International Cartographic Association
Association Cartographique Internationale

Application of InSAR satellite method for mapping of active landslides in Bulgaria - opportunities and perspectives

Mila Atanasova [a, *], Hristo Nikolov [b], Lyubka Pashova[a]

[a] National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, mila_at_zl@abv.bg, lpashova.niggg@geophys.bas.bg
[b] Space Research and Technology Institute, Bulgarian Academy of Sciences, hristo@stil.bas.bg
* Corresponding author

Abstract:Landslides are geological phenomena that are spread on Bulgarian territory mainly along the northern Black Sea coast and on the right banks of the Danube in the western part of the country. Mitigation of the negative effects of these destructive geological phenomena is the compilation of inventory maps of their distribution and registers with the main characteristics of the individual landslides. Conventional methods for making such maps are time-consuming and resource-intensive. Modern satellite, air and ground-based remote sensing technologies facilitate the production of landslide maps, reducing the time and resources required to compile and systematically update them. In this paper, we demonstrate the applicability of Differential Sentinel-1A satellite SAR interferometry (DInSAR) to assess the movement activity and use the information for further updating the national landslide inventories in Bulgaria. We perform several analyses based on multi-temporal InSAR techniques of Sentinel-1A data over selected areas prone to landslides. The use of new opportunities for free access to satellite images, which can be applied in conjunction with other methods, greatly facilitates the processes of inventory, mapping and study of landslides.

Keywords: InSAR, mapping landslides, landslide hazard

1. Introduction

Landslides are part of natural destructive processes that can be natural or artificially caused by human activity. Their manifestation can lead to catastrophic and catastrophic conditions in a number of regions of the world with a negative effect in terms of human casualties, severe socio-economic consequences and deterioration of the ecological environment. This necessitates the use of modern methods and tools for assessment, mapping and taking preventive measures to mitigate the negative consequences of these geologically dangerous processes.

Landslide inventory and the preparation of specialized thematic maps are important stages for documenting and researching landslides in a given region. Conventional methods for making such maps are time-consuming and resource-intensive. Modern satellite, air and ground-based remote sensing technologies facilitate the production of landslide maps, reducing the time and resources required to compile and systematically update them. One of the advanced technologies for dynamic and real-time cartographic visualization in geodynamical active regions with landslide activity is the Differential SAR Interferometry (DInSAR). This method uses SAR data from two phase images obtained for the same region at different time intervals to create interferometric images for quantification of the registered movements of the earth's surface. The phase obtained by interferometric processing has two components; one corresponds to the distance to an object from the surface, and another reflects the phase change caused by the environment. Final output of the said processing are the generated topographic maps or maps of the deformations of the earth's surface using the registered differences of the phase signal during the interferometric process. A widely accepted quality measure for the interferometric phase known as coherence assesses the level of noise in the phase signal. The phase is considered reliable only if its value is above 0.3. The low values of this parameter are due to many external factors: the state of the troposphere during the time of acquisition in the study area, the satellite position, the presence of vegetation, and others. The technology was first employed in 90-ties demonstrated that radar satellite images could be used to detect ground movement at the millimetre scale. During the years, DInSAR becomes a proven method for creating time series of interferometric images through which registered movements of the earth's surface within a fixed time interval are quantified. Recently combined with other scientific research methods and visualization technologies it is widely exploited for geospatial processing of landslide activity, inventorying, mapping, and developing early warning and crisis management tools.

Existing geological conditions, the erosion, weather conditions, improper land use and anthropogenic activities are the main factors triggering the landslides activations in many regions on Bulgarian territory. Especially activations of such processes are observed on the northern Black Sea coast and the Bulgarian coast of the Danube (Bruchev et al., 2007; Berov et al., 2020). The purpose of this study is to demonstrate the applicability of DInSAR method for mapping and long-term monitoring of landslides in the country. For this

Proceedings of the International Cartographic Association, 4, 2021.
30th International Cartographic Conference (ICC 2021), 14–18 December 2021, Florence, Italy. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-4-10-2021

purpose the freely available data from the Sentinel-1 (S-1) satellite were processed with the specialized SNAP software of the ESA. We demonstrate the use SAR data from S-1 processed by DInSAR approach to produce a set of interferometric images (IFIs) for several local regions. In this study includes landslide zones localized in the Northern Bulgarian Black Sea coast and on the high Danube bank in the strip from Vidin to Nikopol towns. These case studies consider the landslide circus "Dalgia yar" and landslide Fish-Fish in the Northern Black Sea coast of Bulgaria (Atanasova et al., 2019) and the Lom-Oriahovo area landslides along the Danube river (Atanasova and Nikolov, 2018).

2. Method

The purpose of this study is to demonstare the applicability of DInSAR method usinginterferometric images to monitor active landslides localized in the Northeastern coastal zone and western Danube River banks of Bulgaria. Geodynamic processes and landslide activity are considered the main engine of horizontal and vertical movements of the earth's crust. One proven method for continuous monitoring of earth deformations is the use of data from active radar remote sensing. These SAR data are the basis for producing interferometric images (IFI) for quantification of the registered earth surface movements within a fixed time interval. A set of IFIs for several areas of the North of Bulgaria was created for this study.

Differential interferometry with synthesized aperture radar is a method for processing SAR data obtained from remote sensing, which can be used to quantify small displacements on the Earth's surface. Using data from satellites, applying DInSAR, topographic mapping is performed, as well as registration of surface motions. The basis of DInSAR is the use of measurements from two-phase images obtained in the same region at different times, which allows accurate measurement of relative distances DInSAR is a method that uses SAR data to create topographic maps or maps of the deformations of the earth's surface based on the registered differences of the phase signal during interferometric processing (Ferretti et al., 2007). It is based on the processing of complex data for the same zone obtained at different time intervals and uses the difference found in the phase signal due to the deformations of the earth's surface. Since the phase obtained by interferometric processing has two components - one is corresponding to the distance to an object from the surface and another reflecting the phase change caused by the environment - a quality measure known as coherence, which is an assessment of the noise level registered in the phase signal. It is widely accepted that one pixel of the phase channel of the interferometric image is considered reliable only if there is a coherence value above 0.3 (Ferretti, A. et al., 2007,). The low values of this parameter are due to many external factors, such as the state of the troposphere at the time of data acquisition, the position of the satellite, which determines the perpendicular baseline, the presence of vegetation in the study area and others.

The end products of DInSAR processing are surface displacement maps showing the mean surface displacements in the LOS direction. Another advantage of the DInSAR results is that they provide dense spatial information only in unforested areas, while in highly forested areas where coherence is low, network interpolation takes place. The radar satellite data processed by DInSAR and the received time series allow us to detect the occurred deformations of the earth's surface and to measure their variations in LOS with an accuracy of one centimetre in time, using freely available data and software. DInSAR can be considered as an attractive technique and operational tool for an inventory of potential geologically dangerous processes, such as detection and monitoring of landslides. It should be emphasized that surface deformations, which are established by satellite data analysis, require accurate calculations and complement field measurements and could support them, but cannot replace them..

3. Case studies

The Northeast Black Sea coastal area of Bulgaria is one of the regions that have been known and studied in last decades because of several active large archaic and modern landslides. From the geological research done in the said region most of the landslides located in it are of complex nature and are considered deep-seated. Figure 1 shows interferometrically processed bursts from the subscene, which covers the coastal zone between Varna and Cape Kaliakra, where the studied landslide is located.. It can be noted that a large part of the image is decorrelated because in this region most of the land cover classes belong to agricultural ones that change their scattering properties for the stated period. But for the narrow strip (about 20km wide) that follows the seashore line the phase signal exhibit good quality which in turn means that for areas located there the information obtained after the unwrapping stage can be considered reliable. This is the reason to focus on the small zone around every landslide that is in full correspondence with the statement of Hanssen (2001) that isolated parts of high coherence can be unwrapped correctly while the result for the larger decorrelated parts will not be accurate.

Proceedings of the International Cartographic Association, 4, 2021.
30th International Cartographic Conference (ICC 2021), 14–18 December 2021, Florence, Italy. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-4-10-2021

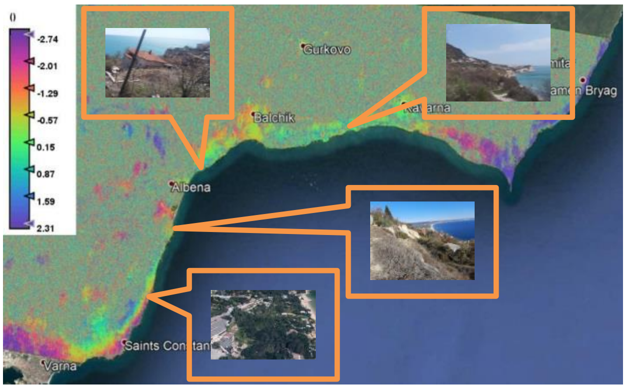


Figure 1. Interferometric image (orbit 36 ascending) for the dates 20Nov2015_11Mar2016 in the Northeast Black Sea coastal area of Bulgaria

3.1 Landslide circus "Dalgia yar"

The case of the landslide circus "Dalgiya Yar" is presented for illustrative purposes. The studied area is found in the Varna landslide region, which includes the coastal strip near the village of Kranevo (Bruchev et al., 2007; Berov et al., 2020). The formation of deep landslides in the area is mainly due to sea abrasion. These are large landslide complexes (circus-type) manifested on the eastern slope of the Frangen plateau - from its edge to the beach. The colour-coded earth displacements in LOS calculated from the phase signal for several periods by processing S-1 data are shown on Figure 1 b-f. The time period covers 4 months for the winter months starting in November 2015 up to March 2020. As it can be seen the calculated displacements are in the range between 2 cm (uplift) and -10 cm (subsidence). The obtained IFIs reveal that the registered deformations are concentrated in some local areas with uneven structure. A map of the concentration of deformations of the earth's crust was created from them. The pixels having coherence values below 0.3 in each IFI have been removed because they are considered unreliable. The colour of the pixels represents the movement of the surface in the dimension meter for the studied period, ranging from dark blue to purple. Particularly vulnerable areas are shown in purple and less vulnerable in yellow and green. The area enclosed by the polygon of geodetic points 208, 209, 201, 102, 111 and 112 (see Fig. 1a) is inaccessible because it has steep slope and highest inclination. These points were not monitored by GNSS measurements in campaign mode(Atanasova et al., 2019; Dimitrov et al., 2020). It is worth noting that the earth surface movements in this area are monitored only by SAR data and have some of the most significant subsidence values for the studied period.

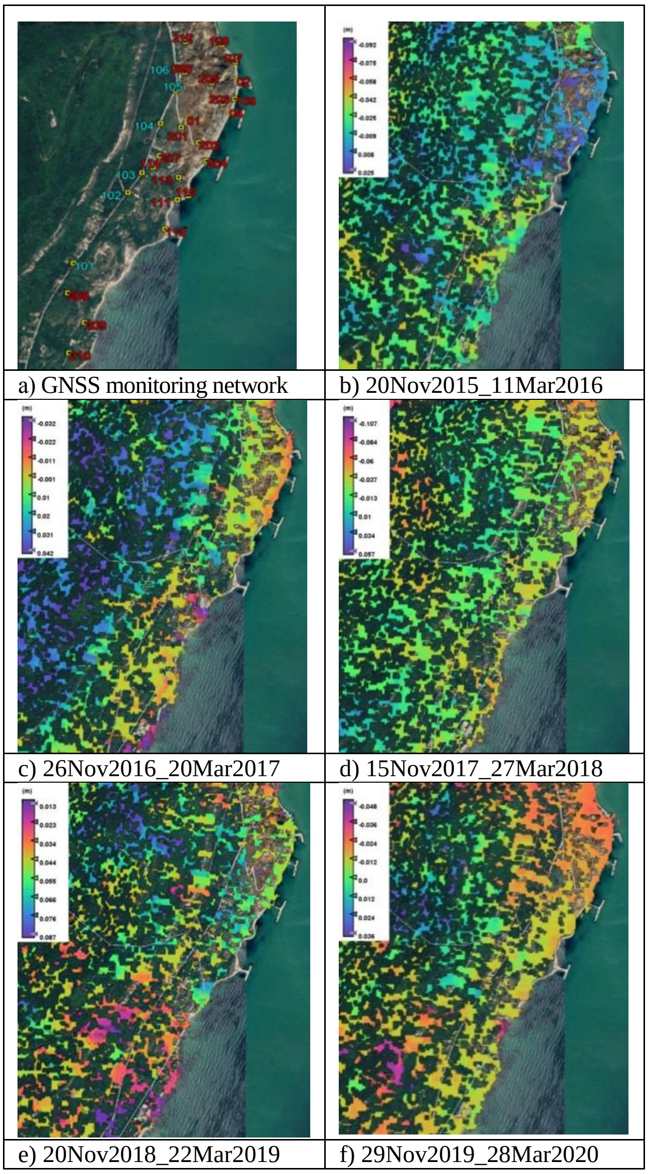


Figure 2. Case of application of the DInSAR research method for the"Dalgiya Yar" landslide: a) geodetic monitoring network; b-f) surface displacement maps

The maps showing the mean surface displacements in the LOS direction are shown on Fig.1 (b-f). The research approach demonstrates the potential and ability of DInSAR to study and monitor landslides and measure their trend in LOS with centimetre accuracy over time using freely available data and software. For monitoring the ground deformation, due to the relativity of the DInSAR technique, other types of measurements such as GNSS, precise levelling, and UAS or LiDAR d need to supplement the data from the satellite remote sensing.

3.2 Landslide "Fish-Fish"

Another landslide on the northern Black Sea coast that has been active in recent years is found in the residential zone Fish-Fish close to the town of Balchik. Its recent activation at large extent is due to the anthropogenic activities (mainly construction of homes) that have been carried out during the last three decades in this area.

Proceedings of the International Cartographic Association, 4, 2021.
30th International Cartographic Conference (ICC 2021), 14–18 December 2021, Florence, Italy. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-4-10-2021

The unfavourable processes that happened in this landslide located on the steep slope slopes of the plateau towards the sea are part of an ancient larger and relatively stabilized landslide. Based on the geological research it was established that the slope is formed by sandy clays, which lie on intact clays and dark gray and light green clay marls having subhorizontal layering at the foundations of the landslide. The landslide development mechanism is predominantly delapsing. In the last years the landslide developed as a detrusive, with larger displacements in its upper zone - about 8-10 mm which at the direction of the shaft they exhibit a decrease of 3 mm or less. The most probable reason for the activation of this landslide is the increased amount of groundwater inflow which in turn leads to rise of groundwater water levels during the years.

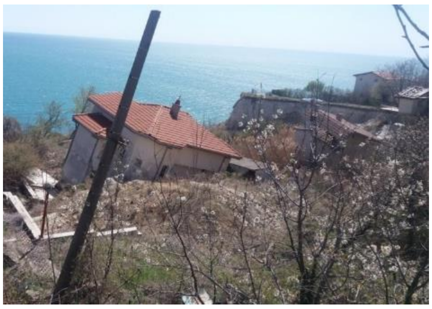


Figure 3. Photo of the active” Fish-Fish” landslide

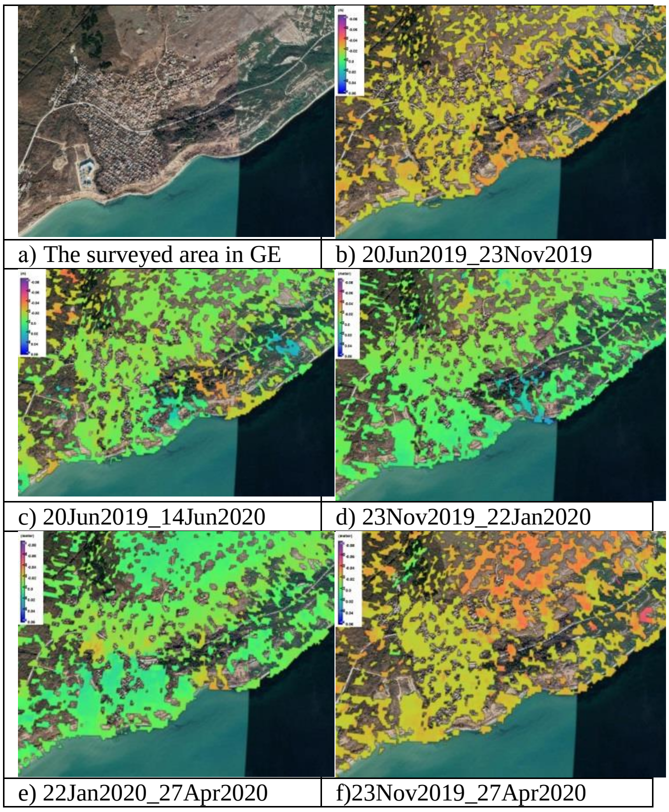
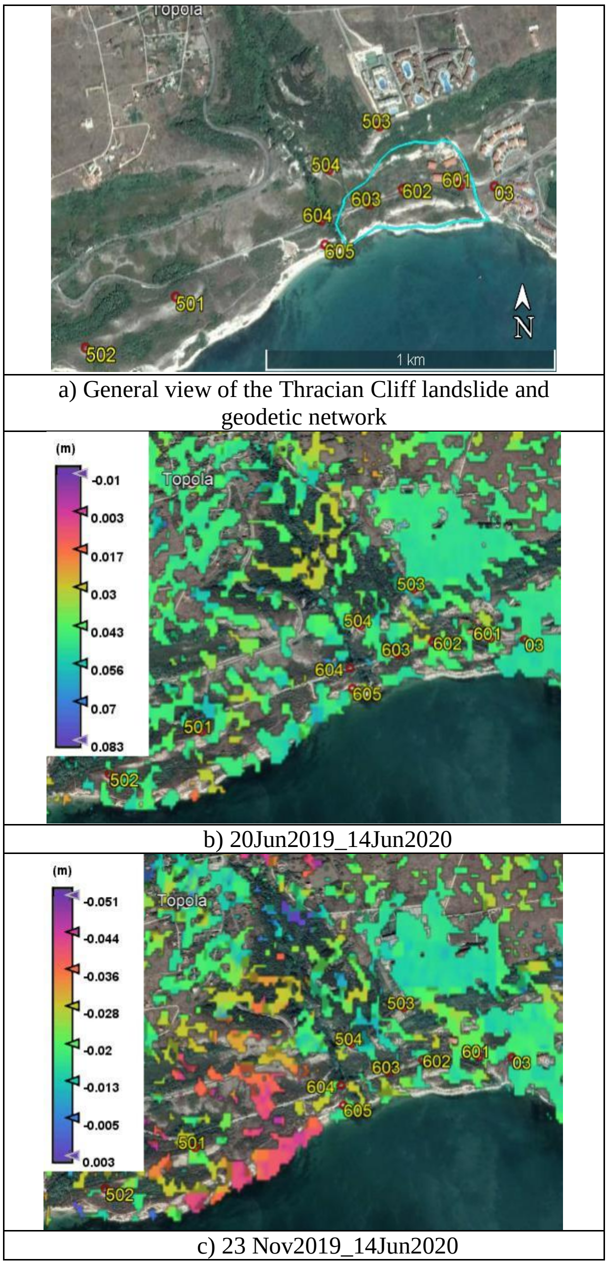


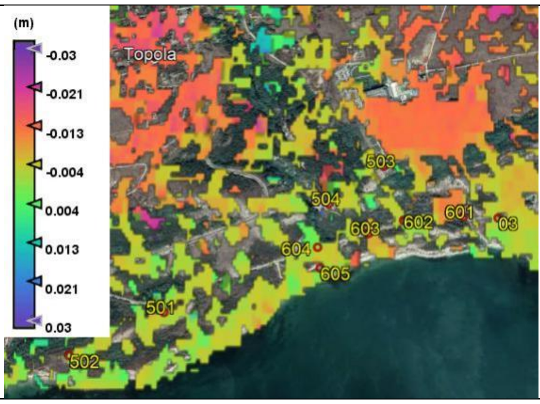
Figure 4. Application of the DInSAR research method for “Fish-fish” landslide: a) Google Earth view of the studied area; b-f) surface displacement maps for it.

3.3 Landslide "Thracian cliffs"

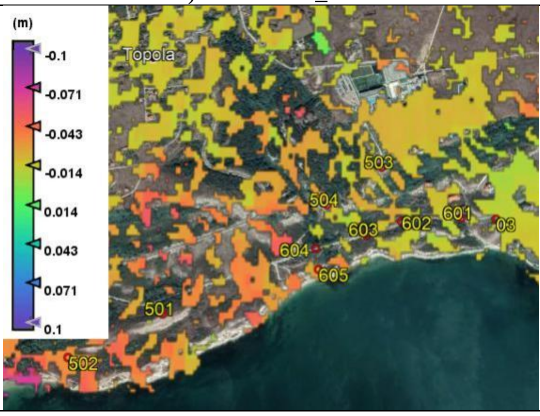
The landslide "Thracian cliffs" is an active landslide located near the village of Topola, Kaliakra municipality. It is filed in the national landslides register as DOB 17.05009-01-03. The landslide is developed along the coastal slope, just before the entrance of the Thracian Cliffs Golf club (Fig. 5a). According to Geozastita Varna Ltd (2018) the Thracian Cliff landslide is manifested in the front of an ancient stabilized landslide “Kalkan tepe”. The main reasons for the activation of the landslide are the over-wetting processes of the earth masses by waters of underminated origin (possibly underground) and the marine abrasion.



30th International Cartographic Conference (ICC 2021), 14–18 December 2021, Florence, Italy. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-4-10-2021



d) 20Nov2015_Mar2016



e) 15Nov2017_27Mar2018

Figure 5 Application of the DInSAR research method for the Tracian cliffs" landslide: a) geodetic monitoring network; b-e) surface displacement maps

3.4 Landslides in the area of Lom-Oryahovo along the Danube River

The impact of the water level of the Danube river and its tributaries is recognized by the scientists and practitioners to be one of the key factors for landslides development in the north-western part of Bulgaria. In this area widely distributed are the Pliocene and sandy clays as well as clayey loess. This specific geological setting of clays changes its strength and physical properties under the waterlogging conditions caused mainly by the increased amount of water from rainfalls and snow to increased water level of the Danube River. It is to be mentioned that in the area investigated from the town of Vidin to town of Nikopol there are a number of landslides both active and stabilized forming one almost uninterruptible strip. Most of the landslides present are at fragile equilibrium very often lost under the increase of the amount of surface and underground water which are considered to be the major triggering factor (see Fig. 6)

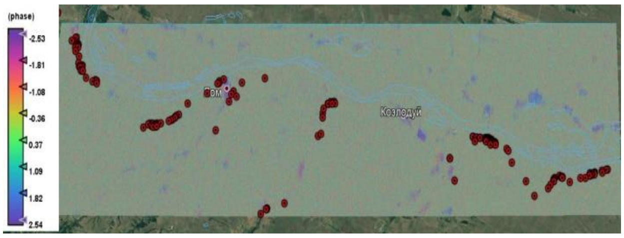
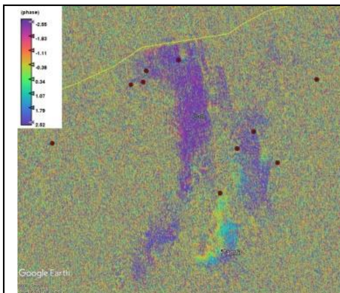


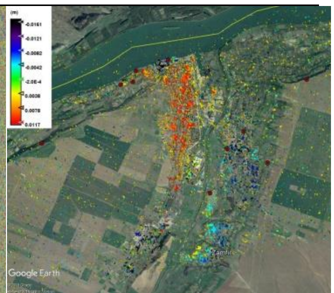
Figure 6. Interferometric image and landslides along the Danube river created from SAR data for the periodJan2015/Jan2018.

In this case, to study the activity of landslides, the method aims to assess the influence of soil moisture. Information from geological and hydrological maps of the region was used to supplement the research. For several areas where there is a concentration of most of the landslides found in the region, interferometric maps have been created to assess the surface deformation around them.

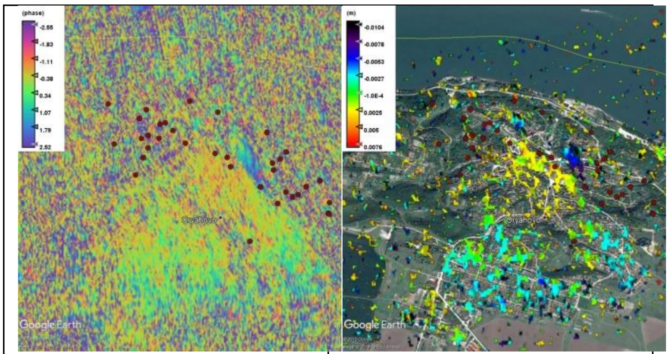
The investigated phenomena are located in the North West part of Bulgaria along the south river banks of Danube since the needed additional data are available and cover only this region. The official public data for landslides distribution is shown of Fig.6. It can be seen that those landslides are concentrated in several areas along the tributaries of the Danube River.

Porous texture of the loess sets good water permeability in the vertical direction and pronounced dectility in the same direction. Consequently, in loess, numerous vertical walls are formed near the banks of the Danube between Kozloduy and Oryahovo (red dots on– Fig. 6). The types of loess in the research area is mainly sandy and typical Sandy loess is seen as a very narrow strip, 2–3 km wide, along the Danube River, between Kozloduy and Oryahovo. The most common causes for activation of deep landslides is the penetration of rainfall and the technogenic waters in the body of the landslide. Coastal erosion plays great role for the landslides activations in the Boruna quarter, near the town of Lom (Fig. 7a, b). Other landslides in the area of Lom town are located 2–3 km away from the river and virtually no erosion affects them. Deep erosion has a significant impact on landslides in the towns of Oryahovo (Fig 7c,d), Ostrov and Nikopol.





a) Interferogram around the town of Lom	b) DInSAR displacement map



c) Interferogram fo the town of Oriahovo	d) DInSAR displacement map

Figure 7. Interferograms and displacement maps of the landslides around the towns of Lom (a,b) and Oriahovo (c,d)

4. Conclusion and discussions

We demonstate several case studies of DinSAR application for the landslide investigations in Bulgaria. This innovative method using satellite data from Sentilel-1 could be used for further landslide inventory and mapping in the presented regions as well as to deliver updated information to the local authorities. We could conclude that having a frequent revisit of the satellite allows the production of information on unexpected landslide activation with reasonable spatial resolution, which is non-dependent on the weather conditions.

All of the above motivates the authors to continue their work in these specific locations in Bulgaria. The information that will be provided as a result of furtherresearch may be useful for a wide range of professionals, scientists and the public to prevent the adverse effects of landslide intensification in these areas.

4.1 Acknowledgements

This study was conducted with financial support of the Bulgarian NSF under the Project № KP-06-OPR 06/1 "Monitoring of landslides on the Northern Black Sea coast of Bulgaria using data from GNSS and InSAR".

5. References

Atanasova M., H. Nikolov, I. Georgiev, A. Ivanov, N. Dimitrov (2019). Monitoring of landslide processes at the NE Bulgaria by joint use of GNSS and InSAR, In: Proceeding 10th Congress of Balkan Geophysical Society, 18-22 September 2019, Albena Resort, Bulgaria, EAGE, 2019, https://doi.org/10.3997/2214-4609.201902640

Atanasova M., H. Nikolov (2018). Study of the relationships between soil moisture and active landslides in Northwestern Bulgaria based on SAR data, In: Proc. of XXVIII Int. Symp. on “Modern technologies, education and professional practice in geodesy and related fields”, Sofia, November 08 – 09, 2018.

Berov, B., N. Nikolova, P. Ivanov, N. Dobrev, M. Krastanov, R. Nankin (2020). Landslide susceptibility mapping using GIS: a case study along Bulgarian Black Sea coast, In Proc. of 8th ICC&GIS conference, (Eds.) T. Bandrova, M. Konečný, S. Marinova, Nessebar, Bulgaria, vol. 1, 287-296, ISSN: 1314-0604.

Bruchev, I., Dobrev, N., Frangov, G., Ivanov, Pl., Varbanov, R., Berov, B., Nankin, R. Krastanov, M. (2007). The landslides in Bulgaria - factors and distribution, Geologica Balcanica, 36, 3-4, pp. 3-12.

Dimitrov N., Georgiev I., Atanasova M., Ivanov A. (2020). Monitoring of the landslide processes at the "Dalgiya Yar" landslide, In: Proceedings of Selected papers, Vol. 20, Book 2.2, 20th International Multidisciplinary Scientific GeoConference, 18-24 August 2020, Albena, Bulgaria, DOI: 10.5593/sgem2020/2.2/s09.011, 87-94.

Ferretti, A., Monti-Guarnieri, A., Prati, C., Rocca, F., Massonnet, D., 2007. InSAR principles: guidelines for SAR interferometry processing and interpretation. ESA Publications, TM-19.

Hanssen R.F., Radar interferometry: data interpretation and error analysis. Dordrecht, Netherlands: Kluwer Academic Publishers; 2001.