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Influence of Ecological Technology Measures on the Annual Sediment Load of the Wuding River

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Abstract: The influence of ecological technology measures on the annual sediment loads of rivers complies with the principles of statistics. In this paper, the annual sediment load of the Wuding River is taken as the dependent variable and the rainfall, rainstorms during the flood period of the Wuding River and areas of ecological technology measures are taken as the independent variables to analyze the influence of ecological technology measures on the annual sediment load of the Wuding River during the years 1956 to 2007. This research uses a stepwise regression method. The result shows that 1) the non-linear regression equation composed of three independent variables including 7–8 monthly rainfalls along the Wuding River, areas of ecological technology measures and maximum daily rainfall along the Wuding River has been calculated and set up; the correlation coefficient is R^2=0.857 and the significance level is α=0.001. 2) R^2=0.717 is adjusted and the regression equation reveals a change of annual sediment load exceeding 71.7% over 52 years; 3) The standardized regression coefficient for ecological technology measure area has the maximum absolute value of the three independent variables shows maximum influence on the change of annual sediment load; and 4) Because of implementing the ecological technology measures, until to year of 2007, when the 7–8 monthly rainfall and maximum daily rainfall are the maximum values in the research section, the annual sediment load is calculated as 149million ton, which is 36% of the maximum value in the history.

Key words: Wuding River; annual sediment load; sediment; ecological technology and evaluation

1 Introduction

The irrational activities of mankind cause degradation to the ecological environment that must be governed and repaired. A single ecological technology measure is not enough to achieve an ideal effect and multiple ecological technology measures are needed to govern comprehensively. For example, the soil and water conservation is to govern soil erosion comprehensively by adopting multiple ecological technology measures of mountain, water, farmland, forest and grass.

The quantity of sediment discharge of Wuding River is closely related to the characteristics of the ecology of the basin, so that changes in the sediment discharge of the river is the main factor (Zhen L *et al*., 2016) for evaluating the ecological effects of the ecological technology measures. Due to the influence of nature and human activity, the impact of ecological technology measures on the sediment discharge of Wuding River must comply with the principles of statistics.

The Wuding River is located in a transition band of forest-steppe zone on the Loess Plateau and dry steppe, so the ecology is vulnerable. The Wuding River basin is an area of animal husbandry which has a long development history. Due to the vulnerable ecological environment and the long-term development and utilization the land, soil erosion here is serious. and the Wuding River is the main rich-sediment

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branch in the rich and coarse sediment area of the middle Yellow River. (Yang H *et al*., 2017) Since 1949, the state has implemented numerous ecological technology measures in the Wuding River basin. Efforts to manage the soil erosion here have been large-scale and continuous, and have served to reduce the annual sediment load fluctuations of the Wuding River (Xu J X, 2007).

The Wuding River is a main multi-sand branch of the Yellow River, making it a key region of state ecological governance. The influence of ecological governance on the sediment of the Wuding River is a key research topic. Previous hydrographic methods and soil conservation methods had defects (Zhang S. L., 1984). This paper can provide a technical foundation for a macro ecological effect evaluation method of ecological technology measures by setting up a regression equation and analyzing the long-term influence trends of ecological technology measures on the annual sediment load of the Wuding River.

2 Study area

The Wuding River originates in the northern slopes of Baiyu mountain in Shaanxi Province. In the north the river flows through Wushen county in Inner Mongolia and then enters Shaanxi at Miaokou village, Henshan county, and finally flows into the Yellow River. The length of the main stream is 491 km, the basin area is 30261 km^2, the mean annual average runoff is 1159 million m^3, and the annual average sediment discharge is 116.8 million t (Yellow River Sediment Communiqué, 2007). The basin has frequent droughts and wind-sand disasters; soil erosion due to ecological environment deterioration affects 29893 km^2. The river is one of the main sources of sediments in the Yellow River, especially rough sediment.

During the 24 years from 1956 to 1979, annual sediment loads stayed at high levels (Fig. 2) with annual sediment loads of 179 million t during the period. The annual fluctuations of sediment load during the period were serious; there was 420 million t of sediment in 1959 and 89 million t in 1960. the annual sediment load during eight years of the period exceeded 250 million t and during five years it exceeded 300 million t. After 1980, the annual sediment load dropped below 100 million t, with the exception of a high annual sediment load in 1994.

Wuding River basin landforms are divided into a river beam area, a wind-sand area and a loess hill-gully area. Different configurations of ecological technology measures have been adopted and directed at the soil erosion ecological problems in the different areas. The main measures in the river beam area and wind-sand area are wind prevention, sand fixation and afforestation technology, blocking technology, and reservoir silt trapping. Comprehensive ecological technology measures for soil and water conservation consisting of forestation, grass planting, landing and damming are adopted in loess hill-gully region. Carrying out each kind of ecological technology measure has improved the ecological conditions of the Wuding River basin and annual sediment loads of the river have been obviously reduced (Shi C. X. *et al*., 2006).

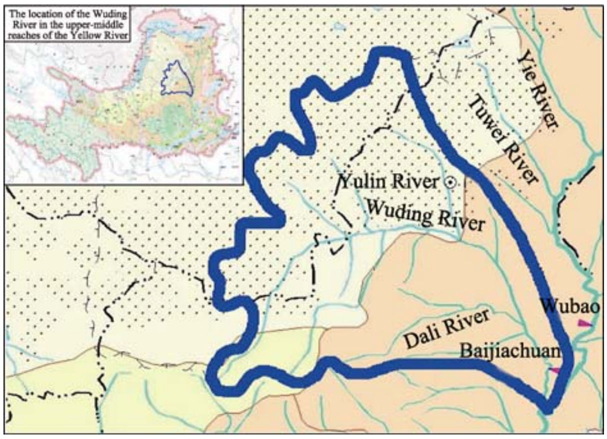


Fig.1 Location of the study area

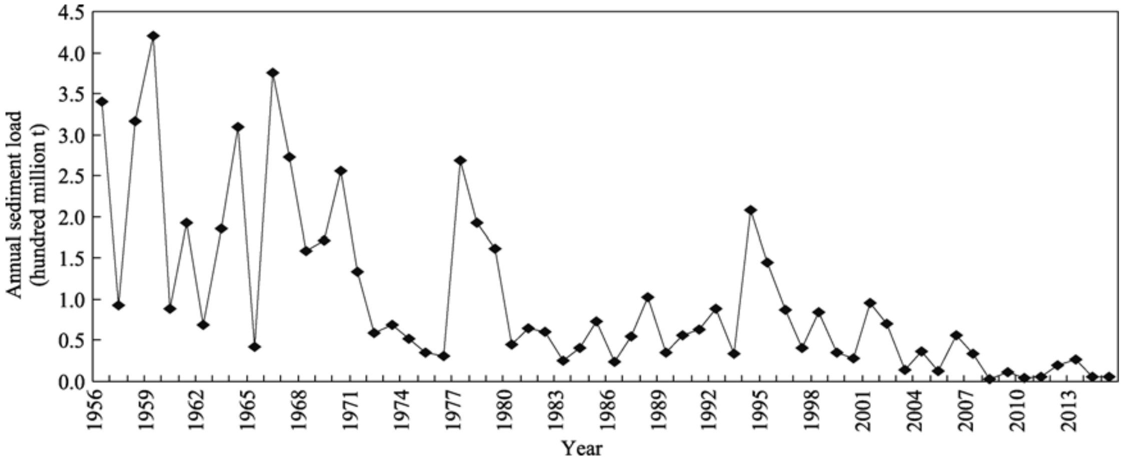


Fig.2 Change of annual sediment load from 1956 to 2015 in the Wu Ding River

3 Data and methods

3.1 Calculation method

The annual sediment load of the river is mainly affected by rainfall and underlying surface change. The change of annual sediment load has obvious inevitability and contingency under the various factors, but it must follow the principle of statistics. A calculation method conforming to objective laws shall be adopted to analyze the reasons for change, simulate the change process, know the rules governing change, and predicate the change trends. In this way the macro ecology effects of the ecological technology measures can be evaluated.

The process that produces the annual sediment loads of the river is regarded as an ash bin or black box. A stepwise regression analysis method is adopted to screen the explanatory factors (independent variable) with physics factor concepts and meaning. data actually measured data is calculated and processed to obtain a calculation result conforming to the basic principles of hydrology and ecology and simulating the effect. Then influence of ecological technology measures on changing annual sediment loads of the river (Li M., 2014) can be researched.

The research shows that the values of sediment discharge and the rainfall or other impact factors have a nonlinear relationship. And the nonlinear relationship may complicated affected by some external affecting factors. In order to conform to the basis principles of rainfall increasing sediment and ecological technology measures reducing sediment, it shall be analyzed and simulated by the nonlinear regression calculation result.

This paper uses an exponential regression equation to express the relationship between the annual sediment loads and rainfall or the ecological technology measures.

3.2 Initial selection and data processing affecting the factor

(1) Time zone: River sand and rainfall in the Wuding River basin have been systematically observed since 1956 and ecological technology measures have been implemented, so the starting time of the research is 1956. The annual sediment load fluctuates slightly after 2007; the end time of the research was 2007. The research time period comprises a multi-sand period before the 1980s and a sediment reduction period after 1980s (Fig. 2).

(2) Selection and data processing of rainfall factor: Sediment in the Wuding River comes mainly from rainfall (rainstorms) during the flood period. Thus, the annual rainfall, 7–8 monthly rainfall, maximum rainfall for three days and daily maximum rainfall have been selected. In view of the complexity of 52a series rainfall and annual sediment load, the natural logarithm (1n) of the rainfall factor shall be switched to take part in calculation screening (Li M. *et al*., 2015.).

(3) Factor selection and data processing of each ecological technology measure: The measures for governing the ecological environment of the Wuding River basin mainly comprise soil and water conservation technology measures and reservoir silt trapping technology measures. The soil and water conservation technology measures comprise terraces built on the slopes, and planted soil and water conversation grass and silt arrester built on the channel. In order to realize the uniformity and identity of the data, the ecological technology measures shall be calculated by area units. To avoid calculating the ecological technology measure areas repeatedly, the soil and water conversation measure areas, and large silt arrester (key dam) and dam control areas of the sediment retaining reservoir shall be coupled and comprehensively processed. After deducing the overlapped areas, the ecological technology measure area (Li M *et al*., 2016.) can be formed.

4 Results and discussion

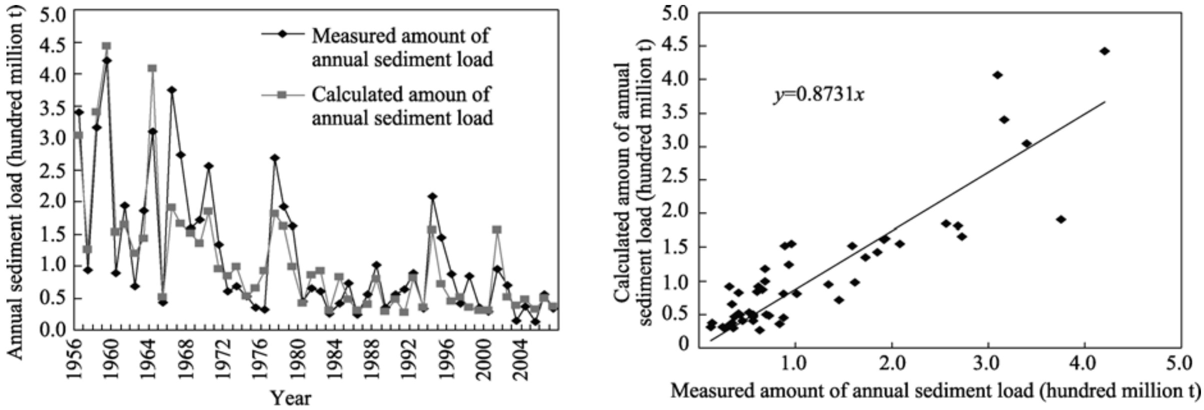
4.1 Analysis on overall calculation result

The stepwise regression has carried out three times for screening calculation (Table 1). In the first calculation, 7–8 monthly rainfall of the Wuding River has been screened; the related coefficient of the factor and the annual sediment load is 0.676. The factor of ecological technology measure area has been added in the second calculation; the related coefficient of the regression equation composed of 7–8 monthly rainfall and ecological technology measure area has been improved to 0.842. After the daily maximum rainfall factor was added in the third calculation, the related coefficient (R) of the regression equation has been increased to 0.857. The inspection result shows that the calculation result is highly remarkable at α=0.001 level. The regression equation has found the change of annual sediment load exceeding 70% (adjust R^2=0.717). DW=1.802, which is close to 2, and it shows that there is no self-correlation. None of the independent variables have a problem of multi-collinearity.

An annual sediment load statistical chart of actually measured annual sediment amounts and the regression equation has been drawn. The matching degree (Fig. 3) of calculation results of the regression equation and actually measured values shall be compared and analyzed. It can be seen from Fig. 3 (a) that the calculated annual sediment load is basically consistent with the overall change trend apart from individual years. The annual change of peak valley fluctuation and continuously reducing trend of annual sediment

Table 1 Summary of the results of stepwise regression analysis

Calculation times	R	R^2	Adjusting R^2	Standard estimated error
1	0.676	0.457	0.446	0.64973
2	0.842	0.710	0.698	0.48000
3	0.857	0.734	0.717	0.46429



(a) Linear graph of the annual sediment load comparison diagram (b) Scatter plot of the annual sediment load comparison diagram

Fig.3 Comparison of measured annual sediment load with calculated annual sediment load

load of Wuding River have been simulated. The acute fluctuation change process of annual sediment load of Wuding River before 1980 and fluctuation reduction process after 1980 have been reflected well, and the overall calculation simulation degree is high.

It can be seen from the scatter diagram in Fig. 3(b) of actually measured annual sediment load and calculated annual sediment load that the data points are basically distributed around the straight line of Y=0.8731X; and it shows that the calculation is close to the actually measured value.

In order to analyze the influence degree of each independent variable on the dependent variable, the regression coefficient of the independent variable is standardized. The influence of different dimensions of independent variables on the regression coefficient is removed, so that the different independent variable coefficients have relative comparability (Table 2).

It can be seen from Table 2 that the standardized regression coefficient of the ecological technology measure area is –0.516 when the stepwise regression is calculated second; the absolute value is slightly less than 0.561 of 7–8 monthly rainfall. This shows that the response of annual sediment load on 7–8 monthly rainfall is remarkably greater than the factor of ecological technology measure area during the regression equation formed by the second gradual regressive calculation. The factor of daily maximum rainfall has been added in the third calculation result of the stepwise regression. The absolute value of the standardized regression coefficient of ecological technology measure area has been increased to 0.540 and this has become the factor with maximum influence on the annual sediment load. So, according to the analysis result of standardized regression coefficient, the response strength of the annual sediment load on ecological technology measure area is obviously greater than the single rainfall factor.

4.2 Annual calculation result discussion of ecological technology level in 2007

The ecological technology measure area in 2007 reached 17300 km^2, which accounts for 57.2% of the total basin area of 3.0261 km^2. The factor of the ecological technology measure area was fixed in 2007. According to the regression equation, the response curve of annual sediment load in 2007 to the ecological technology measure area has been made, and the influence of the ecological technology measure area on the annual sediment load has been directly analyzed (Fig. 4).

Table 2 Coefficient of stepwise regression equation

Calculation times and independent variable		Unstandardized coefficients		Standardized regression coefficient	t	Sig.
		Coefficients	Standard error			
1	(constant)	–2.003	0.289		–6.931	0.000
	7–8 monthly rainfall	0.009	0.001	0.676	6.491	0.000
2	(constant)	–0.806	0.281		–2.866	0.006
	7–8 monthly rainfall	0.008	0.001	0.561	7.097	0.000
	Ecological technology measures area	–0.910	0.139	–0.516	–6.528	0.000
3	(constant)	–1.101	0.307		–3.592	0.001
	7–8 monthly rainfall	0.006	0.001	0.431	4.383	0.000
	Ecological technology measures area	–0.952	0.136	–0.540	–6.985	0.000
	Daily maximum rainfall	0.014	0.007	0.200	2.091	0.042

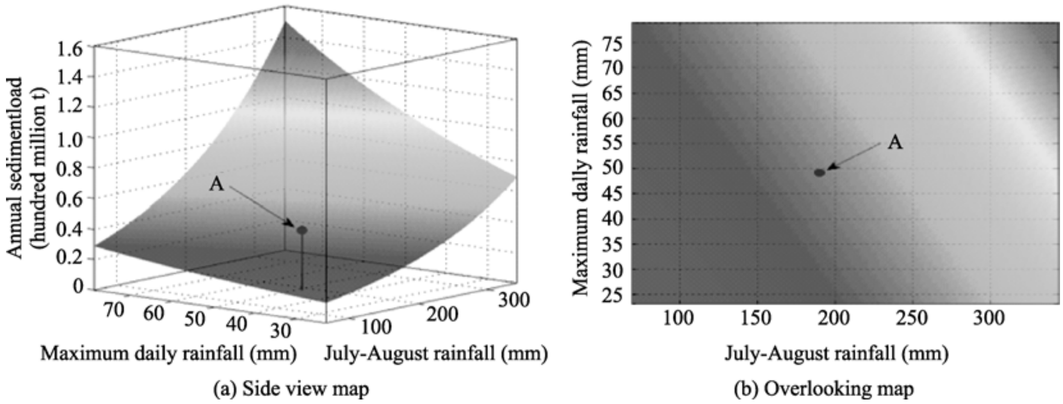


Fig.4 Response surface of annual sediment load for ecological technology measures area in 2007

Firstly, it can be seen from Fig. 4 that even two rainfall factors were the maximum value in observation time bucket, the calculated annual sediment load was 150 million t, which was less than the 179 million t of annual sediment from 1956 to 1979 and far less than the 420 million t of annual sediment in 1959.

Secondly, when two rainfall factors take the arithmetic mean value of the observation value, the annual sediment load is 39.4 million t (point A in Fig. 4).

The result shows that when the ecological technology measure area of Wuding River basin reaches above 50%. The annual sediment load is obviously reduced along the improved ecological regime of basin underlying surface, including microtopography change, increased vegetation coverage, rising channel sediment retaining measure.

4.3 Comparison of section calculation result of 1959 and 2007

According to the regression equation, the response curve (Fig. 5) of the ecological technology measure area of section annual sediment load in 1959 and 2007 should be made continuously.

Firstly, it can be seen that the response curve for annual sediment load in 1959 with lower level of ecological technology measure area is obviously steep under the same three-dimensional system of coordinates, while the response curve for annual sediment load in 2007 is low. This phenomenon shows that the implementation of the ecological technology measure has changed the trend of annual sediment load to rainfall.

The specific influence of two different ecological technology measure areas on the annual sediment load shall be compared. It can be seen from the Fig. 5 that the difference of the two annual sediment load response curve exceeds 450 million t when the two rainfall factors are at maximum value. The difference shows that when the rainfall extreme value occurs, disastrous consequence may appear if the area of ecological technology measure was in the level of 1959. The total storage of Xinqiao reservoir at basin upstream can reach 200 million m^2, however, it deposited over 150 million m^3 sedimentation in 1982. And only in 1959, the annual reservoir sedimentation was around 75 million m^3. Which demaged the Xinqiao reservoir. Correspondingly, when the ecological technology measure area reached to the level in 2007, there was no severe disaster under the same extreme rainfall condition. This shows that the implementation of ecological technology measures has had remarkable ecological effects.

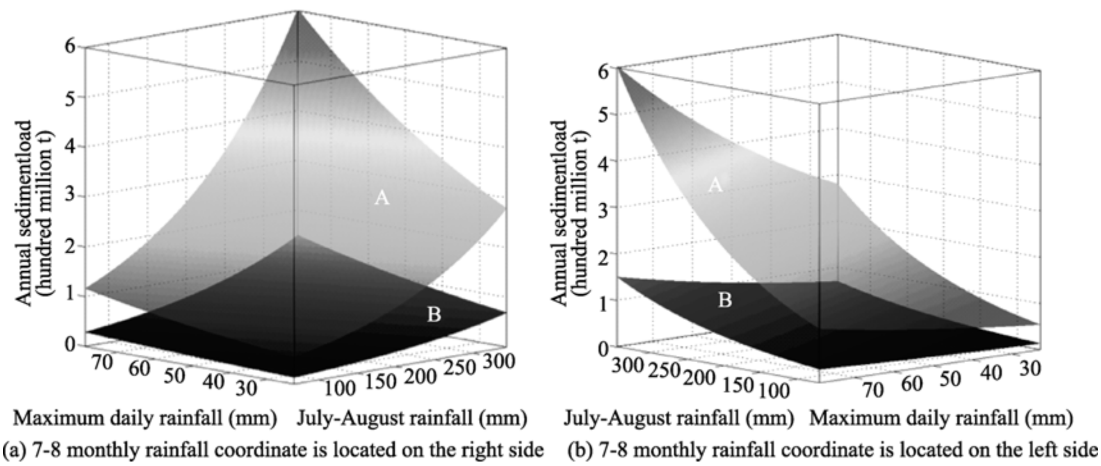


Fig.5 Response curve of annual sediment load for different ecological technology measures area

4.4 Dynamic result discussion from 1956 to 2007

7–8 monthly rainfall and the ecological technology measure area are the main independent variables of the regression equation. In order to display the influence the two factors have on annual sediment loads in 3D space, the factor of daily maximum rainfall is fixed as the average value of the observation value in the research section. The 7–8 monthly rainfall and ecological technology measure area are taken as the independent variables to draw the response curve of the annual sediment load (Fig. 6). Finally, the influence of ecological technology measure area on the annual sediment load under the maximum rainfall in flood period can be continuously analyzed.

It can be seen from Fig. 6 that when 7–8 monthly rainfall is maximum (side A of Fig. 6 a), if the ecological technology measure area is increased from 0 to 5000 km^2, the annual sediment load is decreased to 325 million t from 500 million t, it has reduced 175 million t. And if the ecological technology measure area is in the range of 5000–10 000 km^2, the annual sediment load has reduced 125 million t. When the ecological technology measure area is in the range of 10,000–15,000 km^2, the annual sediment load has reduced 75 million t. In other words, if the ecological technology measure area is less than 7500 km^2, the annual sediment load is decreasing sharply with the ecological technology measure area increase, And if the area is greater than 7500 km^2, the sediment decreasing slowly. However, although the phenomenon of 'diminishing returns' occurred, the overall annual sediment load have dropped continuously, and this shows that the ecological environment of the Wuding River basin has steadily improved.

5 Conclusions

1) A non-linear regression equation composed of three independent variables including 7-8 monthly rainfall in the Wuding River basin, the area of ecological technology measures and daily maximum rainfall in the Wuding River basin has been established according to the statistical relationship between the ecological technology measures area and rainfall and annual sediment loads of the river. After being inspected, each independent variable of the regression equation has no problem of mult-collinearity or obvious autoregression phenomena; and the related coefficient (R) of the regression equation can reach 0.857. The calculation result is highly remarkable at $\alpha = 0.001$ level. The regression equation has found the change of annual sediment loads to exceed 70% (adjusting R^2=0.717). The annual fluctuation change and long-term decreasing change trend of annual sediment load of Wuding River from 1956 to 2007 have been simulated well.

2) The ecological technology measure area explains the phenomenon of decreasing annual sediment loads of the Wuding River since the 1980s. This study shows that ecological technology measure area is the main reason for the reduction of the annual sediment loads of the Wuding River.

3) The ecological technology measure area in 2007 is more than 57% of the area of the Wuding River basin. Under this condition, even 7-8 monthly rainfall and daily maximum rainfall are maximum during the observation, the annual sediment load of Wuding River is only 150 million t/a. It is obviously less than the extreme value of sediment load in the history. It shows that the ecological technology measure area has remarkably affected the trend of annual sediment load of Wuding River.

4) During the calculation section, in the same ecological technology measure area, the greater of 7-8 monthly rainfall, the greater of sediment reducing rate. Under the same extreme rainfall condition during flood season, the total sediment load reducing with the increased ecological technology measure area, which shows that the ecological environment of the basin has been continuously improved.

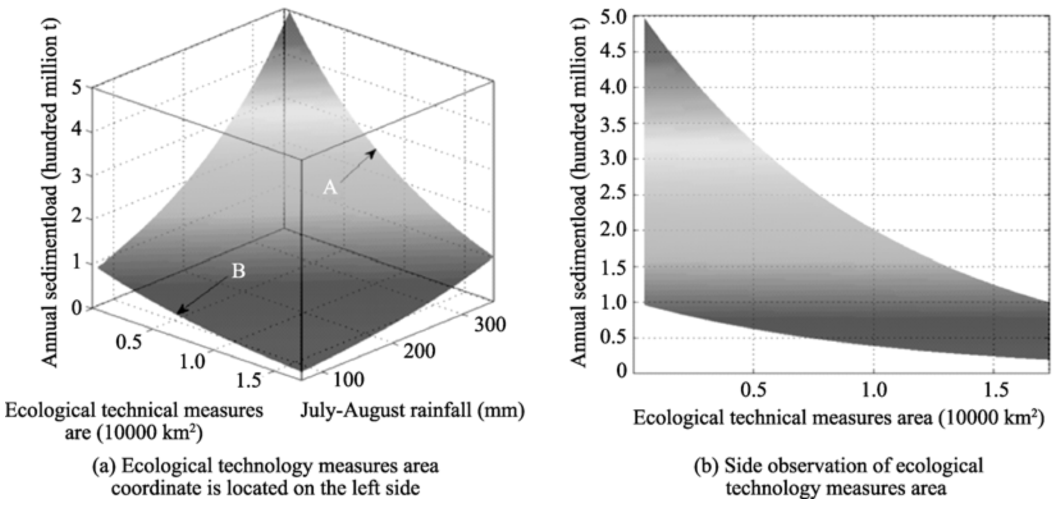


Fig.6 Three-dimensional surface graphics of regression equation

References

Li M., 2014. Effect of soil and water conservation on sediment discharge in the Yellow River. *Science of Soil and Water Conservation*, 12(6): 23–29. (in Chinese)

Li M., Wang F. G., 2015. Analysis of the impact of economic and social development to the sediment load of the middle Yellow River. *Yellow River*, 3: 12–16. (in Chinese)

Li M., Mu X. M., 2016. Study on response mechanism of annual sediment transport to soil and water conservation in He-Long reach of the Yellow River. *Journal of Sediment Research*, 3: 1–8. (in Chinese)

Shi C. X., Guo L. P., 2006. Slope measure sediment reduction and coarse sediment analysis of Wuding River. *Journal of Sediment Research*, 10(5): 22–27. (in Chinese)

Xu J. X., 2007. Change and reason of coarse sediment yield of Wuding River, *Science of Soil and Water Conservation*, 5(6): 1–7.(in Chinese)

Yang H., Shi C. X., 2017. The fractal characteristics of drainage networks and erosion evolution stages of ten kongduis in the upper reaches of the Yellow River. *Journal of Resources and Ecology*, 8(2): 165–173. (in Chinese)

Zhen L., Wang J. J., Jiang Z. D., *et al*.. 2016. Ecological technology evaluation method and global ecology treatment technology research, *Acta Ecologica Sinica*, 36(22): 7152–7157. (in Chinese)

Zhang S. L., 1984. Comprehensive treatment and sediment reduction benefit in Wuding River basin, *Journal of Sediment Research*, (3): 3–13. (in Chinese)

生态技术措施对无定河年输沙量影响研究

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摘 要：生态技术措施对河流年输沙量的影响遵从统计学原理。本文以无定河年输沙量为因变量，以无定河汛期降雨、暴雨和生态技术措施面积为自变量，采用逐步回归方法，分析研究了 1956–2007 年时段生态技术措施对无定河年输沙量的影响。结果表明，（1）计算建立了由“无定河 7–8 月降雨量”、“生态技术措施面积”和“无定河最大一日降雨量”等三个自变量组成的非线性回归方程，相关系数 R^2=0.857，显著性水平 α=0.001。（2）调整 R^2=0.717，说明回归方程“解释”了 52 年时段无定河年输沙量 71.7%的变化。（3）生态技术措施面积的标准化回归系数在三个自变量中绝对值最大，说明其对年输沙量变化的影响最大。（4）通过实施生态技术措施，到 2007 年治理水平年，即使是在 7–8 月降雨量和最大一日降雨量均为研究时段内最大值时，计算年输沙量为 1.49 亿 t，仅为历史最大值的 36%。

关键词：无定河；年输沙量；泥沙；生态技术；评价