Effects of Four-Year Elimination of Human Activities on Sediment Discharge from Devastated Weathered Granite Hills of South China

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Abstract: A wide spread devastated areas in southern China often lead to serious erosion problems. The devastation is closely related to human activities, such as the harvesting of ferns and litter for fuel. However, few quantitative data exist on effects of human activities on sediment yields. Data on sediment yields, and percentages of peak storm runoff in the two basins, one a control form which people have been excluded since 1997, and the other where normal harvesting practices are permitted were used to evaluate how human activity affects sediment discharge. The annual sediment discharge decreased immediately after implementing control practices, despite no marked changes in the percentages of peak storm runoff in the four years after 1997. The four-year period of control practices was too short to affect the relationship between peak rainfall and peak storm runoff, but long enough to contribute to the reductions in sediment discharge in the control basin.

Keywords: devastated granite mountains, sediment discharge, hydrological property, southern China

1 Introduction

In southern China, poorly vegetated hillslopes, highly susceptible to erosion are widespread particularly in deeply weathered granite mountains, and the high sediment discharge from the hillslopes causes downstream flooding and sedimentation (e.g. Woo and Luk, 1990; Sheng and Liao, 1997). Originally, the area has been largely covered with primary sub-tropical forest. However, severe fuel needs of population growth causing unsustainable agriculture, intensive timber harvesting and removal of undergrowth, resulted in widespread deforestation. The government in China therefore has forbidden the cutting of trees to prevent further degradation, but allowed continued undergrowth and litter harvesting to satisfy people’s fuel needs (Smil, 1983; Mo *et al*., 1995).

However, removal of undergrowth and litter reduces the protective vegetation and increases the soil’s susceptibility to detachment and transport (e.g. Woo *et al*., 1997; Geddes and Dunkerley, 1999; Battany and Grismer, 2000). Further, the traditional method of harvesting in southern China using a bamboo rake disturbs the soil surface increasing the detachment of soil particles, so raising the potential for sediment production.

To avoid catastrophic degradation, especially in areas like southern China, greater understanding how human activities affect sediment discharge is needed. Two approximately 1 ha study basins on granite hills in southern China were investigated. The uncontrolled basin (Basin I) had human activities, such as fern and litter harvesting, while human activities were excluded from the control basin (Basin V).

In this study, we aims to evaluate the effects of human activities on sediment yield.

2 Study area

2.1 Topography and vegetation

Over the two study basins close to Dahou village in JianXi Province, China (115° 28′ E, 26° 30′ N; Fig.1), the mean annual precipitation from 1994 to 2000 was 1,875 mm, and the mean air temperature 17.5 ℃. The dominant tree was pine (*Pinus massoniana*) and the dominant undergrowth was fern (*Dicranopteris dichotoma*). The hillslopes were divided into two, the lower hillslope being situated within 10 m to 20 m of a stream with gradients of 15 to 25 degrees, and the upper slopes have angles of 25 to 40 degrees. The surface of the lower slope was covered with pine litter, and had a thin microbiotic crust with sand and silt grains. The highly erodible weathered granite surface was often exposed, particularly on the upper hillslopes. Also, the upper and the lower hillslopes in the study basins lacked significant organic soil deposits (Uchida *et al.*, 2000; Fig.2).

2.2 Soil characteristics, hydrological process, and sediment source area

The mean saturated hydraulic conductivity of the soil surface (0 to 5 cm) on lower slope was smaller than the upper slope: 2.6×10^{-3} cm/sec (lower slope) and 6×10^{-3} cm/sec (upper slope) (Kimoto *et al.*, 1999). In the study basins, Hortonian overland flow is most important flow pathway as a result of low infiltration capacity (Kimoto *et al.*, 1999). Moreover, statistical analysis suggested that sediment discharge in the study basins was largely affected by peak rainfall and percentage of peak storm discharge, compared with the total rainfall volume (Kimoto *et al.*, 1998).

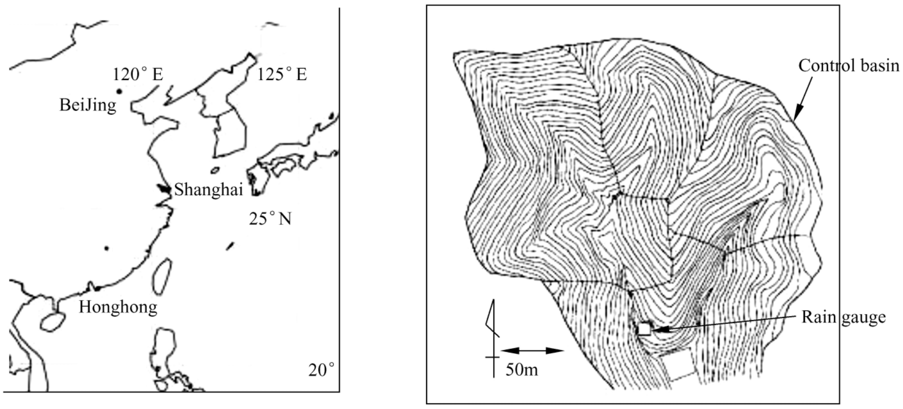


Fig.1 Location and topographic map of study basins

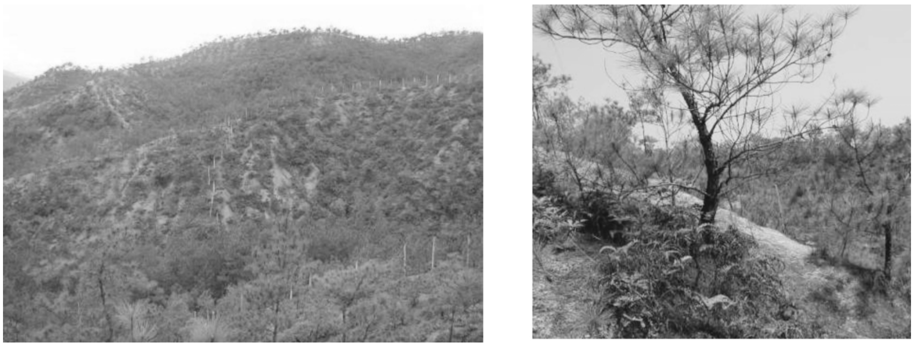


Fig.2 Study area and upper hillslope

2.3 Harvesting practice

In the study basins, local people rake litter and cut and rake fern undergrowth particularly in Autumn and winter (Fig.3). They usually harvest such biomass fuel using a bamboo rake, but the traditional method could lead to the disturbance of soil surface, resulting in highly erosion rate.

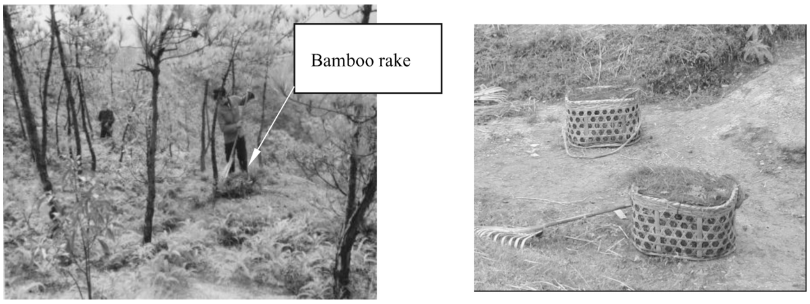


Fig.3 Traditional method of biomass harvesting and a bamboo rake

3 Measurements of rainfall, runoff, and sediment discharge

The rainfall, runoff, and sediment discharge have been measured since January 1994 using methods described earlier and thus not repeated here (Uchida *et al.*, 2000; Fig.1). A rain gauge was installed at a meteorological station near the study basins. A measuring weir with a water-level recorder was installed at the outlet of each basin (Fig.1). At the end of each rainstorm, the sediments in the collector behind the water weir were measured and then cleared out for the subsequent storm.

4 Results

4.1 Time series of rainfall, runoff and sediment yields

About 80 % of the annual rain fell between April and early September (Fig. 4a). Each year the maximum daily rainfall exceeded 90.0 mm, ranging from 96.4 mm (in 2000) to 167 mm (in 1995; Fig. 5a). The base flow changed seasonally in relation to the rainfall over both basins (Figs.4b, c). The daily runoff volumes also changed in relation to the daily rainfall volumes (Figs.4b, c). The maximum daily runoff percentages for daily rainfall volumes of more than 90.0 mm was about 0.55 in both basins through the study period.

Sediment discharge occurred during rain events with about 80 % of the total sediment discharge taking place from April to early September (Fig. 4d). Sediment yields from the two basins showed no obvious differences from 1994 to 1996, although Basin V had smaller sediment yields than Basin I during the control period in 1997—2000. In the control period, the sediment discharge exceeding 20 m^3/km^2 only occurred in 9 % of all rainstorms in Basin V, although such sediment discharges occurred in 43 % of storms in Basin I. After 1998, there were no sediment discharges of more than 20 m^3/km^2 in Basin V, while such sediment discharges still occurred in about 41 % of storms in Basin I, indicating that large sediment yields (exceeding 20 m^3/km^2) were clearly reduced by the control practices.

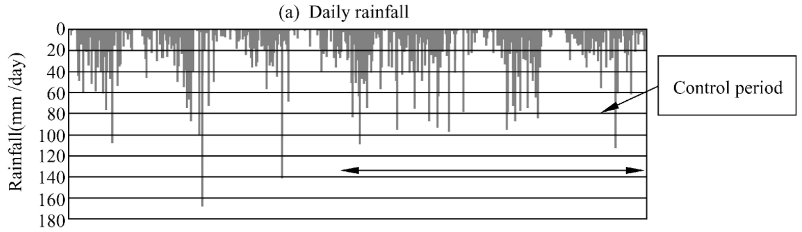
4.2 Peak rainfalls, peak storm discharges, and sediment yield

Statistical tests (t-test) at the 95 % probability level found no significant difference between mean values of the percentages of peak storm discharge in the two basins (Table 1). Also, differences in the percentages of peak storm discharge between the basins, even in 2000, were not significant (at the 95 % probability level), suggesting that the percentages of peak storm discharge in both basins changed extremely little.

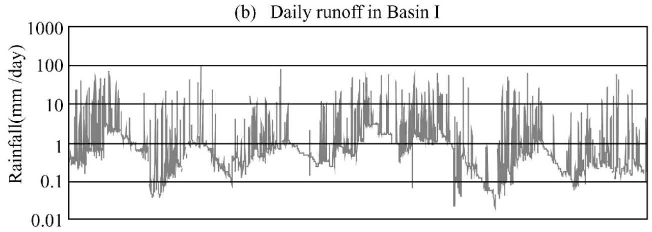
The mean values of sediment yields lacked significant differences between the basins in any classes of peak rainfall (at the 95 % probability level; Table 2). The mean values of sediment yields were also significantly smaller in Basin V than in Basin I regardless of the classes of peak rainfall in the period (at the 95 % probability level).

The above results revealed that the sediment yields for the peak rainfalls clearly decreased after implementing the control practices, and the reductions in sediment yields were independent of the peak rainfalls.

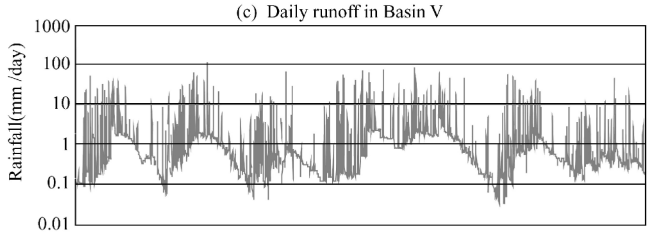
(a) Daily rainfall



(b) Daily runoff in Basin I



(c) Daily runoff in Basin V



(d) Sediment yields in Basin I and V

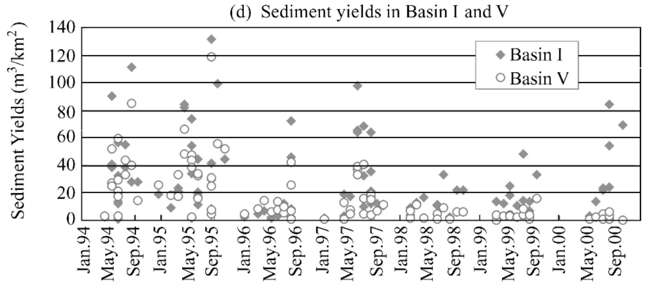


Fig.4 Time series of rainfall, runoff and sediment yields

Table 1 Mean percentage of peak storm discharges and their standard deviations. They are classified into two periods: non-control period and control period. The percentage of peak storm discharge is the proportion of maximum 10-min runoff to maximum 10-min rainfall

Year	Site	Nuber of Rainstorms	Percentage of Peak Storm Discharg	
			Mean	SD
Jan. 1994-Mar. 1997	Basin Ⅰ	49	0.62	0.23
	Basin Ⅴ	49	0.60	0.30
Apr. 1997-Dec.2000	Basin Ⅰ	45	0.55	0.27
	Basin Ⅴ	45	0.55	0.28

Table 2 Peak rainfalls, number of rainstorms, and mean sediment yields and the standard deviations They are divided into the two periods: non-control period and control period

Period (Year)	Peak Rainfall (mm/10 min)	Number of Rainstorms	Sediment Yields (m^3/km^2) Basin I		Basin V	
			Mean	SD	Mean	SD
Jan. 1994-Mar. 1997	<5	10	9.27	11.13	13.33	13.12
	<10	21	23.04	22.08	20.21	15.72
	⩾10	18	57.07	34.76	44.56	25.89
Apr. 1997-Dec. 2000	<5	11	8.92	6.56	3.58	3.55
	<10	14	20.58	18.66	3.47	3.11
	⩾10	21	37.74	26.28	14.22	12.77

4.3 Relationships between observed and estimated sediment yield

The sediment yield for each rainstorm is estimated by bed load transport models (Ashida *et al.*, 1978):

$$\frac{q_{Bm}}{\sqrt{(\sigma/\rho-1)gd_m^3}}=12\tau_*^{3/2}\left(1-0.85\frac{\tau_{*cm}}{\tau_*}\right)\left(1-0.92\sqrt{\frac{\tau_{*cm}}{\tau_*}}\right)$$

where q_{Bm} is sediment yield per unit width, m indicates mean particle diameter. σ and ρ are particle and water density, respectively. g is acceleration of gravity. τ_* is non-dimension bed sheer stress, and τ_{*cm} is critical non-dimension bed sheer stress.

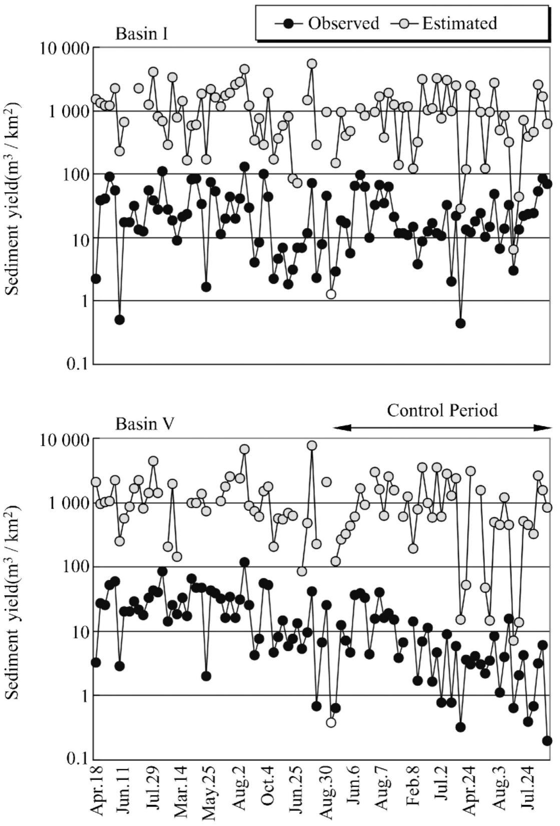
Non-dimension bed sheer stress τ_* is estimated as follows:

$$\tau_*=\frac{HI}{(\sigma/\rho-1)d_m}HI$$

in which H is flow depth, and I is bed gradient.

Here, θ is the channel gradient of the outlet of the study basin. H is obtained from the observed flow depth at the outlet of the study basin.

Fig.5 showed no clear differences of calculated sediment yields in Basin I and Basin V through the observed period. While, the observed values in Basin V tend to decrease after 1997, while such trend was unclear in Basin I (Fig.5). The results illustrated that the transport capacity was not markedly different through the observed period, but the sediment yield observed in Basin V was decreased after 1997. Fig. 6 also suggested that, for the non-control period, most observed values in the both basins ranged from 0.1 to 0.01 times of the estimated values. In contrast, for the control period, the observed values in Basin V ranged from 0.1 to 0.001 times of the estimated values, while the observed values in Basin I still ranged from 0.1 to 0.01. The above results showed that the potential sediment to be transported by surface runoff decreased after eliminating the human impacts.



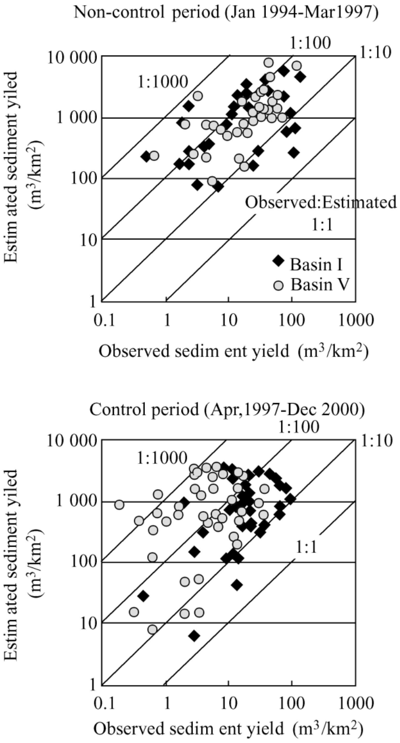


Fig.5 Time series of observed and estimated sediment yield (left)

Fig.6 Relationship between observed and estimated sediment yield (right)

5 Conclusion

Our results showed that the elimination of human activities could reduce sediment discharge independent of the important hydrological factor for sediment discharge, such as the percentages of peak storm runoff at least for four years after eliminating the human impacts. This showed that the four-year control practices were too short to affect the relationship between peak rainfall and peak storm runoff.

In this study, we showed the possibility that sediment discharge from the devastated weathered granite mountain with severe human activities was reduced to some extent by elimination of human activities, even in the absence of clear change in hydrological property. Further, reductions in sediment discharge would be attributed to less erodibility due to the elimination of the disturbance of soil surface, particularly the use of rakes in harvesting ground-level biomass.

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