Soil monitoring using spectral data

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Abstract
Remote sensing is an established technique in environmental studies. The development of environmental applications of optical remote sensing has been largely based on intensive studies of rocks, soils and vegetation spectral properties. Soils are a major component of the Earth surface observed by remote sensing. Soil monitoring in risk areas such as open pit mines, landslides, etc. is associated with rock appearance detection. The actual usefulness of the remote sensing information depends on its accuracy and reliability. Soil spectral properties in the optical domain are associated with soil minerals and organic compounds, water content, and soil particle size. The aim of this paper is to study soils, embedding rocks and their mixtures in relation to color features for soil condition assessment. In the paper we report some results of the colorimetrical analysis of reflectance multispectral data obtained in laboratory, in-situ and airborne measurements. Experimental data was used to model reflectance and color characteristics of soils and relevant soil-rock mixtures. This is of a particular interest in remote sensing as far as the proportion determination of mixtures' components is concerned being an important issue in data interpretation.

Мониторинг на почвената покривка по спектрални данни

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Ключови думи: дистанционни изследвания, околна среда, спектрални данни, спектрално моделиране

Резюме
Дистанционните изследвания имат широко приложение в изучаването на околната среда. Развитието на дистанционните наблюдения в оптичния диапазон за екологичен мониторинг до голяма степен се основава на интензивни изследвания на спектралните свойства на скали, почви и растителност. Почвите са основен компонент на повърхността на Земята, който се проследява чрез дистанционни изследвания. Мониторингът на почви в рискови райони, например открити рудници, свлачища и други, е свързан с разкриването на скалната основа в тези райони. Реалната полза от информацията от дистанционните наблюдения зависи от нейната точност и надеждност. В оптичната област спектралните свойства на почвите са свързани с минералите и органичните съединения в почвата, водното съдържание и размера на частиците на почвата. Целта на тази работа е да изследва почвите, почвообразуващите скали и техните смеси във връзка с цветовите им характеристики, за да се направи оценка на състоянието на почвената покривка. В настоящата работа представяме някои резултати от колориметричния анализ на спектралните данни от лабораторни, теренни и спътникови наблюдения. Експерименталните данни са използвани за моделиране на спектралните и цветовите характеристики на почвите и съответните скално-почвени смеси. Това е важно при дистанциониите изследвания, защото определянето на пропорциите на компонентите в спектралните смеси е важен въпрос в интерпретацията на спектралните данни.

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. 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 dumps are one of the largest risk areas in the environment in this region. That is the reason to start monitoring and rehabilitation activities for the region as a whole ecosystem. Compared all the data taken 20 years ago the spatial precision of the data improved more then twice which result in better decision support. This is the motivation of the team – to develop better understanding of the reclamation process and its monitoring.

Risk areas monitoring by remote sensing is closely connected to vegetation, soil and rock amount estimation. The actual usefulness of the applied methods depends on their accuracy and reliability. A basic problem in data processing and interpretation is spectral mixture decomposition and land cover classification. The objective of this paper is to study the granite, corresponding soils and their mixture in relation to color features. Laboratory and in-situ measurements of the spectral reflectance the granite and soil samples were performed in the visible and near infrared ranges of the electromagnetic spectrum by means of precise multi-channel spectrometers with channel width less than 1 nm. Experimental data was used to model reflectance and color characteristics of mixtures of the granite samples and their respective soils.

In this research data from air-borne instruments 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.

Materials and methods

Ground-based in-situ and laboratory reflectance measurements of the granites and relevant soils (brown and red) were performed in the (400-800 nm) range of the electromagnetic spectrum using precise multi-channel spectrometers with channel width less than 1 nm (Petkov et al., 2005; Iliev, 2000). In laboratory the illumination source was a halogen lamp with power P=2000 W. Barium sulphate was used as a reference standard in both cases.

The mean spectral reflectance curves of granite, brown and red soils are presented in Figure 1a illustrating the large range of soil reflectance signatures.

In the LSMA the mixed pixels (particularly those at the border areas) in the image are expressed as linear combinations of the respective spectra of basic land cover types presented in the image. In this case the measured spectral reflectance r, for every image pixel in any band, can be modeled as follows:

$$r_{\Sigma}(\lambda_i) = p_1 r_1(\lambda_i) + p_2 r_2(\lambda_i) + \dots + p_m r_m(\lambda_i) + \varepsilon = \sum_{j=1}^{m} p_j r_j(\lambda_i) + \varepsilon \qquad (1)$$

where p is the components’ relative amounts (fraction cover), r for the pure component reflectance, λ is wavelength and ε is an error term.

Applying the equation (1) we aim:

- ✓ To calculate pure end-member reflectance and given the end-member fractions;
- ✓ To derive end-member fractions and given the pure components reflectance.

The variety of soil and rock fraction cover was modeled from bare soil reflectance (r_s) and rock reflectance (r_r) using the reflectance additive theory (Mishev, 1991). The spectral reflectance curves of modeled soil-rock mixtures (r_{sr}) are shown in Figure 1b where the impact of the soil type: red (dashed line) and brown soil (solid line) is demonstrated.

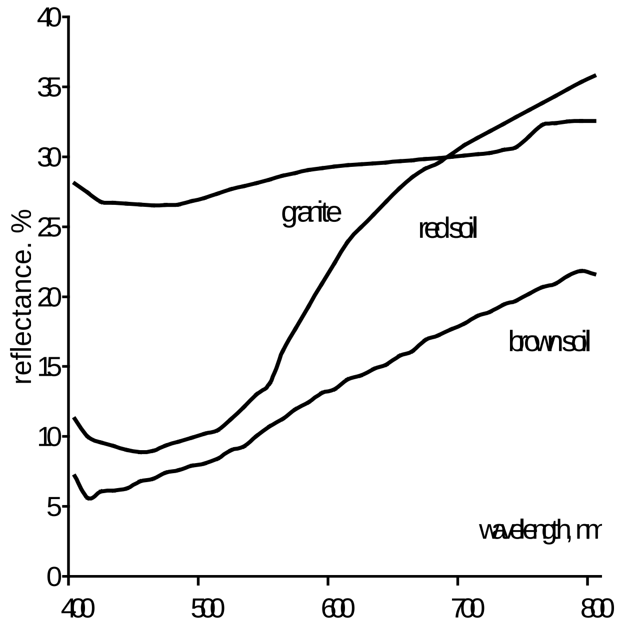

Figure 1a. Reflectance spectra of granite, brown and red soils

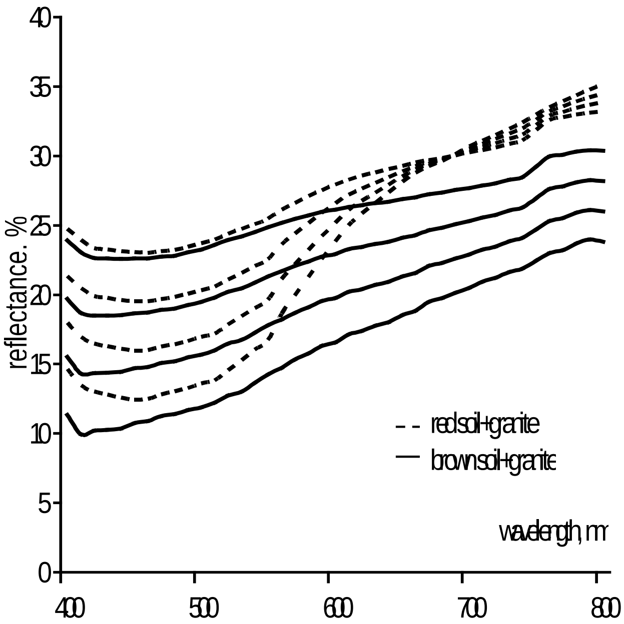

Figure 1b. Reflectance spectra of rock-soil mixtures with different fraction cover (0.2, 0.4, 0.6, 0.8) of granite

From each spectral reflectance signature the colorimetric characteristics (tristimulus values X, Y, Z chromaticity coefficients x, y, z and dominant wavelength λ_d) of the investigated objects and modeled mixtures were computed in the spectral range 450-750 nm according to the CIE 1964 methods and D_{65} light source (Agoston, 1979; Карманов, 1974).
In the case of soil and rock considering $\sum_i p_i = 1$ the mixed reflectance is:

$$r_{sr} = p_s r_s + (1 - p_s) r_r \tag{2}$$

$$r_{sr} = p_s (r_s - r_r) + r_r \tag{3}$$

In correspondence with the additive theory (the same being true for Y, Z and $W = X + Y + Z$) (Mishev, 1992; Kancheva and Borisova, 2003):

$$X_{sr} = \sum_{\lambda} D_{65}[p_s(r_s - r_r) + r_r]\bar{x}\Delta\lambda \tag{4}$$

$$X_{sr} = p_s(X_s - X_r) + X_r \tag{5}$$

$$x_{sr} = \frac{p_s(X_s - X_r) + X_r}{p_s(W_s - W_r) + W_r} \tag{6}$$

As seen from (6), the chromaticity coefficients defining the position of soil-rock mixtures on the color diagram depend on the relative amounts of the pure classes.

Results and discussion

There are only three important groups of colors for natural objects (Mishev, 1986). Rocks, soils and dry vegetation are within the region of yellow to red-orange (575-590 nm). The color coordinates (x, y) of the granite samples, brown and red soils fall into this region. In Figure 2 the wider band of bare soils location is distinguished. The wider λ_d range of the soil cluster within the color locus and the narrower one of light-colored granites suppose bigger errors in assessment of rock fraction cover if the soil type are not taken into account.

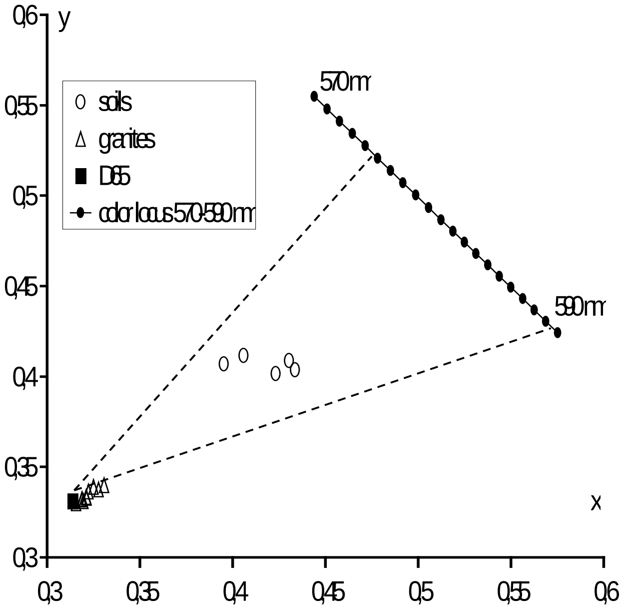

Figure 2. Dominant wavelengths λ_d of the brown and red soils and the granites

In Figure 3 the position on the color locus of two-component mixtures of granite, red and brown soils are presented. The position of chromaticity coefficients of modeled mixtures is on the line connecting pure granites and relevant soils.

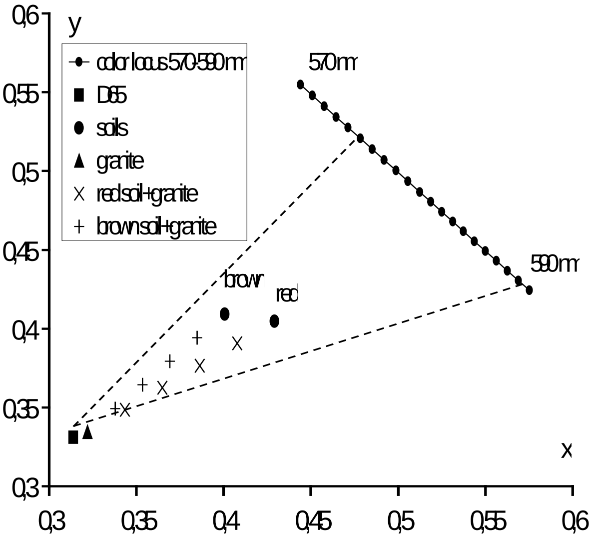

Figure 3. Dominant wavelengths of 2-component mixtures

Region of interest (RoI) in the study area Assarel-Medet is selected based on TM dataset. Forming the representative data sets (we selected at least 200 pixels per class) was made by visually interpreting the multispectral images and modern topographic map of the region. The statistics of those data sets are summarized in the Tables 1.

Table 1. 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	23,811	30,593	47,808	25,662	47,692	35,124
	Confidential interval	1,310	1,683	2,630	1,412	2,624	1,932
"Medet"	Average	162	159	183	92	160	118
	Dispersion	23,688	32,850	34,919	15,404	34,270	25,486
	Confidential interval	0,9711	1,3466	1,4314	0,6314	1,4048	1,0447
"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

In Figure 3 the change of the dump part of Medet deposit in [ha] for the period 1972-2011 is presented. The increasing dump area is caused by the growing extraction of the ore. In 2011 the space of the dump significantly decreases almost twice. We consider the reason of this change is the applied reclamation processes declared by the "Asarel-Medet" owners.

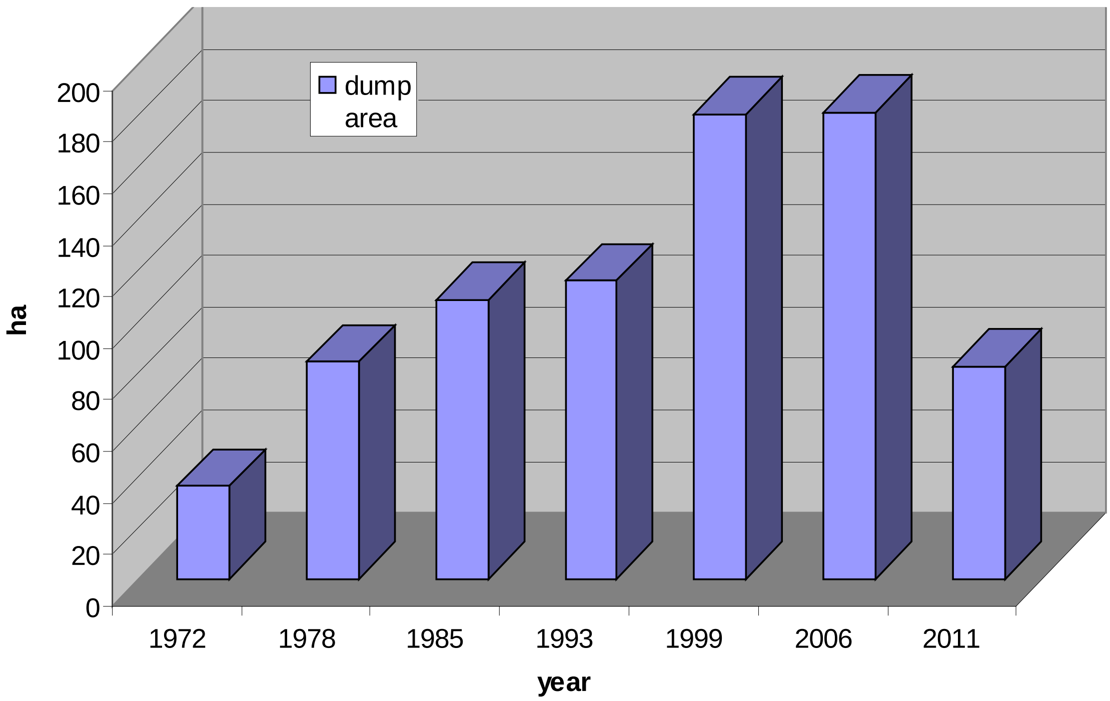

Figure 3. The dump area of Medet deposit in [ha] - 1972-2011.

Conclusions

The advantage in using color features is that the visible spectral range is closely related to physical and biophysical parameters of the objects and that the whole reflectance curve is used normalized on the spectral distribution of the incident radiation. Besides, λ_d allows the comparison of slightly differing color stimuli. As a whole the obtained results are an encouraging confirmation of the potential of mixture analysis for risk areas monitoring. A consistent and reliable methodology for estimation of the area of the regions of open pit mines and dumps using remotely sensed data with relatively moderate spatial resolution is successfully combined with the in- and ex-situ data. Future work is intended in precising the dependences of λ_d on rock and soil fraction cover by larger experimental data sets as well as their verifying and effective accuracy testing using low-height airborne spectral data.

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