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RELATION BETWEEN PRECIPITATION AND SEDIMENT TRANSPORT IN THE DASHA RIVER WATERSHED

ZHANG Jian-chun[1], ZHANG Wei[1], LI Ji-hong[1], SHI Zhi-gang[2], PU Shen-yuan[2]
(*1. College of Territorial Resources and Tourism, Anhui Normal University, Wuhu 241000, P. R. China; 2. Water Conservancy Department of Anhui Province, Hefei 230022, P. R. China*)

ABSTRACT: The study on sediment production and its relationship with climatic and hydrological factors in watershed is a major environment issue of concern in the international community. Based on the observational records covering the period from 1954 to 1999, the characteristics of precipitation changing over the Dasha River Watershed in Anhui Province and its relation to sediment yield were studied using tendency analysis and correlation analysis. Results showed that the precipitation of the Dasha River Watershed has high variability. In those 46 years, 34% of spring rainfall, 58% of summer rainfall and 30% of annual rainfall will be considered anomaly. The gray correlation analysis shows that sediment discharge correlates most closely with the frequency of the rainstorm with a daily precipitation above 100mm, secondly with the frequency of the rainstorm with a daily precipitation of 50–100mm, and thirdly with the number of rainy days. Their correlation coefficients are 0.98, 0.90 and 0.85 respectively. In addition, the paper suggests the major countermeasures and methods for controlling of soil and water losses in this area.
KEY WORDS: rainfall; sediment discharge; Dasha River Watershed

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1 INTRODUCTION

Soil erosion and flood are probably serious environment problems worldwide and major threats to the sustainability of agriculture and economic development. The study on sediment production and its relationship with climatic and hydrological factors in watershed is a major environment issue of concern in the international community. Some Chinese scholars have studied the issues by taking different watersheds as examples (XU, 1994; LIANG *et al.*, 1991; AN, 1994; LI *et al.*, 2001). Some foreign scholars analyzed the interrelations between the precipitation and the sediment yield as well(LANGBEIN and SCHUMM, 1958; GUY *et al.*, 1987; LOAGUE and FREEZE, 1985; THATTAI *et al.*, 2003).

This paper, based on the research methods used by XU Jiong-xin, WANG Qun-ying and LIANG yin (XU, 1994; WANG and GONG, 1999; LIANG *et al.*, 1991), and the data of the monthly average precipitation in Shahefu Hydrologic Station from 1954 to 1999, attempts to analyze the variation of the precipitation resources in the Dasha River Watershed during the past 46 years and to predict the tendency of this variation. Meanwhile, in order to analyze the rainfall-runoff factors and the features of the sediment in the Dasha River Valley, results of the survey concerning silt-carrying runoff in this area from 1970 to 2000 have been employed and further analyzed to see if there is any correlation between the rainfall-runoff factors and the sediment. The results show that these two closely correlate with each other.

2 STUDY AREA

The Dasha River, a 127.6km-long tributary of Caizi Lake water system, originates in Yuexi County, Anhui Province, and flows into Caizi Lake via Shahefu Hydrologic Station, which was established in 1950 and lies in latitude 29°41′N, longitude 116°50′E. The Dasha River controls a watershed area of 460km^2, with a total population of 79 400 in the year of 2000 and

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Biography: ZHANG Jian-chun (1964–), male, a native of Nanjing, Jiangsu Province, professor, specialized in physical geography. E-mail: zhangjianchun@263.net

cultivated land of 0.38ha per capita. Gross output value of agriculture and industry per capita was 918 and 1088 yuan respectively in 2000. In the watershed mountainous region's economy is rather backward, partly because of the soil and water loss in Dabie Mountain, which results in ecological environment degradation and harms the local people living condition and production. Therefore, it is quite meaningful to conduct a study on the natural variation of the precipitation in the Dasha River Watershed and its relation with the sediment transport. Its findings will encourage rational exploitation of water resources, help to prevent and control water loss and soil erosion, and to promote the formulation of the plan for social and economic development.

The elevation of most part of the upper reaches of the Dasha River Watershed is 200–1500m above the sea level. Around 30% of the area is above 500m. The morphology in this watershed is rather contrasting with deeply incised valleys and undulating mountains. Moreover, the parent material of this area is made of metamorphic rocks and granite, etc. This area is full of yellow-red earth down to 400m and yellow-brown earth down to 1000m, the vertical zonal distribution of soil and vegetation is very obvious.

The Huangbo Mountains in the Dasha River Watershed is one of the rainstorm centers in Anhui Province. The maximum daily precipitation in history was 482.8mm (July 16, 1969), while the maximum annual rainfall amounted to 2708.5m (1969), and the minimum one was 781.3mm (1978). The climate of this region is featured as a transition from the typical climate of Northern China to that of Southern China. On average, the temperature reaches 15.4℃ annually, 1–2.1℃ in January and 27℃ in July. While the highest annual temperature amounted to 41℃, the lowest one was only −22℃. The annual precipitation ranges from 600mm to 1500mm, about 60% of which can be accounted by the rainfall in flood period, i.e., from May to September. The area's climate is especially prominent for its much rainstorm and variability of precipitation.

3 VARIATION OF PRECIPITATION

According to the data of precipitation in 1954–1999, the average annual precipitation of this region amounted to 1374.9mm, among which 414.3mm was in Spring, 630.2mm in Summer, 197.4mm in Autumn, and 133.0mm in Winter. Obviously, in this area, precipitation mainly concentrate in summer, from June to August, then in spring, from March to May. The precipitation in these two seasons accounts for 76% of the total annual precipitation. After analyzing the data of the monthly average rainfall obtained from Shahefu Hydrologic Station, from 1954 to 1999, the anomaly percentage curve of the annual rainfall and those of Spring and Summer have been worked out (Fig. 1). If the anomaly percentage 25% is taken as a criterion of judging whether the rainfall is abundant or not in the 46 years (WANG and GONG, 1999), there were 11 summers which can be considered as being rich in rainfall, while 16 others experienced a shortage of rainfall. The results correspond to the severe floods or droughts occurring in that area. The summers when the high positive anomaly percentages of rainfall have been achieved were respectively in 1954 (the anomaly percentage reaches 133.3%), 1969 (98.6%), 1991 (75.2%), 1977 (65.5%), 1963 (59.2%), 1955 (55.0%), 1981 (49.2%), 1983 (38.9%), 1974 (33.6%), 1996 (29.6%) and 1980 (28.9%). On the contrary, the summers when anomaly percentages of rainfall declined to the low negative points were respectively in 1967 (−63.0%), 1978 (−61.2%), 1976 (−59.4%), 1985 (−53.1%), 1990 (−46.6%), 1968 (−43.1%), 1965 (−42.8%), 1989 (−37.4%), 1992 (−37.0%) and 1960 (−35.9%).

In terms of the anomaly percentage of rainfall in spring, there were 8 years in which the percentage is above 25%, and another 8 years with a percentage below 25%. Thus, it can be said that in spring the frequencies of wet springs and dry springs are approximately the same, with the highest anomaly percentage of rainfall of 72.5% in 1963, while the lowest of −48.3% in 1997.

In terms of the total annual precipitation, there were 6 years with anomaly percentages of rainfall higher than 25%, i. e., 1954 (88.7%), 1991 (53.0%), 1983 (48.4%), 1977 (46.8%), 1963 (37.5%) and 1969 (32.1%), and 8 years with anomaly percentages of rainfall lower than −25%, i. e., 1978 (−44.2%), 1967 (−38.7%), 1976 (−36.1%), 1994 (−32.9%), 1966 (−28.4%), 1968 (−26.0%), 1997 (−25.3%) and 1965 (−25.1%).

From the statistics of annual precipitation, it can be found that the 6 years with high precipitation, together with 8 years with low precipitation appeared in the 1960s, 1970s, 1980s and 1990s respectively. In this sense, the annual precipitation of the Dasha River Watershed shows lower variability. But it can be found that 3 of the 8 lowest rainfalls of spring, together with 6 out of the 16 lowest rainfalls of summer appeared in the 1990s. In this sense, the spring and summer rainfalls of the Dasha River Watershed, with an even higher variability, have tended to decline since 1990. In the same way, the annual rainfalls also show decline tendency while varying by stages.

Moreover, accumulated anomaly percentage curve (Fig. 2) has also been worked out so that the long-term annual, spring and summer precipitation variations can be judged. As Fig. 2 indicates, in the past 46 years, it is obvious that the precipitation has undergone variation by stages. Spring rainfall has achieved high variability, with a declining tendency from the end of 1970s to the end of 1980s. Then from 1990 onwards, it has been showing a rising tendency. As regards the summers precipitation, an increasing amount of rainfall has been obtained from the end of the 1980s to the beginning of the 1990s. After that, however, the rainfall has been declining. In general, the annual precipitation has varied in accordance with that of summer, that is, in the middle and late part of the 1990s, both the annual and summer precipitation have been inclined to decrease. But with a view to the whole picture of the rainfall in the past 46 years, a tendency of decline has been shown in spring rainfall, in summer rainfall and annual precipitation.

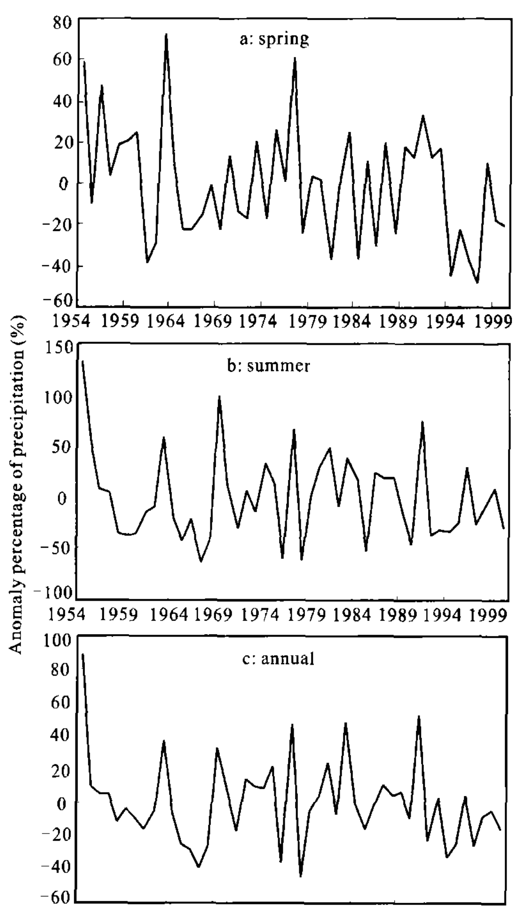

Fig. 1 Anomaly percentage of precipitation in the Dasha River Watershed

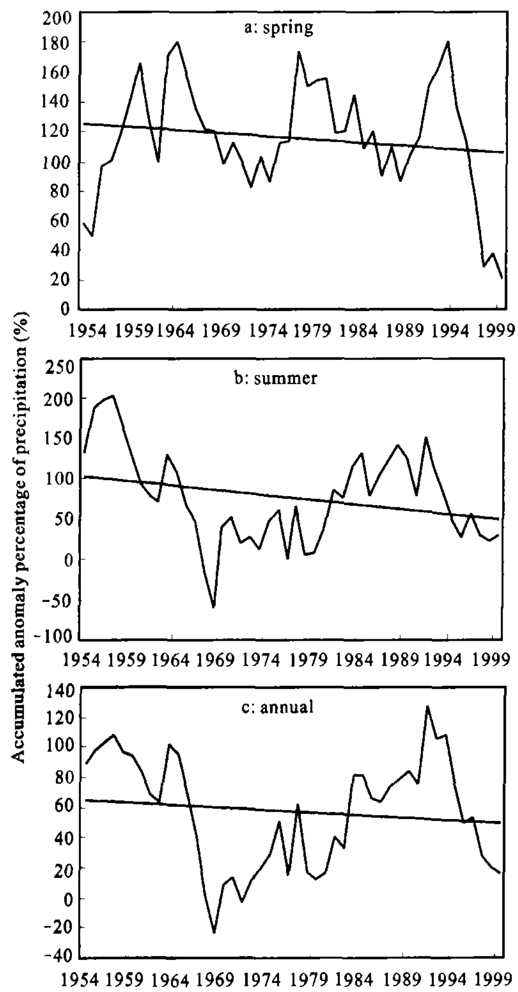

Fig. 2 Accumulated anomaly percentage and trend curve in the Dasha River Watershed

4 RELATIONSHIPS AMONG PRECIPITATION, FLOOD AND SEDIMENT

4.1 Relationship Between Precipitation and Flood

According to the statistics of the average precipitation from 1954 to 1999 in the Dasha River Watershed, 74.8% of the annual precipitation comes in spring and summer, while the precipitation in flood period (from May to September) amounts to 65.2% of the annual precipitation. Moreover, during flood period it is much likely to have rainstorms. From the late March till the beginning of November, rainstorms may occur. On an average scale, the beginning date of rainstorms is the middle part of June, and the ending date is the middle part of August. The days with rainstorms vary from year to year, and more than 10 days with rainstorm per year appeared in 1999, 1991, 1975, 1977 and 1983, while none of days in 1978.

According to the data of the precipitation from 1970 to 2000 (Table 1), provided by Shahefu Hydrologic Station, there were 102 days whose rainfall reached 50 –100mm, and 21 days with daily precipitation above 100mm since 1970. The largest daily rainfalls in the 1970s, 1980s and 1990s, were on July 28, 1977 (201.3mm), July 4, 1983(210mm) and August 6, 1991 (122.2mm) respectively (Table 2). What is more, the rainstorm flow is closely related to the flood discharge in the Dasha River Watershed. For instance, immediately after a strong downpour on July 4, 1983, the largest flood discharge of 2370m^3/s in history so far followed on July 9, which is 5 times as large as the average flow in the 1980s. Another example lies in the fact that, the largest daily flood discharge following the rainstorm on July 28, 1977, was almost twice as large as the average flow of 1977. In the undulating relief of the Dasha River Watershed, a long-time strong rainstorm is bound to scour the bare rock on steep slope and even wash away the thin soil, thus aggravating the soil erosion and further sterilizing the soil on Dabie Mountain. Rainfall and rainfall erosivity are important factors in water and soil losses (LIANG *et al.*, 1991; ZHANG *et al.*, 2002).

4.2 Relations of Sediment with Precipitation and Flood

After analyzing the data from 1970 to 2000 (Table 3, Fig. 1), it could be found that the largest sediment discharge of a year and that of the flood season tend to be influenced by rainstorms and floods. As shown in Table 3, in the 1970s, the annual amount of sediment transport amounted to 243 400t, being 1.42 times as large as the average from 1970 to 2000. Moreover, 83.77% of the sediment discharge of the 1970s, that is, 207 500t, can be ascribed to the sediment transport in flood period. According to the statistics of 1970–2000, on average, the sediment discharge of flood period accounted for 86.04% of that of whole year, while water discharge of flood period took 69.94% of the annual one, and rainfall in flood period, 64.43%. Conclusions can be drawn that sediment discharge is correlated with rainfalls and floods in flood period.

Besides, the average annual amount of rainfall and runoff in the 1980s was larger than that in the 1970s, but the average annual amount of sediment transport is lower than that of in the 1970s. This is because 9 small watersheds, with an area of 180.74km^2, have taken

Table 1 Monthly average sediment discharge and rainfall-runoff factors (1970–2000)

	Sediment discharge (t)	Rainfall (mm)	Runoff ($\times 10^8 m^3$)	Rainstorm days (50–100mm) (d)	Rainstorm days (≥100mm) (d)	Rainy days (d)
January	0.00	34.34	0.06	0	0	8.7
February	0.12	71.30	0.14	0	0	10.8
March	0.84	110.30	0.28	3	0	13.8
April	1.15	129.60	0.33	7	0	13.6
May	4.63	188.50	0.55	21	2	13.6
June	4.53	264.40	0.74	21	12	15.0
July	4.71	203.50	0.77	18	4	14.9
August	2.97	174.50	0.56	17	3	12.2
September	1.10	102.30	0.36	9	0	11.2
October	0.33	77.30	0.21	6	0	9.8
November	0.05	46.30	0.12	0	0	7.3
December	0.00	29.20	0.07	0	0	12.0
Total	20.43	1431.24	4.19	102	21	142.9

Table 2 Largest daily rainfall, flood discharge and silt content in Shahefu Hydrologic Station (1970–2000)

	Largest daily rainfall		Largest daily flood discharge		Largest daily silt content	
	Rainfall (mm)	Date	Discharge (m^3/s)	Date	Content (kg/m^3)	Date
1970s	201.3	1977-07-28	1340.0	1977-08-04	7.74	1979-06-24
1980s	210.0	1983-07-04	2370.0	1983-07-09	8.02	1983-07-13
1990s	122.2	1991-08-06	1550.0	1992-06-14	4.72	1999-09-05

soil-water conservation measures since 1982, the controllable area takes up 82.93% of the total area in the Dasha River Watershed. Compared with the 1970s, the average annual sediment reduction was 43 000t in the 1980s, that is to say, significant profits of reducing sediment yield have been obtained by taking the conser-

Table 3 Distribution of annual rainfall, runoff and sediment discharge in Shahefu Hydrologic Station

	Rainfall			Runoff			Sediment discharge		
	Flood season (mm)	Annual (mm)	Proportion (%)	Flood season ($\times10^6m^3$)	Annual ($\times10^6m^3$)	Proportion (%)	Flood season ($\times10^3t$)	Annual ($\times10^3t$)	Proportion (%)
1970s	919.07	1380.1	65.53	273	380	69.35	207.5	243.4	83.77
1980s	978.77	1473.2	66.47	327	448	73.43	185.2	200.4	92.96
1990s	795.95	1281.2	61.27	236	340	67.03	58.6	69.3	81.39
Average	897.93	1378.2	64.43	279	390	69.94	150.4	171.1	86.04

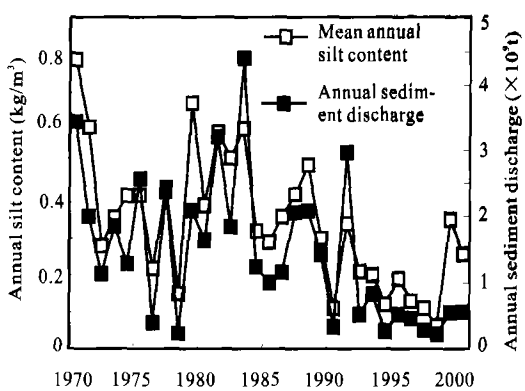

Fig. 3 Variation of annual sediment discharge and silt content in Shahefu Hydrologic Station

vation measures.

4.3 Gray Correlation Analysis of Sediment Discharge and Rainfall-runoff Factors

According to the data provided by Shahefu Hydrologic Station, a table concerning the monthly distribution of the sediment discharge, the precipitation and the runoff of the Dasha River Watershed in 1970–2000 has been worked out (Table 1). Based on these figures obtained from observation, gray correlation analysis, which was proposed by TANG Qi-yi (2002), was conducted to the sediment discharge and various rainfall-runoff factors in the Dasha River Watershed (Table 4). The results calculated in Table 4 indicates that, the sediment discharge correlates most closely with frequency of the rainstorm with a daily rainfall above 100mm, the correlation coefficient is 0.98; in the second place, with a daily precipitation of 50–100mm, the correlation coefficient is 0.90; and thirdly with the number of rainy days, the correlation coefficient is 0.85.

The above findings well correspond to the reality of the Dasha River Watershed. Owing to this area's undulating landforms and poor covering substance, rainfall cannot be totally absorbed and stored by the soil, and most of the rainfall probably become surface

Table 4 Correlation grade between sediment discharge and rainfall-runoff factors

	Rainfall	Runoff	Rainstorm days (50–100mm)	Rainstorm days (≥100mm)	Rainy days
Sediment discharge	0.60	0.71	0.90	0.98	0.85

runoff, resulting in the loss of water and soil erosion. In this sense, it can be said that the sediment discharge correlates most closely with the rainstorm days with daily rainfalls above 100mm and 50–100mm. The number of rainy days in Dabei Mountain appears more than that of other areas, so in the long run, the rainy days will contribute more to soil erosion than others areas. Admittedly, not all the rainfalls lead to surface runoff and soil erosion. Thus, the weakest correlation has been found between the sediment discharge and the monthly average rainfall.

5 CONCLUSIONS

(1) According to the monthly average precipitation from 1954 to 1999, the precipitation of the Dasha River Watershed has high variability. If 25% is set as the criterion of judging whether the rainfall is anomaly or not, in those 46 years, 34% of spring rainfall, 58% of summer rainfall and 30% of annual rainfall will be considered anomaly. Those summer seasons having anomaly precipitation suffer mostly from drought rather than flood.

(2) Periodicity features the variation of precipitation. With respect to the long-term varying process in the past 46 years, a tendency of decline has been shown in spring, summer and annual precipitation.

(3) As shown in the gray correlation analysis of the sediment discharge and the rainfall-runoff factors in the Dasha River Watershed from 1970 to 2000, the rainstorms with daily precipitation above 100mm and of 50–100mm have been identified as the main factors affecting the sediment discharge.

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