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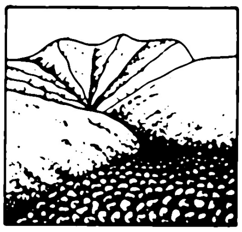

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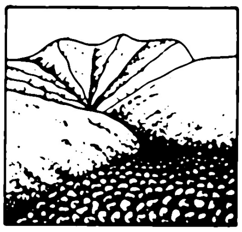

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Analysis of relations between the rainfall trends and eroded sediment transport of debris flows in the 1990s: case study of the Xiaojiang River basin in the upper reach of the Yangtze River

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Анализ связи между тенденцией количества осадков и переносом материала селевыми потоками в 90-е годы 20 века (на примере бассейна р. Сяожианг в верховьях р. Янцзы)

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Статистический метод Манна-Кендалла (M-K) использован для анализа данных по дождевым осадкам в бассейне р. Сяожианг в верхнем течении р. Янцзы за период с 1950-х до 1990-х. Результаты теста M-K с 95% уверенностью показывают тенденцию роста ежегодных осадков в бассейне в 1990-е гг. Проверочный тест M-K также показал значимый тренд роста. Тенденция роста аккумуляции селевого материала в селевом бассейне Жиангжиа, находящемся в пределах водосбора р. Сяожианг, имеет тесную связь с ростом годового количества осадков в 1990-е года. Среднегодовой объем аккумуляции селевого материала в 1990-е был примерно на 0.91 млн. м^3 больше, чем между 1965 и 1989 гг.

The Mann-Kendall (M-K) statistical method was used to analyse the rainfall data of Xiaojiang River basin in the upper reaches of the Yangtze River from the 1950s to the 1990s. The results of the M-K test with 95% confidence interval shows that the annual rainfall amount has a notably increasing trend in the 1990s in the Xiaojiang River basin. The M-K proof-test also presents a notably increasing trend (confidence interval 95%). The result shows that there was a significant increase of annual sediment transport in the 1990s. The average annual sediment yield by debris flows in the 1990s is about 0.91 million more than that between 1965 and 1989.

Dongchuan is an especial district in Kunming city Yunnan Province, which is well-known for the typical region of debris flow disasters in world, located at from 102°47’50”E to 103°08’35”E and from 25°47’05”N to 26°32’52”N in the upper reach of Yangtze River. It provides the groundwork for debris flow to form and develop in the unique frangibility of mountain environment in Dongchuan district of Xiaojian drainage basin, Yunnan Province, which has a characteristic of no-instability and sensitivity. Based on the analysis revealed from remnant deposits of old-debris flow, debris flows had occurred in some gullies of twain banks in Xiaojian drainage basin early in the Middle Pleistocene Epoch of the Quaternary Period, which have reflected the responsive process of formation evolvement of debris flow to the frangibility in mountain environment. It is the most important factor to form the debris flow. A characteristic of rainfall annual change and trends have important infection to hazards frequency of debris flows and society economy and life. Flood disaster had presented high development in Yangtze River basin since 1990s afterwards 1950s of 20 century. And debris flow hazards at Jiangjia Ravine also had presented high development, located at the Xiaojiang River basin in the upper reach of Yangtze River. It is not only relative to the irrational land-use patterns in mountain that have aggravated the level of the debris flow, it is important relative to rainfall change in this region. Some scholars (Su et al.,2003) have considered that flood frequency in1990s is the maximal age among event form had track record in close 1000 age in Yangtze River basin, where occurrence 6 time flood events have occurred since 1990. They have considered that the it is relative to rainfall increase trend in summer for flood events to frequency occur in the middle and dower reach of Yangtze River (Ren et al., 2000). The rainfall trends in 1990s in the Xiaojiang River basin in the upper reach of Yangtze River were analyzed in this article, through Mann-Kendall statistical method using collecting rainfall data in 1956-1999 year in this region. There is tightly relationship between the rainfall trends and a lot of increase of eroded sediment of debris flow since 1990s at Jiangjia Ravine in Yangtze River. It has important significance to realize the background of climate change in this region, to analyze frequency cycle of debris flow hazards, to prevent the degradation of mountain environment, to construct the tactics of eco-security, and to carry out the fine circle in eco-environment, to promote social-economical sustainable development in this region.

1 Data and analyzed method

Basic data are selected in this article, which is through rainfall information from 1956 to 1999 provided by Dongchuan district in the Xiaojiang River, Yunnan Province, which there is information from 1956 to 1979, there is information from 1984 to 1999 formed almanac in this region. The change trends of rainfall information in annual and month have only been analyzed emphases, because origin information difficulty. The lack data from 1980 to 1983 have been carried through interpolation used by the lack data rainfall wave in the front and behind. There is bigger fluctuate of rainfall between apiece years (Fig. 1), because of accepted atmosphere circumfluence and landform infection restrict climatically, where the landform in Dongchuan belongs to northeast plateau in Yunnan, therefore also month data of lack year was difficultly been interpolated through perennial way. So that analyses in this article are lack the month data from 1980 to 1983. M-K method (Libiseller, 2002) is one of general checkout method used time list trend of climate factor, which is famous as well as wide applicability, few of human action, high quantity degree. The formulary:

$$s = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j) \qquad (1)$$

Where sign () is symbol function, when xi-xj < or = or >0, sign (xi-xj) is -1, 0 or 1 separately; If when s is < or = or > in the M-K formulary, z flowing (Libiseller, 2002):

$$z = \begin{pmatrix} (s-1)/\sqrt{n(n-1)(2n+5)/18} & s > 0 \\ 0 & s = 0 \\ (s+1)/\sqrt{n(n-1)(2n+5)/18} & s < 0 \end{pmatrix} \qquad (2)$$

The z value is for the positive cost, which shows increase trend. The z value is for the negative cost, which shows decrease trend. When the z value is for ≥ $|1.28|, |1.64|, |2.32|$, which have passed believe notability checkout (90%, 95%, 99%).

2 Rainfall characteristics and change trend in Dongchuan District of Xiaojiang River in 1990s

There has been a significant increase in average rainfall in Dongchuan District of Xiaojiang River since 1990s. The mean rainfall was 825.23 mm in 1990s, Comparison with rainfall in the period of 1965 to 1989, The change characteristics of annual rainfall as follows:

1) Table 1 shows the average decade rainfall in the period of 1956 to1999, and the comparison of that in 1990s to that of other decades ago. The mean annual rainfall in Dongchuan District from 1950s to 1980s was 691.56 mm. The increase rate in 1990s is 15.13% than one in 1950s, 16.19% than in 1960s, 15.55% than in 1970s, and 14.38% than in 1980s.

2) Table 1 also shows that the maximum value of average decade rainfall was 825.23 mm in 1990s and the minimum was 687.49mm in 1960s. The average rainfall tended to descend from 1950s to 1960s and the descend rate was 12.81 mm/10 yr. The average rainfall tended to upwards from 1960s to 1980s. The increase rate was 2.43 mm/10 yr from 1960s to 1970s, and 12.95 mm/10yr from 1970s to 1980s. Especially from 1980 to 1990s, the upward trend was rapidly and the increase rate was 12.95 mm/10yr. This conclusion is the same as the analysis (Ren et al., 2000). In this reference, the author thought that there has an obvious increase in average annual rainfall since country in 1960s. It may be caused by the rainfall increase trend in the areas of Yangtse River.

Table 1. The comparison of mean rainfall in 1990s to that in 1956-1999 in Xiaojiang River.

Age	1956-1959	1960-1969	1970-1979	1984-1989	1990-1999
A	700.38	687.49	689.92	702.87	825.23
B	56.98	134.32	85.9	132.36	166.78
C	15.13%	16.69%	15.55%	14.83%	
D	0	30%	10%	20%	60%

A: Mean rainfall, mm) ; B: σ_{n-1}variance coefficient; C: 1990s to other age D: >800 mm frequency.

3) Fig. 1 shows that there is an increase trend in the rainfall peak value from 1950s to 1990s.The the maximum is 974mm of 1995. The number of years in that the annual rainfall was more than 800mm accounted for 60% of the 1990s, 30% of the 1960s, 20% of the 1980s and 10% of the 1970s (Table 1).

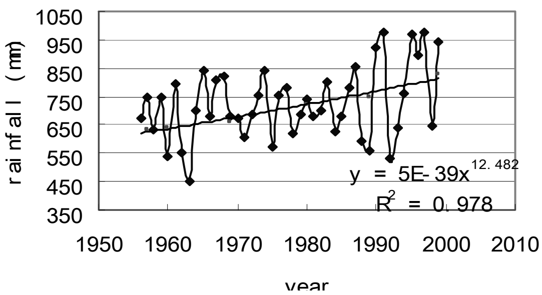

Fig. 1. The change curve of rainfall from 1956 to 1999 in Xiaojiang River.

4) The annual rainfall tends to noticeable increase based on the M-K test (on 95% confidence level). Though the rainfall fluctuation is obvious, the fitting curve (Fig. 1) indicates there is clear increase trend in the annual rainfall in Dongchuan District of Xiaojiang River. The drawing up ratio of curve is 0.9889 (95% confidence area is between 0.8989 and 0.9988), and t value test is 11.5494>t0.01=9.9257.

3 The change characters of eroded sediment transport of debris flows in 1990 s

There are close responded relationship between debris flow occurrence and rainfall, because there are topography and the quality of close solid matter without change in a certainty time. It is the most importance factor to form the debris flow. This could be discussed in detail as the following four aspects.

The rainfall is concentrated in the rain season, especially from June to August. The rainfall of these three months covers 50% amount of the total annual rainfall. At the same time, the period is the high probability that debris flows erupt frequently; There is accordance in abundant rainfall area with the formation zone of debris flow; The mass rain provides sufficient antecedent rainfall for debris flows. it is a kind of little control area by short duration and high intensity point rainstorm; It is the main factor to form catastrophic debris flow. A rain occurs often in the night and it causes the debris flow erupted in the night. It is difficult to guard against the debris flows in the night. It will be easy to cause big tragedy. Above notable increase trend of rainfall since 1990s as well as has strengthened the trigging factor of debris flow occurrence in the region and has accelerated frequency increase and enlarged scale, which have close relationship of the increase of debris flow sediment transport.

The Jiajiang Ravine located in the right bank of the Xiaojiang River Basin, which is located in the branch of Jinsha River of the upper reach of Yangtze River. The drainage area is 48.6km^2, which is type rainfall debris flow ravine. It is a famous debris flow ravine in world for greatness scope (the most discharge for 2820 m^3/s), high frequency (about 10–20 time, the most 28 time/yr), and severity hazards. The observational data of debris flow in the Jiajiang Ravine show that the average eroded sediment transport is about 2.15 million m^3/yr, the average eroded sediment transport in great rainfall year (the peak value) is the 3.6 million m^3 in the period of 1965 to 1989, but the average eroded sediment transport in great rainfall year (the peak value) is the 6.34 million m^3 in 1990s. The average eroded sediment transport in 1990s is 0.91 million than that in the period of 1965 to 1989, which is close relative to rainfall increase in 1990s (Fig. 2).

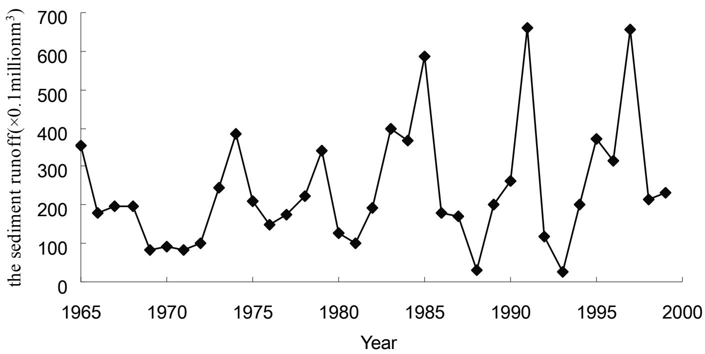

Fig. 2. The comparison of the annual sediment transport (m^3) of debris flows in 1990s to that from 1965 to 1989 in Jiangjia Ravine.

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