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Variability of gully erosion in a small catchment in South-west Spain

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ABSTRACT

Research on gully erosion is carried out as part of an investigation on erosional and hydrological processes in a small catchment in Extremadura, Spain. The amount of gully erosion is estimated by repeated monitoring of transverse sections since summer 1990. Data obtained so far indicate high spatial and temporal variability. High amounts of erosion are related to a channel section with active headcut retreat, whereas net accumulation occurs where the gully is already deep and wide. Present erosion, apart from headcut retreat, is related to lateral undercutting of the channel bank and bank collapsing.

Temporal variability is related with rainfall characteristics and discharge production in the channel. Important sediment losses are produced by highly intensive storms. The most important gully process in the area is shown to be related with the erosive force of flowing surface waters. Furthermore it is discussed whether present active erosion is related to abandonment of cereal cultivation in parts of the catchment about 30 years ago. It is thought that reduced soil erosion on hillslopes due to the change in landuse, and hence lower sediment supply to the channel in the last decades increased gullying.

INTRODUCTION

Research of gully erosion is carried out as part of an investigation about hydrological and sedimentological processes in a small catchment (35 ha) in Extremadura, Spain (Fig. 1). Landuse of the study basin is the so-called dehesa system, which consists of openly spaced evergreen trees with silvo-pastoral exploitation. This landuse type constitutes about 50% of agriculturally used land in the provinces of south-west Spain. The interest of studying physical processes operating in this ecosystem lies in its economical as well as ecological importance (CAMPOS PALACIN & MARTIN BELLIDA, 1987).

The project initiated in 1990 includes studies on runoff and soil erosion at hillslopes, as well as erosion and discharge production of the main channel. The present paper focusses on gully erosion which is mainly observed in a channel section of about 300 m above the catchment outlet. The principal objetives are:

- to explain the spatial variability and the processes involved in gully erosion and the cause(s) for active gullying,

- to explain the reasons for temporal variability of erosion,

- and to estimate the average rate of erosion in the channel.

For this a survey of gully cross-sections is carried out, which give information on spatial as well as temporal variability. Estimations of net erosion or accumulation are related with discharge and rainfall characteristics. Rainfall during the observation period is compared with long-term data from a meteorological station nearby.

THE STUDY AREA

The study basin Guadalperalón is located in the Cáceres peniplain, an upper miocene erosion surface (GOMEZ AMELIA, 1985). After the formation of the erosion surface rivers have incised, so that the present landscape is characterized by gently undulating slopes in the upper parts and steeper slopes approaching the collectors. Soils formed in precambrian schists or granites are brown mediterranean soils, largely eroded to give place to Lithosols.

Climate is Mediterranean, with hot and dry summers and moderately cold and humid winters. Mean annual precipitation amounts to 511 mm. The annual rainfall distribution shows a dry season lasting from June to September and a wet season from October to March.
The bottom of valleys is formed by fluvio-colluvial sediments, which are thought to be related to accelerated soil erosion in historical time. Thickness of the accumulation is one to two metres and the material is composed of silty sand and gravels. This area possesses a dense herbaceous ground cover and trees are absent. Mainly in the lower part of the catchment fluvial erosion in the form of a gully takes place.

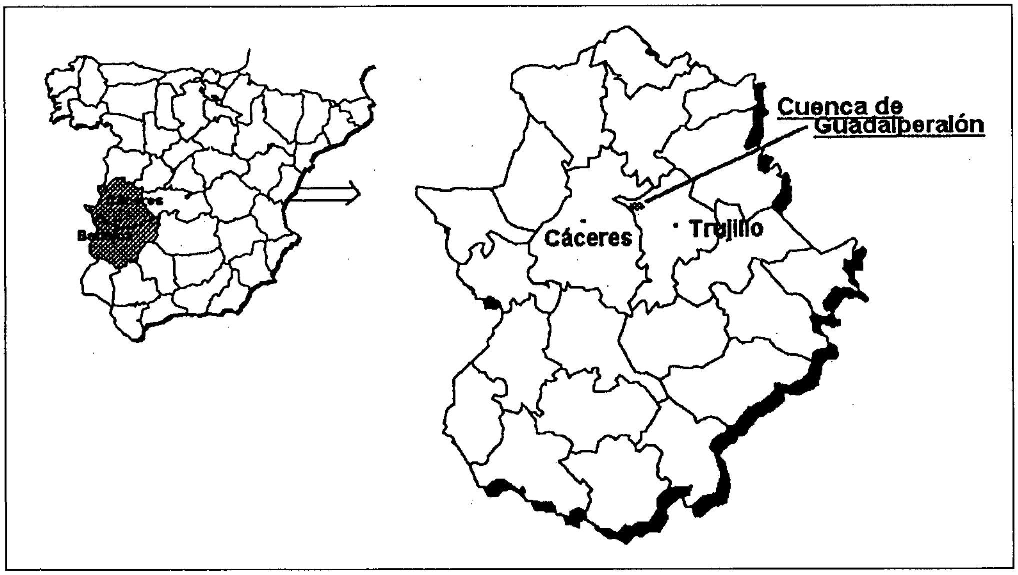

Figure 1. Localization of study catchment. Substrate in the Guadalperalón catchment is exclusively formed by schists. The silty soils are very shallow and have, with about 1,5%, a low content of organic matter. Areas with a tree cover of Quercus ilex alternate with areas lacking oaks. In the treeless zones, where rock outcropping is frequent and a soil is nearly absent, shrubs of the species Lavandula pedunculata are dominant and the herbaceous cover is very poor. At hillslopes where trees are growing herbs are dominant and soils have a depth of 5-20 cm. Slope gradients are in the order of 13% and 25% in the upper and lower parts of the catchment, respectively.

The land is grazed by sheep and pigs. Parts of the catchment were cultivated in the past and were abandoned about 30 years ago.

METHODS

The amount of gully erosion is determined with a repeated survey of topographic cross sections. For this a string is aligned horizontally between two fixed points, consisting of iron poles, at each side of the channel. It is important that the rope is tightly and horizontally fixed. The latter is controlled by a small spirit level which is hung at the rope at different points. For later measurements the string is fastened at the same height, determined as the height above the soil surface at the two iron rods. The distance between the line and the ground surface is measured at intervals of 10 cm with a metal ruler.

Location of fix points as well as headcuts were determined with an infra-red theodolite in order to establish a length profile of the channel and to determine the distance between each transect. Measurements are carried out at least once a year, usually after the rainy period,

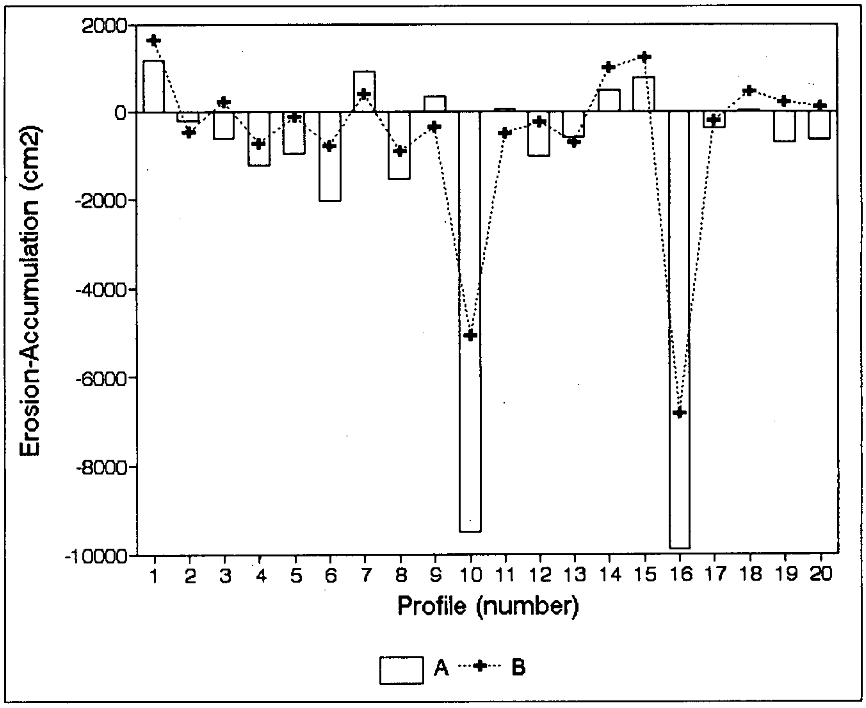

Figure 2. Erosion and accumulation of gully cross-sections: A- total from 1990 until 1993, B - caused by two rainstorms in August 1992.

that is during late spring or early summer. If exceptionally heavy rainstorms occur the survey is repeated.

Net erosion or accumulation of each cross-section is calculated (m²), and the volume is determined as the mean erosion of two neighbouring profiles multiplied by their distance. Total erosion is the sum of the sections. The profiles are surveyed at intenvals of 15 m where possible. In one part of the channel, with active headcut retreat, the transects are more closely spaced.

Rainfall is registered automatically with a tipping-bucket device of 0,2 mm resolution in intervals of 5 minutes. The gauging station at the outlet of the catchment consists of a 3 feet H-flume with a time resolution of 5 minutes using the relationship between water depth and discharge. (U.S. DEPARTMENT OF AGRICULTURE, 1979).

In order to interpret monitored rainfall events with respect to their probability of occurrence, precipitation data from the meteorological station in Cáceres are analyzed. This station is located at about 30 km distance from the study basin. Maximum annual daily ranfall data are available since 1908 and data on maximum annual 30-minute intensities exist for a period of 37 years. Recurrence intervals and probabilities are calculated using the Gumbel Extreme Value Distribution EVI (SHAW, 1988). Furthermore, the annual distribution of 24-hours and 30-minute rainfall is analyzed. The former is based on data from 1908 onwards and the latter is only available for the last 13 years.

RESULTS

Spatial Variability

Erosion along the studied channel section is highly variable.

Figure 2 shows that the total amount of erosion varies between almost -10.000 cm2 and +1.185 cm2. The two peaks of erosion (Fig.2) correspond to cross-sections 10 and 16, which are located at 7,4 and 1,1 m below headcuts, respectively. In contrast, the area immediately above a headcut is only slightly eroding (profile 11 and 17).

Figures 3 and 4 show the development of cross-section 10. It ilustrates strong erosion due to active headcut retreat, and furthermore shows lateral incision, in one case of almost 40 cm, which caused subsequent bank collapse (Fig 4).

Extent of gullying is fairly smaller in the lower channel section with net accumulation above the catchment outlet. The gully in this area typically has a flat bed and almost vertical banks (Fig. 5). Also here, the dominant process seems to be lateral incision with following bank collapse.

No scouring of the channel bed is observed, except for the area where headcuts are present. Sediment accumu-

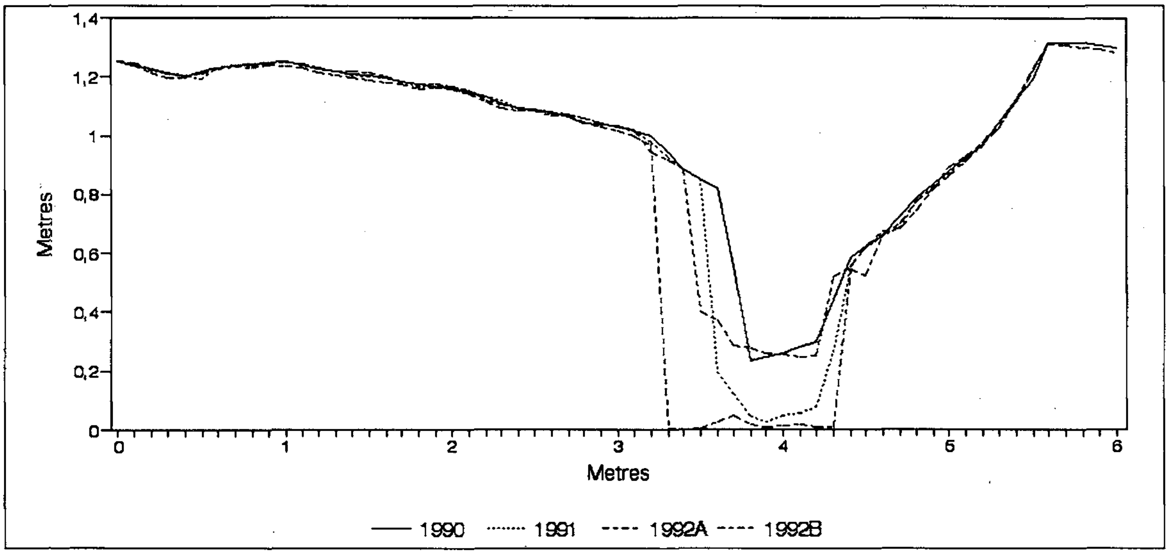

Figure 3. Profile 10, note that 1992A corresponds to June 1992 and 1992B - after two rainstorms in August.

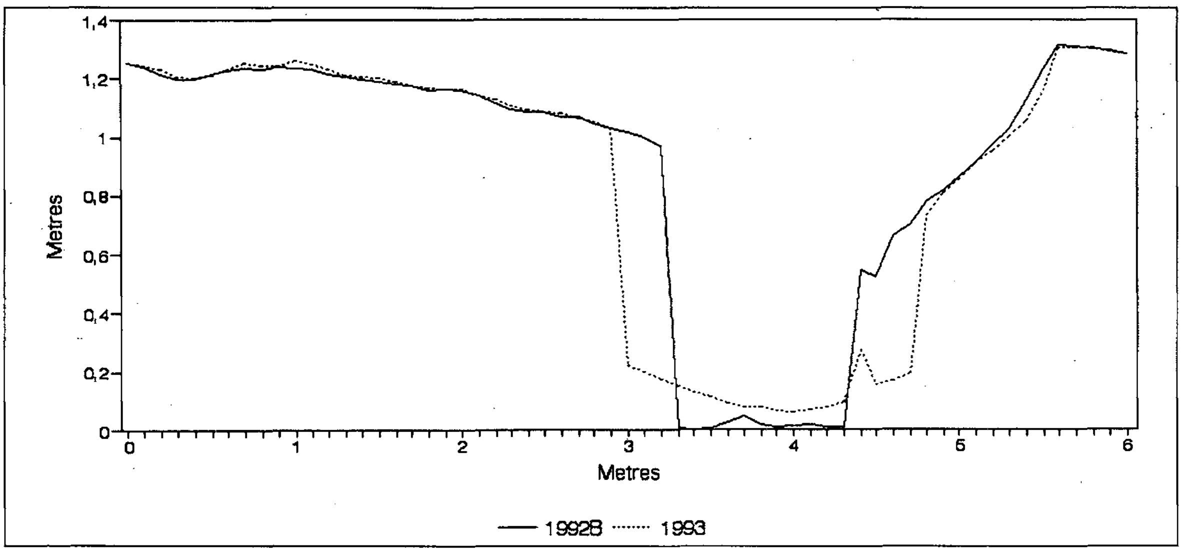

Figure 4. Profile 10, note lateral incision of 1992B causing bank collapse diring the following year.

lated in the channel bed is composed principally of sand and gravels. Figure 6 shows the estimated total volume of sediment eroded or accumulated along the gully, highlighting the described spatial variability.

Temporal Variability

There was high variability of erosion during the three years of observation. Figure 7 shows a maximum corresponding to erosion caused by two heavy rainstorms of August 1992. At some cross-sections 50 % or more of the total amount eroded, is related to these summer storms (Fig. 2). During the hydrological year 1991-92 (except August!) the channel section experienced net-accumulation. The questions related with this temporal variability are:

a) Is there a relationship with discharge and hence rainfall characteritics?
b) Do the results indicate that the dominant processes of gullying are related with the erosive force of flowing water and not, like reported by PIEST et al. (1975), due to moisture saturation causing collapse of banks and headwalls?
c)Is the erosion, which ocurred during August 1992 an extreme event and what does this mean for the estimation of an erosion rate?

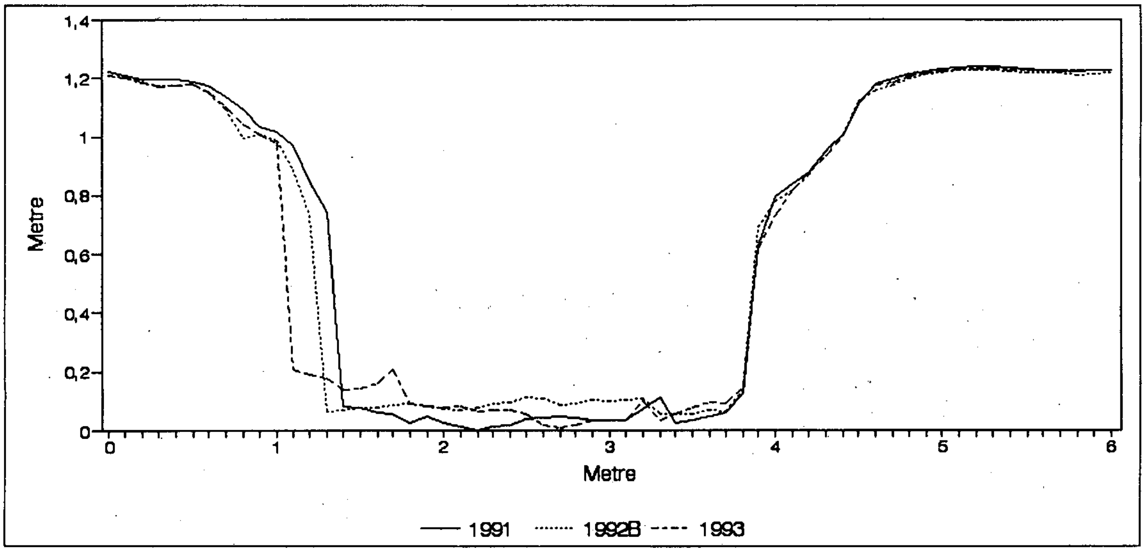

Figure 5. Profile 4, note accumulation during 1991-92, and lateral incision produced by two runoff events in August (1992B) with subsequent bank collapse.

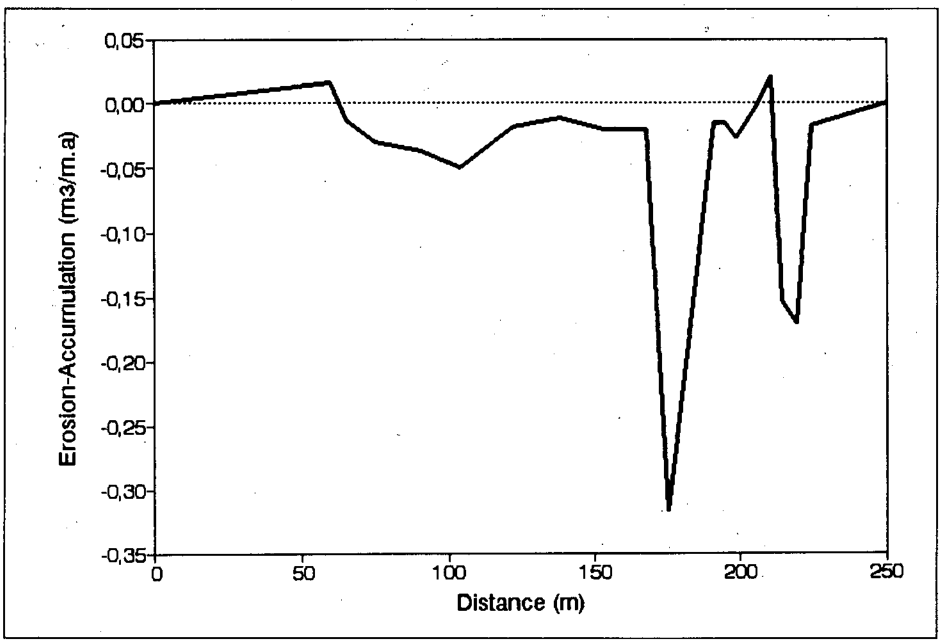

Figure 6. Estimated annual erosion or accumulation along the studied channel section.

No discharge data are available for the first years, and unfortunately also not for the heavy summer storms in 1992. Though, we know that the rainfall at 7/8/1992 of 21,6 mm and with a maximum 10-minute intensity of 60 mm/h caused overflow of the gauging station, which means that maximum discharge was at least 860 l/s. The 10-minute as well as the 30-minute maximum intesity (I-10 and I-30), which constitute the highest observed intensities during the study period, have a recurrence interval of about four years. The rainfall amount has an average annual frequency of five. This event can therefore not be considered a rare one.

Runoff in the cachment is rapidly produced due to the shallow soil cover resulting in rapid discharge production with peak flow occurring 5 to 10 minutes after the precipitation peak. Total discharge is low, with runoff coeficients in the order of 1 to 5% (Table 1). High water flow in the channel is of short duration, usually lasting just one hour or less. Baseflow is insignificant with respect to its erosive force.

Table 1 shows the few observed discharge events, which demonstrates that erosion by flowing water throughout a year is only possible during a small number of days.There is agreement between gully erosion (Fig. 7) and maximum discharge (Table 1). Only a few discharge events having low maximum flows were observed during 1991-92, when net-accumulation was determined. In contrast, highest erosion corresponds to the two rainstorms of summer 1992, and fairly high erosion occurred during 1992-93, when several discharge events of high peak flows were registered.

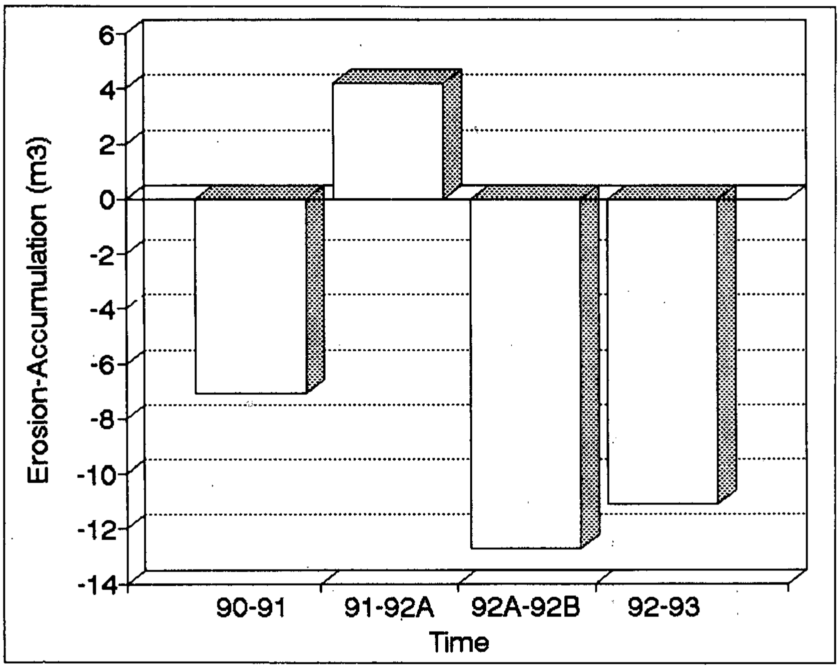

Figure 7. Variability of estimated gully erosion. Each column corresponds to the total of a hydrological year, except for 92A-92B, which is the result of two rainstorms in August.

Linear regression analysis between maximum discharge and rainfall shows best relationship with I-30 (R=0,5, significant at the 0,0000 probability level). Therefore, I-30 data during the study period (Table 2) are compared with average annual frequencies of the meteorological station in Cáceres. During 1990-91 and 1992-93 no I-30 > 20mm/h was observed, which has an a avevage frequency of 1,7. However, 1992-93 had a higher number of moderate intense storms. If the four rainfall events of August 1992 are not considered, the year 1991-92 had a below average number of intense rainfall.

The above described indicates a relationship between rainfall, discharge and gully erosion, and hence suggests that the dominant process of gullying is due to the erosive force of flowing water. In addition, bank collapses have been observed, which were due to heavy lateral incicion of the channel bank.

However several limitations of interpretation exist, especially if short-term data is used for estimating average gully erosion. There is, with two years, too few discharge data available. This is particularly important for the Mediterranean area with its high rainfall variability. Annual rainfall during the observation period was below average (Table 3). The area suffered a prolonged drought starting in April 1991 and lasting until March 1993. As a result the herbaceous ground cover was reduced, culminating during summer 1992 with an almost bare soil surface. The effect of the drought on gully erosion cannot be explained yet. On one hand, reduction of the vegetation cover on hillslopes may increase runoff production and therefore increase peak discharge. Also vegetation cover along the gully channel was reduced which may have increased erosion. Though the latter seems less important as high erosion occurs on channel banks, which are nearly void of vegetation. The heavy rainstorm

On the other hand, we did not experience a humid year with high precipitation totals during succesive events, nor any exceptionally high rainfall amounts (Table 2 and 4), which might produce even higher gully erosion than the observed one.

Average rate of erosion in the channel is 9,41 m^3 or 0,27 m^3/ha. On the basis of the cross-sections the total volume of sediment eroded in the channel was calculated. Taking 9,41 m^3 as the average rate of erosion, it is esti-

Table 1. Discharge and rainfall of Guadalperalón catchment during the hydrological years 1991-92 and 1992-93. PTOT - rainfall total of event, I-10 and I-30 - maximum 10-minute and 30-minute intensity, Q - discharge total, KOEF - runoff coefficient, Q-max - maximum discharge.

DATE	PTOT (mm)	I-10 (mm/h)	I-30 (mm/h)	Q (m^3)	KOEF (%)	Q-max (l/s)
30/03/92	15,6	25,2	12,4	88,6	1,6	49,5
01/12/91	30,2	9,6	7,6	228,6	2,2	41,9
02/04/92	10,1	8,4	7,9	49,1	1,4	17,0
19/02/92	19,6	4,8	4,8	33,5	0,5	6,3
15/06/92	15,4	15,6	12,4	13,6	0,3	3,0
02/04/92	20,2	8,4	4,4	18,6	0,3	2,5
07/08/92	21,6	60,0	32,8	884,6	11,7	860,0
24/04/93	20,4	24,0	14,2	280,7	3,9	295,0
29/10/92	15,8	28,8	14,4	347,2	6,3	226,3
26/09/92	26,4	19,2	12,8	215,9	2,3	86,9
14/04/93	7,8	33,6	14,4	145,4	5,3	74,2
19/10/92	19,0	9,6	8,0	198,7	3,0	73,5
16/10/92	12,2	16,8	9,2	79,7	1,9	69,3
11/10/92	9,2	15,6	5,4	149,4	4,6	62,2
15/12/92	10,8	10,8	8,8	42,4	1,1	28,4
03/05/93	9,2	20,4	16,4	59,3	1,8	24,1
26/05/93	9,4	21,6	10,4	49,1	1,5	17,0
04/12/92	9,4	22,8	12,4	38,7	1,2	17,0
19/12/92	10,2	8,4	7,2	34,9	1,0	14,7
30/04/93	13,8	4,8	4,8	27,1	0,6	2,7

mated that the present gully could have been formed during the last 70 years.

Monitoring of soil loss indicates a fairly low erosion rate, with about 300 g per metre hillslope. Parts of the catchment were cultivated in the past and abandoned about 30 years ago. It is thought that slope erosion has been decreasing with abandonment. Consequently the amount of sediment delivered to the channel decreased. On the other hand, overland flow production is probably equally high, because no increase of the infiltration capacity of the shallow soils can be expected. It is therefore possible that gully formation, or activation of erosion of an existing channel, occurred during the last decates in relation with land abandonment, because a decrease of sediment concentration produces an increase of the erosive force of flowing water. This assumptions seems possible as it can be assumed that the gully is of fairly young age.

CONCLUSIONS

Spatial variability along the studied channel section is high with maximum erosion occurring in an area with active headcut retreat.

The results indicate that the most important gully process in the area is related with the erosive force of flowing water produced by high magnitude and low frequency rainstorms. Gullying is therefore similar to the processes described by LEOPOLD et al. (1964).

At present time the channel is actively eroding. It is possible that gullying was initiated during this century, with an increase of channel erosion due to abandonment of cultivation.

Variation of total erosion with time can be related to variation in rainfall characteristics. However giving the high variability of precipitation in the area, the calculated average rate of erosion (0,24 m^3/ha) can only be considered a crude estimate.

Table 2. Frequency of rainfall amount and rainfall intensity in the study catchment. I-10 and I-30 is 10-minute and 30-minute maximum rainfall intensity, Day - daily rainfall.

	>50	40-50	30-40	20-30	10-20	5-10	0,2-5	Total	Year
I-10				1	6	19	67	93	90-91
(mm/h)	1	1	1	3	6	13	56	81	91-92
			1	5	12	10	57	85	92-93
I-30					6	9	78	93	90-91
(mm/h)			1	1	5	8	66	81	91-92
					9	12	64	85	92-93
Day		1		2	11	9	70	93	90-91
(mm)			1	2	10	13	56	81	91-92
				2	11	15	57	85	92-93

Table 3. Annual rainfall characteristics at Cáceres meteorological station (hydrological years 1907/08 - 1992/93), and annual rainfall during the study period.event of August 1992, producing heavy gullying, coincide with lowest herbaceous ground cover. Since it is the only event of such magnitude during the three year period, no conclusions can be made yet.

		Year	Rainfall (mm)
Mean	511		
Median	495		
Minimum	247		
Maximum	981	1990-9	477
Lower quartile	399	1991-92	407
Upper quartile	597	1992-93	380

Table 4. Daily rainfall and 30-minute intensity for different recurrence intervals.

Recurrence Interval (years)	Daily Rainfall (mm)	30-minute intensity (mm/h)
5	52,1	34,8
10	61,8	40,8
20	71,2	46,5
30	76,8	50,1
50	83,7	54,3
100	92,5	59,8

ACKNOWLEDGMENT

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