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Dynamic sediment discharge in the Hekou–Longmen region of Yellow River and soil and water conservation implications

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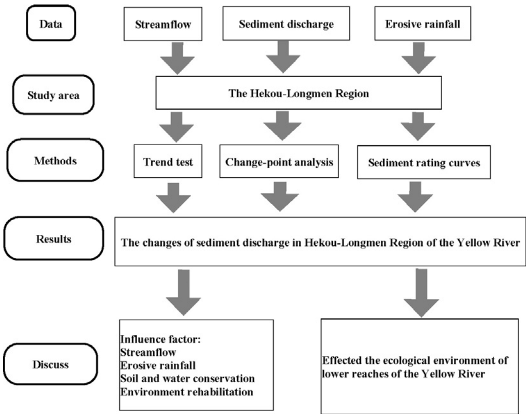
HIGHLIGHTS

- A significant decrease in sediment discharge in Hekou-Longmen region.
- Erosive rainfall showed insignificant change during 1955–2009.
- Sediment rating curves displayed a decreasing trend after change-point year.
- Soil and water conservation played a crucial role in sediment reduction.
- The changes of streamflow and sediment effected the eco-environment of the lower reaches of the yellow river.

GRAPHICAL ABSTRACT



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ABSTRACT

The middle reaches of the Yellow River Basin transport the vast majority of sediment (>85% of the basin's total available sediment load), which has had profound effects on the characteristics of the middle and lower reaches of the Yellow River. Since the late 1950s, soil and water conservation measures have been extensively implemented in the Loess Plateau, China, especially since the 1970s. This has resulted in sediment discharge changing significantly. In this study, data from 22 catchments in the region of the Loess Plateau from Hekou to Longmen in the middle reaches of the Yellow River were analyzed to investigate the responses of the sediment regime to climate change and human activities. The non-parametric Mann–Kendall test and the Pettitt test were used to identify trends and shifts in sediment discharge. All 22 catchments had a significantly decreasing trend ($P < 0.01$) in annual sediment discharge. Change point years were detected between 1971 and 1994, and were concentrated between 1978 and 1984 in 17 catchments. Moreover, erosive rainfall exhibited a tendency to decrease, but this was not a significant trend. Compared to rainfall, human activities, primarily soil and water conservation and environmental rehabilitation campaigns, have played a more prominent role in the changes in sediment regimes. In order to reduce soil erosion and sediment yield, more attention should be paid to proper and rational soil and water conservation and eco-restoration in this region.

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1. Introduction

The Yellow River, the second-longest river in China, has been designated “the cradle of Chinese Civilization” because it provides irrigation and domestic and industrial water for 100 million people living within its watershed and for millions more in the North China Plain (An et al., 2005). The Yellow River has also been a river of disasters (also called “China's sorrow”) because of the large amount of its sediment discharge and serious floods (Yu, 2006). The Loess Plateau, through which the Yellow River runs, has some of the world's highest soil erosion rates due to poor land use choices, poor vegetation cover, easily erodible soils, steep slopes, excessive exploitation and occasional high intensity summer storms (Fu, 1989; Shi and Shao, 2000). Rivers in this region transport about 1.5 billion tons (1919–1985) sediment to the Yellow River every year (Chen, 1996). Serious soil erosion on the Loess Plateau causes the loss of farmland onsite, the siltation of river beds and reservoirs offsite, and causes flooding in the Yellow River Basin and North China Plain (Hessel et al., 2003). Since the 1950s, soil and water conservation practices have been implemented in the Loess Plateau gradually to reduce the sediment discharge of the rivers (Wang et al., 2015). These conservation measures include: terrace and check-dam construction was the main soil erosion control measure in the 1960s and 1970s (Mu et al., 2007; Gao et al., 2011); integrated watershed management was introduced for erosion control in the 1980s and 1990s (Xin et al., 2012); large scale eco-rehabilitation projects as an important control measure has been used to improve the ecological environment and to reduce soil erosion after 2000s (Xin et al., 2015). All of these studies have been confirmed that total amounts of sediment and streamflow discharge have decreased not only along the Yellow River mainstream from upstream to downstream (Zhao et al., 2014), but also in the middle Yellow River basin (Gao et al., 2011; Xin et al., 2015). And the study also confirmed that sediment and streamflow discharge reduced in tributaries of the middle Yellow River basin significantly (Gao et al., 2009; Xin et al., 2015; Zuo et al., 2016).

Although several studies have shown that the sediment and streamflow discharge have decreased in the Yellow River Basin, the magnitude and impact factors of sediment and streamflow discharge reduction are not the same in different geographic regions of the Yellow River. For the middle reaches of the Yellow River, the anthropogenic activities affecting sediment reduction mainly include: construction of large/medium-sized multi-purpose water control projects, soil and water conservation and eco-rehabilitation projects (Gao et al., 2011; Xin et al., 2015). From Hekou to Longmen, the river passes through the longest series of continuous valleys on its main course, collectively called the Jin-Shan Valley. This region also is the most serious soil erosion and the main sediment source area of Yellow River (Ye, 1994). Due to lack of large water conservancy project intercept sediment load, soil and water conservation and eco-rehabilitation might play a more crucial role on the sediment reduction. To study the sediment change process and its influencing factors in Hekou-Longmen region, can fills an information gap of Yellow River sediment research and help us depth and comprehensive understanding of the Yellow River sediment changes. Based on the data from 24 hydrological stations from the Hekou to Longmen region, the objectives of this study were: (An et al., 2005) to analyze the trends and fluctuations in sediment discharge from 1955 to 2009 (Asselman, 2000); to discuss the influencing factors on sediment discharge changes. The findings of this study contribute valuable information for the evaluation and implementation of long term sustainable regional soil and water conservation planning to control soil erosion.

2. Study area and dataset

2.1. The study area

The Hekou–Longmen region is located in the middle reaches of the Yellow River and covers 1.30 × 10^5 km^2 (Fig. 1). It is the main source area of Yellow River sediment, and includes the Coarse Sandy Hilly

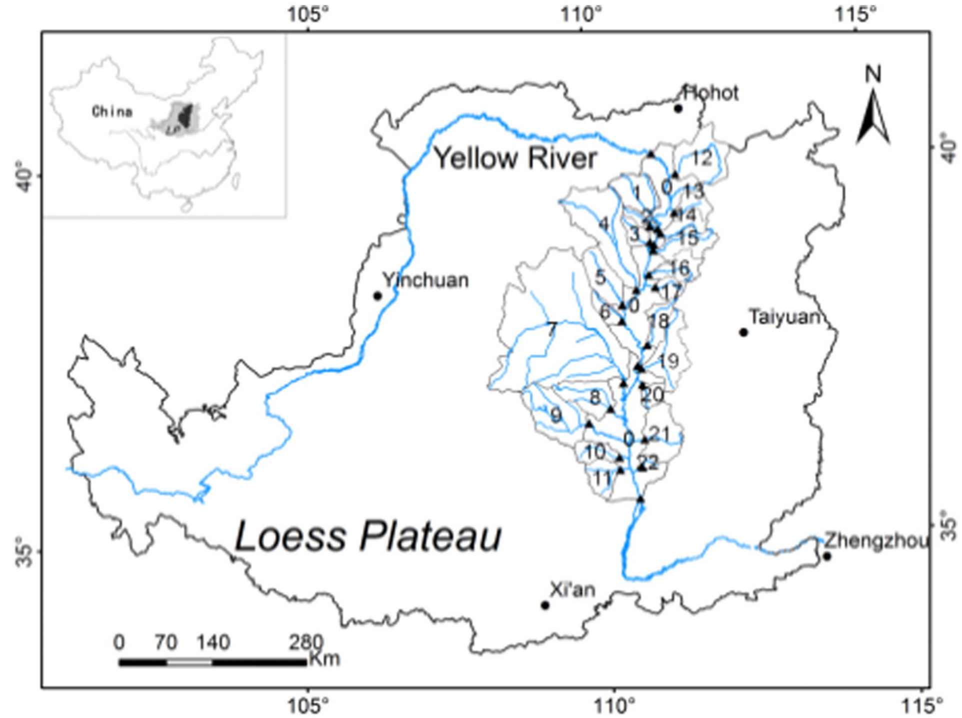

Fig. 1. Location map of the study area within the Loess Plateau. The triangles represent the hydrological stations, the numbers represent the tributaries and “0” represents an area uncontrolled by tributaries' hydrological stations and mainstream area.

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Table 1
The location and data series of the hydrological stations.

ID	Catchment	Station	Control area (km^2)	Longitude (E)	Latitude (N)	Series (annual)
	Yellow River	Hekou	367,898	40°17′	111°02′	Sediment: 1955–2009 Streamflow: 1955–2009
1	Huangfuchuan	Huangfu	3175	39°17′	111°05′	Sediment: 1955–2009 Streamflow: 1955–2009
2	Qingshuichuan	Qingshui	735	39°15′	111°03′	Sediment: 1955–2009 Streamflow: Miss
3	Gushanchuan	Gaoshiya	1263	39°03′	111°03′	Sediment: 1955–2009 Streamflow: 1955–2009
4	Kuye	Wenjiachuan	8515	38°26′	110°45′	Sediment: 1955–2009 Streamflow: 1955–2009
5	Tuwei	Gaojiachuan	3253	38°15′	110°29′	Sediment: 1955–2009 Streamflow: 1956–2009
6	Jialu	Shenjiawan	1121	38°02′	110°29′	Sediment: 1955–2009 Streamflow: 1957–2009
7	Wuding	Baijiachuan	29,662	37°14′	110°25′	Sediment: 1955–2009 Streamflow: 1956–2009
8	Qingjian	Yanchuan	3468	36°53′	110°11′	Sediment: 1955–2009 Streamflow: 1955–2009
9	Yanhe	Ganguyi	5891	36°42′	109°48′	Sediment: 1955–2009 Streamflow: 1955–2009
10	Fenchuan	Xinshihe	1662	36°14′	110°16′	Sediment: 1955–2009 Streamflow: 1967–2009
11	Shiwangchuan	Dacun	2141	36°05′	110°17′	Sediment: 1955–2009 Streamflow: 1959–2009
12	Hunhe	Fangniugou	5461	39°57′	111°33′	Sediment: 1955–2009 Streamflow: 1955–1996
13	Piangguan	Pianguan	1896	39°28′	111°29′	Sediment: 1955–2009 Streamflow: 1957–2009
14	Xianchuan	Jiuxian	1562	39°10′	111°13′	Sediment: 1955–2009 Streamflow: 1960–2009
15	Zhujiachuan	Xialiuqi	2854	38°57′	111°06′	Sediment: 1955–2009 Streamflow: 1957–2009
16	Lanyi	Peijiachuan	2159	38°37′	110°53′	Sediment: 1955–2009 Streamflow: 1955–1996
17	Weifen	Xingxian	650	38°28′	111°12′	Sediment: 1955–2009 Streamflow: 1956–2009
18	Qiushui	Linjiaping	1873	37°42′	110°52′	Sediment: 1955–2009 Streamflow: 1955–2009
19	Sanchuan	Houdacheng	4102	37°25′	110°45′	Sediment: 1955–2009 Streamflow: 1957–2009
20	Quchan	Peigou	1023	37°11′	110°45′	Sediment: 1955–2009 Streamflow: 1963–2009
21	Xinshui	Daning	3992	36°28′	110°43′	Sediment: 1955–2009 Streamflow: 1955–2009
22	Zhouchuan	Jixian	436	36°05′	110°40′	Sediment: 1955–2009 Streamflow: 1959–2009
	Yellow River	Longmen	497,552	35°40′	110°35′	Sediment: 1955–2009 Streamflow: 1955–2009

Catchments (McVicar et al., 2007). There are 22 tributaries (Table 1) in this region, which contribute a large amount of sediment to the Yellow River. This region only occupies 14.8% of the total area of the Yellow River Basin, but its sediment yield accounted for 69.0% of the total sediment discharge of the Yellow River in 1955–1969. And this ratio was reduced to 42.1% in 1970–2009.

The most common soil in this region are inceptisols soil (USDA Soil Taxonomy), which is weakly resistant to erosion (Wang et al., 2009). The dominant vegetation is steppe for all the catchments except for the Shiwangchuan catchment, which is dominated by forest, and the forest steppe shows a gradual transition to the typical steppe and the desert steppe from the southeast to the northwest. The mean annual precipitation ranges from 580 mm in the southeast to <300 mm in the northwest, 80% of which occurs from May to September when there are short-duration and high-intensity storms (Ran et al., 2000). Due to prolonged land use pressures, such as agricultural expansion, stockbreeding overload and population growth, the natural vegetation has almost disappeared. The characteristics of the rainfall and low vegetation coverage cause soil to erode easily (Jiao et al., 2002).

2.2. Data collection

The consecutive annual data of sediment and streamflow discharge at 22 tributaries and 2 mainstream hydrological stations were provided by the Yellow River Water Resources Commission, and were partly collected from the hydrological station (Table 1). The daily precipitation data (1955–2009) from 18 meteorological stations were provided by the National Meteorological Information Centre (NMIC), China Meteorological Administration (CMA) (http://cdc.nmic.cn/). The daily discharge was computed from the water level by using previously calibrated discharge-water level curves. Water was sampled at fixed intervals, and sediment concentration was obtained by measuring water samples in the laboratory. All the measurements data followed national standards issued by the Ministry of Water Conservancy, and were printed in the Hydrological Year-book of the Yellow River. The annual streamflow and sediment discharge at the gauging stations were derived from the daily measured data. The sediment and streamflow discharge of the entire study area were calculated by the difference between Longmen and Hekou station. All the data used in this study

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are of good quality and were checked out by the corresponding agencies before their release.

3. Methods

3.1. Trend test

The Mann–Kendall statistical test is commonly used for trend detection due to its robustness for non-normally distributed and censored data, which are frequently encountered in hydro-climatic time series (Mann, 1945; Kendall, 1975; Hirsch et al., 1982; Burn and Elnur, 2002; Gao et al., 2010). However, the presence of serial correlation can complicate the identification of trends in that a positive serial correlation can increase the expected number of false positive outcomes for the Mann–Kendall test (Von Storch and Navarra, 1995). Any serial correlation should be removed before conducting the Mann–Kendall trend test. In this work the trend-free pre-whitening (TFPW) method (Yue et al., 2003) was used to analyze the trends over time for sediment discharge and erosive rainfall. TFPW can remove any significant linear trend from the raw time series and serial correlation. A Z statistic was obtained from the Mann–Kendall test on the whitened series from TFPW method. A negative value of Z indicates a downward trend, and vice versa.

3.2. Change-point analysis

The change-point analysis in this study was applied to determine the year in which an abrupt change in the sediment record may have occurred. Change points were determined using a robust nonparametric method (Pettitt, 1979) at a significance level of 5%. This method detects

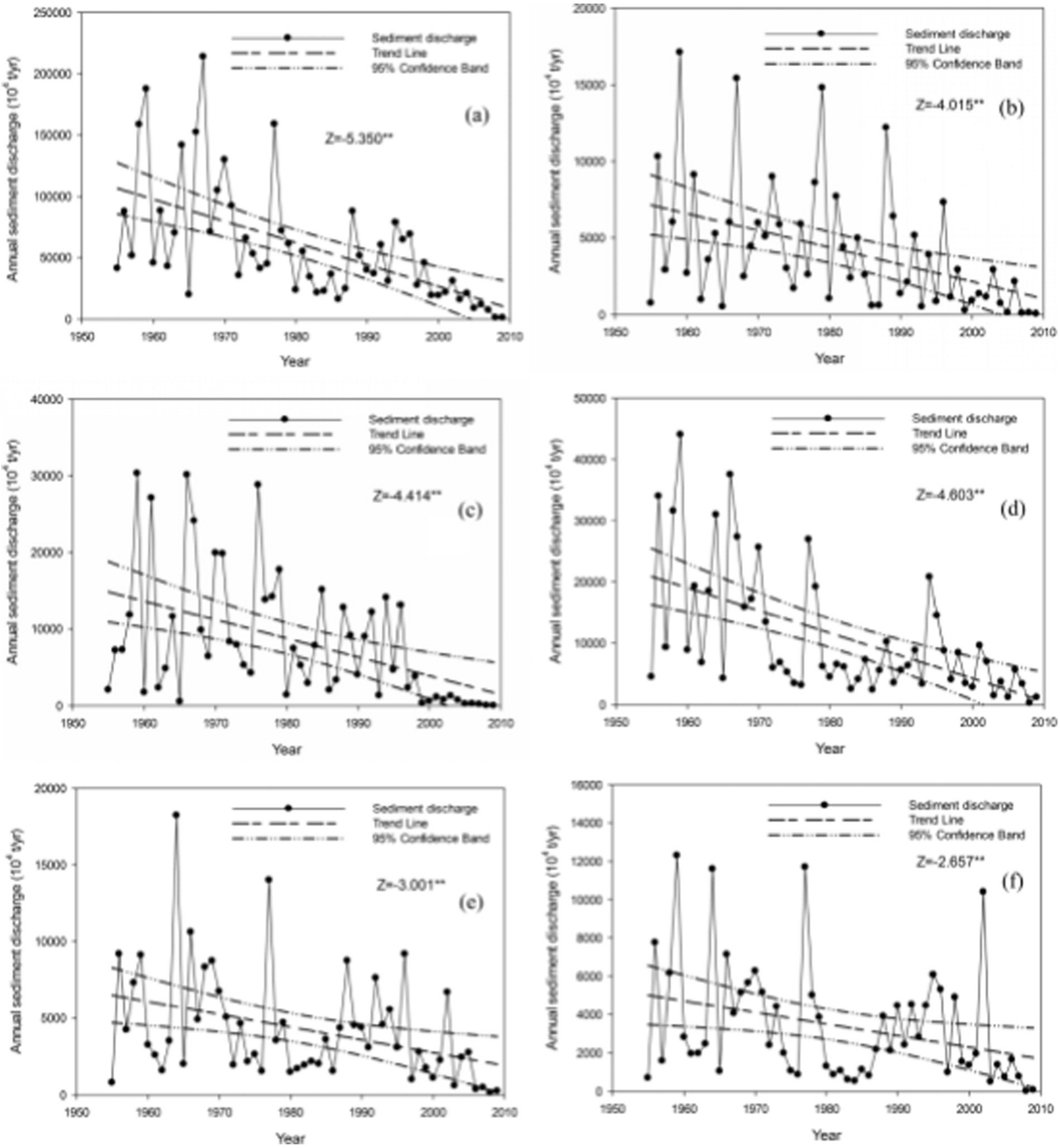

Fig. 2. The variation of the annual sediment discharge during 1955–2009 in the: (a) entire study area, and typical tributaries (b. Huangfuchuan; c. Kuyehe; d. Wudinghe; e. Yanhe, f. Qingjianhe). The Z statistic was obtained from the TFPW test (**: $P < 0.01$).

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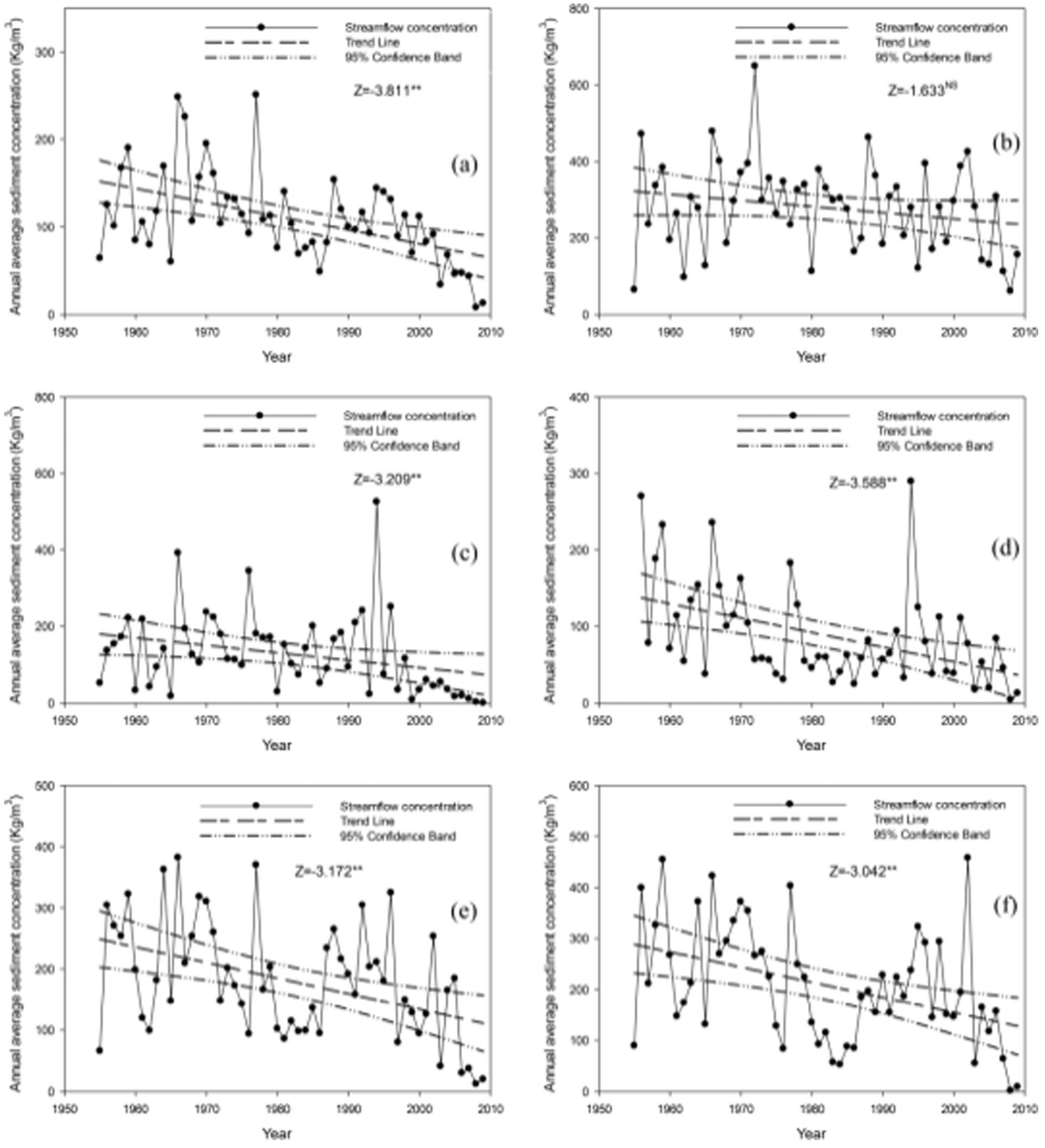

Fig. 3. The variation of the annual average sediment concentration during 1955–2009 in the: (a) entire study area, and typical tributaries (b. Huangfuchuan; c. Kuyehe; d. Wudinghe; e. Yanhe, f. Qingjianhe). The *Z* statistic was obtained from the TFPW test (**: $P < 0.01$; NS: no significant at $p < 0.05$).

a significant change in the mean of a time series when the exact time of the change is unknown.

3.3. Sediment rating curves

The sediment rating curve empirically describes the relationship between sediment concentration and streamflow discharge for a specific location (Syvitski et al., 2000; Hu et al., 2011). It is generally expressed as:

$$C_s = aQ^b \tag{1}$$

where C_s is sediment concentration, Q is streamflow discharge, and a, b are the rating coefficients of the sediment rating curve. Similarly, there are also the same sediment rating curve between sediment discharge (S) and streamflow (Zhang et al., 2012):

$$S = aQ^{b+1} \tag{2}$$

In generally, the sediment rating curve is regarded as a “black box” model and the parameters a and b are estimated by regression analysis without any physical meaning (Asselman, 2000). However, some scholars regard the sediment rating parameters are often associated with riverbed morphology or soil erodibility and erosivity of the river. The parameter a was an index of erosion severity in the river channel, with high values was associated with the area, which is characterized by easily erodible materials and high loads of transported materials (Morgan, 1995). The coefficient b describes the erosive power of the

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Table 2
Results of trend and change point years for sediment regimes and streamflow during 1955–2009.[a]

ID	Catchment	Z statistic with sig. level			Change point year with sig. level		
		SD	SC	Streamflow	SD	SC	Streamflow
1	Huangfuchuan	-4.015^{**}	-1.633^{NS}	-4.668^{**}	1984^{**}	None	1984^{**}
2	Qingshuichuan	-4.639^{**}	X	X	1992^{**}	X	X
3	Gushanchuan	-4.167^{**}	-2.621^{**}	-4.740^{**}	1994^{**}	1994^{**}	1979^{**}
4	Kuye	-4.414^{**}	-3.209^{**}	-5.009^{**}	1996^{**}	1996^{**}	1985^{**}
5	Tuwei	-4.828^{**}	-4.037^{**}	-7.781^{**}	1978^{**}	1998^{**}	1979^{**}
6	Jialu	-4.951^{**}	-3.093^{**}	-7.307^{**}	1978^{**}	1977^{**}	1982^{**}
7	Wuding	-4.603^{**}	-3.588^{**}	-6.759^{**}	1971^{**}	1971^{**}	1979^{**}
8	Qingjian	-2.657^{**}	-3.042^{**}	-1.387^{NS}	1979^{*}	1979^{**}	None
9	Yanhe	-3.001^{**}	-3.172^{**}	-2.621^{**}	1996^{*}	1996^{*}	1996^{*}
10	Fenchuan	-3.666^{**}	-2.962^{**}	-3.883^{**}	1982^{**}	1995^{**}	1994^{**}
11	Shiwangchuan	-6.367^{**}	-5.589^{**}	-4.280^{**}	1983^{**}	1982^{**}	1988^{**}
12	Hunhe	-5.815^{**}	-2.287^{*}	-4.118^{**}	1982^{**}	None	1973^{**}
13	Piangguan	-5.655^{**}	-1.565^{NS}	-6.781^{**}	1983^{**}	None	1982^{**}
14	Xianchuan	-4.755^{**}	-3.404^{**}	-4.576^{**}	1982^{**}	1996^{**}	1982^{**}
15	Zhujiachuan	-3.688^{**}	-2.071^{*}	-3.220^{**}	1982^{**}	1999^{**}	1982^{*}
16	Lanyi	-4.348^{**}	-0.607^{NS}	-2.606^{**}	1982^{**}	None	1971^{*}
17	Weifen	-5.067^{**}	0.455^{NS}	-6.364^{**}	1980^{**}	None	1981^{**}
18	Qiushui	-5.728^{**}	-4.523^{**}	-5.902^{**}	1978^{**}	1978^{**}	1981^{**}
19	Sanchuan	-5.677^{**}	-5.147^{**}	-6.045^{**}	1978^{**}	1978^{**}	1981^{**}
20	Quchan	-3.201^{**}	-3.201^{**}	-2.907^{**}	1981^{*}	1981^{*}	1981^{*}
21	Xinshui	-5.191^{**}	-3.869^{**}	-5.568^{**}	1981^{**}	1981^{**}	1985^{**}
22	Zhouchuan	-6.955^{**}	-6.717^{**}	-7.091^{**}	1980^{**}	1980^{**}	1979^{**}
	Entire region	-5.350^{**}	-3.811^{**}	-6.062^{**}	1979^{**}	1981^{**}	1979^{**}

[a] SD refers to the sediment discharge; SC refers to the sediment concentration. **: significant at $p < 0.01$; *: significant at $p < 0.05$; NS: no significance at $p < 0.05$; X: not applicable.

river, and related to the regional climate pattern, channel morphology, grain-size distribution of sediment and the erodibility in the river basin. A high values indicating strong increase in erosive power of the river (Asselman, 2000; Yang et al., 2007). In this study, we use the sediment rating curve between sediment discharge and streamflow discharge to analyze the sediment characteristic.

4. Results and discussion

4.1. Trends and change point year analysis for sediment regimes

Figs. 2 and 3 shows the observed annual sediment discharge and sediment concentration during 1955–2009 in the Hekou–Longmen region and some typical tributaries (the annual average sediment discharge >4000 × 10^4 t/yr). In the entire study area, the sediment discharge decreased significantly, with the average annual rate of decrease being −1777 × 10^4 t/yr. The change-point year was detected as 1979 ($P < 0.01$), with the decrease in sediment discharge starting in 1980 for the entire region.

The trends and results of change point year analysis for sediment regimes in the entire study area and 22 tributaries are given in Table 2. All sediment discharge has shown a significantly decreasing trend ($P < 0.01$). For the 22 tributaries, the change-point years detected were between 1971 and 1996 when there were downward changes in annual records (Table 2), and for 19 rivers (86%) they were detected in the late 1970s to the early 1980s. For only three rivers (Qingshuichuan, Kuye and Yanhe) were they detected in the 1990s. For the sediment concentration, the entire study area and the majority of tributaries (17 of 22 rivers) indicate significant decrease trends. Except Qingshuichuan River (data miss), only four rivers (Huangfuchuan, Pianguan, Lanyi and Weifen) were shown decrease without a significant trend. All the change points described above are statistically significant.

4.2. Influencing factors on sediment regimes changes

In general, sediment regimes are analyzed in conjunction with river discharge as flow conditions provide a major controlling influence on the mode and rate of sediment transport in rivers (Williams, 1989; Lenzi and Marchi, 2000). The changes in sediment regimes were also strongly influenced by climate change and anthropogenic activities, as the relative importance of the other factors is negligible such as topography, soil type (Zhu et al., 2015; Walling and Fang, 2003; Chakrapani, 2005).

4.2.1. Changes in streamflow discharge from 1955 to 2009

The variation of the annual streamflow discharge during 1955–2009 in the entire study area and typical tributaries were shown in Fig. 4. Annual streamflow in the entire study area and the majority of tributaries (20 of 22 rivers) displays a statistically significant negative linear trend ($P < 0.01$) for the period 1955–2009 (Table 2). The Pettitt's test was also used to detect the change point years for streamflow (Table 2); with 1979 being the detected change point year ($P < 0.01$) for the entire region. For the 22 tributaries, the change-point years detected were between 1971 and 1996 when there were downward changes in annual records but Qingjianhe River (Table 2). It indicates that a significant decrease in streamflow in the study area.

4.2.2. Sediment rating curve in the Hekou-Longmen region

Sediment rating curves in the entire study area and four typical tributaries were obtained for two distinct periods (before and after change-point year) according to the annual streamflow and sediment discharge. All sediment rating curves generally displayed a decreasing trend after change-point year (Fig. 5). It has been mentioned in the methods introduction that the high values of parameter a denote high sediment supply, and large values of parameter b indicate an increased transport capacity of the river (Asselman, 2000). The decreasing a and increasing b after change-point year imply a decreasing sediment supply from the main source area of sediment yield and an increased erosive power in the river channel (Table 3). The results indicate a gradually downward shift after change-point year in response to the sediment reductions induced by human activities, e.g., soil and water conservation and environmental rehabilitation campaigns (Gao et al., 2011; Xin et al., 2012, 2015).

4.2.3. Variation of erosive rainfall from 1955 to 2009

Climate change is the primarily factor affecting sediment discharge because rainfall represents the direct external power of soil erosion.

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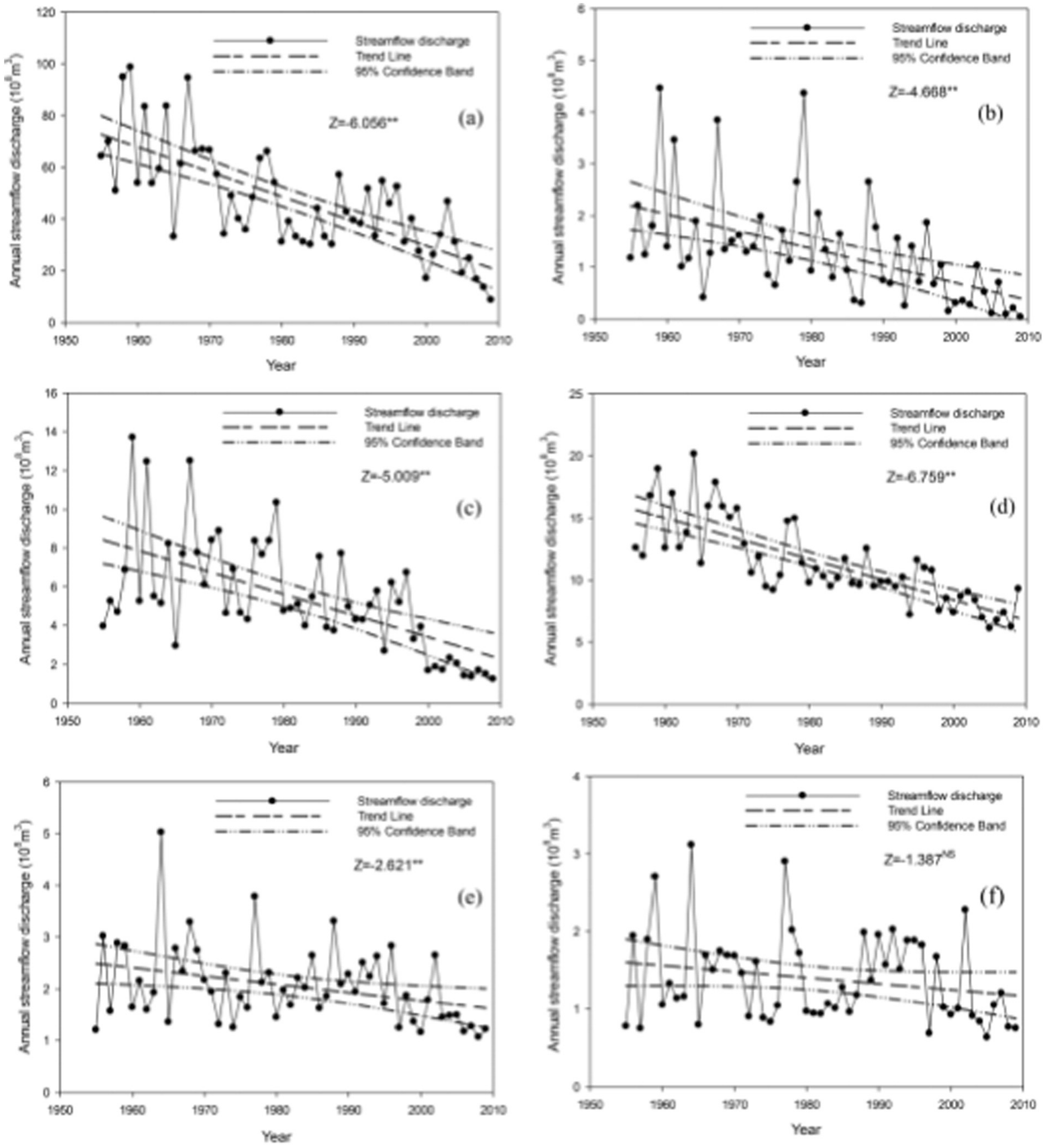

Fig. 4. The variation of the annual streamflow discharge during 1955–2009 in the: (a) entire study area, and typical tributaries (b. Huangfuchuan; c. Kuyehe; d. Wudinghe; e. Yanhe, f. Qingjianhe). The *Z* statistic was obtained from the TFPW test (**: $P < 0.01$; NS: no significant at $p < 0.05$).

However, not all rainfall causes soil erosion. Soil erosion will occur when the rainfall reaches a certain value. Based on standard measures of erosive rainfall (Xie et al., 2000), we investigated the variation in the annual erosive rainfall based on varying daily rainfall rates (≥12 mm/day) from 1955 to 2009 in the Hekou–Longmen region (Fig. 6). In this period annual erosive rainfall decreased without a significant trend. Moreover, the sediment and streamflow discharge in the same period decreased significantly. Besides, the relationship curves of the annual erosive rainfall vs. streamflow discharge and the annual erosive rainfall vs. sediment discharge in the entire study area were shown in Fig. 7. The regression line were lower after the change-point year than before the change-point for both streamflow and sediment discharge. The shift indicates a significant decrease in sediment and streamflow discharge at the same level of erosive rainfall. Since there was no discernible change of the erosive rainfall, the lower regression line demonstrated that the proportionalities between streamflow and erosive rainfall, as well as between sediment discharge and erosive rainfall, were considerably reduced after the change-point year. The changes in regional erosive rainfall were insufficient to explain the significant decrease in sediment discharge. The results indicate that the significant decline in the sediment discharge was not only influenced by rainfall in the Hekou–Longmen region.

4.2.4. Soil and water conservation 1950–1996

Other than rainfall, anthropogenic activity is the most active factor in the sediment regime changes. Many different anthropogenic activities have had an influence on sediment discharge in this study area. Undoubtedly, the rapid adoption of large-scale soil and water conservation

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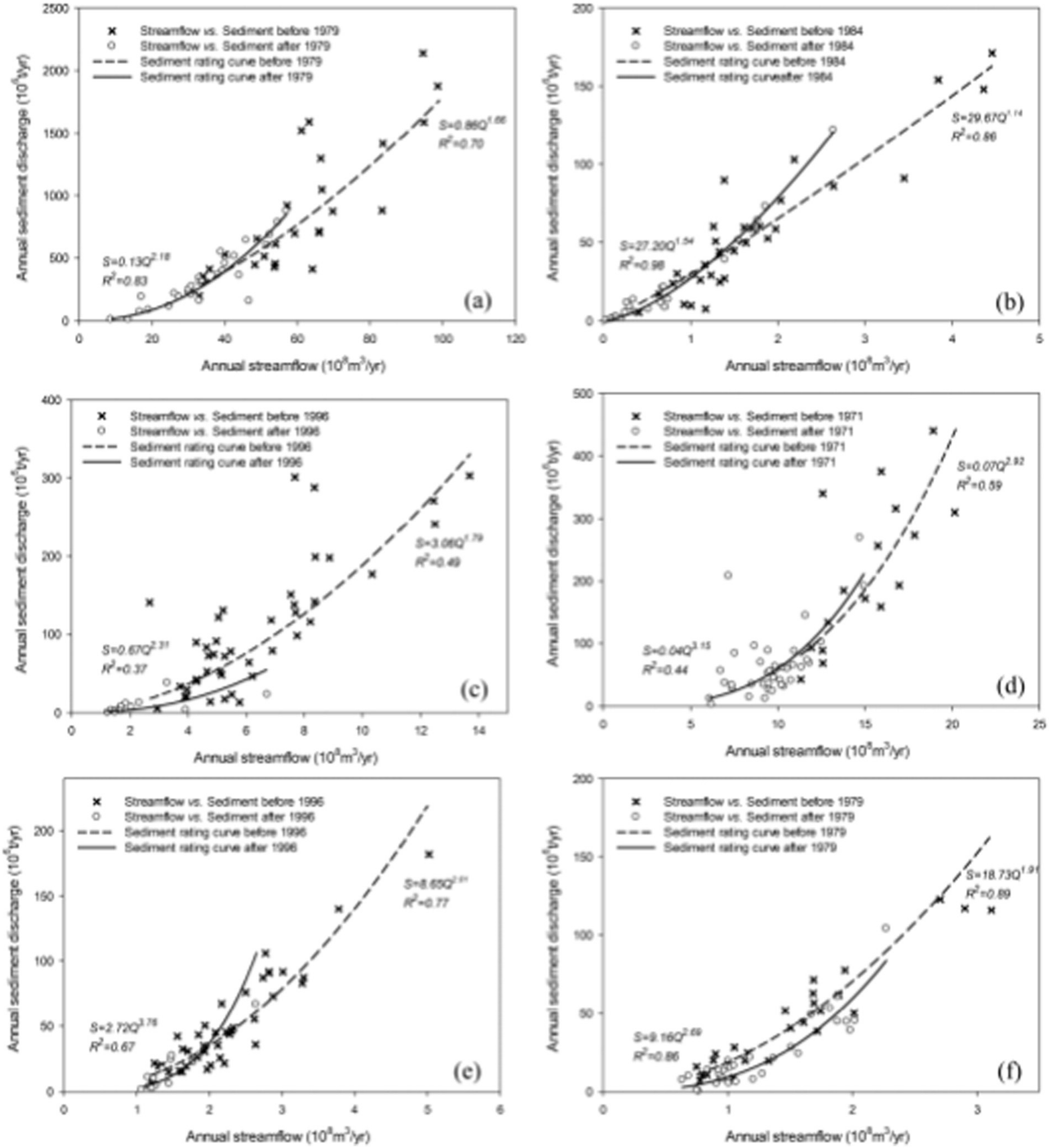

Fig. 5. Sediment rating curves in the (a) entire study area, and typical tributaries (b. Huangfuchuan; c. Kuyehe; d. Wudinghe; e. Yanhe, f. Qingjianhe) for the before and after change-point years (Equations in the upper right corner is the regression equation before change-point years, and in the bottom left corner is the regression equation after change-point years.).

measures and engineering structures, which have been applied through various government sponsored conservation programs and environmental rehabilitation campaigns, are the most influential factor in sediment discharge reduction in the Loess Plateau (Mu et al., 2007; Ran et al., 2000; Gao et al., 2011).

Before 1950, soil erosion in the Loess Plateau has not been effective governance because the longstanding war (Anti-Japanese War and Chinese Civil War), serious soil erosion causes high sediment discharge in the Yellow River. With the establishment of the People's Republic of China, as a key soil erosion governance area in China, the Loess Plateau

Table 3
Sediment rating parameters for the before and after change-point year in entire study area and typical tributaries.[a]

Catchment	Entire study area				Huangfuchuan				Kuyehe				Wudinghe				Yanhe				Qingjianhe			
	a	b	R^2	N	a	b	R^2	N	a	b	R^2	N	a	b	R^2	N	a	b	R^2	N	a	b	R^2	N
Before change-point year	0.86	0.66	0.70	25	29.67	0.14	0.86	29	3.06	0.79	0.49	42	0.07	1.92	0.59	16	8.65	1.01	0.77	42	18.73	0.91	0.89	25
After change-point year	0.13	1.18	0.83	30	27.20	0.54	0.98	25	0.67	1.31	0.37	13	0.04	2.15	0.44	38	2.72	2.76	0.67	13	09.16	1.69	0.86	30

[a] N refers to the sample years number of the before and after change-point year.

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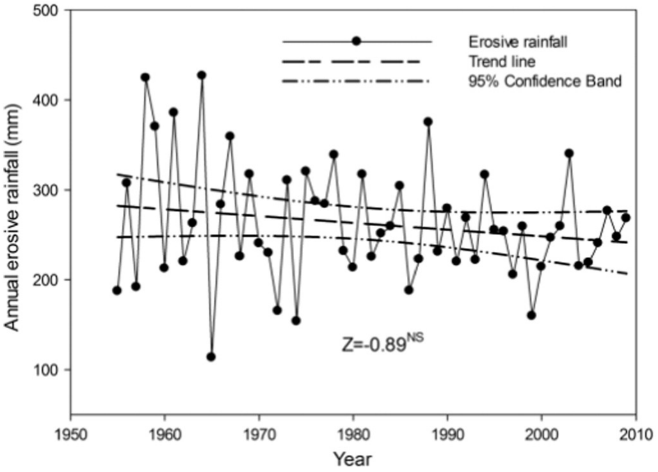

Fig. 6. The variation of the erosive rainfall during 1955–2009 in the entire study area. The *Z* statistic was obtained from the TFPW test (NS: no significant at $p < 0.05$).

gradually began to receive treatment. Soil and water conservation were incorporated into the National Economic Development Plan of China. The investigation and planning of soil and water conservation was begun on the Loess Plateau. However, from 1958 to the beginning of the "Great Leap Forward Campaign", soil and water conservation were forced to a standstill with the Chinese economy a serious setback. When the national economy began to take a turn for the better in 1963, a soil erosion governance plan was formulated and gradually put into practice in 42 key counties of the middle reaches of the Yellow River. But the "Cultural Revolution" meant that the brief resumption of soil and water conservation work was interrupted once again in 1966. In October 1970, as a result of the conference on agricultural development in northern China, soil and water conservation work was reborn in the Yellow River Basin. Soil and water conservation agencies were restored and strengthened. A series of soil and water conservation program promotion and application greatly accelerated the process of soil erosion control.

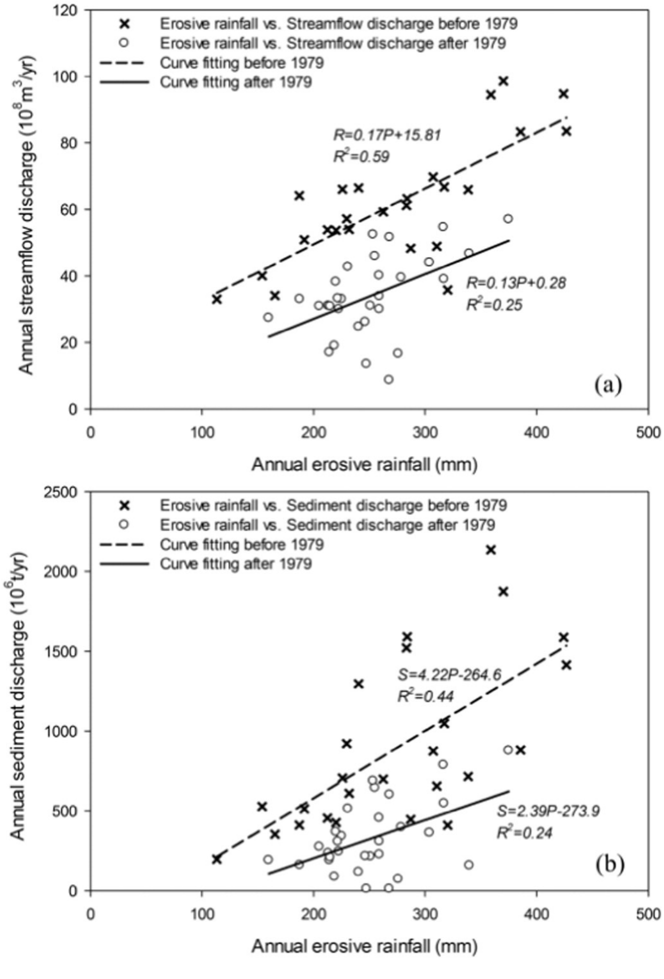

Fig. 7. The relationship between the annual erosive rainfall (*P*) and (a) streamflow (*R*), (b) sediment discharge (*S*) during 1955–2009 in the entire study area.

Since the late 1970s, with the beginning of the "Chinese Economic Reform and Opening-up" and the rapid development of the national economy, the Loess Plateau soil and water conservation work has also received strong economic support from the government. Based on the "Household Contract Responsibility System" policy, the implementation of major ecological projects and the key dam construction for gulley erosion control have contributed to the rapid progress on soil and water conservation after 1980. Combined with ecological measures (e.g. revegetation, planting trees and grass), engineering measures (e.g. fish-scale pits, horizontal trenches and sediment-trapping dams) and farming measures (e.g. contour tillage, furrow and ridge tillage, and conservation tillage), this has greatly improved the level of management of soil and water conservation.

Overall, from 1950 to 1979, due to the lack of economic power and deficiency of science and technology in China, water and soil conservation measures were not at a high level, and the soil erosion control area increased slowly. However, soil and water conservation work carried out in this period in the Loess Plateau has established a solid foundation. After the 1980s, soil and water conservation achieved a sustained, stable and coordinated development. The progress of soil and water conservation practice in 22 tributaries at different dates is shown in Table 4. The progress in the degree of control over soil erosion is consistent with the soil and water conservation work over different decades. The cumulative increase of the area of soil and water conservation measures was slow before 1979. For 22 tributaries, in the 30 years from 1950 to 1979 the average control degree reached 10.4%. However, between 1980 and 1996 the average degree of control increased nearly threefold to reach 29.5%.

4.2.5. Environmental rehabilitation campaigns after 1996

After 1996, more large-scale eco-rehabilitation projects were undertaken on the Loess Plateau. The "Beautiful Landscape Project" in the Loess Plateau started in 1997, closely followed by the "Grain for Green Program" launched in 1999, with the main objective of protecting and restoring the ecological environment and stopping serious soil erosion in a planned way. The implementation of the project was gradually extended to the "Natural Enclosing and Prohibiting Grazing Project" to ensure forest and grass vegetation are restored. The "Grain for Green Program" changed the land use and land cover dramatically, and controlled soil erosion significantly. By 2006, 39,255 km^2 of land was protected by the implementation of various soil and water conservation measures in the Hekou–Longmen region. This included 4928 km^2 of terrace, 27,711 km^2 of afforestation, 5905 km^2 of grass planting and 711 km^2 of dam land. Furthermore, 2566 km^2 of "Natural Enclosure" was implemented after 2000 (Ran et al., 2012).

Large scale soil and water conservation measures including planting trees and grasses, and engineering measures, such as fish-scale pits, horizontal trenches, small water cellar, and sediment-trapping dams were installed widely in the Loess Plateau. These measures intercepted more sediment produced from hill slope erosion before entering the river (Yuan and Lei, 2004). Moreover, vegetation cover was increases by soil and water conservation and environmental rehabilitation campaigns. With greater vegetation cover there is a general reduction in the amount of rainfall transformed into runoff as the vegetation canopy intercepts more rainfall. Furthermore, with the increase of vegetation

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Table 4
Cumulative area of soil and water conservation practice in 22 catchments.[a]

ID	Catchment	Year	SW (Km^2)	RSW (%)	ID	Catchment	Year	SW (Km^2)	RSW (%)
1	Huangfuchuan	1979	313.8	9.9	12	Hunhe	1979	593.0	10.9
		1996	634.6	20.0			1996	1246.3	22.8
2	Qingshuichuan	1979	71.3	9.7	13	Pianguan	1979	314.9	16.6
		1996	143.5	19.5			1996	553.4	29.2
3	Gushanchuan	1979	116.0	9.2	14	Xianchuan	1979	235.5	15.1
		1996	241.2	19.1			1996	630.1	40.3
4	Kuye	1979	598.0	7.0	15	Zhujiachuan	1979	253.0	8.9
		1996	1682.2	19.8			1996	781.1	27.4
5	Tuwei	1979	229.2	7.0	16	Lanyi	1979	250.0	11.6
		1996	1141.0	35.1			1996	772.4	35.8
6	Jialu	1979	184.5	16.5	17	Weifen	1979	135.9	20.9
		1996	468.5	41.8			1996	391.6	60.3
7	Wuding	1979	5250.1	17.7	18	Qiushui	1979	280.3	15.0
		1996	12,321.5	41.5			1996	626.1	33.4
8	Qingjian	1979	241.6	7.0	19	Sanchuan	1979	357.3	8.7
		1996	888.4	25.6			1996	1346.7	32.8
9	Yanhe	1979	430.6	7.3	20	Quchan	1979	119.0	11.6
		1996	1677.4	28.5			1996	187.1	18.3
10	Fenchuan	1979	112.2	6.7	21	Xinshui	1979	206.3	5.2
		1996	511.7	30.8			1996	895.0	22.4
11	Shiwangchuan	1979	110.6	5.2	22	Zhouchuan	1979	32.3	7.4
		1996	321.3	15.0			1996	82.2	18.9

[a] SW refers to the total area covered by soil and water conservation; RWS refers to the proportion of the total area of the entire catchment area covered by soil and water conservation.

cover, near-surface cover also increase, more rainfall infiltration and evaporation/ transpiration increase, and thus further reducing surface runoff (Dunne et al., 1991). This resulting reduced soil erosion on the hill slope and sediment entering the river reduced significantly (Zheng, 2006). All of these protective measures to reduce the risk of soil and water loss and reduce sediment material entering the river finally.

5. Conclusions

This study presents a statistical analysis of changes in the sediment discharge over the past half century (1955–2009) in the Hekou–Longmen region of the middle reaches of the Yellow River Basin. A significant decrease ($P < 0.01$) in sediment discharge was observed, which was related to a significant change-point date identified as 1979 across the entire study area of Hekou–Longmen region. For all the 22 tributaries in this region, sediment discharge has shown a significant decrease ($P < 0.01$), and the change-point years were detected as being between 1971 and 1996 when there were downward changes in annual records. The decrease of sediment discharge in the 22 tributaries coincided well with the intensity and extent of soil and water conservation measures implemented during the last 50 years in the study area. The changes in sediment discharge were influenced by rainfall and anthropogenic activities. Compared to rainfall, human activities, primarily soil and water conservation and environmental rehabilitation campaigns, have played a more prominent role in the changes in sediment regimes. In order to reduce soil erosion and sediment yield, more attention should be paid to proper and rational soil and water conservation and environmental rehabilitation.

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