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Evaluating gullying effects on modeling erosive responses at basin scale

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ABSTRACT

The objective of this research was to assess the effect of gullying on the erosive response at the basin scale by modeling. For this purpose, a distributed hydrological model, which includes erosion by raindrop, rilling and gullying, was configured and applied in a Mediterranean basin in southern Spain. The results show a range of parameters close to those provided by the literature and good agreement with field measurements. However, the simulations indicate that the rill erodibility parameter at the surface is overestimated by as much as 70% to compensate for gullying processes. Other parameters, such as the subsoil erodibility of the soil profile, play an important role in the erosive response of the basin. A geomorphological threshold for sediment yield that relates density of gullies and erodibility parameters was found. These responses are especially relevant in semiarid environments where the intense pulses of precipitation have important effects on landscape evolution.

1. Introduction

On hillslopes, where the dispersive nature of flow constrains water and sediment circulation (Simpson and Schlunegger, 2003; Hopp and McDonnell, 2009), the processes involved offer a wide variety and present complex relationships for basin scale modeling. The impact of rain drops and concentrated flow have been generally considered to be the dominant processes in erosion modeling (Nearing et al., 1989; Merritt et al., 2003). Other processes such as small-scale landslides, subsurface soil washing or gully erosion could notably increase the hillslope erosive rate (de Vente et al., 2008) but are poorly understood in terms of modeling. In particular, gullies have been responsible for important soil losses in semi-arid environments (Wasson et al., 2002; Martínez-Casasnovas, 2003; Casalí et al., 2009; Vigiak et al., 2011), with percentages exceeding 95% of the total sediment yield (Poesen et al., 2003).

Predictive models that have dealt with gullying processes have focused on local changes in gully morphology (Sidorchuk and Sidorchuk, 1998; Sidorchuk, 1999), gully headcut migration (Alonso et al., 2002; Flores-Cervantes et al., 2006; Campo-Bescós et al., 2013; Rengers et al., 2016; Vanmaercke et al., 2016) and the topographic conditions for gully inception (Montgomery and Dietrich, 1992; Prosser and Abernethy, 1996; Millares et al., 2012; Torri et al., 2012; Torri and Poesen, 2014; Rossi et al., 2015).

However, from a physical based modeling point of view, the influence of gullying on sediment yield has received less attention (Merritt et al., 2003; Borja et al., 2018). There are issues about how different parameters, such as soil properties, vegetation cover, topography, land use changes, and their spatial distributions, interact with gullying stages, including their inception, development and relationship with other surface and subsurface runoff processes (Bocco, 1991; Torri and Poesen, 2014). In most cases, the sediment contribution and responses related to the aforementioned processes have not been analyzed at basin scale (de Vente and Poesen, 2005).

The main goal of this work is to analyze the effect of soil parameters and erosion processes on gullying when modeling erosive responses at the basin scale. With this aim, the interaction between different erosive processes, such as raindrop impacts, concentrated flow in rills and gullies and their headcut migrations have been modeled with a semi-physically based and distributed hydrological model. The model, which considers the spatial variability of soil parameters (including hydraulic conductivity, pressure potential head and soil erodibility), has been calibrated and validated with suspended load measurements in a steep semiarid subbasin in southeastern of Spain, where gullying processes exhibit a remarkable activity.

2. Model description

The model developed works at the event temporal scale, with adaptive calculations of Δt on the order of approximately 1–2 s according to the Courant-Friedrichs-Levy condition and the Digital Elevation Model (DEM) and with a spatial resolution of Δx = 30m as the

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