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Main types of soil mass failure and characteristics of their impact factors in the Yuanmou Valley, China

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ABSTRACT

Gully erosion is a dominant process causing soil loss in the Yuanmou Valley of Yunnan Province, China. Soil mass failure is a common process involved in gully development. The development of the gully and the occurrence of mass failure are interdependent and mutually promotive, but mass failure types have not been very well understood. In this study, we identify the main types of soil mass failure and the characteristics of their impact factors in the Yuanmou Valley. A detailed field survey was conducted in May 2010 in a representative area of the studied region, and selected soil parameters were measured in the field and laboratory. Results showed that there are four different soil mass failure types: falling, sliding, exfoliating, and toppling, each having unique characteristics of geology, topography, soil, and climate. Examination of these characteristics indicates that the occurrence of mass failure is controlled by four factors: 1) the typical geological structure of the Yuanmou Group represented by alternating layers of sand and clay; 2) the different terrain and landforms; 3) the different gully development stages; and 4) the particular soil properties under special weather conditions, including a dry–hot climate with distinct wet and dry seasons.

1. Introduction

The soil mass failure refers to the rapid downhill movement of soil mass and is commonly associated with the process of the gully headcut or sidewall retreat, especially in gullies with different distributions of soil layers (Brooks et al., 2009; Bull and Kirkby, 2002; Collison, 2001). Mass failures of steep gully sidewalls are a primary mechanism of sidewall retreat (Martínez-Casasnovas et al., 2004). Mass failures due to undercutting in a plunge pool also caused headcut migration (Chen et al., 2013; Stein and LaTray, 2002). Mass failures not only accelerated the gully enlargement (Bull and Kirkby, 1997; Thomas et al., 2009), but also resulted in sediment production, sediment deposition in channels, and nutrient loading in higher order streams (Martínez-Casasnovas et al., 2003; Poesen et al., 2002; Vandekerckhove et al., 2003).

The occurrence of mass failure is attributed not only to the internal characteristics of lithology (Crosta and Prisco, 1999), soil type (Vandekerckhove et al., 2000), and terrain (Moeyersons, 2003), but also to external meteorological and hydrological conditions (Thomas et al., 2009), and human activities (Wilson et al., 2008). Mass failure in the development process of gullies was caused by flow hydraulics and gravity. Examples of flow hydraulics are: piping erosion (Gutiérrez et al., 1997; Wilson et al., 2008), tunnel erosion (Wilson et al., 2005), subsurface or seepage erosion (Crosta and Prisco, 1999), and fluting erosion (Veness, 1980), etc.

Mass failure has been usually classified according to the topography and the geology of the hillslope where mass failure occurs. In hillslopes mainly consisting of rocks, Attewell and Farmer (1976) identified four types of mass failure based on the instability of slope rock: slabstone damage, rock mass falling, rock avalanche, and rock exfoliation. In hillslopes made up of both rocks and soil, Abramson et al. (2002) recognized five types of mass failure: falling, toppling, sliding, spreading, and flowing. In mountain areas, Hu (1985) divided mass failures (based on formation mechanisms) into five classes: toppling, slipping, bulgy, pull-splitting, and faulting. Alternatively, mass failure can be divided into colluvial soil mass failure, surface soil mass failure, and sedimentary soil and bedrock mass failure (Yamada et al., 1980). Although some mass failures also have been classified according to different classification principles, few studies have specifically addressed the classification of soil mass failure in gully development.

Soil mass failure also often occurs in the process of the gully development in Yuanmou Valley of southwestern China. Gullies are well developed, followed by the occurrence of different mass failures in this region.

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Unfortunately, the classification of soil mass failure in this region is not clear. In this study, we first classify soil mass failure types in the Yuanmou Valley in terms of soil materials, geological structure, and topography of collapsed soil bodies. Secondly, we identify the characteristics of impact factors of each mass failure type.

2. Materials and methods

2.1. Description of the study area

Yuanmou Valley (101°35′–102°26′E, 25°23′–26°06′N, 898–1600 m above sea level, covering an area of more than 2000 km^2) is surrounded by mountains of the Yuanmou Basin, south of the lower Jinsha River, Yunnan Province, China (Fig. 1) and is part of the Yuanmou Group. The Yuanmou Group (Qian and Zhou, 1991) is widely distributed in the Yuanmou Basin and has an average thickness of 674 m. Analysis of sedimentary characteristics and fossil content, together with magnetostratigraphic dating, shows that the Yuanmou Group consists of four members and 28 beds, which are deposits of fluvial facies, lacustrine facies, and their alternates. These deposits involve multiple layers of sand, silt, loam, and sandy gravel. As such, the Yuanmou Group is susceptible to erosion. Gullies often developed in the quaternary fluvial–lacustrine deposits with a loose structure at altitude 1000 to 1350 m (Dong et al., 2014). The gully network forms in a leaf vein-like mode, and the gully development accompanies the occurrence of different types of soil mass failure. Gully erosion plays a dominant role in overall soil erosion, with a gully density ranging from 3 to 5 $km \cdot km^{-2}$, with the highest density of 7.4 $km \cdot km^{-2}$, and average rate of the gully headward erosion is above 50 $cm \cdot yr^{-1}$, with the highest rate of 200 $cm \cdot yr^{-1}$ (Chen et al., 2011; Su et al., 2014).

The Yuanmou Valley has a typical southern subtropical climate with distinct wet and dry seasons within a year. The dry season lasts about half a year from October to the following April. The wet season spans from May to September with more precipitation in June and July. The total annual average precipitation is 615 mm, 90% of which concentrates in the wet season. The annual average evaporation is 3569 mm, 5.8 times higher than the amount of annual average precipitation. The annual average temperature is 21.5 °C with extremely high temperatures ranging from 35.3 to 42 °C and low temperatures varying from −5.1 to −3.6 °C.

Topographically, the Yuanmou Valley belongs to an alpine and canyon terrain and contains deep cutting valleys, mountains, hills, valley basins, and river terraces. Longchuan River is the main stream flowing through the valley from south to north. The Yuanmou Valley primarily consists of Luvisols with high content of gravel and silt and Vertisols with high content of clay expanding silicate clay minerals (He and Huang, 1995).

The zonal vegetation type in the area is mainly tropical bushveld with a few trees, though there are more than 30 kinds of herbs. The vegetation coverage is nearly 71%. The dominant species are *Heteropogon* and *Bothriochloa pertusa*. Trees and shrubs are primarily *Dodonaea viscose*, *Phyllanthus emblica*, *Albizia julibrissin*, *Terminalia franchetii*, and *Bumbaz malabaricus*.

2.2. Field survey and measurements

A detailed field survey of soil mass failure was conducted in May 2010 in a representative area (i.e., Julin Town 101°49′19″–101°51′49″ E, 25°50′28″–25°51′48″N, Yuanmou County) within the valley which experiences severe gully erosion. Three representative soil bodies with potential collapse were selected for each mass failure type, which resulted in 12 (3 × 4) sample locations. Each soil body was observed and its morphological parameters (such as slope shape, slope gradient, and slope aspect) were recorded using a tape measure and a compass. In order not to destroy the soil bodies, all composite soil and cutting ring (ø50mm × 50 mm) samples were taken at hillslope near the selected soil bodies according to different soil layers. The particle size distributions of soil samples were measured by pipette method, and bulk density was measured by oven dry weight (Liu et al., 1996).

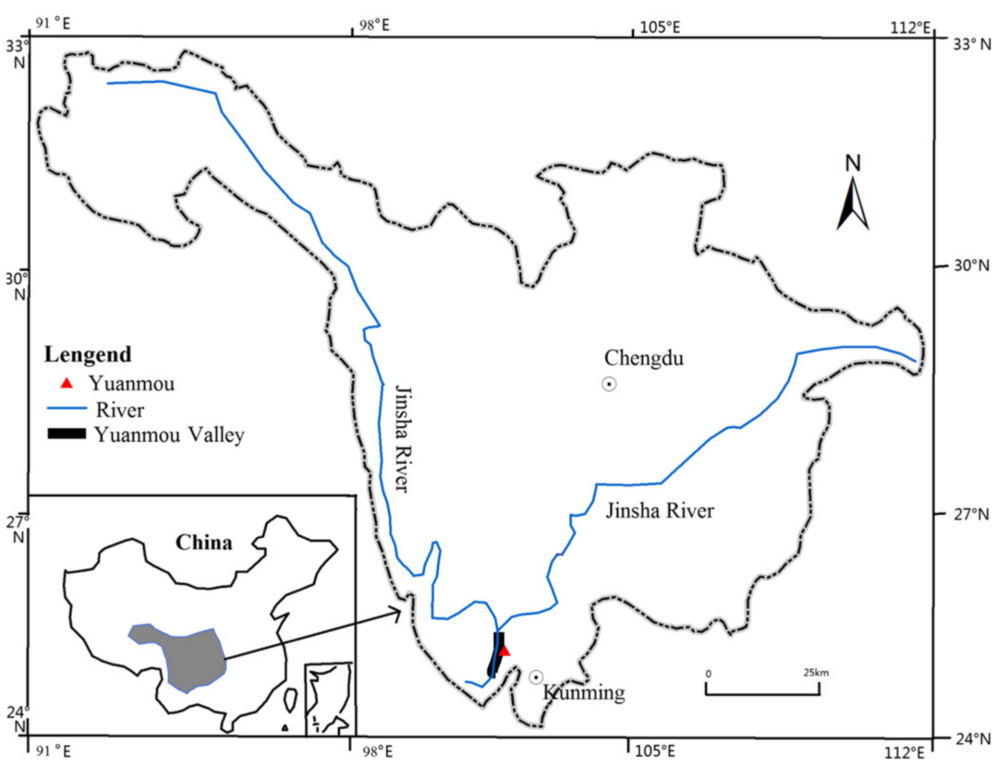

Fig. 1. Location of Yuanmou Valley, China.