coordinate systems”. Her scientific interests and research tasks are focused on the study of the geodynamic processes and deformations of the Earth's crust for the territory of Bulgaria and the Balkan Peninsula; This includes determination of plate motions, deformation analysis and analyzed and monitoring of landslide processes through the InSAR method. Up to now she has 55 publications

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From 2012, the scientist analyzing data from tide gauge stations at Bulgarian Black sea coast.The interests of the scientist are related to the statistical methods of harmonic, spectral and regression analysis.One of the leading tasks studied by the scientist is to determine the variation of the mean sea level and its trend.

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