Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation
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THE DIVERSITY OF SEDIMENT YIELD FROM ABANDONED FIELDS OF THE CENTRAL SPANISH PYRENEES

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ABSTRACT By means of small closed plots (2.5-3.5 m^2) the authors have documented the water and sediment yield of different geomorphic micro-environments defined in abandoned fields of the Central Spanish Pyrenees. Plots defined as "null erosion" yield little water which generally flows away with low sediment concentrations. At the opposite extreme, plots with severe sheet wash erosion and undermining yield a great deal of runoff that is also usually heavily loaded with sediment. Both plant density and structure have been established as the main factors in explaining the different hydromorphological functioning of the geomorphic micro-environments. The authors conclude that abandoned fields can develop in two ways, according to the initial conditions of the soil and to the management of the plant cover.

INTRODUCTION

Under 1600 m a.s.l. the southern slopes of the Spanish Pyrenees show the effects of intense human activity. After centuries of cultivation, even on very steep slopes, the landscape is now dominated by abandoned fields, partially colonized by scrub. A variety of geomorphic processes produce heavy soil loss after abandonment; in many cases the abandoned plots show great stoniness on the surface, and bedrock appears locally, but in other cases scrub almost completely covers the soil and impedes the direct impact of raindrops. The problems addressed are: what are the factors that explain this heterogeneity, both in soil loss and in plant cover? What differences can be found in the hydromorphological functioning of each different environment within the abandoned fields? Is sediment yield an important problem within the abandoned fields?

We already have some information about the spatial and temporal distribution of geomorphic processes (Ruiz-Flaño *et al.*, 1990 and in press) and we have identified the key-geomorphic microenvironments within the abandoned fields, but no information about sediment yields has been available until now. In this paper the first results concerning the variability of runoff and suspended sediment are presented, the data having been obtained from small plots located in different geomorphic microenvironments.

THE STUDY AREA

The study was carried out in the Aisa Valley, in the central-western part of the Spanish

Pyrenees (Fig. 1). The area of maximum agricultural use originally coincided with that of the Eocene flysch hillsides, on slopes that could be over 40%, with stony colluvium and shallow brown soils. The cultivated area reached its maximum extent between 1000 and 1200 m a.s.1. The sunny slopes were extensively farmed, whereas the shady slopes retained the original forests. Areas facing east or west were also heavily farmed. The most important crops were cereals, even under very severe topographic conditions, while meadows occupied very little of the land. In this area the majority of the fields are sloping, with small terraces, and, in the worst cases, were used for nomadic agriculture. The abandonment began during the last decades of the 19th century, especially for the most remote and worst fields, and reached its maximum during the first half of the 20th Century (Lasanta, 1988 and 1990; García-Ruiz & Lasanta, 1990).

The study area experiences a continental mediterranean mountain climate. Annual rainfall ranges from 800 mm in the lower areas to 2000 mm in the divides at 2000 m a.s.1. A major part of the precipitation falls in Spring and winter, although in autumn heavy storms can be recorded. Summers are cool, with few storms. *Pinus sylvestris* woods dominate the shady areas, and the remainder of the area is characterized by abandoned fields with small *Quercus gr. faginea* woods and submediterranean scrubs including *Buxus sempervirens, Genista scorpius, Echinospartum horridum and Juniperus Qxycedrus* (García-Ruiz & Puigdefábregas, 1982).

METHODS

By means of geomorphic transects, a rapid evaluation of the characteristics of the geomorphic processes was obtained (see Ruiz-Flaño *et al.*, in press). In order to obtain information about runoff and sediment yield, 19 closed plots were installed in different abandoned fields, all of them small in size (from 2.5 to 3.5 m^2). At the lower end of the plots a Gerlach trap was located and to a 62-l container to collect the water and sediment generated by each rainfall event. After each event, the quantity of water recorded was measured in the field, and a sample was taken to obtain the sediment concentration in the laboratory by evaporating the water at 110°C.

The location of the plots took into account the most representative geomorphic microenvironments selected by means of geomorphic transects. Thus, there were 3 plots with null erosion, 6 plots with mild sheet wash erosion (3 of them in pasture meadow and the other 3 in scrub), 4 with severe sheet wash erosion, 3 with stone pavements and 3 with what we call undermining around isolate bushes.

At Esposa, a small village in the valley, there is a meteorological station with a pluviograph. Moreover, several pluviometers were installed close to the plots in order to obtain not only the intensity and duration of each rainfall event, but also its spatial variability within the study area. Thus, differences of 40% have been recorded for several storms within no more than 5 km in a straight line.

RESULTS

The gradient of the plots ranged from 21 to 46%, although this is not a very important factor, since the steepest plot coincides with null erosion and the least steep, with-stone pavement. Stoniness and plant cover are closely related to the geomorphic environment. Thus, plots with null erosion have a plant cover of 100% (a dense scrub cover of *Genista scorpius*

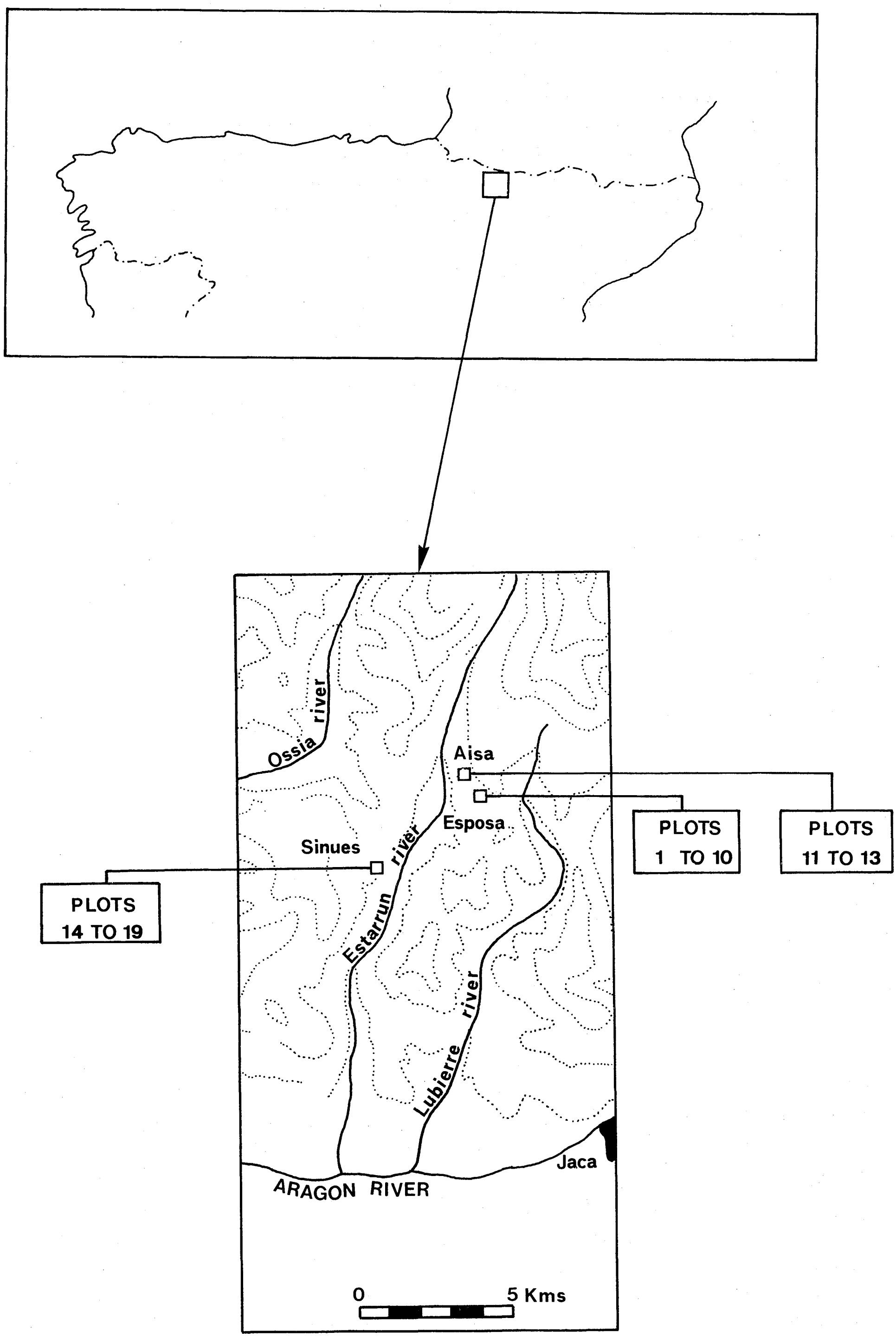

FIG. 1 The study area.

and only a 10% cover of stones on the surface. Plots with mild sheet wash erosion also have a lot of vegetation (95% in the six cases) and few stones (between 12 and 30%). Severe sheet wash erosion is characterized by scarce plant cover (between 20 and 30%), with many stones (70%), whereas the stone pavement is totally covered (100%) by stones and has very sparse vegetation (10-15%). Finally, on the plots with undermining, plant cover reaches 60-80% of the surface and stoniness ranges between 30-50%. From this one can distinguish two groups of plots according to plant cover and stoniness. On the one hand, there are plots with null erosion and mild sheet wash erosion, which support a high plant cover and a low percentage of stones on the surface; and, on the other hand, there are plots with severe sheet wash erosion and stone pavements, with little vegetation and many stones. Plots with undermining occupy an intermediate position.

During the study period (from April, 1, to October, 30, 1990) 65 rainy days were recorded in Esposa, with a total precipitation of 723.5 mm. Figure 2 shows the distribution of rainfall events, with two marked seasons: Spring and Autumn. May and June were espe-

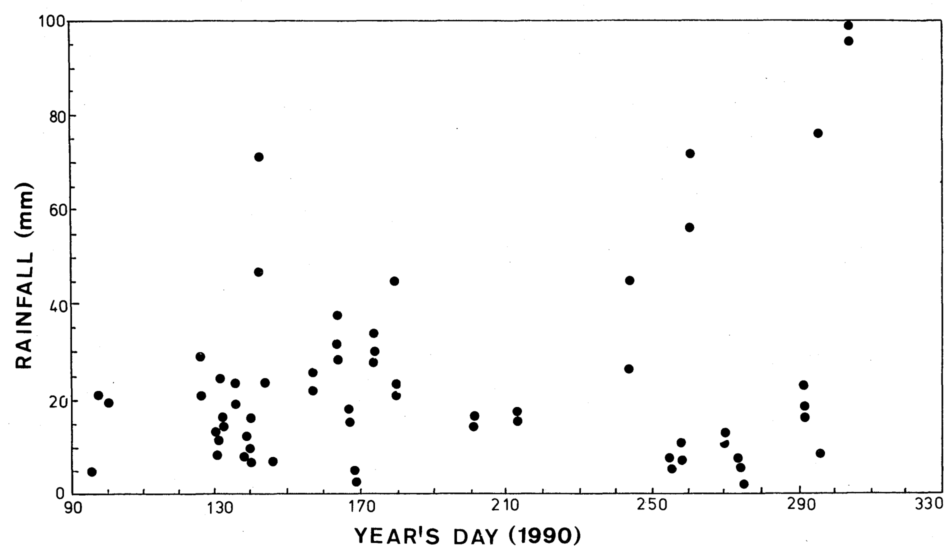

FIG. 2 Rainfall distribution within the study period.

cially wet, although the individual storms rarely exceeded 40 mm in a day. The 1990 Summer produced only a few unimportant rainfall events, while, in the Autumn, high precipitation intensities occurred (80 mm on 22 October, and 93 mm on 30 October).

Overland flow and runoff coefficients and sediment concentrations vary markedly. This variability is both temporal, i.e., throughout the study period, and spatial, according to the environmental heterogeneity that characterizes each of the plots. Runoff coefficients range from 0 to 75%. Most of the coefficients were lower than 15%. The sediment concentrations also vary greatly from less than 10 mg l^{-1} to 60310 mg l^{-1}.

Table 1 illustrates the relations between several variables for each experimental plot. An acceptable relationship exists between precipitation and runoff, except in the case of plots with null erosion. These plots have a random hydrological behavior, owing to the effect of plant interception and to the effect of a deeper soil. On the contrary, the shallowness

TABLE 1 Correlations between several variables in each experimental plot.

Correlations between	Plots					
	A	B	C	D	E	F
Rainfall / runoff (l m^{-2})	.642	.230	.708	.841	.709	.695
Runoff / sediment conc.	.044	-.166	-.288	.156	.016	.271
Runoff / soil loss (mg m^{-2})	.481	.657	.614	.632	.734	.521

A, All the plots; B, Plots with null erosion; C, Plots with mild sheet wash erosion; D, plots with severe sheet wash erosion; E, Plots with stone pavements; F, Plots with undermining around bushes.

of the soil and the almost total absence of plant cover on the plots with severe sheet wash erosion explain the close relation between precipitation and runoff. No relationship exists between runoff and sediment concentration, as one would expect, because low runoff can produce high concentrations, and, on the contrary, the highest runoff can be characterized by low concentrations, in spite of high overall erosion being recorded. Nevertheless, acceptable correlations are obtained in some cases between runoff and soil loss.

Table 2 includes information about the variability of runoff coefficients for different microenvironments. Plots with null erosion record the lowest coefficients (1.5%) because of the effect of the dense scrub cover which encourages infiltration in a deep and well structured soil and increases rainfall interception.

TABLE 2 Runoff coefficients in different geomorphic microenvironments; significance level is 0.002.

Geomorphic Micro-environment	Runoff coefficient (average, %)	Standard deviation	Monitored cases
Null erosion	1.51	5.32	83
Mild sheet wash erosion	11.94	16.71	153
Severe sheet wash erosion	19.00	15.06	118
Stone pavement	7.73	10.83	82
plots with undermining	18.04	21.48	88

The greatest runoff is produced from plots with severe sheet wash erosion (19%) and by plots with undermining (18%).In the first case, plant cover is very poor, and this accounts for the severe erosion. In the second case, though plant cover is sufficiently developed (60-80%), microtopography induces water concentration around the mats of bushes. Plots with mild sheet wash erosion and stone pavements have a lower water yield, but this is still higher than from the plots with null erosion.

TABLE 3 Analysis of Variance (ANOVA) of sediment concentration (mg l^{-1}) in runoff yielded by different geomorphic micro-environments; significance level is 0.002.

Geomorphic Micro-environment	Sediment concentration Average (mg l^{-1})	Standard deviation	Monitored cases
Null erosion	1663	1918	83
Mild sheet wash erosion	3001	5788	153
Severe sheet wash erosion	3993	4168	118
Stone pavement	3709	5238	82
Plots with undermining	4278	5510	88

Sediment yields have been analyzed in terms of both sediment concentration (mg l^{-1}) and soil loss (g m^{-2}). Both cases are very similar, although interesting trends can be distinguished. According to the geomorphic microenvironments, plots with null erosion record the lowest concentration and the lowest soil loss, followed by plots with mild sheet wash erosion, stone pavement, plots with severe sheet wash erosion, and plots with undermining (see Tables 3 and 4).

TABLE 4 Analysis of Variance (ANOVA) of sediment yield (mg m^{-2}) in different geomorphic microenvironments; significance level is 0.002.

Geomorphic Micro-environment	Sediment yield Average (mg m^{-2})	Standard deviation	Monitored cases
Null erosion	307.5	476.5	83
Mild sheet wash erosion	4 333.3	11 414.0	153
Severe sheet wash erosion	25 240.8	47 781.6	118
Stone pavement	9 124.4	19 259.9	82
Plots with undermining	26 310.5	90 533.4	88

The soil loss data (in mg m^{-2}) show that plots with null erosion behave moderately, because they must have suffered sediment outputs of 50.5 mg m^{-2} in all 153 cases. Plots with mild sheet wash erosion have had losses around 663 mg m^{-2}, i.e. 12 times more. Plots with stone pavement must have lost 1400 mg m^{-2} that is, 28 times more. Plots with severe sheet wash erosion must have lost about 3800 mg m^{-2} of sediment and, finally, plots with undermining have exported about 4600 mg m^{-2}.

DISCUSSION AND CONCLUSIONS

The use of microplots introduces important limitations associated with the progressive exhaustion of sediment and the modifications to the soil caused by their installation. However, these problems do not negate the information obtained. The purpose of the micro-plots was not to obtain accurate estimates of erosion rates for which more complex procedures are necessary, but to provide comparative data for the different geomorphic microenvironments. The results, in mg l^{-1} or in mg m^{-2}, give a good indication of the order of magnitude of erosion and confirm the validity of the geomorphic patterns selected.

The results obtained suggest the following conclusions:

- The plots with null erosion yield little water and this generally is associated with low sediment concentrations. Total soil losses, therefore, are very low.
- At the opposite extreme, plots with severe sheet wash erosion and with undermining yield a great deal of runoff that usually is highly charged with sediment. The result is a high soil loss.
- In the case of plots with undermining, which are those with the highest losses (both in terms of concentration and total output), the moderate plant cover cannot prevent high rates of soil loss. This points to the importance of the availability of a deep soil to be eroded during each storm, and the role that runoff concentration plays within the zone beneath the scrub.
- Plots with stone pavements yield a moderate quantity of runoff, even lower than plots with mild sheet wash erosion, but the water contains almost as much sediment as the more active plots. From this one can conclude that stones encourage infiltration but that runoff can still mobilize sediment, probably from between the stones.
- Plots with mild sheet wash erosion occupy an intermediate position, though, in each case, a long way from that of the plots with null erosion. This suggest that once the erosion process has begun, soil losses increase more than might be expected.

Both plant density and structure can be seen to be fundamental factors in explaining the differences between the geomorphic microenvironments. Their importance is so great that a small decrease in plant density, e.g. from 100% to 90%, is sufficient to increase the sediment yield by several orders of magnitude.

With few stones, a deep soil and a dense plant cover, the majority of the precipitation remains within the plot itself. An increase of stoniness is proof of the importance of previous soil loss, producing a decrease of infiltration capacity and of plant cover. The result is a greater runoff coefficient and, obviously, a greater soil loss. When stoniness is extremely high (close to 100%), plots with stone pavements represent the most advanced stage in the evolution of abandoned fields. In this case, a progressive exhaustion of sediment sources occurs, unless stones are removed or disturbed by the passage of animals.

The hydromorphological behavior of the different geomorphic micro-environments suggests that abandoned fields can develop in two ways. If the conditions on abandonment are good (deep soils) and if plant colonization is not interrupted, fields develop until they are covered with very close scrub, which protects the soil against erosion processes. But if the fields are located on a convex hillslope (generally with thin soil) and, moreover, if overgrazing and fires alter the plant cover, erosion rates increase markedly, a large part of the soil is removed and stones are concentrated on the soil surface. In such a way, plots with severe sheet wash erosion and with undermining show maximum negative evolution, a situation in which all factors encourage soil loss.

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