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USE OF IMAGING SPECTROSCOPY TO ASSESS THE IMPACT OF LAND USE CHANGES IN A SEMI-ARID KARSTIC LANDSCAPE: LOS MONEGROS, SPAIN

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ABSTRACT

Significant land use changes, mainly in the form of changing agricultural practices, are transforming a semi-arid karstic environment in NE Spain that encloses numerous saline lakes (playa lakes), forming a unique habitat. The introduction of irrigation systems in an area characterized by a semi-arid climate, closed basin hydrology, and karstic geology of evaporitic sediments, is changing the water balance and soil properties of the playa lakes and surrounding areas. As a result changes in the distribution and magnitude of salt affected soils have been observed through the analysis of a time series of satellite data. In this work, we offer a refinement of the methodology used to detect and monitor changes in soil composition and status by utilizing hyperspectral and multispectral data. Soil endmembers from a spectral library obtained in a similar semi-arid environment were applied to the study site by means of the Spectral Angle Mapper classifier. The spatial distributions of three soil groups were obtained and related to land use changes affecting the playa lakes and their environments. The soil groups showed different contents of soluble salts and their mineralogy is closely correlated to the underlying geological units. This exercise illustrates the transferability of spectral information across time, space and sensor type. Future work will include the creation of a site specific spectral library from two sets of hyperspectral HyMap images taken during the wet and dry season, so that short term seasonal changes can be differentiated from long term progressive changes in the soil and water interface of the playa lakes and surrounding areas.

INTRODUCTION

The Los Monegros area of NE Spain is a semi-arid region that is experiencing significant land use change due to the implementation of an extensive irrigation system that is converting semi-natural vegetated areas into arable land (i,ii). This region is characterized by its semi-arid climate, sparse vegetation and shallow as well as poorly developed soils. The study area lies within the central part of the Ebro basin and its landscape is typical of a karstic environment. Current agricultural policy encourages farmers to plow semi-natural areas irrespectively of their profitability. The effect of plowing, combined with the subsequent land use changes, may trigger or accelerate land degradation processes, such as water and/or wind erosion, soil alkalinization or salinization, and vegetation loss (i, ii).

Numerous small playa lakes are found within a plateau area in the study site *(Figure 1)*. These lakes form in small karstic depressions by the dissolution of evaporitic subsurface layers, mainly gypsum and limestone. These dolines or sinkholes, which are the result of collapsing surface sediments, are subsequently filled with water from shallow aquifers (iii). The lakes are saline due to the effect of surface water evaporation leading to the precipitation of salts at the land surface, and they form a very particular and fragile environment with a unique habitat adapted to this ecosystem. The playa lakes are usually dry in the summer and fill with water during the rainy season when the water table rises (i).

A time series of Landsat 5 TM images of the Los Monegros area covering a time period of 13 years (1984, 1991 and 1997) was used by (ii) for detecting and mapping land use/cover changes and their effect on soil salinity in this karstic environment. The author (ii) was able to demonstrate that the implementation of large-scale irrigation systems in such an environment has triggered an increase in areas affected by soil salinization problems (gypsum and calcite rich soils), which are detectable on the land surface by multispectral sensors. At the same time the author suggests that these land degradation processes may be controlled by the geology in this area (lithology and structures). Studies carried out in other dryland regions have shown a close relationship between the expansion of irrigated lands and increased rates of soil and water salinization (iv, v).

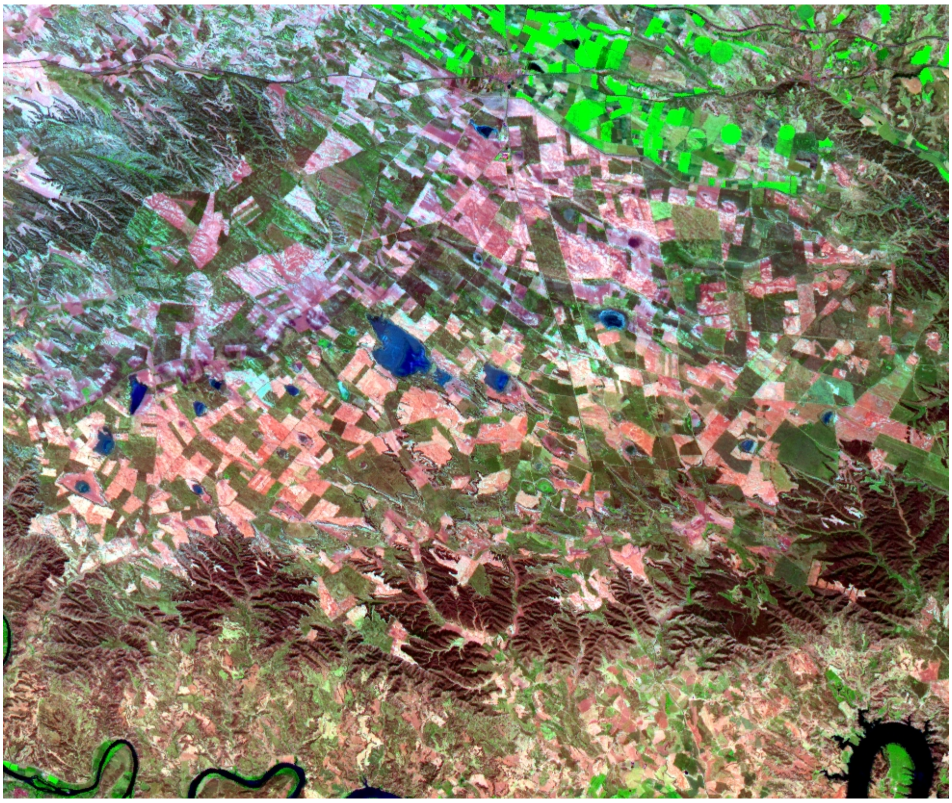

Figure 1: ASTER image (29 May 2003) of the study area in Los Monegros (bands 2, 3, 1 as RGB). The image shows a plateau area with numerous playa lakes surrounded by irrigated (bright green) and non-irrigated agricultural fields and bounded in the south by the Ebro river escarpment. The image covers an area of 15 km x 12 km.

The present work offers a refinement of the methodology implemented in an earlier work (ii), by utilizing a spectral library developed for a semi-arid wetland zone in La Mancha, Spain (vi). The spectral library is based on airborne hyperspectral data (DAIS 7915) combined with field spectral information (ASD FieldSpec Pro spectrometer) for validation, and was successfully applied to the problem of mapping salt affected soils and vegetation in a wetland area in La Mancha with similar climatic conditions to those in Los Monegros (vii). In the present work, the spectral library of the La Mancha site is used to obtain high spectral resolution information of salt affected soils in order to implement these spectral signatures to a lower resolution multispectral image (ASTER) of the Los Monegros site. The purpose is to improve the detection and classification of soils associated to playa lakes and/or sink holes so that their degradation stage can be monitored over time based on a time-series of multispectral images such as those acquired by the Terra ASTER or the Landsat TM/ETM+ sensor. A second objective of this paper is to outline a methodology for future work that will include the use of multi-temporal hyperspectral data from the airborne HyMap sensor. At this point we have completed the first stage of our workflow where multispectral data have been successfully used to discriminate and monitor salt affected soils in a semi-arid environment. We have also acquired preprocessed hyperspectral data within the framework of the HyEurope program in 2004 that was jointly organized by the German Aerospace Centre (DLR) and HYVISTA Corporation. This data acquisition is in preparation for the development of a methodology that will encompass multispectral as well as hyperspectral data for assessing the effects of changing agricultural practices (mainly in the form of large-scale irrigation schemes) on the surface conditions of playa lakes (sink holes) and their fringe area. Preliminary results of this effort are presented here.

MATERIALS AND METHODS

A multisensor and multitemporal approach is utilized in this study with the aim of characterizing changes occurring to the soils and water regime of playa lakes in a semi-arid karstic environment. *Figure 2* shows the significant impact that changing agricultural activities have had on the playa lakes area between 1984 and 1997. In this figure two Landsat TM scenes (20 August 1984 and 7 July 1997) were normalized using the histogram matching procedure in order to facilitate their visual comparison. A generalized geological map of the area confirms the close relationship between surface terrain features (agricultural fields, playa lakes, dolines or sink holes, and escarpments) and subsurface conditions (rock/sediment and soil composition).

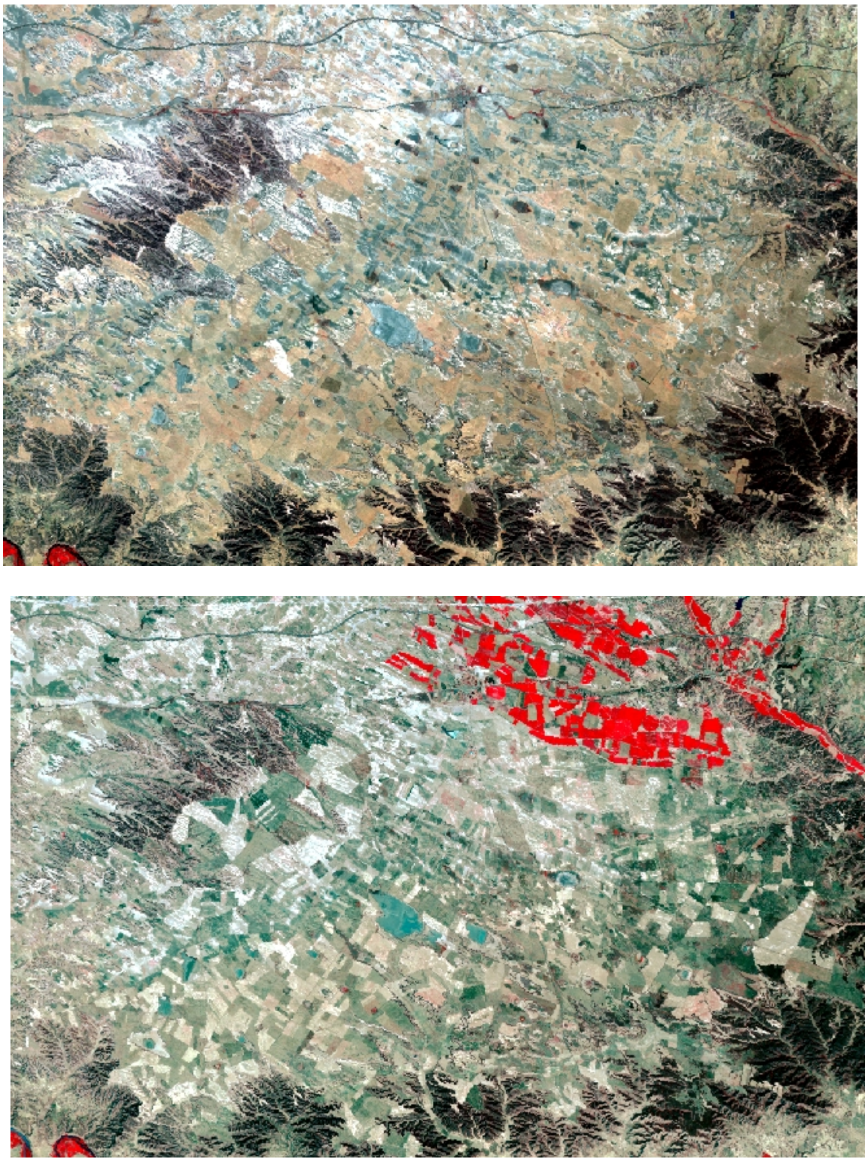

Figure 2: Landsat TM images of 20 August 1984 (top) and 7 July 1997 (bottom) illustrating the dramatic changes that occurred to the landscape after the introduction of irrigation (red area) in the region. The images cover an area of 33 km x 22 km and the band combination is 4, 5, 2 (RGB).

Also, a pair of ASTER subscenes corresponding to 29 May 2003 and 16 June 2004 which mark the end of the wet season and the beginning of the dry summer period, were acquired to match as closely as possible the season when the first of two flight campaigns of the airborne hyperspectral

HyMap sensor was conducted over the Los Monegros area in May 2004 *(Figure 3)*. The path of the HyMap flight lines were chosen so that they would cross the plateau area from N to S and NNE to SSW covering various aspects of the landscape including irrigated and non-irrigated fields, playa lakes and small karstic depressions, and the edge of the Ebro River escarpment in the south. The HyMap images were taken only three months apart on the 17 May and 12 August 2004. However, significant changes to the land surface can be observed especially concerning the status of irrigated versus non-irrigated fields. The selection of appropriate image acquisition dates is important in order to analyze and differentiate seasonal from progressive changes in a dynamic ecosystem that is being transformed by human activities. The two HyMap image pairs in *Figure 3* represent the wet as well as the dry season and are appropriate for detecting seasonal changes affecting the soil, vegetation and water bodies.

Figure 3: HyMap image pairs acquired on 17 May (left) and 12 August 2004 (right) over the playa lake area in Los Monegros. The HyMap strips are respectively 30 km and 25 km long and the band combination is 25, 16, 9 (RGB).

In summary, the image data set that is available for this study comprises a Landsat TM/ETM+ time series covering selected summer months between 1984 and 2000, a shorter time series of ASTER images covering similar dates in the summer of 2002, 2003 and 2004, and finally two HyMap image pairs taken within the same year of 2004 but in two different seasons, i.e. during the wet spring and the dry summer season.

The overall methodological approach of this study is outlined in *Figure 4*. It comprises of three phases that are grouped according to the type of data (multispectral, hyperspectral and field data) being processed and analyzed. In the first phase, multispectral data are processed for detecting changes in composition and status of salt affected soils in the playa lakes and surrounding agricultural fields. Therefore, endmembers are selected from spectral libraries obtained in similar environments and are applied to the multispectral images through the Spectral Angle Mapper (SAM) classification method. The purpose is to determine the distribution of the surface composition in areas that have not been extensively surveyed by using spectral endmembers derived from well-defined spectral libraries that are supported by ground truthing carried out in a similar environment.

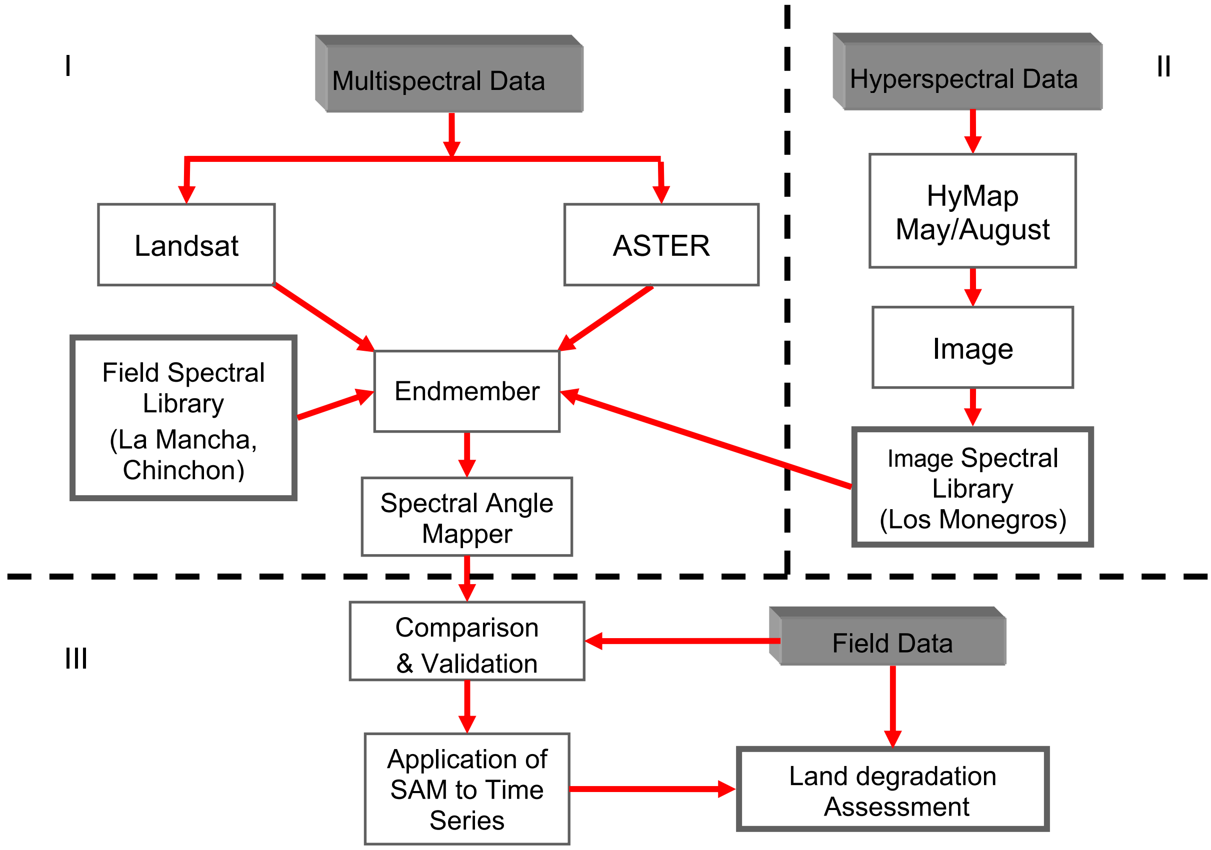

Figure 4: Flow diagram outlining the three main phases in the methodological approach used in this study.

The second phase of the adopted methodology foresees the use of hyperspectral data to obtain site-specific image endmembers and compile them in a spectral library of the study site. Selected endmembers from this image spectral library will be applied to the multispectral data using the same SAM classification procedure as in phase I. The SAM classifications based on the image endmembers and the spectral library endmembers, are then compared and validated in the field. This activity constitutes the third phase of the study. Once the SAM results are validated in the field and the suitability of endmembers in characterizing soils and their degradation status is confirmed, a change detection analysis based on the SAM procedure can be carried out on a time series of multispectral images. The ultimate goal of this methodological approach is to test whether representative endmembers of land degradation processes are transferable in time, space and across sensor types.

RESULTS

The results presented in this paper pertain to the first phase of the methodological approach outlined in *Figure 4*. The La Mancha Spectral Library containing a pool of soil endmembers was utilized to select five endmembers with various levels of salt content. The selection was based on the similarity between two types of spectra, namely the reference spectra (e.g., spectral library endmembers) and the image spectra. The similarity is measured in radians and represents the angular distance between the spectra (viii). The SAM output images (one per reference spectrum) are subsequently used to produce a final classified image using the ENVI image processing software (ix). The use of the La Mancha spectral library endmembers is justified by the similarities found between the soil compositions in the seasonal hypersaline playa lake area of La Mancha with those in Los Monegros. Similar features that can be found in both playa lake environments are the salt crust that develops in the summer months when the lakes dry up, the playa soils in the fringes of the wetland areas, and the soils with high concentrations of salt efflorescence that are mainly found in the surrounding upland areas. Their spectra are shown in *Figure 5a* where the original spectral curves that were measured by the airborne hyperspectral DAIS 7915 sensor in La Mancha have been rescaled to match the multispectral resolution of the ASTER sensor.

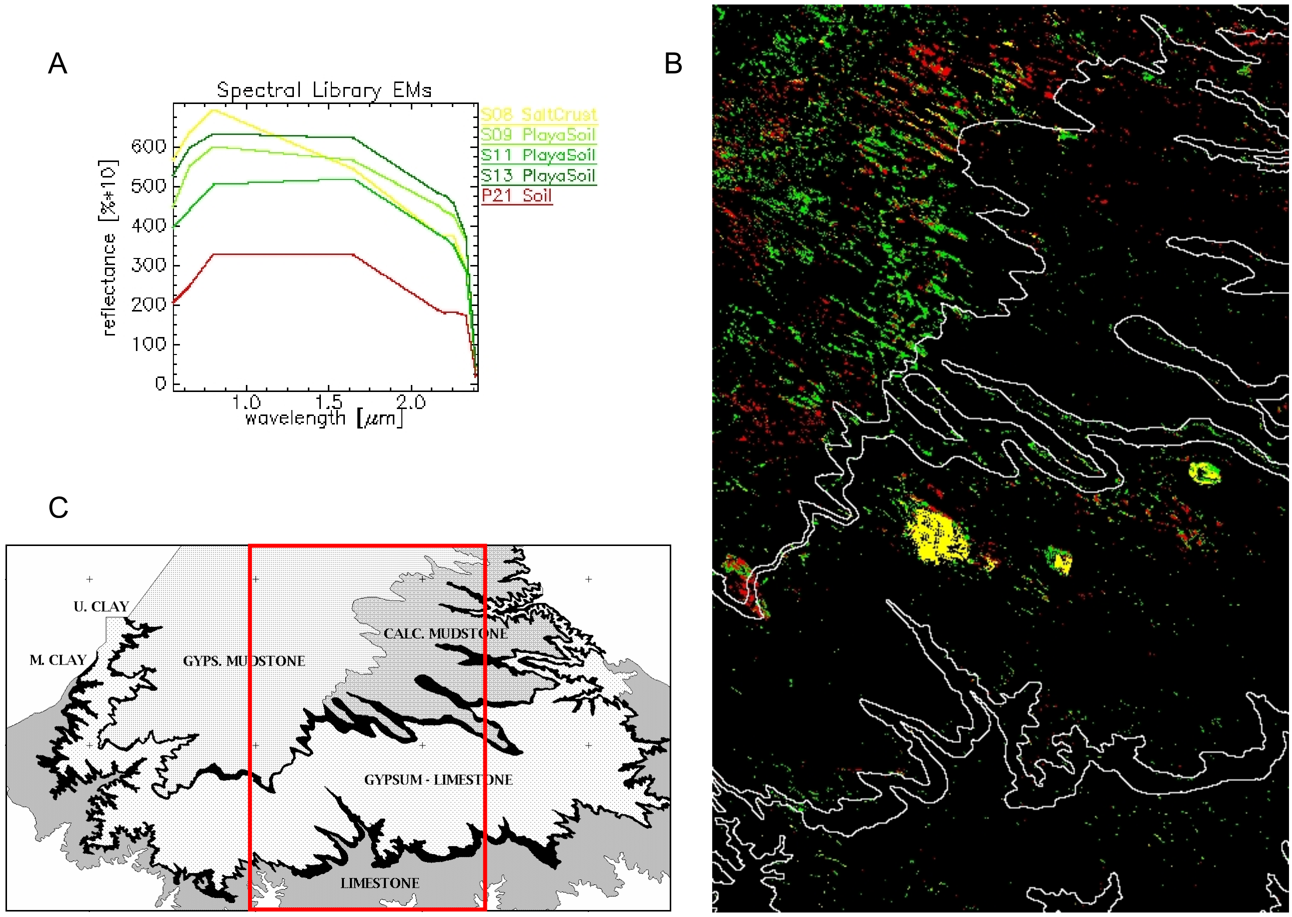

Figure 5: Soil endmembers from the La Mancha spectral library (a) that were used as reference vectors in the SAM classification (b) shown here with overlaid geological units from the geological map in (c).The red box in (c) outlines the area in (b).

In *Figure 5b* a vector file outlining the general geological units is overlaid on the SAM classification result of the five soil endmembers. *Figure 5c* shows the main units of the geological map, which are: 1) a mudstone sequence composed of a gypsum rich facies towards the west and a calcite rich facies towards the east, 2) a gypsiferous limestone sequence forming the plateau area where most of the playa lakes are located, and 3) a limestone unit constituting the escarpment area of the Ebro River. Thin clayey layers of reduced hydraulic permeability separate all three units, thus, preventing local subsurface water flows from reaching deeper regional aquifer systems. The overlay in *Figure 5b* shows an interesting spatial relationship between salt affected soils, playa lakes and subsurface geology. An enlarged image and its classification result in *Figure 6* confirm the close relationship that exists between soil characteristics, landforms, and geology. Here the playa lakes are covered by the salt crust endmember (yellow), which has a very high content of soluble salts and some gypsum. The salt affected soils (in green) appear as salt efflorescence mainly in karstic depressions and around the playa lakes. This endmember is also found in the upland soils overlaying the gypsiferous mudstone unit *(Figure 5b)*. And finally, concentrations of the gypsiferous soils (gypsiric regosols shown in red) occur as expected in the gypsiferous mudstone unit with some isolated patches in the playa lake area. It is possible that the effects of changing agricultural activities in this area have triggered an increased appearance of salt precipitations on the land surface. The introduction of irrigation water in this karstic environment has mobilized soluble salts from the underlying evaporates which are subsequently deposited on the surface by capillary rise of the subsurface water. In contrast, salt crusts in the playa lakes are formed by evaporation of the lake water leaving a thin layer of precipitated salt on the surface during the hot and dry summer months. To determine the causes of surface salt accumulations (whether natural or human induced) a change detection analysis will be undertaken in the next phase of this project, where we intend to use multitemporal images of hyperspectral and multispectral resolution to detect and evaluate land degradation processes.

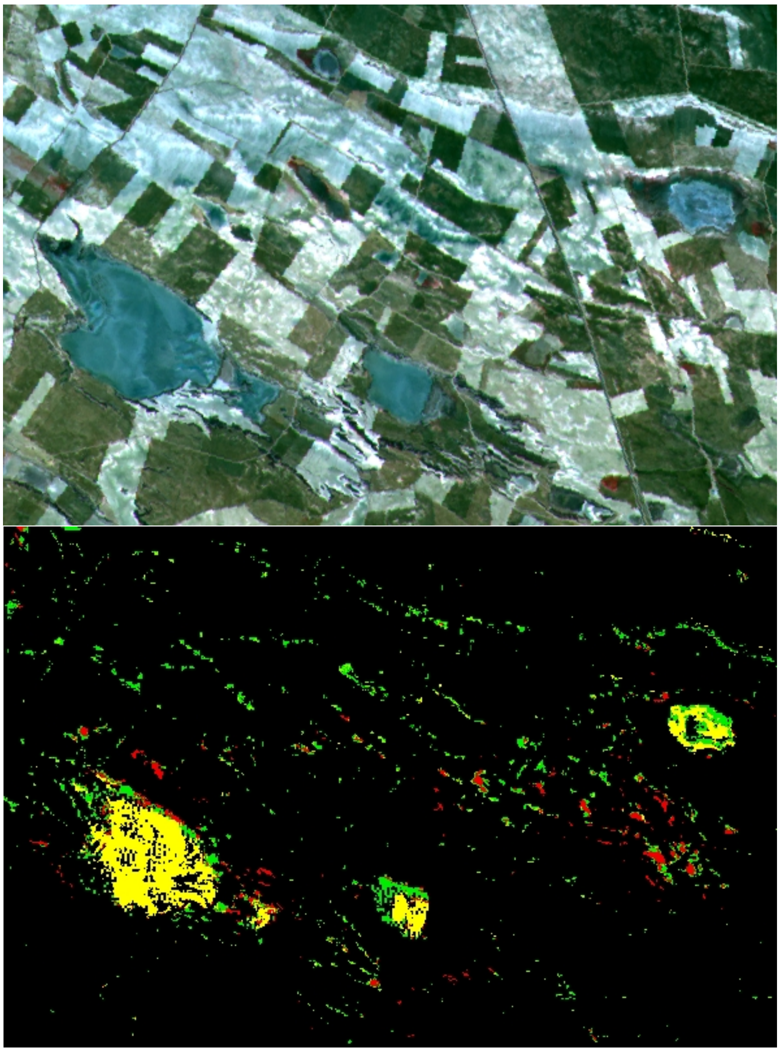

Figure 6: Enlargement of the playa lakes area as shown by a false color composite (bands 3, 2, 1) of the ASTER image (top) and the corresponding SAM classification output (bottom). The images cover an area of 8.5 km x 6 km.

CONCLUSIONS

High-resolution spectral curves from the La Mancha spectral library (Central Spain) were used as reference vectors to map soil distribution as related to natural and human induced processes. The results show the following:

Selected soil endmembers from a spectral library obtained in a similar semi-arid environment were applied to the study site with various rates of success.

The spatial distribution of three soil groups were obtained applying the SAM procedure and can be related to land degradation processes caused by type of land use, landform and geology.

The salt crust endmember is mainly found in saline playa lakes where the precipitation of salts is high due to evaporation of open lake water. The salt affected soil endmembers are probably caused by low quality irrigation water used in agricultural activities, which increases the soil salinity. The distribution of the gypsiferous soil endmember is associated to the geology of the study area and is mainly found in the gypsiferous mudstone facies.

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