

Hydrological Effects of Water and Soil Conservation Measures in Loess Plateau

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Abstract: Taking the two typical tributaries in the loess plateau as an example, the hydrological effects of water and soil conservation measures were studied with parallel comparative analysis method. The results show that water and soil conservation measures can reduce annual runoff and sediment module, cut down flood peak discharge and lower sediment concentration efficiently. And meanwhile, it also can delay the occurred time of flood peak; shorten the flood duration in small-scale watershed. Although the measures can change the relationships between runoff, sediment and rainfall, it has no significant effects on correlativity between these factors.

Keywords: loess plateau, water and soil conservation measures, hydrological effects

1 Introduction

Loess plateau is famous in the world with serious losses of water and soil, and it is the key areas of water and soil conservation eco-environment construction in great development in western China as well. Analysis on hydrological effects of water and soil conservation measures in loess plateau is the basis of research on basic laws of water and soil losses, benefit assessment and eco-environment construction planning. At present, effect of forest vegetation cover and soil conservation measures on runoff has been studied by many scholars in world wide with the means of parallel comparative analysis and hydrological simulation. And many conclusions obtained are also helpful to forest vegetation cover protection and reasonable utilization of water resources. But these results are seldom concerned with sediment. Taking the two adjacent gullies (Yangdao and Chacaizhu) in gullied rolling loess region as an example, the hydrological comprehensive effects of water and soil conservation measures are preliminarily analyzed with parallel comparative method. And the results are expected to provide scientific-technical support for comprehensive harnessing of water and soil losses in loess plateau.

2 General information of typical basins

Yangdao and Chacaizhu are two adjacent gullies with same flow direction in Lishi County in Shanxi province, and they are located at left side in upper reaches of Wangjiagou tributary in loess plateau. Soil type, geomorphology and topography in the two basins are very similar. And watershed area of the gullies is 0.206km² and 0.193km² respectively. In order to study benefits of water and soil conservation measures, many measures were taken in Chacaizhu gully in 1954, and harnessing percentage of the gully was up to 78.3% in 1956, and meanwhile, Yangdao gully was still in natural state.

Because the two gullies are adjacent and their area is very small, the rainfall condition in the basins can be taken as same to each other. According to the data from 1956—1970, statistical results showed that mean annual precipitation was about 544mm, and precipitation in flood period from June to September accounted for 72% of annual precipitation. Water and soil losses were caused by several high-intensity storms in the period, so runoff and sediment were concentrated in flood period. Precipitation in drought period was little and density was weak, there was less runoff and sediment yielded in the period. The mean annual runoff modules in the two gullies were 27,740 m³/km² and 14,115m³/km², and mean value of annual sediment modules was 20,811t/km² and 8,504t/km² respectively.

3 Effects of water and soil conservation measures on annual runoff and sediment

As rainfall condition is very similar in the two gullies, the recorded runoff and sediment differences between the two gullies' gauged station have reflected the benefits of water and soil conservation measures. To take 1963, 1967 and 1957 as typical years i.e. rainy year, median year and low flow year are selected, considering the precipitation in a year, flood period and times comprehensively. According to the data of runoff, sediment and rainfall for years, the effects of water and sediment conservation measures on annual runoff and sediment under different rainfall condition are analyzed. The statistical values of hydrological characteristics in the two gullies are shown in Tab. 1.

Table 1 Statistical values of hydrological characteristics in Yangdao gully and Chacaizhu gully

Item	Annual precipitation (mm)	Annual runoff module (m^3/km^2)		Water reduction Benefits		Annual sediment module (t/km^2)		Sediment reduction benefits	
		Yangdao gully	Chacaizhu gully	(m^3/km^2)	(%)	Yangdao gully	Chacaizhu gully	(t/km^2)	(%)
Rainy year (1963)	732.7	35,600	19,900	15,700	44.1	31,562	14,023	17,539	55.6
Median year (1967)	492.8	21,600	10,000	11,600	53.7	18,730	6,902	11,829	63.2
Low flow year (1957)	376.5	7,300	2,400	4,900	67.1	3,674	645	3,030	82.5

The results in Tab. 1 show that water and sediment reduction benefits of measures are different under the various rainfall conditions. In rainy year (1963), water and sediment reduction modules of water and soil conservation measures are $15,700\text{m}^3/\text{km}^2$ and $17,539\text{t}/\text{km}^2$ respectively, and corresponding benefit percentage is 44.1% and 55.6%. In median year (1967), water and sediment reduction modules are less than that in rainy year, but corresponding benefit percentage is higher than that in rainy year. In low flow year (1957), water and sediment reduction modules are the smallest, they are $4,900\text{m}^3/\text{km}^2$ and $3,030\text{t}/\text{km}^2$ respectively, and corresponding benefit percentage is the highest. The reason is that runoff and sediment modules are small in low flow year. Water and sediment reduction modules are also small. And in rainy years, the runoff and sediment generation modules are great and the capacity of water and soil conservation can be fully used. Water and sediment reduction modules are also greater than that in other years. But because the denominator is greatest, the benefit percentage is relative less than that in other years.

4 Effects of water and soil conservation measures on flood and sediment

Flood and sediment process is controlled by ground cover and precipitation conditions. If there is no difference in ground cover between two basins, then flood and sediment process should be similar to rainfall in the two basins. Chacaizhu gully and Yangdao gully are difference in ground cover because they are affected by measures of water and soil conservation. The flood and sediment process is compared by same rainfall of the two gullies. The difference can reflect the influence of water and soil conservation measures on flood and sediment.

Discharge and sediment content process of the two gullies in 19660813-rainfall condition is plotted in Fig.1. Results from Fig.1 show that there is a great difference in flood and sediment content in the two gullies. Hydrograph in Chacaizhu gully harnessed is short and fat, runoff-yielding time is later, rising limb and recession of the hydrograph are changed gradually, and flood duration is short. The maximum discharge with same rainfall in natural Yangdao gully is $4.08\text{m}^3/\text{s}$ and it's about 3.3 times of that in Chacaizhu gully ($1.25\text{m}^3/\text{s}$). Flood peak time in the natural gully occurred is 4min before harnessing. The sediment content in the two gullies decreases slightly after it is up to peak value. But sediment content in natural gully is obviously higher than that in harnessed gully. And meanwhile, the peak value reached is earlier than that in Yangdao gully.

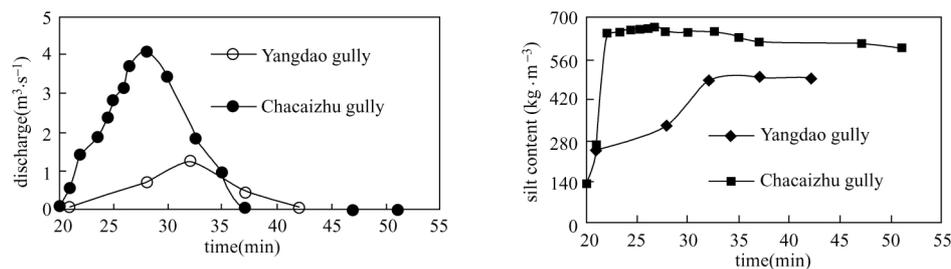


Fig. 1 Discharge and silt content process of Yangdao gully and Chacaizhu gully in 19660813

Analytic results show that water and soil conservation measures increase vegetation cover degree in one hand; they also change soil structure and increase soil porosity in the other hand. And then soil infiltration ability and water storage capacity are also increased and flood peak discharge is cut down. Low discharge recession can be effectively controlled to make flood duration short with storage capacity increasing in the basin. At the same time, soil eroded by precipitation and surface flow can be decreased with vegetation cover degree increasing, and sediment content is also decreased.

In order to compare the effects of water and soil conservation measures under different rainfall amount and intensity, 3 typical rainfall events with approaching amount but different intensity or approaching intensity, and different rainfall amount are selected. The values of runoff and sediment characteristics under the typical rainfall conditions in Yangdao gully and Chacaizhu gully are given in Tab. 2.

Table 2 Values of runoff and sediment characteristics under typical rainfall conditions in Yangdao gully and Chacaizhu gully

Number of flood	Watershed	Rainfall amount (mm)	Rainfall intensity (mm/hr)	Flood duration (hr:min)	Runoff depth (mm)	Sediment module (t/km ²)	Maximum discharge (m ³ /s)	Flood peak module (m ³ /(s · km ²))
19640820	Chacaizhu gully			0: 37	0.09	9.3	0.017	0.088
	Yangdao gully	9.2	5.51	0: 40	0.32	118.2	0.11	0.534
	Benefits (%)				71.9	92.1	84.5	83.5
19660728	Chacaizhu gully			0: 32	0.8	625.9	0.475	2.461
	Yangdao gully	9.5	11.31	0: 38	2.3	2,970	2.181	10.587
	Benefits (%)				65.2	78.9	78.2	76.8
19580729	Chacaizhu gully			7: 31	12.9	12,190.2	2.228	11.544
	Yangdao gully	48.7	11.46	8: 29	18.2	13,521.1	3.325	16.141
	Benefits (%)				29.1	9.8	33.0	28.5

The results from Tab. 2 show that the ability of retaining runoff and sediment in harnessed basin is improved obviously compared with natural basin. The former is about 29%—72% under the 3 typical rainfall events, and the latter is about 10%—93%. The reduction rate of peak discharge is about 25%—85%, and flood duration is shortened to different degree. The effects of conversation measures are different under the different rainfall conditions, and the less the rainfall amount and intensity are, the more obvious the effects are.

5 Effects of water and soil conservation measures on relationships between rainfall, runoff and sediment

The correlative analysis between rainfall amount in different interval, annual runoff and sediment

show that the relationships between annual runoff and sediment are very close and correlative coefficients exceeds 0.95. The correlation between annual runoff, sediment and rainfall amount in short interval is more obvious and correlative coefficients between annual runoff, sediment and rainfall amount yielded are more above 0.80. These results show that rainfall intensity affects water and sediment yielding greatly. And these correlative coefficients in harnessed basin are very close to the natural basin. The results show that water and soil conservation measures have less influenced on correlation between runoff, sediment and rainfall.

According to the data from 1956—1970, the linear relationship formula between runoff, sediment and precipitation of runoff yielding are established and correlative diagram are given in Fig. 2.

$$\begin{aligned} W_{YDG} &= 0.019P_f - 0.3384 & W_{CCZG} &= 0.0089P_f - 0.1368 \\ S_{YDG} &= 0.0137P_f - 0.2278 & S_{CCZG} &= 0.0062P_f - 0.1556 \end{aligned}$$

where: W_{YDG} and S_{YDG} is runoff and sediment module in Yangdao gully respectively, W_{CCZG} and S_{CCZG} is runoff and sediment module in Chacaizhu gully respectively, P_f is runoff-yielding precipitation.

In Fig.2, the corresponding comparison show that runoff and sediment module in natural gully is obviously greater than that in harnessed gully at the same rainfall condition, and difference between these module is more obvious with precipitation increasing. The results also indicated runoff and sediment reduction module caused by water and soil conservation measures is greater under the greater rainfall condition.

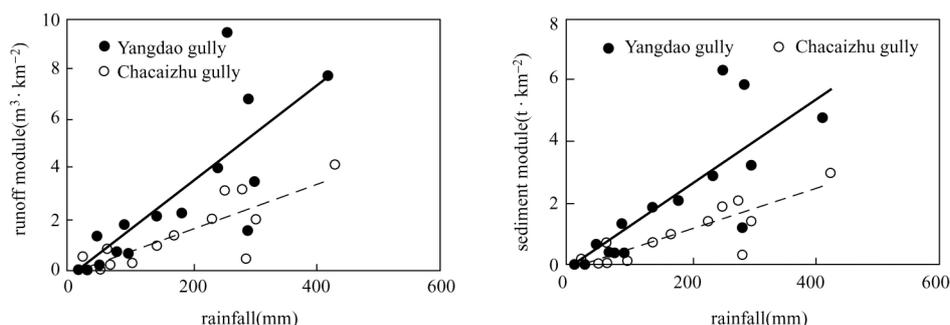


Fig. 2 Correlative diagram between runoff module, sediment module and precipitation of runoff yielding

Runoff and sediment calculation formula in harnessed basin is different from that in natural basin. Slope in natural liner calculation formula is obviously greater than that in harnessed one. This shows that unit precipitation increasing would make runoff and sediment amount in natural basin larger than that in harnessed basin. Water and soil conservation measures changed relationship between runoff, sediment and precipitation, and reduced water and sediment amount.

6 Summarization

Hydrological effects of water and soil conservation measures in small-scale basin in loess plateau have been studied with parallel compared analysis method. Results show that water and soil conservation measures can reduce annual runoff and sediment module, cut down flood peak discharge and reduce sediment concentration efficiently. And meanwhile, it also can delay the occurred time of flood peak; shorten flood duration in small-scale watershed. Although the measures can change the relationships between runoff, sediment and rainfall, it has no significant effects on correlation of precipitation and runoff-sediment. At the same time, parallel compared analysis method can only derive comprehensive effects of many measures. Though some scholars have also studied the effects of single measure on runoff and sediment with experimental data in small area, the problem how to separate hydrological response of

single measure in middle and large-scale basin should be further analyzed.

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