Geoecological monitoring using InSAR Technology

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Abstract: - The manuscript is addressed to engineers involved in geoecological monitoring for mining sector. Interferometric Synthetic Aperture Radar, abbreviated InSAR, is one of the growing technologies that use satellite images in various fields of study such as: lift earth's crust, digital terrain modelling (DTM), subsidence/strains, landslides or hazards and many others. InSAR can provide extensive monitoring data, from large geographic areas, without using expensive instruments or put humans' subjects in jeopardy. Most mines can affect the landscapes within different systems, as Geotopes or Geofacies, therefore monitoring the geographic areas from and surrounding a mining perimeter can provide valuable information required for assessing the geoecological effects on the environment. With over a decade experience in mining ecology and many various projects conducted within the Romanian national program of closed mines monitoring, the authors concluded that InSAR Technology combined with geoecological principles represent a good approach to evaluate the severity of mining operations impact referring to topo-stability inabilities of landscape, as a general method. In the same time, for a better understanding, the manuscript presents a case study regarding to tailing ponds topo-stability evaluation as an example of how to link InSAR and Geoecology.

Key-Words: - Geoecology, Mining, Monitoring, InSAR, Tailing ponds, Landscape

1. Introduction

The useful mineral substances needed for durable economic development of any country, are obtained by mining and oil industries. That's why these industries are very important in the global economic chain.

In the same time, like any other industry, mining must manage the operations (exploitation of earth's solid mineral resources) in respect to environment protection. [2] But in spite of all security measures taken by companies and authorities, this industry creates inabilities for diverse elements of geographic landscapes, due to their basic activities that generate:

- open pits,
- soil stripping,
- landscape changes,
- dumps and tailing ponds, or
- major technical accidents.

Mining is thus is associated with geo-ecological inabilities potential for the surrounding environment, generated by landslides, loss of stability, deforestation or environment pollution which is some of the most publicized examples. [3]

Therefore, it is very important to monitor the geo-ecological indicators to prevent or intervene and eliminate any instability before its appearing.

However, monitoring data should consider not only the past and present situation but should highlight trends, observed and in perspective, for different processes or sources of degradation of the system's units. [7]

In this context, monitoring refers to [1]:

- factors, when is a scientific activity aimed to decipher the behaviour and functioning of ecosystems, that help to predict when changes happened, identify or diagnose the problem and source;
- flows and trends, when is seeking to quantify and suggest long term strategies to follow.

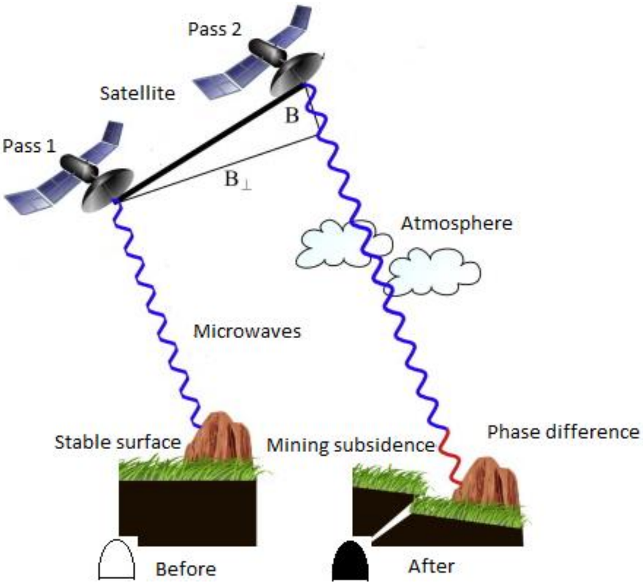
The soil erosion/landslide begins when transporting fluid energy (water or air) exceeds the forces of cohesion between particles. On the other hand, when the speed of fluid decreases to the specific level, where particles cannot be retained in suspension, the sedimentation process takes place (tailing ponds). The depth, slope's angle and length, friction or surface roughness determine the process.

The cohesion of the soil particles is affected by the type of ground (size and aggregation) and the soil binder effect, generated by vegetation.

Surface erosion/deformation is a process that can be observed using satellite images.

Different deformations occurring inside the terrain or slopes, started from hardly visible cracks to slides or wet flows of material, are nascent signs of buckling slope. Therefore, the study of deformation is the main source of data to forecast the stability of different components of a landscape [4], as is presented in Figure 1.

Fig.1 InSAR detection [4]



InSAR can provide extensive monitoring on a weekly or monthly basis, without using expensive instruments (theodolite, GPS) or put humans in jeopardy (for example in underground subsidence, wet landslides or tailings ponds failures).

For the geographical purposes, in terms of spatial scale [3], InSAR can monitor:

- Geosystems, which corresponds to a territorial complex, well individualized, occupying areas from tens to hundreds square kilometres,
- Geofacies, corresponding to a homogeneous local area characterized by its own physiognomy, whose spatial extent is one to tens square kilometres,
- Geotopes, which are the lowest level of the spatial scale, less than one square kilometre.

Analyzed in the context of spatial system, most mines can generate the instability of landscapes within Geotopes or Geofacies, therefore monitoring the geographic areas from and surrounding a mining perimeter will provide most of the information required for assessing the geoecological effects on the environment.

Analyzed in the context of economic system, the extraction and processing of useful mineral

In these conditions, monitoring the stability of tailing ponds, as a geo-ecological key indicator of the landscape health, for a very long

substances is between the geological research (as input) and metallurgical processing (as output); the boundary between geology and metallurgy is narrow since there are situations of overlap and even substitution of some activities, such as exploitation of minerals from geological works and recovery of metals by re-processing slugs from dumps.

Processing the ore a useful component (concentrate) results, that contains a small percentage of sterile and a new sterile component which also contains relatively (determined by technological limitations) small amounts of useful mineral.

After this first processing, the path of the two branches splits: sterile component is deposited in the tailing ponds (as waste) and the useful component (concentrate) goes to factory.

The tailing ponds resulting from ore processing are relatively large as geographic extent and they are fundamentally changing the geomorphology of the Geo-topes, becoming potential factors or sources of natural-technical landscape inabilities.

On the other hand, because the technological evolution, what is now considered "waste" tomorrow could be "preserved resource".

period of time (over 30 years), is more than necessary and InSAR is the instrument for this job.

2. Problem formulation

Mining operations are confronted with frequent hazards caused by natural-technical inabilities.

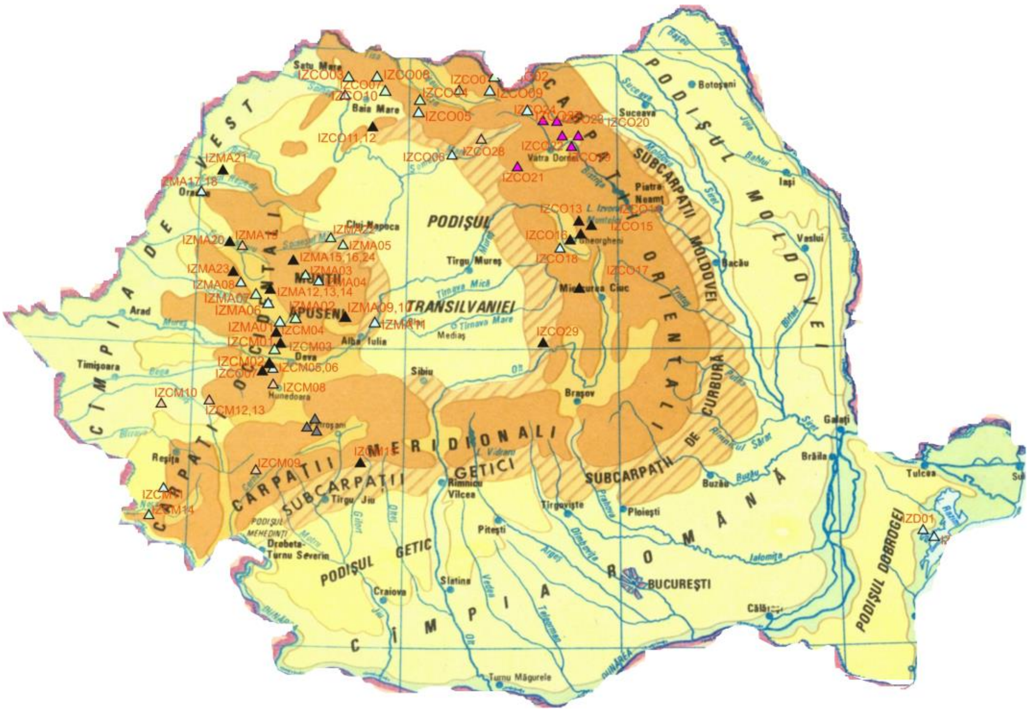
In the context of past intensive development of extractive activities, Romania has not developed adequate environment legislation in the past for the various problems that involve efficient management of tailing ponds. [2]

This inappropriate approach caused serious environmental problems, many of them after the 556 underground mines and open pits closure (result of the mining sector restructuring), layoffs of specialized staff and diminishing financial resources allocated to maintenance and monitoring of tailing ponds and dumps.[5]

Large quantities of mining waste are registered in 77 tailings ponds (amounts greater than 340 million cubic meters), occupying over 1500 hectares, and 557 dumps (amounts greater than 1800 million cubic meters), occupying over 5500 hectares. [3]

In Romania, from geographical points of view, tailing ponds are located mostly in the mountains geo-systems, near former mining areas, almost exclusively from Moldavia and Transylvania Regions, as it is seen in Figure 2. [6]

Fig.2 Tailing ponds - geographical distribution



To monitor the stability of mining perimeters as general techniques such as topo-metric, GPS or InSAR measurements are generally used.

To evaluate the topography and stability of the landscape (as geoecological indicators), it has been decided [5] to start satellite monitoring measurements using InSAR technology, technique that can potentially measure millimetre-scale changes in deformation over days to years from large geographic area; X-band radar images have been used, acquired by the German Terra SAR-X satellite.

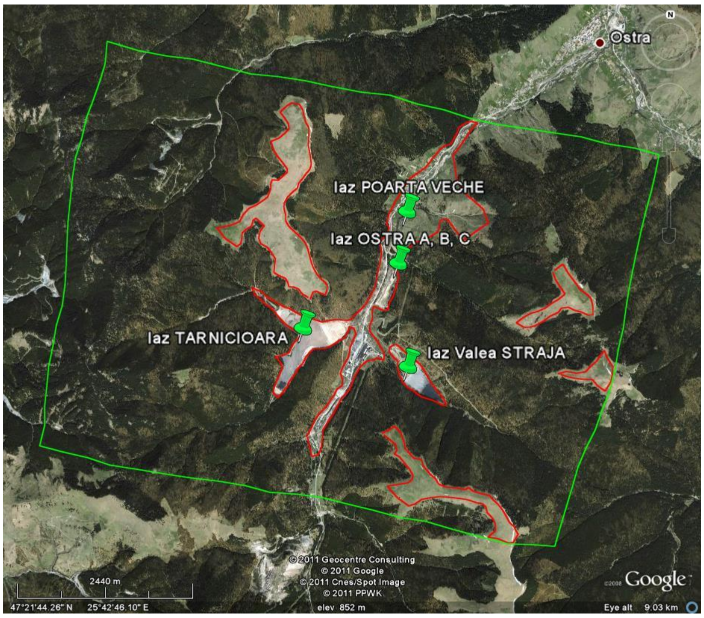
The desired product, after applying this technique, was a geo-referenced map of deformations within the interest zone.

InSAR measurements were accompanied, in the second phase, by GPS measurements, in order to validate the results obtained.

Because of their special landscape conditions, the four tailings ponds within the geosystem located in the north of Moldavia: Tarnicioara, Ostra (A, B, C), Valea Straja and Poarta Veche, from Suceava County have been chosen for this study, as seen in Figure 3. [5]

These four ponds generated many technical accidents by loss of stability, due to specific hazards conditions (violent rains especially) and large extent (Tarnicioara with its two branches Scaldatori and Tarnicioara have over 33 hectares and 80 meters maximum height).[6]

Fig.3 General View of the monitored zone



3. Problem solution

Given the extent of the area of interest and the desired resolution, both horizontally and vertically, it was decided to use TerraSAR-X sensors, in High Resolution Spotlight acquisition mode, with horizontal resolution average of 1x1 meters and millimetre accuracy for deformation measurements of the tailing ponds.

Fifteen images from TerraSAR-X were available for the study, acquired in downward orbit with 30° vertical angle of the satellite antenna (Table 1).[5]

These images "captured" the area of interest for five month (May to October), once every 11 days, and have been used to generate maps of deformation.

Table 1 "Captured" images data

No.	Sensor	Data	Hour	View angle	Direction
1	TRS-X	2011-05-18	04:34:44	30°	D
2		2011-05-29	04:34:44		
3		2011-06-09	04:34:44		
4		2011-06-20	04:34:44		
5		2011-07-01	04:34:44		
6		2011-07-12	04:34:44		
7		2011-07-23	04:34:44		
8		2011-08-03	04:34:44		
9		2011-08-14	04:34:44		
10		2011-08-25	04:34:44		
11		2011-09-05	04:34:44		
12		2011-09-16	04:34:44		
13		2011-09-27	04:34:44		
14		2011-10-08	04:34:44		
15		2011-10-19	04:34:44		

InSAR measurements were accompanied by two phases of GPS measurements taken between May and November, to validate the results.[5]

In order to establish an optimal distribution of GPS calibration points, preliminary acquired radar images have been analyzed that provided locations with maximum response to the radar's signal (unobstructed by diverse artificial or natural objects).

To determine the direction of the radio signal in the field, the geocentric coordinates of two-three successive positions of the satellite have been transformed in Stereo70 coordinates, thus obtaining the orientation of the orbit in a known system.

As the radar signal is transmitted perpendicularly to the satellite orbit, the direction of the signal in stereo system could be calculated.

Knowing the signal direction and angle of incidence the shape of radar image in the studied area could be estimated.

This information was translated on a photo image of the area also existing in Stereo70 system.

In the first phase of measurements, considering the conditions imposed by location, type of soil and the technical requirements of monitoring, locations have been chosen in order to be able to study two special situations:

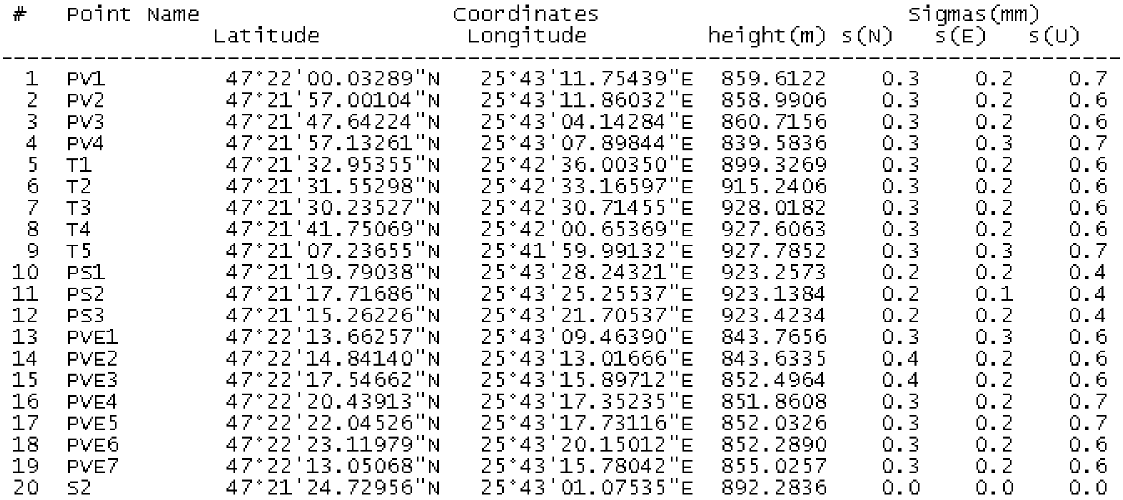
- landmarks in "fresh" filled terrain, called "experimental landmarks 1", and
- landmarks in more stable terrain, but still on the surface of tailing ponds, called "experimental landmarks 2".

In the second phase of measurements, for tracking deformation and subsidence that may occur in the ponds perimeters, were used the same equipment and the same methods of measurement and calculation of tracking network as in the first phase. This condition is absolutely necessary, because there should be no errors of measurement resulted from calculation method or use of other devices than the first phase.

In order to eliminate errors due to ponds instability, in each phase measurements have been integrated from one or two points considered stable, named S1 and S2.

The accuracy of the determination of GPS points, relative to a fixed point S2, has been in millimetre, as shown in the table. 2

Table 2 Example of GPS points accuracy



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 #   Point Name                       Coordinates                              Sigmas(mm)
                Latitude               Longitude          height(m) s(N)    s(E)    s(U)
-----------------------------------------------------------------------------------------
  1  PV1          47°22'00.03289"N   25°43'11.75439"E   859.6122      0.3      0.2      0.7
  2  PV2          47°21'57.00104"N   25°43'11.86032"E   858.9906      0.3      0.2      0.6
  3  PV3          47°21'47.64224"N   25°43'04.14284"E   860.7156      0.3      0.2      0.6
  4  PV4          47°21'57.13261"N   25°43'07.89844"E   839.5836      0.3      0.3      0.7
  5  T1           47°21'32.95355"N   25°42'36.00350"E   899.3269      0.3      0.2      0.6
  6  T2           47°21'31.55298"N   25°42'33.16597"E   915.2406      0.3      0.2      0.6
  7  T3           47°21'30.23527"N   25°42'30.71455"E   928.0182      0.3      0.2      0.6
  8  T4           47°21'41.75069"N   25°42'00.65369"E   927.6063      0.3      0.2      0.6
  9  T5           47°21'07.23655"N   25°41'59.99132"E   927.7852      0.3      0.3      0.7
 10  PS1          47°21'19.79038"N   25°43'28.24321"E   923.2573      0.2      0.2      0.4
 11  PS2          47°21'17.71686"N   25°43'25.25537"E   923.1384      0.2      0.1      0.4
 12  PS3          47°21'15.26226"N   25°43'21.70537"E   923.4234      0.2      0.2      0.4
 13  PVE1         47°22'13.66257"N   25°43'09.46390"E   843.7656      0.3      0.3      0.6
 14  PVE2         47°22'14.84140"N   25°43'13.01666"E   843.6335      0.4      0.2      0.6
 15  PVE3         47°22'17.54662"N   25°43'15.89712"E   852.4964      0.4      0.2      0.6
 16  PVE4         47°22'20.43913"N   25°43'17.35235"E   851.8608      0.3      0.2      0.7
 17  PVE5         47°22'22.04526"N   25°43'17.73116"E   852.0326      0.3      0.2      0.7
 18  PVE6         47°22'23.11979"N   25°43'20.15012"E   852.2890      0.3      0.2      0.6
 19  PVE7         47°22'13.05068"N   25°43'15.78042"E   855.0257      0.3      0.2      0.6
 20  S2           47°21'24.72956"N   25°43'01.07535"E   892.2836      0.0      0.0      0.0
```

For this particular case study, maps of deformation and deformation profiles were achieved using a software package developed at the University of Delft adapted by ASRC, a Romanian company [5], generally using the following steps:

1. Planning the satellite for the purchase of 15 radar images - through DLR (German Space Agency);
2. Aligning the images with better accuracy of 0.1 pixels;
3. Obtaining a model of land (Digital Elevation Model) to remove topography information from data;
4. Projecting the terrain model in radar geometry and create a simulated radar image;
5. Aligning radar simulated terrain model to real radar images and eliminate the radar signal phase coming from topo surveying;
6. Creating radar consecutive pairs;

7. Estimating the residual topo surveying values by linear regression using all 15 images;
8. Refining terrain model by applying corrections;
9. Re-calculation using the new accurate model of land;
10. Eliminating of atmospheric turbulence;
11. Creating profiles for each target;
12. Creating final deformation maps of tailing ponds and surrounding areas, as is seen in figures 4 and 5.

Fig.4 Example – Tarnicioara tailing pond

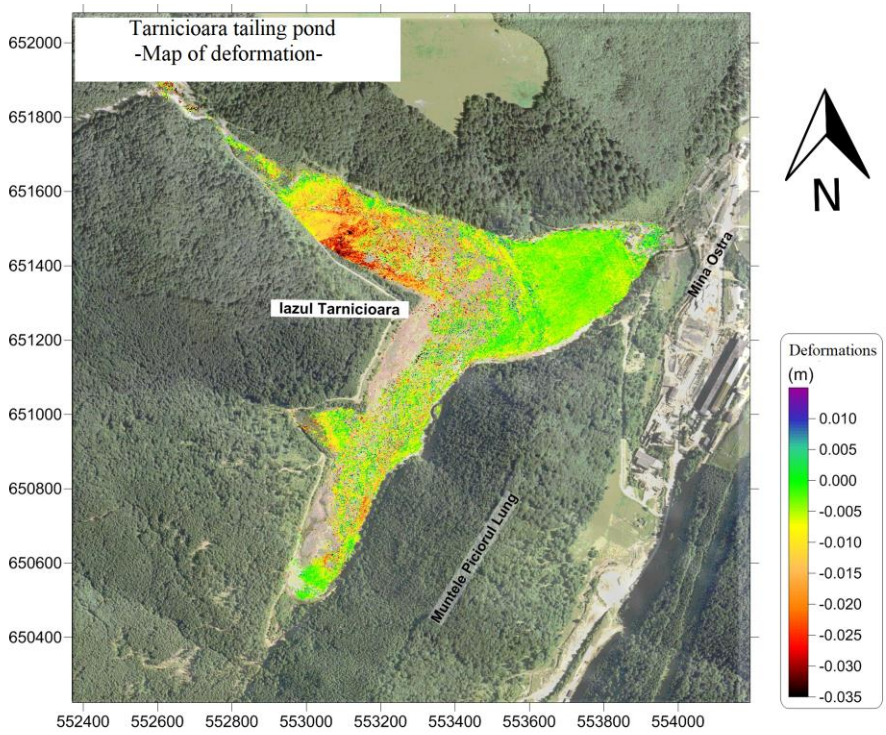
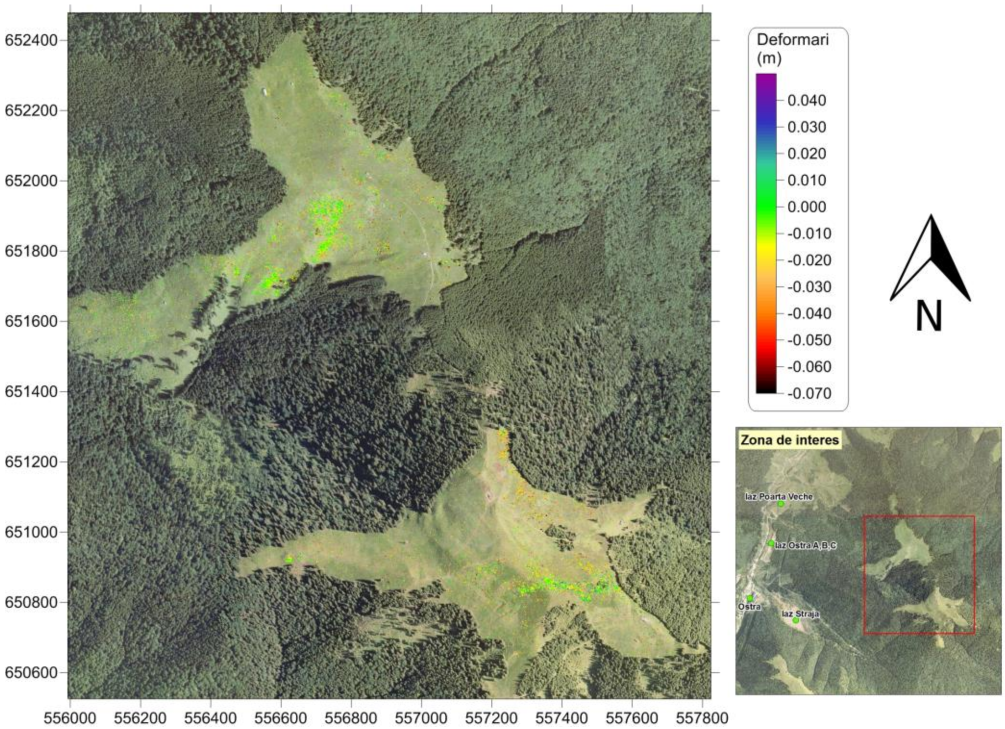


Fig.5 Example – Surrounding areas affected by deforestations (see Fig.3)



4. Conclusions

Although the image of the hazardous phenomena had a major public impact, after a correct geoecological evaluation followed by a precise engineering and works, the landscape recover and return to its natural state.

Using InSAR technique profiles of deformation in time for about 1000 points on Tarnicioara, 700 points on Straja, 1500 points on Ostra and 100 points on Poarta veche were calculated.[5]

Tarnicioara and Straja tailing ponds had stability issues observed during September and October; for the first are located not only on the Scaldatori branch which is more visible but the main dam and Tarnicioara branch. Since the instability of the main dam of Tarnicioara increased to the final period of monitoring is necessary to determine if it was a past event or if the movement continues as sliding.[5]

Ostra and Poarta veche tailing ponds become relatively stable by natural recovery of the landscape.

Deforested areas, located in the vicinity of tailing ponds, visible on the maps, are generally stable, the Geofacies hemoroby improving in time. There is a Geotop in the eastern side with a slight tendency to slip/subsidence (2.3 cm/six month) were cohesion of the soil particles is affected because the lack of the forest due to anthropic actions (exploitation), that increase the human pressure by forest.

Former mines and private properties from Ostra village, located in the monitored area, are also stable improving the human pressure on the landscape.

This type of study offer the possibility to measure tens of thousands of points, providing detailed information about the landscape physiognomy impossible to determine for such large areas of terrain or clearly defined objectives (as buildings or dams) with other techniques, in the same time.

Another advantage is the ability to monitor multiple targets simultaneously in the same conditions of accuracy.

The results recommend InSAR as a Best Available Technique (BAT) for geoecological monitoring to mining perimeters.

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