Creating a thematic geodatabase for monitoring the landslide processes of the landslide circus “Dalgia yar”

Mila Atanasova¹, Hristo Nikolov², Ivan Georgiev¹, Keranka Vassileva¹, Nikolay Dimitrov¹, Anton Ivanov¹

¹National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Acad. G. Bonchev Street, Bl. 3, 1113 Sofia, Bulgaria
²Space Research and Technology Institute, Bulgarian Academy of Sciences, Acad. G. Bonchev Street, Bl. 1, 1113 Sofia, Bulgaria
m.atanasova@geophys.bas.bg

Abstract. Impact on the process of landslide origin and activation is result of many factors both endogenous and exogenous. The purpose of this study is to provide possibility for analysis and assessment of the geo-processes in the "Dalgia yar” landslide located at Northern Black Sea coast of Bulgaria in order to prevent risks and disasters of natural and anthropogenic origin. An important stage was to seamlessly include data from different sources such as geodetic measurements, satellite SAR (Synthetic-aperture radar) data as well as geological and geophysical data. The established geodatabase structures the collected information on dangerous geo-processes in the mentioned area and introduces them into the GIS (Geographic information system) environment. Its purpose is to facilitate the analysis of the available geological data for this landslide and to integrate them with results of measurements from regular monitoring. Interferometric images (IFIs), data from permanent GNSS (Global Navigation Satellite Systems) stations and from local geodynamic GNSS network, geological, seismic and geophysical data, updated geological maps and maps of the risk of landslide processes are included in the database. The IFIs have been produced using well established procedure for processing large number of Sentinel-1 SAR data of the purposely created local archive. Other key element used to improve the final results of SAR data processing and important part of the geodatabase is the precise Digital Elevation Model (DEM), which is much better in terms of horizontal and vertical resolutions than the open accessed ones (SRTM). The coordinates and velocities of the GNSS points are obtained from adjustment and analysis of two epoch measurements of the geodynamic control network of landslides "Dalgia yar”. Since the area has complex geological structure, small scale maps reflecting the geological and geophysical hazards are integral part of the geodatabase. Having all this information the analysis concerning the ongoing geodynamical processes in the study area is significantly improved and more reliable information is produced for better regional planning by the local authorities and residents.

1. Introduction
The complex geological structure and intensive tectonics determine the activation of erosion-abrasion processes in the coastal zones and the triggering of landslides of various types and mechanisms, which occur in sloping terrains sea shores. Important conditions for the development of erosion, abrasion and landslide processes on the slopes are: specific diversity of rocks and soils, inclination of the layers, the presence of clay layers, weak layers, tectonic disturbed areas, the presence of groundwater. [1] The
slopes are influenced by natural and man-made factors, which contribute with varying degrees to the landslide occurrence. Natural factors are associated with the undercutting of the foot of the slopes caused by the erosive action of rivers and their tributaries by forming ravines as well as the sea abrasion. There is a close relation between the areas with active erosion and abrasion and the occurrence of gravitational processes – landslides, rockfalls, and slope creeping. Since the subject of this research has, regional focus data regarding geology, land cover/land use, seismicity were investigated as driving factors for the landslides occurrence and temporal development. [2]

The main contribution of this study is to implement the multitemporal DInSAR method based on satellite SAR data to register and calculate the surface motions produced by the slow moving landslides in the region of interest (ROI) and as final information product to obtain inventory maps concerning their temporal behaviour. It needs to be highlighted that for some areas in the ROI this might be the only approach to regularly obtain information about this phenomena since the slopes in some locations impedes direct in-situ measurements. Other peculiarity of the method used is that no information is provided from the phase signal of a single SAR image and for this reason at least two images are needed to study a single slope failure event. Prerequisites for reliable results is the closest acquisition geometry between the two passes and short revisiting intervals both satisfied by the data obtained by Sentinel-1 mission. In this specific study to produce interferometric images with highest possible quality, a local DEM was used that has spatial resolution that is close to the processed data. Since in this specific ROI the dominant surface movement subjects of this research are in west-east direction this predetermines the used SAR data to be from descending satellite orbit. From the said orbit direction the radar shadowing for the investigated ROI is relatively small if any.

2. Region - landsides area “Dalgia yar”
For the study ROI it needs to be pointed out that at its southern part the length along the direction of the movement of the earth masses reaches 1000-1200 m. The coastal part of this area is part of an ancient landslide ridge starting from the Golden Sands resort to south of the town of Kranevo. Specific for this section of the coast are the negative depressions, block rises, local swamps and shallow groundwater. Inside of this ancient relatively stabilized landslide zone separate local active landslide areas have been developed - the bus stops “Kiparis”, “Obzor”, “Far Ekrene”, “Panorama” and “Ribarsko Selishte”.[3].

On October 8, 2012, at 3.30 am a huge landslide intensified in the area of Ekrene lighthouse. Several tens of thousands of cubic meters of earth have collapsed. The strip covered by it is nearly 2 km and the most affected is the fishing village on the beach. The landslide entirely destroyed the 100-year-old lighthouse. The road leading to the sea was completely destroyed, buried were the fishing vans that have been located on the beach. The concrete lane at the seafront was raised by 15 m. The road Golden Sands - Kranevo is in danger of collapsing.

A characteristic feature of landslides in north part of the ROI is that the sliding surface of the old and recent landslides has its end high on the slope so these landslides could be classified as hanging landslides. For them it should be pointed that the marine erosion is not directly related to the stability of the landslide.

The landslide between points 212 and 108 started its development in 1998, in 2012 extended more and currently the affected area is estimated to be 7.5 ha. The main reasons for the activation of modern landslides are the infiltrated atmospheric and wastewaters, which worsen the strength indicators of the rocks. In the central part of this landslide, the indentation is higher than 10 m. Currently it is considered to be slowly moving, but active and continues its enlargement in north direction which is evidenced by extension of the existing cracks and appearance of new ones. [3]
In the area of the next landslide, the following points are located – 201, 202, 203, 0001 and 205. The first registered and filed activation of this is in 1971. A landslide notch with a height of up to 15 m and a landslide shaft in the sea with a height of 4.0 m were formed as well as displacement of land masses up to 17 m were established. This landslide is about 250 m long and about 800 m wide. In the period 1971-1983, about 30 villas were completely destroyed while others were partially affected. The main reasons for its activation are complex – the geological and hydrogeological conditions; the sea erosion; the construction activities and water supply of this villa zone; the lack of sewage. [3]

The studied landslide area is portrayed on Figure 2 where the approximate locations of the known and registered landslides are provided.

3. Method and data

3.1. GNSS permanent network
A method for monitoring the deformations of the landslide processes using GNSS technology has been proposed. It is based on data from two types of GNSS networks, with reference stations located on geologically stable terrain and points located in the landslide body. Data for the stable points located in non-deformable zones in the region are provided by the stations from the permanent GNSS network - continuously operating reference stations (CORS) - from the National GNSS Network maintained and pre-processed by NIGGG-BAS (see figure 1).

All measurements from the local geodetic network are processed and analyzed using data from CORS present in the research area. In this study, long-term processing of data from continuously operating reference stations is performed to obtain the coordinates and velocities of the stations, because this also affects the local geodetic network established for studying the landslide area.

Figure 1. Stations from national permanent geodetic network (red triangles), major faults (blue and brown lines) and regional faults (black dashed line) [4].

GNSS data from six continuously operating reference stations from National GNSS network for three years and a half period were processed and analyzed. Time series with coordinates, mean square errors (north, east and up) and residuals from multi-year solution were obtained.
The velocities of the points from the National GNSS network in the northern Black Sea region are relatively small, less than 1 mm/year. In other regions of Bulgaria they can reach 3-4 mm/year. To obtain the movements of the points from the local geodynamic networks, it is possible to process their GNSS measurements together with the GNSS measurements from the points of National GNSS network but the velocities of the CORS station must be taken into account.

3.2. Local geodetic network
For this specific study a local GNSS network covering the landslide area "Dalgiya yar" (see figure 2) was established. It consists of a total 30 stabilized points with some being metal pipes 35 cm long while other are metal bolts nailed in the rock. In the mentioned geodynamic network "Dalgiya yar" all old six points that were found on the ground from the network used to monitor deformations along the road are included. The GNSS measurements were carried with 2 receivers of type CHC i80 GNSS with horizontal precision 2.5 mm + 0.1 ppm RMS and vertical 3.5 mm + 0.4 ppm RMS and 1 receiver - P3E GNSS sensor used for reference station. Static mode with an interval 1 sec. and duration of one hour was applied for the GNSS measurements. The results of the GNSS measurements were processed using „CHC Geomatics Office 2“ software in the coordinate system WGS84. This newly established geodynamic network located inside the landslide area was measured once a year. The first measurement cycle of the geodynamic network was carried out in June 19-23 2019, second in June 22-27 2020 and the third will be measuring cycle in June 21-28 2021. The deformation analysis of the geodynamic networks will be done after the third measurement cycle by applying an appropriate approach.

3.3. DInSAR approach
Differential interferometry (DInSAR) is a technique for processing SAR data obtained from active remote sensing of the Earth that can be used to quantify small displacements on the surface – usually in the range of centimetres. Using data from the radar instrument processed by DInSAR two main tasks can be solved – mapping the topography of large areas as well as registration of displacements on the surface. To apply the DInSAR method needed are two SAR images containing the backscattered phase signal from the earth's surface obtained over the same region at different dates. This manner it is possible to accurately measure the relative distance to specific area on the ground for

![Figure 2. Local geodetic network used to monitor the landslides in “Dalgiya yar” area and the areas of the investigated landslides](image-url)
each of the dates and if there is difference between them it can inferred that a surface motion took place at this area. It needs to be taken into account that the radar instrument is side looking and therefore the registered movements are in range direction of the so-called line of sight (LoS), which is determined by the position of the satellite. In order to obtain the displacements horizontal and vertical planes the LoS vector has to be decomposed additionally. The processing of the SAR data starts with subscene selection, then orbital information is used to establish the position of the satellite at time of the acquisition for both data sets. After that, joint registration of both images is performed with additional corrections, if needed, and then a differential interferometric image (IFI) based on the change in the phase signal is generated form the stack. This IFI contains information relating to the occurred surface motions. At this step one more important data is produced known as coherence, which is used as measure for the reliability of each pixel in the IFI. Next steps of the processing include high pass filtering, phase signal unwrapping, conversion from integer values of $\pi$ to metric units and finally transformation to the required cartographic projection.

The main results product of this research are from two sources – in-situ and satellites. Former consists of processed data from national permanent GNSS network, major faults as registered in EDSF [4] and local faults as introduced in the national geological map scale 1:100 000- map sheet Varna, Shabla (see. Figure 1) while the latter is the Sentinel-1 mission of ESA. In order to highlight the importance of the results other auxiliary data were used such as CoastalZones 2018 product [5], terrain slopes [6] and approximate landslide contours [3].

3.4. SAR data

In this study the main source of SAR data used to obtain information reflecting the geodynamic movements in the selected ROI is the radar instrument located on board the Sentinel-1 satellite mission operated by ESA. The radar itself is operating in the C band (5.4 GHz). In order to obtain reliable information on the displacements resulting from the landslides activations pre-processed images in SLC format obtained in IW mode of the instrument were downloaded from the data warehouse maintained by ESA. To study the ongoing geodynamic processes in the ROI a local archive with SAR data from the Sentinel-1 mission was created. Using the method described above for production of IFIs a set of raster images containing phase and coherence values was created at intervals of 1, 4, 8 and 12 months.

In the course of their processing some 30 interferometric pairs (IFPs) were formed to track the surface displacements. The information obtained from the said data is based entirely on the registered changes in the phase component of the radar signal backscattered from the Earth’s surface. This information is saved in the form of raster IFIs made possible determination the magnitude of the deformations that occurred for every studied period. The time interval between the SLC imaged forming single IFIs was selected in way that minimal time decorrelation was ensured. This selection was based on the high values of the estimated coherence of each IFP even at the stage of their coregistration, which was a guarantee for the quality of the results obtained by them in the following stages of the DInSAR processing.

As mentioned in the previous section to obtain reliable information after processing SAR data selection of the correct orbit direction – ascending (direction S-N) or descending (direction N-S) – plays a has key role. This choice is important because for the Sentinel-1 satellite the antenna of the radar always points to the right. The type of orbit determines the angle at which the studied areas on the earth’s surface are “seen” by instrument and therefor the registered relative displacements are different for both types of orbits. For this research, it resulted that processing data from descending orbit provides better results thus the results regarding the SAR derived information shown on Figure 4, Figure 5 and Figure 6 are from this orbit.
In order to obtain the magnitude of the surface displacements in the course of interferometric processing it is essential to eliminate the contribution of the relief into the phase signal thus an external reference DEM is needed. In this research the authors used extensively validated product from SRTM mission with a horizontal resolution of 1arcsec (~ 30 m in the horizontal plane).

In order to increase the signal-to-noise ratio in the phase signal an adaptive filter was applied to the spectral density of the signal power, which reduces the broad-spectrum noise available in the data at the expense of reducing the image resolution. This procedure is crucial since even small distortions of the phase signal lead to inaccuracies in the registered surface motions.

The interferometric processing of SAR data was performed entirely through the SNAP software. [7] This software was created and made available for free use by ESA while other software products were used for better visualization and additional analysis.

The validation of the information received from the IFI was performed using the data from the created local GNSS network.

An important element in this study was the availability of local digital elevation model for this ROI (see Figure 3). This DEM was used in establishing the position for the points included in the local geodetic network and during the interpretation of the IFIs. It was also considered in the process of analyzing the produced information justifying the results.

![Figure 3. Local geodetic network used to monitor the landslides in “Dalgia yar” area overlaying a DEM with horizontal resolution of 8 m.](image)

4. Results and discussions
Main objective of this research is to create local geodatabase in order to improve the knowledge and to facilitate future GIS-based research in one of the landslide areas located at Northeast coastal area of Bulgaria – namely the region of “Dalgia yar” landslide zone. Pivot elements of this geodatabase are the raster layers produced from SAR data processing – interferometric and coherence images as well as images of the unwrapped phase signal. All mentioned layers are in WGS84 coordinate system in order to be useful in most of the current and future applications. Besides the mentioned layers, others
were also included in order to enhance the understanding of the ongoing geodynamical processes and to assist in assessing the damages caused by activation of the landslides. The selected structure of this geodatabase is to integrate in seamless manner as much freely available spatial geo-datasets as possible that are processed and analyzed by open source software.

On Figure 4 provided is the IFI created from SAR data for the period 26th 2016 – March 20th 2017. From it can be concluded that in the area designated by the red rectangle there are some movements indicated by the clearly visible interferometric fringes especially at edges of the ridges of the “Dalgia yar” zone, which is in the middle of the shape. Also we need to answer the question why some areas are decorrelated and a possible answer is that this due to vegetation, despite the winter season, and due to air humidity that was impossible to take into account during the SAR data processing.

**Figure 4.** Stations from national permanent geodetic network (red triangles) with underlying raster from sample IFI.

On Figure 5 shown is a raster map of the displacements from the produced IFI obtained from SAR data covering the period Nov 26th 2016 – March 20th 2017. They were obtained after executing the unwrapping procedure on the phase signal and after transforming the integer $\pi$ values into metric units. This is an example from the set of IFIs included in the created thematic geodatabase. The color of the pixels represents the movement of the surface in the dimension of a meter for the studied period, ranging from dark blue (corresponding to $-0.14$ m) to red (corresponding to $0.07$ m). Particularly vulnerable areas are shown in dark blue, and less vulnerable in yellow and green.
Figure 5. Local geodetic network used to monitor the landslides in “Dalgia yar” area overlaying a raster corresponding to displacements registered for period Nov 26th 2016 – March 20th 2017.

It is visible on the same figure that there are “blank” areas, that is because for those areas the values for the coherence raster are below the threshold of 0.3 and for this reason were removed (see Figure 6). Following this approach only meaningful and reliable information is provided for further analysis to the expert users.

The area enclosed by the polygon from points 208, 209, 201, 102, 111 and 112 is inaccessible as it has the highest degree of inclination and therefore it was not possible to place geodetic points and perform GNSS measurements. Displacements in this area will be monitored only by SAR data and have some of the highest sinking values for the period. An example of estimating landslide activity based on this IFI shown in figure 5, is that the subsidence varies to -92 mm.

On Figure 6 presented is the raster layer with the coherence values for the same area as shown on Figure 5. The importance of those values was stated above, but it needs to be noted that for the points of the local geodetic network their magnitude is high, which is represented by colors varying from light gray to white.
Figure 6. Local geodetic network used to monitor the landslides in “Dalgia yar” area overlaying a raster layer corresponding to coherence values registered in the IFI for period Nov 26th 2016 – March 20th 2017.

On Figure 7 presented is an excerpt from the CoastalZones 2018 product [5] for the investigated ROI mixed with points of local geodetic network. As seen there are several classes – 11120 dense urban fabric (IMD =>30-80%)" in red; semi-natural grassland" in yellow; natural and semi-natural broadleaved forest in green; coastal cliffs in gray. This layer of the geodatabase is used to indicate the threat that is posed by the investigated landslides mainly to the houses and infrastructure of the local inhabitants and to the landscape. (Figure 8)

On Figure 7 shown also are the slopes of the relief (in degrees) of the ROI. The reason to include this information in the realized geodatabase is the need to assess the susceptibility for future landslides activation caused by natural (rain, sea erosion) and technogenic (illegal construction, water pipes failures) activities. Combined with the information from Figure 7 better landscape management plans could be prepared or crisis preparedness will be achieved.

Figure 7. Local geodetic network used to monitor the landslides in “Dalgia yar” area overlaying the classes from CoastalZones 2018 product [4].
Figure 8. Local geodetic network used to monitor the landslides in “Dalgia yar” area and slopes inclination [5].

On Figure 9 all currently included layers in the elaborated GIS geodatabase are shown. Its purpose is to assist scientists, practitioners and local authorities in investigating the ongoing geodynamical processes by providing reliable information from thematically processed SAR data and combining it with other available data in order to facilitate the analyses in GIS environment. It needs to be underlined that is planned to integrate more SAR derived layers and results from local geodynamic network as they are produced and this way to enable their multitemporal studying.

Figure 9. Layers included in the created geodatabase for monitoring the landslides in “Dalgia yar” area.

5. Conclusions
The results from the SAR processing stated above confirm the fact that the IFIs produced from satellite SAR data deliver reliable data for studying the ground displacements that occurred as result of landslide movement. For some areas of the “Dalgia yar” zone of this information can be considered as the only source for surface motions since the relief hampers the accessibility to them. This information
is the key element of the created local geodatabase for the studied region and this why one of the challenges is to ensure its reliability, while other data sources are considered to be validated before provided to the public. It is worth noting that the developed product could be seen as first step towards development of regional datacube in the near future, which could be used to tackle much broader set of problems than those pointed out in the text above.

Acknowledgment
This paper has been made available with the financial support provided by the National Science Fund. Project number KP-06-OPR 06/1.14.12.2018 "Monitoring of landslide processes on the Northern Black Sea coast of Bulgaria through cooperate use of data from GNSS and interferometric images from SAR”.

References
[1] B. Berov, N. Nikolova, P. Ivanov, N. Dobrev, M. Krastanov, R. Nankin, “Landslide susceptibility mapping using GIS: A case study along Bulgarian Black Sea coast” Proceedings Vol. 1, 8th International Conference on Cartography and GIS, 2020, Nessebar, Bulgaria, ISSN:1314-0604, Eds: Bandrova T., Konečný M., Marinova S. - icegis2020.cartography-gis.com.
[2] P. Ivanov, R. Nankin, V. Zaalishvili,” Assessment of Landslide Susceptibility and Hazard along the Northern Bulgarian Black Sea Coast” Proceeding of 1st International Conference on Environmental Protection and Disaster RISKs, E-ISBN-13: 978-619-7065-39-8Print-ISBN-13: 978-619-7065-38-1, pp: 392-404, 2020.
[3] Annual report of Geozastita Ltd., 2019 (in Bulgarian).
[4] The European Database of Seismogenic Faults [Online] 2013. Available at: http://diss.rm.ingv.it/share-edsf/.
[5] Coastal Zones [Online] 2018 [Acessed May 2021] Available at: https://land.copernicus.eu/local/coastal-zones.
[6] Slope Angle ancillary map of ELSUS v2 [Online] 2018 [Acessed May 2021] Available at: https://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus-v2.
[7] SNAP, Science Toolbox Exploitation Platform [Online] 2021 [Acessed May 2021] Available at: https://step.esa.int/main/toolboxes/snap.