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Use of reservoir deposits to reconstruct the recent changes in sediment yields from a small granite catchment in the Yimeng Mountain region, China

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ABSTRACT

Information on recent changes in sediment yields from small catchments provides a better understanding of temporal trends in soil loss from certain physical and human-influenced landscapes that have been subjected to recent environmental changes, and will help bridge the current knowledge gap that exists between hillslope erosion and sediment transport in rivers. The Yimeng Mountain region, characterized by alternating granite and limestone, is one of the most susceptible regions to soil erosion in northern China, and has been subjected to intensive anthropogenic activity in recent years. Soil loss from areas underlain by granite is particularly obvious, and is the main sediment source for the Yihe River. In this study, we used reservoir deposits to estimate the changes in sediment yields over the past ~50 years from a small catchment underlain by granite, namely the Jiangzhuang catchment in the Yimeng Mountain region. Three cores were collected from the Jiangzhuang Reservoir in the catchment. The activities of ^{137}Cs and $^{210}Pb_{ex}$ at different depths, clay (grain size < 5 μm) contents, and sedimentary organic carbon (SOC) contents in the cores were analysed with reference to human activity and environmental change in the catchment. The chronologies of the cores were established by ^{137}Cs and $^{210}Pb_{ex}$ dating. The area-specific sediment yield (*SSY*) for different time periods since dam construction was estimated from each core by referring to the original capacity curve of the reservoir. The results indicate that the depth profiles of ^{137}Cs, $^{210}Pb_{ex}$, clay, and SOC contents in cores from the Jiangzhuang Reservoir reflect the general history of human disturbances on the catchment over the past ~50 years. The estimated *SSY* value from each core for each period ranged from 7.2 ± 2.7 to 23.7 ± 8.3 t ha^{-1} y^{-1}, with a mean of 12.5 ± 4.6 t ha^{-1} y^{-1}. *SSY* decreased during 1954–1972, and then showed a general tendency to increase. The temporal pattern of the sediment yield largely reflects the history of environmental change influenced by human activity in the catchment.

1. Introduction

1.1. General background

Soil erosion and sediment loss associated with human-influenced intensive environmental change in the past ~50 years are causing degradation of our surroundings by, for example, reducing soil productivity, silting watercourses, transporting contaminants, and damaging aquatic ecology (Pimentel, 2006; Krasa et al., 2010; Rickson, 2014; Hancock et al., 2015; Matteo et al., 2016). These impacts are particularly noticeable in the rocky mountain region in northern China (Fang et al., 2012; Fang, 2015; Shi et al., 2013; Yuan et al., 2015; Sun et al., 2016), where the intensity of human activity has increased markedly in recent decades.

The sediment yield is defined as the total outflow of sediment from a catchment over a specified period of time (Vanoni, 1975). It represents only part of the total erosion (i.e., net erosion) within the catchment, and can be expressed in terms of the area-specific sediment yield (*SSY*) (e.g., t ha^{-1} y^{-1}) (Walling, 1994; Verstraeten and Poesen, 2001). Both historical and present-day patterns of sediment yield vary depending on the physical and human contexts. Generally, climate, topography, and catchment area are considered the dominant controlling variables at the global scale (Einsele and Hinderer, 1997; Syvitski and Milliman, 2007; Vanmaercke et al., 2011). However, other factors, such as lithology, soil type, and human disturbance, may control the sediment yield at a local scale (Walling, 1997; Romero-Díaz et al., 2007; Nadal-Romero et al., 2011). In the light of the increased attention directed at global change issues in recent years, it is useful to assess and gain an improved

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understanding of the changes and temporal trends in sediment yields over the past ~50 years (Dearing, 1992; McIntyre, 1993; Walling, 1997). Moreover, it is particularly useful to investigate the sediment yields from small catchments (10–10,000 ha) to assist our understanding of the linkages between soil erosion processes on hillslopes and sediment transport in large rivers (Verstraeten and Poesen, 2001).

Reservoirs, lakes, and other similar water bodies receive sediment inputs from the upstream catchment, and so deposits trapped in these environments can be examined to obtain useful information on sediment yields. For example, we can estimate *SSY* (de Vente et al., 2013) and obtain knowledge about recent temporal trends in sediment yields from the catchment (White et al., 1997; Owens et al., 1999; Collins and Walling, 2007; Rowan et al., 2012; Royall and Kennedy, 2016). Numerous studies worldwide have investigated *SSY* from catchments at different scales and with different physical and human backgrounds by surveying the sediment volume in the reservoirs. Most of these studies estimated the mean *SSY* values for the period since dams were constructed (e.g., Gert et al., 2003; Haregeweyn et al., 2005; Romero-Díaz et al., 2007; Kouhpeima et al., 2010; Mattheus and Norton, 2013; Zhao et al., 2017). A few studies have also reconstructed recent historical changes in sediment yields by establishing the sediment chronology (e.g., Foster and Walling, 1994; Zhang et al., 2006; Zhao et al., 2015).

1.2. Soil erosion in the Yimeng Mountain region

The Yimeng Mountain region (~17,180 km^2 in area) is a rocky mountainous region in northern China, and is one the most susceptible areas to soil erosion in the country (Zhang et al., 2012a). Its lithology is characterized by alternating granite (including granite gneiss) and limestone substratum (Fig. 1). The area is in the warm temperate zone and has a continental monsoon climate. The mean annual precipitation is 800–900 mm, of which ~70% falls between July and September. The area has a high population density, with approximately 630 people km^{-2}. Farmland covers most of this region; forest cover represents only ~17% of the land use, and the forest is mostly confined to the upper slopes of the mountains (Linghu et al., 2013). Although the elevation difference between Linyi City and the peak of the Yimeng Mountains is approximately 1100 m, most of the soil erosion occurs below ~360 m a.s.l., mainly because of the intensive farming in this elevation range.

Based on the FAO soil classification (FAO, 1998), there are two main soil groups in the Yimeng Mountain region: Cambisols developed from granite, and Chromic Luvisols developed from limestone, which cover ~46% and ~34% of the region, respectively (Editorial Board of Linyi Chorography, 1999). The two soil types show significant differences in textures and erodibility (Wang et al., 2013). In general, the Chromic Luvisols contain about twice as much clay as the Cambisols, meaning they are much finer than the Cambisols, which are coarse, sandy, porous, and susceptible to human disturbances and erosion (Zhang, 1986; Liu et al., 2014). Moreover, disturbances caused by human activities, including deforestation, cultivation (especially mechanized tillage), excavation, and filling, have been particularly severe in the granite regions. As a result, the areas underlain by granite (Fig. 2) experience severe soil erosion, and have become the primary sediment source for the Yihe River, a tributary of the Huaihe River (Zhang et al., 2014).

In recent years, soil erosion in the Yimeng Mountain region has attracted increasing attention. Various studies have already been carried out, during which erosion has been monitored; rainfall-driven erosion has been simulated on experimental plots (e.g., Lin et al., 2009; Wang et al., 2013; Liu et al., 2015); and soil redistribution rates on hillslope have been estimated (e.g., Zhang et al., 2010b). Data of the sediment yields from the Yihe River basin (9383 km^2) are also available. However, little information is available for small catchments, which act as an important link between slope erosion and sediment transport in the Yihe River.

The objectives of this study are therefore to estimate the historical *SSY* values for a small granite catchment in the Yimeng Mountain region over the past ~50 years using reservoir deposits, and explain the recent temporal patterns in sediment yield from this small granite catchment that is subject to human-influenced environmental change. This is the first such research to be undertaken in the region, and we hope it will provide valuable reference information on the sediment yields from small catchments in granite areas of the Yimeng Mountain region, and help narrow the knowledge gap about the links between slope erosion and sediment transport in the Yihe River. We also hope that this information will support the development of effective catchment-scale countermeasures to mitigate sediment loss from granite areas in the Yimeng Mountain region. Specifically, the temporal patterns might provide information as to what kind of human activity or land use led to increases in the sediment yield from the catchment. Based on this information, land use practices could accordingly be curtailed or changed, and countermeasures could be designed to reduce future soil erosion.

2. Study catchment

The Jiangzhuang catchment, a small granite catchment, was chosen for our study (Fig. 1). The reservoir within this catchment that is referred to in this study is called "Jiangzhuang Reservoir". We collected information about the catchment and reservoir from field surveys, interviews with local people, local records, and water conservancy and land management agencies.

The Jiangzhuang catchment, which is entirely underlain by granite, covers an area of ~17 ha, and has a ~400 m long gully that directly connects the catchment with the reservoir. The soil type is Cambisols, with a general thickness of less than ~100 cm. The dam construction was completed at the end of 1953. The reservoir has not been dredged since then. The original reservoir maximum capacity (Fig. 3) was ~36.7×10^3 m^3 and the average depth of the sediment deposits in the reservoir at the time of sampling was ~2.2 m, indicating a current maximum capacity of ~23.1×10^3 m^3. There have been three flood discharge events (1974, 1993, and 2009) since the dam was constructed. The main crops in the catchment are wheat (*Triticum aestivum*), maize (*Zea mays*), and peanut (*Arachis hypogaea*). Before 1958, ~70% of the catchment was covered with forest; however, after the extensive deforestation in the year, forest cover was reduced to ~10%. In the subsequent period, there was rapid regeneration of some vegetation (grass and bush) because of minimal anthropogenic disturbance. However, most of the remaining forest and the restored vegetation were cleared after 1973 to allow for expansion of cultivation. A country road was constructed across the northern part of the catchment in 1986. Cultivation has intensified significantly since the end of the 1990s because of the mechanization of farming. Currently, only sparse tree plantations remain near both sides of the river channel, while vegetation (mainly grass and brush) thrives on the channel bank. Jiangzhuang Village lies outside of the catchment, about 100 m downstream of the reservoir. The population of the village has increased from ~200 to ~600 since the 1950s. Croplands in the catchment are cultivated by the village residents.

There are limited opportunities for studies of larger catchments with reservoirs in this region as, while there are many large reservoirs in the Yimeng Mountain region, most of them have been dredged frequently since their dams were constructed, so their deposits cannot be used to reconstruct the historical sediment yield pattern for the past ~50 years. Moreover, the aim of this research was to estimate sediment yields from the granite catchment; as such, the underlying lithology needed to be relatively homogeneous, so a small catchment was more suitable. In addition, (1) the elevations (~127 to ~159 m) of the Jiangzhuang catchment are within the elevation range of the most erosion-susceptible granite area in the Yimeng Mountain region (~120 to ~300 m);