Time and Spatial Variation Features of Sediment Yield Intensity on the Loess Plateau

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Abstract: Based on the distribution of hydrological stations and it's observation series of sediment information，and the different soil erosion type areas on the loess Plateau, the study area was divided into 292 soil erosion units. The time and spatial variation of sediment yield intensities on the loess plateau were analyzed. The results are showed that sediment intensities have changed evidently because of rainfall factor and the effects of soil and water conservation, and the sediment area with erosion modulus ＞10,000t/(km^2 • a) reduced rapidly. And taking sediment yield intensity ＞10,000t/(km^2 • a) as a criterion, there are 7 sediment yield centers on the Loess Plateau.
Keywords: loess plateau, sediment yield intensity, time and spatial variation

On the Loess Plateau, soil and water loss is terrible, environment is weak, and it's high sand yield makes the river-way in the lower reaches of the Yellow River filled up, riverbed driven up, flood threaten pricked up, and result in great hidden troubles to the controlling of flood and the running of irritation works of the Yellow River. Since 1970's in the 21st century, because of the effects of rainfall and soil-water conservation measures, the sand pouring into the Yellow River has been decreased evidently. Although there were a good many scientific research units which have carried though the research work on the changing of runoff and sediment in the Yellow River, including on the reason of runoff and sediment changing, the low of erosion sediment yield, the benefits of soil and water conservation, the trend of soil loss, and so on, and so many research achievements have been obtained; but the research work on the time and spatial variation of sediment yield intensity have been less carried out [1—7]. The soil erosion intensity is the basic information for investigating the rule of soil erosion, programming soil and water conservation, evaluating the benefit of erosion control measures, and detecting the dynamic of soil and water loss [8]. Therefore, the systemic analysis on the features of time and spatial variation of erosion sediment yield intensity would have signality on the entironment construction, soil and water conservation programming, and the benefits of soil and water conservation evaluation on the Loess Plateau these days.

1 Plot of soil erosion unit

In the calculation of regional erosion sediment yield and the study of sediment spatial variation features on the Loess Plateau, the data could be utilized directly and reliably are the observation sediment information of hydrological stations in these area. However, on the Loess Plateau, the soil erosion type is complex, the regional diversity is large, and there are usually several soil erosion types and erosion patterns in a watershed with small area. The sediment yield observed in hydrological station can only show the average condition of sediment yield in a watershed, not make out the erosion intensity variation of different erosion type areas of the watershed. Therefore, based on the distribution of hydrological stations and it's observation series of sediment information on the Loess Plateau, the study area was divided into 120 hydrological control areas firstly which is the minimum area can be made out, the distribution map of the 120 hydrological control areas was drawn, and then draw the map of soil erosion type area [9] on it. In the same hydrological control area, the soil erosion units were plotted out according to the borderline of different soil erosion type area, and the separated areas with same erosion type are different soil erosion units. In this way, 292 soil erosion units were marked off in the study area.

2 Calculation of erosion sediment yield intensity

2.1 Calculation of erosion sediment yield intensity of hydrological control areas

In the area controlled by a single hydrological station, the erosion sediment yield of hydrological station controlled area in the upper reaches of drainage basin or of tributary of the drainage basin is replaced by the sediment amount of the station, and the sediment amount of the station divided by the station catchment area is the erosion modulus of the station controlled area.

In the area controlled by several hydrological stations, the erosion sediment yield of the area between the station in the lower reaches of drainage basin or of tributary of the drainage basin and one station or several stations in the upper reaches of drainage basin or of tributary of the drainage basin is the sediment amount of the lower station minus that of the upper station or stations, and the result divided by the stations controlled area is the erosion modulus of this area.

In the lower reaches of a drainage basin with no hydrological station, the main stream of the Yellow River is divided into several sections according to the distribution of hydrological stations along the river, and the station controlled area is the area among stations of tributaries in the section between two stations in the main stream of the Yellow River, and the erosion sediment yield is the sediment amount of the station in lower reaches of the Yellow River minus that of the station in upper reaches of the Yellow River and stations of tributaries in the section, and the result divided by the stations controlled area is the erosion modulus of this area.

In the area controlled by several hydrological stations and the area with no hydrological station, the sediment yield are regarded as zero when the calculated results are negative, and it shows that the sediment is alluvial along river.

2.2 Calculation of erosion sediment yield intensity of soil erosion units

In the hydrological station controlled area with single erosion type, the controlled area is one soil erosion unit, and it's erosion modulus and sediment yield is replaced by the data of the controlled area directly.

In the hydrological station controlled area with several erosion types, the erosion modulus and sediment yield of soil erosion units were calculated step by step according to the size of units area. Firstly, calculate the sediment yield of the units with small area, and then use the sediment yield of the controlled area to minus the sediment yield of the units with small area, the result is the sediment yield of the maximum unit which is the main soil erosion type area in the controlled area. The calculation of sediment yield of units with small area is generally replaced by that of close-by unit with same erosion type, and replaced by that of controlled area with single erosion type in the most conditions. When the erosion modulus of units with small area can not be replaced by that of close-by unit with same erosion type, it can be calculated after the erosion modulus of units with large area is replaced by that of close-by unit with same erosion type. For example, in the controlled area between Dingjiagou and Zhaoshiyao in Wuding River, it can be divided into 3 soil erosion units according to the soil erosion type. They are Unit 68 which area is 2,591.1km^2 in the loess *Mao* hill gully region, Unit 69 which area is 1,538.4 km^2 in the wind sand loess hill gully region and Unit 70 which area is 3,967.5 km^2 in the wind sand steppe region. Unit 68 and Unit 72 are joined, and Unit 72 is the Lijiahe station controlled area in Dali River which is the single loess Mao hill gully region, so the erosion modulus of Unit 68 can be replaced by that of Unit 72; Unit 70 and Unit 60 are joined, Unit 60 is Hanjiamao station controlled area which is the single wind sang steppe region, and the erosion modulus of Unit 70 can be replaced by that of Unit 60; then the erosion modulus of Unit 69 can be calculated by the dispersion of the total sediment amount of the controlled area and the sediment yield of Unit 68 and Unit 70 divided by the area of Unit 69, the formula is as follows:

$$S_{69}=(S\times A-S_{68}\times A_{68}-S_{70}\times A_{70})/A_{69}$$

In the formula above: S_{69} is erosion modulus of Unit 69 t/(km^2 •a); S is erosion modulus of controlled area between Dingjiadou and Zhaoshiyao t/(km^2 • a); A is area of the controlled area between Dingjiadou and Zhaoshiyao (km^2); S_{68} is erosion modulus of Unit 68 t/(km^2 • a); A_{68} is area of Unit 68 (km^2); S_{70} is erosion modulus of Unit 70 t/(km^2 • a); A_{70} is area of Unit 70 (km^2); A_{69} is area of Unit 69 (km^2).

3 Structural features of erosion sediment intensity

Based on the calculated sediment yield of 292 units, the structural features of erosion sediment yield on the Loess Plateau were analyzed in 3 conditions which are in uncontrolled condition (1955—1969), in controlled condition (1970—1989) and in average condition (1955—1989), see in Table 1 and Table 2.

Table 1 Area structural characteristics of erosion intensities

Grade	Criterion t/(km^2 • a)	Area (km^2)			Area proportion of the grades in total area			Changes of increase or decrease before and after control %
		Uncontrolled 1955—1969	Controlled 1970—1989	Average 1955—1989	Uncontrolled 1955—1969	Controlled 1970—1989	Average 1955—1989	
Feeble erosion	<1,000	92,166.9	118,657.9	105,651.5	29.7	38.3	34.1	28.7
Low-grade erosion	1,000—2,500	30,799.8	29,371.5	28,869.1	9.9	9.5	9.3	–4.6
Moderate erosion	2,500—5,000	39,827.8	57,168.4	42,901.9	12.8	18.4	13.8	43.5
Intension erosion	5,000—7,500	32,577.9	51,749.9	39,707.6	10.5	16.7	12.8	58.8
Violence erosion	7,500—10,000	27,399.1	28,551.4	35,947.5	8.8	9.2	11.6	4.2
Mighty violence erosion	10,000—15,000	58,740.9	18,406.7	46,243.5	18.9	5.9	14.9	–68.7
Acute erosion	15,000—20,000	18,557.9	4,292.1	7,017.3	6	1.4	2.3	–76.9
Mighty acute erosion	>20,000	10,033.7	1,906.1	3,765.6	3.2	0.6	1.2	–81.0
Above acute erosion	>15,000	28,591.6	6,198.2	10,782.9	9.2	2	3.5	–78.3
Above mighty violence erosion	>10,000	87,332.5	24,604.9	57,026.4	28.2	7.9	18.4	–71.8
Above intension erosion	>5,000	147,309.5	104,906.2	132,681.5	47.5	33.8	42.8	–28.8
Above moderate erosion	>2,500	187,137.3	162,074.6	175,583.4	60.3	52.3	56.6	–13.4

According to the average condition of 35 years from 1955 to 1989, the sediment yield of the Loess Plateau are mainly come from the violence erosive area with erosion modulus ＞5,000t/(km^2 •a), the area of it made up 42.8% of the total sediment yielding area, and the sediment from it amounted to 85.0% of the total amount of erosive sediment yield. And the mighty violence erosive area with erosion modulus ＞10,000t/(km^2 • a), the area of it only made up 18.4% of the total sediment yielding area, but the sediment from it amounted to 50% of the total amount of erosive sediment yield. In the 8 grade of erosion intensity, the sediment yield from the area with erosion modulus 2,500—15,000t/(km^2 • a) amounted to about 90% of the total amount of erosive sediment yield, and the sediment of the area with erosion modulus 10,000—15,000t/(km^2 • a) reach 35.0%.

Table 2 Sediment yield structural characteristic of erosion intensities

Grade	Criterion t/(km² • a)	Sediment yield (10⁴t) Uncontrolled 1955—1969	Controlled 1970—1989	Average 1955—1989	Sediment proportion of the grades in total amount Uncontrolled 1955—1969	Controlled 1970—1989	Average 1955—1989	Changes of increase or decrease before and after control %
Feeble erosion	<1,000	1,539.2	3,199.3	2,624.1	0.8	2.6	1.7	107.9
Low-grade erosion	1,000—2,500	4,457.7	5,359.6	4,837.3	2.3	4.4	3.1	20.2
Moderate erosion	2,500—5,000	15,069.6	22,037.9	16,343.4	7.7	18.1	10.6	46.2
Intension erosion	5,000—7,500	20,260.2	32,639.7	25,239.4	10.4	26.8	16.3	61.1
Violence erosion	7,500—10,000	24,182.5	24,700.3	29,840	12.4	20.3	19.3	2.1
Mighty violence erosion	10,000—15,000	73,007.5	20,735.8	53,936.6	37.4	17	34.9	–71.6
Acute erosion	15,000—20,000	32,149.6	7,479.6	11,555.3	16.5	6.1	7.5	–76.7
Mighty acute erosion	>20,000	24,765.5	5,669.3	10,118.6	12.7	4.7	6.5	–77.1
Above acute erosion	>15,000	56,915.1	13,148.9	21,673.9	29.1	10.8	14	–76.9
Above mighty violence erosion	>10,000	129,922.6	33,884.7	75,610.5	66.5	27.8	48.9	–73.9
Above intension erosion	>5,000	174,365.3	91,224.7	130,689.9	89.2	74.9	84.6	–47.7
Above moderate erosion	>2,500	189,434.9	113,262.5	147,033.3	96.9	93	95.2	–40.2

Based on the statistical results before and after control, the erosion sediment intensities have changed evidently because of rainfall factor and the effects of soil and water conservation. From the view of structural features of sediment area, the sediment area with erosion modulus >10,000t/(km² • a) reduced rapidly, from 8.7×10^4 km² (1955—1969) to 2.5×10^4 km² (1970—1989), reduced 71.8%, and the proportion in the total area decreased from 28.2% to 7.9%. And the sediment area with erosion modulus >15,000t/(km² • a) reduced from 2.9×10^4 km² to 0.6×10^4 km², reduced 78.3%; the area with erosion modulus >20,000t/(km² •a) reduced from 1.0×10^4 km² to only 0.2×10^4 km², reduced 81.0%. In the 8 grades of erosion intensities, the sediment area with erosion modulus >20,000t/(km² • a), 15,000 t/(km² • a)—20,000 t/(km² • a) and 10,000 t/(km² • a)—15,000t/(km² • a) decreased greatly , and the reductive degree is 81.0%, 76.9% and 68.7% respectively. And from the view of structural features of sediment yield, the proportion of sediment yield of mighty violence erosive area with erosion modulus >10,000t/(km² • a) in that of total area reduced from 66.0% to 27.8%. And sediment yield reduced more greatly is the area with erosion modulus >20,000t/(km² • a), 15,000 t/(km² • a)—20,000 t/(km² • a) and 10,000 t/(km² • a)—15,000 t/(km² • a), the reductive degree is 77.1%, 76.7% and 71.6% respectively.

From the view of synchronization of the sediment area and sediment yield structure of erosion intensities, the decrease degree of sediment area and sediment yield are accordant basically in the mighty violence erosive area with erosion modulus >10,000t/(km² • a), they are 71.8% and 73.9% respectively. In the 8 grades of erosion intensities, with the exception of the increase or decrease degree of sediment area and sediment yield of feeble erosion, low-grade erosion and violence erosion are not consistent, the others are consistent.

4 Spatial variation of erosion sediment intensity

Based on the calculated erosion sediment intensity of 292 units before and after control, the map of variation of erosion sediment intensity, and the regional spatial distribution of erosion modulus

＜5,000t/(km^2 • a), 5,000 t/(km^2 • a)—10,000 t/(km^2 • a) and ＞10,000 t/(km^2 • a) on the Loess Plateau before and after control were drawn up (Fig. 1—3). It showed that the regional variation of erosion sediment intensity before and after control on the Loess Plateau have following features.

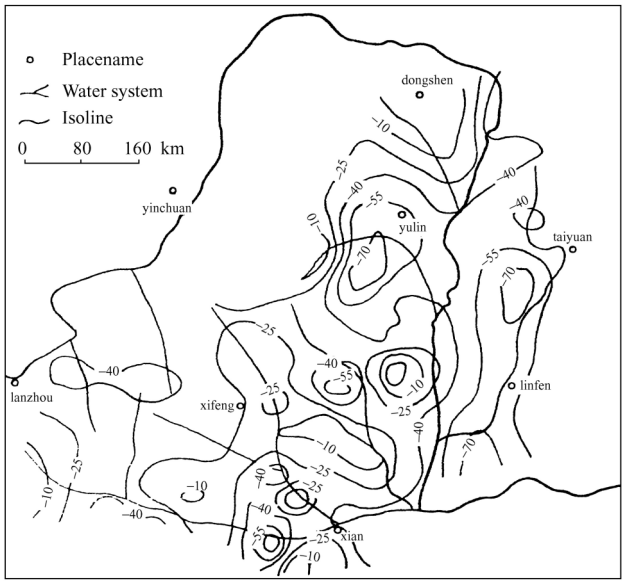

Fig. 1 The variety extent of sediment intensity between before and after control on the Loess Plateau

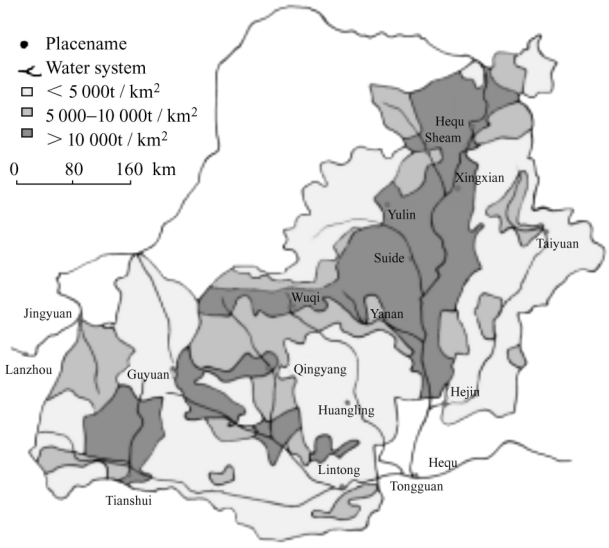

Fig. 2 The spatial distribution of sediment yield intensities on the Loess Plateau (1955—1969)

① After soil and water conservation, the regions where the sediment yield reduced evidently are mainly distributed in the mighty violence erosive area in the around of Wuding River and the majority of Fen River, the reductive degree is above 50%. The reductive degree is 30%—50% in the vicinity of Yanhe River. The reductive degrees in other regions are not marked.

② Before soil and water conservation (1955—1969), the regions with erosion modulus ＞10,000t/(km^2 • a) were distributed in the majority of the mainstream reaches of Yellow River between Hekouzheng and Longmen area, the upper reaches of Beiluo River, the most part of upper and middle

reaches of Jing River, and the majority area of Hulu River and Sandu River in Wei River basin. After soil and water conservation (1970—1989), the regions with erosion modulus ＞10,000t/(km^2 • a) were scattered in Huangpuchuan River, the lower reaches of Kuye River, Jialu River, Wuding River and Qiushui River near to the mainstream reaches of the Yellow River, and the riverhead of Beiluo River and Jing River.

③ After control, the area with erosion modulus ＞10,000t/(km^2 •a) in Hekouzheng - Longmen area, the upper reaches of Jing River and Wei River decreased on a large scale, and the erosion modulus reduced to 5,000 t/(km^2 • a)—10,000 t/(km^2 • a); the area with ＜5,000 t/(km^2 • a) has changed not too much.

5 Centers of sediment yield

Taking sediment yield intensity ＞10,000 t/(km^2 • a) as a criterion, and based on the average sediment results over the interval 1955—1989, it can be marked off 7 sediment yield centers on the Loess Plateau (Fig. 4), the area and erosion intensity of the 7 centers are shown in Table 3. In the 7 sediment yield centers, the center with maximum area is in the Hupuchuan, Gushanchuan, Qingshuichuan, Kuye River and part area above Hequ in the main stream of the Yellow River, the area of it is 13,707.6 km^2; and the center with minimum area is between Nanhechuan and Gangu, Qinan, Wushan in Wei River, the area is 1,495.5km^2. The center with maximum sediment yield intensity is in the lower reaches of Kuye River and Tuwei River, and the most part of Jialu River, the average erosion intensity is 21,473.6 t/(km^2 • a), in the maximum area arrived to 34,447.3 t/(km^2 • a); and the center with minimum sediment yield intensity is also between Nanhechuan and Gangu, Qinan, Wushan in Wei River, the average erosion intensity is 10,776.5 t/(km^2 • a). As a whole, the area of the 7 centers made up 15.5% of the total sediment yielding area, however, the sediment yield amounted to 42.1% of the total amount of erosive sediment yield.

Above all, the sediment yield poured into the Yellow River has being reduced evidently since 1970. The reason for sediment reducing are changing of rainfall and actualizing of soil-water conservation measures, and they have bigger effect on the area and sediment yield with higher erosion intensity. Therefore, the keystone of soil and water conservation should be put into the intense soil erosion regions firstly.

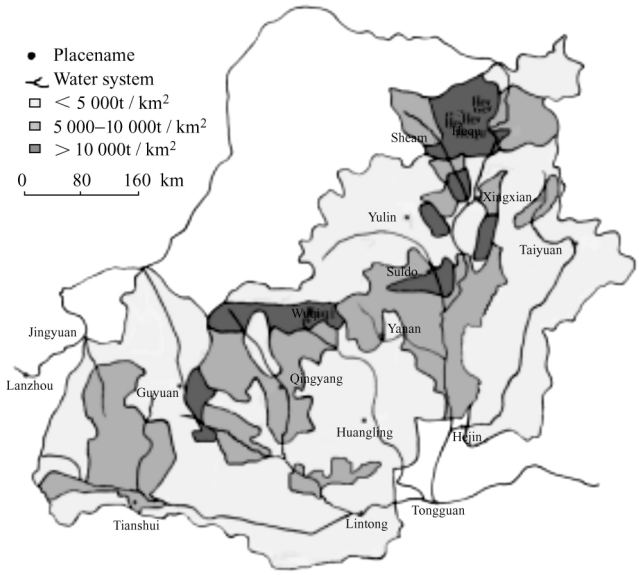

Fig. 3 The spatial distribution of sediment yield intensities on the Loess Plateau (1970—1989)

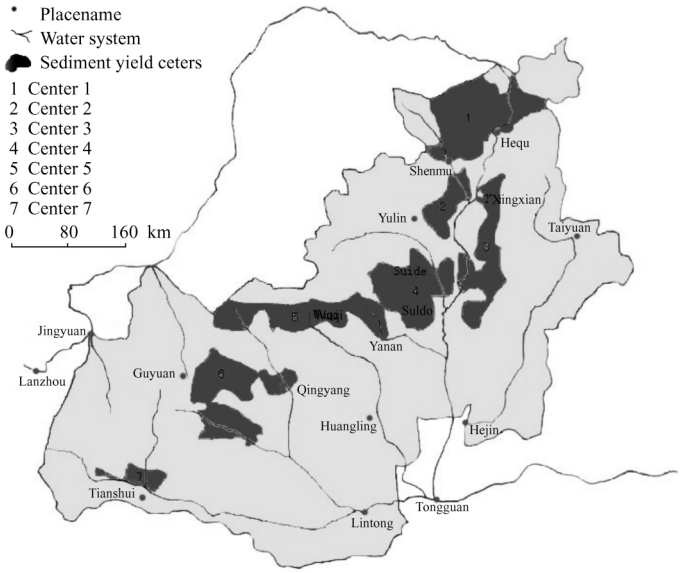

Fig. 4 The 7 sediment yield centers on the Loess Plateau

Table 3 Sediment yield features of the 7 centers on the Loess Plateau

No.	Scope	Erosion sediment			The proportion in the whole (%)		Erosion intensity in the hardcore area	
		Area (km^2)	Erosion intensity $t/(km^2 \cdot a)$	Sediment yield ($10^4 t \cdot a$)	Area	Sediment yield	Area (km^2)	Erosion intensity $t/(km^2 \cdot a)$
1	Hupuchuan, Gushanchuan, Qingshuichuan, Kuye River and part area above Hequ in the main stream of the Yellow River	13,707.6	14,253.9	19,538.7	4.4	12.6	635	28,638.6
2	The lower reaches of Kuye River and Tuwei River, the most part of Jialu River	3,238.7	21,473.6	6,954.7	1.0	4.5	1,212.3	34,447.3
3	The part area of Lanyi River, Weifen River, Qiushui River, Sanchuan River, Quchan River and Xinshui River in the east bank of the Yellow River	7,104.2	12,350.8	8,774.3	2.3	5.7	1,517.1	14,426.9
4	The interval between Baijiachuan and Dingjiagou & Suide in Wuding River, between Suide and Qingyangcha & Lijiahe in Dali River, and the area above Yanchuan in Qingjian River	8,794	12,426.9	10,928.2	2.8	7.1	2,902	14,850.5
5	The area above Yanan in Yanhe River, above Zhidan and Wuqi in Beiluo River, and above Hongde in Jing River	8,695.3	13,177.6	11,458.3	2.8	7.4	3,216.6	15,797.2

Continued Table 3

No.	Scope	Erosion sediment			The proportion in the whole (%)		Erosion intensity in the hardcore area	
		Area (km^2)	Erosion intensity $t/(km^2 \cdot a)$	Sediment yield ($10^4 t \cdot a$)	Area	Sediment yield	Area (km^2)	Erosion intensity $t/(km^2 \cdot a)$
6	The part area above Yangjiaping in Jing River, and the area between Qingyang and Hongde & Yuele in Malian River	4,993.2	11,900.8	5,942.3	1.6	3.8	1,540.2	12,806
7	The area between Nanhechuan and Gangu, Qinan, Wushan in Wei River	1,495.5	10,776.5	1,611.6	0.5	1.0	1,495.5	10,776.5

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