Code no. Abs-32/IC-2019

Study on the Change of Soil erosion and Its Influencing Mechanism in the Loess Plateau of the Middle Reaches of the Yellow River in Different Periods since the Middle of the 20th Century

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[Abstract] The annual sediment transport in the Yellow River is the expression carrier for soil erosion on the Loess Plateau, with an average of 1.6 billion t/year in the natural state. As of 2015, the comprehensive management measures for soil and water conservation in the middle reaches of the Yellow River reached 260,000 km^2, and the degree of governance exceeded 62%. The annual sediment transport volume of the Yellow River has not exceeded 500 million t/year in more than ten years, and the minimum year is less than 100 million t/year. The statistical analysis of the sediment transport volume of the Yellow River in 1954-2015 was conducted in three periods. The results show that: 1) Before the 1960s, the effect of soil and water conservation on the sediment transport of the Yellow River was not obvious; 2) during the period from 1967 to 1987, the effect of soil and water conservation on reducing the amount of sediment transported in the Yellow River was significant; 3) the period from 1988 to 2015, only a factor of "degree of soil and water conservation" can "interpret" the change of the annual sediment transport volume of the Yellow River by nearly 80%; 4) when the degree of soil and water conservation is more than 55%, the annual sediment transport calculated by the regression model is less than 200 million t/year; 5) in recent years, the amount of sediment reduction by the soil and water conservation to the Yellow River has exceeded 1 billion t/year; with a confidence of 80%, the annual sediment load of the Yellow River is less than 500 million t/year.

[Key words] Yellow River, Loess Plateau, annual sediment transport, soil and water conservation, sand reduction

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Foundation： Ecological technology screening, configuration and test example of ecological management and ecological civilization construction in topic V of state key research planning project (2016YFC0503700)

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1 Introduction

The Loess Plateau in the middle reaches of the Yellow River is the region with the most serious soil erosion in the world. The Yellow River flowing through the Loess Plateau is one of the largest rivers in terms of sediment transport in the world. In the natural state, the annual amount of sediment transport is 1.6 billion tons[1][2][3][4]. The fluctuation of sediment transport in the Yellow River in 1954-2015, entering the 21st century average is only 260 million tons (Fig. 1).

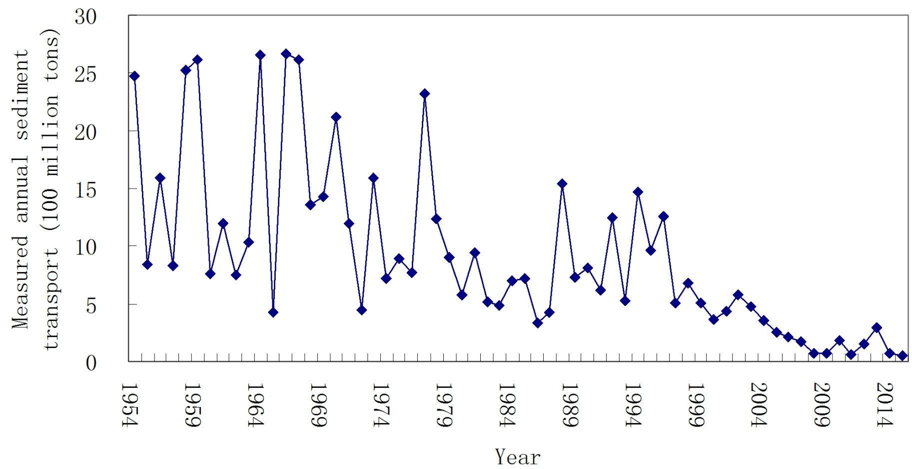


Fig.1 Variation of sediment transport in the Yellow River from 1954 to 2015

Soil and water conservation in the Loess Plateau in the mid-20th century was included in the national key governance[5]. The preserved area of soil and water conservation in the middle reaches of the Yellow River since the 1980s has continued to increase with linear characteristics (Fig. 2).

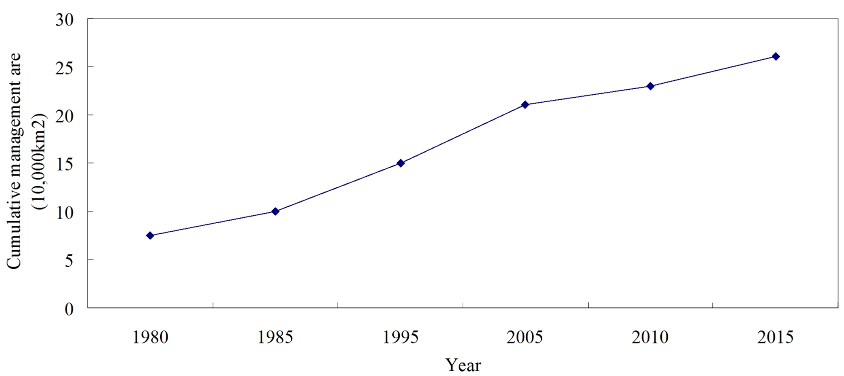


Fig.2 Changes of soil and water conservation preservation area in the Loess Plateau in the middle reaches of the Yellow River

The change of sediment transport in the Yellow River is closely related to rainfall and soil and water conservation. In the past, in the study of the relationship between soil and water conservation and the amount of sediment transported in the Yellow River, "Hydrological" and "Soil and Water Conservation" methods were used [6][7][8][9][10].

Theory and practice show that under the “interference” of nature and human activities, the impact of soil and water conservation on river sediment transport is in accordance with statistical principles. This article is based on the exploration of data processing, analysis methods, to establish the regression equations, and analysis the long-term effects of soil and water conservation measures for the amount of annual sediment transported in the Yellow River, to provide a technical basis for establishing a mathematical model of soil and water conservation in the Yellow River Basin.

2 Research methods（Material and methods）

2.1 Research area and time period

The sediments of the Yellow River basically come from the Loess Plateau, include the tributaries of the Weihe River, Beiluohe River, Fenhe River and Hekou Town to Longmen section. The study area is the control area of Weihe River (Huaxian Station), Beiluo River (Zhuangtou Station), Fenhe River (Hejin Station) and Helong Section (hereinafter referred to as “4 Stations Area”). The 4 stations area is 300,500 km^2(Fig. 3).

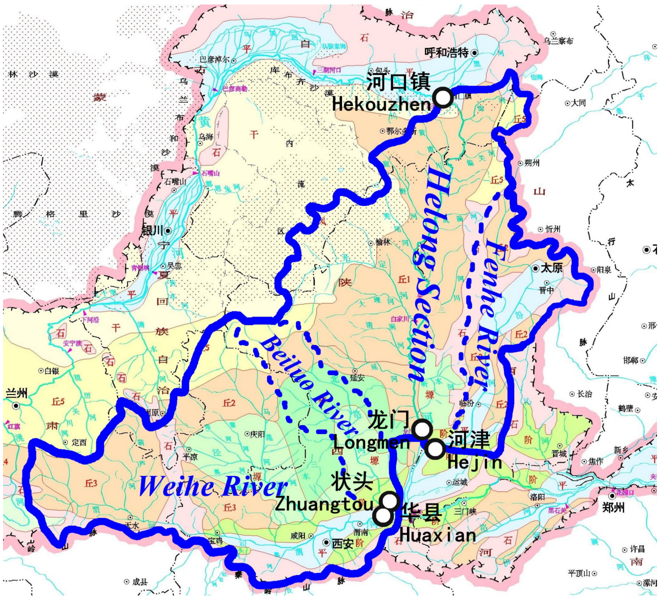


Fig. 3 Schematic diagram of study area

The study period was from 1954 to 2015, a total of 62 years.

2.2 Research methods

According to the basic principles of hydrology and soil and water conservation, the annual variation of sediment transport in rivers follows statistical laws, and the sand-reducing benefits of soil and water conservation measures follow statistical laws. Therefore, this paper will study the generation process of the annual sediment transport of the Yellow River as a gray box or black box, and use the stepwise regression analysis method to screen the explanatory factors (independent variables) with the concept and meaning of physical genesis, and calculate the data of different time periods, obtaining a calculation result consistent with the basic principles of hydrology and soil and water conservation, and the simulation results are good[11].

2.3 Rainfall factor selection

It is known that the Yellow River sediment mainly originates from the section of Hekou Town to Longmen (hereinafter referred to as “Helong Section”), and it is derived from rainfall during the flood season (storm). Therefore, for the rainfall factor, the annual rainfall in the four stations is selected, and the annual rainfall, including the five sub-regions of the Helong section, the July-August rainfall, the maximum three-day rainfall, and the maximum daily rainfall. A total of 22 rainfall factors were initially selected.

2.4 Soil and water conservation factor selection and pretreatment

Soil and water conservation measures include slop measures(such as grass, tree and Terraced field) and gully measures(such as large silt dam and key dam). In order to make the soil and water conservation slope measures coordinate with the silt dam, "coupling" treatment of soil and water conservation slope area and large dam (backbone dam) dam control area (Fig. 4) [12][13].

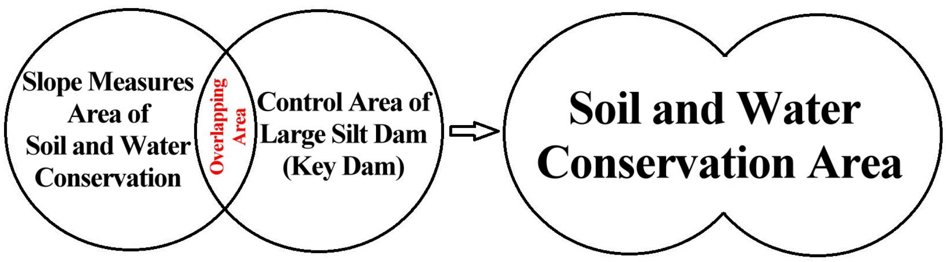


Fig.4 Schematic diagram of "Soil and Water Conservation Area"

In order to make the calculation results of different time and space scales comparable in the future, In this paper, the “degree of soil and water conservation” is taken as a variable. The definition of “degree of soil and water conservation” is:

$$D = (\frac{A_1}{A_2}) \times 100\%$$

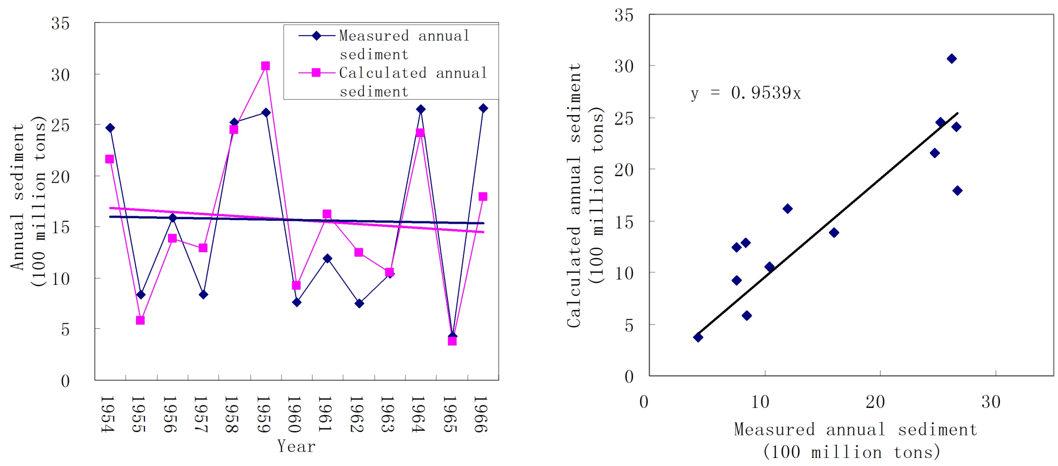
Where: D is the degree of soil and water conservation, %; A_1 is the area of soil and water conservation, 10,000 km^2; A_2 is the area of soil erosion, 10,000 km^2.

3 Calculation results and analysis

3.1 Calculation results from 1954 to 1966 period

Due to the large amount of sediment transported in the Yellow River in the study area from 1954 to 1966 period, the annual fluctuations were severe; at the same time, the scale of soil and water conservation projects was small. The calculation results of this period of time data show that only a factor of “July to August Rainfall in Hewu interval” can “interpret” the change of annual sediment transport volume by nearly 80% (R=0.892330,adjusted R^2=0.777731),linear regression significance level $\alpha = 0.001$.

Comparing the calculated and measured values (Fig.5), Calculating the annual sediment transport volume and the measured annual sediment transport volume are well fitted. The scatter plot shows that the calculated annual sediment transport (y) is 0.9539 times the measured annual sediment transport.



a)Line graph b) Scatter plot

Fig. 5 Comparison of measured annual sediment transport volume with calculated annual sediment transport volume in 1954-1966 period

Among them, the standard deviation of 2.1846 in 1966, the calculated value of the year is significantly smaller than the measured value. Preliminary analysis, the reason for this phenomenon is that there was a large local heavy rain in the Yellow River Basin during the year. It has destroyed some soil and water conservation engineering measures, causing the sediments that have been reduced in the past years to be washed into the Yellow River. The “July to August Rainfall in Hewu interval” cannot “interpret” these sediments. Therefore, the calculated annual sediment transport is significantly smaller than the measured annual sediment transport[14][15][16].

3.2 Calculation results from 1967-1987 period

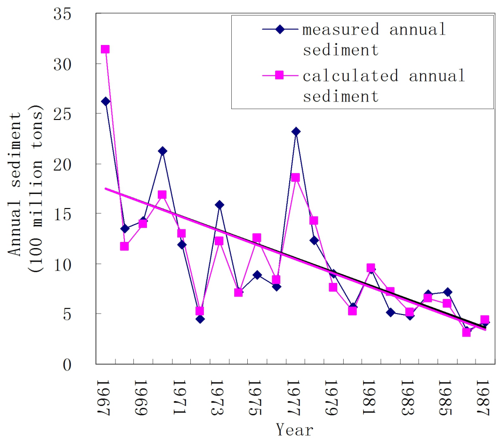
3.2.1 Overall analysis of calculation results

Stepwise regression method for data from 1967 to 1987 period, through four calculations, a nonlinear regression equation consisting of four independent variables is established. The four independent variables are “July to August Rainfall in Hewu interval”, “degree of soil and water conservation”, “maximum daily rainfall in the Helong interval” and “ln‘annual rainfall in the four stations’”. Correlation coefficient R=0.954689 (Table 1), significance level $\alpha = 0.001$.

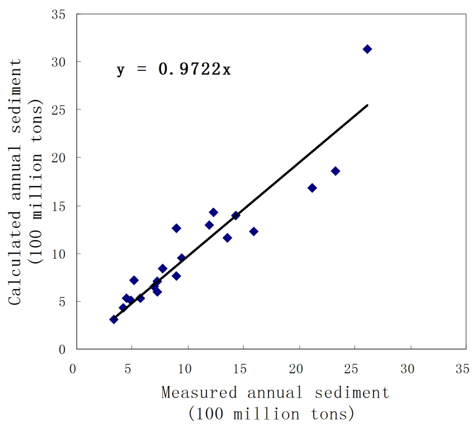
Table 1 Summary of regression calculation results from 1967 to 1987

Number of calculations	R	R^2	Adjusted R^2	standard error estimate	Durbin-Watson
1	0.804379	0.647026	0.628449	0.355502	
2	0.875099	0.765799	0.739777	0.297513	
3	0.926906	0.859155	0.834300	0.237407	
4	0.954689	0.911431	0.889288	0.194057	2.149

According to the regression equation, to calculated annual sediment transport, compare it with the measured annual sediment transport(Fig.5), and fitting the measured annual sediment transport volume is very good.



a)Line graph



b) Scatter plot

Fig.5 Comparison of measured annual sediment transport volume and calculated annual sediment transport volume from 1967 to 1987

3.2.2 Analysis of standardized regression coefficients

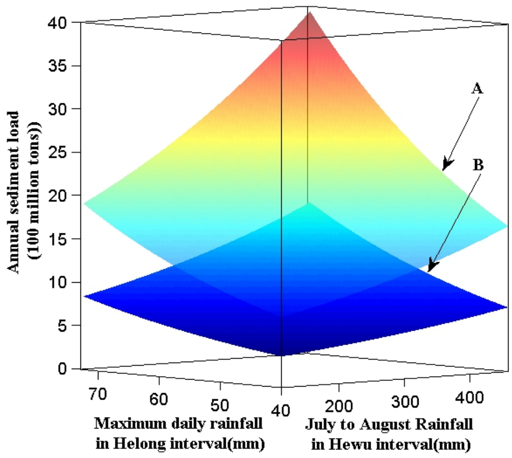
Standardization conversion of four independent variable coefficients(Table 2), analysis of the relative importance of independent variables in regression equations. The standardized regression coefficient of soil and water conservation degree is-0.440812， absolute value is the largest. Explain in the regression equation consisting of these four independent variables, the degree of soil and water conservation has the greatest impact on the annual change of sediment transport, It is the main factor for the sudden drop of sediment transport in the Yellow River during this period.

Table 2 1967-1987 regression coefficient

	Non-standardized regression coefficient	**Standard error**	**Standardized regression coefficient**	**t**	**Sig.**
(constant)	-6.096755	2.239052		-2.722918	0.015048
July to August Rainfall in Hewu interval	0.002110	0.000868	**0.269321**	2.431454	0.027161
degree of soil and water conservation	-0.038777	0.007816	**-0.440812**	-4.961234	0.000142
maximum daily rainfall in the Helong interval	0.026357	0.006156	**0.352553**	4.281482	0.000572
ln'annual rainfall in the four stations'	1.147400	0.373375	**0.276551**	3.073048	0.007279

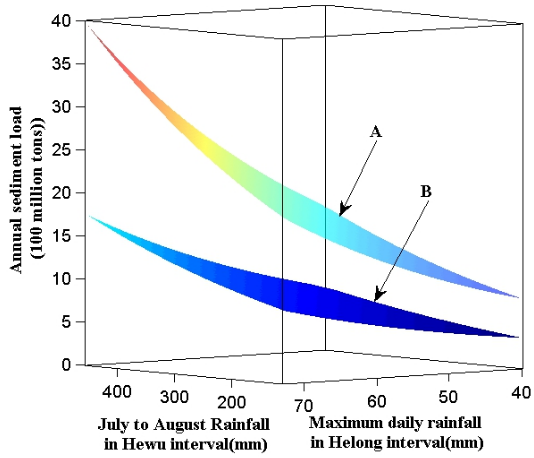
3.2.3 3D spatial graphics analysis

As a nonlinear relationship, different degrees of soil and water conservation have different effects on annual sediment transport, the process of influence (trend) is also different. According to the regression equation, three-dimensional surface graphics with different views of different soil and water conservation under the same rainfall conditions are made. Visual comparison and analysis of different degree of soil and water conservation. In order to make 3D graphics, ln 'annual rainfall in the four stations' contribution rate is the smallest, and it is fixed as the average of the time period. Select the beginning of the period (1967) and the end of the period (1987), make a surface for comparative analysis (Fig. 6).



a) The coordinate of “maximum daily rainfall in the Helong interval” is on the left

Note: In the figure, A is the annual sediment transport response surface of the degree of soil and water conservation in 1967, and B is the annual sediment transport response surface of the degree of soil and water conservation in 1987.



b) The coordinate of “maximum daily rainfall in the Helong interval” is on the right

Note: In the figure, A is the annual sediment transport response surface of the degree of soil and water conservation in 1967, and B is the annual sediment transport response surface of the degree of soil and water conservation in 1987.

Fig. 6 Response surface of annual sediment transport to different degrees of soil and water conservation

As seen generally from Fig. 6, The degree of soil and water conservation in 1967 and 1987 have a significantly different effects on annual sediment transport. At the highest point of the surface, that is, when both rainfall factors are at the maximum, In 1987, the sediment transport response surface was reduced by about 2 billion tons compared with the 1967 sediment transport response surface. At the lowest point of the surface, that is, when both rainfall factors are at a minimum, the difference between the two-year sediment transport response surface is about 500 million tons. Comparative analysis description, with the increase in the degree of soil and water conservation, on the one hand, in general, the amount of annual sediment transport decreased significantly; on the other hand, The annual sediment transport response surface under high rainfall condition is reduced more than the low rainfall condition[11]. This phenomenon also explains, soil and water conservation has not only greatly reduced the amount of annual sediment transported in the Yellow River, moreover, the "sensitivity" of annual sediment transport to rainfall change response is reduced.

3.3 Calculation results from 1988 to 2015 period

3.3.1 Change of annual sediment transport in the Yellow River four stations

During the 1988-2015 period, the annual sediment transport volume of the four stations of the Yellow River has fluctuated drastically, significantly reduced (Fig. 7), of this, only 0.55 billion tons in 2015.

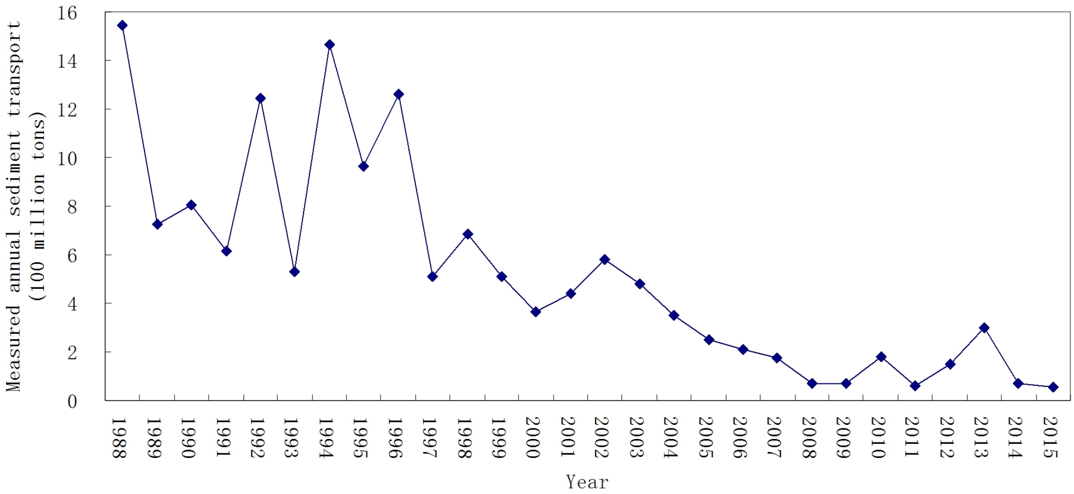


Fig. 7 Changes in annual sediment transport in the Yellow River Station from 1988 to 2015

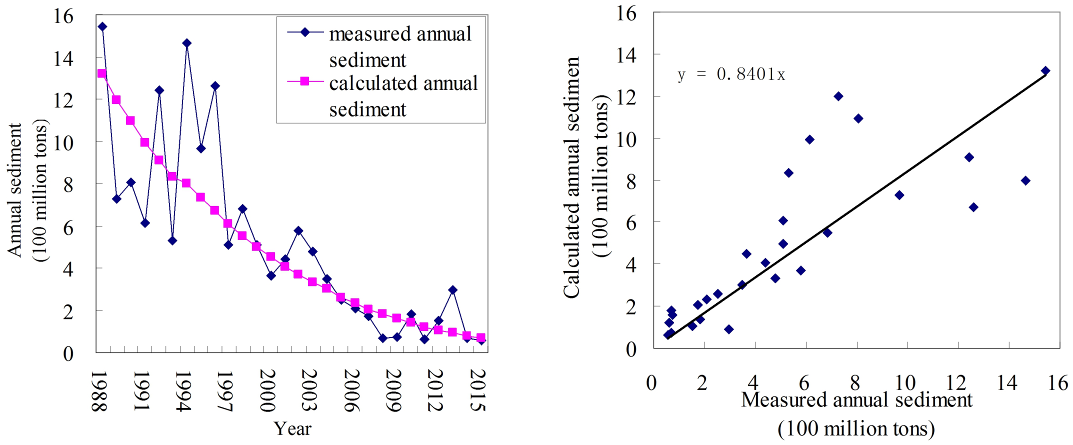
3.3.2 Summary of regression calculation results

1988-2015 period, the impact of soil and water conservation on the amount of sediment transported in the Yellow River is very significant. Regression analysis shows that only a factor of "degree of soil and water conservation" can "interpret" the change of annual sediment transport in the Yellow River by nearly 80% (Table 3). The correlation coefficient R of the regression equation reaches 0.886165. Significant level $\alpha = \mathbf{0.001}$.

Table 3 Summary of 1988-2015 regression calculation results

Number of calculations	R	R^2	Adjusted R^2	standard error estimate	Durbin-Watson
1	0.886165	0.785289	0.777031	0.47772	1.753

Although the annual rainfall in the Helong interval has increased during this period, however, the amount of annual sediment transport is still at a "low level". Only a factor of "degree of soil and water conservation" can better simulate the change of annual sediment transport in the Yellow River (Fig. 8).



a)Line graph b) Scatter plot

Figure 8 Comparison of measured annual sediment transport volume and calculated annual sediment transport volume from 1988 to 2015 period

Because the “degree of soil and water conservation” has increased linearly, it can better fit the trend of the amount of annual sediment transport in the four stations, but it cannot "interpret" fluctuations due to changes in interannual precipitation(Fig.8 a)). As seen from the scatter plot, the overall calculated value is 0.84 times the measured value. Look at the segment, the calculated value is smaller in the measured value (about 500 million t or less) less discrete; when the measured value exceeds 600 million tons, the calculated value is more discrete from the measured value.

3.3.3 Analysis of sand reduction during the period 1988-2015

Further analysis of the results of the 1988-2015 regression, calculated at 80% and 95% confidence, regression calculation upper and lower limits, analyze the trend of annual sediment transport in the Yellow River (Fig. 9). As can be seen from Fig. 9, in 2000, the degree of soil and water conservation reached 40%, and the annual sediment transport was less than 500 million tons, and the upper limit of 80% confidence was less than 1.2 billion tons; in 2011, the degree of soil and water conservation was over 55%, and the annual sediment transport was only 120 million tons, and the upper limit of 80% confidence was less than 400 million tons. This result shows that, according to the data analysis from 1988 to 2015, in the current degree of soil and water conservation, unless there is a rare rainfall event, the annual sediment transport volume of the Yellow River will be less than 500 million tons with an 80% confidence level.

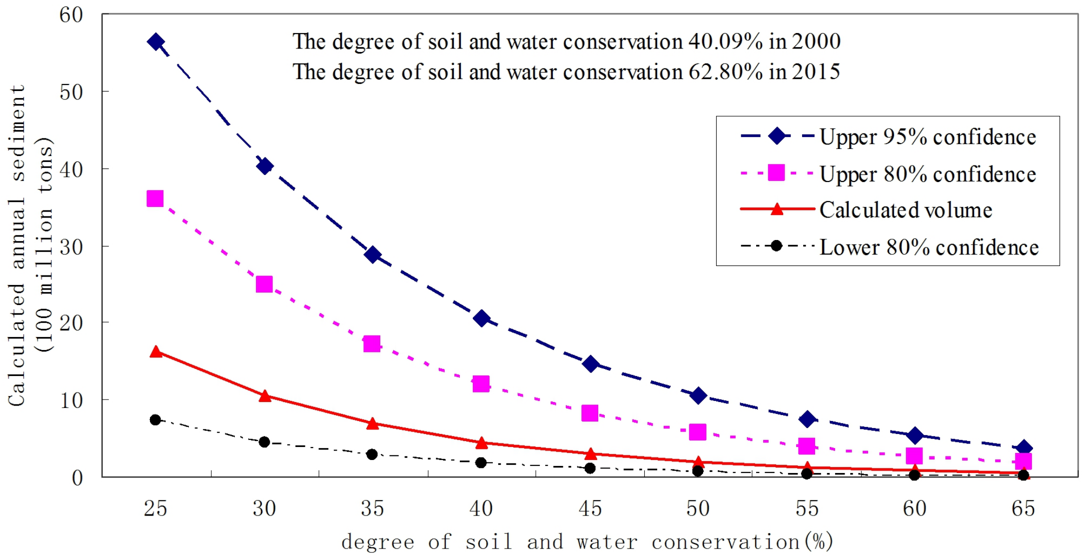


Fig. 9 Prediction and analysis of regression results from 1988 to 2015

Compared with the annual sediment transport in the natural state of the study area, in the early 21st century, the annual sediment reduction by soil and water conservation measures in the Loess Plateau of the middle reaches of the Yellow River is more than 1 billion tons..

4 Conclusions and discussion

1) According to the statistical relationship between soil and water conservation and rainfall and the annual sediment transport volume of the Yellow River, three time periods are divided, and the observation data is calculated and analyzed by regression method. The results show that the degree of soil and water conservation has a good "interpretation" of the sharp decline in annual sediment transport in the Yellow River since the 1980s, indicating that soil and water conservation is the main effective factor for the reduction of sediment transport in the Yellow River.

2) During the calculation period (taking 1967-1987 as an example), under the same rainfall conditions, the increase of degree of soil and water conservation significantly reduces the amount of annual sediment transported in the Yellow River on the one hand; on the other hand, with the improvement of soil and water conservation, the response of annual sediment transport to rainfall tends to be "slow". Therefore, from 1988 to 2015, only one factor of the degree of soil and water conservation can explain the change of annual sediment transport in the Yellow River very well.

3) Based on existing data analysis, when the degree of soil and water conservation is more than 55% (the level of governance in 2011), predicted with 80% confidence, the amount of annual sediment transported in the Yellow River will be less than 500 million tons. At present, due to soil

and water conservation, the annual soil erosion in the Loess Plateau in the middle reaches of the Yellow River has been reduced by more than 1 billion tons.

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