Prediction of Soil Loss under Different Rainfall Conditions and Control Degrees on the Loess Plateau

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Abstract: Based on the hydrological station and zoning of type of soil erosion, the loess plateau ($31.0\times10^4 km^2$) is divided into 292 erosion units. And take the erosion modulus $>5,000 t/km^2$ as a criterion, the emphases control area ($14.9\times10^4 km^2$)of the loess plateau is demarked, and is divided into 10 control regions. The controllable area and the location of control measures are conformed, level terraces are mainly collocated on the 3°—15° slopes, woodland and grassland are collocated on the >15° slopes, and the proportion between woodland and grassland is 8:2 in the forest belt, 5:5 in the forest steppe belt, and 2:8 in the steppe belt. The 9,000 combinations of soil and water conservation measures in different rainfall conditions are obtained by the permutation and combination method, according to the 9 rainfall frequency and the controllable areas of level terrace, woodland and grassland at 10% control progress rate. The quality standards of level terrace, woodland and grassland are ascertained. And the benefits of soil-water conservation, sediment reducing amount and soil erosion modulus of the 10 regions, the emphases control area and Yellow River in the different rainfall conditions and control degrees are predicted, it could provide a decision-making tool for soil and water loss control on the loess plateau.

Keywords: loess plateau, rainfall, conservation, soil loss, prediction

Since 1970's, the soil loss amount on the loess plateau has varied with rainfall conditions and the effects of irrigation works and soil-water conservation measures. Therefore the rainfall conditions, the soil-water conservation benefits of the measures in different rainfall conditions, and the amount, quality and distribution of soil and water conservation measures are the basis of the prediction of soil loss. And the study on the prediction of soil loss under different rainfalls and control degrees on the loess plateau will has instructional significance to the programming and designing of soil and water conservation, soil and water loss controlling and entironment renewing.

1 Regionalization of emphases control area

The approaches of regionalization are as follows:

(1) Based on the distribution of the hydrological stations and it's observation series of sediment information on loess plateau, the study area was divided into 120 hydrological control area firstly, then according to the map of soil erosion type area [1] and the distribution map of 120 hydrological control area, taking the borderline of the soil erosion type area as guideline to plot the soil erosion unit which is the unabridged area with same soil erosion type in a hydrological control area, the areas which have the same soil erosion area but incontinuous in a hydrological control area are taking as different units. Above all, the study area was divided into 292 soil erosion units (Fig.1).

(2) Based on the erosion intensity of 292 erosion units over the interval 1955—1969, the regions which erosion modulus $\geqslant 5,000 t/(km^2 \cdot a)$ are regarded as emphases control region. In order to keeping the emphases control region continuously, some nearby units which erosion modulus $< 5,000 t/(km^2 \cdot a)$ are merging into the emphases control region, and some units which erosion modulus $\geqslant 5,000 t/(km^2 \cdot a)$ in the upper reaches of Wei river, north foothill of Qinling Mountain and the middle and upper reaches of Fen river are not include into the emphases control region, because of the far distance from the emphases control region and scattered distribution. And the area of the emphases control region marked off is 14.9

$\times 10^4 km^2$.

(3) On the basis of the regionalization of the emphases control region, taking the soil erosion type as the main factor, and taking the vegetation-climate belt and integrality of region into account, the emphases control region was divided into 10 control areas. They are ① wind-sand steppe region in the upper reaches of Kuye river and Huangpuchuan river, ② loess flat hillock hill and gully region between Hequ and Toudaoguai area, ③ loess "*Mao*" hill and gully region between Hequ and Wubu area, ④ loess "*Mao*" hill and gully region in the lower reaches of Qingjian river, Wuding river and Sanchuan river, ⑤ loess "*Liang*" hill and gully region in Yan river, Xinshui river and Fenchuan river, ⑥ wind-sand loess hill and gully region in the northwestern part of the emphases control area, ⑦ arid loess hill and gully region in the upper reaches of Jing river and Beiluo river, ⑧ loess plateau and gully region in the middle and lower reaches of Jing river, ⑨ loess plateau and gully region in the upper reaches of Zuli river and Qingshui river, and ⑩ loess plateau and gully region in the upper reaches of Wei river (Fig.2). The soil loss characteristics of the 10 regions are shown in Table 1.

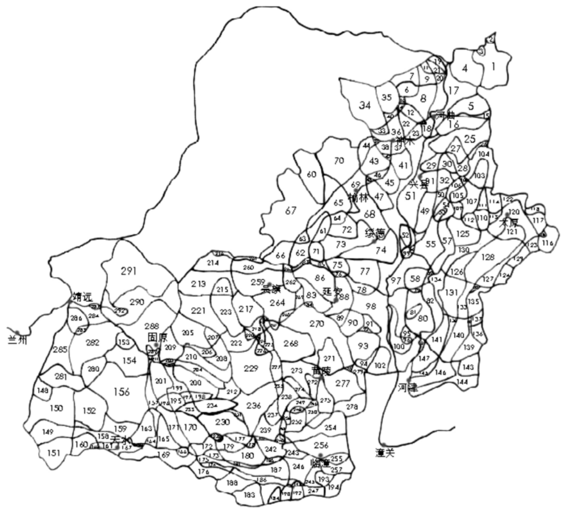

Fig. 1 The spatial distribution of soil erosion units

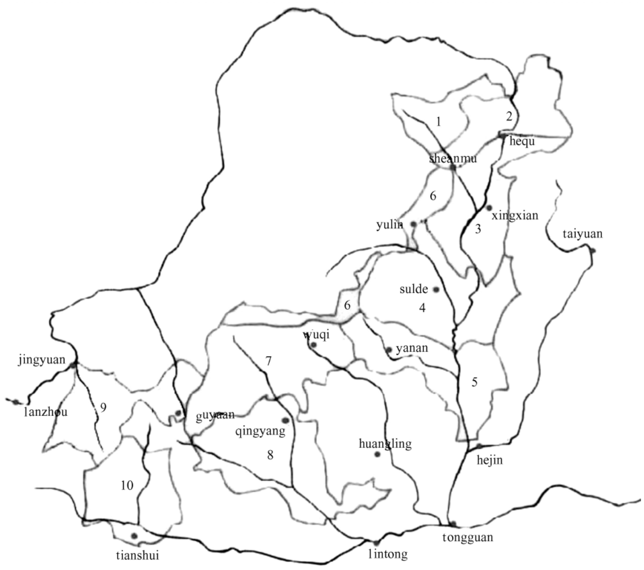

Fig. 2 The regionalization of the emphases control region

Table 1 The soil loss in the 10 control regions

Regions	Area /km²	Erosion modulus /t/(km² • a)		The ratio of the erosion modulus of control regions in that of the whole study area*		Sediment yield /×10⁴t		The proportion of the sediment yield of control regions in that of the whole study area* /%	
		1955—1969	1970—1989	1955—1969	1970—1989	1955—1969	1970—1989	1955—1969	1970—1989
1	6,574.2	9,493.7	9,146.7	1.51	2.33	6,241.4	6,013.2	3.2	4.9
2	13,091.9	12,170.7	9,551.1	1.93	2.43	15,933.8	12,504.2	8.2	10.3
3	16,073.5	18,468.5	11,178.8	2.93	2.85	29,685.3	17,968.2	15.2	14.8
4	20,125.3	15,337.0	7,251.3	2.43	1.85	30,866.2	14,593.5	15.8	12.0
5	15,636.7	12,103.1	6,857.8	1.92	1.75	18,925.3	10,723.3	9.7	8.8
6	7,809.1	7,562.5	3,744.8	1.20	0.95	5,905.6	2,924.4	3.0	2.4
7	17,835.8	11,895.5	8,313.9	1.89	2.12	21,216.6	4,828.5	10.9	12.2
8	23,742.2	8,300.5	5,851.5	1.32	1.49	19,707.1	13,892.6	10.1	11.4
9	13,641.1	6,314.1	3,599.3	1.00	0.92	8,613.1	4,909.8	4.4	4.0
10	14,472.6	9,626.6	6,011.3	1.53	1.53	13,932.1	8,700.0	7.1	7.1

*The average erosion modulus of the whole study area was 6,302.1t/(km^2 • a) over the interval 1955—1969, 3,928.4 t/(km^2 • a) over the interval 1970—1989; the average sediment yield was 19.5×10^{8}t over the interval 1955—1969, 12.2×10^{8}t over the interval 1970—1989

2 Collocation of control measures

2.1 Principle of collocation

(1) Taking soil erosion reducing as the main goal

The main effect of the soil and water conservation measures is to reduce or avoid soil and water loss, and to decrease the sediment in the Yellow River. The effect of slope measures is mainly to reduce sand, and the effect of gully measures is mainly to block sand. Thus, in order to reduce sediment, the slope measures include terrace, woods and grass are collocated in the paper.

(2) The collocation of terrace combining with the gradient of plowland

According to the features of soil erosion taking place in the field with different gradient [2,3,4,5], terraces are collocated on the sloping field with gradient 3°—15°.

(3) The collocation of woods and grass following the rule of vegetation zone distribution

Geographical distribution of vegetation are restricted by the factors such as climate, landform, soil and so on., especially the condition of water and heat. The different combinations of water and heat result in the disciplinary subrogation of climate, vegetation and soil in geographical distribution. From southeast to northwest, there are 4 vegetation belts on the loess plateau, i.e. forest, forest steppe, typical steppe and desert steppe. Therefore, in the collocation of woods and grass, the proportion of woods and grass should be chosen according to the vegetation zone.

2.2 The results of collocation

(1) Conformation of the total controllable area

In one region, not all of the land exist serious soil-water loss and are needed to control, thereby, it should ascertain the controllable area of the 10 control regions firstly, and then collocate the different combination of terrace, woods and grass in the controllable area. The controllable area of the control regions is the total land area minus residential area, industrial estate, mining area, transportation area, water area, bare rock and gravel area and <3° plowland area.

(2) Controllable area of terrace

Based on the gradient grade information of counties on the loess plateau and the area proportion of counties in the 10 control regions respectively, the gradient grade data of the 10 control regions are obtained. In one control region, the area of 3°—15° plowland is the controllable area of terrace.

(3) Controllable area of woods and grass

The controllable area of woods and grass is the total controllable area minus controllable area of terrace in a control region. Based on the regional distribution of the 10 regions, region 1, 2, 3, 6 and 9 are in the steppe belt, region 4, northwest from Yanan of region 5, region 7, northwest from Xifeng of region 8 and region 10 are in the forest steppe belt, southeast from Yanan of region 5 and southeast from Xifeng of region 8 are in forest belt; and the collocation proportion of woods and grass is 8:2 in forest belt, 5:5 in forest steppe belt, and 2:8 in the steppe belt.

(4) Area collocation of control measures in different rainfalls

In order to analyze the sediment reducing benefit under different rainfall and control conditions, it need to collocate the combination of the rainfall index under different rainfall conditions and the area of terrace, woodland and grassland under different control degrees stochastically. And the 9,000 combinations of soil and water conservation measures in different rainfall conditions are obtained by the permutation and combination method, according to the 9 rainfall frequencies (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%) and the controllable areas of level terrace, woodland and grassland at 10% control progress rate.

3 The prediction of soil loss under different rainfall and control conditions

3.1 Conformation of rainfall frequency

The relationship between soil loss amount and annual maximum 1 hour rainfall amount, annual maximum 24 hours rainfall amount, annual maximum 30 days rainfall amount, flood season (from May to Sept.) rainfall amount were analyzed respectively, the results should that the relationship between soil loss amount and annual maximum 30 days rainfall amount is the best one, and the next is the relationship between soil loss amount and flood season rainfall amount. According to the availability of rainfall data, flood season rainfall amount was chosen for rainfall index to predict soil loss in this paper. The observation rainfall data of 3—5 hydrological stations in one control region with 35 year time series (1955—1989) were selected to analyze the frequency of flood season rainfall amount, and the flood rainfall amount in different frequency of the 10 regions are obtained.

3.2 Conformation of control degree

Usually, the control degree is expressed as the ratio of controlled area and controllable area. It is difficult to build the relationship between sediment reducing benefit and control degree as a result of the difference in sediment reducing amount per acreage of control measures. For example, the benefit of sediment reducing benefit of 1mu of terrace and 1mu of woodland is different, it is possible that sediment reducing amount of 5 mu of woodland is equal to that of 3 mu of terrace, and the sediment reducing benefit of woodland and grassland is effected by it's coverage. Accordingly, taking terrace area as criterion area, and the sediment reducing benefit of woodland and grassland with various coverage under different rainfall conditions are standardized as the coefficient for converting the area of woodland and grassland to criterion area. The formula for calculating control degree is as follows:

$$C=(T+F\times \xi_1+G\times \xi_2)/A\times 100\%$$

In the formula above: C is the control degree (%); T is the area of terrace; F is the area of woodland; G is the area of grassland; A is the controllable area; ξ_1 is the coefficient for converting the area of woodland to criterion area, it is the ratio of the sediment reducing benefit of woodland and terrace in the same rainfall conditions; ξ_2 the coefficient for converting the area of grassland to criterion area, it is the ratio of the sediment reducing benefit of woodland and terrace in the same rainfall conditions.

In the meanwhile, the quality of the soil-water conservation measures affects the sediment reducing benefit very greatly, so in the study, the quality of the control measures are supposed that the bank of level terrace is in good condition, the field of level terrace is flat or anti-sloping and fertile, there is no soil and water loss under 5% frequency rainfall condition in the terrace fields; and the coverage of woodland is 70%, the coverage of grassland is 80%.

3.3 The calculation of soil loss amount in uncontrolled condition

Soil loss amount in uncontrolled condition of a region should be enumerated firstly to calculate the soil-water conservation benefits and predict the trend of soil loss, especially the soil loss amount in uncontrolled condition under different rainfalls. The year 1970 is the time division between un-control and control, so the data adopted to calculate soil loss amount in uncontrolled condition of the control regions are the rainfall and sediment information of hydrological stations before 1970 (1955—1969). Firstly, to calculate the areal rainfall amount of control regions by choosing more than 3 representative hydrological stations in one region; and then to build the relationships between soil loss amount and areal rainfall amount. Considering 15 years series is short to reflect soil loss under various rainfall condition, the frequency of flood rainfall over the interval 1955—1989 are analyzed, with the relationship concerned above, the soil loss amount in uncontrolled condition under different rainfall frequency of the 10 regions are obtained

3.4 The sediment reducing benefit of soil and water conservation measures

The sediment reducing benefit of high quality level terrace can reach 100% under 10% frequency rainfall conditions. But in actual, this index is on the high side because of the effect of rainfall factor and the quality of level terrace such as the flatness of field, the height and fastness of bank. Thus, it is determined that the flood rainfall amount under which the sediment reducing benefit is 100% is 450mm, according to the rainfall erosion data of runoff plots in sloping fields and level terrace on the loess plateau. When flood rainfall amount is smaller than 450mm,the sediment reducing benefit is 100%; and when flood rainfall amount is bigger than 450mm, the sediment reducing benefit is 95%.

According to the analysis on rainfall erosion information of runoff plots in woodland and grassland, the relationships between sediment reducing benefit of woodland and grassland and rainfall, coverage are as follows:

Woodland: $S(\%)=223.923-3103.189(1/v)-30.985\log(PI_{30}\cdot v)$ $r=0.682^{**}$ $n=88$

Grassland: $S(\%)=-108.520+46.194\log(v/PI_{30})+84.813\log(v)$ $r=0.787^{**}$ $n=110$

In the equations above：S（%）is the sediment reducing benefit of woodland or grassland（%）; V is the coverage of woodland or grassland (0—100); and PI_{30} is the rainfall index, i.e. the product of rainfall amount minus maximum 30min rainfall intensity in an individual rain（3.20 mm^2/min—100 mm^2/min）。The sediment reducing benefit of woodland and grassland are calculated by the equations above.

In region or watershed, the sediment reducing benefit of slope control measures include sand reducing amount in slope, and the sand reducing amount in gully owing to the runoff reducing amount in slope not pouring into gully. In loess hill and gully regions, the intergully and gully land is about 50% of the total area, and the erosion of gully and intergully is respectively about 60% and 40%. A half of the gully erosion, at least, is caused by intergully runoff flowing down the gully[6]. Therefore, the soil-water conservation measures in slope could reduce 40% sediment in slope and 30% sediment in gully, that is to say, 70% sediment in a watershed. In the gully, there are some terrace, woodland and grassland which suppose that having 10% sediment reducing benefit, Hence, the maximum sediment reducing benefit of terrace, woodland and grassland could account for 80% sediment of one watershed. And the formula for calculating the sediment reducing benefit of terrace, woodland and grassland is as follows:

$$\triangle S=0.8S\times S\%$$

In the formula above：$\triangle S$ is the sediment reducing amount of slope measures（t）; S is the total sediment amount of watershed（t）; S% is the sediment reducing index of slope measures（%）.

3.5 Soil loss under different rainfall and control conditions

3.5.1 Soil loss in different control regions

The sediment reducing benefit, sediment reducing amount and soil loss amount of 10 regions in different rainfall frequencies and control degrees are shown in Table 2. When rainfall frequency would be 50% and control degree would be 90%, the sediment reducing benefit of the 10 regions vary from 50% to 58%, the erosion modulus of the 10 regions would be below 4,000 t/(km^2 • a) and there would be 7 regions in which erosion modulus would be below 3,000 t/(km^2 • a), 3 regions in which erosion modulus would be below 2,000 t/(km^2 • a).

3.5.2 The trend of soil loss in the emphases control area

(1) When control degree would reach 50%, the sediment reducing benefit of terrace, woodland and grassland would be 30.5%, and soil loss amount would reduced from 10.4×10^{8}t to 7.2×10^{8}t in average year (*P*=50%); the sediment reducing benefit of terrace, woodland and grassland would be 31.1%, and soil loss amount would reduced from 6.5×10^{8}t to 4.5×10^{8}t in low-flow year (*P*=80%); and the sediment reducing benefit of terrace, woodland and grassland would be 29.3%, soil loss amount would reduced from 20.6×10^{8}t to 14.6×10^{8}t in high-water year (*P*=20%).

(2) When control degree would reach 80%, the sediment reducing benefit of terrace, woodland and grassland would be 48.7 %, and soil loss amount would reduced from 10.4×10^8 t to 5.3×10^8 t in average year(*P*=50%); the sediment reducing benefit of terrace, woodland and grassland would be 49.7%,

Table 2 The sediment reducing benefit, sediment reducing amount and soil erosion modulus under different rainfall frequencies and control degrees of the 10 regions

Control region	Rainfall frequency	Sediment reducing benefit				Sediment reducing amount				Soil erosion modulus			
		30%	50%	70%	90%	30%	50%	70%	90%	30%	50%	70%	90%
1	10	17.8	29.7	41.6	53.5	2,381.4	3,968.9	5,556.2	7,143.6	16,701.2	14,286.5	11,872.0	9,457.5
	20	18.5	30.8	43.2	55.5	1,536.3	2,560.4	3,584.5	4,608.5	10,290.6	8,732.9	7,175.2	5,617.6
	50	19.4	32.4	45.4	58.3	860.7	1,434.4	2,008.1	2,581.8	5,422.1	4,549.5	3,676.8	2,804.2
2	10	17.2	28.7	40.2	51.6	5,067.7	8,445.7	11,823.5	15,201.4	18,621.9	16,041.7	13,461.5	10,881.5
	20	17.8	29.7	41.5	53.4	3,124.5	5,207.2	7,289.9	9,372.5	11,024.8	9,434.0	7,843.2	6,252.4
	50	18.6	31.0	43.4	55.8	1,648.7	2,747.7	3,846.6	4,945.5	5,511.1	4,671.6	3,832.2	2,992.8
3	10	17.1	28.4	39.8	51.2	4,227.1	7,044.9	9,862.6	12,680.1	12,782.4	11,029.4	9,276.4	7,523.5
	20	17.6	29.3	41.0	52.7	2,533.4	4,222.2	5,910.8	7,599.4	7,397.9	6,347.3	5,296.7	4,246.2
	50	18.2	30.4	42.6	54.7	1,287.6	2,145.9	3,004.2	3,862.4	3,589.2	3,055.3	2,521.3	1,987.4
4	10	17.4	29.1	40.7	52.3	7,897.6	13,162.0	18,426.2	23,690.2	18,573.4	15,957.6	13,341.9	10,726.3
	20	18.0	29.9	41.9	53.9	6,135.3	10,225.0	14,314.5	18,403.8	13,917.9	11,885.8	9,853.8	7,821.8
	50	18.7	31.1	43.6	56.1	3,135.9	5,226.2	7,316.5	9,406.7	6,780.3	5,741.6	4,703.0	3,664.4
5	10	16.9	28.1	39.4	50.6	4,688.1	7,813.0	10,937.9	14,062.7	14,775.5	12,777.0	10,778.6	8,780.2
	20	17.4	29.0	40.6	52.2	3,827.9	6,379.5	8,931.0	11,482.4	11,627.5	9,995.7	8,364.0	6,732.3
	50	18.1	30.2	42.3	54.3	2,205.4	3,675.4	5,145.4	6,615.3	6,377.7	5,437.6	4,497.5	3,557.5
6	10	17.4	29.1	40.7	52.3	1,598.8	2,664.5	3,730.2	4,795.8	9,685.5	8,320.7	6,956.1	5,591.5
	20	18.1	30.2	42.3	54.4	1,205.2	2,008.6	2,812.0	3,615.3	6,960.4	5,931.6	4,902.9	3,874.2
	50	19.1	31.9	44.6	57.3	579.6	965.9	1,352.2	1,738.5	3,140.1	2,645.4	2,150.7	1,656.0
7	10	17.4	28.9	40.5	52.1	6,110.3	10,183.4	14,256.2	18,329.0	16,299.6	14,016.0	11,732.5	9,449.0
	20	17.9	29.9	41.8	53.8	4,728.0	7,879.6	11,031.1	14,182.5	12,140.4	10,373.4	8,606.5	6,839.6
	50	18.7	31.1	43.6	56.0	2,367.4	3,945.5	5,523.5	7,101.5	5,777.9	4,893.1	4,008.3	3,123.6
8	10	15.5	25.8	36.1	46.5	5,551.2	9,251.4	12,951.6	16,651.7	12,752.9	11,194.4	9,635.9	8,077.5
	20	15.9	26.5	37.1	47.7	4,185.4	6,975.3	9,765.1	12,554.8	9,326.4	8,151.3	6,976.3	5,801.3
	50	16.4	27.4	38.4	49.3	1,966.4	3,277.2	4,587.9	5,898.6	4,207.7	3,655.6	3,103.5	2,551.5
9	10	17.7	29.5	41.3	53.1	1,912.3	3,187.0	4,461.7	5,736.3	6,511.0	5,576.5	4,642.1	3,707.7
	20	18.2	30.4	42.6	54.7	1,565.4	2,608.8	3,652.2	4,695.5	5,141.6	4,376.7	3,611.8	2,846.9
	50	19.0	31.6	44.3	56.9	918.0	1,529.9	2,141.8	2,753.7	2,874.4	2,425.8	1,977.3	1,528.7
10	10	16.8	28.0	39.2	50.4	3,076.2	5,126.6	7,177.0	9,227.4	10,531.1	9,114.3	7,697.5	6,280.8
	20	17.2	28.6	40.1	51.5	2,529.4	4,215.5	5,901.5	7,587.4	8,424.8	7,259.8	6,094.9	4,929.9
	50	17.7	29.5	41.3	53.1	1,492.7	2,487.7	3,482.6	4,477.6	4,793.5	4,106.0	3,418.5	2,731.1

and soil loss amount would reduced from 6.5×10^8t to 3.3×10^8t in low-flow year (*P*=80%); and the sediment reducing benefit of terrace, woodland and grassland would be 46.8%, soil loss amount would reduced from 20.6×10^8t to 11.0×10^8t in high-water year (*P*=20%).

(3) When all the controllable area would be actualized with soil and water conservation measures, i.e. control degree would reach 100%, the sediment reducing benefit of terrace, woodland and grassland would be 60.9%, and soil loss amount would reduced from 10.4×10^8t to 4.1×10^8t in average year (*P*=50%); the sediment reducing benefit of terrace, woodland and grassland would be 62.2%, and soil loss amount would reduced from 6.5×10^8t to 2.5×10^8t in low-flow year (*P*=80%); and the sediment reducing benefit of terrace, woodland and grassland would be 58.5%, soil loss amount would reduced from 20.6×10^8t to 8.5×10^8t in high-water year (*P*=20%).

3.5.3 The prediction of sediment amount in the Yellow River

The average sediment amount of the emphases control area over the interval 1955—1969 was 15.2×10^8t, and the sediment amount in the Yellow River (the sum of sediment amount of Hejin station in Fen river, Longmen station in mainstream of Yellow River, Huaxian station in Wei river and Zhuangtou station in Beiluo river) was 17.8×10^8t in the same series, the sediment yield of the emphases control area come up to 85.4% of the sediment yield in the Yellow River. According to the sediment yield proportion relationship between the emphases control area and the Yellow River, the calculated sediment yield in the Yellow River under different rainfalls and control degrees are as following:

(1) When control degree would arrived to 50%, the sediment yield of the Yellow River would decreased from 12.2×10^8t to 8.5×10^8t in average year (*P*=50%), decreased from 7.6×10^8t to 5.2×10^8t in low-flow year (*P*=80%), and decreased from 24.1×10^8t to 17.1×10^8t in high-water year (*P*=50%). In the average conditions, the sediment yield of the Yellow River would decreased from 17.8×10^8t to 12.5×10^8t, and the reducing amount would be 5.3×10^8t, when it were calculated as the sediment reducing benefit being 30%.

(2) When control degree would arrived at 80%, the sediment yield of the Yellow River would decreased from 12.2×10^8t to 6.2×10^8t in average year (*P*=50%), decreased from 7.6×10^8t to 3.8×10^8t in low-flow year (*P*=80%), and decreased from 24.1×10^8t to 12.8×10^8t in high-water year (*P*=50%). In the average conditions, the sediment yield of the Yellow River would decreased from 17.8×10^8t to 9.3×10^8t, and the reducing amount would be 8.5×10^8t, when it were calculated as the sediment reducing benefit being 48%.

(3) When control degree would arrived at 100%, the sediment yield of the Yellow River would decreased from 12.2×10^8t to 4.8×10^8t in average year (*P*=50%), decreased from 7.6×10^8t to 2.9×10^8t in low-flow year (*P*=80%), and decreased from 24.1×10^8t to 10.0×10^8t in high-water year (*P*=50%). In the average conditions, the sediment yield of the Yellow River would decreased from 17.8×10^8t to 7.1×10^8t, and the reducing amount would be 10.7×10^8t, when it were calculated as the sediment reducing benefit being 60%.

(4) When all the controllable area would be actualized with soil-water conservation measures, i.e. control degree would reach 100%, the sediment yield of the Yellow River calculated on the basis of the sediment yield being 16×10^8t over the interval 1919—1969 would decreased to 6.4×10^8t.

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