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Soil Erosion Trend Analysis Using Multi Temporal Landsat Imagery

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Abstract
Cartographic methods such as satellite imagery are very useful for researching the soil erosion trends of large areas. This study proposes a cartographic method which uses indicators of the erosive state of soils for the spatial and temporal analysis of soil erosion triggered by forest fires. The continuity of the organic horizon, the surface stoniness and the vegetation cover degradation or regeneration have been used as criteria for imagery classification in the multi-temporal analysis using Landsat images in the western sector of the Cantabrian Range (NW of Spain). Within the study area (48857 ha) 7377 ha are recovering and 2326 ha are in the process of degradation.

Keywords: soil erosion trends; satellite imagery; multi-temporal analysis; forest fires.

Analyse De La Tendance De L'érosion Du Sol À Travers L'imagerie Multi Temporelle Landsat

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Résumé analytique
Les méthodes cartographiques, telles que l'imagerie satellitale, sont très utiles pour la recherche des tendances de l'érosion du sol sur de larges surfaces. Cette étude propose une méthode cartographique qui utilise des indicateurs de l'état d'érosion du sol pour l'analyse temporelle et spatiale de l'érosion du sol causée par des feux de forêt. La continuité de l'horizon organique, la gravellosité de la surface et la régénération ou dégradation de la couverture végétale ont été utilisées en tant que critères de classification de l'imagerie pour l'analyse multi temporelle au moyen des images Landsat dans le secteur occidental de la Cordillère Cantabrique (au Nord-ouest de l'Espagne). Sur toute la surface d'étude (48 857 ha) 7 377 ha sont en situation de récupération et 2 326 ha sont en procès de dégradation.

Mots clés : tendances de l'érosion du sol, imagerie satellitale, analyse multi temporelle, feux de forêt.

1. Introduction

In areas under wetter climate regimes, vegetation protects the soil from the impact of raindrops and overland flow, but if the vegetation is replaced by crops or destroyed by forest fires, erosion becomes one of the main causes of soil degradation. Large areas in the northwest of the Iberian Peninsula suffer from the process of soil erosion due to the fact that, for centuries, forest fires have been a common way of managing the terrain. These areas suffer from strong soil degradation, which in many cases affects their hydrological behaviour and their capacity to support vegetation (Fernandez et al., 2005). The real damage which these soils have suffered is difficult to establish because vegetation often recovers very quickly after fire.

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In general, diagnosing the erosive status of damaged soil is a difficult problem to solve when soil erosion processes do not leave marks on the soil surface. To this effect, aerial and satellite remote sensing offer different possibilities for soil erosion research. Satellite images have been used to directly survey affected areas in arid or semiarid climates where the vegetation cover is not very dense (FrazierYaan Cheng, 1989; Metternicht and Zinck, 1998; Hill and Schütt, 2000). Landsat TM images have also been used by Ben-Dor and Banin (1994) and also Martínez –Ríos and Monger (2002), to study changes in the properties of damaged soils, but all this research has been developed in arid and semiarid climate conditions and there have not been enough studies under wetter climate conditions.

The study area is under wetter climatic regimes with continuous vegetation cover which undergoes rapid changes on account of small and frequent forest fires. Due to this, the fundamental goal of this study has been to develop a valid indicator to diagnose the erosive states of these soils. This indicator should be useful for researching the tendency of soils to deteriorate or recover over large mountainous areas. In order to do this a mapping method based on the multi-temporal analysis of satellite images has been developed. This method enables the study of the present state of erosion and the stages of degradation or recuperation that soils have gone through before reaching their current status. These erosive states have been established by using both soil properties (such as the continuity of the organic horizon and the surface stoniness) and patterns of vegetation cover.

2. Materials and methods

The study area occupies 48,857 ha on the North Face of the Cantabrian Mountain Range (Atlantic zone of the Iberian Peninsula). The mean annual precipitation is between 1,500-1,700 mm, the monthly maximum being in February with precipitation that surpasses 200 mm and the minimum in August with precipitation between 40-60 mm. The mean annual temperature is between 8-10º C.

The present abrupt relief of the area is caused by the alpine tectonics and the subsident downcutting of the hydrographic network. Large (average of 1,150 m length) and steep (average of 30º slope) hillsides and very downcutting rivers characterize the relief pattern in the area. The highest areas reach an altitude of 1,860 m and drops down to 440 m, which is the average altitude of valley floors. Ordovician quartzite and sandstones are the main substrata and very acidic (pH below 4.5) sandy and stony soils, rich in unsaturated organic matter developed over these rocks (*Leptosol* and *Regosol*).

The vegetation cover corresponds to different acidophilus forest vegetation series (*Quercus pyrenaica*, *Fagus silvatica* and *Betula celtiberica* forests). Most of the terrain was, however, deforested centuries ago for farming and mining, and has undergone intense degradation due to forest fires. At present there are large areas of thickets dominated by heathers and gorses (*Erica* species) or brooms (*Cytisus* and *Genista* species), chasmophytic vegetation on rock slopes and mixed oligotrophic secondary forests with birches (*Betula celtiberica*)In order to analyze both the erosive state of soil and its tendency for recovery or degradation in the study area, 9 Landsat -6 TM imageries (1993-99) and 3 ETM (2000-02) have been used. Digital Elevation Model (DEM) with a resolution of 30 m has also been used.

2.1. Imagery classification

1- A series of nine Landsat TM and ETM images were selected, with a frequency of one image per year taken in the summer-autumn period (from 1993 to 2002). *2*- The images were corrected for atmospheric influence, georeferenced and topographically rectified (Bukata et al., 1983). *3*- The fieldwork involved selecting 49 plots in order to define several homogeneous units for the state of erosion, using the following criteria: surface stoniness, continuity of the organic horizon and structure of vegetation cover. Using these criteria five erosive states or classes have been recognised. *4-* Changes in reflectance related to rock fragments in soil surface, microtopography morphologies or vegetation cover have been used to classify images. For the classification, bands 4, 5 and 7 transformed into HSI images have been used. A supervised classification was applied to the images year by year. At this stage, the maximum likelihood enhanced neighbour classifier with neighbourhood modification in a 5x5 filter was applied. *5-* In order to validate the results of an annual classification, orthophoto on a scale of 1:25000 from year 1996, was used. 1020 random points were located on the orthophoto and the state of erosion was allocated for all points. These points were intersected with the classified image from 1996 and 83.2% of them agreed with the manual classification.

2.2. Multi-temporal analysis

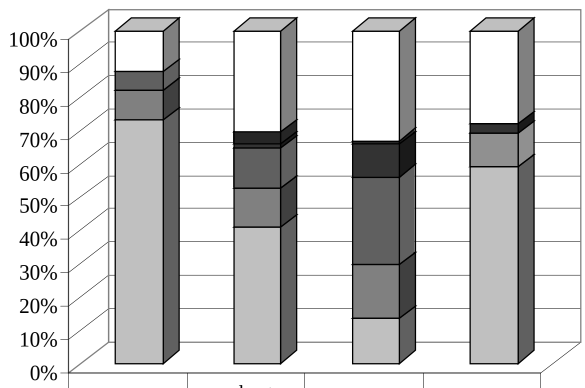
In order to carry out the multi-temporal analysis, the classified images were crossed in order to obtain the evolution trend of erosion in the study area. This evolution has been analysed pixel by pixel on the final image by using a series of iterative search and classification procedures programmed in Visual Basic 6, specifically designed for this application. In the overall image of the nine years, each pixel is associated with a sequence of 9 scores arranged in chronological order. Each of these nine scores corresponds to the erosive state in the corresponding year.

3. Results and discussion

In this research, Bands 4 and 7 appear to be the most suitable for discriminating the erosion states, although Band 5 provides an additional criteria for this classification. The accuracy of the classification method, validated by orthophoto, was 83.2%.

3.1. Erosive states map and evolutionary tendency

For each of the nine years an erosive state map has been obtained which contains five erosion classes: 1- continuous vegetation; 2- moderate erosion; 3- severe erosion; 4- talus scree and 5- burnt surfaces. In the final map which was obtained by crossing the nine erosive state maps, every pixel has been assigned 2 digits: the first refers to the predominant erosive state in the sequence (2, 3, 5 or 7) and the second to the type of sequence (0, 1, 2, 4, or 5). By analysing the sequences, the following trends have been obtained: 1- *Stable areas.* 2- *Areas of directional changes* (Evolution towards degradation or evolution towards recuperation). 3- *Areas of changes with a dominant tendency*. 4- *Areas of changes without a dominant tendency*. 5- *Areas with no clear dominant score and without any particular trend in changes*.



	vegetation	moderate erosion	severe erosion	talus scree
errors	2398	5312	779	1257
tendency to degradation	1132	611	27	
degradation		205	231	120
tendency to recuperation		2119	620	460
recuperation	1722	2070	386	
stable ares	14364	7105	315	2639

The erosion pattern in the year 2002 (Figure) is 19.6 ha without erosion, 17.4 ha which present signs of moderate erosion, 2.4 ha with severe erosion and 4.5 ha of talus scree. These results viewed in percentages of the study area mean

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that 45% of the area shows no sign of surface erosion, 40% shows evidence of moderate erosion, 5% displays an intense degradation and 10% of the terrain is composed of talus scree. In the year 2002, the continuous vegetation cover class increased in 1.7 ha which came from the regeneration of the moderate erosion class. Also, 2.1 ha which came from the severe erosion class have undergone a process of regeneration and have become part of the moderate erosion class.

4. Conclusions

The features used in this analysis (type, structure and continuity of vegetation cover, continuity of organic horizon and surface stoniness) are directly related to environmental degradation caused by the forest fires and were useful in defining both the erosive state of the soils and the vegetation cover at different moments. However, never before had the continuity of the organic horizon along with the surface stoniness been tested as criteria in order to characterize the erosive state using satellite remote sensing.

The multi-temporal analysis shows that the natural trend of the area is to recuperate its soils and vegetation cover. A total of 7,397 ha have been recuperated or show a tendancy towards recuperation while only 2,641 ha come from the degradation of the terrain or are in transition towards a more severe state of erosion. This evolution can be linked to the fact that in the last few years the frequency of fires has decreased considerably.

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