Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium, July 1996). IAHS Publ. no. 236, 1996.

Recent studies of the role of soil conservation in reducing erosion and sediment yield in the loess plateau area of the Yellow River basin

MOU JINZE
Yellow River Conservancy Commission, Ministry of Water Resources, Zhengzhou 450003, China

Abstract The high sediment load transported by the Yellow River is derived mainly from soil erosion on the loess plateau in the middle reaches of the Yellow River. The most severe erosion occurs in the gullied rolling loess area and a primary sediment yield area is located in the Hekouzhen-Longmen reach on the middle Yellow River. The concentrated erosion and sediment yield are caused by rainstorms and heavy storms. In the 1980s, the average annual observed amount of sediment transport by the middle Yellow River was only 799×10^6 t, the minimum value for a 10-year series since the beginning of records. The average annual sediment reduction through comprehensive management of the catchment in the middle Yellow River in the 1980s was 252×10^6 t, of which sediment reduction through soil conservation measures was 176×10^6 t, making up 69.8% of the average annual sediment reduction through catchment management. However, the increased sediment due to damage by human activities is about 47×10^6 t, counteracting the effect of sediment reduction through catchment management by 18.6%. Although the average annual sediment flowing into the Yellow River will be reduced about 500×10^6 t in the next 50 years, the Yellow River will still be a hyper-sediment concentrated river due to the influence of unfavourable factors of geology and climate.

CHARACTERISTICS OF EROSION AND SEDIMENT YIELD IN THE LOESS PLATEAU

The Yellow River is the second largest river in China, running through nine provinces with a total length of 5464 km and a catchment area of 752×10^3 km^2 (Fig. 1). The area of loess plateau within the Yellow River basin is 640×10^3 km^2. The average annual precipitation over most of the area is 400-500 mm and the mean annual specific sediment yield is 3700 t km^{-2}. The main characteristics of erosion and sediment yield over a large area of the loess plateau are as follows:

(a) **Water and gravitational erosion are the main types of erosion and sediment yield** There are five types of erosion on the loess plateau: water, wind, gravity, freeze-thaw and man-made. Water erosion is the main type of erosion on the loess plateau and gravitational erosion is also important in that region. Wind erosion is important only in the northern region of the loess plateau and man-made erosion is usually associated with irrational farming and reclamation activities and mining and road construction work.

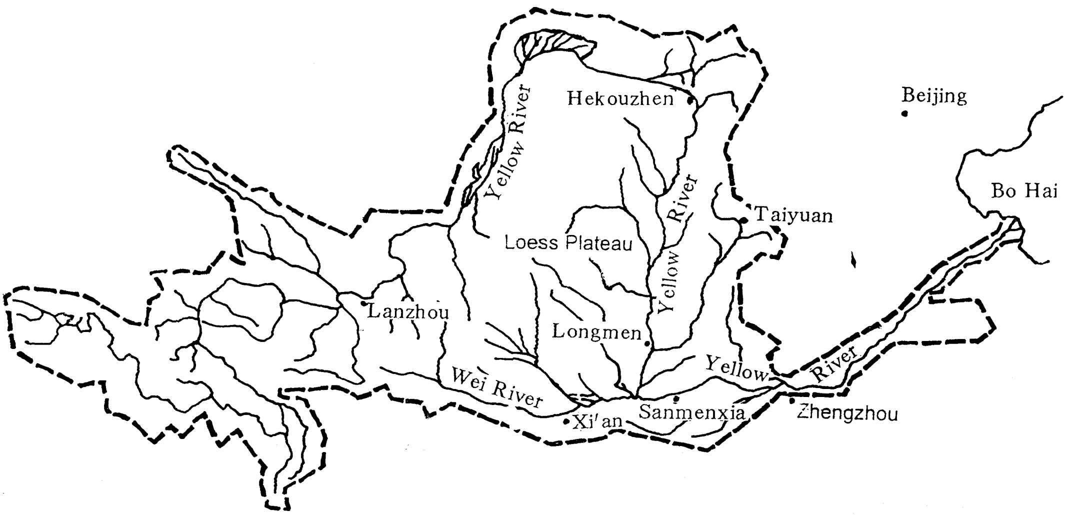

Fig. 1 The Yellow River basin.

(b) **A high proportion of the land has a high intensity of soil erosion** The total area of the loess plateau affected by soil erosion is 430 $\times$ 10^3 km^2. The intensity of soil erosion exceeds 5000 t km^{-2} $year^{-1}$ on 36.3% of this area. Rates of erosion exceed 10 000 t km^{-2} $year^{-1}$ on 77 $\times$ 10^3 km^2; and values greater than 15 000 t km^{-2} $year^{-1}$ are found on 33 $\times$ 10^3 km^2. These regions of high intensity soil erosion are almost all located in the gullied rolling loess area.

(c) **Sediment is mainly produced in the Hekouzhen-Longmen reach of the middle Yellow River** The average annual sediment load from the area above Sanmenxia is 1600 $\times$ 10^6 t and the average annual runoff is 42.4 $\times$ 10^9 m^3 (statistics for 1919-1960). The area above Hekouzhen contributes 58% of the runoff and only 9% of the sediment yield. The Hekouzhen-Longmen reach contributes only 18% of the runoff and 57% of the sediment yield of the whole basin. The water of the Yellow River therefore comes mainly from the area upstream of Hekouzhen, whereas the sediment comes mainly from the Hekouzhen-Longmen reach of the middle Yellow River.

(d) **Heavy storms cause concentrated erosion and sediment yield and deposition in the lower river course** Analysis of data from runoff plots at the Soil Conservation Stations of the Yellow River Conservancy Commission show that soil erosion occurring during the annual flood season of June-September accounts for up to 90% of the annual total. The total annual amount of erosion is usually concentrated into a few storms with as much as 60% occurring in a single storm.

Concentrated erosion results in concentrated sediment yield. According to the records of sediment transport for the major rivers in the middle reaches of the Yellow River, sediment transport in 3 days can account for 23-65% of the annual total, whereas in 5 days and 10 days the values are 33-75% and 49-89%.

Concentrated sediment yield causes serious deposition in the river channel. Records indicate that 11 hyper-concentrated floods occurred in the lower Yellow River during the period 1950-1985. These were the result of severe soil erosion and sediment yield caused by heavy storms which occurred in the coarse sediment region of the loess plateau, and accounted for 55% of the total deposition in the lower channel of the Yellow River over a period of 35 years. In addition, according to the data for 1979-1989 the accumulated sediment deposition in the lower course of the Yellow River over the 10 year period was 412 $\times$ 10^6 t, while the amount of deposition in the lower channel during 44 days from 2 July to 14 August 1988 was as much as 586 $\times$ 10^6 t, i.e. more than the total for 10 years.

THE ROLE OF SOIL CONSERVATION IN REDUCING EROSION AND SEDIMENT YIELD IN THE LOESS PLATEAU DURING THE 1980S

Runoff and sediment data for the loess plateau from the 1980s have been analysed to assess the effects of precipitation amounts and soil conservation in reducing erosion and sediment yield.

Catchment management in the 1980s

The statistics indicate that 2.3 $\times$ 10^6 ha in the middle Yellow River (Hekouzhen-Longmen reach) have been controlled during the 1980s. This involves 438.2 $\times$ 10^3 ha of terraces, 1427 $\times$ 10^3 ha of afforestation, 411.3 $\times$ 10^3 ha of grassland and 23.5 $\times$ 10^3

Table 1 Annual volumes of water and sediment in the main sections of the upper and middle reaches of the Yellow River in the 1980s.

River section	Above Hekouzhen		Hekouzhen-Longmen		Rivers of Jing, Luo, Wei & Fen		Above Sanmenxia	
Area in km^2	385 966		111 591		170 391		667 948	
Item	sediment	runoff	sediment	runoff	sediment	runoff	sediment	runoff
1980	54	18.42	243	3.30	323	5.85	620	27.57
1981	143	31.36	548	4.05	418	10.64	1109	46.05
1982	91	25.52	336	3.42	172	6.69	599	35.63
1983	181	32.81	210	2.55	280	13.93	671	49.29
1984	142	30.13	239	3.48	464	14.81	845	48.42
1985	121	25.32	361	4.34	361	10.61	843	40.27
1986	76	21.57	164	3.56	188	5.45	428	30.58
1987	15	11.05	244	2.73	158	5.69	417	19.47
1988	33	14.60	867	5.54	717	10.98	1617	31.12
1989	113	26.61	509	4.40	212	7.74	834	38.75
10-year average	97	23.74	372	3.73	330	9.23	799	36.70
Long-term average	142	24.78	908	7.46	556	10.10	1606	42.34

Units: Water volume $\times$ 10^9 m^3; sediment volume $\times$ 10^6 t.

ha of land with check dams. By the end of 1989, the total area controlled through soil conservation in the Hekouzhen-Longmen reach was 4678 $\times$ 10^3 ha.

Water and sediment regimes in the 1980s

The water and sediment regimes in the 1980s are compared with the average annual runoff and sediment yield of the upper and middle reaches of the Yellow River in Table 1. This indicates that the area of the upper and middle reaches of the Yellow River above Sanmenxia was characterized by low runoff and reduced sediment load during the 1980s. The 10-year average runoff of 36.7 $\times$ 10^9 m^3 is reduced by 13.3% compared with the mean annual volume of 42.34 $\times$ 10^9 m^3. The 10-year average sediment load of 799 $\times$ 10^6 t was reduced by 50.3% compared with the average annual sediment load of 1606 $\times$ 10^6 t, and represents the minimum value for a 10-year series of sediment loads since the beginning of the record. In addition, the reduction in sediment yield for the Hekouzhen-Longmen reach, which is located in the hyper-concentrated and coarse sand source region with an area of 111.6 $\times$ 10^3 km^2, was particularly marked. The 10-year annual runoff average volume in the 1980s was only 3.73 $\times$ 10^9 m^3, 50% less than the long-term average of 7.46 $\times$ 10^9 m^3. The 10-year average annual sediment load of 372 $\times$ 10^6 t, was 59% less than the long-term average of 908 $\times$ 10^6 t.

Analysis of sediment reduction caused by reduced precipitation

Precipitation exerts a direct effect on the sediment yield of a catchment. Records indicate that the 1980s marked the lowest 10-year precipitation total in the last 40 years for the middle Yellow River. The 10-year average annual precipitation was only 404 mm, which is 5% less than the long-term average value. Sediment yield is not only related to the total precipitation, but the intensity of precipitation is also important. The precipitation records for the Hekouzhen-Longmen reach have been analysed and the results, shown in Table 2, indicate that for the Hekouzhen-Longmen reach, where the sediment yield was sharply reduced in the 1980s, the precipitation for the main flood season in July and August was 12% less than the long-term average value. The number of days with rainfall events and the accumulated rainfall totals for medium rain (daily precipitation greater than 10 mm), heavy rain (daily precipitation greater than 25 mm) and heavy storms (daily precipitation greater than 50 mm) were 13-35% less than the

Table 2 Characteristic precipitation indices for the Hekouzhen-Longmen reach of the coarse sand region of the middle Yellow River in the 1980s.

	Precipitation in July-Aug. (mm)	Medium rain Day/event (d)	Medium rain Accumulated (mm)	Heavy rain Day/event (d)	Heavy rain Accumulated (mm)	Heavy storm Day/event (d)	Heavy storm Accumulated (mm)
Mean value	191	6.5	156	2.1	83	0.4	24
Long-term mean value	217	7.5	188	2.5	106	0.5	37
Variation %	−12	−13	−17	−16	−22	−20	−35

long-term average. The number of days with heavy storms was 20% less and the accumulated rainfall associated with heavy storms was 35% less. Thus, the main reason for the reduced sediment load of the Yellow River is the notable reduction of days with events and accumulated rainfall associated with heavy storms in the region of coarse sand and hyper-concentrated flows.

In order to calculate the degree of sediment load reduction associated with the reduced rainfall, the relationship between the index of heavy storm rainfall and sediment yield for the catchment under natural conditions has been established. By comparing the long-term rainfall index with the rainstorm index for the 1980s, a reduction in sediment yield of about 400×10^6 t in the middle Yellow River caused by reduced rainfall in the 1980s has been estimated (Wang Yunzhang *et al.*, 1992).

Calculation of sediment reduction resulting from soil conservation

Calculating total sediment reduction Calculation of total sediment reduction resulting from catchment management should consider not only the effects of hydraulic engineering measures (such as reservoirs and irrigation) and the role of soil conservation measures (such as slope land measures and warping dams), but also sediment increase factors associated with the destructive impact of human activities and the effects of variations in scouring and deposition on the river bed. The basic relationships are:

$$Ws = W's + \Delta Ws \qquad (1)$$

$$\Delta Ws = \Delta Ws_s + \Delta Ws_g + \Delta Ws_r + \Delta Ws_i \pm \Delta Ws_c - \Delta Ws_h \qquad (2)$$

in which Ws is the sediment yield of the catchment before the effects of human activities; $W's$ is the sediment yield of the catchment after the effects of human activities; ΔWs is the increase or decrease of sediment yield from the catchment after the effects of human activities; ΔWs_s is the reduction in sediment generation from slope land through soil conservation measures; ΔWs_g is the reduction of sediment yield by warping dams; ΔWs_r is the reduction of sediment yield by reservoirs; ΔWs_i is the reduction of sediment yield by irrigation; ΔWs_c is the amount of scouring or deposition in the channel; and ΔWs_h is the increased sediment production caused by destructive human activities.

Using the above relationship, the sediment reduction was calculated for each tributary and each section of the upper and middle reaches of the Yellow River. The total amount of sediment reduction for the loess plateau through catchment management was calculated and is shown in Table 3. Table 3 indicates that as a result of comprehensive management of the catchment, the average annual sediment reduction in the upper and middle Yellow River during the 1980s was 311×10^6 t. Of this, the sediment reduction in the upper Yellow River (the section above Hekouzhen) was 59×10^6 t, whereas in the middle Yellow River (Hekouzhen-Sanmenxia reach) the reduction was 252×10^6 t. The Hekouzhen-Longmen reach is the main region of sediment reduction. This reach only occupies 16.7% of the area of the upper and middle Yellow River basin, but the amount of sediment reduction represents 52.6% of the value for the whole catchment. Therefore, from the point of view of Yellow River management and sediment reduction, soil conservation works in this region must be strengthened and the

Table 3 Total sediment reduction in the loess plateau area of the Yellow River basin in the 1980s.

	Upper reach	Middle reach						Upper & middle reaches
Tributary or main section	Above Hekouzhen	Hekouzhen-Longmen	Beiluo R. (Zhuangtou)	Jin R. (Zhangjiashan)	Wei R. (Huaxian)	Fen R. (Hejin)	Middle reaches	Above Sanmenxia
Catchment area (km^2)	385 966	111 591	25 165	45 373	61 125	38 728	281 982	667 948
Mean annual sediment reduction	59	163.5	7.1	28	32	21.4	252	311

Unit: sediment $\times 10^6$ t

100 000 km^2 of the Hekouzhen-Longmen reach which is the source area for coarse sediment should be intensively managed.

Calculating the role of individual factors In order to understand the role of the various factors in reducing sediment yields, each factor contributing to sediment reduction in the middle Yellow River region has been analysed and evaluated (see Table 4). The results presented in Table 4 show that the role of these factors in the middle Yellow River region in the 1980s was as follows: the average annual sediment reduction through soil conservation measures was 176×10^6 t; the average annual sediment reduction through engineering measures was 124×10^6 t; the average annual scouring of the channel was -1.0×10^6 t; and the average annual manmade increase in sediment was -47×10^6 t (Task Group of the Yellow River Soil Conservation, 1993).

This analysis demonstrates firstly that soil conservation was the main cause of sediment reduction in the 1980s, accounting for almost 70% of the total average annual sediment reduction in the middle Yellow River region. Thus, soil conservation must be seen as one of the fundamental measures for controlling the sediment load of the Yellow River. Secondly, although the channel may be scoured or aggraded during each flood, the average annual amount of scour and fill is small and the average annual scouring in the 1980s represented only 0.3% of the total average annual sediment reduction. Thirdly, the increased amount of sediment resulting from the destructive impact of human activities reduces the effect of sediment reduction through catchment management by 20%. Preventative soil conservation measures must therefore be strengthened,

Table 4 The role of various factors in reducing erosion and sediment yield in the middle Yellow River in the 1980s.

Average annual sediment reduction in 1980s	Average sediment reduction by soil conservation measures Quantity	%	Average annual sediment reduction by engineering measures Quantity	%	Average annual scouring and deposition of channels Quantity	%	Average annual man-made sediment increase Quantity	%
10^6 t	10^6 t	%	10^6 t	%	10^6 t	%	10^6 t	%
252	176	69.8	124	49.1	−1	−0.3	−47	−18.6

% is the percentage of the average annual sediment reduction due to each of the factors.

to limit manmade destruction of the environment and thereby control sources of increased sediment yield.

Analysis of sediment reduction associated with individual soil conservation measures The main soil conservation measures comprise building of terraces, planting of trees and grasses on slopes and building check dams, warping dams and key dams in gullies. The effectiveness of these various measures has been assessed and the results are presented in Table 5. These results indicate that gully control measures accounted for 45% of the reduction in sediment yield in the middle Yellow River during the 1980s. Terraces accounted for 24% and afforestation for 24%. Thus measures to control sediment production from the hyper-concentrated and coarse sand region of the middle Yellow River should involve firstly the building of gully erosion control works involving key dams and warping dams in the region, and secondly supplementing these with terraces and afforestation of slope land, to achieve the goal of comprehensive management of the catchment and successful sediment retention.

Table 5 Sediment reduction by individual soil conservation measures in the middle Yellow River basin during the 1980s.

Average annual sediment reduction by soil conservation measures	Sediment reduction by slope control measures: Terraces Quantity	%	Afforestation Quantity	%	Grass Quantity	%	Sediment reduction by gully erosion control measures Quantity	%
176	42	24	43	24	12	7	79	45

Units: sediment quantity $\times 10^6$ t; % is the percentage of the sediment reduction due to the individual conservation measure.

FORECASTING TRENDS IN EROSION AND SEDIMENT YIELD REDUCTION IN THE LOESS PLATEAU

The severe soil and water loss which characterizes the loess plateau reflects the joint effect of natural erosion (geological erosion) and accelerated erosion (erosion under the impact of human activities). The accelerated erosion has been controlled through soil conservation, thereby reducing the amount of sediment entering the Yellow River. The results of the recent study have demonstrated four important features of the erosional behaviour of the loess plateau. First, natural erosion makes up 70%, and accelerated erosion 30% of the total erosion on the loess plateau. Natural erosion of the loess plateau still remains the most important (Lu Zhongchen *et al.*, 1991). Second, the gullied rolling loess area, which is the most severely eroded area of the loess plateau, has at present developed into the middle stage of erosion, and the gullied loess plateau has developed to the end of the early stage of erosion. Third, at present, the loess plateau is still in the rising stage of a new tectonic movement. Fourth, the climate in the coming 100 years is likely to be humid. Surface runoff will increase and erosion will become correspondingly worse compared to the drought period in the first half of the century. Soil erosion in the loess plateau will therefore still be very serious in the near future in the light of the trend of geological and climatic factors that effect the development of soil erosion.

According to plans for future sediment reduction schemes in the loess plateau, the total annual amount of sediment reduction associated with engineering and soil conservation measures will be reduced sharply to 195×10^6 t by the year 2030, if no more continuous management and no more new hydraulic engineering works are introduced. By the year 2000, the present level of $300 \sim 400 \times 10^6$ t of annual sediment reduction in the upper and middle reaches of the Yellow River can be maintained if soil conservation measures are developed at the same rate as in past decades. By the year 2030, the annual sediment reduction could reach 500×10^6 t. Even then, the Yellow River will still be a muddy river for the next 50 years.

REFERENCES

Lu Zhongchen, Jia Shaofeng, Huang Kexin & Yuan Baoyin (1991) *Catchment Geomorphologic System*. Dalian Publishing House.

Task Group of Scientific Research Fund of Soil Conservation of the Yellow River Catchment (1993) Study report of benefits of sediment reduction through soil and water conservation and water and sediment variation trend of coarse sand region in the middle Yellow River (a restricted material, in Chinese). Zhengzhou.

Wang Yunzhang, Peng Meixiang & Wen Liye (1992) Characteristics of precipitation of the middle Yellow River in 1980s and its effects to the amount of sediment flowing into the Yellow River. *The People's Yellow River* (in Chinese) **5**, 10-14.