EFFECT OF TOPOGRAPHY ON RETREAT RATE OF DIFFERENT GULLY HEADCUTS IN BARDENAS REALES (NAVARRE, SPAIN)

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1. Introduction

One of the most important aims of (gully) erosion models is to relate potential soil loss with definable topographic parameters. Precisely, contributing area upslope of the gully headcut (C_{area}) and slope gradient (S) are recognized as the most important topographic factors related to gully erosion (e.g., De Santisteban et al. 2005). As regards different measuring techniques, photogrammetry has proved to be a very useful tool to compute topographic factors such as those mentioned above (e.g., Oostwoud Wijdenes et al., 2000).

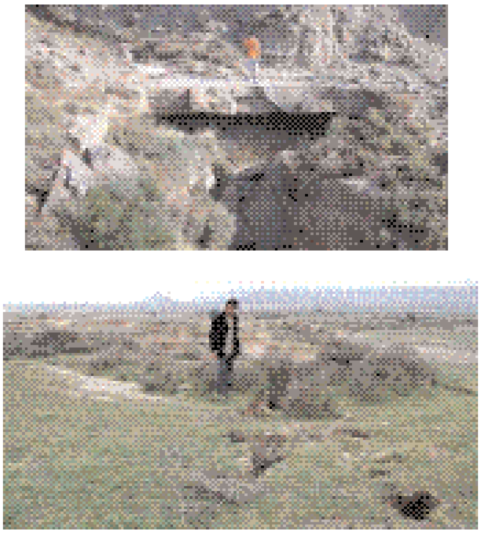

Fig. 1. Above: sandstone gully headcut. Below: piping associated gully headcut.

In Northeast Spain, gullying is a widespread phenomenon. This type of erosion is especially intense in Bardenas Reales (Navarre) where at least two major typical kinds of gully headcut are present. A first group developed in soil material (named, conventional gully headcut), and second group of gully headcut with a sandstone layer as a top horizon (named, sandstone gully headcut) (Fig. 1). In addition, within the former group, we can distinguish a subgroup of gully headcuts developed in soils particularly prone to piping and tunnelling due to the dispersive condition of the materials (named piping associated gully headcut) (Fig 1). In this situation, a question arises: to what extent simple topographic parameters account for the retreat rate of the different kind of gully headcuts observed in the region of Bardenas Reales? The aim of this study was to investigate and gain insight in this issue.

2. Material and methods

A 300-ha watershed, namely Cantalar, within Bardenas Reales, was selected for this study (Fig. 2). This was formed in Tertiary Continental and Quaternary materials (Del Valle and Del Val, 1990). The average slope grade is *ca*. 9% and maximum slope is *ca*. 74%. Height 385 m on average (from 325 to 450 m) and. Annual precipitation is 402 mm.

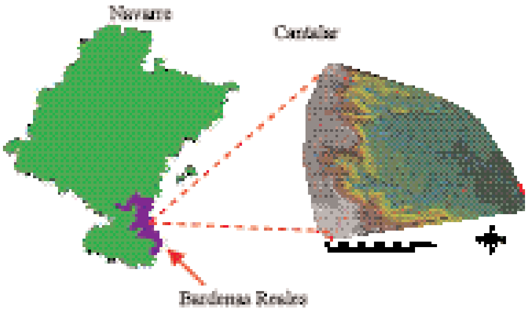

Fig. 2. Location of the Cantalar watershed.

Aerial photographic stereo-pairs covering the study area were used. These were taken on 1976 (1:17,500), 1982 (1:13,500) and 2003 (1:20,000). Manual restitution of photographs was carried out by a public enterprise. 1m-resolution DEMs were obtained by triangular interpolation (Triangular Irregular Network). From the aerial photos and the DEMs, ortho-photographs with a final resolution of 0.40 m were made. The geocoding of these scenes had a Root Mean Square error of 0.13 m in both X and Y directions and of 0.18 m in Z (altitude). Different kind of gully headcuts (as described above) previously recognized by field survey were identified in the photos.

Several topographic parameters related to every gully present in the field were calculated from the DEM of 2003.

Furthermore, from the ortho-photographs, volumetric headcut retreat rates were determined as the product of the lineal retreat and a representative section of each headcut.

Finally, simple models to estimate volumetric gully headcut retreat rate through topographic parameters were carried out by regression analysis.

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3. Results and Discussion

Average gully headcut retreat rate (GHRR) for *conventional* and *sandstone* gully headcuts, for the period 1967-2003, was around 4 and 2 $m^3\ ha^{-1}\ y^{-1}$, respectively. However, this figure arises to about one order of magnitude for *piping associated* gully headcut (Table 1). This is in agreement with GHRR of 12 permanent gullies reported by Vandekerckhove et al. (2003) in southeast Spain for a time period of 20-40 years: between 1-5 $m^3\ ha^{-1}\ y^{-1}$. Nevertheless, they also reported a GHRR of *ca*. 90 $m^3\ ha^{-1}\ y^{-1}$ in two others gully headcuts.

Contributing area is the only topographic parameter high (and positive) correlated (R= 0.97) with volumetric retreat rate, but only for *conventional* gully headcuts (Fig. 3). This is in agreement with previous findings of Vandekerckhove et al. (2003) (Fig. 3). The reason why average slope gradient of the contributing area is not related with gully retreat is uncertain.

C_{area}, surrogate of discharge at the inlet of headcut, does not significantly account for *sandstone* GHRR as soil is somewhat protected against erosive runoff by a low erodible top layer. GHRR is then lower in *sandstone* gully headcuts than in *conventional* gullies (Table 1). In the other hand, *piping associated* gully headcuts are not well related to C_{area} (Fig. 3) since piping and tunnelling are mainly dependent not only on intrinsic characteristics of the material but also on subsurface flow energy (Bull and Kirkby, 2002).

Table1. Average gully headcut retreat rates (GHRR).

	G $m^{3}\ y^{-1}$	H $m^{3}\ y^{-1}$	R $m^{3}\ y^{-1}$	R $kg\ m^{-2\dagger}\ y^{-1}$	$n^{\dagger\dagger}$
	Date				
Headcut	1967 1982	1982 2003	1967 2003	1967 2003	
Sandstone	0.52	0.37	0.43±0.29	0.29	16
Piping assoc.	1.17	1.18	1.18±0.15	9.36	3
Conventional	1.26	0.92	1.04±0.55	0.57	21

† area (m^2) refers to C_{area}. Bulk density = 1500 kg/m^3. ††n: total number

Unlike *conventional* gully headcuts, *piping associated* gully headcuts may present an important erosion rate despite a relative small C_{area}. This leads to very high GHRR values when the headcut erosion is expressed in terms of unit of contributing area (see the last column in Table 1). Therefore, caution should be taken to avoid underestimate the erosion rate of this kind of gully headcut when the estimation is based on the contributing area.

4. Conclusions

In Bardenas Reales and for a time period of few decades, gully erosion by headcut retreat is an important source of sediment: around 2-4 $m^3\ ha^{-1}\ y^{-1}\ m^3$. However, in dispersive soil where piping erosion is a notorious process, the last figure can easily be one order of magnitude higher. Statistical analysis showed that volumetric gully headcut retreat rate of gullies developed in soil material (i.e., *conventional* gully headcuts) are well correlated with the contributing area upstream of the headcut. This confirms the importance of runoff discharge entering the headcut. This finding was put forward and documented by Vandekerckhove et al. (2003). Nevertheless, our study shows that when gully headcut development is either mainly controlled by piping or tunnelling erosion or gullying is somewhat hampered by a top layer of a consolidated material, simple topographical parameters do no account for the medium-term (few decades) headcut retreat rate.

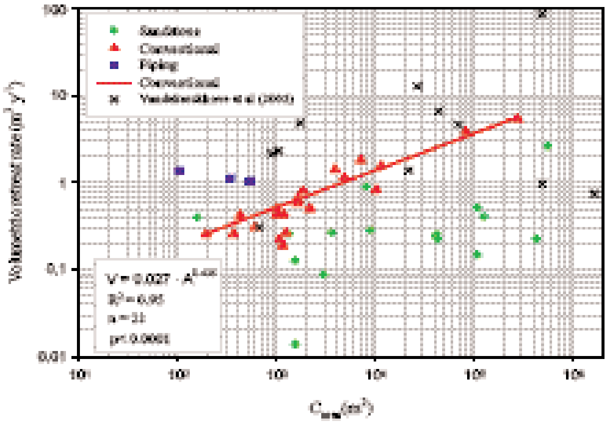

Fig. 3. Power relationship between contributing area (C_{area}) and volumetric gully retreat rate for different kind of headcuts.

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