Teledetección aplicada a la gestión de recursos naturales y medio litoral marino. VII Congreso Nacional de Teledetección.
Universidad de Santiago de Compostela - Asociación Española de Teledetección.
Santiago de Compostela, 26-28 de junio de 1997. pp. 85-88.
Editores: Carlos Hernández Sande y Juan E. Arias Rodríguez.

MAPPING THE DISTRIBUTION OF EVAPORITIC SOILS IN LOS MONEGROS USING SPECTRAL UNMIXING METHODS

Magaly Koch and Lluís Solé-Sugrañes

Instituto de Ciencias de la Tierra (Jaume Almera)
Consejo Superior de Investigaciones Científicas (CSIC)
Lluís Solé i Sabarís s/n, 08028 Barcelona, Spain

RESUMEN: La zona semiárida de los Monegros (Aragón) ha sido estudiada a partir de una técnica de clasificación difusa basada en un modelo de mezcla lineal de miembros puros para cada pixel. Algunos de los principales problemas de esta región es la salinidad y degradación del suelo producida tanto por la presencia de niveles con yeso muy abundante y por nuevas técnicas de laboreo intensivo y regadío, que ponen en explotación tierras poco aptas para la agricultura, rompiendo el frágil equilibrio ambiental. Los primeros resultados del análisis de imágenes TM han demostrado que las técnicas de clasificación difusa a partir de modelos de mezcla lineal son válidos siempre que se comparen miembros con una variabilidad semejante.

ABSTRACT: This paper presents a methodology based on spectral unmixing techniques to produce information on the spatial distribution of the different soil types in the semi-arid region of Los Monegros (Aragón) that is being increasingly used for agricultural purposes. Soil erosion and soil salinity are two of the problems encountered in this area due to plowing and to the use of irrigation systems in a gypsum rich environment. Preliminary results show that it is possible to differentiate and map the main soil types using a mask derived from a vegetation index. Knowledge of the distribution and abundance of gypsum-rich soils may be used as a land degradation indicator.

INTRODUCTION

The region of Los Monegros (NE Spain) is characterized by its semi-arid climate, sparse vegetation and shallow as well as poorly-developed soils. It lies within the central part of the Ebro basin, which is triangular in shape and is bounded to the north by the Pyrenees, to the southwest by the Iberian Mountain Chain, and to the southeast by the Catalonian Coastal Mountain Range.

Part of Los Monegros is being used for agriculture that is sustained by an extensive network of irrigation channels bringing water from the Ebro river and its tributaries to the fields. Current agricultural policies are triggering substantial land use changes in an area characterized by a very fragile ecosystem with infertile soils developed in a gypsum rich karstic environment. New arable lands are being located in areas that are not naturally suitable for agriculture. These changes in land use may have a negative influence on soil properties and may thus contribute to a change in erosion patterns and soil salinization patterns. Therefore, considerable importance must be given to the impact of current and future agricultural policies on the functioning of natural ecosystems, since the effects on the natural ecosystems in semi-arid environments with easily-eroded soils may be very significant.

This paper presents a methodology based on analysis of remotely-sensed images to map and characterize soils in a karstic environment which is undergoing important land use changes. Two aims are set: 1) to develop a methodology that is capable of estimating the spatial variation in the bare soil component of the image, and 2) to characterize the soil composition in terms of mineralogical properties with an emphasis on calcium, gypsum and clay content. The distinction between bare soil and vegetated areas (crops or forested areas) is important in determining the degree of soil protection. Erosion by water as well as wind is generally more effective on bare soil areas with a poorly-developed or immature soil profile and located on steep slopes than on vegetated soils. Finer particles which contain fertile organic matter may be washed out or carried away by the wind leaving a nutrient-depleted soil. Irrigation water may dissolve underlying evaporitic rocks causing soil and water salnization problems.

At present, farmers are encouraged to plow semi-natural areas irrespective of their profitability through government subsidy. The effects of plowing, combined with the subsequent land use changes, may trigger or accelerate land degradation processes in Los

Monegros. Remote sensing technology can be used to detect and monitor these changes over time and space. Maps showing the distribution and abundance of evaporitic soils as well as the spatial relationship between vegetation and bare soil can be used as land degradation indicators.

SPECTRAL UNMIXING METHODOLOGY

There are several remote sensing methods that can be used to map and characterize surface materials. The most common procedures are based on the application of various classifiers such as maximum likelihood and neural network algorithms. These methods give good results if the mapped surface features are large and homogeneous relative to the pixel area so that each pixel is unambiguously allocated to one of a pre-defined number of classes. This approach is referred to as "hard" classification. Although most pixels can be assigned to a specific class there is often a problem with mixed pixels that contain two or more land cover types.

The "fuzzy" classification approach does not make the assumption that each pixel belongs to a unique class. Rather, it is assumed that a pixel has a probability of membership of several classes, and the output from a "fuzzy" classifier is a set of maps each showing the probability of membership of a specific class. This approach is justified when important features are present at a sub-pixel scale and mixed with other features of contrasting nature. Thus two or more materials with very different spectral signatures and covering an area of less than a pixel unit will give a mixed spectral response. This would be the case for sparsely vegetated areas where each single pixel is likely to be made up of differing proportions of soil, vegetation, bare rock and other land cover types.

A conventional image classification of an area with mixed pixels may give inaccurate results because the less abundant surface material will appear subdued and the predominant material will appear to be over-emphasized. While "fuzzy" classification procedures can be used in an attempt to depict the proportions of each pixel that are represented by the different cover types, linear spectral unmixing is a methodology that aims directly at the mapping of the spatial distribution of the proportions or fractions of relatively "pure" surface components [1]. These components, or endmembers, are pure or unmixed pixels. The combination of these endmembers in various proportions reproduces all other pixels in the image. There are two assumptions underlining this methodology. The first one is that materials mix linearly, which means there is no spectral interaction (scattering) between materials. The second assumption is that materials have sufficient spectral contrast in order to be identified as separate surface materials [2].

Spectral unmixing was used in this study to investigate sub-pixel properties in order to identify and map the main soil types of the lagoon area south of Bujaraloz. For this purpose a section of a Landsat TM image of 1000 by 640 pixels was selected which delineates the study area (Figure 1). The selected image area is characterized in geologic and geomorphic terms as follows: the central and main part of the image area is a plateau area made up of gypsum and marly limestone with interbedded red silts, which contains many dolines, some of which are filled with water (saline lagoons). This area is bounded to the northwest by a gentle escarpment with some semi-natural forest vegetation and to the south and southeast by the Ebro river escarpment, which is more densely forested.

The first and most difficult step is the selection of appropriate endmembers. Endmembers should have the most extreme spectral signatures within the image. A principal component analysis (PCA) was performed to determine the maximum variance of the image data so that extreme (decorrelated) pixel spectra can be extracted. This was done by displaying pairs of principal components (PCs) in 2-D scatter plots, and examining the data distribution. ENVI image processing software allows an interactive examination of the data by clicking within the data cloud so that the corresponding pixels are highlighted in the image. This way any pixel of the PC scatter plot can be visually analyzed within the image context. Next, the most decorrelated PCs are chosen for delimiting the extreme corners of the data cloud. The respective spectra of these areas are read, and used as input data for the spectral unmixing program.

DISCUSSION AND RESULTS

Four endmembers were identified using PCA as described above. These endmembers are labeled as shallow water, bare soil, green vegetation, and forest. Their mean spectra are shown in Figure 2. It is obvious that their spectral curves are quite different which means that they represent contrasting materials and therefore fulfill one of the requirements for applying the spectral unmixing method. However, it was found that the soil component shows little spectral variation, and only one type of soil could be identified on the PC scatter plots. It is possible to identify at most six endmembers using the six TM reflective bands, as the number of endmembers cannot exceed the number of spectral bands.

After performing the spectral unmixing on the six TM image bands, four fraction images were obtained that proved to be unsatisfactory in mapping the distribution and quantity of the four pre-selected surface types (water, soil, vegetation, forest). A fifth image shows the RMS error, which is expressed as the difference between the calculated pixel values (the sum of each fraction image value for each pixel) and the measured pixel value (by the sensor). This image indicates a poor result of the unmixing method, which could be attributed to the insufficient number of endmembers or to inappropriate selection of reference areas for endmember collection [3].

Consequently, a second approach was investigated for the collection of endmembers, that would specifically allow a better discrimination of soil types. A ratio image using TM bands 5 and 4 was used to separate green vegetation from the other surface cover types. By means of thresholding the range of ratio pixels corresponding to vigorous vegetation a mask was constructed, which was subsequently applied to the PCA. In this way surface material variability is reduced by excluding crops with high near-infrared response in order to study the spectral variance between soil types in more detail.

Figure 3 shows the mean spectra of 4 endmembers as extracted from a 2-D scatter plot of PC 1 and 3. It was found that endmembers are better extracted from one set of PC pairs because the occurrence of overlapping endmembers is avoided. All four spectral curves indicate the presents of different soil types. A common feature of all four endmembers is that their curves show a peak at 1.65 µm (diagnostic peak of soils) and no steep slope between 0.66 and 0.83 µm which is characteristic for vegetation spectra.

Spectral unmixing was performed using these new endmembers and applying the mask built from the TM 5/4 ratio image (see above). The resulting fraction images and RMS error image show a substantial improvement with respect to the first method. The RMS error range was lowered from 0.004-37.269 (first trial) to 0-11.296 (second trial).

After examining the histogram of each unmixed or fraction image a threshold function was used to select values corresponding to the purest pixels. These fractions were highlighted in different colors and overlaid on the original band 7 image. The overlay shows clearly a distribution pattern of the different soil types. Soil type 1 shows a spatial concentration around the upper left corner of the image area. The spectral curve indicates overall low values with a drop between 1.65 µm and 2.22 µm. This class is surrounded by soil type 2 (overall high spectral values and pronounced drop between 1.65 µm and 2.22 µm). Both soil types do not appear to be spatially associated. Moreover, they indicate well-discriminated soil units, which are associated with different geomorphic/geologic units. The second group, soil type 3 and 4, are spatially related since they appear next to each other clustered along the central lagoon area of the image. Although both soil types have very different spectral curves (especially in the range of 1.65 µm and 2.22 µm) they are found in close proximity to each other.

CONCLUSIONS

Although the outlined methodology does not allow an absolute identification of the mineralogical content of each soil type, some reasonable conclusions can be drawn based on their spectral curves, corroborated by field work. Soil type 1 represents a gypsum-rich clayey soil with layers of pure gypsum. These layers are more resistant to erosion and thus form the escarpment visible in the upper left corner of the image. Underlying this unit is a more calcium rich unit, soil type 2, which appears on a pediment area below the escarpment. Soil type 3 and 4 are located within the lagoon area and are difficult to discriminate. They appear to be mixtures of clayey soils with gypsum and calcite. Further detailed investigation will reveal their nature and depositional history. In addition, fraction maps generated from a time series of TM images will show how the distribution of the four identified soil types may vary spatially as well as temporally. Trends showing an increase or decrease in the proportion of specific soil types (for instant gypsum-rich soils) may lead to an indication of the severity of land degradation processes as a result of the conversion of semi-natural vegetation into arable land.

REFERENCES

[1] F. VAN DER MEER 1995. Spectral unmixing of Landsat Thematic Mapper data. Int. J. Rem. Sens., v. 16, n. 16, pp. 3189-3194.

[2] K. WHITE, N. DRAKE 1993. Mapping the distribution and abundance of gypsum in South-Central Tunisia from Landsat Thematic Mapper data. Zeitsch. Geomorph. N.F., vol. 37, no. 3, pp. 309-325.

[3] J.B. ADAMS, M.O. SMITH, A.R. GILLESPIE 1989. Simple Models for complex natural surfaces: a strategy for the hyperspectral era of remote sensing. Proceedings of the IGARSS'89 Symposium, Vancouver, vol. 1, pp. 16-21.

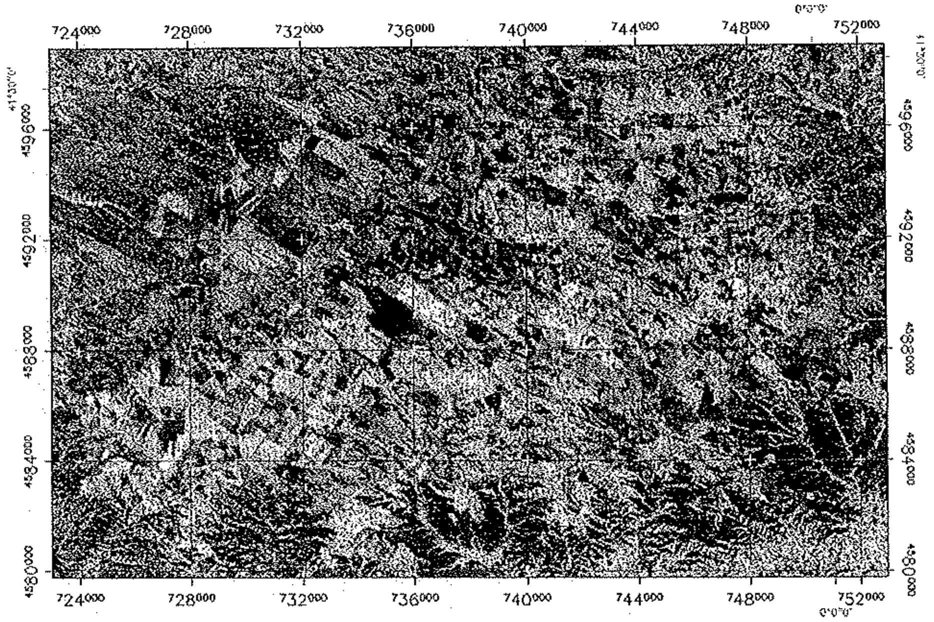

FIG. 1) TM band 7 showing the study area in Los Monegros.

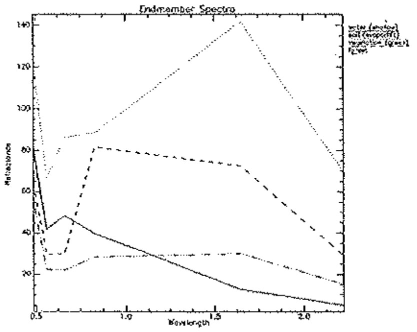

FIG. 2) Plot of spectral endmembers: water (solid line), soil (dots), vegetation (dashes), and forest (dash-dots).

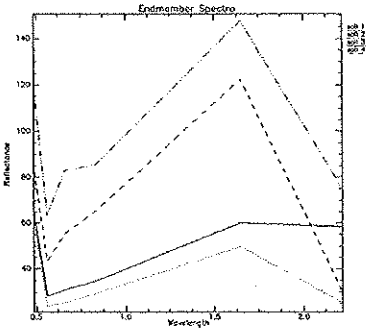

FIG. 3) Plot of spectral endmembers: soil 1 (dots), soil 2 (dash-dots), soil 3 (solid line), and soil 4 (dashes).