Earth-Science Reviews 130 (2014) 73–85

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

A review of topographic threshold conditions for gully head development in different environments

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ARTICLE INFO

Article history:
Received 12 March 2013
Accepted 16 December 2013
Available online 3 January 2014

Keywords:
Catchment area
Slope gradient
Rock fragment
CN-method
Climate
Gully density

ABSTRACT

Gully head development represents a significant geomorphic process in a wide range of environments. Several studies investigated the critical topographic conditions, expressed by local slope gradient (s) and drainage area (A), controlling the development and position of gully heads in various landscapes. This review examines over 39 publications. After critically analysing the reported threshold data and after standardisation of the procedure to determine the critical topographic conditions for gully head development, i.e., $sA^b > k$ or $s > kA^{-b}$ some data sets were discarded because they were not compatible with the standard presentation of data as reported by the majority of studies. Hence, a detailed analysis was made of 63 reported *s*–*A* relationships for overland-flow induced gully-heads extracted from data sets collected in various parts of the world. A first examination of the behaviour of both the exponent *b* and the threshold coefficient *k*, which reflects the resistance of the site to gully head development, shows clear effects of land use on the value of k whereas the value of b does not seem to be affected. Further analyses are conducted of the recalculated threshold coefficients k, for two predefined constant values of the exponent *b*. The lowest *k*-values were observed for cropland followed by values for rangeland, pasture and forest. Effects of climate, rock fragment cover at the soil surface and water storage capacity of the gully catchment on *k*-values were also shown. The most interesting result is that for a given and constant *b*-value, the threshold coefficient *k* can be predicted using soil and vegetation characteristics, based on the NRCS Runoff Curve Number values and on surface rock fragment cover.
Furthermore, the underlying physical processes explaining the value of the exponent *b* were analysed. Finally, a physically-based model, well anchored in the established theories, is proposed as a first step to predict gully head development in various landscapes and under changing environmental conditions. The results of this review clearly show that better and more reliable models can be built, including effects of land use, climate changes and natural disasters.

Contents

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0012-8252/$ – see front matter
http://dx.doi.org/10.1016/j.earscirev.2013.12.006

1. Introduction

A gully is an intermittent water course, where processes of channel erosion can be very intense. Due to the importance of gullies as a sediment source, lines of preferential connection between upland areas and the main channel network, as well as their capacity to modify water and sediment connectivity during intense rainstorms, especially in cropland, gully erosion needs to be better understood, managed and its effects mitigated (Poesen et al., 2003, 2011; Li et al., 2004; Valentin et al., 2005). The first step requires the development of a standardised system for evaluating site susceptibility to gully erosion, linking the susceptibility to local topography, soil types and management practises. This can be achieved without producing a proper calculation of gully erosion rates, for which the rain event intensity and its spatial and temporal characteristics are needed.

One of the most discussed and data-rich characterisation of gullies is based on the topographic control of the gully head position. A gully head represents the position at which the processes of erosion cannot continue expanding upslope under the given rainstorm intensity and other boundary conditions such as land use, vegetation cover and soil type. Hence, this offers the opportunity of evaluating the relative importance of the various factors influencing gully formation, which is crucial for a better understanding of gully erosion. A significant number of publications have reported field data about gully head positions in a range of environmental settings. Usually the topographic threshold conditions for gully heads are reported as double logarithmic plots of upslope area (A), and slope gradient (s), where A (ha) is the area of the catchment draining towards the gully head (GH) and s (tangent, m/m) is the local slope of the soil surface at the gully heads (Fig. 1, see Eqs. (2a), (2b)). A recent review of studies dealing with topographic thresholds for gully head development by Poesen et al. (2011) suggests a variable exponent (b) for A. Montgomery and Dietrich (1994) proposed a possible interval of variation for b, depending on the degree of runoff turbulence (laminar flow condition – $0.5 <= b < 0.857$ – turbulent flow condition). The majority of the threshold lines appears to suggest almost laminar flow conditions (Montgomery and Dietrich, 1994; Torri and Borselli, 2003) which are rare for concentrated flow conditions in the field (Torri and Borselli, 2003). Moreover, the intercept (k, see Eqs. (2a), (2b)) and exponent (b) values do not follow any proper trend. When the data are plotted all together, they clearly show an increase of the threshold values when passing from cropland through rangeland to forest, as one would expect and which is clearly shown

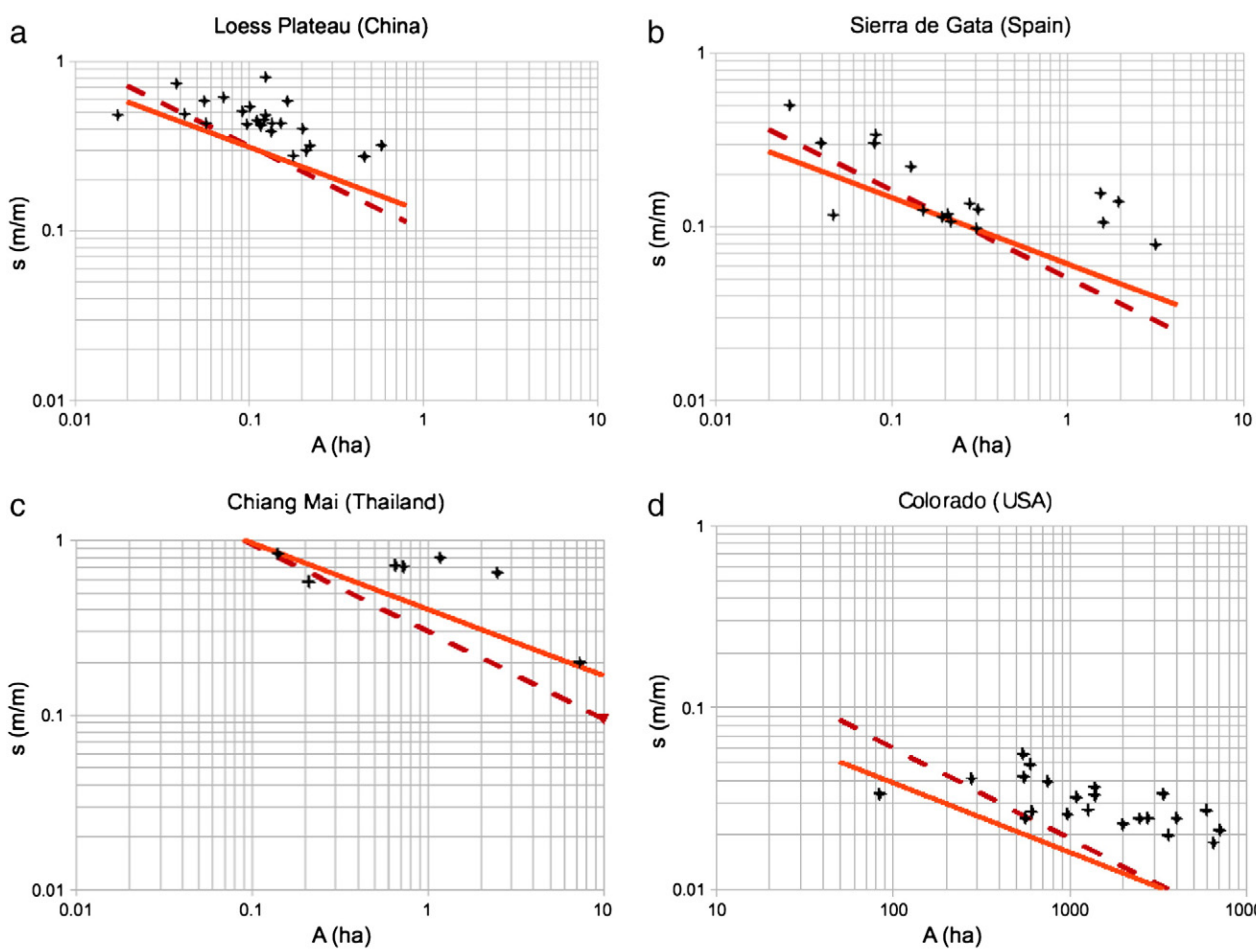

Fig. 1. Illustration of topographic threshold data of gully heads incised by concentrated overland flow, collected in different environments: a) Loess Plateau (Wu and Cheng, 2005), b) Sierra de Gata (Vandekerckhove et al., 2000), c) Chiang Mai (McNamara et al., 2006), d) Colorado (Patton and Schumm, 1975). s is slope gradient of the soil surface at the gully head; A is catchment area. The threshold lines correspond to two exponents (b in Eq. (2): b = 0.38 (solid line) and b = 0.5 (dashed line).