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Flow-driven soil erosion processes and the size selectivity of eroded sediment on steep slopes using colluvial deposits in a permanent gully

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ABSTRACT

Colluvial deposits with loose, coarse material are easily erodible in permanent gullies, but the mechanisms of erosion and sedimentation during overland flow remain obscure. Hence, the processes and mechanisms of the transportation of soil particles by overland flow were investigated in this study. Experiments were carried out in a 5.0 m long by 1.0 m wide flume using colluvial deposits. The slope gradient varied from 36 to 84%, and the flow rate ranged from $0.72\ L\ m^{-2}\ min^{-1}$ to $2.88\ L\ m^{-2}\ min^{-1}$. The runoff rate and sediment yield rapidly increased with increasing overland duration. Runoff and sediment were highly variable when the flume was treated with a high flow rate compared with a low flow rate, with the fluctuation of sediment concentration under the high flow rate usually reaching $500\ g\ L^{-1}$. The slope gradient and overland flow rate have strong impacts on sediment transport capacity. The mean flow velocity and the unit stream power can be an optimal composite force predictor for estimating sediment transport capacity. Experimental results also revealed that the percentage of gravel-sized particles increased with increasing flow rate and slope gradient, but silt and clay fractions observed opposite trend. The average enrichment ratio (ER) of gravel was usually < 1. However, the ER of silt and clay fractions decreased following the increase of the flow rate and slope gradient, and the values stabilized in the range of 1.1 to 1.4. The predicted values of runoff, sediment yield, and sediment concentrations were simulated by an empirical equation with measured values, and the regression coefficients were 0.983, 0.996 and 0.877, respectively. When the flow rate was $> 2.16\ L\ m^{-2}\ min^{-1}$, the bed load transport became an important mechanism; however, the simulation model overestimated these values.

1. Introduction

The southeast of China is speckled with gullies of a type that is unusual in a global context but is extremely common in this region, to the extent that their local name is "*benggang*" (Jiang et al., 2014; Xu, 1996) or permanent gully (Lin et al., 2015) (Fig.1A). The archetypical permanent gully has an inverted-teardrop shape, with a broad head wall that narrowly progresses to a slender scour channel, and the topography of a permanent gully is similar to those of the "*lavaka*" in Madagascar (Cox et al., 2010; Voarintsoa et al., 2012) or the "*calanchi*" in central Italy (Moretti and Rodolfi, 2000). According to a national survey by the Monitoring Center of Soil and Water Conservation of China, > 239,100 permanent gullies are present in the south of China (Jiang et al., 2014). These gullies develop quickly and collapse suddenly, with the annual erosion of sediments in these areas averaging over 50 kt per km^2 (Zhong et al., 2013). The growth of the gully creates a hazard to both people and farmland, and sediment from the outfall is an issue during the rainy season from June to September, when it is carried to fields and destroys crops (Xu, 1996).

These particular types of gullies are generally composed of an upper catchment, a collapsing wall (Fig. 1D), a colluvial deposit (Fig. 1 C and E), a scour channel, and an alluvial fan (Fig. 1B). Colluvial deposits are the packed material under the collapsing wall, which form the original mountain slope surface under hydraulic pressure and gravity. Colluvial deposits usually form in a cone or fan, with the slope surface several to tens of meters long and a several meters thick (Jiang et al., 2014). The character of colluvial soil is quite different from that of undisturbed soils within the collapsing walls. Colluvial soils have high contents of gravel, sand, and loose materials that have a weak structure, low cohesion, poor stability, and high erodibility. After water immersion, colluvial deposits disintegrate rapidly, and the particle sizes become more ideal for water transportation (Jiang et al., 2014). Colluvial deposits contain several to tens of ephemeral gullies or rills, which are small channels eroded by a concentrated flow from an upper catchment. Rills are the principal source of eroded sediment and an effective link for transferring overland flow and sediment from colluvial deposits

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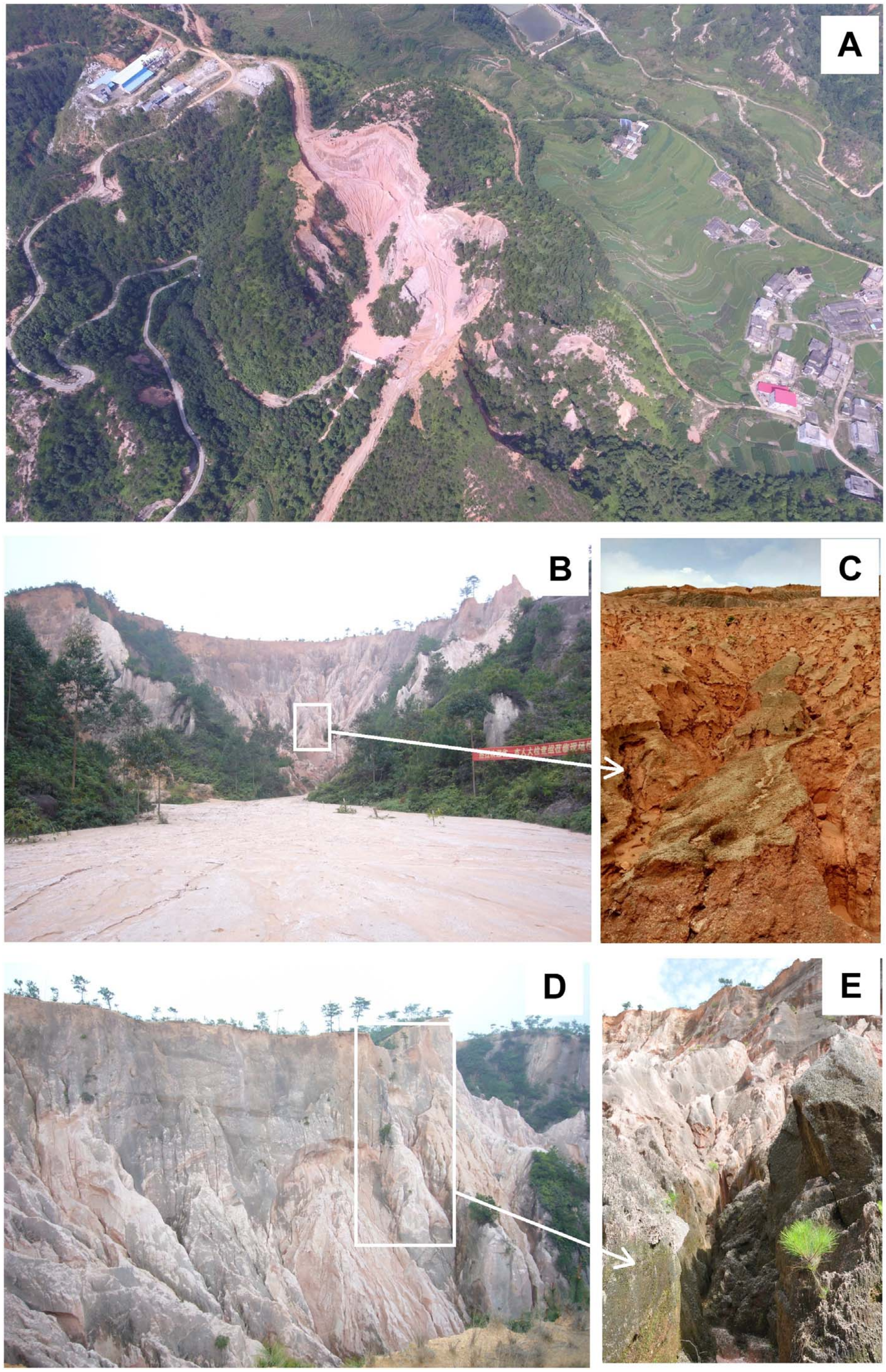

Fig. 1. A typical permanent gully in the study area, locally called "Benggang" (A) aerial photo of a permanent gully in the study area; (B) permanent gully with collapsing wall, colluvial deposit and alluvial fan; (C) colluvial deposit; (D) collapsing wall and colluvial deposit.

to channels or rivers (Capra et al., 2009; Lin et al., 2015). Furthermore, these rills will re-form by additional runoff events; the steep slope gradient can accelerate interrill and rill erosion after several void-filling cycles (Poesen et al., 2003; Torri et al., 2012). A high amount of sediment is generated and flows out of the permanent gully through scour channels under these cycles, and a colluvial deposit contributes approximately 60–80% of the total soil loss (Gong et al., 2011). A better understanding of the colluvial deposits' erosion processes, the dynamics of the sediment size distribution and their potential effects is of paramount importance to identify the innate characteristics of soil erosion under overland flow and consequently improve erosion modeling.

Colluvial soils have a weak soil structure, low cohesion, poor stability, and high erodibility. However, the dynamics of colluvial sediment sorting and their potential effects in erosion processes still unknown. It has been reported that soil erosion processes are size-selective (Asadi et al., 2007; Shi et al., 2012; Wang et al., 2014). The general observation of selective sediment transport has been attributed to the insufficient ability of overland flow to transport large detached particles (Shi et al., 2012; Zhang et al., 2003) or to the selective deposition of coarse sediment (Proffitt and Rose, 1991). However, there are conflicting reports in the literature regarding sediment sorting. Meyer et al. (1992) reported that sediment transported by inter-rill erosion was coarser than the in situ soils and the rill sediment.