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Assessing the sources of sediment transported in gully systems using a fingerprinting approach: An example from South-east China

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ABSTRACT

Eroded sediment is an important feature of permanent gully's development; however, obtaining the specific characteristics of the sediment transport in the gully can be difficult. Thus, a composite fingerprinting technique, incorporating uncertainty analysis, has been employed to investigate the mean relative contribution of sediment sources in permanent gullies. In this study, 31 tracers were measured at 62 different sampling sites from three layers of a gully wall [surface layer (SL), sandy soil layer (SSL), and semi-weathering rock layer (SWL)] and 36 sediment samples from the slumping deposit and alluvial fan of the gullies. The sediment source tracing procedure was therefore used to assess the relative contribution of each source. The mean relative contribution from the SL to the sediment of the slumping deposit is higher in the active gully (G1), and is relatively lower in the potentially stable (G2) and stable gullies (G3); thus there was no obvious gully bank retreat in G2 and G3. In different places of the G1 alluvial fan, the mean relative contribution of the SL, SSL and SWL ranged from 9–11, 36–43 and 46–55%, respectively. However, the sediment contribution of the SL increased in G2 and G3 due to the changes in the erosion type. The mean relative contributions of the SL were 33 ± 5 (G2) and 30 ± 3% (G3). These findings have important implications for the establishment of a scientific basis for permanent gully sediment transport management and control policies.

1. Introduction

Gully erosion (especially from a permanent gully) is a widespread phenomenon in many agricultural landscapes (Poesen et al., 2003) and it is a serious land management issue in many parts of the world (Betts and DeRose, 1999). Granitic regions are some of the most seriously affected areas of gully erosion in southern China (Feng et al., 2009). Gullies usually initiate from fluvial transport and rapidly develop into mass movement complexes (Betts et al., 2003). Erosion gullies can be as large as 3.5 ha for a single gully, and the erosion modulus can reach 2.3×10^4 t km^{-2} per year. These gullies cause soil loss, downstream aggregation, and increased degradation of agro-ecological systems; thus, more research is focusing on gully erosion.

Long-term studies report that gullies develop in association with mass movement in natural landscape evolution that is linked to the degradation of vegetation cover. Many studies have described gully processes, such as gully initiation, development and growth (Martinez-Casasnovas et al., 2003; Porto et al., 2014; Sidorchuk et al., 2003; Vandekerckhove et al., 1998). Gully development processes that have been modeled include initiation, gully bank retreat, sediment detachment, and sediment transport (Butler and Memon, 1999; Casali et al., 2003; Conoscenti et al., 2014; Herzig et al., 2011; Peter et al., 2014; Prosser and Slade, 1994). Gully erosion occurs randomly with sediment from the gully bank being deposited into a slump or moving into an alluvial fan. Thus, simulation of the sediment movement within a gully is difficult. Despite the existence of models of gully development processes, few studies have been able to define the specific characteristics of the sediment transport within a gully, although understanding the sediment sources and transport is important for developing sediment budgets and yield models (Wilson et al., 2011). Therefore, it is necessary to find a new way to assess sediment sources and transport within gullies.

The fingerprinting method has been used to identify sources of sediment since the 1970s. This method identifies a single or multiple soil chemical parameters of different sources and uses mixing models to delineate the relative contribution of each source (Collins et al., 1997a; Collins et al., 2013; Smith and Blake, 2014; Voli et al., 2013; Walling et al., 1999; Wilson et al., 2011). Wilson et al. (2011) used total carbon to identify the sediment sources in a small-plot runoff experiment. Different soil parameters have been used to identify sediment sources, such as various minerals, mineral-magnetic properties, chemicals, isotopic and radiometric properties, and physical size parameters (Collins et al., 1997a, 2001; Deboer and Crosby, 1995; Schuller et al., 2013; Walling et al., 2008). Collins et al. (2010a) refined the existing approaches and developed a modified fingerprinting technique incorporating the weighting of properties and prior information. Following its development, the fingerprinting technique has been used in various studies. However, to our knowledge, it has never been employed to quantify gully sediment transport.

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On the basis of its proven and successful application in other soil erosion studies, the fingerprinting approach was selected as the most appropriate method to identify sediment sources in large, permanent gullies. The objectives of this study were (1) to determine the relative contribution of various sediment sources to slumping deposits and alluvial fans, (2) to examine the sediment sources within the gully systems, and (3) to provide reliable sediment contribution data to improve the accuracy of gully model use in southern China.

2. Material and method

2.1. Study area

This study was conducted at the Longmen catchment of Anxi County, Fujian Province, in southeast China (Fig. 1). This location has a subtropical monsoon climate, an annual mean temperature of 18 °C and a mean precipitation of 1800 mm during the past 30 years (from 1980–2010). Approximately 70% of the annual precipitation occurs from June to September.

The Longmen catchment represents one of the largest and most typical gully erosion areas of southern China due to the soil properties and intense precipitation periods. The parent materials of the soil is granite, and because tropical weathering often produces a deep weathering profile, the depth of the soil is over 10 m in the research area (sometimes exceeding 50 m). The regolith consists of quartz grains and felsic clay minerals (Sheng and Liao, 1997). Soils can be divided into three layers in each gully wall; the soil layer characteristics are summarized in Table 1.

Local researchers describe a permanent large gully as a "collapsing hill" or "collapse gully" (Feng et al., 2009). The gully erosion in the

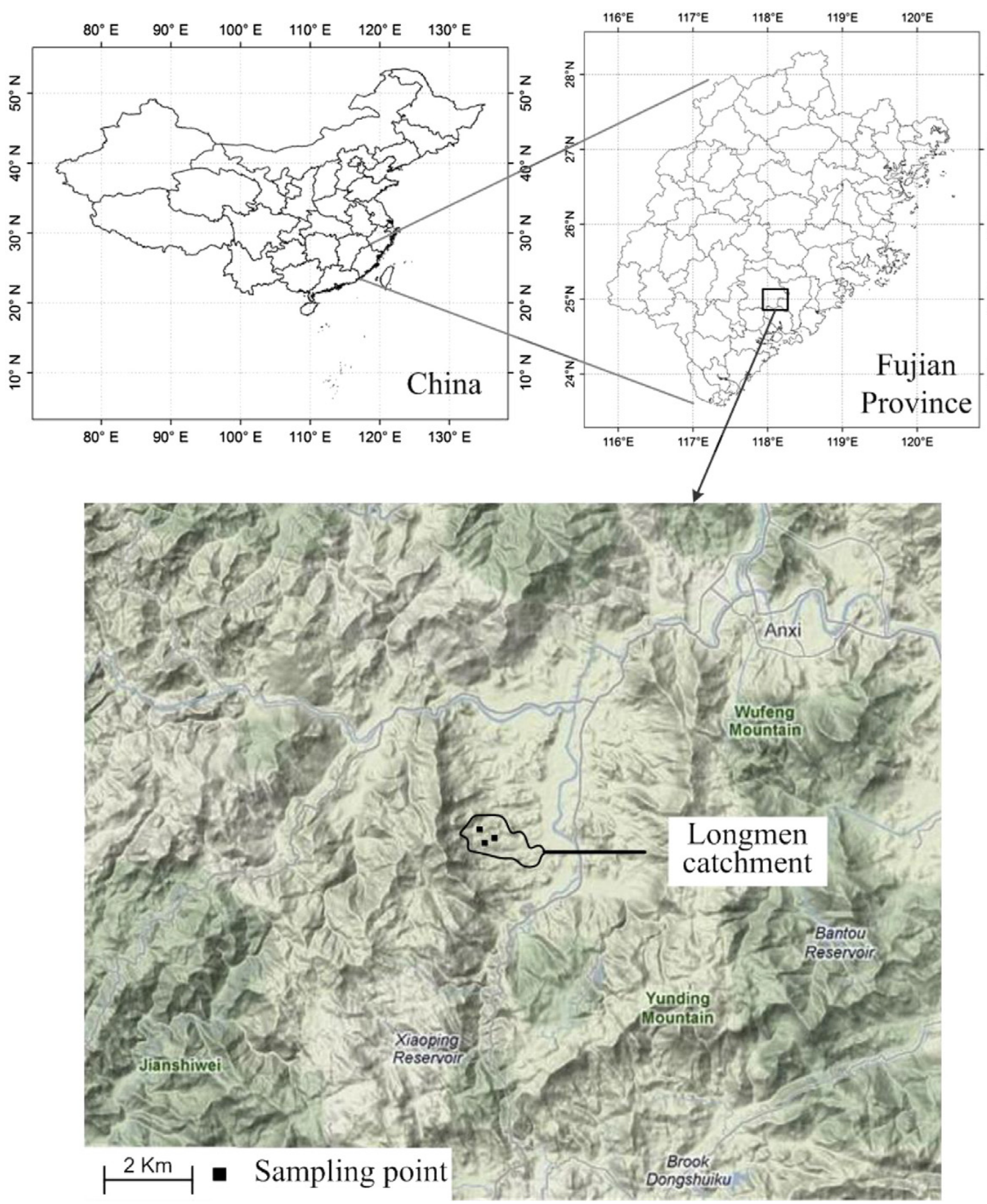

Fig. 1. Location of study catchments and sampling sites.