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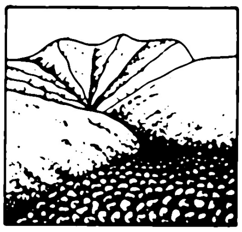

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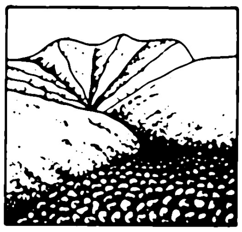

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Impacts of rainfall on eroded sediment transport of debris flows: case study of the Xiaojiang River basin in the upper reach of the Yangtze River

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Воздействие ливней на перенос материала селевыми потоками (на примере бассейна р. Сяожианг в верховьях р. Янцзы)

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С 1990 г. селевая опасность р. Жиангжиа, находящегося в бассейне р. Сяожианг, увеличилась. Дискуссионным вопросом является связь между изменениями осадков и объемами селевых выносов. Результаты показывают, что сезонные и месячные осадки имеют тенденцию к заметному увеличению. Рост количества селевых выносов р. Жиангжиа был тесно связан с ростом осадков в 1990-е гг. Это доказывает, что осадки значительно влияют на изменения селевой эрозии.

Since 1990, debris flow hazards in the Jiangjia Ravine located in the Xiaojiang River basin have developed. The relationship between the rainfall change and sediment is the main question discussed. Results show that seasonal and monthly precipitation has notably increased. The tendency towards an increase in sediment delivered by debris flows at Jiangjia ravine has a close relationship with the increase in rainfall in the 1990s. This suggests that precipitation significantly influenced the changes of sediment transport.

Dongchuan is an especial district in Kunming city Yunnan Province, which is well-known for the typical region of debris flow disasters in world. It provides the groundwork for debris flow to form and develop. The rainfall is the most important factor to form the debris flow. The characteristic of rainfall annual change and trends have important impact on hazards frequency of debris flows and society economy and life. Since 1990s, debris flow hazards at Jiangjia Ravine had presented high development, and the annual rainfall had presented the increase trend too. The tight relation between annual rainfall change trend and sediment transport of debris flow has stated in other paper: the relative analysis on the rainfall trends to eroded sediment transport of debris flow in 1990s. So in this article, the seasonal and monthly rainfall change trend in Dongchuan is analyzed detailed to explain the relationship between the seasonal rainfall and sediment transport based on the rainfall data from 1956 to 1999. It is important to realize the background of climate change in this region, to analyze frequency cycle of debris flow hazards.

1 Data and analyzed method

The rainfall data in Dongchuan District from 1956 to 1979 come from the reference (Du et al., 1987), and the data from 1984 to 1999 are provided by almanac in this region. M-K method is used to analyze the precipitation trend in Xiaojiang River Basin. M-K method 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.

2 The analysis of monthly rainfall

It is important to analyze the monthly rainfall in Xiaojiang River where debris flows are very active. The rainfall concentrates on June, July and August, and there is the high probability for debris flows to occur frequently in the same period. The average rainfall of July from 1950s to 1980s is 138.41 mm. The average rainfall is 154.84 mm in 1990s, which that increases 16.43 mm more than the former.

2.1 The change characteristics of monthly rainfall in 1990s

Fig.1 shows the month average rainfall contrasts of that in 1950s–1980s and that in 1990s. Both two curves belong to single apex form and the expanded figure is similar. The common is that the rainfall begins to ascend quickly from the middle of April and comes into rainy season. The shape of these two curves from April to June is similar and these two curves almost overlap. The rainfall slightly has descended comparing to the quick increase in rainfall from May to June since July. Though the shape of two descended curves from July to December is resemble, they separate each other between July and September. It indicates that the month average rainfall in 1990s is more than that in1950s–1980s. It plays an important role in the eruption frequency of debris flows and the increase of sediment transport (Fig. 4).

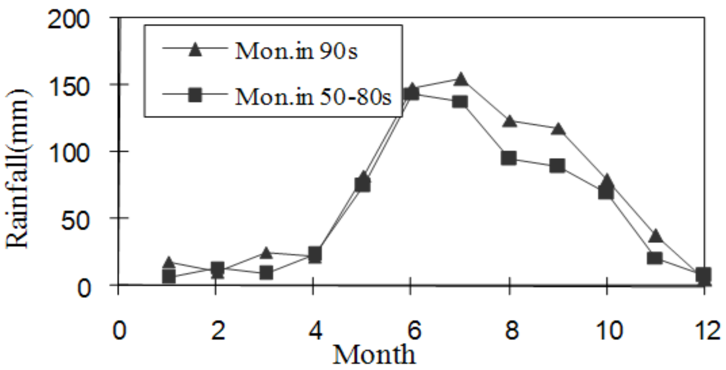

Fig. 1. The comparison of month average rainfall in 1990s to 1950-1980s.

Table1 describes the month average rainfall contrast between 1950s–1980s and 1990s. The average rainfall of most months in 1990s tends to increase. The rainfall increase of Aught and September in 1990s is the largest. The average increase is 28.9mm in Aught and 28.7 mm in September, the increase range reaches 23% and 24%. The increase of January, March, July and November is about 11–16 mm. The rainfall of February, April and December in 1990s decrease comparing to that in 1950s–1980s. The difference of other months is very little.

Table 1. The comparison of mean monthly rainfall between in 1990s and in 1956-1989 in Xiaojiang River (mm).

Month	1	2	3	4	5	6	7	8	9	10	11	12
A	18.5	10.5	25.3	21.8	82.5	148.3	154.8	124.1	118.1	78.8	37.3	5.2
B	6.6	14	8.8	23.7	74.6	143.8	138.4	95.2	89.4	68.7	21	7.9
C	11.9	-3.5	16.5	-1.9	7.8	5	16.4	28.9	28.7	10.1	16.3	-2.7

*A: Mean month in 1990s; B: Mean month in 1950s-1980 s; C: Comparison of that in 1990s to another

Table1 also indicates the comparison of the peak value of month average rainfall in 1950s–1980s to that in 1990s. The peak value of 1990s occurred in July, which is 154.84 mm. The peak value of the period in 1950s–1980s occurred in June, which is 143.84 mm. The peak value the former delayed almost one month comparing to the latter. The antecedent rainfall of May and June makes the soil reach critical saturation, and little of rainfall in July may cause the debris flow. For example, the process rainfall on July 4th 1997 was only 12.5 mm, which caused debris flow. The duration of debris flow has been 1 h 57 min and the sediment transport was 0.43 million m^3.

2.2 The change trend of monthly rainfall in 1990s

The trends of month rainfall data from 1956 to 1999 have been analyzed using M-K method. The result indicates that majority of monthly rainfall tend to increase and only the rainfall in December tends to decrease. The increase trend of January, August and November pass the notability test of 95%. Then the increase trend of February, March, April, May, June and September are not evident. Only the decrease trend of December passes the notability test of 90%. There are not obvious changes in July and October.

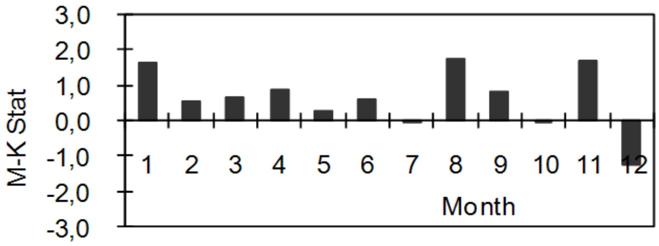

Fig. 2. MK monthly mean rainfall trend in 1956-1990s

3 The analysis of season rainfall in 1990s

The rainfall change between seasons is very big, affected by violent plateau south-west monsoon and landform of Dongchuan District. The average rainfall of spring (March, April and May), summer (June, July and August), autumn (September, October and November) and winter (December, January and February) occupies respectively 15.21%, 54.16%, 26.66% and 3.99% of annual rainfall.

1) Fig.3 describes the comparison of the every season average rainfall in 1990s to that in 1950s, 1960s, 1970s and 1980s respectively. The majority season average rainfall (93.75%) in 1990s tend to increase comparing with that in other four decades. The spring rainfall in 1990s increases to different degree comparing with all other decades. The increase highest of that reaches 36.57% comparing that in 1990s to that in 1960s. In summer, the rainfall in 1990s increases a little comparing with all other decades. The increase extent in 1990s reaches 6.03% comparing with 1960s, which is the least. The autumn rainfall in 1990s increases with more degree comparing with all other decades. In winter, the rainfall in 1990s tends to decrease comparing with 1950s, and the decrease degree is 30.62%. The winter precipitation in 1990s increases too much comparing with other three decades. And the increase trend (55.45%) is evident in 1990s comparing with 1980s.

2) The comparison of season average rainfall in 1990s to that in 1950s-1980s: The spring average rainfall in 1990s increase 22.52 mm than that in 1950s–1980s which the increase extend is 17.38%. The summer average rainfall in 1990s increase 49.75 mm than that in 1950s–1980s, which the increase extend is 11.65%. The autumn average rainfall in 1990s

increase 55.21 mm than that in 1950s–1980s, which the increase extend is 23.58%. The winter average rainfall in 1990s increase 5.67 mm than that in 1950s–1980s, and the increase extend is 16.6%. This conclusion is identical with some researches (Wang et al, 2005).

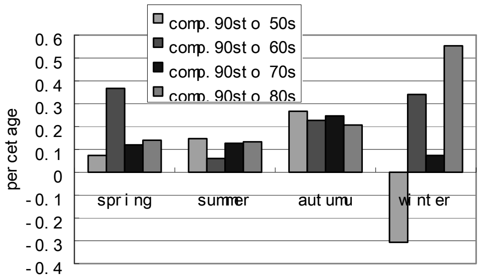

Fig. 3. The comparison of every season mean rainfall in 1990s to that in 1950s, 1960s, 1970s and 1980s.

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

There are close relationship between debris flow occurrence and rainfall. It is the most important factor to form the debris flow. 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 runoff. The observational data of debris flow in the Jiangjia Ravine show (Chen et al, 1996) that the average eroded sediment transport is about 2.15 million m^3/ yr, the sediment in great rainfall year(the peak value) is the 3.6 million m^3/yr between 1965 and 1989. The average eroded sediment is about 3.06 million m^3/yr, the sediment in great rainfall year (the peak value) is the 6.34 million m^3/ yr in 1990s.The average eroded sediment transport in 1990s is 0.91 million than that in 1965–1989, which is close relative to rainfall increase in 1990s (Fig.4).

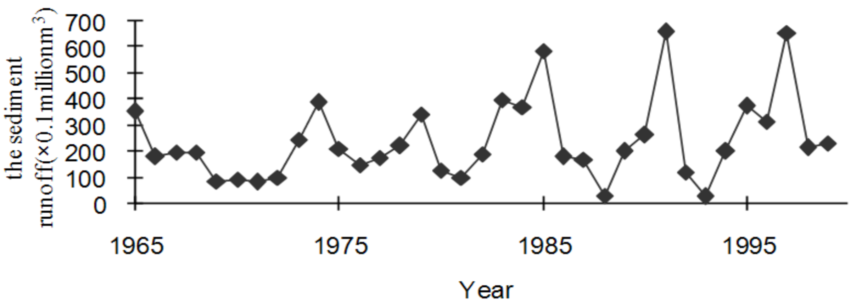

Fig. 4. The comparison of the annual sediment runoff (m^3) of debris flows in 1990s to that from 1965 to 1989 in Jiangjia Ravine.

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