EFFECTS OF SLOPE PROCESSES AND MANAGEMENT IN GULLYING

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1. Introduction

Most erosion studies have been typically done in rill and interrill areas because the complexity of gullies and their large size have made their study very difficult.

Morgan (1979) and Hudson (1985) define gullies as water courses with very steep walls that are submitted to spasmodic flows during storms. More recently, permanent gullies are defined as channels too deep to be ameliorated with ordinary farming tools (Soil Science Society of America, 2001; Poesen et al., 2003). Gullies range from 0.5 m to up 25-30 m depth.

FAO (1978) indicates that gully evolution takes place by means of several processes, which can act together or separately. Schnabel (1997) points out that the main processes on gully erosion are headcut retreat, channel deepening, undermining and scouring. Bull and Kirkby (2002) and Poesen et al., (2002) show that most gullies expand by headcut retreat and sidewall retreat. In our study area there is piping as another important process on gully erosion (Desir et al., 2005; Desir and Marín, 2006). Piping has been described as one of te most important process acting on dispersive clays (Martínez-Casanovas et al., 2004). In our study 7area where dispersive clays are common gullies reach a great extension. To know and understand the way in which each processes interact can help us to explain the landform and which factors influence on the origin and evolution of gullies. Having two different behaviours related to slope exposure as it is the case, it is possible to highlight the differences in morphology, development and processes involved. To reach this objective piping, slope and thickness have been measured on both slopes between more than 90 gully heads although only the most representative piping areas have been represented.

2. Regional setting

The Bardenas Reales is an erosive depression located in the south-eastern margin of Navarra Province, in the middle-western sector of the Tertiary Ebro Basin. The erosional depression takes up 415 km^2 with steep slopes at the margins and deeply dissected valleys at the centre. The geology is built in Tertiary and Quaternary sediments.

The Tertiary materials, of Miocene age, correspond to different lithologies: Lerín Gypsums, Tudela Formation and Limestones of Sancho Abarca (Castiella et al., 1978; Gracia, 1985).

Quaternary deposits are Holocene clays and silts, originate from erosion of the surrounding clays of the Tudela Formation. Since this material is poorly lithified it can be easily incised. In these sediments deep gullies have developed that mobilize large quantities of material during important rainfall events. Within the Holocene materials, 3 levels can be differentiated: an upper laminated unit, an intermediate massive unit and a lower laminated unit (Marín and Desir, 2004). The upper laminated unit is composed of an alternation of laminar and massive layers of clays, covered by a biocrust and crowning by a charcoal level. The massive intermediate unit is loamy with a high density of pipes and rills. It also shows well-developed popcorn morphologies. The lower laminated unit is made of clays with laminar structure alternating with massive layers.

Climatically, it is a semi arid zone with mean annual precipitation of 350 mm of stormy, the annual distribution showing two maximum. The mean annual temperature is 13°C.

3. Description

The studied site is a tabular relief (Cabecico Losado), 300 m a.s.l. and 6.60 Ha in surface (Fig. 1) that is composed of Holocene materials and crowned by a 30 cm thick soil profile. At present half of the area is managed as a crop field with cereal in fallow and the rest is covered by shrubs. On cropland the soil profile has been nearly removed and the upper Holocene level is exposed. The area is drained by two permanent gullies surrounding the platform. These gullies act as a local base level. The northern gully is placed over the Tertiary formations which control and limit it. On the other hand, the southern one develops over sediments that filled previously existing gullies. This last gully is permanent with steep slopes evolving by topples, undermining and headcut retreat.

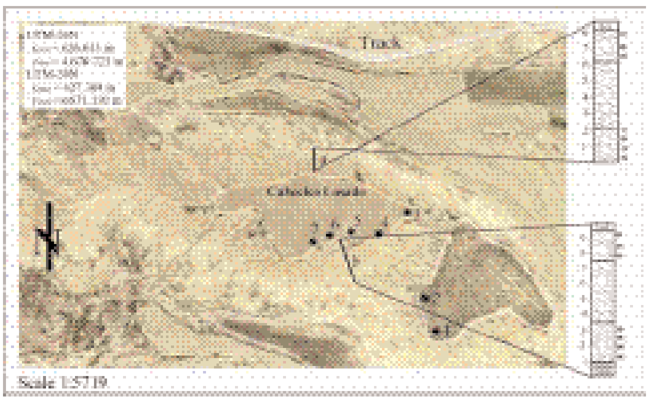

Fig. 1. Sketch of the studied zone included the schematic stratigraphic columns on the northern and southern margin and the points where pipes have been measured.

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The slopes of the tabular relief show two different erosional behaviours related with slope exposure and the vecinity of first order gullies. Because gullies act as drainage collectors of the area, the more or less proximity to those gullies will affect slope processes and form. On both sides, mesa slopes are developed over the three Holocene levels despite the southern one that ends over gully sediments actually incised by a permanent gully (Fig.1). Gentle slopes of the northern face, 10º, show a high sinuosity degree and low hierarchy order (Table 1). Although the south facing slope is steeper, 40º, rills and gullies do not reach a high sinuosity showing straight and deep low order channels.

Table 1. Differences between north (N) and south (S) slopes.

	Thickness	Slope	Rill order
Upper (N)	2.00 m	10-11°	2
Massive (N)	4.10 m	13°	3
Lower (N)	2.00 m	8°	2
Upper (S)	2.00 m	45°	2
Massive (S)	4.00 m	42°	2-3
Lower (S)	2.5 m	35°	2
Filling Sed	1 m	0°	1-0

In both cases piping processes are restricted to the gully headwall where it takes place in the upper laminated unit. Physico-chemical properties show high SAR and ESP values across the slope profile (Desir et al. 2005). In this location piping is reported on the upper laminated unit and on the intermediate one. Piping related to gully heads is found on the upper laminated level whereas piping on the intermediate one are not. Although piping is present on both sides the highest degree is reached on the southern part.

4. Discussion

Rills and gullies show a different trend and evolution in relation to slope exposure, gully vicinity and land management. Gully evolution can be separated in two parts; headcut retreat due to piping and fast channel deepening in the first slope segment and channel widening and slope processes in the middle lower segment.

It is significant that piping only develops over the south facing slopes of both parts of the mesa, on both cropland and scrubland. The highest piping density is located on the platform surface close to the scarp where the hydraulic gradient is higher. Minor pipes are also present in the middle slope segment where the intermediate massive unit crops out. These minor pipes play an important rule on rilling processes and may control the higher stream order and slope retreat of this unit.

One significant factor is the role played by the first order gullies acting as a local base level. The gully on the south-facing slope from the southern part is much deeper and has a greater drainage basin area than the northern one. The gully depth controls slope steepness and therefore final runoff velocity. In the northern one, slopes are smoother and rills show a high sinuosity. On the contrary, on south slopes rills draw straight and steep profiles that greatly increase channel incision and runoff velocity in a short space lapse. An inverse relationship between sinuosity and piping density exists. With increasing sinuosity slope gradient and runoff velocity decrease and therefore piping may be neglected.

Pipes are located along the southern rim. The biggest ones are situated on points 1, 2, 3 that correspond to shrub areas. Nevertheless, it would be better developed on the crop field because the soil profile, acting as surface protection, has been erased by farming. During farming activities, pipes could be periodically filled so they aren't as well developed as those on the natural shrub area. This could be the reason for not developing on the crop field.

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