Optimization of Sentinel 2 data for supporting geological mapping and monitoring of mining areas

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Abstract. Sentinel-2 is ESA’s medium spatial resolution super-spectral instrument aimed at ensuring data continuity for global land surface monitoring of Landsat and SPOT. This paper aims at evaluating Sentinel 2 image products relating to the geologic and mining science community. Different mining and post mining areas have been chosen as pilot test sites in the Mediterranean countries of Greece, Cyprus and Morocco. The methodology has been developed within the EU GeoCradle project to define the roadmap that facilitates the use of Sentinel 2 data in issues related to mining. Identification, collection, assessment and use of available EO - Sentinel 2 data, along with in-situ products and relevant monitoring information are included during all test sites analysis. The evaluated image products of Sentinel 2 VNIR and SWIR bands demonstrate the capacity in mapping features of interest to geologic community and the mining sector. It is also shown that the development of a Monitoring System can be supported for the mitigation of illegal quarrying activities along with the long-term monitoring, mapping, and management of abandoned mining sites. It is expected that the methodologies elaborated on the pilot sites will have a universal character and could be applied on other mining areas too.

1. Introduction

The life cycle of a mine includes different stages like prospecting and exploration, development, extraction, and closure/rehabilitation. Prospecting and exploration are precursors to mining and often occur simultaneously, while they can take several years to complete, and may be quite costly. Different environmental problems occur during mining. One of the major outstanding environmental problems related to mining is that of abandoned mine sites. Land degradation from mine operations is well known in almost all countries. It is also well documented that illegal quarrying activities are related to severe economic, social and environmental impacts affecting not only the restricted area where such activities take place, but also wider areas.

Earth Observation data can be used in all phases of the mining life cycle. 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 [1]-[2]. Prospection can also make use of medium resolution to perform geological and mineral exploration interpretation, while the derived geological maps can be used to assess the location of
potential mineral deposits [3]-[6]. The aim of the study is to evaluate the use of Earth Observation data and in particular of the multi-temporal Sentinel 2 data to prospecting and monitoring of mining/quarry areas or abandoned mines on regional and local scales. Three different pilot project areas, figure 1(a), are used in order to assess prospecting, quarrying and rehabilitation activities. The selected test sites represent different problems that accrue in the mineral resources sector. The general plan of the methodology applied and the data used for the pilot sites is shown in figure 1(b).

Multitemporal Sentinel 2 data for the time interval of 2015 to 2017 have been collected for each site along with ancillary information, figure 1. Research has been accomplished following step by step analysis including (1) Pre-processing of EO data, (2) Image processing, (3) Application of neural network classification techniques, (4) Application of GIS techniques, figure 1. Consultation with End Users has been carried out and this has been integrated in the various stages of analysis.

2. Enhancement of the resolution of Sentinel 2 images
In modern remote sensing applications, image resolution increase is achieved by image fusion, which is based on the concept of Super-Resolution image reconstruction [7]. A work which proposes a novel resolution enhancement method for multispectral and multiresolution images, such as these provided by the Sentinel 2 satellites, is presented in [8]. The geometric details that are inherent in the available High-Resolution bands are encoded as pixel properties independently from their reflectance. Then, the Low-Resolution bands get unmixed by propagating the particular band-independent information to preserve subpixel details. The method is applied to Sentinel 2 images so that to bring all bands down to the highest resolution at 10 m/pixel.

The SR fusion comprises the inverse problem of recovering the original HR image by fusing the input images of the same scene, based on assumptions or prior knowledge about the observation model.

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S/W & DATA
TNTgis Integrated application of raster/vector techniques http://www.microimages.com/products
Sentinel 2 https://cophub.copernicus.eu/dhus/#/home
The pan-European component of Copernicus https://land.copernicus.eu/pan-european
Greek quarry data http://www.latomet.gr/ypan/default.aspx
Aster DEM https://earthexplorer.usgs.gov
Geologic maps available in Geological Surveys of Greece, Cyprus

Figure 1. (a) Pilot project areas (b) overview of data and methods of analysis.

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thus about the image acquisition system [9]. Since SR image reconstruction is generally an ill-posed problem, various regularization techniques have been proposed to stabilize its inversion [10]. The resolution enhancement which is based on a single LR image is also called SR and is an ill-defined inverse problem without a unique solution. Therefore, additional constraints have to be applied in the process so that to limit the number of possible solutions and achieve results approximating better the ground truth. Single image SR approaches can be roughly classified into the following three categories. Interpolation-based methods, such as bicubic interpolation, are efficient, but they tend to lose many details of the images. Reconstruction-based methods [11] usually assume some degraded models and solve the inverse problems in order to acquire the HR images. These methods’ performance strongly depends upon a rational prior imposed on the required images. Learning-based methods [12] assume that high-frequency details lost in an LR image can be recovered by learning the relationships between the LR-HR image patch-pairs.

Sentinel 2 systems cover 13 different spectral bands with a spatial resolution ranging from 10 to 60 meters. In future research work the 10 m spatial resolution of the Sentinel 2 imaging data could be further enhanced thus become a finer spatial resolution which would enable more information extraction from the observations of mining areas.

3. Processing of the pilot study areas

3.1. Greece
The pilot application in Greece refers to the use of processed Sentinel 2 data for the mapping/monitoring of surface changes attributed to quarrying activities (legal and/or illegal). Several pilot sites with quarries have been identified in Attica region, figure 1(a). Figure 2 shows the results obtained by processing two quarry areas.

![Figure 2](image)

**Figure 2.** (a) Monitoring quarry activity without valid permit. Surface works have been extended by 10212 m² for the time interval of 2015 to 2017 (b) Quarry area with activity outside valid permit.

The application of the methodology shows that Earth Observation techniques can support the monitoring of quarrying activities like: (i) Potential illegal activities taking place in active quarries with a valid permit, and (ii) extraction activities in unpermitted sites, figure 2(a),(b). Monitoring is supported through change analysis, figure 2(a). The methodology can support field inspections of quarries to ensure national regulations are met. Regular updates can be obtained (seasonal / monthly / bi-monthly or even more frequently). EO tools assist in mapping & monitoring surface activity. Aspects of the activities have to be field verified by the End User.

3.2. Cyprus
The Asbestos mine on the Troodos Ophiolite in Cyprus, is an opencast type mine that operated between 1904 and 1988. Between these years, it is estimated that 130 million tones of rock have been excavated and 1 million tones of asbestos fibers were produced. The sudden closure did not allow any
programmed closing down procedures to be initiated and consequently left a serious problem not only of the instability of the waste dumps, but also the overall environmental destruction created by the long mining history, needing badly mitigation measures. The consequences due to its closure were: the adverse effects on the environment; the enormous open pit; the extensive waste dumps; the pollution of the soil and water; the stability of the waste dumps and the barren nature of the dumps. Therefore following the termination of the mining lease in 1992, the Cyprus Government undertook eventually the rehabilitation works in 1995. The application of the developed methodology can be used for the determination of the land use changes and monitoring progress of restoration works, along with the identification of the local pollution related to former mining activities, figure 3.

The use of Sentinel 2 satellite data allows the monitoring of all mining rehabilitation activities in bi-monthly or yearly time intervals, figure 3(a). Combined watershed analysis along with estimates of index of Fe oxides shows the direction of surface water flows which can be used for risk assessment as it might affect the population living in the surrounding areas (Kato Amiantos village), figure 3(b). The rehabilitation works which are taking place in Asbestos mine can be monitored. Rehabilitation through reforestation on part of the mine area has taken place and this can be mapped and monitored quite accurately, figure 3(c). Monitoring of “reforestation” is particularly important to be carried out on Asbestos mine and this is of special interest to the Forestry Department.

![Figure 3](image-url)

**Figure 3.** (a) Monitoring of Asbestos mine in 2015, 2016 & 2017 (b) Watershed analysis with surface flows directed towards Kato Amiantos village and estimates of Fe Oxide Index (c) NDVI for reforested areas of the mine.
2.3. Morocco
Azegour is a skarn deposit which was most intensively mined between 1931 and 1947. The assessment of the contribution of Sentinel 2 data on mapping geologic features on local scales is included, figure 4.

![Figure 4. Sentinel 2 processed satellite image of 70 km² (a) Enhanced and annotated (b) 3D annotated representation. An area of 0.4 km² (ELLIPSE) is under detailed investigation.](image)

As it is shown on the figure 4 information concerning the general tectonic outline of the area along with the mapping of different lithology and mineral alteration patterns can be accomplished. In particular when investigating the spatial patterns it is revealed that there is a good capacity of the proposed Sentinel 2 image products to map the geological structure, lithology, mineral alterations and environmental setting at scales up to 1:20,000.

4. Discussion of results
The immediate benefits of the developed methodology can be summarized as following:
- Discrimination of geologic setting - geologic feature extraction to optimize field reconnaissance. This is of particular interest during the initial planning of exploration activities. Supporting spectral analysis for the detection of "specific target mineral types" that are suspected to be present within target areas of interest in high concentration.
- Mapping disturbed / undisturbed land. Map land cover changes identification and characterization of the nature of the changes observed – identify compliance with permitting regulations.
- Rehabilitation monitoring of the conditions of lands related to mining areas. Delineation of areas where potential restoration activities may take place can be proposed.
- Other types of satellite data (i.e Pléiades, RapidEye, WorldView Images with 0.5 meter resolution) can also be included for an improved mining exploration, mining site mapping and monitoring.

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