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TECHNICAL ARTICLE

Using Remote Sensing to Assess Impact of Mining Activities on Land and Water Resources

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Abstract Environmental impact assessment is now an integral part of mining operations. Remote sensing data enables the identification, delineating, and monitoring of pollution sources and affected areas, including derelict land, and changes in surface land use and to water bodies. The aim of this work was to evaluate the use of multi-temporal Landsat-5 and Landsat-7 images, SPOT Panchromatic, and ASTER data to map the natural environment on a local scale, and to assess the impact of mining activities by indicating the changes on land and water resources. Three case studies are presented: Lake Vegoritis and the Amynteon mine (both located in northern Greece) and the Lavrio mine area, in central Greece. We found that using high resolution satellite remote sensing data and state of the art GIS techniques with parallel development of a fully integrated geospatial database system provided monitoring and feedback at appropriate spatial scales; therefore, such data can be used for long-term environmental management and monitoring of reclamation and rehabilitation of mining areas.

Keywords ASTER data · Environment · Landsat · Mining activities · Pollution · Risk assessment · Vegoritida · Water management

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Introduction

The environment, including ground and surface water, is put under constant stress by various human activities and natural processes. Remote sensing data can provide information on changes to surface water and land cover over time, which is essential for environmental monitoring in mining areas. Remote sensing data are also ideal for environmental impact assessment due to their broad spectral range, affordable cost, and rapid coverage of large areas. Synergistic use of remote sensing and ancillary data can be used to create a GIS database, which can be used to store, process, and retrieve the environmental data.

The use of Landsat and SPOT images in geomorphologic and geologic mapping is well established. Multispectral satellite data and aerial photographic data have been used for environmental impact assessment and monitoring of mining activities (Jhanwar 1996; Rathore and Wright 1993), and, in general, the method has proved to be quite effective in monitoring environmental pollution related to heavy metals (Stefouli and Tsombos 1998). However, there have been continuous improvements in the capabilities of satellite systems and thus, an improvement of the quality of the image data provided to the end user. The relatively new ASTER satellite system has been successfully used for land cover change detection (French et al. 2008) but has not been widely exploited for monitoring land cover changes related to mining area. Our objective in this study was to assess the potential use of integrated remote sensing and WEB-GIS techniques to map the natural environment on a local scale, and to assess the impact of mining activities by indicating the changes on land and water resources for regions in which extensive mining activity is taking place. Three case studies were used: the Lake Vegoritis and the Amynteon mine, located in the Vegoritis hydrological basin in northern Greece, and the Lavrio mine area, in central Greece.

Study Area

The Vegoritis hydrological basin (Fig. 1) is environmentally sensitive; within its boundaries, there are four inland lakes that are hydraulically connected by swampy areas. Three of these lakes are very shallow; most of their area is less than 1 m deep. Any change to their level has a great impact on their areal extent and also affects the other lakes downstream. Extensive mining and agricultural activities are taking place in the basin, including five open cast lignite mines; these produce 55×10^6 t of lignite and 290×10^6 m^3 of waste material annually (DEI internal report 2005; Dimitrakopoulos et al. 2003). We have focussed on the environmental aspects of Vegoritida Lake, as it is the final receiving body of the surface runoff of the basin and considerable changes of the water level of the lake have been observed during the period of 1957–2007 (Dimitrakopoulos et al. 2003; Vavliakis et al. 1993). The initial drawdown can largely be attributed to water use by the hydroelectric power plants located in the area but these extractions have diminished during the last 20 years, while withdrawal for irrigation and other uses have increased. Additionally, the exploitation of the lignite mines has environmentally affected the land and water resources of the area, due partly to the dewatering measures undertaken to protect the mines. The Amynteon mine, also located in the Vegoritis basin, began exploitation in 1989. The average lignite production is 8×10^6 tn/year and the average excavation is 7×10^7 m^3/year. The mining method is continuous surface mining, using bucket wheel excavators, spreaders, and belt conveyors. The depth of the mine is about 150 m. Extensive dewatering takes place to protect the mine from groundwater. On average, 7×10^6 m^3/year of groundwater are pumped out annually (period 2005–2008), using water wells in the periphery of the mine.

Lavrion is located 40 km southeast of Athens. The first traces of mining activity in the area go back to 3.000 BC. Systematic and intensive exploitation of the silver and lead ores, though, started with the birth of the Athenian Democracy in 508 BC, the glory of which was based substantially on the Lavrion mine. Later, mining declined, and then was restarted in 1867 by a French-Italian company. The natural landscape and the rich forest vegetation deteriorated. Mineral wastes containing potentially toxic metals were dumped on the surface, covering extensive areas. In 1989, the company ceased mining, and the area faced a serious economic crisis, in addition to its environmental degradation.

Data Sources

The data used in this study included: topographic maps (1: 50,000 scale) published in 1970 by the Hellenic Geographic Service; geologic maps (1: 50,000 scale) produced by the Institute of Geologic Mineral Exploration; Landsat TM, SPOT, and ASTER data of various acquisition dates; mining maps; and a variety of hydrologic, meteorological, and land use data. Field work was conducted to identify places

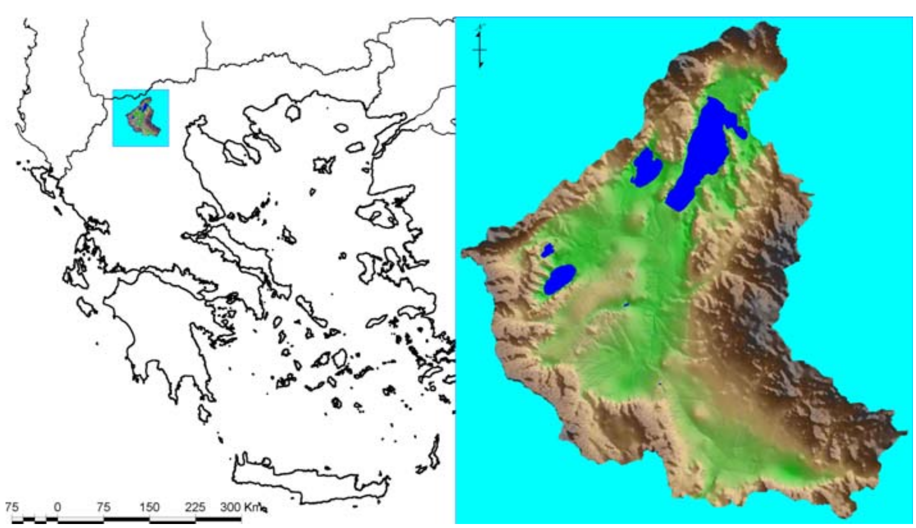

Fig. 1 The pilot project area of the Vegoritida basin

of special interest and to calibrate the results of the analysis. The characteristics of the Landsat, the SPOT Panchromatic, and the ASTER images used in the analysis were:

1. Landsat 7 ETM (acquisition date 10/11/1999)
    - Spectral Bands (μm): 1: 0.45–0.515, 2: 0.525–0.605, 3: 0.63–0.690, 4: 0.75–0.90, 5: 1.55–1.75, 6: 10.40–12.5, 7: 2.09–2.35, 8: 0.52–0.90 (Panchromatic).
    - Spatial Resolution 30 m (60 m for band 6) (15 m for band 8)
2. A Landsat 5 image was also used (acquisition date 26/10/1986)
3. ASTER image (acquisition date: 5/10/2001)
    - Spectral Bands (μm): 1: 0.52–0.60, 2: 0.63–0.69, 3 N: 0.78–0.86, 3B: 0.78–0.86, 4: 1.600–1.700, 5: 2.145–2.185, 6: 2.185–2.225, 7: 2.235–0.285, 8: 2.295–2.365, 9: 2.360–2.430, 10: 8.125–8.475, 11: 8.475–8.825, 12: 8.925–9.275, 13: 10.25–10.95, 14: 10.95–11.65.
    - Spatial Resolution 30 m for bands 4–9, 90 m for bands 10–14, 15 m for bands 1–3B.
4. SPOT Panchromatic image (acquisition date 14/10/1996)
    - One spectral band covers the range of 0.51–0.73 μm, with a spatial resolution of 10 m

Methodology

The analysis mostly depended on the Landsat and ASTER images; the SPOT image was used to extract certain features like the surface extent of lakes. These data sets were processed using the image-processing software TNT MIPS by Microimages. The assessment included a study of the environmentally critical areas of land degradation and water pollution (Koutsoubidis 1999), as well as changes in land use in the Vegoritis Basin.

Processing Techniques

Various image processing and vector GIS techniques were used for the analysis of the satellite imagery, the collected map data, and the field information:

1. Georeferencing and resampling: The images used were geodetically corrected into the Transverse Mercator Projection using the Hellenic Geodetic Reference System (HGRS'87). Georeferencing was followed by image-to-image registration in order to detect changes in Landsat images Resampling was carried out using the nearest neighbor method.
2. Color composites: The pseudo-color composite RGB-753 was used on the ASTER and the Landsat images in order to emphasize the mining areas, which have high spectral reflectance. This composite accentuated the mining areas and discriminated vegetation from barren soil.
3. Intensity hue saturation (IHS) images: The IHS transform was used to fuse the SPOT panchromatic band of higher spatial resolution with the multispectral bands of the ASTER and Landsat images so that the inherent land cover classes in the mining areas could be identified. The final image derived from this procedure was the 453-PAN composite.
4. Unsupervised classification techniques using neural networks: Arificial Neural Networks (ANNs) are generally quite effective for the classification of remotely sensed data (Vassilas and Charou 1999). For classification purposes, the Self Organizing Map (SOM) ANN method was used on the ASTER image in order to discriminate all inherent land cover classes of the satellite images. Different land cover types were mapped in the mined areas and the surface extent for each cover type was estimated. In Fig. 2, vegetation is shown with green colors, while red colors correspond to excavated areas or recent dump areas.
5. Identification of areas of interest with respect to land and water surfaces: This area of interest included the Vegoritida Lake Basin, on which this analysis was concentrated.
6. Automated combination of the classification result of multi-temporal imagery: 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.
7. Automated conversion of raster to vector data: the raster output of the classification (Fig. 2) and/or interpretation process was converted to vector data and these data were analyzed with the corresponding map data and field observations. Statistics for the classification result have been estimated related to areas. Estimates of surface area extent have been obtained. The estimates were checked in the field and proved to be accurate.
8. Collection, input, coding, storage, management, retrieval of various data: all ancillary data (raster, vector, ASCII) selected in this study were aggregated in the GIS in order to assess the natural risk caused by mining activities.
9. Processing and analysis: further processing and analysis was performed to derive information concerning changes identified in the study area.

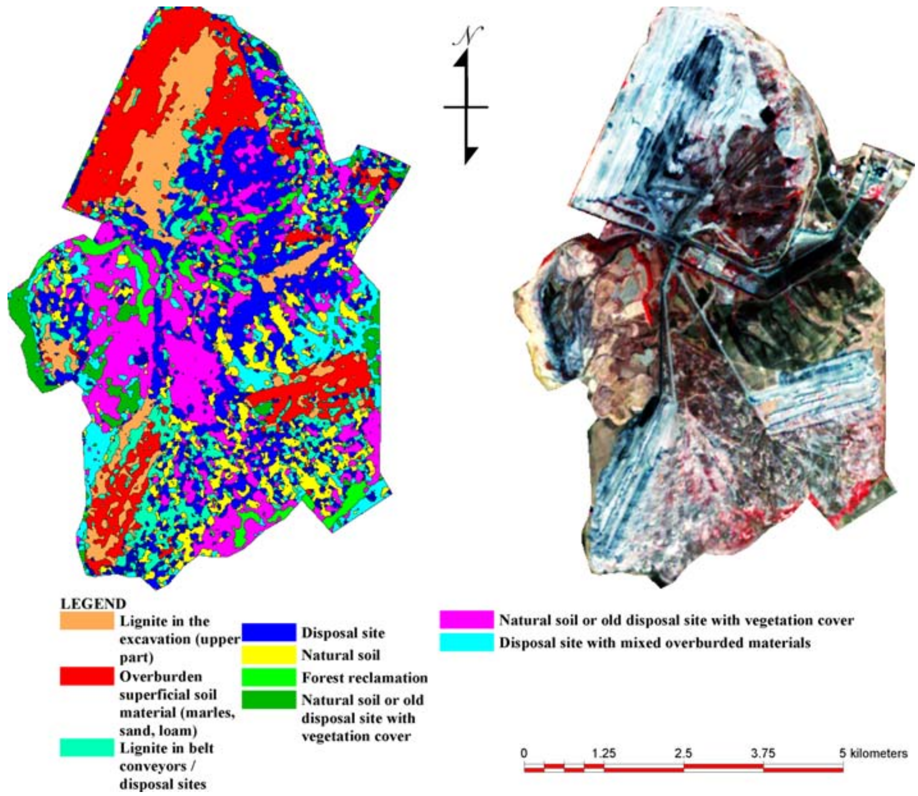

Fig. 2 Classification result (*left* image) and false color image of the ASTER subset (*right* image) of the Amynteon lignite mine (area 36.69 km^2)

10. Presentation and display, map making, and distribution of information using free software (freeware).

Results and Discussion

Changes to Lake Vegoritida

The areal extent of Vegoritida Lake significantly decreased during the course of this study (Table 1; Fig. 3). The change concerns not only the land cover but the land use as well. Decreases in areal extent of Vegoritis Lake over time were estimated relative to the 1970 Hellenic Geographic Service topographic map.

This decrease in areal extent is in accordance with the lake level measurements, which show a constant drawdown of the water level, which, during this time period, was primarily due to increased agricultural use and, secondarily, due to dewatering of the mines and industrial use. In the Amynteon basin, which is a sub-basin of the Vegoritida basin, the number of water wells used for irrigation has constantly increased during the last 30 years (Fig. 4), as has the amount of irrigated land (Dimitrakopoulos 2001; Lykoudi et al. 2003). Additionally, from Fig. 3, it is

Table 1 Decreases in the areal extent of the lake relative to the reference topographic map

LANDSAT 1986	SPOT 1996	LANDSAT 1999	ASTER 2001
−7.4 km^2	−20.1 km^2	−20.3 km^2	−21.4 km^2

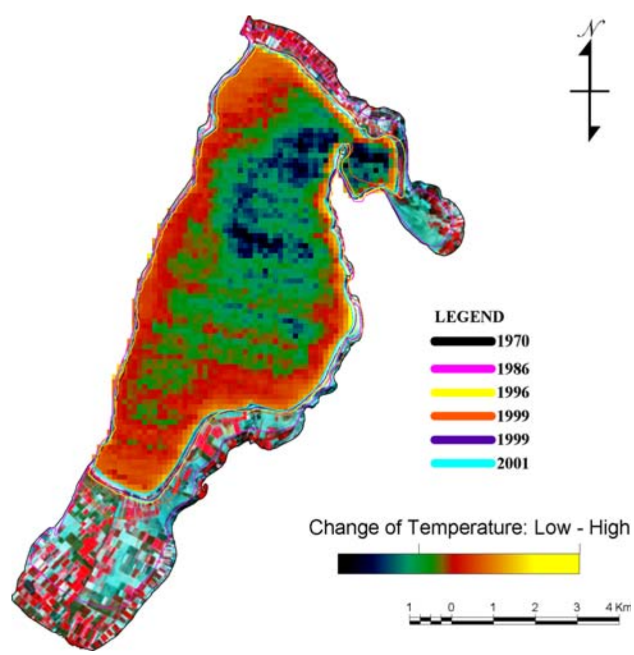

Fig. 3 ASTER raster data extracted according to: the coastline of the topographic map dated 1970 and the land/water boundary of the image dated 2001. The interpreted coastlines from the multi-temporal satellite imagery were also plotted on the image

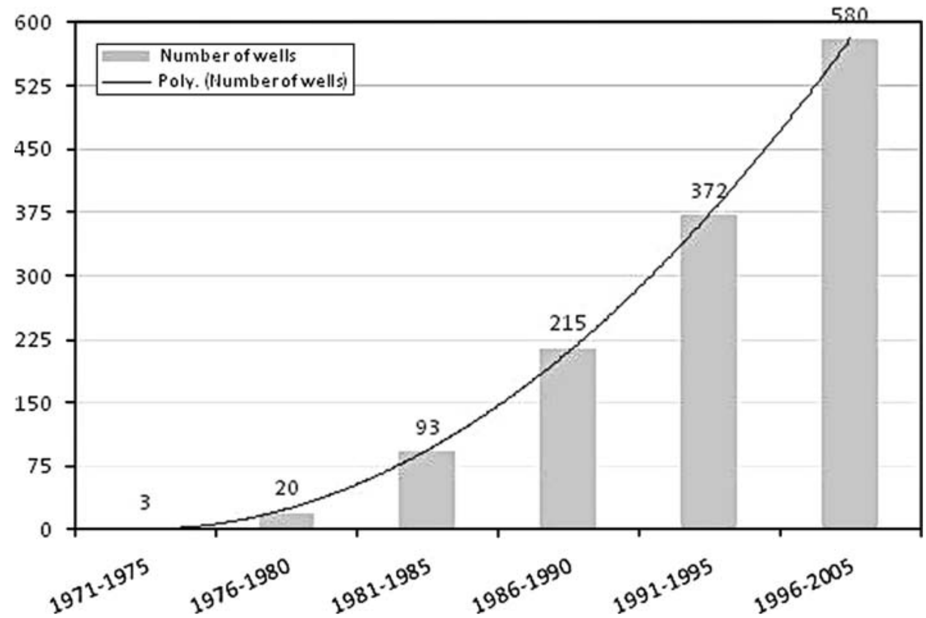

Fig. 4 Number of irrigation wells in the Amynteon Basin

estimated that 90% of the former lake area, which was exposed after the drawdown of its water level, has been used for agriculture.

Thermal anomalies (Fig. 3) in the lake have been mapped due to the 12 bit radiometric resolution of the ASTER data, which are not shown on the Landsat time series data of the study. This is related to the inflow/outflow of the water due to sinkholes that have formed at the bottom of the lake because of the karstic limestones of the area.

Analysis of Mining Activities

The false color composites of ASTER, LANDSAT, and the Panchromatic SPOT images present the extent of the mining activities (Fig. 5). This enabled the classification of the subset of mine area into different categories: active mine works (generally covered by bare soil); formerly mined or recently rehabilitated areas; and waste dump areas. The mining activities could also be monitored, as illustrated in Figs. 5 and 6.

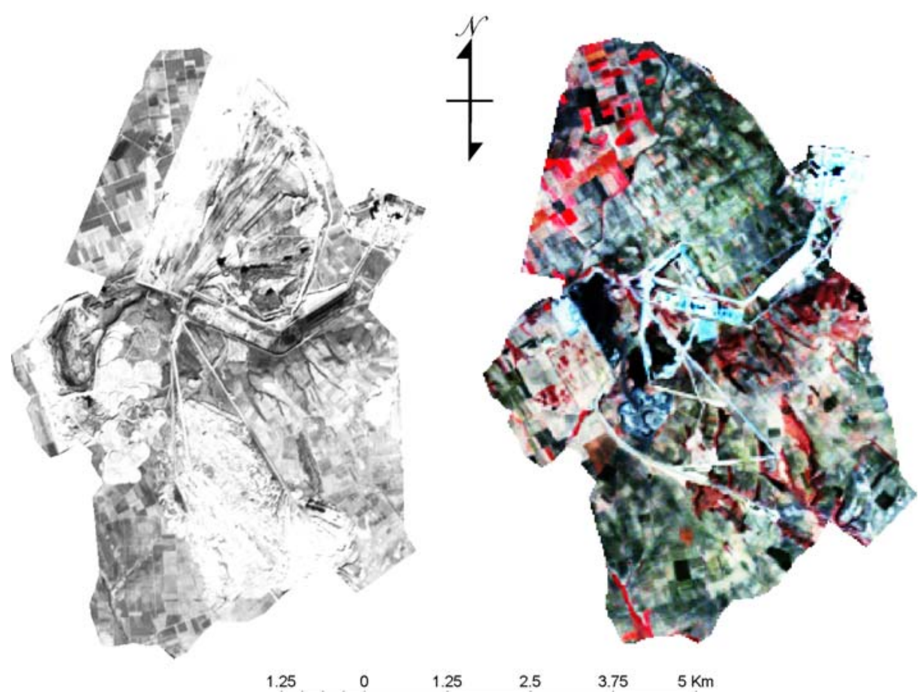

Fig. 5 *Left* image shows the SPOT image with an acquisition date of October, 1996; the *right* image shows the Landsat 5 false color image, dated October, 1986

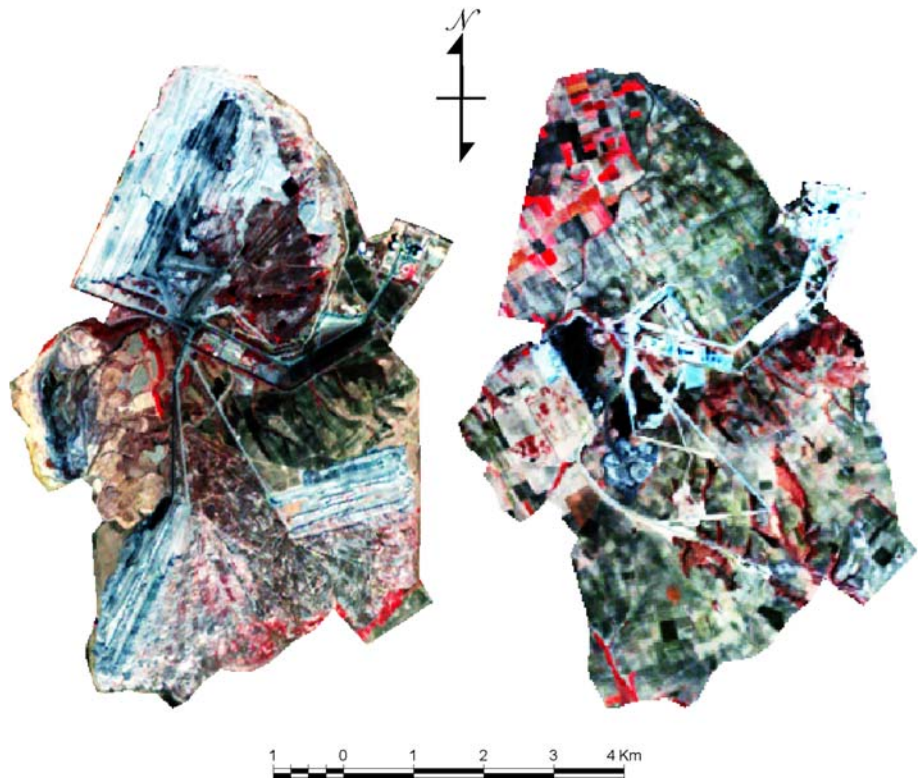

Fig. 6 The ASTER image of October 2001 is shown on the *left*; the Landsat 5 image is on the right, for comparison

These satellite images complement each other and allowed us to detect the different types of land surfaces and monitor environmental aspects. Changes in activities were easily interpreted on the multi-temporal imagery. Work in the mining areas had just been initiated during October 1986 and then have gradually progressed until October 2001. Vegetation cover of the restored areas (shown with bright red colors in Figs. 6 and 7) could also be monitored quite effectively. White and blue–white areas represent newly exposed areas (mining) or waste dumping. Dark colors indicate former waste dumping areas.

The same methodology was also evaluated using multi-temporal satellite imagery for the Lavrio area. The mine waste areas can easily be observed from the satellite

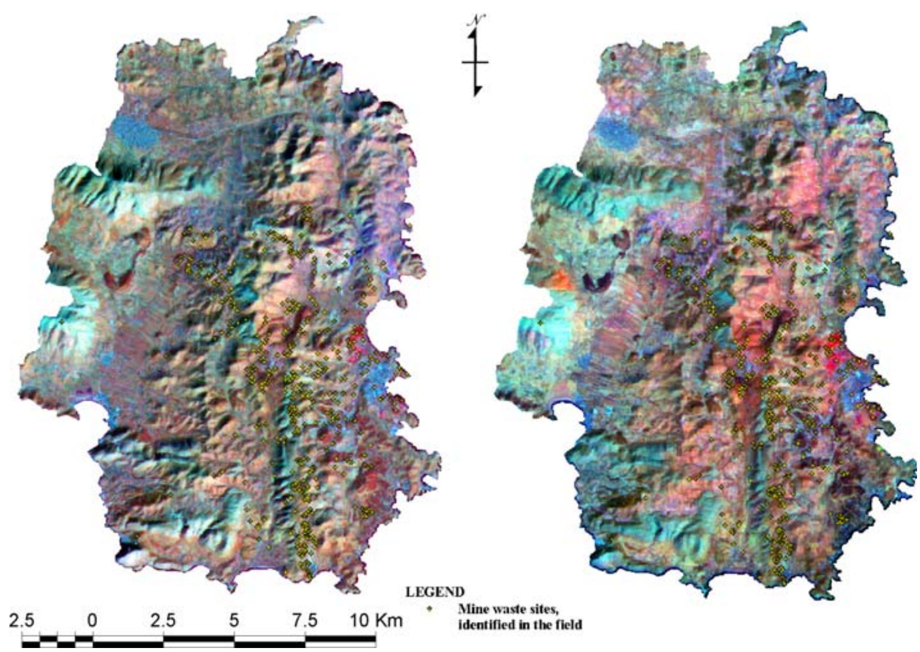

Fig. 7 *Left* image shows the Landsat 5 false color combination with thermal band of January 1988, while the *right* image shows the same band combination during the summer of 1994

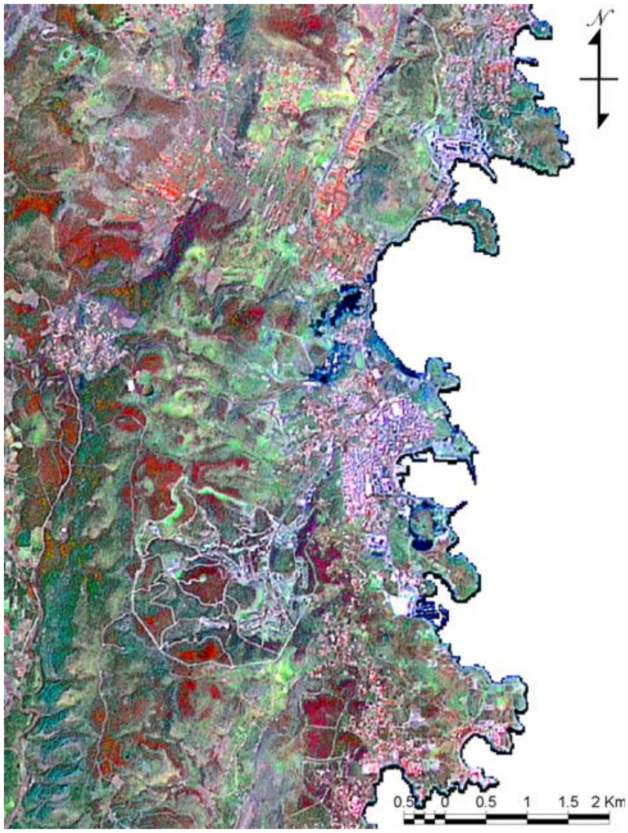

Fig. 8 False-color composite of the infrared bands of the Landsat-7 image (acquisition date: August, 1999)

imagery (Fig. 7), where it has a bright red color due to its high surface temperatures. An increase of the surface expanse was observed between the two dates. This has been verified in the field; the mine wastes have been used as construction materials. The same sites are still shown with dark colors on the August 1999 image of Fig. 8, where the infrared bands have been combined.

The research has resulted in data that could be useful to those who are responsible for the environmental management of the area. All data were organized in an informational atlas, which can be distributed as a CD or on the WEB.

Conclusions

The use of the multi-temporal ASTER, Landsat, and SPOT images is an inexpensive and effective tool for mapping large mining districts and indicating land and water use and changes, and can be used to supplement data from environmental studies. The satellite data can be processed and analyzed in order to generate a proper GIS database. ASTER imagery proved to be an ideal data source for land use/cover change detection in the mining areas, given its relatively higher spatial resolution (15 m in visible and near-infrared regions) and reasonable cost. ASTER data can be efficiently used to:

- monitor land cover changes in mining areas;
- monitor thermal anomalies of water surfaces;
- supplement Landsat data (although it did not affect this study, since 2003. Approximately one-fourth of the data in a Landsat 7 scene is missing due to a malfunctioning scan line corrector); and
- monitor reforested areas to ensure that land reclamation complies with environmental regulations.

New environmental policies require many agencies to provide public access to information gathered with public funds. An additional advantage of the proposed approach was the provision of a variety of data to end-users and its contribution to efficient analysis and prediction of environmental impacts. By virtue of its geographically structured approach, an atlas offers an intuitive, self-paced, and self-contained way to provide secure public viewing of data. These data include multi-temporal information provided by satellite systems, census data, land cover/use, and available hydrogeological information.

References

DEI (2005) 100 years of lignite. Internal report, 7th edn. The public power corp of Greece (DEI), Athens, 52 pp

Dimitrakopoulos D (2001) Hydrogeological conditions of Amynteon lignite mine. Problems during the exploitation and their confrontation. Ph.D. thesis, National Technical University of Athens (in Greek), 202 pp

Dimitrakopoulos D, Grigorakou E, Koumantakis I (2003) Aquatic balance in Vegoritis Lake, West Macedonia, Greece, relating to lignite mining works in the area. Abstracts, EGS-AGU-EUG Joint Assembly, Nice

French AN, Schmugge TJ, Ritchie JC, Hsu A, Jacob F, Ogawa K (2008) Detecting land cover change at the Jornada experiment range, New Mexico, with ASTER emissivities. Rem Sens Environ 112:1730–1748

Jhanwar MC (1996) Application of remote sensing for environmental monitoring in Bijolia mining area of Rajasthan. J Ind Soc Rem Sens 24:255–264

Koutsoubidis E (1999) Ecologic research on the Lakes and Rivers of Florina County: Research Programme 1984–87. Internal report, Florina County Division of Chemical Services, Florina, 104 pp

Lykoudi E, Grigorakou E, Dimitrakopoulos D, Vassiliou E (2003) Interaction of land use and aquatic changes in Vegoritis hydrological basin, West Macedonia, Greece. Proceedings of the 2nd international conference on ecological protection of planet earth, Sofia, pp 418–425

Rathore CS, Wright R (1993) Monitoring environmental impacts of surface coal mining. Int J Rem Sens 14:1021–1042

Stefouli M, Tsombos P (1998) Identification and monitoring of surface mining and smelter pollution using remote sensing techniques: a case study in Lavreotiki Peninsula, Attiki prefecture, Greece. Proceedings of the colloquium space techniques for

environmental management in the mediterranean region—EURUSYS, Athens, pp 176–282
Vassilas N, Charou E (1999) A new methodology for efficient classification of multispectral satellite images using neural network techniques. Neural Process Lett 9(1):35–43
Vavliakis E, Albanakis E, Antonopoulou E, Geramian A (1993) Influence of human activity to the evolution of Vegoritida lake. Proceedings of the 3rd Hellenic geographic congress, pp 275–289