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Analysis and classification of hyperspectral data for mapping land degradation: An application in southern Spain

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Abstract

Desertification is a severe stage of land degradation, manifested by “desert-like” conditions in dryland areas. Climatic conditions together with geomorphologic processes help to mould desert-like soil surface features in arid zones. The identification of these soil features serves as a useful input for understanding the desertification process and land degradation as a whole. In the present study, imaging spectrometer data were used to detect and map desert-like surface features. Absorption feature parameters in the spectral region between 0.4 and 2.5 μm wavelengths were analysed and correlated with soil properties, such as soil colour, soil salinity, gypsum content, etc. Soil groupings were made based on their similarities and their spectral reflectance curves were studied. Distinct differences in the reflectance curves throughout the spectrum were exhibited between groups. Although the samples belonging to the same group shared common properties, the curves still showed differences within the same group.

Characteristic reflectance curves of soil surface features were derived from spectral measurements both in the field and in the laboratory, and mean reflectance values derived from image pixels representing known features. Linear unmixing and spectral angle matching techniques were applied to assess their suitability in mapping surface features for land degradation studies. The study showed that linear unmixing provided more realistic results for mapping “desert-like” surface features than the spectral angle matching technique.

Keywords: Linear unmixing; Spectral angle mapper; End members; Absorption features; Desert-like surface features

1. Introduction

Although broadband data from sensors, such as SPOT HRV, Landsat MSS and Landsat TM have been used for mapping soil, they do not provide sufficient information to characterise soil differences, because their 100–200 nm bandwidth cannot resolve diagnostic spectral features of terrestrial materials (De Jong, 1994). The development of scanner systems that acquire data in many narrow-wavelength bands allow the use of almost continuous reflectance data in studies

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of the Earth's surface. This not only produces laboratory-like reflectance spectra with absorption bands specific to the object's properties, but also helps to increase the accuracy of mapping as reported by various researchers (Pieters and Mustard, 1988; Kruse, 1989; Clark et al., 1990). Broadband data are well suited to asking the question "what is there?" but hyperspectral data are well suited to asking the second question: "what proportion is there?" Techniques developed for analysing broadband spectral data are, however, incapable of taking advantage of the full range of information present in hyperspectral imagery (Cloutis, 1996). Hyperspectral image classification requires new approaches, such as spectral matching techniques. With so much data available, the well-known problem of mixed pixels can be also solved using a mixture model, assumed to occur in a linear fashion (Singer and McCord, 1979).

Factors affecting soil reflectance and soil specific absorption features have been described by De Jong and Epema (2001); Van der Meer (2001); Mulders (1985); Baumgardner et al. (1985); Hunt (1980). Spectral reflectance characteristics of soils are the combined result of their physical and chemical properties: texture, structure, mineral composition, iron content, type of clay minerals, organic matter and soil moisture. In addition, topography, sun elevation and varying soil surface conditions influence surface reflectance (De Jong and Epema, 2001; Shrestha and Zinck, 2001). With so many factors playing a role and each individual soil property having its influence on soil reflectance, a particular reflectance curve cannot be representative for a given soil type. Moreover, a soil consists not only of surface materials but also of specific horizons that have been altered by the interaction of climate, relief, and living organisms over time. A taxonomic soil type incorporates its horizons and the corresponding properties. Thus, selecting pure spectra using spectral library of pure minerals is not representative of typical soil types. Although Shepherd and Walsh (2002) have developed spectral libraries for characterization of soil properties, their use in mapping soil distribution cannot be so straightforward. Characterisation of surface features, which indicates certain soil processes, i.e. soil salinity development, erosion, etc., would be more useful for mapping their extent. In arid and semi-arid regions, the climatic conditions together with geomorphologic processes help in moulding the so-called desert-like soil surface features. Desertification is a severe stage of land degradation, manifested by desert-like conditions in dry-land areas outside the desert boundaries (Rapp, 1986). The transportation by either wind or water of surface loose materials leaves behind desert pavement, which is a continuous layer of gravel and small stones on the soil surface. Similarly, due to high evaporation rates and lack of leaching and percolating to deeper horizons many low-lying areas may be saline and/or alkaline. In the same way, calcium carbonate and gypsum may often be present in abundance, forming hard pans and contributing to the formation of surface crusts. The identification of these soil surface features serves as a useful input for assessing desertification and land degradation as a whole. In the present study, imaging spectrometer data has been used to detect and map desert-like surface features. Overall objectives of the study are as follows: (i) analysis of the measured reflectance spectra in order to see if absorption features related to desert-like soil surface features exist in specific wave bands, (ii) grouping of soils based on their chemical and physical properties measured in the laboratory and checking their similarities in spectral measurements and finally, (iii) assessing performance of two classification techniques, namely spectral angle mapper and linear unmixing in mapping land degradation.

2. Methods and techniques

2.1. Study area

The study area is located in the surroundings of Tabernas in the Province of Almeria in Spain (Fig. 1). The exact site corresponds with the coverage of the HYMAP airborne hyperspectral image, with its flight line starting at 37°02′32″N and 2°30′14″W and ending at 37°04′25″N and 2°16′40″W. The Tabernas basin is a structural depression in the Alpine nappes of the Betic Cordilleras of Southern Spain, which is bounded by major strike-slip fault (Kleverlaan, 1989). The terrain is relatively rugged and sparsely vegetated. The mountain ridges on the northern and southern sides of the basin are acting as main barriers for precipitation, resulting in pronounced dry conditions causing desertification. The climate can be characterised as