APPLICATION OF MULTI-SENSOR OPTICAL DATA FOR MONITORING LAND USES WITHIN THE MERCURY MINING AREA OF ALMADÉN, SPAIN

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1. INTRODUCTION

The most important mercury deposits in the world are located within the Mediterranean basin and the largest concentration is situated in Almadén, Spain [1]. Cinnabar is the predominant mineral and a history of the mining activities within the region spans over a time period of more than two thousand years, providing nearly a third of the total known mercury produced throughout the world [2]. Mining activities have dominated in the region till the closure of the mines in 2002. Besides the extensive mining activities, main land uses of the area are pasture land for livestock and cultivation of legumes and cereal crops in dryland farming. These land uses have gained importance after the mining activities ceased and the rehabilitation of areas affected by the mining are the main priority within the region. Studies on the distribution of mercury in the environment of Almadén and restoration techniques have been carried out as part of ongoing research in CIEMAT within the framework of the National Plan of Research and Development in Spain. This includes: field surveys, laboratory and lysimeter experiments; development of applications using remote sensing and geospatial information technologies to determine the impact of areas affected by mining activities, and recommending strategies to restore these areas [3].

The main objective of this study is to identify and monitor abiotic and biotic characteristics of the region affected by mining activities as well as alternative human-induced activities. To achieve this, a monitoring of areas recovered from mining and given a subsequent different land use in the Almadén region is carried out applying data from numerous sources and at different spatial scales and time periods. Field work and laboratory analyses are used to determine abiotic and biotic characteristics from selected test plots, and remote sensing and Geographic Information Systems (GIS) techniques are implemented to carry out a regional characterization. Specific objectives include: 1) identifying spectral characteristics of land cover components applying hyperspectral data; 2) using hyperspectral image-derived endmembers to improve the classification of mining affected areas with multispectral data; 3) monitoring of human-induced activities implementing a time-series of multispectral data; and 4) GIS management and analyses to compile a database containing source data with field, laboratory and cartographic information, intermediate results and final classification maps.

2. METHODOLOGY

A methodological procedure was adapted and implemented to determine and monitor surface characteristics affected by mining activities and alternative activities in the region. Field campaigns have been carried out on a yearly basis since 2002, which included the characterization of the area and a final selection of ten test plots of approximately 1 ha. Initial observations were taken to establish the environmental conditions, general landscape features and coordinate references of numerous locations with GPS. Soil and vegetation samples were obtained for laboratory analyses and classification. The laboratory analyses include the physical, chemical and biological characterization of the samples. Satellite data acquisitions from optical sensors include hyperspectral and multispectral image data from the earth observation missions EO-1 (Hyperion acquired 17 July 2006), EOS (ASTER acquired 8 April 2006 and 30 June 2007) and Landsat (ETM+ and TM acquired 22 April 2002 and 23 March 1989, respectively). Furthermore, aerial photography as well as ancillary data and maps (meteorology, topography, lithology, geomorphology, vegetation and land use) are used as support and reference data. A GIS was used to manage and compile a georeferenced database including the field data, soil analyses, vegetation classifications, meteorological data as well as the remotely sensed data. Furthermore, GIS techniques were applied to obtain a digital terrain model (DTM) and to determine surface relief features such as drainage patterns, slope classes and relief orientation. Pre-processing of the satellite image data was required to obtain calibrated and corrected data. In this case, radiometric, atmospheric and geometric corrections were applied according to standard procedures [4]. Spectral characteristics of surface covers affected by mining activities were identified with Hyperion data. Image processing procedures from the ENVI program [5] include the Minimum Noise Fraction, Pixel Purity Index and n-dimensional visualizer to determine image-
derived endmembers from the hyperspectral data and obtain a pool of key endmembers. The Spectral Angle Mapper (SAM) procedure was used where selected endmembers and different multispectral data were applied to determine the spatial distribution of the individual surface components for the corresponding dates. In each case, the spatial distribution was verified according to field and cartographic surveys. Therefore, a monitoring of specific land covers was carried out using the multispectral time-series data. Final classification maps are obtained indicating changes of surface characteristics affected by the mining and alternative activities.

3. RESULTS AND DISCUSSION

An important result of this work was the compilation of a georeferenced data base containing data from numerous sources and at different spatial scales and time periods. Data from the test plots included details of site specific characteristics at the field scale. This facilitated the work of identifying surface cover characteristics (soil, vegetation and water) affected by the former mining activities and areas that are rehabilitated as well as ongoing alternative activities carried out in the region. The analyses for soil surface samples collected during the field surveys show pH values that range from acidic to near neutral conditions, organic matter content ranging from 2% to over 20% and with a texture from sandy loam to clay loam. Total mercury content ranges from 5 to 1710 mg kg⁻¹, soluble mercury content ranges from < 0.02 to 1.04 mg kg⁻¹, and concentrations of exchangeable Hg are in the range 0.15 and 7.3 mg kg⁻¹. In this case, higher concentrations are found at an old metallurgy site and in areas where mine tailings are present. Parameters such as pH, organic matter content and texture influence the amount of available mercury [3]. Numerous areas which were severely affected by the mining activities have been cleaned up according to standard National procedures. Image-derived endmembers were obtained mainly within agricultural and urban areas as well as from areas were surface mineral extraction occurred. Therefore, the image-derived endmembers from the Hyperion data determine a series of surface components that are associated to mining and alternative activities within the region. SAM classification results using selected endmembers and multispectral data for the respective years distinguished changes occurring in a number of surface covers related to mining and cultivated areas, water surface, sparsely vegetated forest areas with rain fed cultivation and dense Mediterranean forest areas on upper hill slopes. The results correlate well with the ground truth data obtained from the different test plots. A DTM was used to separate the different areas according to slope classes and their exposition. This separates the non accessible natural areas on steep slopes from the anthropogenic affected areas. Furthermore, an overlay of the classification results obtained with the SAM onto the DTM enhances the number of classes and therefore improves the final classification. Monitoring results show that the distribution of areas affected by mining activities is rapidly diminishing in the most recent years. This coincides with the time after mining activities ceased in 2002 and is due to the important effort of the company Minas de Almadén y Arrayanes, S.A. to rehabilitate areas affected by the mining of mercury. This work forms part of an ongoing effort to be able to incorporate hyperspectral and multispectral data from other and future hyperspectral and multispectral sensors to enhance results and continue the monitoring of the region.

4. REFERENCES


