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RESEARCH ARTICLE

Xiaoming ZHANG, Xinxiao YU, Sihong WU, Wenhong CAO

Effects of changes in land use and land cover on sediment discharge of runoff in a typical watershed in the hill and gully loess region of northwest China

Abstract Land use plays a much more important role than other factors, such as climate, soil properties, topographic features, vegetation coverage, human activities and others, in affecting soil erosion and sediment discharge. In order to understand the effects of changes in land use on sediment discharge and to provide a theoretical basis for land use planning, management and ecological restoration, we used the controlled Qiaozidong watershed and the uncontrolled Qiaozixi watershed in the third sub-region of the Loess Plateau as examples and analyzed the effects of land use and land cover on the discharge of sediments. The results show that the impact of land use and land cover on the annual amount of sediment discharge is significant. Compared with the uncontrolled watershed during similar periods, the amount of sediment discharged from the controlled watershed was reduced by 44%, 75% and 86%, respectively, in wet, normal and dry years. In the controlled watershed, compared with the period from 1986 to 1994, the amount of sediments discharged was less during the period from 1995 to 2004. The impact of land use and land cover on sediment discharge demonstrated characteristics of seasonal fluctuation. The effects of sediment reduction in the controlled watershed were greater than those in the uncontrolled watershed in May and September. In the controlled watershed, the reduction effect coincided with the distribution of rainfall. The amount of discharged flood sediments is closely correlated with rainfall, rainfall intensity in a 60 min period and the volume of flood. The rainstorm-runoff process and the rainstorm-sediment discharge process demonstrate that land cover has a strong regulatory and control function in the flood process and sediment discharge in rainstorms. For the controlled watershed, given the same precipitation frequency distribution, the average amount of sediment discharged during the land use period from 1995 to 2004 was less than that during the earlier land use period from 1986 to 1994 under every recurrent period.

Keywords land use and land cover change, sediment discharge, frequency distribution, hill and gully region of the Loess Plateau

1 Introduction

Land use change is one of the most important factors in affecting soil erosion and sediment discharge in a watershed among the factors of climate change, soil, topology, vegetation and anthropogenic activities etc. (Kosmas et al., 1997; Walling, 1999; Carroll et al., 2000; Verstraeten et al., 2003). Many results reported show that changes of land use and land cover can increase or decrease soil erosion and sediment discharge (Kusumandari and Mitchell, 1997; Rai and Sharma, 1998; Fu et al., 2000; Lu and Huang, 2003). Runoff and soil erosions can be reduced by adjusting the land use structure due to the difference in the mechanisms of soil and water loss in various land use types and land use structures (Kusumandari and Mitchell, 1997; Rai and Sharma, 1998; Sanchez et al., 2002). Currently, most studies on erosion focus on the scale of slope plots, while research on the scale effect of a watershed under land use changes is limited. Information loss occurs when descriptions of runoff and erosion on the scale of plots are extended to larger areas such as a watershed (Bergkamp, 1998; Seth, 1998; Ludwing et al., 1999). Soil and water loss

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Xiaoming ZHANG (✉), Wenhong CAO
China Institute of Water Resources and Hydropower Research, Beijing 100044, China
E-mail: zxmwq@126.com

Xinxiao YU
Key Laboratory of Soil & Water Conservation and Desertification Combating, Ministry of Education, Beijing Forestry University, Beijing 100083, China

Sihong WU
Department of Land and Water Resources Engineering, Royal Institute of Technology, Stockholm, SE-100 44, Sweden

from experiments in simulations of slope plots cannot accurately predict these losses in a catchment scale or on the scale of a landscape (Trimble, 1999; Güntner and Bronstert, 2004; Hao et al., 2004). Studies of soil erosion on the scale of a catchment area are often simulated using different simulation scenarios and models. Runoff and soil erosion processes are largely affected by different land use and structures in diverse landscapes (Yuan and Shi, 2001; Zuazo et al., 2004). The requirements for larger areas would provide sufficient information and parameters to improve the validity of the model. Since it needs much input in terms of time and labor to obtain the required information on land cover and its attendant difficulty of quantification, studies on the relation between soil erosion and vegetation change in a watershed remain of major concern in this field (Lu and Huang, 2003).

Soil and water loss in the hill and gully areas of the Loess Plateau is most serious in China and even on a global scale. High intensity and concentrated rainfall, loose soil and unsuitable land use lead to serious loss of soil and water in the hill and gully area of the Loess Plateau. Soil and water loss not only limits the sustainable development of this region, but also causes a series of ecosystem and environmental problems. To rebuild the ecological environment in the Loess Plateau seems to require the same level of dedication as seen in the project of "Converting Farmland to Forest or Grassland in China". The effect of soil and water loss on the hydrologic state of the Yellow River basin and its hydrophilous ecosystem in the catchment area has been of major global concern. The Qiaozigou watershed, located in the third sub-region of the hill and gully area of the Loess Plateau, is used as a case study to compare the effect of land use on watershed sediment discharge and to determine the relationship between land use and sediment discharge by analyzing the data at different stages using regression models. Thus, it can provide solutions for land use planning, management and the rebuilding of the ecology.

2 Site description

The Qiaozigou watershed is located in the north of the Qincheng District, Tianshui City, Gansu Province (34°34′N, 105°43′E) and belongs to the third secondary area of the hill and gully loess region. The area is mainly covered with black drab loess soil, accounting for 60% of the total area and partly covered with a rhogosol, drab loess soil, accounting for 20%. The Qiaozigou watershed, with a total area of 2.45 km^2, can be divided into two separate offset ditches: the Qiaozidong and the Qiaozixi watersheds. The Qiaozidong watershed (controlled watershed) takes on a half-scallop shape with an area of 1.36 km^2 and the feathering shape of the Qiaozixi watershed (uncontrolled watershed), 1.09 km^2 (Fig. 1). The major geographic characteristics are shown in Table 1. The Qiaozidong watershed has similar natural conditions as the Qiaozixi watershed. In the Qiaozidong watershed, *Robinia pseudoacacia*, *Populus davidiana, Ulmus pumila* and *Prunus sibirica* forests occur and there are artificial grasslands on the gully slopes. Terraces have been built and wheat, maize and potatoes grown. There are no soil and water conservation and control measures in the Qiaozixi watershed. The main wild herbal species in the Qiaozigou watershed include *Pennisetum flaccidum*, *Roegneria kanoji*, *Elymus dahuricus* and *Pedicularis* spp.

A dry, continental climate dominates this area with annual precipitation of 526.1 mm, with large variation between and within years, where 84% of annual precipitation falls within May to October. Intense storms in summer are a major force causing severe soil erosion. The soil erosion modulus of the controlled watershed (Qiaozidong watershed) was 2310.4 t/(km^2·a) from 1986 to 2004 and 4270.6 t/(km^2·a) of the uncontrolled watershed (Qiaozixi watershed). The sediment discharged in the flood period accounts for 98% of the total amount per year.

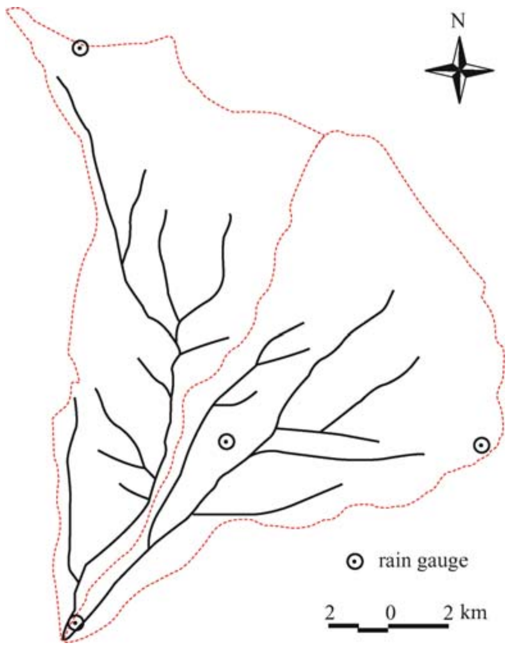

Fig. 1 Branch distribution of Qiaozigou watersheds

Table 1 Main geographical characteristics of Qiaozidong and Qiaozixi watersheds

watershed	area/km^2	shape	length/km	width/km	shape factor	channel gradient/%	relative difference in elevation/m	gully density/ km·km^{-2}
Qiaozidong (controlled)	1.36	oval	2.00	0.68	0.34	8.0	377	5.13
Qiaozixi (uncontrolled)	1.09	strip	2.18	0.50	0.23	8.0	377	5.09

3 Methods

3.1 Data collection

Hydrological data used in our investigation was supplied by the Tianshui Soil and Water Conservation Bureau. Four recording rain gauges are installed in each of the upper, middle and downstream parts of the watershed (Fig. 1). The amount of precipitation in the watershed is represented by the mean value of the records of the three gauges. To measure the watershed runoff and sediment discharged, an observation station was set up at the outlet of the two watersheds. The speed of runoff was measured by using a buoyage. The water-flow level was measured through rules in light of the riverbed and bottomland. The flood flow was calculated based per section area and channel slope. The runoff was measured twice at 08:00 and 20:00 every day. During the flood season, the runoff was measured 5–10 times every day and 20–40 times every day when the flood was strong. Sediment discharge measurements were conducted using one point samples. The sampling time coincided almost with the time of flow measurements.

3.2 Land use change

A GIS based database had been established for land use and forest patterns in the watershed using 1:10000 topographic maps, land use maps and remote-sensing images in 1985, 1995 and 2004. Additional data were obtained through field investigations.

We found no significant discrepancy between the 1995 and 2004 land use types and rate of land use in the controlled watershed. Therefore, the land uses of 1985 and 1995 were selected for our research analysis. In contrast, land use in the uncontrolled watershed has not changed since 1985. Data for different land uses and land covers of the controlled and uncontrolled watersheds in 1985 and 1995 are presented in Table 2.

In the controlled watershed, it is clear that both periods dominating land uses were forests, terraces, sloping farmlands and sparse forests. Between 1985 and 1995, the watershed has shown improvement in coverage of by an increase of 5%, 11%, 8% and 14% in forestland, terraces, sparse forests and orchards, respectively, and a 36% decrease in sloping farmland.

Comparing the land use of the uncontrolled watershed, we can conclude that the proportion of forests, grass land and terraces in the controlled watershed is far larger. The proportions of forest, grass and shrub land areas increased by 25% and 51% between 1985 and 1995 and the proportions of sloping farmland and barrens decreased roughly 60% and 13%. This change will have a great impact on the hydrology of the region (Table 3).

The slopes in both watersheds were above 5°, which is the critical slope of the appearance of surface and rill erosion in the Loess Plateau (Lu and Huang, 2003).

4 Results and analysis

4.1 Annual sediment discharge

4.1.1 Effect of land cover on annual sediment discharge

The gradients of surface slopes of the controlled watershed are larger than those of the uncontrolled watershed. The vegetation coverage in controlled watershed was about 26% and 51% higher than that in uncontrolled

Table 2 Annual proportion of land use types in controlled and uncontrolled watersheds (unit: %)

land use type	proportion of land use			change of proportion in controlled watershed	difference between controlled and uncontrolled watershed	
	controlled watershed	uncontrolled watershed				
	1985	1985	1995		1985	1995
forest	0.88	13.96	18.59	4.63	13.10	17.70
grass land	0.48	2.42	0.63	−1.79	1.90	0.20
terrace	2.83	16.08	26.97	10.89	13.30	24.10
sloping farmland	77.46	54.20	18.04	−36.16	−23.30	−59.40
shrub	1.10	1.48	1.34	−0.14	0.40	0.20
sparse forest	0.00	9.16	17.31	8.15	9.20	17.30
orchard	0.57	1.63	15.94	14.31	1.10	15.40
barren	14.54	0.84	1.17	0.33	−13.70	−13.40
residential area	2.14	0.23	0.02	−0.21	−0.90	−2.10

Table 3 Proportion of different slopes in controlled and uncontrolled watersheds (unit: %)

slope	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	> 25°
controlled watershed (Qiaozidong watershed)	5.38	38.17	44.27	1.16	0.42	10.60
uncontrolled watershed (Qiaozixi watershed)	6.46	63.83	14.60	2.22	3.14	9.75

watershed in two periods of land use. Sloping farmland and barrens decreased as well. The effect of land use changes on watershed sediment discharge was analyzed using sediment discharge data from both watersheds from 1986 to 2004 (Fig. 2).

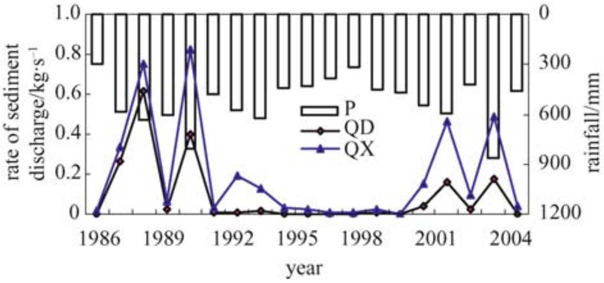

Fig. 2 Change of annual rainfall-sediment discharge rate
Note: P: rainfall; QD: Qiaozidong watershed (controlled watershed); QX: Qiaozixi watershed (uncontrolled watershed). The same below.

From Fig. 2, it can be seen that the variation in the annual sediment discharge rate is consistent with variation in rainfall. The area of the controlled watershed is larger than that of the uncontrolled watershed, but the observed amount of annual sediments discharged was less. Rainfall frequencies from 1986 to 2004 were analyzed to investigate the reduced amounts of sediment discharged in the controlled watershed compared with the uncontrolled watershed under different rainfall conditions. Precipitation frequencies of 10%, 50% and 90% were counted to calculate the rainfall of wet, normal and dry years. In the wet years (rainfall $>$ 630 mm), sediment discharge rate was reduced by 44% compared with that of uncontrolled watershed. In the normal years (rainfall 450–630 mm), the amount discharged was reduced by 75% and by about 86% under conditions of very little water yield in the dry years (rainfall $<$ 450 mm).

Precipitation, a climate factor, has a direct impact on watershed runoff and sediment discharge. Under the conditions of similar precipitation, runoff and sediment discharge are reduced owing to the increase of land cover. However, with an increase in precipitation, the effectiveness of land cover becomes weaker. It has been reported that increased rainfall would reduce the effect of the underlying surface on runoff and sediment discharge (Hao et al., 2004) which is similar to our results.

4.1.2 Effect of land use change on annual sediment discharge

Our investigation was based on hydrological data of different land uses in two periods in the controlled watershed, so it was necessary to remove the effect of precipitation in order to analyze the effect of land use on watershed sediment discharge. The regression equations of annual sediment discharge as a function of land use runoff in the controlled watershed were established for the 1986–1994 and the 1995–2004 periods, as shown by equations (1) and (2).

$$1986-1994:\quad S_1 = 0.04Q_1 - 160.46 \quad \left(R^2 = 0.99,\ n = 9\right) \tag{1}$$

$$1995-2004:\quad S_2 = 0.05Q_2 + 26.49 \quad \left(R^2 = 0.98,\ n = 10\right) \tag{2}$$

where S_1, S_2 are the annual amounts of sediment discharged of two periods of land use (t), Q_1 and Q_2 annual runoff of two periods of land use (mm). n is the sample size.

Runoff has been considered as the main forecasting factor in studying sediment discharge and sediment discharge delivery (Sharma and Dickerson, 1980; Hained and Mayer, 1983). According to Fitzgerald and Karlinger (1983), precipitation is a potential forecasting factor in multiple regression models. Precipitation was used as one of the forecasting factors in the study of watershed sediment discharge and sediment discharge delivery (Peng et al., 2002).

Regression equations (1) and (2) show that sediment discharge is linearly related to the amount of runoff in the two different land use periods. Sediment discharge in individual years from 1986 to 2004 was calculated according to equations (1) and (2) and the predicted sediment discharge deliveries under similar precipitation, runoff conditions and different land use conditions can also be obtained. Figure 3 shows that with the same precipitation, due to the vegetation coverage, the later period is higher and the areas of barren and sloping farmland reduced. The sediment discharge in the later period is less than that in the former period. Especially in the initial period of land use, the effect of the reduced amounts of sediments discharged was considerable. In the dry years (precipitation $<$ 450 mm), sediment discharge in the 1995–2004 land use periods had changed slightly from the initial period under the same precipitation and runoff

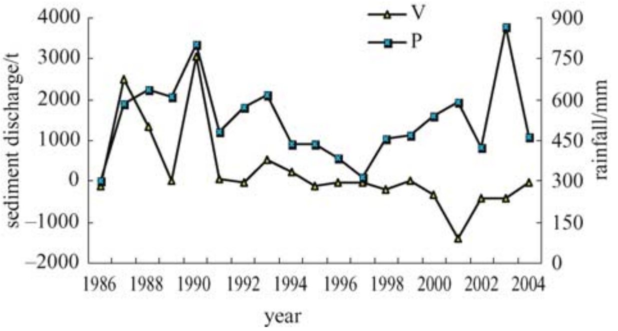

Fig. 3 Annual rainfall and variation in difference of observed to predicted sediment discharge in controlled watershed for 1986–2004
Note: V: variation of sediment discharge.

conditions. However, in the normal and wet years (precipitation > 450 mm), the sediment discharge in the 1995–2004 periods was greatly reduced compared with the initial period. A study has shown that ‘‘grain for green’’ has a strong effect on the reduction of water and sand runoff in years of abundant rainfall (Peng and Zhang, 2001). This indicates that the increase in vegetation cover and decrease in sloping farmland can reduce small watershed sediment discharge and sediment delivery to some extent.

4.2 Monthly sediment discharge

4.2.1 Analysis of monthly sediment discharge from different land covers

In order to avoid the effect extreme values, a monthly average sediment discharge was selected to investigate the impact of land cover on seasonal sediment discharge. Figure 4 presents a comparison of the average monthly precipitation and sediment discharge in the controlled and uncontrolled watersheds from 1986 to 2004. The variations in trends were similar in the controlled and uncontrolled watersheds. Sediments were mainly discharged from April to October, the period of concentrated rainfall. The variation of average monthly rainfall was small during the period of June and September, but the average amount of monthly sediment discharged in June and August was clearly less than that in July and September. This is because of vegetation growth features and rainfall conditions. In the controlled area, in June, deciduous plants have small leaf areas, scarce shrubs and grasses under the forest and crops grow poorly. The effect of land cover on rainfall interception and runoff detention was weaker than in other months. In August, strong rainfall of high intensity and short duration were the main factors affecting watershed sediment discharge in the Loess Plateau. (Peng et al., 2002).

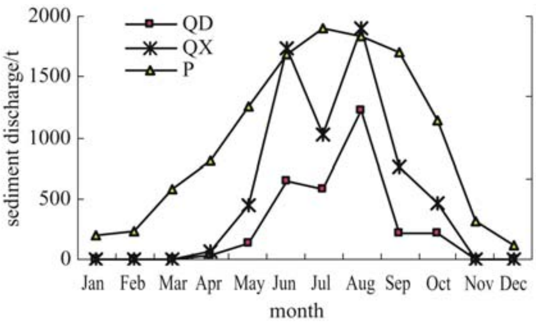

Fig. 4 Average monthly rainfall and sediment discharge in controlled and uncontrolled watersheds for 1986–2004

Average monthly sediment discharge in the controlled watershed decreased by about 36% to 72% compared with the uncontrolled watershed. The reduction in sediment discharge in May and September was significant. We conclude that seasonal variation in land cover had an effect on sediment discharge delivery. The greater the vegetation coverage, the stronger the reduction of sediment discharge.

4.2.2 Analysis of monthly sediment discharge in different land use periods

Average monthly precipitation, runoff and amounts of sediment discharge were our study objects and we established relationships among these factors by means of regression equations.

$$1986-1994:\quad S_1=12.22P_1+23.19Q_1-248.93 \quad \left(R^2=0.657,\ n=12\right) \tag{3}$$

$$1995-2004:\quad S_2=1.67P_2+52.38Q_2-18.35 \quad \left(R^2=0.769,\ n=12\right) \tag{4}$$

where S_1, S_2 are average monthly amounts of sediments discharged (kg/m^3), P_1, P_2 average monthly precipitation (mm), Q_1, Q_2 average monthly runoff (mm).

In comparing the seasonal effect of land use in different periods on sediment discharge, the amount of sediment discharged was calculated using the regression model based on average monthly precipitation and runoff conditions in order to remove the effect of precipitation and runoff. Figure 5 is the accumulated forecasting curve of the average amount of sediment discharged in the two different land use periods which shows that the average monthly amount of sediment discharged in the later periods was less than that in the initial period.

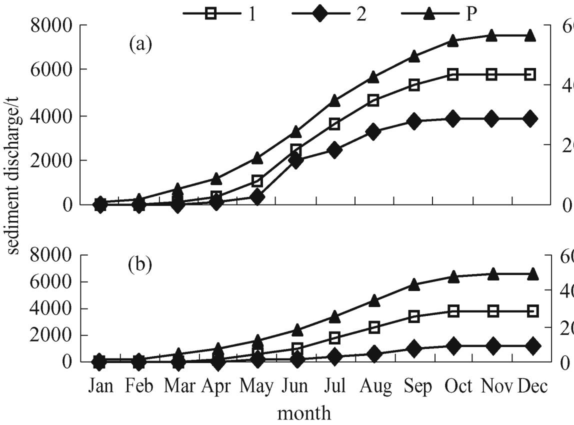

Fig. 5 Comparison of sediment discharge accumulation in two land use periods
Note: (a): rainfall and runoff for 1986–1994; (b): rainfall and runoff for 1995–2004. 1: 1986–1994; 2: 1995–2004. The same below.

The slopes of the curves of land use in the two periods were steep from May to October. After October the curves became flat. This indicates that sediments were mainly discharged in the rainy season from May to October and there was little or almost no erosion during the other months. The rainfall from May to October accounts for 84% of the annual rainfall. With increasing rainfall, the intensity of rainfall increased. According to Peng and Zhang (2001), the effect of vegetation on the reduction of runoff and sediment was strong in the rainy season. The different amounts of rainfall in the two land use periods resulted in different rates of speed of forecasting curves in Figs. 5a and 5b. Average monthly and yearly rainfall decreased in the 1995–2004 period, thus erosion was reduced and the slope of the curve increased at a decreasing rate.

4.3 Impact of changes in land use and land cover on sediment discharge during floods

4.3.1 Analysis of sediment discharge by flood in paired watersheds with different land covers

The Horton runoff theory is the main runoff formation in the Loess Plateau. Serious soil erosion occurs mainly due to heavy, short duration and high intensity rainfall (Hao et al., 2004). Data from flood peaks over 1 m³/s from 1986–2004 were used for our analysis. Figure 6 shows that there is a good correlation between flood runoff and sediment discharge in the controlled and uncontrolled watersheds. The slope of flood runoff and sediment discharge in the controlled watershed was less than that in the uncontrolled watershed, which means that sediment discharge induced by floods in the controlled watershed was greater than that in the uncontrolled watershed. Multiple regression equations were established for sediment discharge, the dependent variable, as a function of total rainfall, rain intensity and flood runoff. It was found that the correlation between the sediment discharge, total amount of rainfall, maximum rainfall intensity in 60 min and flood runoff was statistically more significant than the correlation between the sediment discharge, total amount of rainfall, maximum rainfall intensity in 30 min and flood runoff. These relationships are shown in equations (5) and (6).

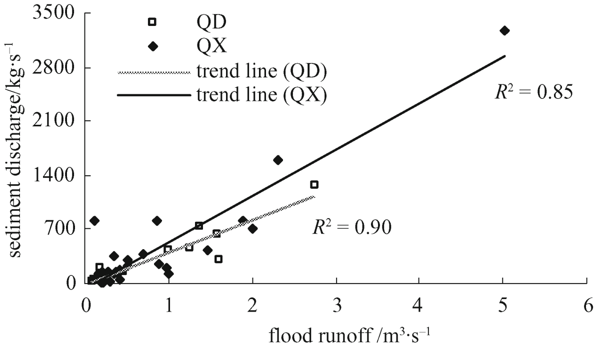

Fig. 6 Scatter plot of flood runoff and sediment discharge in controlled and uncontrolled watersheds

Controlled watershed:

$$S = -1.67P + 3.23I_{60} + 48.75Q + 55.65$$

$$(R^2 = 0.92,\ n = 25) \qquad (5)$$

Uncontrolled watershed:

$$S' = -4.14P' - 0.29I'_{60} + 152.47Q' + 102.41$$

$$(R^2 = 0.86,\ n = 28) \qquad (6)$$

where S, S' are amounts of sediment discharged by flood (kg/s), P, P' rainfall (mm), I_{60}, I_{60}' the maximum rainfall intensity in 60 min (mm/min) and Q, Q' flood volumes (m³/s).

Equations (5) and (6) show that the rainfall intensity in 60 min had greater impacts on sediment discharge in the uncontrolled watershed than in the controlled watershed. Therefore, in the Loess Plateau, short duration and high intensity rainfalls are important factors causing serious soil erosion, especially under worsening vegetation conditions.

Rainstorm-flood hydrographic and flood-sediment discharge processes can directly reflect the impacts of land use and vegetation change on flood and sediment discharge, which is important in the study of the impacts of land use change on runoff and sediment yield. The largest rainfall-runoff and sediment discharge process is used as an example (Figs. 7 and 8). The storm rainfall began at 14:58, on 7 August and ended at 13:00 on 8 August with a

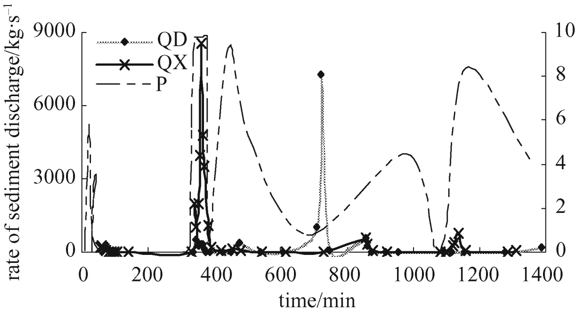

Fig. 7 Rainfall-flood runoff process of controlled and uncontrolled watersheds on 7–8, Aug., 1988

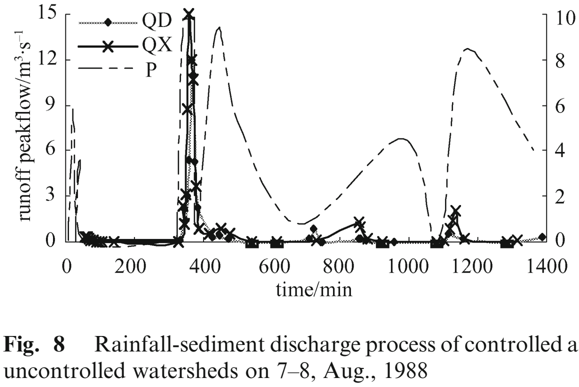

Fig. 8 Rainfall-sediment discharge process of controlled and uncontrolled watersheds on 7–8, Aug., 1988

rainfall amount of 94.2 mm, a maximum rainfall intensity of 0.85 mm/min in 60 min and 1.3 mm/min in 30 min. The initial losses duration was 335 min in the controlled watershed and 55 min in the uncontrolled watershed. The better vegetation led to the initial losses duration being postponed by 280 min. After 85 min of precipitation, the amount of rainfall increased rapidly to 50.3 mm in 50 min, with the rainfall intensity increasing fast and the flood peak was as high as 12 $\mathrm{m^3/s}$ in the controlled watershed and 15 $\mathrm{m^3/s}$ in the uncontrolled watershed. The flood peak in the controlled watershed was lower and shows a more even fluctuation than that in the uncontrolled watershed. Rainfall ended after 1015 min, and the runoff ended after 1054 min in the controlled watershed and after 1258 min in the uncontrolled watershed.

In addition, Figs. 7 and 8 show that the fluctuation in the curve of the sediment discharge process retained a trend consistent with the curve of the flood process in the uncontrolled watershed. The maximum values of the amount of sediment discharge and flood volume coincided 360 min after the start of rainfall. However, the maximum amount of sediment discharged lagged 360 min behind that of the volume of flood. From a comparison between the controlled and uncontrolled watersheds, it is seen that the maximum amount of sediment discharged from the controlled watershed is 15% less than the maximum amount from the uncontrolled watershed, but lagged 640 min behind the incidence of the maximum amount in the uncontrolled watershed. The total amounts of flood runoff and sediment discharge decreased by 15% in the controlled watershed than those in the uncontrolled watershed. The better vegetation in the controlled watershed provided greater control during the rainfall-flood and sediment discharge processes.

4.3.2 Response of land use change to sediment discharge by flood

Figure 9 shows the frequency-distribution curves for precipitation and flood by rainstorm in two land use periods of the controlled watershed. The data used for this analysis contains information of flood peaks over 1 $\mathrm{m^3/s}$. The two following regression equations (7) and (8) demonstrate that sediment discharge is closely related to maximum rainfall intensity and flood volumes in both land use periods. The amounts of sediment discharged by flood under the same conditions of precipitation frequency and flood frequency were calculated using these regression equations. The results are shown in Fig. 10.

$$1986-1994:\quad S=490.03Q-5.44I_{60}+281.05 \quad \left(R^2=0.836,\ n=18\right) \tag{7}$$

$$1995-2004:\quad S'=335.43Q'-3.86I'_{60}+226.13 \quad \left(R^2=0.928,\ n=22\right) \tag{8}$$

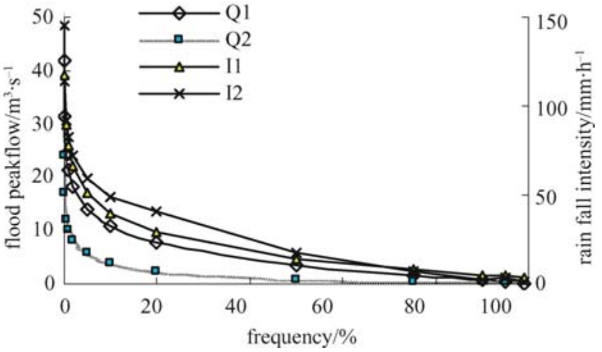

Fig. 9 Duration curves of rainfall intensity and peak flow for the two periods

Note: Q1: flood peak flow in 1986–1994; Q2: flood peak flow in 1995–2004; I1: rainfall intensity in 1986–1994; I2: rainfall intensity in 1995–2004.

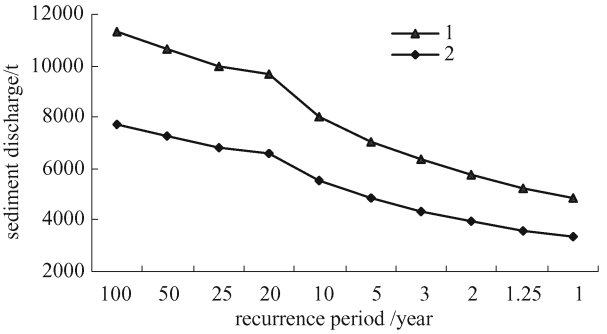

Fig. 10 Comparison of sediment discharge corresponding to the same frequency of precipitation for the two periods

where S, S' are amounts of sediments discharged by flood (kg/s), I_{60}, I_{60}' the maximum rainfall intensities in 60 min (mm/m) and Q, Q flood volumes ($\mathrm{m^3/s}$).

From Fig. 10 it can be seen that sediment discharge during the 1995–2004 land use period was markedly less than that of the earlier nine year period during the same intensive flood incidences. Both Figs. 9 and 10 indicate that during any recurrent period, the average concentration of sediment discharged in the later land-use period was less than that of the earlier period, given the same precipitation frequency distribution.

5 Conclusions

The impact of land use and land cover on annual sediment discharge in the Loess Plateau is considerable. The amount of sediment discharged from the controlled watershed has been reduced by 44%, 75% and 86%, respectively, in wet, normal and dry years compared with the uncontrolled watershed. A comparison of the amounts of sediment discharged during the period of 1995–2004 and 1986–1994 in the controlled watershed shows that in a dry year, the reduction was smaller or even zero, but in wet and normal years, it was rather large.

Therefore, the response of vegetation change on sediment yield in this watershed increased with acceleration in the amount of precipitation and is an effective measure in the reduction of sediment discharge when vegetation coverage increased and the areas of sloping farmland and barrens in the watershed decreased.

The impact of land use and land cover on sediment discharge demonstrates characteristics of seasonal fluctuation. Sediments are mainly discharged from April to October, when rainfall is heavy. The variation of average monthly rainfall is small from June to September. However, average monthly amounts of sediment discharged during June and August were clearly less than those during July and September. In this case, the results are deemed to have come about from the joint actions of land cover and fluctuations in seasonal rainfall. It is a fact that the effects of reduced amounts of sediments discharged from the controlled watershed are greater than those from the uncontrolled watershed during the months of May and September, i.e., 71% and 72%, respectively. In the controlled watershed, the effect of reduced sediment discharge coincided with rainfall distribution. For example, in a month with 45 mm precipitation, the mean monthly amount of sediments discharged during 1995–2004 was reduced by 12% than during 1986–1994, while in a month with 80 mm precipitation, the reduction was 25%.

The flood-sediment discharge is closely related with the amount of rainfall, rainfall intensity in 60 min and the volume of flood water. The impact of flood-sediment discharge in the uncontrolled watershed is greater than that in the controlled watershed. Rainstorm-runoff processes and the rainstorm-sediment discharge processes demonstrate that large vegetation coverage plays a strong role in regulating and controlling the flood process and the sediment discharge process during rainstorms. At the same time, precipitation and flood peak discharge frequencies have shown indications that in any recurrent period, the average amount of sediment discharged with the same precipitation frequency distribution during a land-use period in the controlled watershed was smaller than that of the uncontrolled watershed.

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