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Distribution of local landforms at head and end points of gullies on different grid spacing

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ABSTRACT

Local landforms described by signs of curvatures can be considered as potential indicators of gully formation. However, the role of these landforms is not generally investigated in literature. Hence, the goals of the present research are: (*i*) identification of the relationships of land surface attributes at the head and end points of gullies with the size of these gullies, at different grid spacings of a digital elevation model (DEM); (*ii*) explanation of the frequency of occurrence (FO) of local landforms.

Investigations were conducted on the example of 439 gullies of the Hronská pahorkatina Hill Land in Slovakia. The sizes of the gullies were described by their area and perimeter. Altitude, slope steepness, maximal catchment area (*MCA*) and curvatures were calculated at the head and end points of these gullies. 12 types of main local landforms (MLLFs) were identified by the signs of six curvatures. For calculation of land surface attributes, a set of DEMs with grid spacings at every 10 m interval from 10 m to 100 m was prepared.

At the head points of gullies, significant Spearman's rank correlation coefficients (r_s) show that *MCA* and curvatures related with gully size at DEM grid spacings from 10 m to 30 m. At the end points, such relationships are observed at all grid spacings. A negative r_s between gully size and slope steepness is obtained. At the head points, it is demonstrated that the large gullies reached more flat locations in comparison with small gullies. At the end points, negative r_s indicates that large gullies are characterized by flatter outlets in comparison with small gullies. The FO of MLLFs at the head and end points of gullies – relative to their frequency for the whole DEM – indicate that only four types of MLLF are systematically related to gully occurrence.

1. Introduction

The determination of geomorphic thresholds is an important direction of gully erosion investigations (*e.g.* Horton, 1945; Patton and Schumm, 1975; Poesen et al., 2003). However, pure geomorphic thresholds vary over a broad range of intervals (Valentin et al., 2005) since gullies are triggered by a complex set of factors (*e.g.* Vandekerckhove et al., 2000; Parkner et al., 2006). In this situation, researchers have often focused on small areas with relatively homogeneous non-geomorphic factors of gully formation. The determination of geomorphic thresholds that can be useful over large areas with different environments is rare (*e.g.* Torri and Poesen, 2014), but it remains an important task of geomorphology (*e.g.* Pike et al., 2009).

Investigations of gully formation/burial cycles on the Holocene time scale are important for the understanding of geomorphic prerequisites of gully development (*e.g.* Dotterweich, 2005; Vanwalleghem et al., 2005, 2006; Superson et al., 2014). These and similar investigations (*e.g.* see review in Dotterweich, 2008) show that thalwegs of new and buried surfaces are not strongly shifted laterally. This shows that the geomorphic prerequisites of gully development are relatively stable over time; at least on the Holocene time scale.

Different combinations between slope steepness and catchment area are often used for the determination of a geomorphic threshold for gully formation (*e.g.* review in Poesen et al., 2003; Valentin et al., 2005). The coefficients of such “threshold indexes” depend on the physical-environmental conditions of the study areas (*e.g.* Begin and Schumm, 1979; Vandaele et al., 1996). A comparison of different threshold indexes calculated with the help of catchment area and slope steepness was undertaken by Daggupati et al. (2013). With the example of two study areas in the state of Kansas (US), these authors show that the “slope area index” of Moore et al. (1988) was the most effective attribute. However, the “slope area power index” of Vandaele et al. (1996) is, probably, most often used for the determination of geomorphic thresholds for gully formation (Torri and Poesen, 2014). A well-known

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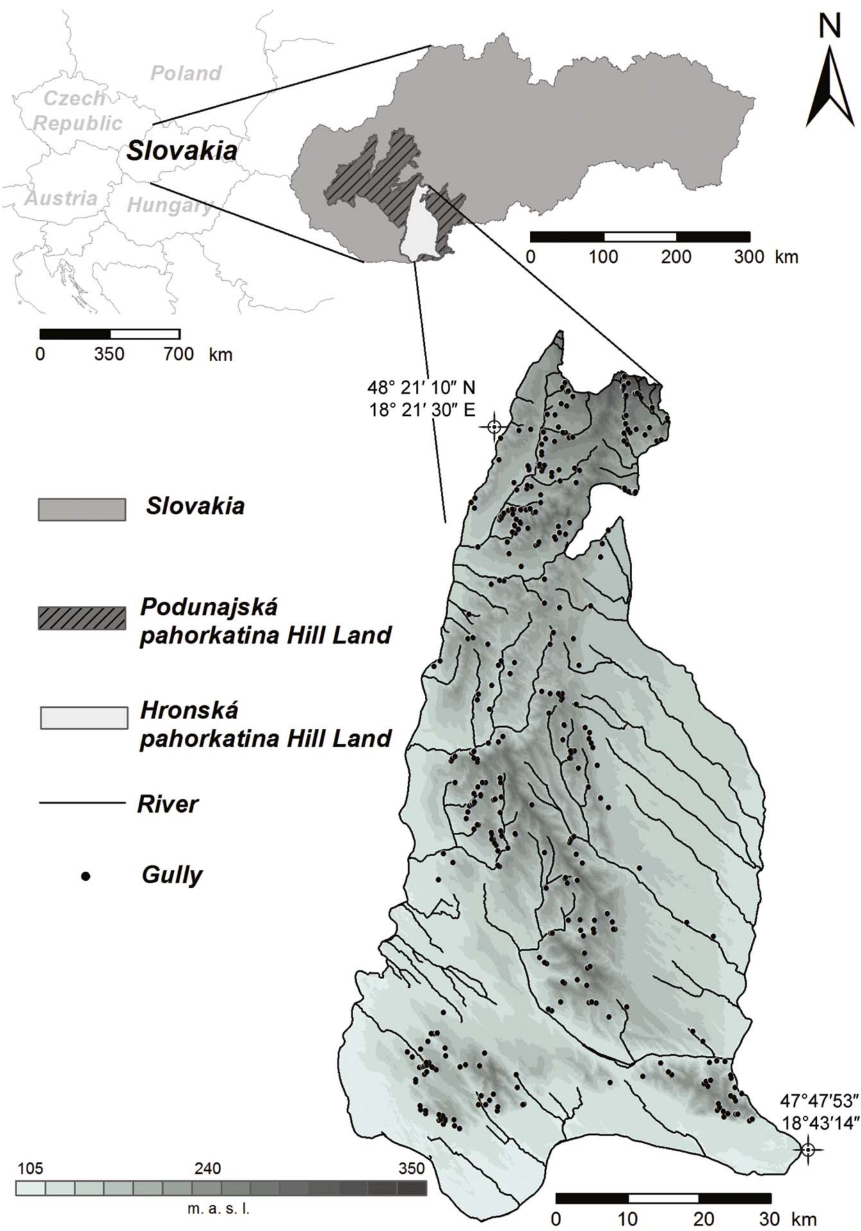

Fig. 1. Location of the Hronská pahorkatina Hill Land and gullies. Gully locations are marked by dots because their real shape is not visible at this scale.

"compound topographic index" can be directly used as a process-based predictor of gully location (*e.g.* Parker et al., 2010; Momm et al., 2013). The same land surface attributes were used in inventory-based models for the successful prediction of ephemeral gullies (Pike et al., 2009). The models in Pike et al. (2009) were constructed with the help of logistic regression and neural networks. Kheir et al. (2007) used 'tree-based' regression models and showed that the "wetness topographic index" and "sediment transport capacity index" explained up to 80% of the variability of gully size. Svoray et al. (2012) compared the geomorphic threshold method of Patton and Schumm (1975) with a statistical model based on decision trees. They show that geomorphic thresholds overestimated the probability of gully formation in conditions of semi-arid climate. Hence, such basic attributes as slope steepness and catchment area are not enough for effective gully modelling.

Curvatures describing the land surface in plan and profile are often used as important extensions in modern gully predictive models (*e.g.* Kheir et al., 2007; Gutiérrez et al., 2009; Pike et al., 2009; Chaplot, 2013; Conoscenti et al., 2013; Conoscenti et al., 2014; Dewitte et al., 2015; Bergonse and Reis, 2016). As one of the first teams, Lanyon and Hall (1983) experimentally showed that gullies started from accumulative zones characterized by negative values of curvatures in both plan and profile. Mitas and Mitašová (1998) were one of the first who used these curvatures to model soil erosion. The main problems in such applications are selection of the correct combination of curvatures, and a correct understanding of their different roles in processes of lateral and gully erosion.

Combination of different curvatures can be used for the identification and classification of local landforms. The term "local" means that for the determination of such landforms only the area around a sampling point should be considered (*e.g.* Shary et al., 2002). The classification of local landforms by signs of vertical and horizontal curvatures (Troeh, 1964) is well-known. In the framework of general geomorphometry Shary (1995) suggested a more precise classification describing 12 types of the main local landforms (MLLFs). However, the role of these local landforms for processes of gully formation has been little studied.

One of the critical problems in practical application of these local landforms is their dependence on the grid spacing of digital elevation models (DEMs). The dependence of morphometric variables (MVs) on the horizontal resolution of DEMs is well-known (*e.g.* Thieken et al.,