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# Study on the storm-sediment yield model of the Baizhang Creek small watershed

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**Abstract.** Mastering the sediment yield in the watershed was the basis for the comprehensive management planning of the basin, the prevention and control of soil erosion, the rational utilization of the water resources. Due to the simple structure of the statistical model and the convenient calculation, the statistical prediction model of sediment yield was a powerful tool for the prediction of sediment yield. Based on the measured data of the Baizhang Creek small watershed in Zhejiang province, the impact factors of sediment were systematically analyzed. And then the main factors were considered to be rainfall, runoff depth, flood peak discharge and mean rainfall intensity, which were used to established statistical model of sediment yield in rainstorm. The statistical prediction model had a certain precision.

## 1. Introduction

Soil erosion is one of the greatest ecological and environmental problems faced by human beings. China is one of the most serious soil erosion countries in the world. Small watershed as a runoff collection, soil erosion, the basic unit of soil and water conservation work, its study of erosion and sediment yield models are one of the key areas in the field of international soil erosion. Many researchers had established different empirical statistical models based on their respective research area and research methods [1-3]. Based on the correlation analysis of runoff volume, the mean gradient of river basin, silt content and vegetation action coefficient, a prediction formula for storm runoff and sediment yield in a small watershed was established [4]. Mu [5] believed that the sediment yield in the drainage area of the river basin was determined by the incoming sediment and sediment-carrying capacity of flow, and these were related to many complex combination factors. Lu [6] studied the relationship between runoff erosion power and sediment transport modulus, and runoff erosion power was applied to predict sediment transport modulus. China had done a lot of research in this field [7-9], and many models were established. The researches of these models scientifically guided the evaluation of the benefit of different watershed management, the planning of soil and water conservation and ecological environment construction. Based on the monitoring data of typical small watershed, the prediction models for sediment yield in hilly area of South China were established by statistical analysis. The purpose was to provide the relevant parameters for the planning and design of water and soil conservation in small watershed and provided a tool for the prediction of erosion and sediment yield in small watershed.

## 2. Materials and Methods

### *2.1 Small watershed introduction*

The Baizhang Creek small watershed is located in the north of Yuhang District (E119°41′9.265″-E119°44′50.924″, N30°30′42.765″-N30°33′41.809″), Hangzhou city, China. The catchment area is 15.56km$^2$. The topography in the small watershed are mainly mountainous and hilly, the overall topography is reduced from north to south, with an average slope of 19.5 degrees. The main channel of small watershed has six obvious small streams. The total length of channels is 44.425km, the main channel length 5.974km, average gradient by 0.033, and the gully density is 2.86km/km$^2$. The average annual rainfall of the watershed is 1568.6mm, the rainfall mainly occurs in 6-8 months, of which the rainfall accounts for 44.5%. There are 4 subtypes of soil in the small watershed, which are sandy viscous yellow mud soil, yellow mud soil, yellow mud sandy soil, red mud soil. The area of yellow mud soil is 58.5%. The area of woodland in small watershed accounts for 89.14% and cultivated land accounts for 4.11%. There are small areas of steep sloping cultivated land and orchard land, but they are the main sources of soil erosion.

### *2.2 Monitoring data*

In this study, from 2011 to 2015, the monitoring and investigation in the small watershed had been carried out for 15 times. The relevant data was collected. The indexes of collecting and investigating include rainfall, mean rainfall intensity, peak discharge, runoff depth, sediment yield. The statistical results of various monitoring indicators are shown in Table 1.

Table 1. Statistics of various monitoring indicators

| Date | *Rainfall* $P$ /mm | *Peak discharge* $Q$ /m$^3$·s$^{-1}$ | *Runoff depth* $H$ /mm | *Mean rainfall intensity* $I$ /mm·h$^{-1}$ | *Sediment yield* $A$ /t |
|---|---|---|---|---|---|
| 20110609 | 126.0 | 21.5 | 83.9 | 2.07 | 969.0 |
| 20110908 | 49.0 | 6.7 | 20.5 | 1.29 | 228.0 |
| 20110929 | 41.0 | 1.6 | 5.4 | 0.69 | 65.0 |
| 20120507 | 47.5 | 8.9 | 21.5 | 2.64 | 140.0 |
| 20120529 | 68.0 | 17.8 | 54.4 | 2.00 | 473.0 |
| 20120626 | 57.5 | 7.8 | 31.8 | 1.80 | 218.0 |
| 20120802 | 50.5 | 14.6 | 23.4 | 1.01 | 275.0 |
| 20120807 | 206.5 | 54.5 | 160.4 | 4.05 | 1298.0 |
| 20140620 | 66.5 | 6.7 | 30.5 | 1.58 | 42.9 |
| 20140625 | 86.5 | 13.5 | 48.5 | 1.27 | 92.8 |
| 20140924 | 60.5 | 5.3 | 23.0 | 1.83 | 24.6 |
| 20150515 | 14.5 | 1.8 | 3.9 | 1.32 | 15.0 |
| 20150607 | 73.0 | 11.8 | 53.3 | 1.78 | 160.5 |
| 20150615 | 54.5 | 7.8 | 28.5 | 0.73 | 148.5 |
| 20150710 | 128.5 | 22.2 | 108.8 | 3.13 | 514.5 |

During the 15 rainfall observations, the maximum rainfall was 128.5mm, the minimum was 14.5mm. The rainfall variation range belonged to the daily rainfall range of small watershed. In the observed flood peak discharges, the maximum peak discharge was 54.5m$^3$/s, and the minimum peak discharge was 1.8m$^3$/s. The variation range of runoff depth was between 5.4mm to 160.4mm. The mean rainfall intensity range was 0.69mm/h - 4.05mm/h. The sediment yield was between 15t - 1298t.

## 3. Results and Analysis

### *3.1. Correlation analysis*

Table 2 showed the Pearson correlation coefficient of 11 curves between the single influence factor and the sediment yield. From the table, it can be seen that the relationship between influence factor and sediment yield was different. Among them, it found 10 significant relationships between rainfall and sediment yield. While there were 9 kinds of significant relationship between the flood peak discharge, the runoff depth and the sediment yield. The mean rainfall intensity was significantly related to the one kind of curve. In all relationships, the correlation coefficients of linear, quadratic and cubic curve between rainfall, flood peak discharge, runoff depth and sediment yield were high. In which, the correlation coefficients of quadratic and cubic curve between rainfall and sediment yield were above 0.80. Meantime, three correlation coefficients also were above 0.80 between flood peak discharge and sediment yield.

Table 2. The Pearson correlation coefficient of influence factors

| Equation | *P-A* | *Q-A* | *H-A* | *I-A* |
|---|---|---|---|---|
| Linear | 0.791** | 0.840** | 0.789** | 0.521* |
| Logarithmic | 0.561** | 0.602** | 0.512* | 0.387 |
| Inverse | 0.222 | 0.222 | 0.176 | 0.243 |
| Quadratic | 0.811** | 0.848** | 0.799** | 0.600 |
| Cubic | 0.820** | 0.891** | 0.799** | 0.616 |
| Compound | 0.525* | 0.573** | 0.567** | 0.311 |
| Power | 0.577** | 0.701** | 0.613** | 0.234 |
| S | 0.442* | 0.447 | 0.418 | 0.142 |
| Growth | 0.525* | 0.573** | 0.567** | 0.311 |
| Exponential | 0.525* | 0.573** | 0.567** | 0.311 |

Note: ** indicated significant at the 0.001 level, * indicated significant at the 0.005 level. The same below.

Table 3. The Pearson correlation coefficient of binary complex factors

| Equation | *PI-A* | *PQ-A* | *PH-A* | *QH-A* |
|---|---|---|---|---|
| Linear | 0.753** | 0.770** | 0.794** | 0.757** |
| Logarithmic | 0.599** | 0.626** | 0.546* | 0.568** |
| Inverse | 0.243 | 0.118 | 0.091 | 0.110 |
| Quadratic | 0.761** | 0.873** | 0.815** | 0.848** |
| Cubic | 0.763** | 0.875** | 0.819** | 0.859** |
| Compound | 0.415 | 0.394 | 0.435 | 0.389 |
| Power | 0.505* | 0.701** | 0.617** | 0.675** |
| S | 0.398 | 0.388 | 0.342 | 0.335 |
| Growth | 0.415 | 0.394 | 0.435 | 0.389 |
| Exponential | 0.415 | 0.394 | 0.435 | 0.389 |

Table 4. The Pearson correlation coefficient of ternary complex factors

| Equation | 0.684** | 0.684** | 0.713** | 0.677** |
|---|---|---|---|---|
| Linear | 0.585** | 0.643** | 0.578** | 0.590** |
| Logarithmic | 0.078 | 0.124 | 0.105 | 0.093 |
| Inverse | 0.831** | 0.812** | 0.762** | 0.778** |
| Quadratic | 0.831** | 0.812** | 0.868** | 0.778** |
| Cubic | 0.308 | 0.315 | 0.352 | 0.314* |
| Compound | 0.672** | 0.643** | 0.582** | 0.632** |
| Power | 0.327 | 0.350 | 0.346 | 0.229 |
| S | 0.308 | 0.315 | 0.352 | 0.314 |
| Growth | 0.308 | 0.315 | 0.352 | 0.314 |
| Exponential | 0.308 | 0.315 | 0.352 | 0.314 |

In terms of the correlation of binary complex factor (Tabel3), there were 5 significant relationships between binary complex factors and sediment yield. These relationships were linear, logarithmic, quadratic, cubic and power function respectively. Although the 5 relationships were significant, the correlation was different. Similarly, the correlations of linearity, quadratic and cubic were better. The correlation coefficients of quadratic and cubic between four kinds of binary complex factors and sediment yield were all above 0.80. Through the correlation analysis of ternary complex factors (Tabel4), the correlation characteristics between ternary complex factors and sediment yield was similar to binary complex factors. The correlation coefficients of quadratic and cubic between three kinds of ternary complex factors and sediment yield were all above 0.80.

Through the analysis of influence factors and complex factors, it was concluded that, among the influence factors, the correlation coefficients between rainfall and sediment yield were relatively high. On the curve type, the correlation coefficient of the linearity, quadratic and cubic were relatively good.

*3.2 Model structure and parameter calculation*

According to the correlation analysis between influence factors, complex factors and sediment yield, the basic forms of the four models were defined as follows:

Multivariate linear model (Model 1) $A = aP + bQ + cH + dI + k$

Binary combination model (Model 2) $A = aPI + bPQ + cPH + dQH + mQI + nHI + k$

Ternary combination model (Model 3) $A = aPQH + bPIQ + cPIH + dQIH + mPQIH + k$

High order hybrid model (Model 4) $A = aQ^3 + bP^2Q^2 + cP^2Q^2H^2 + k$

Where the A was the sediment yield, t. The P was rainfall, mm. The Q was flood peak discharge, $m^3 \cdot s^{-1}$. The H was runoff depth, mm. The I was mean rainfall intensity, mm·h-1. The a, b, c, d, m, n and k were model parameters.

The calculation of the model parameters was mainly based on the multiple regression function provided in the Origin software analysis module. The results of the calculation of the parameters of the 4 models were shown in Table 5.

Table 5. The model parameters

| Model | *a* | *b* | *c* | *d* | *m* | *n* | *k* | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.8718 | 19.4929 | 0.0851 | | | | -97.1349 | 0.8052 |
| 2 | -4.7268 | 0.1553 | 0.3475 | -1.1909 | 48.1830 | -7.3789 | 80.2904 | 0.8595 |
| 3 | 0.0065 | 0.1331 | -0.0317 | 0.0956 | -0.0021 | | 49.0746 | 0.9518 |
| 4 | 0.0594 | $5.1\times10^{-5}$ | $-4.5\times10^{-9}$ | | | | 64.2178 | 0.9095 |

In the model 1, the explanation of the independent variable to the dependent variable was about 80.5%. The influence of flood peak discharge on sediment yield was the largest and the influence coefficient was 0.91, the factor parameter was divided by the sum of all factor parameters, followed by the rainfall factor, the influence coefficient was 0.09. It can be seen that in the three factors of the model, the flood peak discharge played an absolute role in the sediment yield. At the same time, the coefficients of the three factors were all positive, which showed that the rainfall, peak discharge and runoff depth were all positively related to the sediment yield.

In the model 2, The determination coefficient of the model was 0.8595, which indicated that the explanation of the independent variable to the dependent variable was about 85.9%. The QI binary complex factor had the greatest impact on sediment yield, influence coefficient 0.78. Followed by the HI binary complex factor, the influence coefficient 0.12. The rest of the binary complex factor was relatively small, the influence coefficient for a total of 0.10. At the same time, the coefficients of QH and AH binary complex factors were negative, however the other coefficients of binary complex factors were positive. Because of the overlapping effect of complex factors, multiple effects in the model may be embodied by different complex factor. It eliminated in the form of difference.

The determination coefficient of model 3 was the highest. The degree of explanation for the dependent variable was about 95.2%. The PQI ternary complex factor had the greatest impact on sediment yield, influence coefficient of 0.49. The QHI ternary complex factor also had great influence on sediment yield, and its influence coefficient was 0.36. In addition, the influence coefficient of PIH ternary complex factor was 0.12. The coefficients of PIH and PQIH complex factors were negative, which mainly reflected the overlapping effect among the factors in the model.

In high order hybrid model (Model 4), the determination coefficient was 0.9095, indicating that the degree of explanation for the dependent variable was about 90.9%. The three power of flood peak discharge had the greatest influence on the sediment yield, and the influence coefficient was nearly 1.00. However, as the number of high order complex factors was very large, for example, the P2Q2H2 complex factor, the calculation value was above 8 orders of magnitude, or even up to 12 orders of magnitude. Therefore, although its influence coefficient was small, its contribution to the sediment yield cannot be ignored. At the same time, it can be seen that the coefficient of the $P_2Q_2H_2$ complex factor was negative; It mainly reflected the overlapping effect among the factors.

*3.3 Precision analysis*

Through the analysis of the model in Origin software, it was concluded that the adjustment coefficient of the four models and the relative error of the regression data were shown in Figure1.

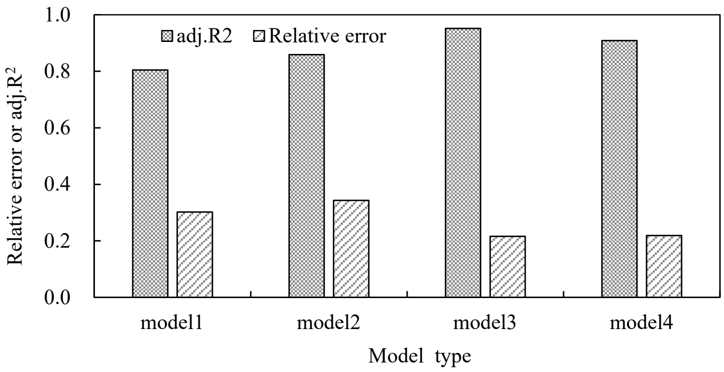


Fig.1. The adjustment coefficient and relative error of different models

In the aspect of adjustment determination coefficient (adj.R2), the relationship of the four models was as follows: model 3 > model 4> model 2> model 1. The adjustment determination coefficients of model 3 and model 4 were more than 0.90, of which model 3 was best 0.952, while model 1 and model 2 were relatively small. The relative error was model 2 > model 1 > model 4 > model 3, that meant the relative error of model 3 and model 4 were relatively small, the range in 0.21 - 0.22. While, the relative error of model 1 and model 2 was between 0.30 to 0.35. Therefore, in general, model 3 was the best, followed by model 4 had relatively good prediction results, while the prediction results of model 1 and model 2 were relatively poor.

Figure 2 reflected the degree of coupling between the predicted values of the four models and the actual values. The 4 models can all predict the overall peak and valley change of the data, but on the whole, the consistency of model 3 and model 4 was higher. However, the four models have great differences in the prediction of some values. For example, the absolute difference predicted by model 1 in June 9th, 2011, June 25th, 2014, May 15th, 2015 and June 7th, 2015, was significant. The large difference in prediction value of model 2 occurred mainly in May, 2012, in June 25th, 2014 and June 7th, 2015. The prediction ability of model 3 was better, and the difference of forecast value occurred mainly in June 25th, 2014. The prediction ability of model 4 was also good, and the difference of forecast value was mainly in June 26th, 2012 and June 25th, 2014.

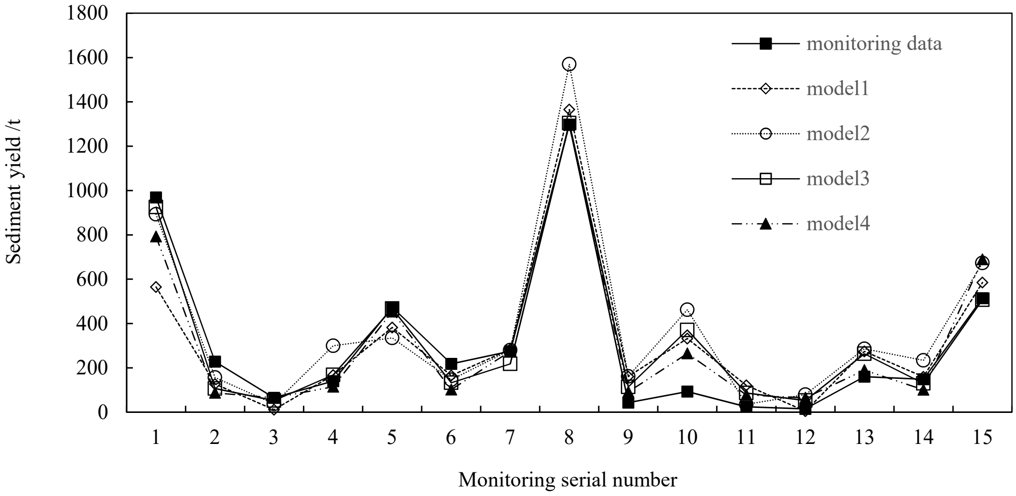


Fig.2. The predicted value and the monitoring data of different models

In summary, the prediction ability of the four models was different, of which model 3 and model 4 were suitable for the prediction of sediment yield in this small watershed. The maximum difference in predictive value difference of four models appeared in June 25th, 2014. It can be seen that this sediment yield had certain particularity. The mean rainfall intensity was small, which belonged to the process of continuous rainfall, and the monitoring data of sediment yield was smaller than that of the predicted value. Therefore, the model established in this study was mainly suitable for predicting the sediment yield of short diachronic storm.

## 4. Conclusions

Erosion and sediment transport in the watershed was a complex dynamic process, and its influencing factors include rainfall, runoff, topography, vegetation, human activity and other factors. The factors that affected the sediment transport in small watershed were analyzed synthetically, and the statistical models of sediment yield was established. In the Baizhang Creek watershed, because the underlying surface was relatively fixed, the topography and vegetation were regarded as homogeneous. Therefore, the factors that affected the sediment yield in small watershed were mainly rainfall, runoff and flood peak discharge. The complex factor analysis showed that the ternary complex factor was most closely related to the sediment yield. Accordingly, this paper recommends a comprehensive expression of the ternary combination model for the sediment yield in the small watershed.

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