

# Research of sediment yield statistical model for single rainstorm in Chabagou drainage basin

LIU Ji-gen<sup>1</sup> – LIU Jian-hua – SUN Hou-cai

<sup>1</sup>Changjiang River Scientific Research Institute, Changjiang Water Resources Commission, Wuhan 430010, China. E-mail: [jigenliu@163.com](mailto:jigenliu@163.com)

## 1. Abstract

Research on drainage basin erosion and sediment yield amount is not only an important task in physiognomy, but also an important one in river harnessing and water conservancy. This paper tries to conducted an integrated analysis of the effect of rainfall, runoff and physiognomic forms on drainage basin sediment yield, on the basis of considering sediment yield mechanism and to establish sediment yield formula for single rainstorm in Chabagou drainage basin which will have a certain sediment yield mechanism. Through integrated analysis of the effect of rainfall, runoff and physiognomic factors on sediment yield, we can find that as for the effect of rainfall amount and its temporal and spatial changes on drainage basin sediment, the correlation coefficient of rainfall amount and rainfall intensity product PI with drainage basin sediment yield modulus  $M_s$  is the highest. But when we consider rainfall runoff effect on drainage basin sediment yield, rainfall action has become negligible, the main factors affecting sediment yield are runoff depth H and flood peak discharge  $Q_w$ . The effect of runoff depth H on sediment yield is essential, but its effect on sediment yield of different scales of drainage basins is the same. Flood peak discharge  $Q_w$  is mainly accountable for the remarkable difference in sediment yield of drainage basins of different scales. With the increase of area, the effect of flood peak discharge  $Q_w$  on drainage basin sediment yield also weakens. Of the physiognomic factors, drainage basin area and ravine density play the leading role, and drainage basin channel gradient ratio is on the comparatively secondary position.

**Key words:** Drainage basin sediment yield; Rainfall factors; Runoff factors; Physiognomic factors; Statistical models

## 2. Introduction

Research on drainage basin erosion and sediment yield amount is not only an important task in physiognomy, but also an important one in river harnessing and water conservancy construct. Many researchers according to their study region and measures, established different empirical statistical models (Jiang Z S, 1980; Mou J Z, 1980; Mou J Z, 1983; Yin G K, 1989; Wang M L, 1990; Wang Z H, 1992; Cao W H, 1993). Although many empirical statistical models were established, their involving in factors were not same. Foreign statistical models such as USLE (Wischmeier W H, 1978) and RUSLE (Renard G R, 1991), in which sediment yield rules and mechanism in different scales were not better presented. This paper tries to conduct an integrated analysis of the effect of rainfall, runoff and physiognomic forms on drainage basin sediment yield, on the base of considering sediment yield mechanism, established sediment yield prediction formula for single rainstorm in Chabagou drainage basin which will have a certain sediment yield mechanism. At the same time, it also offers some references for other researchers in establishing drainage basin statistical models.

## 3. Description of research area

The study was conducted in Zizhou runoff station, located in first stair branch of Dalihe river Chabagou drainage basin in Zizhou county in Shaanxi province, founded in 1958 and retracted in 1969. Chabagou drainage basin area 205 Km<sup>2</sup>, successively setting up 9 hydrological stations, more than 40 precipitation rain fall stations and 3 runoff fields. Chabagou is a branch of Dalihe river, Caoping station upwards catchment area 187 Km<sup>2</sup>, channel length 24.1 Km, drainage basin average width 7.22 Km, and channel intensity 1.05 Km/Km<sup>2</sup>, drainage basin shape on the whole symmetry. Actual measuring datum from 1959 to 1969 showed, annual average rainfall 480 mm, rainfall seasons distribute asymmetry, 70% concentrated on 6~9 month, and many were intensity great, timing short rainstorm. Drainage basin average erosion modulus 22200 t/Km<sup>2</sup> · a, highest erosion modulus reached 71100 t/Km<sup>2</sup> · a, least also reached 2110 t/Km<sup>2</sup> · a. Drainage basin soil erosion characteristic is that vale growth, loess layer loose, granule fine and coherence bad. Hillslope and vale very easily sediment yield, and channel conflux and sediment transport expedite. Slope gradient steep, rainstorm intensity great, flood violent, deducing hillslope overflow and channel conflux sediment transport capacity all quite high. Climate dryness, vegetation sparsity, earth surface soil lacked protection. Slopeland farming were not reasonable, enhancing water and soil loss.

## 4. Analysis of results

### 4.1 Rainfall and its temporal and spatial diversification effect on drainage basin sediment yield

Rainfall and its intensity diversification have below 5 common indexes forms: (1) rainfall P; (2) rainfall intensity I; (3) rainfall time T; (4) rainfall and rainfall intensity product PI; (5) rainfall and rainfall time product PT. A

great deal actual measuring datum researches showed, on the inartificial rainfall condition, soil erosion with single rainfall relation were not consanguineous. Its relation with rainfall intensity has some improvement, but still not perfect, and that relation with reflecting rainfall concentrating extent short timing biggest rainfall intensity is the most consanguineous. Many researchers used rainfall erosion power index  $EI_{30}$  to denote rainfall effect on soil erosion. But because rainfall kinetic energy  $E$  and biggest 30 minutes rainfall intensity  $I_{30}$  were difficult to gain, we used rainfall and rainfall intensity product  $PI$  or rainfall and rainfall time product  $PT$  as substitute. According to Chabagou drainage basin 6 small drainage basins rainstorm actual measuring datum, correlation coefficient matrixes of above 5 dynamical indexes with sediment yield modulus were achieved. Taking Dujiagou correlation coefficient matrix as a example(Fig 1), it showed that rainfall and rainfall intensity product  $PI$  with sediment yield modulus  $M_s$  correlation coefficient was most. From dynamical condition speaking, if drainage basin rainfall was great, but time was long and intensity was low, then sediment yield modulus  $M_s$  was not always great. On the contrary, if rainfall was great, but time was short and intensity was high, then sediment yield modulus consequentially great.

**Table 1 Correlation coefficient matrix of rainfall dynamics and sediment yield modulus in Dujiagou drainage basin**

	$M_s$	P	I	T	PI	PT
$M_s$	1	0.286	0.299	-0.105	0.536	-0.028
P		1	0.090	0.633	0.663	0.782
I			1	-0.390	0.628	-0.219
T				1	-0.020	0.896
PI					1	0.162
PT						1

#### 4.2 Runoff and diversification effect on drainage basin sediment yield

Runoff, besides itself eroding on soil, it also is the carrier of sediment transport, its magnitude and diversification with sediment transport has direct relation. Researches on drainage basin sediment yield on rainfall, usually used runoff gross volume  $Q$  and flood peak discharge  $Q_w$  combination factor to calculate drainage basin sediment yield(Dragoun F J, 1962; Williams J R et al, 1977; Jiang Z S et al, 1980; Mou J Z et, 1980). Jiang Z S et al(1980) and Mou J Z et al(1980) analyzed  $Q$  and  $Q_w$  combination factor different combination with drainage basin sediment yield on Loess hill region. We through regressing analysis and comparing, finding runoff depth  $H$  with drainage basin sediment yield modulus  $M_s$  relation were more fine. So we selected runoff depth  $H$  and flood peak discharge  $Q_w$  as measurement indexes. According regressing analysis sediment yield modulus with runoff depth  $H$  and flood peak discharge  $Q_w$  on different scales in Chabagou drainage basin(Fig 2), it showed regressing relation of drainage basin sediment yield modulus  $M_s$  with runoff depth  $H$  was more fine than that of sediment yield modulus with flood peak discharge  $Q_w$ . It means that runoff depth effect on sediment yield is main. It is because that runoff depth not only represent rainfall gross volume and itself action, but also reflect rainfall and runoff concentrating degree to a certain extent. However, regressing coefficient of sediment yield modulus  $M_s$  with runoff depth  $H$  on different spatial scales change little, regressing coefficient of sediment yield modulus  $M_s$  with flood peak discharge  $Q_w$  soon descend with drainage basins area increasing, its coefficient with drainage basins area has below relation:

$$y = -48.007 \ln(A) + 241.43 \quad R^2=0.87(n=6) \quad (1)$$

Where  $y$  is the regressing coefficient of drainage basin sediment yield modulus  $M_s$  with flood peak discharge  $Q_w$ ;  $A$  is drainage basin area( $Km^2$ ). It shows runoff depth on different spatial scales effects on drainage basin sediment yield are same, but flood peak discharge effects on sediment yield on different spatial scales are different, the more small, the more remarkable its influence. Thus it can be seen, that runoff magnitude on different spatial scales effects on drainage basin sediment yield change little, runoff diversification rate is the important factor that influences drainage basin sediment yield remarkably diversity. In small drainage basins, due to its hillslope cracked, channel gradient rate great, powerful flood peak discharge would convey substance out of drainage basin outlet. that were not easy eroded and conveyed But in big or medium drainage basins, due to its channel gradient rate become small, main channel become length, even if flood peak discharge can destroy some substance that were not easy eroded and conveyed, it still is not easy to convey them out of the outlet. So with drainage basins area increasing, flood peak discharge effects on drainage basin sediment yield become little as well.

**Table 2 Regression of sediment yield modulus  $M_S$  with runoff depth  $H$  and flood peak discharge  $Q_W$  in different drainage basins**

Station	Area	$M_S$ - $H$ regression relation	$R^2$	$M_S$ - $Q_W$ regression relation	$R^2$
Shejiagou	4.72	$M_S=710.53H-299.51$	0.98	$M_S=203.39Q_W+464.98$	0.84
Tuoerxianggou	5.74	$M_S=748.88H-532.92$	0.97	$M_S=149.07Q_W+229.29$	0.87
Sanchuankou	21	$M_S=722.24H-110.69$	0.93	$M_S=61.218Q_W+421.76$	0.93
Xizhuang	49	$M_S=826.19H-447.87$	0.99	$M_S=29.42Q_W+230.57$	0.64
Dujiagou	96.1	$M_S=802.08H-499.57$	0.99	$M_S=27.59Q_W+145.09$	0.79
Caoping	187	$M_S=782.82H-248.42$	0.98	$M_S=16.207Q_W+245.82$	0.83

If we took rainfall and runoff composite function into account, then we would gain sediment yield modulus with product of rainfall and rainfall intensity  $PI$ , runoff depth  $H$ , flood peak discharge  $Q_W$  statistical models on different spatial scales in Chabagou drainage basins:

$$\text{Caoping: } M_S = 10^{1.79} (PI)^{-0.00664} H^{0.517} Q_W^{0.616} \quad R=0.981 \square n=47 \square$$

$$\text{Dujiagou: } M_S = 10^{2.222} (PI)^{0.02758} H^{0.621} Q_W^{0.39} \quad R=0.988 \square n=43 \square$$

$$\text{Xizhuang: } M_S = 10^{2.484} (PI)^{-0.108} H^{0.825} Q_W^{0.36} \quad R=0.976 \square n=41 \square$$

$$\text{Sanchuankou: } M_S = 10^{2.178} (PI)^{-0.0184} H^{0.554} Q_W^{0.626} \quad R=0.979 \square n=42 \square$$

$$\text{Tuoerxianggou: } M_S = 10^{1.961} (PI)^{0.07957} H^{0.736} Q_W^{0.632} \quad R=0.984 \square n=32 \square$$

$$\text{Shejiagou: } M_S = 10^{2.69} (PI)^{-0.0486} H^{0.822} Q_W^{0.318} \quad R=0.988 \square n=24 \square$$

Where  $M_S$  is drainage basin sediment yield modulus ( $t/Km^2$ );  $P$  is rainfall for single rainstorm (mm);  $I$  is rainfall intensity (mm/h);  $H$  is runoff depth (mm);  $Q_W$  is flood peak discharge ( $m^3/s$ ). Compound correlation coefficients all are above 0.97. However, when we took rainfall runoff effects on drainage basins sediment yield into account, the action of rainfall had become very little, it was runoff depth  $H$  and flood peak discharge  $Q_W$  that played an important role. For example, above 6 drainage basins statistical models about sediment yield modulus with product of rainfall and rainfall intensity  $PI$ , runoff depth  $H$ , flood peak discharge  $Q_W$ , relation of  $PI$  with drainage basins sediment yield modulus  $M_S$  becomes minus correlation in Caoping, Xizhuang, Sanchuankou and Shejiagou, it mainly is because that the action of runoff depth  $H$  and flood peak discharge  $Q_W$  gloss over the effect of rainfall. Our stepwise regression on 6 drainage basins rainfall runoff factors also show, runoff depth  $H$  and flood peak discharge  $Q_W$  are main factors influencing drainage basin sediment yield. Therefore, regression models of drainage basin sediment yield modulus  $M_S$  with runoff depth  $H$ , flood peak discharge  $Q_W$  on different spatial scales in Chabagou drainage basins were founded:

$$\text{Caoping: } M_S = 10^{1.901} H^{0.593} Q_W^{0.54} \quad R=0.980 \quad (n=47)$$

$$\text{Dujiagou: } M_S = 10^{2.303} H^{0.672} Q_W^{0.363} \quad R=0.987 \quad (n=43)$$

$$\text{Xizhuang: } M_S = 10^{2.297} H^{0.746} Q_W^{0.355} \quad R=0.972 \quad (n=41)$$

$$\text{Sanchuankou: } M_S = 10^{2.163} H^{0.564} Q_W^{0.595} \quad R=0.979 \quad (n=42)$$

$$\text{Tuoerxianggou: } M_S = 10^{2.13} H^{0.919} Q_W^{0.551} \quad R=0.981 \quad (n=32)$$

$$\text{Shejiagou: } M_S = 10^{2.177} H^{0.797} Q_W^{0.672} \quad R=0.936 \quad (n=24)$$

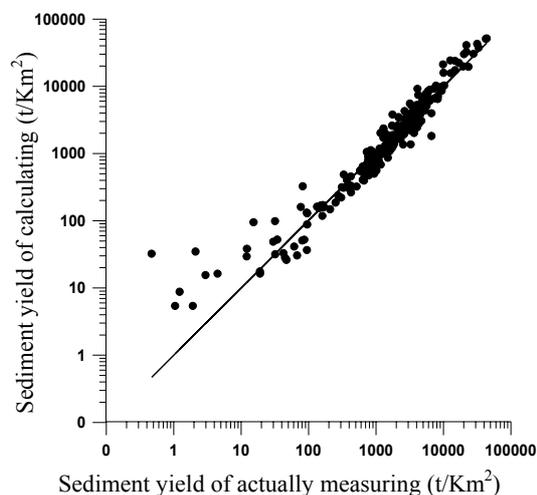
### 4.3 Drainage basin physiognomic characteristic effects on sediment yield

Drainage basin physiognomy is not only the index of now surface erosion incision status, but also one of important factors that influence drainage basin sediment yield. Looking from ground conditions, influencing drainage basin sediment yield factors have drainage basin areas  $A$  ( $Km^2$ ), drainage basin ground ravine density  $D$  ( $Km/Km^2$ ) and arterial channel gradient ratio  $J$  (%). We stepwise regressed those that influence drainage basin sediment yield rainfall, runoff and physiognomic factors, composite expression for single rainstorm in Chabagou drainage basin was achieved<sup>7</sup>

$$M_S = 10^{2.805} H^{0.659} Q_W^{0.523} A^{-0.413} D^{1.052} \quad (2)$$

It shows, in the case of geomorphic characteristic fixed, drainage basin sediment yield modulus increase with runoff depth and flood peak discharge increasing; in the case of rainfall runoff characteristic fixed, sediment yield decrease with drainage basin area increasing, but increase with ravine density increasing. At the same time,

it can be seen, to a certain extent drainage basin area reflecting channel gradient ratio variety, therefore drainage basin arterial channel gradient ratio, relative to drainage basin area and ravine density, is on the station of comparatively secondary in drainage basin sediment yield. In order to check up formula (2) precision, 233 measuring flood datum of 6 outlets in Chabagou drainage basins were calculated by formula (5). Sediment yield modulus of calculation and actually measuring were drawn in Fig 1. Average sediment yield modulus of actually measuring 233 floods is  $3924\text{t/Km}^2$ , calculating average sediment yield modulus by formula (2) is  $3839\text{t/Km}^2$ . Correlation coefficient of formula is 0.973, and standard error is  $473\text{t/Km}^2$ , that is 12.1% of actually measuring sediment yield modulus.



**Figure 1 Contrast between measuring values and calculating value of sediment yield in Chabagou drainage basin**

## 5. Conclusions

Runoff and sediment yield in drainage basin is a complicated dynamical process, but its influence factors basically include rainfall, runoff, physiognomy, geology, vegetation and so on. We can synthetically analyze influencing sediment yield all factors in drainage basin, on the base of considering sediment yield mechanism, establishing sediment yield statistical model in drainage basin. In Chabagou drainage basin owing to underlying horizon comparatively fixation, geology and vegetation in whole drainage basin were thought homogeneous, so influencing sediment yield factors in drainage basin main are rainfall, runoff and physiognomic factors.

Through synthetically analyzing influencing sediment yield rainfall, runoff and Physiognomic factors, it shows: rainfall amount and its temporal and spatial change effects on drainage basin sediment, mainly is that rainfall amount and rainfall intensity product  $PI$  with drainage basin sediment yield modulus  $M_s$ , correlation coefficient is uppermost. But when we consider rainfall runoff effects on drainage basin sediment yield, rainfall action has become very little, main factors influencing sediment yield are runoff depth  $H$  and flood peak discharge  $Q_w$ . Runoff depth  $H$  effect on sediment yield is central, but its effects on different scale drainage basin sediment yield is coequal, it is because of flood peak discharge  $Q_w$  that make different scale drainage basin sediment yield remarkable difference. With area increasing, peak discharge  $Q_w$  effect on drainage basin sediment yield also weaken. In physiognomic factors, main factors are drainage basin areas and ravine density, and drainage basin channel gradient ratio is on the station of comparatively secondary.

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