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The origin and development of a valley bottom gully in a small rangeland catchment; influences of land use in the growth model

Álvaro Gómez Gutiérrez, Susanne Schnabel, Francisco Lavado Contador, Ángel Jariego García

Geoenviromental Research Group, Physical Geography Area, University of Extremadura, Cáceres, Spain
e-mail: alvgo@unex.es

Abstract: In the present paper, 8 aerial orthophotographs were used for analysing the evolution of a valley bottom gully and its relationship with land use and vegetation cover in SW Spain. In addition, the growth model observed was compared with the literature. Results showed an increase in the area affected by gullying during the period by 314 m^2 and a clear relationship between the areas affected by gullying and land use intensity was found.

Keywords: gully erosion, aerial photographs and orthophotographs, land use and vegetation cover

Introduction

Gully erosion is an important soil degradation phenomenon in a wide variety of environments around the world. Since 90s few studies have dealt with gullying in rangelands of the Iberian Peninsula (Schnabel & Gómez Amelia 1993, Schnabel 1997, Gómez Gutiérrez et al. 2009a, b). In these environments, gullies are frequently located in valley bottoms where they erode shallow alluvial deposits, found in the concavities of first or second order catchments of the widespread peneplains. These soils play a key role controlling the hydrological behaviour of the catchment (Ceballos & Schnabel 1998) and retaining water by reducing drainage.

The intensity of gullying processes can be defined as a function of lithology, soils, climate, topography and land use and vegetation cover (Poesen et al. 2003). The influence of land use and vegetation cover is highly variable and depends on the density of vegetation cover and vegetation morphology (Rey et al. 2004). Several recent studies have approached the impact of gradual or sudden changes in land use and exploitation systems on the initiation and development of gullies (Poesen et al. 2003). In this line, Harvey (1996) relates the advance of gullies during the 9th and 10th centuries in the UK to an anthropic change in vegetation cover. In a similar way, Bork et al. (1998) attribute the growth of large gully systems in central Europe during the 14th century to high human pressure together with extreme rainfall events. In southern Spain Faulkner (1995) relates the expansion of almond crops with the increase of gully density. In the Spanish *Penedés* region (NW) gullying occurs mainly in vineyards (2000). In Italy, Zucca et al. (2006) described the impact of agricultural actions on the activity and density of gullies. However, not only agriculture has been reported of being responsible for gullying. Overgrazing in rangelands has been attributed to the formation of large gully systems (Webb & Hereford 2001, Podwojewski et al. 2002, Gómez et al. 2003, Nyssen et al. 2004).

On the other hand, a previous work by the authors (Gómez Gutiérrez et al. 2009b) has highlighted the influence of land use and vegetation cover determining gully erosion processes. Authors found a close relationship between gully erosion and land use, especially with the amount of cultivated areas within the catchment where the gully is and also grazing intensity. Another recent work in rangelands of SW Spain has showed the vegetation cover as one of the most important variables determining the existence of gullies in these environments (Gómez Gutiérrez et al. 2009a).

The main objective of this work is to analyze the evolution of a valley bottom gully and its relationship with land use and vegetation cover in a small rangeland catchment completing the data presented by Gómez Gutiérrez et al. (2009b). In this previous work, 6 aerial orthophotographs were used to map gullies together with land use and vegetation cover. In the present paper, 2 aerial orthophotographs for the years 1982 and 1984 are used to complete the series and to add knowledge about the evolution of the permanent gully in the *Parapuños* experimental catchment. In addition, growth rates of the gully are compared to existing growth models presented in the literature, such as the asymptotic model (Graf 1977), the cyclic model based on extrinsic causes (e.g. Huntington 1914) and the cyclic model based on intrinsic causes (e.g. Thornthwaite et al. 1942). Theories about the origin of the gully are also presented and discussed.

Study area

The study was carried out in the *Parapuños* experimental catchment (99.5 ha), located in SW Spain (Fig. 1), representative of the peneplain geomorphic unit and the dehesa land use in SW Spain. The topography is undulated with an average altitude of 396 m a.s.l. and a mean slope of 7.91%, ranging from almost flat surfaces in the valley bottoms (0.0%) to 11.9% at the hillslopes.

The gully is a second order discontinuous channel that drives ephemeral flows. The gully presents a total length of 996 m (in 2006) with a tributary joining the main branch at 174 m from the basin outlet. Average dimensions of the gully were 3.3 m width and 0.6 m depth (in 2001). A total of 22 headcuts could be observed along the channel, including one in the upper limit and 2 very active headcuts on the tributary. The valley bottoms are filled by an alluvial deposit with a thickness of approximately 1.5 m. Soil formation in these sediments has been very reduced, showing only a shallow *A* horizon, the soil being classified as a *Regosol*. The soils in the catchment are developed mainly on schist, have low organic matter content and depending on their depth can be classified as *Leptosols* and *Cambisols*. In the upper part of the catchment pediment deposits, composed of gravelly sand and loam give rise to soils with an argillic *B*-horizon (*chromic Acrisols*). All of the soils have low organic matter content, low pH and very low phosphorous content.

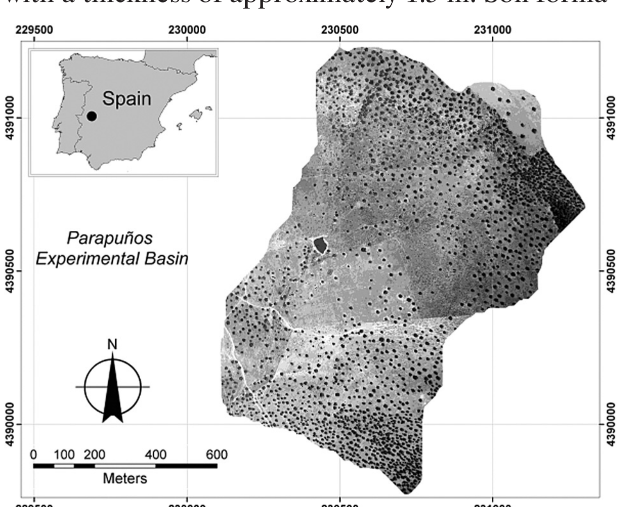

Fig. 1. Location of the study area

Climate is Mediterranean and presents a pronounced dry season. Rainfall shows a high annual and interannual variability with an annual average of 510 mm. Regarding land use, the catchment belongs to the savannah-like wooded rangelands that occupy large parts of the southern half of the Iberian Peninsula and are known as *dehesas* in Spanish language. The tree layer in the catchment is dominated by Holm oaks (*Quercus rotundifolia*) of varying density (with an average of 21 trees ha^{-1}) and the herbaceous layer is characterized by therophytes. At steeper slopes shrubs are frequent (mainly composed by *Retama sphaerocarpa, Cytisus multiflorus* and *Genista hirsuta*). The exploitation system is essentially based on sheep and pig ranching.

Methodology

A complete description of the methods used can be found in Gómez Gutiérrez et al. (2009b). The basic information of this work comprises maps of gullying, land use units and vegetation cover which were produced for the years 1945, 1956, 1982, 1984, 1989, 1998, 2002 and 2006 using aerial photographs. Table 1 presents the characteristics of these photographs. It was possible to acquire directly digital orthophotographs for the years 1998, 2002 and 2006. For the rest of the years (1945, 1956, 1982, 1984 and 1989) it was necessary to rectify the aerial photographs. The first step consisted in digitizing the original images with a resolution of 21 μm using a photogrammetric scanner and then orthorectifying the photographs.

The determination of the area affected by gullying was based on digitizing on screen and on the orthophotographs gully walls and headcuts. Several techniques of digital image treatment (such as edge detection algorithms and automatic and manual equalization of the histogram) were necessary at this stage. Orthorectification can provide high degrees of geospatial accuracy, however is not commonly employed by geomorphologist because it requires sophisticated software and is generally more labor and data-intensive (Hughes et al. 2006). The quality and precision of the resulting orthophotographs were tested. A deep description of this procedure is pre-

Table 1. Characteristics of the aerial photographs and the resulting orthophotographs. In grey, new data added to the previous work by Gómez Gutiérrez et al. (2009b)

Date	Photography Scale	Orthophoto-graph pixel size (m)	Error in area measurements (%)	Colour mode
28–30/09/1945	1:44,000–43,000	0.5	6.0	Grey scale
17/04/1956	1:35,000	0.5	2.5	Grey scale
06/1982	1:18,000	0.5	3.7	Grey scale
10/1984	1:30,000	0.5	4.2	Grey scale
08/1989	1:20,000	0.5	1.2	Grey scale
02/1998	1:40,000	1.0	2.7	Grey scale
19/06/2002	1:6,000	0.2	0.9	RGB
26–29/04/2006	1:30,000	0.5	1.1	RGB

sented in Gómez Gutiérrez et al. (2009b). On the other hand, a catalogue of possible land uses and associated vegetation covers for the last 60 years was constructed using information of different sources: field observations (since 2001), interviews of historical witnesses (owners and farmers) and studies realized by Plieninger (2006) and Plieninger & Harald (2006). Starting from this catalogue, a hierarchical legend was built (Fig. 2). Afterwards, each of the orthophotographs was interpreted and homoge-

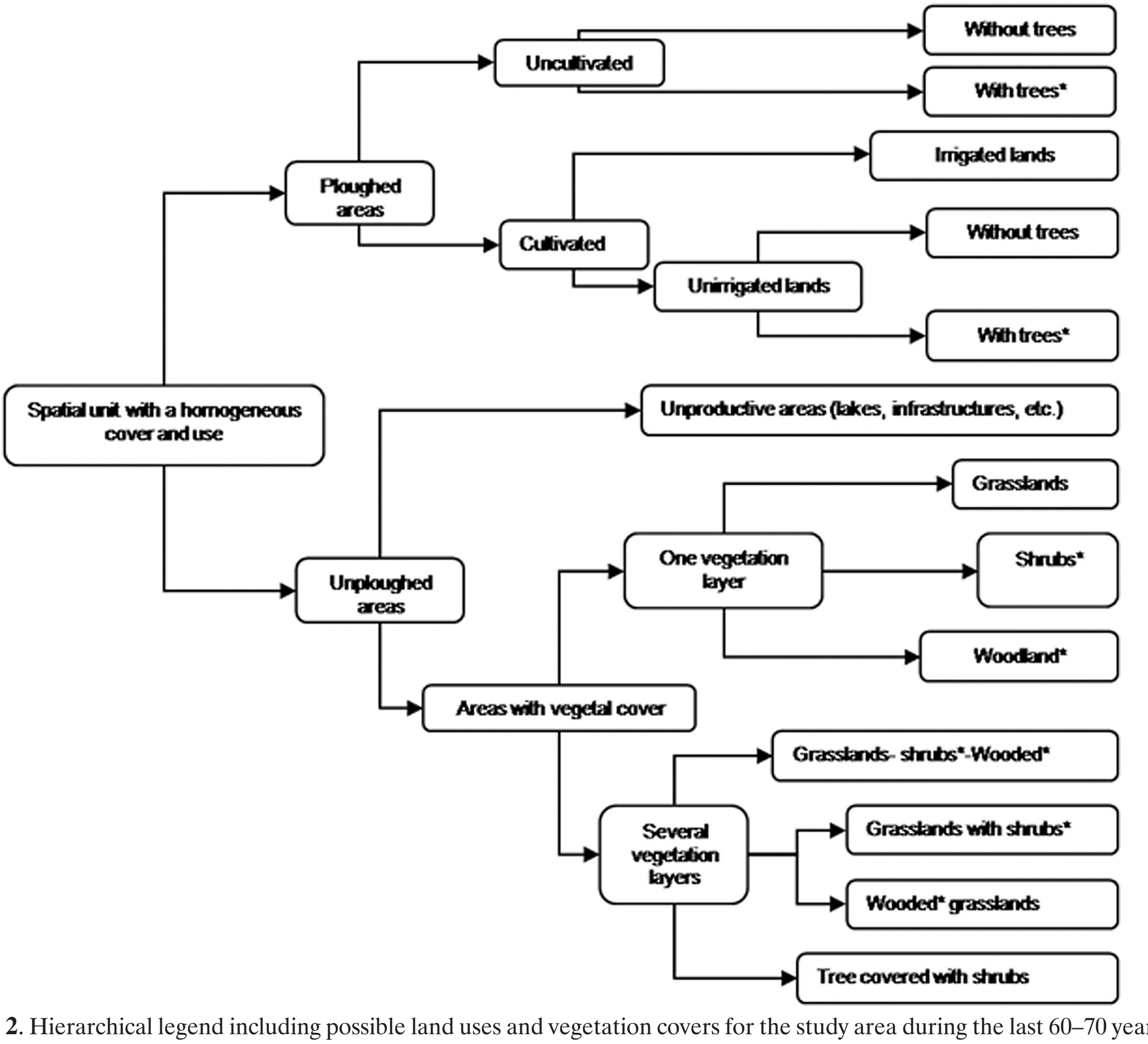

Fig. 2. Hierarchical legend including possible land uses and vegetation covers for the study area during the last 60–70 years (after Gómez Gutiérrez et al. 2009b). *Four vegetation cover density classes were defined: disperse (up to 10%), low density (between 10–35%), dense (between 35–75%) and very dense (above 75%)

neous vegetation cover units were delimited based on texture, colour-tonality and presence of elements (analyzing their density, size and form). Finally, each homogeneous vegetation cover unit was associated with a land use of the catalogue, obtaining in this way the maps of land uses and vegetation covers. It was necessary to make some changes in the catalogue of land uses and associated vegetation covers proposed by Gómez Gutiérrez et al. (2009b) due to the observation of a new land use unit in the orthophotograph of the year 1982: ploughed-uncultivated areas (Fig. 2).

Results

The results showed an increase in the area affected by gullying during the study period by 314 m^2 (5.2 $m^2\ yr^{-1}$), reaching a maximum in 1956 with a surface of 1560 m^2. During PI (1945–1956) almost half of the catchment was transformed to cropland (41.8%) including the immediate vicinity of the gully. Therefore, the increase of the area affected by gullying during PI coincided with the land use change in the catchment. In fact, the gullied area and the cultivated surface followed a similar evolution during the whole study period (Fig. 3).

During periods II, III and IV (1956–1989) the area affected by gullying decreased from 1,560 m^2 to 688 m^2. However the decrease in the gullied area was not constant and happened mainly after 1984 and before 1989. After 1982 and before 1984, most of the agricultural activity was abandoned and regeneration of the natural vegetation took place, especially in the valley bottoms. After 1998 the gullied area increased again with rates of 34.4 and 68.1 $m^2\ yr^{-1}$ for PIV and PV, respectively. This growth coincided with an increment of the cultivated surface in the catchment. However, vegetation cover in the catchment was not modified substantially by cropping. It is thought that the evolution of the gullied area was probably related with an increase in livestock density during the last years (Fig. 3).

Important changes of land use and vegetation cover were observed in the catchment during the study period (Table 2). The land use and vegetation cover units presented in the Figure 2 were grouped into 5 larger groups in order to simplify the explanation of land use and vegetation cover evolution. It can be concluded that vegetation cover experienced a reduction during the study period. The main changes can be summarized as follows:

a) reduction of grasslands with a moderately dense cover of woody species,
b) increase of grasslands with a scarce cover of woody species,
c) maintenance of the densely vegetated surface areas,
d) reduction of landscape complexity,
e) a strong reduction of vegetation cover between 1945 and 1956 due to an intensification of land use (cereal cropping in 41.8 % of the catchment).

As can be deduced from the orthophotographs, gully growth rates did not follow the exponential decay function proposed by Graf (1977). Neither the gully was observed as a stable channel with defined stretches migrating upstream and being filled downstream (Reid 1989). In fact, gully evolution seemed to be similar to the growing model for a discontinuous channel proposed by Heede (1967).

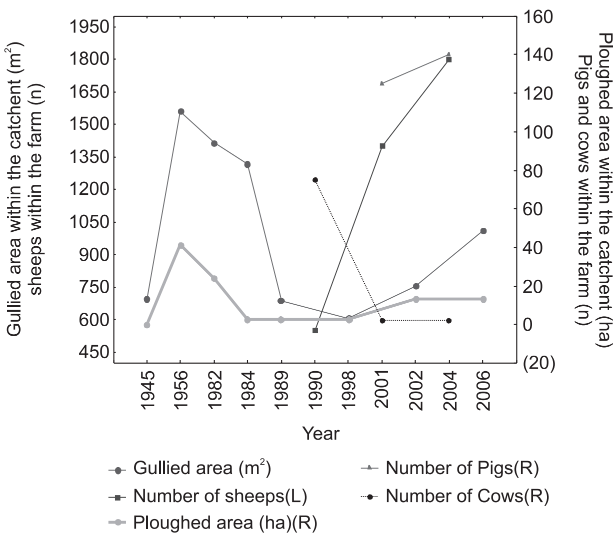

Fig. 3. Evolution of the gullied area, the ploughed surface area within the catchment and the number of sheep, pigs and cows within the farm

Table 2. Evolution of vegetation cover types, obtained grouping the homogeneous units delimited in the orthophotographs and gullied area. In grey, new data added to the previous work by Gómez Gutiérrez *et al.* (2009b)

Year	1945	1956	1982	1984	1989	1998	2002	2006
Grasslands with scarce wood vegetation (%)	40.7	16.6	48.1	68.5	68.5	68.5	60.3	60.3
Grasslands with wood vegetation (%)	47.3	39.5	18.3	19.4	19.4	19.4	16.9	16.9
Densely vegetated areas (%)	12.0	2.1	9.1	9.0	9.0	9.0	9.0	9.0
Ploughed areas and crops (%)	–	41.8	24.2	2.9	2.9	2.9	13.6	13.6
Unproductive (%)	–	–	0.2	0.2	0.2	0.2	0.2	0.2
Gullied area (m^2)	695 21	156020	1415	1318	6884	6058	7543	10096

This growing model is based on the alternation of stable and non-stable periods when high amounts of erosion can be registered. The last stage of this model is a continuous connected and mature channel characterized by almost stable conditions. In *Parapuños* the activation of incision seems to be related to external variation in environmental conditions especially cropping extent (e.g. Faulkner 1995) and overgrazing (e.g. Zucca et al. 2006).

In addition, the average growth rate indicates that the gully could well be originated in the 18th century. This procedure presents several methodological deficiencies considering climate, land use and vegetation cover constants. However, there are historical evidences of important land use changes at the end of the 17th century when large surfaces were released for crops and pastures (Rodríguez Grajera 2004).

Conclusions

Data obtained from the orthophotographs in *Parapuños* showed that the increase in the gullied area was influenced by land use changes taking place within the catchment during the study period: first by the transformation of large areas to croplands and afterwards with the increase in stocking density. These changes originated a reduction in vegetation cover and presumably caused an increase of erodibility of the sediments in the valley bottom and enhanced runoff production. These observations agree with those authors who observed incision phases as a consequence of extrinsic variations in environmental conditions.

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