Introduction of Remote Sensing Methods for Monitoring the Under Restoration Amiantos Mine, Cyprus

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ABSTRACT

Amiantos Mine, in Cyprus, which is an abandoned Asbestos mine has been selected as a pilot within the GEO-CRADLE project (http://geocradle.eu/en/). Main selection criteria were the user's needs and the spatial distribution of the sites that had to be placed in the Region of Interest (RoI) (Balkans, Middle East and North Africa). Following the termination of the mining activities and the mining lease in 1992, after a long operation period of the mine (1904-1988), Cyprus Government undertook rehabilitation works, which are in progress. Geological Survey Department of Cyprus has undertaken the monitoring of the rehabilitated slopes mainly with in situ measurements. The usage of space born data together with the in-situ data will enhance the evaluation of the stability of the rehabilitation works and the assessment of any environmental pollution in the surrounding area. Main activities that are discussed in this paper and are extensively analyzed in respective pilot - feasibility study, focus on (1) monitoring progress of restoration works – using estimates of various biophysical parameters like NDVI, soil moisture, Fe / mineral alteration indexes and land use changes extracted from the analysis of multi-temporal Sentinel 2 data, (2) the determination of ground stability of the mining waste dumps, taking under special consideration the slope mass movements and vertical ground motions - using satellite interferometry method and (3) the identification of the potential pollution sources – air and water monitoring with support of multispectral satellite images of new generation which identify and map materials through spectroscopic remote sensing.

Keywords: Remote Sensing, Cyprus, Mines, GEO-CRADLE

1. INTRODUCTION

GEO-CRADLE project (http://geocradle.eu/en/) has received funding from the European Union's Horizon 2020 Research and Innovation Programme and will be running from 2016 to 2018 with the aim to tackle challenges such as adaptation to climate change, improved food security & water extremes management, better access to raw materials and energy and many more and to promote the uptake and exploitation of Earth Observation activities in North Africa, Middle East and the Balkans.

The project attempts to enhance the current knowledge of existing EO capacities in the region (through an ongoing survey), facilitate the cooperation between EO stakeholders (through a networking platform and several events), identify the gaps and the maturity level (through analysis) and boost the maturity of the different countries in the region. Further on it will enable the exchange of EO data (by setting up a Regional Data Hub), showcase concrete ways of tackling regional challenges related (through feasibility studies) and finally propose a roadmap for the implementation of GEO, GEOSS and Copernicus in the three regions.

In the frame of the "access to raw materials" challenge the aim of project was to define the roadmap that facilitates the access and exploitation of mineral resources in extensively under-explored areas, thus creating well sustained businesses, in compliance with widely recognised environmental protection principles.

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To achieve this goal, pilot sites (mining or post-mining areas) were chosen as feasibility studies. For this reason, a thorough communication with stakeholders and end users in the RoI was elaborated in order to identify areas facing problems related for example to: (a) long term monitoring of ground deformation during or after mining activities, (b) mapping of waste materials left over in abandoned mines and (c) development of an appropriate protocol for the evaluation of the environmental impact, together with feasibility assessment of extractive or mining waste potential to become exploitable secondary resources.

To reach concrete mining sites, all identified geology and raw materials related institutions in the RoI were asked to fill in a short questionnaire, which aimed at defining potential pilot sites. From the 7 proposals, 4 were chosen for further feasibility studies as a representation of most interesting mining and post-mining areas from the point of view applicability of the EO methods.

This paper concentrates on one of the pilots, the Amiantos, an abandoned Asbestos mine located in the central part of Troodos Ophiolite in Cyprus. As a result of constant operation works between 1904 and 1988, the mine had significant effect on the surrounding environment, including enormous open pit, extensive waste tips, pollution of the soil and water, unstable slopes of the abandon structure and waste tips and the barren nature of the tips.

2. DESCRIPTION OF THE PILOT SITE

The Amiantos (asbestos) mine (Fig. 1), is located in the central part of Cyprus and it is situated in a mining lease covering a surface of about 12 square kilometers. It is of opencast type, where chrysotile asbestos has been exploited since 1904 until 1988. It is located within a Natura 2000 site in the Troodos National Forest Park, at the eastern slopes of Troodos mountains. Moreover, the area of Amiantos old mine belongs to the Troodos Geopark, which was declared in 2015, as one of Global Unesco Geoparks[1].

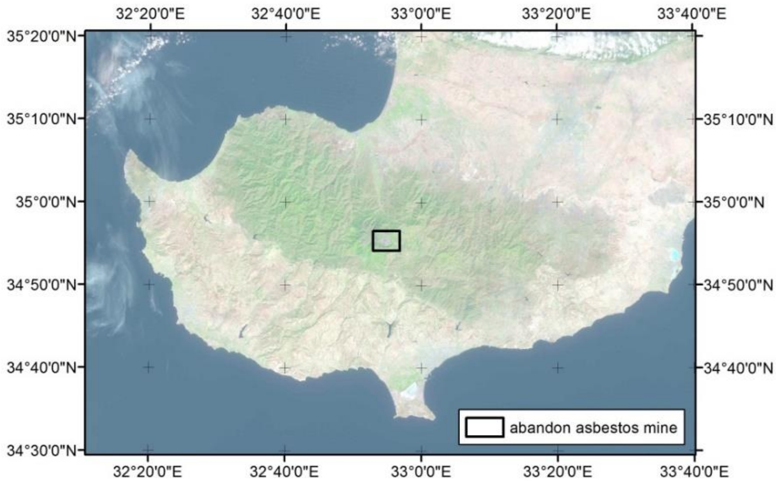

Figure 1. Location of the Amiantos Mine in central Cyprus.

Troodos Ophiolite complex is regarded as the most complete and studied ophiolite in the world. It is a fragment of a fully developed oceanic crust, consisting of plutonic, intrusive and volcanic rocks and chemical sediments. The stratigraphic completeness of the ophiolite makes it unique. It was created during the complex process of oceanic spreading and formation of oceanic crust and was emerged and placed in its present position through complicated tectonic processes relating to the collision of the Eurasian plate to the north and the African plate to the south.

Tectonised harzburgite is the dominant rock type in the Mt. Olympus area (highest peak of Troodos range), where it forms the central core of the Troodos massif. It is always coarse-grained with a xenomorphic granular fabric. Serpentinisation is pervasive throughout the harzburgite mass and ranges from 40% to 100%.

On the eastern side of Mt. Olympus, where the pilot site is located, the harzburgite is totally serpentinised, intensely sheered with abundant chrysotile occurrences, serpentine breccias and breccia zones[2] (Fig. 2). Mineralization occurs in veins, which vary in thickness from a few mm up to 1.5 cm. The average grade of the deposit was 0.8-1.0%.

The asbestos mine pit is bound by Livadhi valley in the North and the Loumata valley in the South and the two valleys meet about 700-800 m downstream of the mine pit. Mining operations, in the early part of the 20th century, were of a small scale. Selective open cast mining was carried out by a large labour force and the waste material was tipped in the nearby Livadhi valley at the lowermost part of the slopes. In this way substantial amounts were washed downstream thus making room for more wastes. The tip that was formed during the early years of operation of the mine covers an area of some 35 hectares (0.35 Km^2) in plan and the maximum depth of waste is of the order of 25-30 m.

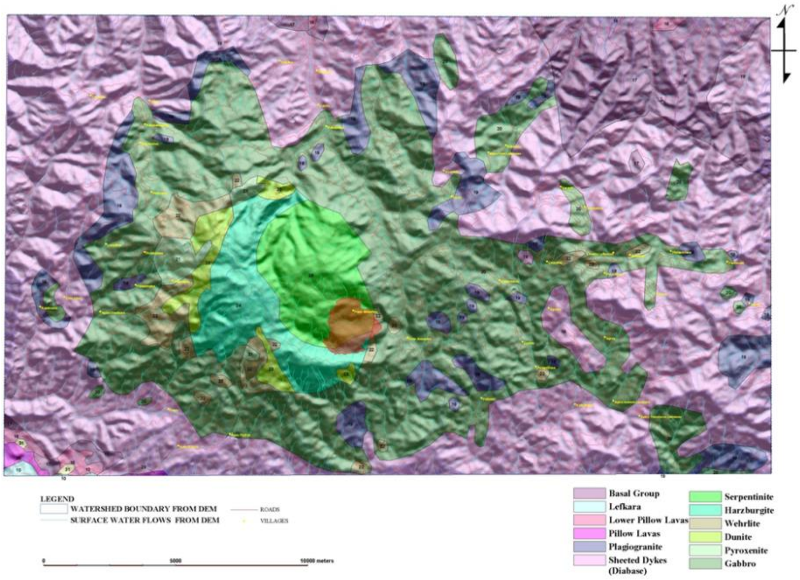

Figure 2. Geological map[2] of mine's greater area.

In the early 50´s the mine was fully mechanized and the use of modern mining equipment changed radically the scale and concept of mining operations. The annual production of rock was of the order of 6 million cubic meters, which after crushing, treatment and fiber extraction it was tipped as a waste. These operations resulted in huge volumes of waste material (known as "old tips") which the steep slopes of the existing dumping areas could not accommodate. In an effort to alleviate the problem, the mining company started to dump the waste material in the nearby Loumata valley. For drainage purposes a 1.3 Km long, concrete gallery was built along the valley bottom and wastes were dumped over the gallery infilling the valley. It is estimated that about 60 million cubic meters of waste were dumped in this valley. When maximum heights of the order of 100 m above the gallery were reached, the culvert itself started to show signs of distress and structural failure. Dumping over the culvert was discontinued and only partial dumping in the side slope was allowed. The waste tips in the Loumata valley are known as the "new tips" and they consist of the lower level tip at elevation 1350 and the upper level tip at elevation 1450 m amsl [3].

Since 1995 the mine is under restoration and the area is a State Forest Land that later was declared as a Natura 2000 site.

The rehabilitation works have included (a) Re-profiling and stabilizing of the waste dumps, (b) Construction of berms and soil-covering, (c) Reforestation and revegetation of the berms, (d) Risk assessment due to the existence of the mine and (e) Future use of the area.

The need for reprofiling the slopes of the waste tips was dictated by safety, environmental and other practical reasons. Possible instability of the tip could endanger lives and property in the village of Kato Amiantos which is situated approximately 1 Km downstream of the tips. Thus, the primary aim of the reprofiling works was the stabilization of the waste tips. Furthermore, flow of waste materials downstream of the pits could result in serious contamination of the river water and as a consequence, of the reservoir of Kouris dam, further downstream, which is the main water supply reservoir for domestic and irrigation purposes in the southern part of the island. Environmentally the artificial slopes of the wastes contrasted the natural slopes and the general topography of the neighbouring area (Fig.3). Proper reinstatement of the environment, essentially required some form of reshaping and reprofiling of the slopes to blend with the rest of the environment [3].

In deciding this issue, it was considered essential that the form of reprofiling would intercept surface water flows thus preventing flow of fibers in the valley streams. Furthermore, in view of the alkaline nature of the wastes, which prevents the grow of any form of vegetation, it became apparent that access to lorries would be essential on the new slopes for the transportation of fertile soil, planting and irrigation. Following consultations with the experts of the Forestry Department it was decided that the maximum slope that would facilitate the grow of vegetation would be 2:1 (horizontal: vertical accordingly). In addition, berms 8 m wide at 15 m elevation intervals, would be required for the planting of trees. A typical profile adopted and implemented at the Loumata valley tips. This slope is the highest man-made slope in Cyprus with a total height in excess of 240 m.

Figure 3. The waste tips before reprofiling [3].

Figure 4. The waste tips after restoration [4].

Following completion of the stabilization (reprofiling) works at the two main waste tips, it was considered essential to monitor movements both for safety reasons and for better understanding of the geomechanical behaviour of the waste material. In extensive monitoring system that involves the measurement of surface and deep-seated ground movements and water levels, has been installed. The system includes survey monitoring stations and surface movement markers and inclinometers. Movements recorded, indicate that the old tips are prone to small creep type movements which seem to be more pronounced during the wet winter months[3].

Further attempts for the restoration of a part of Amiantos old mine area has been undertaken between 2013 and 2015 by the Department of Forests of the Ministry of Agriculture, Natural Resources & Environment of Cyprus under the project "Biodiversity Conservation in Restoration and Management of the Amiantos Asbestos Mine, in Troodos National Forest Park" [5] (Fig. 4).

3. THE PROBLEM – THE USER NEEDS

One of the major outstanding environmental problems related to mining is that of abandoned mine sites, a legacy of centuries old practices, of inadequate, insufficient or non-existent mine closure plans. The potential costs of rehabilitation, the lack of clearly assigned or assumed responsibility, the absence of criteria and standards of rehabilitation as well as other factors have delayed action by all parties – industry, governments and communities. Yet, land degradation from old mine operations is well known in almost all countries. While derelict sites are extensively referred in the literature, there have been few systematic surveys to quantify how many sites need attention. There has been even less work to quantify the nature of associated problems so as to prioritize remediation efforts. The impact of mining sites is significant concerning environmental and safety problems including: altered landscape; unused pits and shafts; land no longer useable due to loss of soil, pH, or slope of land; abandoned tailings dumps and dams; changes in groundwater regime; contaminated soils; subsidence; and changes in vegetation. Results of such impacts include: loss of productive land; loss or degradation of groundwater; pollution of surface water by sediment or salts; changes in river regimes; risks of falls into shafts and pits; and landslides. The resulted delineated waste materials areas advance the knowledge on the critical hazardous areas for remediation purposes. The proposed roadmap promotes specifications and methodologies for engaging future operations fitted to raw materials demand, minimising the environmental footprint, and improving the evaluation of the sustainability and management of the post-mining areas.

In the case of Cyprus 32 out of 33 mines are abandon. The chosen Asbestos mine located in central part of Troodos Ophiolite is one of the examples. As a result of constant operation works between 1904 and 1988, the mine had significant effect on the surrounding environment, including enormous open pit, extensive waste tips, pollution of the soil, air and water, unstable slopes of the abandon structure and waste tips and the barren nature of the tips. Therefore, the proposed activates were chosen with the aim to define the roadmap for long-term monitoring, mapping, and management of the rehabilitation works, also assessing the ground changes and site degradation relating to mineral exploitation.

The Geological Survey Department, which acted as user within GEO-CRADLE, is responsible to evaluate the situation of each abandoned mine in terms of a) potential source for secondary mineral resources, b) actual sources of environmental pollution and c) to propose and implement remediation measures for the benefit of the affected communities. Even though there are a lot of in-situ data, they never hold or used any space born data for the active or abandoned mines. The opportunity to obtain and use space born data will help develop the necessary skills in order to plan and execute more comprehensive and effective solutions / measures for a) long term monitoring of ground deformation /stability waste dumps, b) mapping waste dumps and abandoned mines as potential exploitation for both primary and secondary mineral resources with parallel environmental restoration and c) developing better practices for the rehabilitation of abandoned mines.

Through the usage of space born data and in-situ data that holds the Geological Survey it is expected to evaluate the stability of the rehabilitation works at the asbestos mine that were carried out so far as well as any environmental pollution in the surrounding area. If any instabilities are identified, they shall be faced to prevent any landslides or other instabilities and take into account the findings and incorporate them in the ongoing and future rehabilitation works.

The space born data could be also used to assess the existing field data and develop a protocol for the restoration and closure of the mine preventing any environmental pollution of the surrounding area.

4. METHODOLOGY - METHODS OF IMPLEMENTATION

4.1 Determination of the land use changes

Environmental monitoring is now an integral part of mining operations. Remote sensing enables the identification, delineation, and monitoring of mining areas, including derelict land, and changes in surface land use[6,7]. The aim of this pilot site is to evaluate the use of Earth Observation and in particular of the multi-temporal Sentinel 2 data to map and monitor the Asbestos mine on a local scale, and to assess the rehabilitation activities by indicating the changes on land. The general plan of the analysis includes, mapping and monitoring (change analysis / track any detectable potential changes of surface morphology) based on satellite Sentinel-2 data; identification and evaluation of rehabilitation activities; and evaluation of the contribution of Earth Observation data on supporting studies of mapping and monitoring of abandoned mines. Following methods has been applied:

Colour composites: Various pseudo-colour composites like the RGB-843 have been used of the Sentinel 2 data in order to emphasize the quarry areas, which have high spectral reflectance. The composites accentuated the quarry areas and discriminated vegetation from barren soil.

Intensity hue saturation (IHS) images: different resolution data were combined using data fusion techniques. This was effective for the land cover and the interpretation of geologic features because complementary information for the same target area was combined. The IHS transform was used to fuse the bands of higher panchromatic spatial resolution with the multispectral bands of the Sentinel-2 so that the inherent land cover classes in the quarry areas could be identified.

PCA has been applied of the bands with higher resolution for data noise reduction, while PC1 component has been used as the panchromatic image -PAN in the data fusion process. Final image products derived from this procedure was the 8,4,3-PAN and similar RGB-PAN composites.

Normalized Difference Vegetation Index (NDVI) calculation: for better vegetation identification and its and masking in other analysis.

Image Classification Unsupervised: classification techniques using neural networks, Artificial Neural Networks (ANNs)[8] and SOM- Self Organizing Map ANN method, were used for classification purposes in order to discriminate all inherent land cover classes of the satellite images. Different land cover types can be mapped in the mining areas and the surface extent for each cover type can be estimated.

4.2 Ground Stability Monitoring

Space-borne differential synthetic aperture radar interferometry (DInSAR)[9] and in particular new advanced processing techniques such as Permanent Scatterer Interferometry (PSInSAR or PSI)[10], offer a unique possibility for wide-area, regular monitoring of ground surface displacements. Furthermore, under suitable conditions it should be possible to detect precursory deformations associated with the initiation of ground instability, a key element for early warning and hazard mitigation[10].

It is a technique in which the phase component of a return radar signal from two or more satellite radar images (of the same location) is processed to detect motion on the ground. The relatively low cost of the method (one radar photo covers an area of about 10,000 km²) and non-invasive nature have led to its wide application in various disciplines, like geohazards, related to land surface displacements caused by natural factors, human activities, or the combined effect of these two. DInSAR method has been implemented since 1992 with its help on the analysis of seismic movements, volcanic activity, landslide and subsidence and other phenomena that have a direct impact on economic, environmental and human safety are identified. The need for more precise and reproducible data has led to the development of new algorithms over the past few years, including the development of a Persistent Scatters Interferometry (PSInSAR, PSI) algorithms[11], initiated in Italy in 2001[10].

Unlike conventional radar interferometry (DInSAR), PSInSAR method consists in processing of a very large amount of data (the number of radar scenes must be greater than 15). As a result, remain only these pixels that have high coherence within whole set of scenes, which allow to identify continuous measurement points - PS (permanent scatterers). They are usually buildings, bridges, outcrops rocks, etc. The characteristics of the movement of these objects are recorded and calculated with a millimeter accuracy throughout the period covered by the satellite data.

Undoubtedly, the disadvantage of the PSInSAR technique is the difficulty in predicting the quantity and location of PS before processing. As a rule, the positive effects are partially guaranteed in urbanized areas, dry climate areas and rocky areas. Furthermore, satellite PSI data have to be referenced to well ground truth measurements, because they reflect performance of targets, whose actual or apparent displacements may arise from a variety of causes (e.g. slope movements, fill settlement, subsurface civil engineering, mining and fluid extraction, differential movements between cut and fill parts of a building site, structure deterioration, expansion/shrinkage of soils). Also, it is worth remembering that it is a remote sensing technique and therefore measured PS point does not always can corresponds to the benchmark on the ground, measured by traditional geodetic measurements

4.3 Identification of the potential pollution sources

Remote sensing methods are very useful for monitor pollution from mining at less cost and to common standards across the EU, faced with increasing environmental pressure and regulatory controls due to surface and groundwater pollution, soil contamination. The mining industry and decision makers need innovative and cost-effective tools for environmental data acquisition and processing that provide basis for sustainable economic development of the sector. These tools can help in decision-making process. EO methods could potentially be used in future sustainable information systems that locate and monitor environmental risks. Regularly updated information stored in databases related to mining environments is used to draw up Environmental Management Plans (EMPs). To collect this information innovative earth observation techniques should be used. Existing Hyperspectral imaging sensors and multispectral satellite images of new generation which identify and map materials through spectroscopic remote sensing produce data that can characterize the chemical and/or mineralogical composition of the ground surface. The primary advantages of this future space-borne imaging technique are the reduction unconventional, time consuming and expensive field sampling methods and its capability to gather repeat data, which assists in monitoring mining pollution.

5. RESULTS FROM SELECTED REMOTE SENSING TECHNIQUES

5.1 Determination of the land use changes and monitoring progress of restoration works

The processing was performed on the atmospheric corrected and resampled Sentinel-2 satellite scenes from years 2015, 2016 and 2017 (Fig. 5). Through the analysis of the processed multi-temporal data, the following layers have been identified: changes of surface area of the mine, waste material / deposition areas and changes of vegetation cover. It should be noted that change analysis has been very sensitive to acquisition date of the satellite data and to shadows due to intense relief of mining area. Rehabilitation through reforestation on part of the mine area has taken place and this can be mapped and monitored quite accurately (Fig. 6). Monitoring of “reforestation” is particularly important to be carried out on Asbestos mine and this of special interest to the Forestry Department.

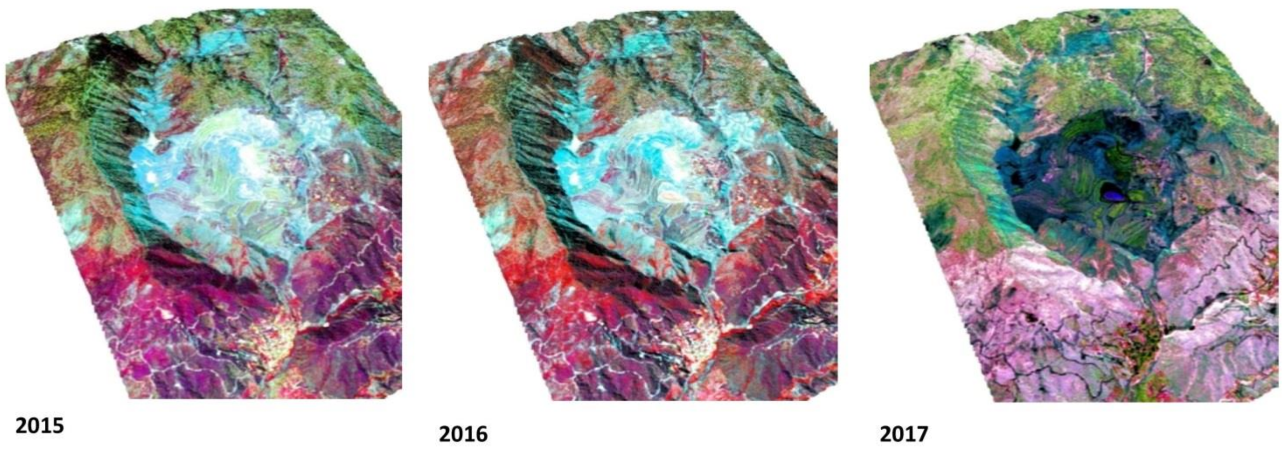

Figure 5 Sentinel-2 multitemporal analysis for determination of the land use changes and monitoring progress of restoration works.

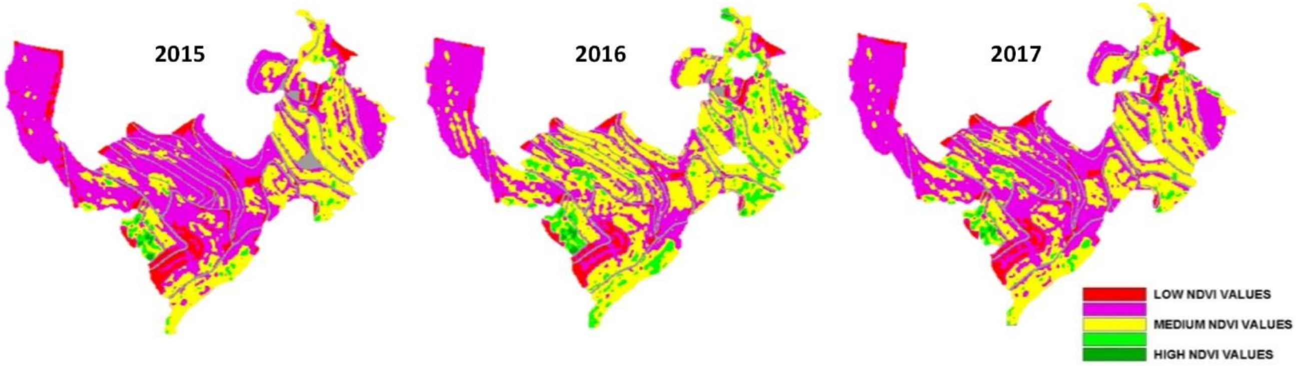

Figure 6 NDVI index analysis for different dates based on Sentinel-2 data. The analysis can support the monitoring of reforestation process carried out in the mine.

5.2 Ground Stability Monitoring

In order to obtain information on the stability of the mine's slopes, PSInSAR processing was planned, preceded with the basic analysis of possible PSInSAR data acquisition:

- **The analysis of the SAR data acquisition**. The analysis was done using Seninel-1 Data Hub (https://scihub.copernicus.eu/) viewer. Cyprus has very good covered of both SAR geometries: ascending and descending. The abandon asbestos mine is in the central part of Cyprus. For the ascending geometry it seems that the processing should include data from two frames to ensure full coverage. For the descending geometry however, the one frame covers nearly whole island. Data acquisition ensure new scene each 6th day.
- **The analysis of land coverage and elevation model.** Land cover has a significant impact on the results of the processing. PS points are created in pixels with objects strongly and stable in time reflecting the radar wave. These are mainly buildings, roofs, railways, roads, bridges and other metal objects, but also outcrops of rocks. In forest areas or vegetation cover, PS points are difficult to identify due to the absorption of radar waves and the variability of coverage over time.

  The analysis was done visually on the Landsat images, Corine Land Cover GIS layer[12] (Fig 7). Additionally, digital elevation model SRTM[13] was downloaded (Fig. 7). Abandoned mine is located in the central part of the mountain chain. Surroundings of the mine area are characterized by a large altitude changes and forest cover. In the nearest vicinity of the mine there are no urban or urbanized objects. This makes the terrain difficult for interferometric analyzes, especially when using the C-band radar (ERS, Envisat and Seninel-1 scenes). It would be advisable to use

L-band radar scenes with a wavelength of 23 cm. The radar L-band penetrates the vegetation much better than the C-band, but such scenes are not freely available.

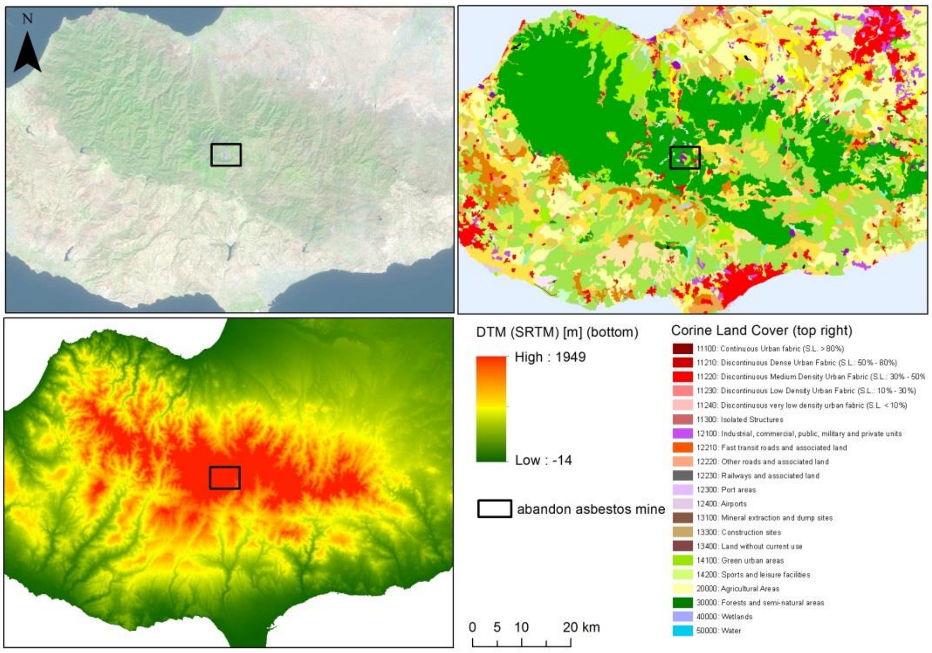

Figure 7 (top left) natural color satellite image. (top right) Corine Land cover GIS layer. (bottom) SRTM DTM. In black square the abandon asbestos mine area.

PS visibility analysis. Altitude differences are the basis for checking which satellite geometry will be best for this particular area. The data are collected at the angle, not in the vertical direction. This affects the visibility of terrain pixels, especially in mountain areas. Some areas are obscured from the satellite point of view by adjacent slopes. The visibility of the terrain pixels can be calculated based on the geometry parameters, that can be obtain from metadata of the scenes[14,15,16]. The visibility index was calculated for archive European Space Agency satellites – ERS and Envisat and for Sentinel-1. All three are available free of charge. The results are presented in Fig. 8. The geometries for these three satellites are similar, therefore, the results show almost the same picture. It reveals that descending geometry is much better for PS identification in the area of abandon Asbestos mine.

The PSInSAR processing was done based on 30 Seninel-1A Single Look Complex scenes (orbit number 17739), which cover period 26 July 2016 to 9 July 2017. Time interval between scenes is 12 days. The processing was limited to the 3350 km^2 area of the central part of Cyprus. It was performed in ENVI SARScape software using SBAS algorithm. For the final results PS with coherence greater than 0.5 were chosen. Finally, 75 691 points were identified, which this corresponds to 22 PS points per square kilometer.

Unfortunately, the resulting set of data give no information in the study area of abandon asbestos mine. The points with high coherence values, i.e. the ones that are reliable, are identified only in the more urbanized areas with less vegetation located at the foot of the mountains. These points show stability in the processed period, with no significant movements.

Lack of information in the study area results from the earlier discussed reasons. The area is covered by forest, therefore in C-band it is hard to distinguish reliable PS points. However, as the preprocessing steps reviled, the area has potential for InSAR processing, which can be improved by larger set of data (e.g. 40-50 scenes) or data from L-band satellite.

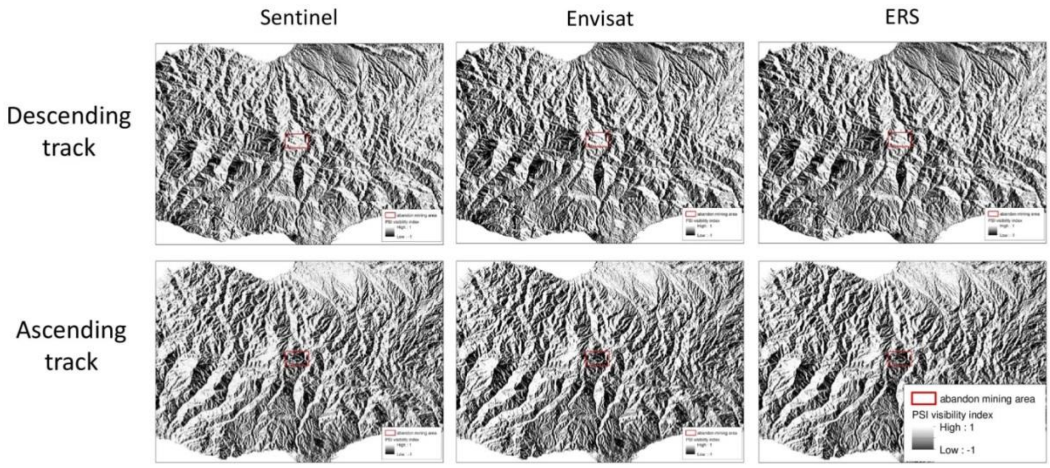

Figure 8. PS visibility index calculated for Sentinel-1, Envisat and ERS satellites for both geometries: descending and ascending.

6. DISCUSSION

The processing of multi-temporal Sentinel-2 data helped in automatically identification not only the surface extent of the mine but also to identify the different activities like deposition areas, waste disposal, restored surfaces, reforestation. Regarding the application of classification techniques, we have not gone far from traditional "image classification" approach, which is hardly comparable to the outcomes of visual techniques, while a system for automated identification of all the different types of "activities in a mine" is still absent. Given the richness of contextual information embedded in quarry areas, in the form of texture or zoning, it is conceivable to use this valuable information using spatial-spectral hybrid techniques. Such a system should specifically adopt to analyse the spatial–spatial pattern, as well as the multiple wavelength spectral ranges. Furthermore, it is indicated that the developed methodology cannot only support the monitoring activities of the mining area but it can support the poly parametric analysis of different data layers for the identification of problematic areas – i.e. the designation of specific areas where there might be pollution problems and so identify, which activities may have to be undertaken. The potential of using Seninel-1 data for ground motion monitoring was shown, however in order to obtain good results, the data should cover long time span with dense time-series.

It was shown that activity on the mining area can be monitored, while a general evaluation and quantitative aspects of certain parameters can be accomplished. However, it is also shown that there are restrictions in using Sentinel-2 data due to its medium resolution and key features related to inspections cannot be recognized easily, while misinterpretations can also occur. Also, using Sentinel-1 data in InSAR processing has limitations, as the area in covered by vegetation and is characterised by high altitude changes. Acquisition of 3D data may also be required to be obtained using satellite or UAV airborne photogrammetric methods in order to get the third dimension of the depth of excavations and / or restoration.

The overall results of the analysis proof that using the medium and high-resolution satellite remote sensing data and integrated image processing and GIS techniques with parallel development of a geospatial database system provided monitoring and feedback at appropriate spatial scales for further use by the user. The methodology can be used for long-term environmental management and monitoring the mining area along with issues related to reclamation and rehabilitation.

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