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THE IMPACT OF ENVIRONMENTAL CHANGE AND CONSERVATION MEASURES ON EROSION AND SEDIMENT LOADS IN THE YELLOW RIVER BASIN

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ABSTRACT Early in history, under conditions of natural erosion, the Yellow River was a heavily sediment-laden river. Subsequent deterioration of the environment caused sediment loads in the 1950s and 1960s to increase to 70% more than those of the past 3000 years. In the 1980s, the sediment load of the river decreased by about 500 million tons because of the effects of sediment retention by water and soil conservation measures and less precipitation. The sediment load of the Yellow River could be further reduced in the future by wider application of watershed management in the loess plateau, but the Yellow River will still be a muddy river.

THE IMPACT OF ENVIRONMENTAL CHANGE ON EROSION AND SEDIMENT YIELD IN THE LOESS PLATEAU

Soil erosion has existed in the Yellow River basin throughout the period of geological history and the intensity of erosion has increased gradually with historical changes in the environment. The Yellow River has been a heavily sediment-laden river for thousands of years. According to the studies of Jing Ke & Chen Yongzong (1983) the mean annual sediment load was 1075 x 10^6 t in the mid Holocene (4000-1020 BC) and increased to 1160 x 10^6 t in the late Holocene (1020 BC-1194 AD), an increase of 7.9%. Human activity in the loess plateau has subsequently damaged the vegetation cover and increased soil erosion. In the period 1494-1855, the average sediment load was as high as 1330 million tons, an increase of 170 million tons, with 78 million tons caused by accelerated erosion due to human activity. During the period 1919-1949, although the population of the loess plateau showed a slight decrease (still 9 x 10^6 more on average than that in the former period), forest cover was greatly decreased (58% less on average than that in the former period), due to frequent wars. The ecological environment deteriorated rapidly because of disorderly reclamation, denudation, herding and improper land use, and the mean annual sediment load increased to 1680 x 10^6 t which is 349 x 10^6 t more than in the former period, of which 244 x 10^6 t were contributed by accelerated erosion consequent upon human activity.

In the 40 years since the founding of new China, soil erosion and sediment loads in the loess plateau of the middle reaches of the Yellow River have entered a new phase. This can be divided into two periods: The first period was from 1950-1970, when the mean annual sediment load was 1741 x 10^6 t, an increase of 61 x 10^6 t compared bo the former period, reflecting the impact of destructive activities such as reclamation caused by a greatly increased population (double that of the former period) and the effects of water and soil conservation measures in retaining sediment on the loess plateau of the middle reaches of the Yellow River were limited. The second period was from 1971 to 1985 when the mean annual sediment load was reduced to 1154 x 10^6 t as a result of the large scale development of management in the loess plateau area. Forest cover also increased greatly (36% on average) and water and soil conservation measures were widely applied to retain sediment. According to available data the mean annual amount of sediment retained by check dams and reservoirs on the loess plateau area in this period was 603 x 10^6 t. The actual annual sediment yield of the loess plateau in this period was therefore 1757 x 10^6 t, including the observed annual sediment discharge of 1154 x 10^6 t. This represents a slight increase over the former period.

In short, the erosion and sediment yield of the Yellow River basin have increased in response to historic changes in the environment of the loess plateau of the middle Yellow River (see Table 1). The actual sediment yield of the Yellow River has increased about 70% in 3000 years.

TABLE 1 Changes in the population, forest cover and sediment load of the Middle Yellow River basin during the Holocene; increases noted with (+) and decreases noted with (-).

Period	Sediment Load			Population		Forest Cover	
	Total	Change		Total	Change	Total	Change
	10^9	10^9	%	10^6	10^6	10^3 km^{-2}	%
Middle Holocene							
4000 —1020BC	1.075	—	—	—	—	—	—
Late Holocene							
1020BC—1194AD	1.16	+0.085	+7.9	8-9	—	250-200	—
1194 —1855	1.330	+0.170	+14.6	9-30	+11	200-80	-38
1919 —1949	1.680	+0.350	+26.3	30-27	+9	80-37	-58
1950 —1970	1.741	+0.061	+3.6	27-56	+13	37-50	-26
1971 —1985	1.154	-0.581	-33.7	56-72	+23	50-86	+36

RECENT RESEARCH ON CHANGES IN THE SEDIMENT LOAD OF THE MIDDLE YELLOW RIVER

Recent research on the effects of environmental change on sediment loads has mainly concentrated on the impact of climate change and watershed management. Compared with the mean annual sediment load of the 1950-1970 period, during the last 15 years (1971-1985), the two factors mentioned above have caused a reduction in the sediment load by 587 x 10^6 t or 33.7%.

The effects of climate change

The sediment load of the middle Yellow River has been mainly effected by changes in precipitation. Records indicate that the climate of the loess plateau has been drier during the last 15 years. Mean annual precipitation was 11% less than in the period 1950-1970 and as a result the sediment load was reduced by 286 x 10^6 t, representing 48.7% of the total reduction in sediment load.

Heavy rainstorms greatly affect the sediment load of the middle Yellow River. The sediment load of the middle reaches of the Yellow River is mainly produced by a few major storms during the flood season (daily precipitation ≥ 100-200 mm). In some areas the sediment load of one storm event flood could be more than 50% of the total annual load. For example, in the Wuding River (30217 km^2 drainage area), the Huangpu River (3199 km^2 drainage area) and the Kuye River (8706 km^2 drainage area), three tributaries of the Yellow River, the maximum sediment discharge in 5 days was 42.2%, 56.8%, and 75.2% of the total discharge of the whole year respectively.

High magnitude storms can increase the annual sediment yield of small watersheds by a factor of two or more. In the Tanghuyuan Experimental Area, for example, which is located on the gullied loess plateau area, the storm event of 6 August 1988 with a duration of 4 hours, produced a total precipitation of 160 mm, and a maximum average intensity of 1.27 mm min^{-1}. in 110 minutes. This extraordinary storm resulted in a sediment discharge from the Tanghu Gully, a small watershed with a drainage area of 2.83 km^2, as high as 61650 t km^{-2} and with 85% of the area controlled, sediment had been retained within the gully for more than 20 years, but the sediment transport during that flood was as much as 15000 t km^{-2}, with the gully becoming a major sediment source.

The effects of watershed management

Watershed management has been developed on a large scale since the 1970's. By 1985, about 102600 km^2 had been controlled preliminarily, representing 23.7% of the total eroding area of the loess plateau. As a result of water and soil conservation measures applied in the last 15 years (1971-1985), sediment loads have been reduced by 301 x 10^6 t compared to those in the period of 1950-1970, providing 51.3% of the total reduction in sediment transport.

The benefits of sediment yield reduction by soil conservation measures

The soil conservation measures applied in the middle Yellow River are mainly as follows: tillage practices for soil conservation, afforestation, grassing, terraced fields and silted up land. According to a comprehensive analysis of test data obtained from experimental stations in the gullied rolling loess area, the sediment reduction produced by these measures is remarkable. The levels are, 40% by grassing, 85% by afforestation, 94% by terraced fields and 45000 m^3 ha^{-1} by silted up land. It must, however, be recognized that these results are obtained from plots which are likely to show higher benefits in terms of sediment reduction. The sediment reduction produced by soil conservation measures for a larger area might be far smaller than the values mentioned above, if the situation worsens over a large area and the damage to conservation measures caused by rainstorms are considered. In addition, the benefits of sediment reduction produced by soil conservation measures are influenced by rainfall amounts. The smaller the rainfall, the higher the benefits of sediment reduction and the greater the rainfall, the lower the benefits.

The benefits of sediment yield reduction by comprehensive management of watersheds

Benefits of sediment yield reduction by comprehensive management of watersheds in different areas Taking a small watershed as a unit for comprehensive management is the most effective way to control soil erosion and reduce sediment entering the Yellow River. At present, more than 3000 small watersheds (drainage area less than 30 km^2) on the middle reaches of the Yellow River have been managed. The tributaries of the Wuding River and the Sanchuan River that are located in the severe soil erosion area of the middle Yellow River have been considered to represent a key control area by the state since 1983. The benefits of sediment yield reduction at different levels have been gained through concentrated and continuous management of those small watersheds and key control areas (see Table 2). Generally speaking, the benefits of sediment reduction are easier to obtain in small watersheds than in large watersheds. Under the same conditions of management, the benefits of sediment reduction in small watersheds are higher than those in large watersheds (Mou, 1986).

TABLE 2 Benefits of sediment yield reduction through comprehensive management of watersheds in different areas.

	River or section	Drainage area km^2	Control area km^2	Control degree %	Sediment Yield Reduction (%) Total	Effect by precip.	Effect by water & soil conservation
Small watersheds	Wangmao Gully	5.97	4.07	68.1	89.0	—	—
	Wangjia Gully	9.10	6.43	70.7	90.6	—	—
	Nanxiaohe Gully	36.3	21.1	58.0	97.2	—	—
Tributaries of key control	Sanchuan	4102	953	34.5	63.4	31.8	31.6
	Wuding	30 217	11 896	51.4	64.2	27.6	36.6
Coarse sand area	Hekouzhen-Longmen	129 600	42 800	33.0	39.5	19.4	20.1
Upper & middle Y.R.	Longyanzxia Taohuayu	640 000	102 600	23.9	33.7	16.4	27.3

Relationship between watershed management level and benefits During the process of comprehensive management of a watershed or area, the benefits of sediment yield reduction increase with an increase in management level (see Table 3). This not only reflects the high sediment delivery ratios of the loess plateau area (the sediment delivery ratio of the first sub-region of the gullied rolling loess area if close to 1), but also clearly shows that the objective of greatly reducing sediment entering into the Yellow River can be achieved by comprehensive management and increasing the level of control.

TABLE 3 Benefits of sediment yield reduction for different watershed management levels.

River	Drainage area km^2	Year	Control degree %	Annual reduction $10^6 t$	Benefits gained by water & soil conservation %
Sanchuan River	4102	1975	12.7	3.88	10.8
		1982	16.9	6.83	19.0
		1986	34.5	11.36	31.6

The role of individual measures of sediment yield reduction in comprehensive watershed management Under normal conditions, for large and medium-sized basins and especially for large basins with several dams and reservoirs, the benefits achieved by using conservation measures on gullies are greater than those obtained using other measures on the slopes such as terraced fields, trees and grasses (see Table 4). Taking the Wuding River and the Sanchuan River as example, the sediment yield reduction achieved by using dams and reservoirs is 88.29% and 56.16% respectively, but only 11.71% and 43.85% where terraced fields and trees and grasses are respectively used. This is mainly because the soil loss from gullies on the loess plateau is greater than that from the slopes. Terraces, trees and grasses are mainly applied on slopes, while dams and reservoirs can not only effectively control severe gully erosion, but also trap the sediment from slopes that have not been controlled by terraces, trees and grasses.

TABLE 4 Effects of single measures on sediment reduction in comprehensive management watershed.

River	Drainage area km^2	Measures on slope				Measures on gully			Total %
		Terra. %	Tree %	Grass %	Sub- %	Check %	Reser- %	Sub- %	
Sanchuan R.	4102	11.16	21.96	10.73	43.85	53.48	2.67	56.16	100
Wuding R.	30 217	2.40	6.17	3.14	11.71	43.65	44.64	88.29	100

LONG-TERM TRENDS IN SOIL EROSION AND SEDIMENT YIELD

Based on the trend of environmental conditions within the middle Yellow River and a qualitative assessment, soil erosion and sediment yield from the loess plateau could increase in the future. The first reason is that the climatic status of the loess plateau and nearby areas has become increasingly dry during the last 10000 years. At present, it is entering a warmer and wetter phase. The second is that although the middle Yellow River has experienced a dry period which has caused significant sediment yield reduction during the last 10 years or so, the future long-term hydrological series might exhibit an increased incidence of storms and floods with high sediment concentrations. The present situation of substantial sediment yield reduction because of reduced precipitation cannot continue. The third is that at present the Yellow River drainage system still has a very high capacity for erosion and sediment transportation. The loess is still accumulating, topographic differences in elevation are still increasing and severe soil and water loss are continuing according to an analysis of geological and geomorphological conditions.

Quantitative analysis indicates that about 1×10^9 t of sediment currently enter the Yellow River annually due to natural erosion processes which are difficult to control totally. Soil and water loss caused by human activities can be controlled. If comprehensive watershed management can be extended in the coming 60 years as effectively as in the last 30 years, the sediment load entering the Yellow River could be reduced by about 400×10^6 t by water and soil conservation measures (Xiong *et al.*, 1988) and a 50% reduction in sediment yield could be achieved through longer term effort. Nevertheless, the sediment load entering the Yellow River at that time would still be 800×10^6 t year^{-1} and the Yellow River would still be a muddy river.

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