

Assessing the effects of land-use changes on sediment yield and channel dynamics in the central Spanish Pyrenees

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Abstract During the last 40 years land management of the central Spanish Pyrenees has changed much. For centuries, sunny, steep slopes were cultivated with cereals. At present, most of the hillslopes have been abandoned and the old fields are colonized by different shrubs or have been reforested with pines. These changes result in a decrease in runoff and sediment yield. At a basin scale changes in the location and extent of sediment sources have been detected, and as a consequence of these changes channels have partially stabilized their sedimentary structures.

INTRODUCTION

Until the first decades of the twentieth century, land management in the central Spanish Pyrenees was characterized by a large proportion of agricultural land. Approximately 30% of the land located below 1600 m a.s.l. was cultivated, mainly on sunny aspects (Lasanta, 1989). At present most of the original cultivated area has been abandoned and many hillslopes have been reforested with conifers (Ortigosa *et al.*, 1990). The livestock pressure has also greatly diminished both in the high and the middle mountain, and the use of fire, as a strategy to improve the quality of pastures, faces many legal restrictions. All these land-use changes affect the dynamics of the natural system and especially the hydrologic and geomorphological functioning of hillslopes and stream channels. This paper is a synthesis of the studies carried out by the Department of Soil Erosion and Land-Use Changes of the Pyrenean Institute of Ecology, which have attempted to document the changes in sediment yield and channel dynamics associated with these land-use changes.

THE STUDY AREA

This study focuses on the Flysch area of the central Spanish Pyrenees, where the most significant land use changes have occurred. The experimental part of the research has been carried out in the Aisa Valley (Fig. 1).

The Eocene flysch bedrock is intensively folded, but lithological homogeneity causes more uniform relief, dominated by smooth divides that decrease progressively in height towards the south, and by slopes with gradients between 20 and 40%. The

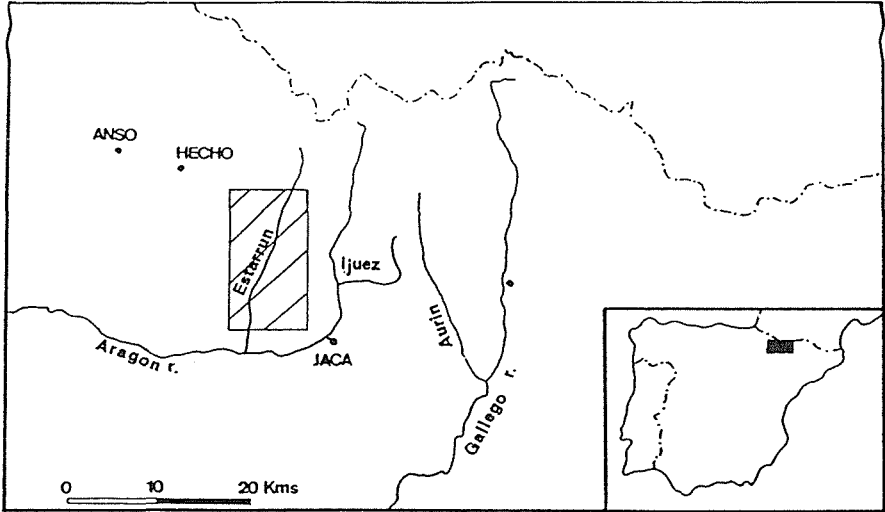


Fig. 1 The study area.

highest divides rarely exceed 2000 m. Annual precipitation varies between 800 mm in the lowest sectors and 2000 mm along the divides, falling mainly in the cold season (October-May). *Pinus silvestris* woods prevail on the shady slopes, and the rest of the territory is dominated by abandoned fields, small *Quercus gr. faginea* woods, and submediterranean shrubs.

METHODS

Since 1987, the Department of Soil Erosion and Land-use Changes of the Pyrenean Institute of Ecology has studied soil erosion and runoff in relation to human activities in mountain areas, at the hillslope and basin scales. This work includes studies of the effects of traditional agriculture, farmland abandonment and afforestation. A selection of the methods used is as follows:

- (a) Geomorphic transects (Ruiz-Flano *et al.*, 1992) allow us to define the geomorphic processes operating in fields abandoned since the beginning of the twentieth century.
- (b) Between 1990 and 1992, 19 closed plots were installed in different environments on slopes cultivated several years ago and now abandoned. All the plots are small in size (around 3.5 m²), with a Gerlach trap located at the lower end of the plots. There were replica plots with 100%, 85%, 65%, 40% and 15% shrub cover, and with 85% meadow cover.
- (c) In the Aisa Valley Experimental Station, eight closed, 10 × 3 m plots have been installed, including a system of tipping buckets connected to data loggers, in order to record the runoff from each plot continuously. The plots reproduce different land-uses, including shifting agriculture, fallow land, cereals (application of chemical fertilizer), burnt plots, dense shrub cover, meadows and stubble. In 1993 the plot in fallow passed to cereal, whilst the cereal plot was left as stubble, initiating a process of abandonment.

- (d) The effects of afforestation have been studied by comparing the channels of 25 afforested and 17 non-afforested basins, with a surface area between 4 and 10 km² (Ortigosa & Garcia-Ruiz, 1995). In the field, information on the geomorphological and geobotanical features of the taluses and channels was obtained. In each basin the channel and talus were studied by means of 12 geomorphological transects.
- (e) On alluvial fans, information on the surface area occupied by the most active sectors was extracted from aerial photographs (1956 and 1987).

RESULTS

Geomorphological dynamics during traditional land management

Farming activity reached its maximum extent at the end of the nineteenth century, the period of greatest population density. On average, almost 28% of the land below 1600 m was cultivated (Lasanta, 1989). Cultivated fields occupied all possible locations, including steep slopes and stony soils. Coinciding with the maximum pressure, shifting agriculture without soil conservation techniques (slash and burn), yielded poor cereal crops. On average, in the central Spanish Pyrenees, 22.8% of the farmed area was occupied by slash and burn fields, 18.3% by sloping fields, 36.4% by bench terraces and 22.5% by flat fields.

Figure 2 shows the mean sediment concentration for several traditional land-uses based on the results obtained in the Aisa Valley Experimental Station. The greatest sediment concentrations are recorded for fallow land, followed by shifting agriculture. In contrast, the plot with a fertilized cereal crop does not present

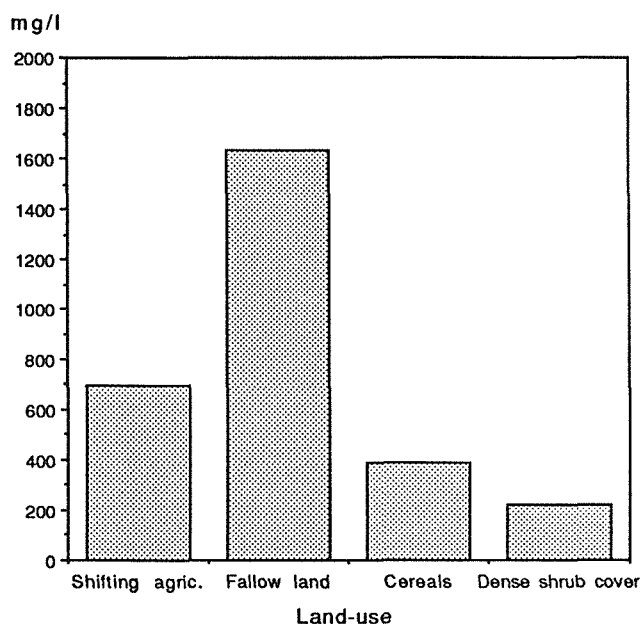


Fig. 2 Average sediment concentrations for several traditional land-uses.

Table 1 Runoff coefficients and soil loss under different land-uses.

Land-use	Runoff coefficient (%)	Soil loss (t ha ⁻¹)
Shifting agriculture	6.1	10.0
Fertilized cereal	3.1	5.2
Fallow land	5.5	15.5
Abandoned field	2.1	2.1
Dense shrub cover	1.4	1.1

important problems, except in terms of its biannual fallow phase. Table 1 includes runoff coefficients and soil loss estimates for one year. The lowest values are recorded for the plot with a dense shrub cover, while fallow land and shifting agriculture show much higher values.

Several authors point out that the traditional farming of steep slopes is the reason for landscape degradation. Marti *et al.* (in press) suggest that the large debris flows occupying some valley bottoms were probably associated with general deforestation followed by cereal cropping. Geomorphological mapping of the Flysch area (Garcia-Ruiz & Puigdefábregas, 1982) confirms that cereal cropping was the main source of sediment on the steepest slopes, causing intense soil erosion. As a result, the rivers draining the Flysch area were characterized as torrents, transporting large volumes of bed load and aggrading the alluvial plain. Some of the main rivers also showed marked geomorphic activity at the beginning of this century, with very unstable channels (Rubio & Hernandez, 1990). Furthermore, most of the alluvial fans are closely related to human activities on the steep slopes (Gomez-Villar, 1996). At a larger scale, the growth of the Ebro Delta was especially rapid in the sixteenth and nineteenth centuries (Maldonado, 1972), coinciding with the expansion of shifting agriculture.

Land-use changes and their geomorphological effects

Lasanta (1989) confirms that most of the cultivated fields were already abandoned in 1957. Cereals have almost completely disappeared from the mountain areas and have been substituted, when the fields were not abandoned, by grazing and hay meadows. Likewise, many former cultivated hillslopes have been reforested with conifers. All these changes affect the hillslope hydrologic cycle and the capacity for supplying and transporting sediment.

Studies carried out on erosion from abandoned fields (Ruiz-Flano, 1993; Ruiz-Flano *et al.*, 1992; Garcia-Ruiz *et al.*, 1996) demonstrate that the extent of soil erosion on abandoned fields depends on the efficacy of plant colonization processes. During the first years, severe sheet wash erosion is the most extensive process, due to the sparse plant cover on recently abandoned fields. After 10 years, once the herbaceous cover protects 70-80% of the soil surface, mild sheet wash erosion is the prevailing process. After 25-30 years, when a dense shrub cover is present, runoff and soil erosion are reduced to minimum values.

The results obtained from the small experimental plots show the importance of shrub cover. Fig. 3 provides information on the runoff and sediment concentration associated with each plot. Plots with a dense shrub cover give the lowest runoff

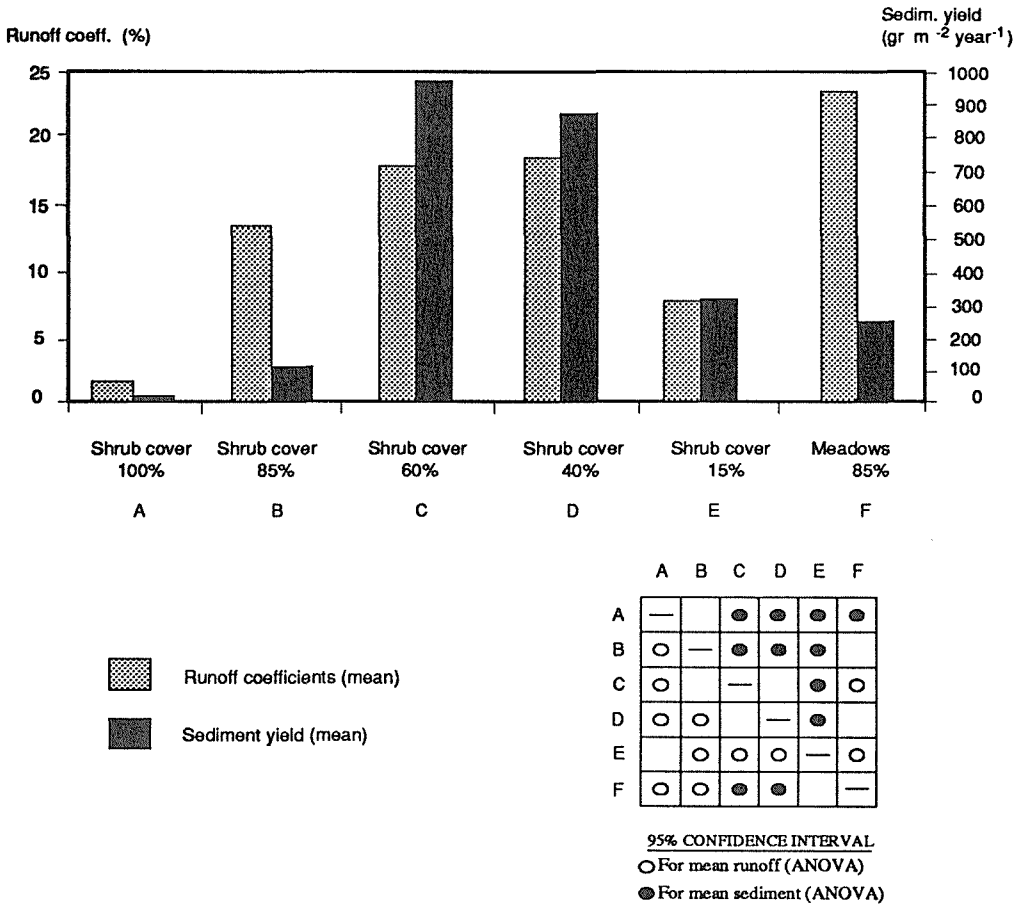


Fig. 3 Runoff and sediment concentration under different plant cover.

coefficients. However, as the density of the plant cover decreases, the quantity of runoff increases by several orders of magnitude. The greatest runoff is yielded from plots where the shrub cover is 40-60%. Plots with 15% shrub cover yield an intermediate quantity of runoff, probably because of the large numbers of stones on the surface, which encourage infiltration (Poesen *et al.*, 1994). In the same way, plots with a dense shrub cover record the lowest sediment concentrations. The highest concentration recorded is from the plots with 60% shrub cover. A very interesting result is that meadows yield high quantities of runoff but this is relatively sediment free.

Figure 2 and Table 1 also confirm the moderate behaviour of the shrub cover. Thus, runoff is about 2.5-3 times greater from the plots with shifting agriculture and fallow land and the total soil loss is around 10 times greater from the plots with shifting agriculture, and 15 times greater from the fallow land plot compared with the dense shrub cover plot. This is a very important point, since the general trend is for colonization of old cultivated fields by different shrub communities. For example, in the Aisa Valley, 81.6% of the abandoned fields have been colonized by

shrub communities and dense shrubs with some trees.

Information about the effects of afforestation is also available. Table 2 shows the results obtained by comparing the channels of afforested and non-afforested basins. The channels of afforested basins have the greatest proportion of plant cover, the lowest values of bare soil and gravel on the surface, as well as the highest values of fine sediments. The Analysis of Variance also shows that taluses in rivers of afforested basins are better covered by vegetation and are less affected by rilling and other erosive processes.

Studies carried out in Pyrenean rivers show that most of the bars are now covered by vegetation. In many rivers, the channels have undergone incision of up to 2m during the last 20 years, leaving small terraces on both banks. Gomez-Villar (1996) has arrived at similar results by studying the evolution of large alluvial fans, where the most active sector is now restricted to the channel itself. Garcia Ruiz *et al.* (submitted) have demonstrated that all these changes have occurred without substantial changes in the available stream energy.

Finally, it is important to note that under the traditional land management system almost all the middle mountain contributed to the sediment load of the rivers, except the areas of shady aspect covered by forest. At present, based on a preliminary evaluation made by González *et al.* (in press) in the Loma de Arnás experimental basin, it is estimated that only 1% of the territory supplies sediment to the channels due to plant colonization after farmland abandonment. These authors suggest that the most important sediment sources are the bare taluses on the banks of the channel and the channel itself. The rest of the basin now behaves very moderately.

Table 2 Analysis of variance of channels and taluses in afforested and non-afforested basins, considering several characteristics.

	Non afforested basins	Afforested basins
In channels		
% Plant cover	42.0	79.7
% Bare soil	72.6	20.9
% Gravels	56.3	23.9
% Fine material	32.1	60.9
On taluses		
% Moderate or nil erosion	65.7	77.5
% Rills	7.1	1.3
% Plant cover	74.6	93.8
(Significance level greater than 95%)		

DISCUSSION AND CONCLUSIONS

The recent socio-economic changes in the Pyrenees have resulted in a strong decrease in population, a reduction in the cultivated area, and general changes in land-use and plant cover. These changes have had profound effects on the hydromorphological dynamics of the mountains, and particularly on runoff and sediment yield as well as on the location of sediment sources.

The accumulation of sediment on alluvial plains, alluvial fans and deltas, as well

as the behaviour of the channels and the inherited characteristics of the landscape indicate that soil erosion was very intense under the traditional land management system. Shifting agriculture, with a very low productivity, was the most important sediment source.

At present most of the hillslopes have been abandoned. This change has allowed recolonization by dense shrub and forest communities, encouraging infiltration, increasing interception and evapotranspiration (Gallart & Llorens, 1996) and reducing overland flow. A comparison of aerial photographs of different periods suggests that the areas affected by severe sheet wash erosion have been greatly reduced in extent. Sediment sources have also been controlled by afforestation.

Nevertheless, it is important to take into account that the great volume of sediment accumulated in the channels and the high susceptibility to erosion of some taluses will ensure the availability of sediment for decades. Furthermore, if rivers incise into their own sediments, it is because land-use changes have caused an imbalance between discharge and sediment transport, suggesting that the expansion of the shrub cover and the increased forest cover produce a greater reduction in sediment mobilization than in runoff from the hillslopes. This is why the rivers erode sediment from the channel, developing small terraces in a few years.

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