Assessment of the Reclamation Activities near Non-Operating Mine by Remote Sensing

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Surface mining activities in Europe are estimated to cover an area of 5–10 000 km^2. In this paper we suggest that the availability of Landsat Thematic Mapper (TM) for Earth observation allows the collection of environmental and mine-related data for use in the planning and undertaking of mine restoration work on cost-effective basis. The advantage is that these data are acquired digitally and can be easily processed and utilized in various information formats. Important step in the data processing is the verification of airborne data. For this purpose ground spectrometry measurements of samples taken from test sites have been performed. In the last decade several mining areas and corresponding dumps are subject to reclamation process in Bulgaria. We focused our research on one of the most important in the copper production for 20 year period for our country – Asarel-Medet deposit. This mining complex consists of an open mine, the dumps and a processing plant. After ceasing the exploitation of Medet deposit in 1994 a rehabilitation program for soil cover and hydrographic network was established and launched. A continuous task is the monitoring of these activities from the beginning for at least 15 years period, which is to end this year. To process the data, which characterize the progress of the land cover restoration, several techniques, both standard, such as basic and advanced statistics, image enhancement and data fusion, and novel methods for supervised classification were used. The results obtained show that used data and the implemented approach are useful in environmental monitoring and are economically attractive for the company responsible for the ecological state of the region.

Introduction

The geological exploration of the copper-bearing rocks in the Sredna gora region, located in the middle of Bulgaria, started in the late 50-ies of 20-th century. As a result the mining plant “Medet” was built who started its production 1964. The main activity of this plant is extraction and recovery of copper together with all relevant engineering and commercial actions. The experience for exploration and mine plant construction gained on this site was implemented on other mine plants across Bulgaria during 60 and 70-ies of same century. In 1994 the open pit mine “Medet” was closed, but the newly developed “Asarel” mine started its operation.

In both cases the ore deposits are developed by open pit mining and together with them the dump areas are one of the largest pollutants of the environment in this region. That is the reason to start monitoring and rehabilitation activities for the region as a whole eco system. A monthly bulletin about the quality of the air and water is published and distributed in by local authorities. In the 2003 the company Assarel-Medet SJSCo implemented an integrated control system according to the international standards ISO part of which is an environmental standard ISO 14001:1996. This policy for ecologically clean production could be supported to great extend by data obtained by existing and new remote sensing instruments having moderate to high spatial resolution. Compared with the data taken 20 years ago the spatial precision of the data improved more then twice which may result in better decision support. This is the motivation of the team – to develop better understanding of the reclamation process and its monitoring.

The methodology of widely used *change* detection, based on *in-situ* digital data, is the process related to the changes of the land-cover properties. By this means the changes in the land cover between two dates are highlighted. Change detection has been used in many applications such as land-use changes, rate of deforestation, urban areas alteration implementing remotely sensed data along with spatial and temporal analysis procedures and digital image processing techniques.

In this research data from Landsat TM/ETM+ combined with in-situ and ex-situ measured data was used. Four main types of land cover were considered during this study namely - bare rocks, bare top soils, grass and bushes, trees. The other natural phenomena subject to the negative influence of the mining activities, the water, was not studied since the hydrographic network has smaller spatial dimensions than the resolution of the instrumentation used to gather data and this why field measurements were not carried out.

The exploitation of mineral resources is always associated with change of the land cover. Thorough monitoring of degraded areas is an essential task for effective management of surface mine recovery [1]

Materials and Methods

Study area

Region of interest (RoI) in the study area Assarel-Medet is selected based on TM dataset. Assarel-Medet – an open pit copper mine encompass an area 200 thousand sqm, about 1000 m above sea level, 90 km south-east from the capital of Bulgaria, Sofia, in the *Sashtinska Sredna Gora* mountain.

During field campaign 2005 in RoI granite, brown soil and grass samples are collected for ex-situ analysis of their mineral and chemical reference. Pinkish medium-grained granite samples consist of average 50% orthoclase, 35% quartz, 15% plagioclase, 1% biotite and 1% magnetite. The parent material of the brown sandy loam soil sample is granite. The soil sample has moderate to coarse prismatic structure, very hard and friable with neutral pH (6.5) 1% organic carbon, 12% clay, 25% silt and 62% sand. The grassland vegetation type is presented by Green Rye grass.

Spectral data

1. The main source for airborne data for the spectral reflectance of the land cover was the freely available data sets from Landsat TM/ETM+ instrument [2]. The acquisition dates for both scenes are in first decade of June which

guarantees equal illumination conditions and phenological state of the vegetation.

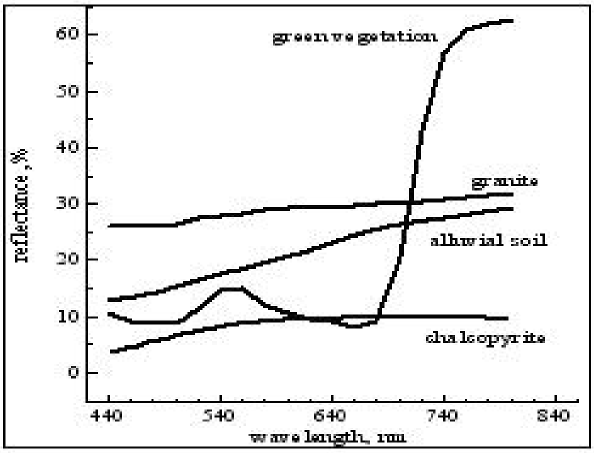

Fig.1. Generalised spectral reflectance curves major types of land cover (adapted from[5])

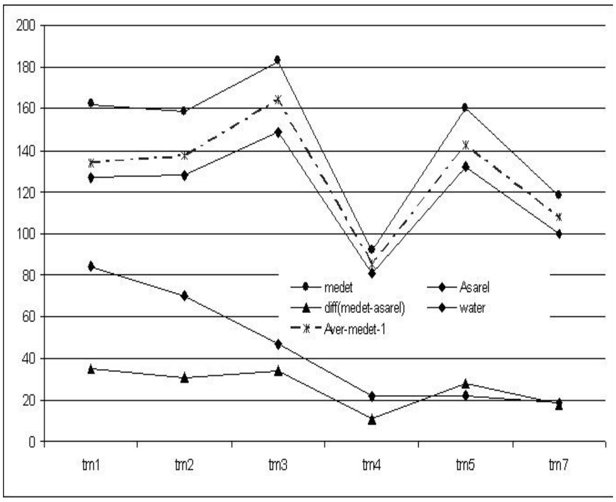

Fig.2. Reference reflectance spectra of the class "open pit mine"

Since the region under study falls into edges of two adjacent scenes from different dates of year 1987 (path183/row30 and path183/row31 of WRS of Landsat) first a mosaic of them was made and a subset of this data was produced. After this procedure the geometric and radiometric properties were not distorted which resulted in correct data. From this dataset the target areas were extracted by their visual discrimination from the surroundings. The same procedure was applied on data from year 2000. This way the data necessary for change detection procedure were created. The following land cover types have an important influence on the ecological state in the region:

1) Open pit mines Asarel and Medet.
2) Dumps as a part of copper plant Asarel.
3) Landfills – part of copper plant Asarel.
4) Urban area of the town Panagyurishte.

Multi-temporal spectral signatures are acquired in RoI in summer 2005 to monitor inter-annual changes at the surfaces.

2. The in-situ reflectance spectra are obtained by means of Thematically Oriented Multichannel Spectrometer (TOMS) designed and constructed in Remote Sensing Department at STIL-BAS in collaboration with AAMU-USA [3].

3. Ex-situ measurements in laboratory conditions are performed with spectrometric system SPS-1 [4] also designed and built in the Department. Five spectra as average of 100 internal spectra are acquired over each target. After being acquired, the spectra are corrected for relative reflectance with the spectrum of a barium sulphate surface used as white reference, to obtain absolute reflectance measurements. Post-processing of the field and laboratory reflectance data included removal of defective data, averaging of the five spectra per target, and if necessary smoothing of the resulting spectra.

As a main indicator for the ecological state of the areas under study the density or at least presence of the vegetation cover was chosen. The reasons for this decision were twofold – first it can be reliably estimated by remotely sensed data (see Figure 1) and second we obtained additional information about the region, mainly from geographic and ordnance surveying sources, in regards of the state of those areas before the exploitation of the deposits had started.

Data processing

The accuracy of the digital numbers comprising these data sets was verified comparing them with in-situ and ex-situ reference reflectance spectra of the similar types of land cover acquired in a field campaign. Even an in case of mixed pixel (which is the case for pixels from the borders of the areas), implementing the methodology of the unmixing theory [6,7] on the data, the vegetation/soil proportion was determined easily thus increasing the precision in determining the areas covered by a specific end-member (mine, dump, vegetation). This approach was implemented in our research eliminating more than 15% of incorrectly taken pixels for dump sites and 8% for the mine region. In fact they represent mixed pixels containing reflectance from at least two components - soils and Cu-bearing minerals embedded in granites and volcanic rocks.

To estimate the impact of the mining activities on the environment as major indicator of the ecological state the areas covered by vegetation and the top soil chemical composition in the region under study was adopted. The main assumption in this case is that using spectral properties of main types of land cover their current state could be estimated with acceptable error [5]. Especially for the mentioned types this holds to be true since their spectral reflectance is quite dissimilar [8]. The curves shown on Figure 1 are a close approximation of main types of land cover present in the whole area of study which comprises about 30 km^2.

Results and discussion

The representative data sets (selected were at least 200 pixels per class) were formed by visually interpreting the multispectral images (from different dates) and modern topographic map of the RoI. The statistics of those data sets are summarized in the Tables 1 and 2. Graphic representation of the data sets corresponding to the open pits is depicted on the Figure 2. There are two lines corresponding to "Medet" open pit since in the bottom of pit water was found and for this reason we had to remove the pixels corresponding to it thus forming new class "Medet-1". This new class is closer to the other reference class "Asarel" as it is expected to be this way forming the whole class *open pit*.

TABLE I
Statistics for open pit mines Asarel, Medet and Medet-1

Spectral class	Statistical parameters	TM-channel					
		TM1	TM2	TM3	TM4	TM5	TM7
"Asarel"	Average	127	128	149	81	132	100
	Dispersion	23,81	30,59	47,81	25,66	47,69	35,12
	Confident. interval	1,310	1,683	2,630	1,412	2,624	1,932
"Medet"	Average	162	159	183	92	160	118
	Dispersion	23,69	32,85	34,92	15,40	34,27	25,49
	Confident. interval	0,971	1,347	1,431	0,631	1,405	1,045
"Medet -1"	Average	134	137	165	85	143	108
	Dispersion	18,2	23,1	32,2	15,7	31,3	21,6
	Confidential interval	1,3550	1,7199	2,3974	1,1689	2,3304	1,6082

TABLE II
Number of pixels and corresponding areas of RoI

	Open pit	Dump
1987	942 pixels	580 pixels
	847 800 area [m^2] *	522 000 area [m^2] *
2000	984 pixels	1070 pixels
	885 600 area [m^2] *	963 000 area [m^2] *
Change	37 800 area [m^2] *	441 000area [m^2] *
* the areas are calculated with spatial resolution 30m/pixel		

In the table above, for both open pit and dumps, the number of pixels and the corresponding areas are given. The results for both areas are quite different since the main mining activities from year 1987 was turned to the deep exploration the deposits. The observed change in the landscape near the mine site is mostly due to expansion of the roads leading to the dumps.

On the next step NDVI values for the pixels covering the areas of interest could be calculated [9]. Based on them the edges of both regions were accordingly corrected once again.

The area of the dump sites were calculated the same way. This manner one could estimate the reclamation of the dump sites that should have been started in 1996, but even now we don't observe any major changes towards improving the density of the vegetation – reclamation activities done so far. This conclusion is based on the multispectral data (ETM+) we used in this research i.e. up to year 2000 and recently made field surveys (see Figure 3).

The steps quoted in the paragraphs above a simple, but reliable methodology for change detection of the vegetation cover in mine regions is introduced. In our future research it will be implemented for other mine sites in Bulgaria and especially in the adjacent one in the area of Elacite mine.

Additional information for the dump sites is the chemical composition of the ore material. In the case of Asarel-Medet opencast mine the presence of copper and copper oxides are considered as a potential pollutant in the region.

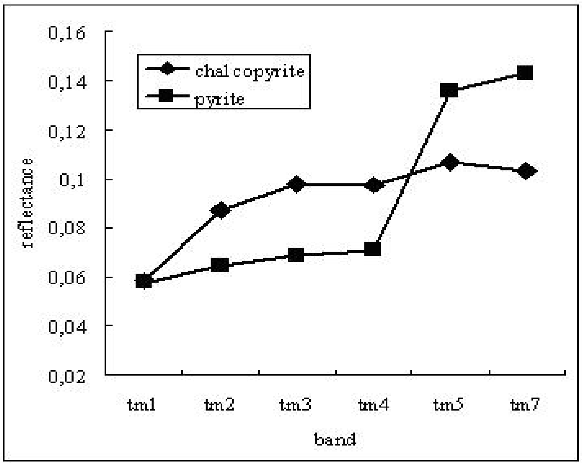

Fig.3. Spectral reflectance curves of pyrite and chalcopyrite

Conclusions

Two conclusions are result of this study. The first one is that a consistent and reliable methodology for estimation of the area of the regions of mines and dumps using remotely sensed data with relatively moderate spatial resolution. The second one is more practical – for these areas we expected some reclamation activities to be found (measured by reflectance of the land cover) we proved that until year 2000 they haven't started. The steps quoted in the paragraphs above a simple, but reliable methodology for change detection of the vegetation cover in mine regions is introduced. In our future research it will be implemented for other mine sites in Bulgaria and especially in the adjacent one in the area of Elacite mine. Another goal of this study is forming of representative reflectance curves for copper-bearing ores from this specifically region which can be uploaded into freely available spectral libraries such as SPECCHIO.

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