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Identification of eroded areas using remote sensing in a badlands landscape on marls in the central Spanish Pyrenees

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ABSTRACT

Identification of erosion areas on a regional scale can be very useful for environmental planning, and can help reduce land degradation and sediment yield to streams and reservoirs. Remote sensing techniques were used to determine erosion and erosion risk areas in a badlands landscape in the Ésera River catchment (Spanish Pyrenees). The size, sparse vegetation cover, and high erosion level in the badlands, enabled good visual and digital discrimination relative to other land covers and surfaces. The maximum likelihood algorithm was used for obtaining a spectral distance map to the bare soil signature characteristic of badlands on marls. The ROC (receiver operating characteristic) curve analysis was applied to this map for obtaining an optimum classification of the badlands. Two alternative classification thresholds were set to determine erosion areas and areas at risk of erosion. Two classification performance statistics, the model's sensitivity and specificity, were calculated as a means of expressing the uncertainty–omission and commission errors–associated to both maps. Most erosion risk areas coincided with low vegetation cover surrounding the badland areas.

1. Introduction

Maps of active erosion areas and areas at risk of erosion are of great potential use to environmental (governmental and private) agencies, as they allow erosion prevention efforts to be concentrated in those places where the benefit will be highest. There is no single straightforward method for assessing erosion, and erosion evaluation is highly dependent on the spatial scale and the purpose of the assessment (Warren, 2002). For limited spatial scales (less than 100 ha), field surveys can provide an accurate means of analyzing erosion damage (Herweg, 1996). However, for focal area selection over larger areas other approaches that integrate available spatial data need to be applied. Studies on erosion undertaken at spatial scales covering local to regional areas (Vrieling et al., 2006) have provided both quantitative information (e.g., erosion rates) and qualitative information (e.g., erosion risk areas).

Methods for evaluating erosion risk on catchment and regional scales (10 to 10,000 km^2) include the application of erosion models or qualitative approximations using remote sensing and geographic information (GIS) technologies. Merrit et al. (2003) have exhaustively described current erosion models. However, in most cases erosion models have been created for use at small scales, so their extrapolation to larger scales (catchment or regional) is very complex and sometimes leads to errors (Kirkby et al., 1996; Schoorl et al., 2000; Yair and Raz-Yassif, 2004). The use of remote sensing and GIS techniques has been shown to have potential for erosion assessment on regional scales, including identification of eroded surfaces, estimation of factors that control erosion, investigation of soil and vegetation characteristics, and monitoring the advance of erosion over time (Muchoney and Haack, 1994; Lambin, 1996).

In most cases remote sensing techniques have been applied simply to identify the characteristics (or the absence) of the vegetation cover, largely because of limited visibility of the soil surface in humid and sub-humid environments (Vrieling, 2006). Other studies have demonstrated the usefulness of remote sensing techniques in determining temporal and spatial erosion patterns (Pilesjo, 1992; Rode and Frede, 1997; Metternicht and Fermont, 1998; Szabo et al., 1998; Millward and Mersey, 1999; Reusing et al., 2000; Haboudane et al., 2002; Metternicht and Gonzalez, 2005). Calculation of the percentage of bare ground has also been used to estimate erosion risk (e.g., De Jong, 1994; Paringit and Nadaoka, 2003). Other methodologies applied to inventories and monitoring of erosion processes include band ratios (Pickup and Nelson, 1984; Frazier and Cheng, 1989), vegetation indices (Pickup and Chewings, 1988; Tripathy et al., 1996), combinations of reflective and microwave data (Koopmans and Forero, 1993; Singhroy, 1995; García-Meléndez et al., 1998; Metternicht and Zinck, 1998; Singhroy et al., 1998), and combinations of remote sensing data and other ancillary data (Floras and Sgouras, 1999; Mati et al., 2000; Giannetti et al., 2001; Shrimali et al., 2001; Zinck et al., 2001; Haboudane et al., 2002; Ma et al., 2003; Symeonakis

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and Drake, 2004; Beguería, 2006a). No studies have explored the application of the receiver operating characteristic (ROC) curve analysis, which allows for selecting the optimum classification map based on the omission and commission errors, to the generation of an erosion map.

Several studies have estimated erosion in the Spanish Pyrenees using remote sensing at the regional (Beguería, 2005) and the catchment scales (Fargas et al., 1997). These studies have shown that the badland systems developed on Eocene marls constitute the main sediment sources in the Pyrenees, with important consequences for the silting of reservoirs (Valero-Garces et al., 1999). The term badlands is used to describe areas of unconsolidated sediment or poorly consolidated bedrock, with little or no vegetation. They are typically associated with accelerated erosion and consequent unstable landscapes, so that their fixation requires considerable effort. Badlands develop in a wide range of climatic zones, but particularly in semiarid areas. In sub-humid and humid regions the development of badlands is linked to lithological and topographical factors (Regüés et al., 1995; Morgan, 1997; Oostwoud-Wijdenes et al., 2000), and to climatic conditions such as freeze–thaw cycles in winter, and wetting–drying in spring–summer. In the Spanish Pyrenees, a combination of favorable relief and climatic conditions is coupled with highly erodible marls outcrops, explaining the presence of badland systems with intense soil erosion processes (Regüés et al., 1995; Gallart et al., 2002; Nadal-Romero et al., 2007, 2008).

The objective of this study was to test a method for identification of areas of severe erosion (badlands) and areas of erosion risk by means of remote sensing classification techniques. The method involved several steps: i) application of a supervised classification algorithm to areas with active erosion features to obtain a map of the spectral distance; ii) selection of a classification threshold based on the ROC curve and error statistics; and iii) assessment of the uncertainty associated with the predictions. The study area corresponded to the corridor of Eocene marls in the middle section of the Ésera River basin, in the central Spanish Pyrenees.

2. Study area

The study area is located approximately 23 km north of the Barasona reservoir, in the Spanish Pyrenees, and is an integrated badlands landscape developed on Eocene marls orientated north–southeast (Fig. 1) at 620 m to 2149 m (Fig. 2) altitude. The badlands system is conformed by a group of typical hillside badlands developed on sandy marls with clay soil, and is strongly eroded over convex hillsides with a moderately inclined slope. Runoff from this area enters the Viu and Rialvo rivers in the catchment of the Ésera River, and the Viyacarti River in the catchment of the Isábena River.

The climate is defined as mountainous, humid, and cold, with influences from the Atlantic Ocean and the Mediterranean Sea (García-Ruiz et al., 1985). The average annual temperature is 11 °C, and the average annual precipitation is approximately 876 mm (Fig. 3). Precipitation is irregular throughout the year, with a maximum in spring between 80 and 70 mm (April and May, respectively), and a minimum in July–August when precipitation does not exceed 70 mm.

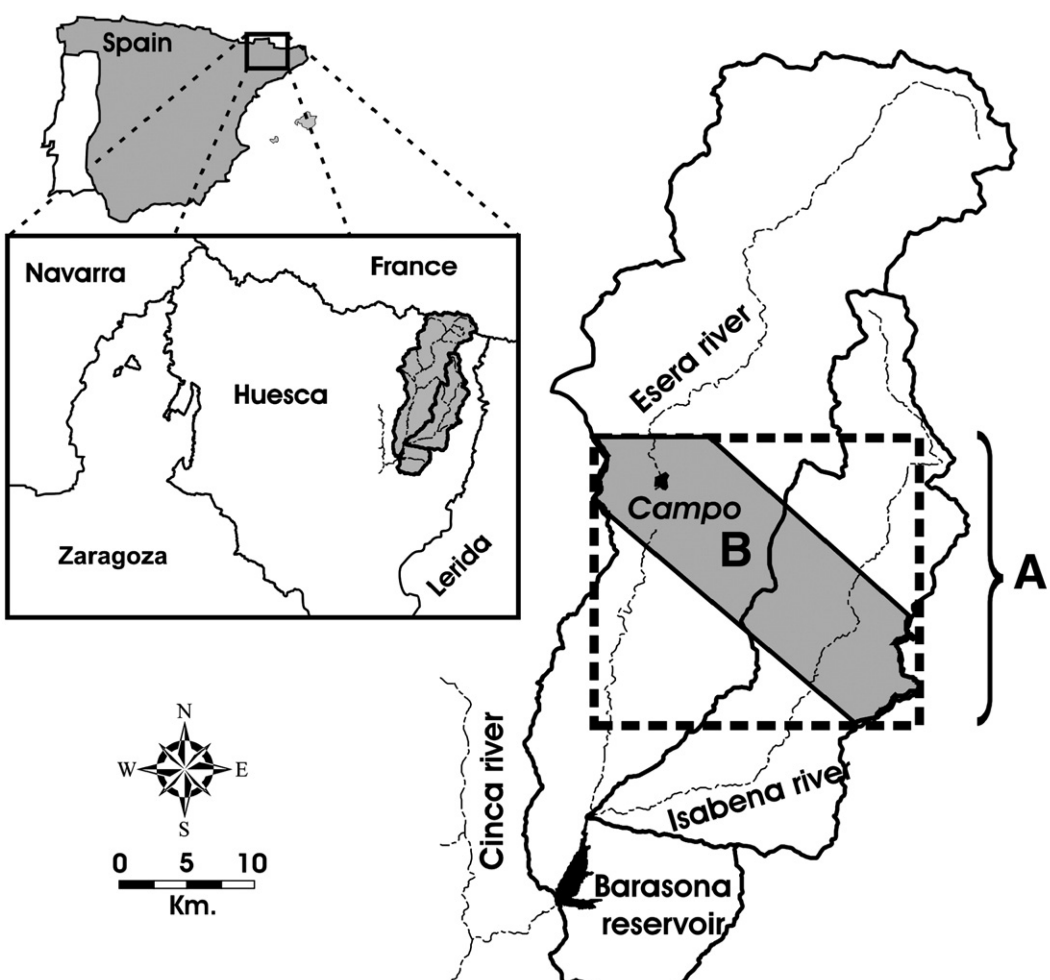

Fig. 1. Location of the study area: A, area of the Landsat scene; B, location of badland areas on marls (236 km^2).