Combined use of multispectral and thermal data for assessing iron distribution in mine areas

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Introduction

Earth observation applications in the mining industry include the production of thematic maps for ground inspection and mineral alteration maps for exploitation. 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 (Parks et al., 1987). The geological exploration of the iron deposit in the Kremikovtsi region started in the late 50-ies of 20-th century. As a result the mining plant "Kremikovtsi" was built who started its production 1963. The main activity of this plant is extraction and recovery of iron 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 both cases the ore deposits are developed by open pit mining and together with 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 whole region. Correct estimation of the iron distribution in open pit mines and the neighboring regions is a key issue for the ecological state assessment of land cover.

Materials and Methods

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 (Mishev, 1986). Especially for the mentioned types this holds to be true since their spectral reflectance is quite dissimilar (Clark, 1999).

As a main indicator for the ecological state of the investigated areas the density or presence of the vegetation cover was chosen. The two reasons for this decision are: (i) it can be reliably estimated by remotely sensed data and (ii) we obtained extensive knowledge, mainly from geographic and ordnance surveying sources, about the state of these areas before the exploitation had started.

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 (GLCF, 2005). The acquisition dates for both scenes are in first decade of June which guarantees equal illumination conditions and phenological state of the vegetation.

Since the region under study falls into edges of two adjacent scenes from different dates of year 1987 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 two target areas (open mine and dumps) 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 accuracy of the digital numbers comprising these data sets was verified comparing them with laboratory reference reflectance spectra of the similar types of land cover acquired in a field campaign. Even in case of mixed pixels (which is the case for pixels from the borders of the areas) implementing the methodology of the unmixing theory (Kancheva, Borisova, 2003; Borisova et al., 2005) 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.

Samples from field explorations were collected near Kremikovtsi open pit mine and slag dump. The iron content was determined by:

— *laboratory analysis*: chemical analysis performed in the laboratories of UMG, multispectral data obtained with field instrument TOMS (assembled in STIL-BAS) in visible range and part of NIR range of EMS, emissive spectra carried out using instrument Thermal Infrared Emissivity Spectrometer (TIRES) of Institute of Electronics (Bulgarian Academy of Sciences) in TIR range. Laboratory measurements of the spectral properties of goethite, hematite and siderite (5 samples each) were performed with multi-channel spectrometers TOMS-1 (Petkov et al., 2005). The TOMS-1 instrument provides data in the spectral range 0.4-0.95 μm with programmable number of bandwidths. The reliability of this data is guaranteed by integrating 10 spectra per sample per measurement. In the stated range we put focus on NIR range (0.7-0.95 μm) since for iron-containing ore minerals there is a specific minimum in the reflectance curve. The measurements of the emissive spectra of mineral and rock samples are performed in TIR range (8-14 μm) with resolution of 0.2 μm. The system reliability and accuracy are tested by multiple calibration measurements and statistical procedures;

— *field spectrometric measurements* — they were resulted to be of little use since more informative wavelength for the minerals studied was out of its operational range. They were considered only as reference data with the laboratory ones;

— *airborne* — ETM+ data were obtained from GLCF for June of year 2000 (path 183/row 30 and path 184/row 30 of WRS of Landsat) which is believed to deliver enough spectral information for the objects included in this research. Before processing the data the ortho and geo rectification had already been applied. This allowed us to make direct visual selection of the RoI thus incorporating more a priori knowledge in the unmixing process. From the whole dataset the data corresponding to the thermal band was extracted and not considered in the processing.

Results

Chemical analysis of the collected mineral samples was made to estimate the iron content. In figures 1 and 2 the absorption at 0.8-1.1 μm range (local minimum) corresponding to the iron content in ore minerals (hematite, goethite and siderite) and basalt (as reference iron-containing rock) is observed in the laboratory spectra as well as in TM spectra. Spectral data were obtained with field version of the TOMS-1 instrument in the visible range of the electromagnetic spectrum.

Data for the studied minerals obtained under laboratory conditions with TIRES (fig. 3) exhibit coincidence with similar data from other sources (Christensen et al., 2000; Hamilton, 1999). These promising results guarantee that the data from TIRES are reliable and could be used in mineral composition investigation.

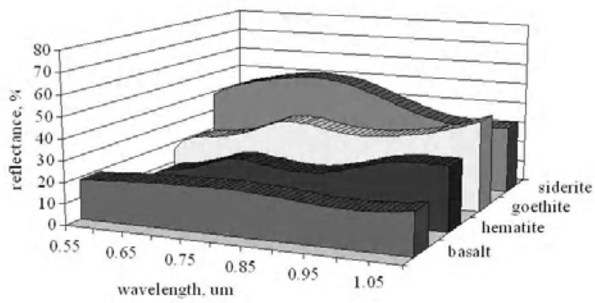

Fig. 1. Reflectance spectra of iron-containing ore minerals and basalt measured with TOMS-1

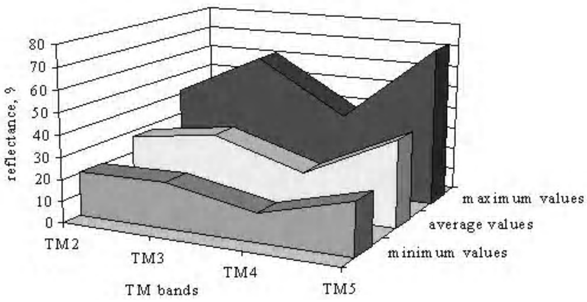

Fig. 2. TM mixed reflectance spectra of the study area

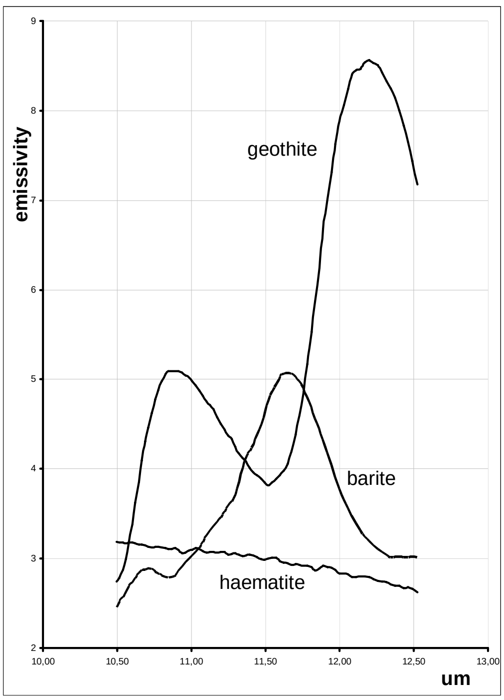

Fig. 3. Emissive spectra measured with TIRES

Conclusions

In this paper a practical approach to establish correspondence between laboratory, field and airborne measurements for ore minerals has been discussed. The conclusion of this study 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 above results prove that methodology for spectral decomposition technique is capable of estimating the end-member fractions quite accurately. The main advantage of the presented technique is that mixed pixels are used during the training phase. Compared to these other techniques, the present one is simple, cheap and objective.

Future work

Further regression and cluster analysis, based on the results from unmixing, for distinguishing between end members "*dump*" and "*open mine*" is planned. As future work we consider more in-depth development of the unmixing models including more minerals, rock types and soils and of the relations between their chemical composition and spectral features.

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Комбинирано използване на дистанционни данни в различни диапазони за определяне на разпространението на желязо в минни райони

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Резюме. Коректното определяне на разпространението на желязото в различни форми в открити минни райони и прилежащи територии е съществена задача при оценката на състоянието на околната среда. Този проблем е от особена значимост за района на Кремиковци, тъй като е разположен в близост до много населени места. За настоящето изследване бяха използвани съвместно многоспектрални данни (Landsat ETM+, включително и термалния канал), данни от полеви и лабораторни експерименти с цел определяне на състоянието на околната среда в района на затворени минни разработки. Методът на спектралната декомпозиция бе подбран с цел класифициране на земното покритие. По време на полевата кампания в изследвания район бяха събрани образци от минерали, скали и почви с цел статистическа коректност на данните. Лабораторните изследвания на тези образци бяха два типа: 1) традиционен химичен и минералогичен анализ и 2) спектрометриране във видимия и близкия инфрачервен (TOMS, 0.45-0.9 μm) и топлинния (TIRES, 8-14 μm) диапазони с различни спектрометрични системи. Всички лабораторни и полеви данни бяха използвани за създаване на модел за определяне на съдържанието на желязото в изследваните образци. След това бе разработен модел за потвърждаване на данните от Landsat ETM+, като данните бяха подбрани от представителни пиксели за изследваната територия, където растителността е под 40%. Получените резултати показват добра корелация между моделираните и реалните многоспектрални данни. За термалните данни бе тестван практически метод за конвертиране на данните от излъчването към температура.