



Remote sensing in management of mining land and proximate habitat

by K. Koruyan*, A.H. Deliormanli*, Z. Karaca†, M. Momayez‡, H. Lu‡, and E. Yalçın*

Synopsis

Although remote sensing technology has been available for many years, it has rarely been used for monitoring mining activity. Recent studies indicate that remote sensing is also a valuable tool for managing and planning certain aspects of the mining operation. In this paper, we examine areal expansion of marble quarries and the affected vegetation over a period of 10 years in the Mugla region in Turkey, using geographic information system (GIS) and remote sensing (RS) techniques. Images captured by ASTER Level 3A01 (3D Ortho Data Set), Landsat 5, and Landsat 7 satellites between 2001 and 2009 were used for the analysis. Changes in the natural vegetation as a function of the production level in the marble quarry were calculated using the normalized difference vegetation index. According to the study results, land cover and natural vegetation decreased by less than 3 per cent and 1 per cent respectively between 2001 and 2009, following an upsurge in mining activity in the region.

Keywords

GIS, remote sensing, normalized difference vegetation index, marble quarry

Introduction

The societal and environmental impacts of mining activity are the focus of greater interest today than ever before. Many emerging economies are in the process of developing environmental policies for the first time. These new policies will surely affect how mining operations are expected to perform: producing the raw material needed to drive the economy at the lowest possible cost becomes as important as implementing a responsible, efficient management plan to help develop neighboring communities and sustainable land use. To achieve this objective, the management plan must incorporate ways to mitigate environmental issues, including land cover change, waste rock and tailing disposal, dust and noise, water use and re-use, and pollution, that may affect communities and the natural habitat near mining operations. Remote sensing including aerial photography, photogrammetry, and satellite imagery can play an important role in environmental monitoring and reclamation of mining areas.

The main advantages of remote sensing are its ability to cover large areas, high temporal frequency, and lower cost compared to ground-based investigation and monitoring.

A number of recently published papers¹⁻¹¹ have demonstrated the usefulness of monitoring the environmental impact of mining using various remote sensing methods. Felinks *et al.*¹² ascertained the exact location of each site in the study area by satellite imagery (Landsat TM), airborne imagery (CASI), and ground-based methods, notably habitat mapping and vegetation sampling. Environmental impacts and the decrease of natural vegetation caused by the open pit mining activities were identified from NOAA-AVHRR and Landsat satellite images. Latifovic *et al.*⁷ employed the normalized difference vegetation index to determine the decrease in natural vegetation. Research by Antwi *et al.*¹⁰ focused on detecting the effect of disturbance on habitat diversity and land cover change using GIS and remote sensing in post-mining areas. Mouflis *et al.*⁹ assessed the environmental impact of marble quarries on the landscape of the Greek island of Thasos by employing remote sensing, landscape metrics, and viewshed analysis.

This paper presents the results of a study that examined the areal expansion of both abandoned and in-service marble quarries, and the subsequent changes in vegetation in the Mugla region from 2001 to 2009. Mugla province in western Turkey has been an important marble production centre since ancient times. The area holds a large number of operations producing block marble, abandoned quarries, and active marble processing plants. The region is densely covered in vegetation, in particular pine trees.

* Dokuz Eylül University, Department of Mining Engineering, Turkey.

† Çanakkale Onsekiz Mart University, Department of Geological Engineering, Turkey.

‡ University of Arizona, Department of Mining and Geological Engineering, USA.

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Marble extraction in the Mugla region is conducted by open pit mining method. Marble is cut in blocks during the extraction process. The original vegetation is destroyed, and the overlying soil is removed as overburden. As a result, marble extraction activities have a serious impact on the ecology and landmass re-use⁹. In this study, GIS and remote sensing techniques were used to determine the environmental impacts of the quarries. We employed standard image-processing techniques in conjunction with a temporal decision tree and GIS maps of mine permits and wetlands to map active and reclaimed mines, and track changes through time. Mine permit coordinates obtained from the General Directorate of Mining Affairs (MIGEM) identified the location of the quarries, while ASTER and Landsat satellite images acquired between 2001 and 2009 provided the data source for this project.

Material and methods

In order to determine the environmental impact of marble production, quarries were located in the Mugla region. This was accomplished using a combination of the coordinates found in the MIGEM mine permits and the Landsat and ASTER images. Next, the landscape metrics of quarries were estimated. Finally, the environmental impact, and in particular, changes in the vegetation cover were quantified. The analysis steps are shown in the flow chart in Figure 1 and are explained in more detail.

Image data

Satellite images taken in the summer of 2001 to 2009 were used to determine the vegetation cover. ASTER and Landsat images have 15 m and 30 m resolution respectively. The images from ASTER VNIR were downsampled to 30 m resolution in order to use a consistent set of data. Satellites and image dates are given Table I.

Study area

Figure 2 shows the general study area in red and a number of smaller land patches consisting of the marble quarries. A satellite image mosaic for this region was created, and the data was enhanced by applying geometric and radiometric corrections. The main study area is delineated by extending the boundaries of the marble quarries in all directions, providing a buffer zone of 800 m around each quarry. The size of the buffer zone allows for all activities supporting marble block extraction, such as transportation and storage, to be represented in the images. The quarries in the general study area are in Landsat boundaries. However, unlike Landsat images, ASTER images do not correspond to a standard area image. Therefore, ASTER images for the year of interest were produced by combining images for the years 2003 and 2005, using image mosaic methods.

Image processing

First, standard processing procedures were applied to each image used in the general study area. As the coordinates of objects were not the same in most images, geometric correction was performed using over 20 ground control points (GCP) on topographic maps with a scale of 1:25 000. Next, the contrast and details in the image were enhanced by stretching and similar colours were mapped to a single value using spatial filtering techniques.

Determining the expansion of marble quarries

The boundaries of marble quarries for each year were determined using image processing and GIS. Marble quarries

cannot be observed clearly in images at 30 m resolution. Therefore, standard image processing techniques were applied to make the boundaries better defined. In the first step, statistical filters were applied to the raw data as shown in Figure 3a. Sharpening filters were applied to bands 1, 2, and 3 of ASTER images and bands 2, 3, and 4 of Landsat images. The result is shown in Figure 3b. In the last step, the 'median' statistical filter¹³ was found to provide the best quality image (Figure 3c). The same filtering techniques were used for RGB (red, green, blue) clustering and transforming images from raster to vector format.

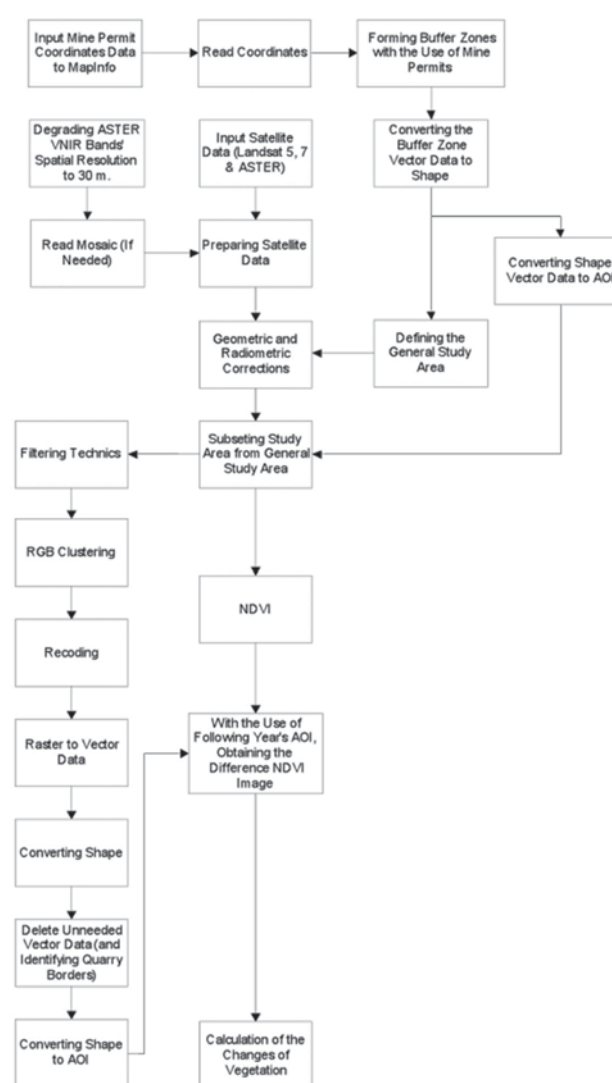


Figure 1—Flow chart of analysis methods

Table I
Satellites and image dates

Satellites	Date
ASTER Level 3A01	27 July 2003; 28 August 2003; 10 August 2005; 17 August 2005; 2 September 2005; 6 July 2007
Landsat 5 (180/34)	25 July 2008 19 July 2009
Landsat 7 (180/34)	September 2001

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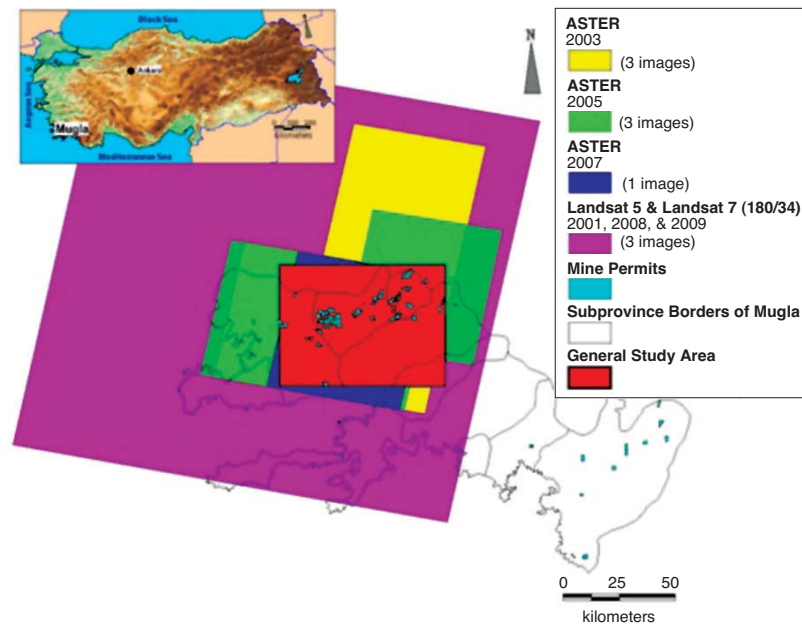


Figure 2—Study areas and satellite images

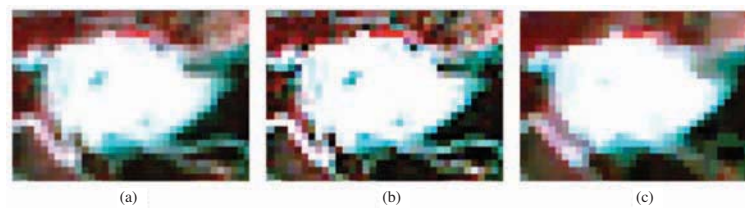


Figure 3—Image filtering: a) raw image, b) sharpened image; c) image after statistical filtering

Following the application of sharpening and statistical filters to the ASTER and Landsat images, RGB clustering was performed to merge the three bands into one. The RGB clustering method performs a relatively simple unsupervised classification. Contrast stretching was also used in the clustering process. A linear contrast stretch was applied to uniformly expand the range of values in each image to cover the full range of values.

As seen in Figure 3, marble quarry outlines can be clearly improved using filtering and grouping techniques. These processing techniques also remove undesired and unnecessary pixels from the raster images. Images for years 2001–2009 after RGB clustering process were recoded and pixel classes were grouped in such a way as to separate marble and non-marble rocks. Recoding consists of assigning a new value to marble quarries (white) and a different value to all other rock types. A bi-colour image is produced to differentiate the stone units from the surrounding landmass (Figure 4).

Recoding from raster to vector data allows for polygonization of the stone formations. Following this process, changes in vegetation and marble quarry boundaries can be determined. Vectorized data shown in Figure 5 includes few unwanted fragments due to artifacts generated by:

- i) Areas in the satellite images having a reflection coefficient close to that of marble quarries
- ii) Difficulty in separating separate pixels representing stone formations from neighboring pixels during the RGB clustering process.

Band rationing techniques used by Sultan *et al.*¹⁴ and Abdeen *et al.*¹⁵ are also used to discriminate and identify rock formations. Three pairs of ratio images (band ratios 4/7,

4/1, (2/3)×(4/3) for ASTER and 5/7, 5/2, (3/4)×(5/4) for Landsat) were co-registered and projected as composites. Lithological units, especially serpentinite, granite, and marble can easily be identified. In Figure 6, marble quarries are shown in pink.

Estimation of change in the natural vegetation

Vegetation Indices (VI) are computed using numerical brightness values, biomass and measuring the vegetation energy¹⁶. One vegetation index is calculated by adding, dividing and multiplying several spectral values. Vegetation indices assess whether the observed target contains live green vegetation or not¹⁷. Qinjiu and Xiangjun¹⁸ reported that close to 40 vegetation indices have been developed by researchers over the past 40 years. The most common

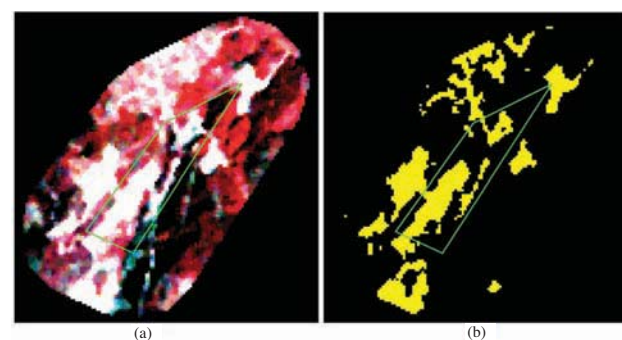


Figure 4—Recoding process (on a section of 2005 image after clustering, a) before recoding, b) after recoding, yellow colour represents stone units)

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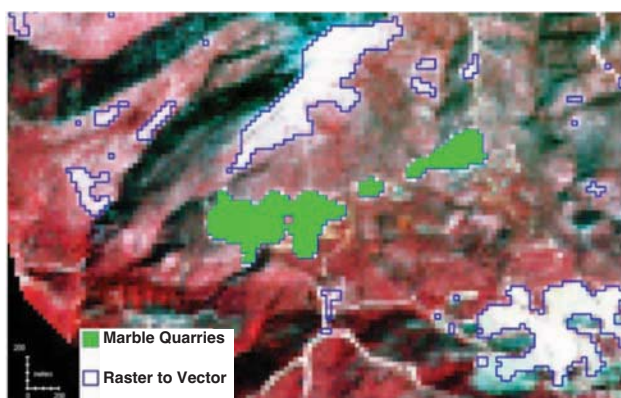


Figure 5—Vectorized data from 2005 ASTER (RGB-321) images (blue) and sharpened boundaries of marble quarries (green)

vegetation indices (used by various investigators) are listed below:

- Normalized difference vegetation index (NDVI) = $(\text{NIR}-\text{R}) / (\text{NIR}+\text{R})$ (Rouce *et al.*¹⁹)
- Transformed vegetation index (TVI) = $(\text{NDVI}+0.5)0.5$ (Deering *et al.*²⁰)
- Perpendicular vegetation index (PVI) = $\sin(a)\text{NIR}-\cos(a)\text{R}$ (Curran²¹)
- The enhanced vegetation index (EVI) = $2.5[(\text{NIR}-\text{R}) / (\text{NIR}+6\text{R}-7.5\text{B}+1)]$ (Anderson²².)

where 'NIR' is the near-infrared band, 'R' is the red band, 'B' is the blue band, and 'a' is the angle of incidence of between the sun's rays irradiated on a surface and the line normal to this surface.

In this study, changes in the natural vegetation as a function of production rate were determined using the NDVI. Tucker²³ reported that the NDVI changes between -1.0 and +1.0 in general, and more specifically between +0.1 and +0.7. NDVI values were calculated using the (4-3) / (4+3) band ratio for Landsat images and the (3-2) / (3+2) band ratio for the ASTER images. The effect of marble quarries activities on vegetation from 2001 to 2009 is determined using NDVI images and vector data from quarry boundaries for each year. The subset method was used to calculate the yearly changes by converting the vector data into an area of interest layer (AOI). To determine the extent of vegetation loss, NDVI images from one year to the next were subtracted from the AOI images. Figure 7 shows the result of this transformation from 2001 to 2003.

NDVI vegetation difference images similar to those in Figure 7 were created for the years 2001 through 2009. The pixel resolution is 30 m and the pixel area is 0.09 hectares.

Results and discussions

Table II presents the results from the analysis of the images to determine the extent of marble quarries expansion over an area totaling 36 390 hectares. The comparison of the land areas exploited between 2001 and 2009 reveals a five-fold increase in quarrying activity in the intervening eight years. The rate of increase grew from 0.54 per cent in 2001 to 2.89 per cent in 2009 over of the entire study area. The expansion is directly related to an increase in existing quarry activities. The boundaries of quarries are determined from vectorized data. The changes in the boundaries between years 2001 and 2009 are given as an example in Figure 8.

The associated natural vegetation cover reduction calculated using the NDVI is shown in Table III.

The measured vegetation cover in the study area is 12 254.08 ha. The change in the cumulative vegetation is related to the expansion of marble quarries between 2001 and 2009 and is estimated to be 256 ha or 2.09 per cent. The vegetation decrease in the study area is 4064.17 ha or 33.17 per cent. The loss of vegetation from marble quarries constitutes 6.30 per cent of the total decline in the study area. The region is covered with large pine forests. Many forest fires occur in this region every year, especially during the summer months, and these fires account for 86 per cent of the total vegetation loss. Although several reforestation efforts are currently underway in the burned areas (shown in the last column as negative value in Table III), the loss of vegetation has increased dramatically.

Another important point is that the observed upward trend in the number and the size of operating quarries and associated reduction in the vegetation cover in the study area have been documented (Figure 9). The study area is one of the major marble production regions located in south west of Turkey. Marble production has been continued since ancient times in these areas, and many quarries were opened before 2001. Therefore, vegetation around the quarries was influenced by the mining operations. Mostly vegetation near the expansion areas of quarries was damaged. For this reason, hence the rate of vegetation loss is less than the rate of pit expansion as shown in Figure 9. However, both show an increasing trend as a function of time.

Natural revegetation becomes more precarious as quarries cover larger land areas. Therefore, one cannot rely on the

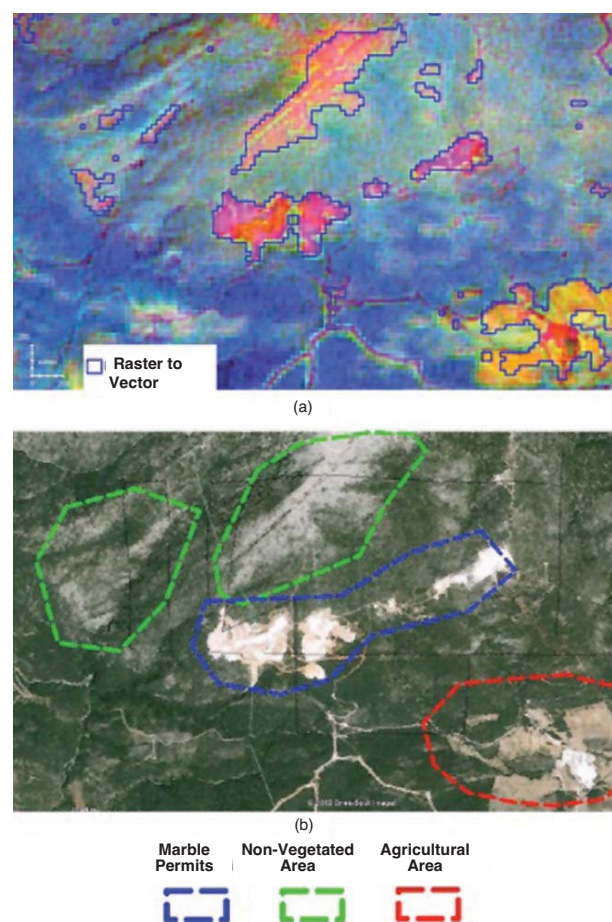


Figure 6—Vectorized data from 2005 ASTER images (green), sharpened boundaries of marble quarries (blue) and agricultural area (red)

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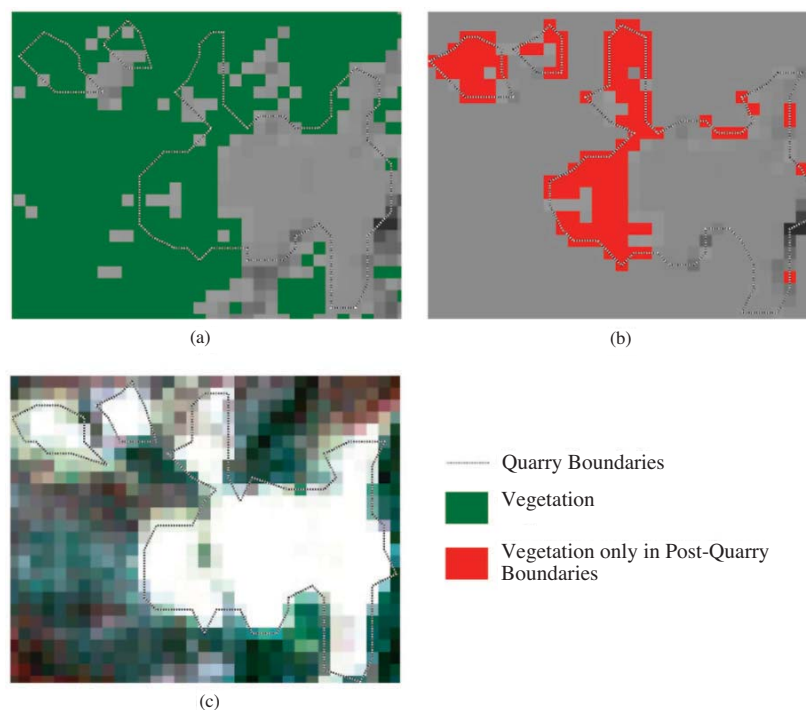


Figure 7—The effect of marble quarry activities on vegetation: a) NDVI image of 2001 (green) and quarry boundaries of 2003, b) NDVI image of 2001 (red) only in quarry boundaries of 2003, and c) RGB-432 view and quarry boundaries of 2003

Table II
Marble quarry expansion from 2001 through 2009

Years	Expansion (hectare)	Cumulative total (hectare)	Rate of expansion (%)
2001–2003	197.08	197.08	0.54
2003–2005	260.01	457.09	1.26
2005–2007	208.53	665.62	1.83
2007–2008	164.61	830.23	2.28
2008–2009	221.94	1052.17	2.89

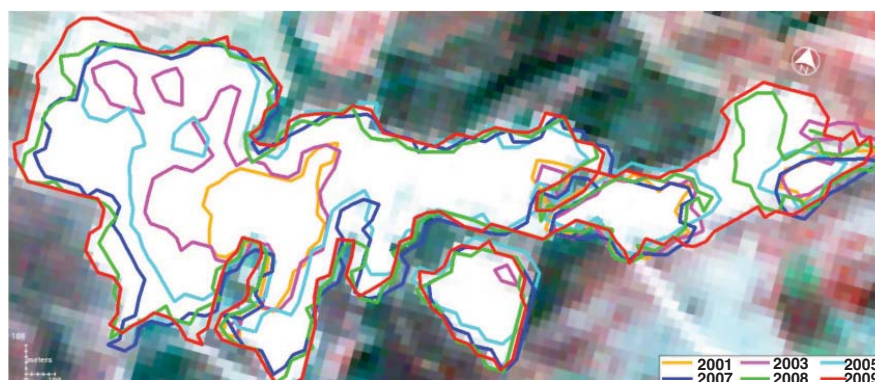


Figure 8—An example of the expansion of marble quarries between 2001 and 2009 (different colours represent quarry boundaries related to the years)

natural revegetation process as it would take hundreds of years to restore the habitat to its original state. It is estimated that human-induced restoration could speed up this process, and would require only a decade or less to accomplish.

Conclusions

A quick review of the literature shows that satellite-based remote sensing is a widely accepted and utilized technique in

many scientific disciplines to monitor and evaluate the impact of natural processes and human activity on the environment. However, few studies have been carried out to assess the environmental impacts of mining using remote sensing. In this research, the authors present an estimation of the areal expansion of marble quarries and the associated change in the vegetation in the Mugla region in Turkey between the years 2001 and 2009, using geographic information system

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Table III

Change in the natural vegetation cover between 2001 and 2009

Years	Change in vegetation			
	Quarries		Study area	
	Area (hectare)	Cumulative total (hectare)	Area (hectare)	Change from the previous year (hectare)
2001–2003	65.39	65.39	10355.22	1898.86
2003–2005	55.44	120.83	10887.57	-532.35
2005–2007	54.18	175.01	10645.47	242.1
2007–2008	52.65	227.66	7313.67	3331.8
2008–2009	28.71	256.37	8189.91	-876.24

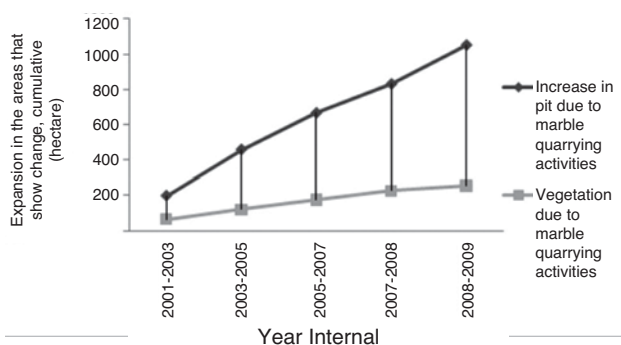


Figure 9—Increase in pit area and vegetation loss due to marble quarrying activities

and remote sensing techniques. ASTER (the Advanced Spaceborne Thermal Emission and Reflection Radiometer) Level 3A01 (3D Ortho Data Set), Landsat 5 and Landsat 7 images were analysed for this purpose. The change in the natural vegetation cover was calculated using the normalized difference vegetation index (NDVI), and is observed to be related directly to the production of marble. Estimation of the expansion of the quarries from Landsat TM images was performed using the band rationing technique.

Modern open pit mining techniques utilize heavy equipment. As a result, dramatic changes in the land cover take place in a very short period of time, affecting the neighbouring habitat both ecologically and hydrologically. The maps produced from remote sensing data can provide timely and valuable information for subsequent assessment of the impact of the mining activity in the area. The use of remote sensing and geographical information systems plays an ever-increasing role in the management of mining land. Together, they provide information and statistical data for assessing habitat diversity and land cover change while a mine is in operation, which can be used for formulating policies and guidelines for post-mining land management, reclamation, monitoring, and landscape characterization.

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