Rainfall Characteristics and the Related Geological Hazards of Slag Disposal Pit in Shanghang Region, China

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There were lots of geological hazards in kinds of slag disposal pit these years. The rainfall, in particular the heavy rain, was direct dynamic factor for geological hazards, but the occurrence probability of geological hazards was different because of the sensitivity of the geological environment though of the same rainfall intensity. This study took a Gold-Copper deposit in Shanghang region, China, as an example, mainly analyzed the relationships between geological hazards and critical rainfall. According to the nearly 80 heavy rainfall data and related hazard events from 2002 to 2010, the rainfall characteristics in the region were studied, and the regional rainfall threshold for debris flow was obtained.

Key words: rainfall characteristics, rainfall threshold, debris flow, geological hazards, slag disposal pit

1. INTRODUCTION

To obtain the characteristics of soil erosion under the rainfall condition, the rainfall characteristics and its related hazards of slag disposal pit of a certain Gold-Copper Deposit in Fujian province was analyzed by the meteorological and rainfall data. The regional rainfall threshold was obtained which was provided reference for the rainfall value design of artificial rainfall test model in laboratory for the soil erosion of slag disposal pit and also used for the analysis of numerical simulation of debris flow of slag disposal pit.

2. THE ANALYSIS OF RELATIONSHIP BETWEEN RAINFALL AND GEOLOGICAL HAZARDS

2.1 The relationship between regional rainfall and geological hazards

The adequate water was the most important condition for the debris flow’s formation, which was also the power source for the debris flow in slag disposal pit. The source of water was mainly from the rainfall, then the melting snow ice. The water, on the one hand, was the component of debris flow, which was the multi-phase flow of solid, liquid and gas, on the other hand, it was the dynamic condition for the debris flow starting, because once more and more rainfall formed into the powerful stream flow, it brought a huge of soil and debris into the debris flow.

The rainfall-type debris flow was the most one and distributed all over the China, but the rainfall condition in which results the debris flow was complicated. According to the rainfall ranges, there were two different types, the one was the local torrential rain with small rainfall range and short duration, the other was the regional rainstorm with large rainfall range and long duration, for example, the rainstorm of Longmenshan in northwest China on July 13th, 1981 and the Dongte rainstorm on July 26th, 1982. These two extreme rainstorms resulted in extreme debris flow disasters. For example ,there were 51 ditches happen triggered by the heavy rain in Pingwu-Songpan area of Sichuan Province On August 19, 1981(Lu, 1986). Every year there was about no less than one billion Yuan loss in China, therefore, there were many the long-term observation study for the rainfall triggered debris flow by a large number of researchers.

After the rainfall was on the ground, when the composition effect surpassed the threshold, which was composed of various factors from the air and the ground, then the rainfall triggered debris flow happen (Kang, 1987; Tan et al., 1992). The discriminative model to forecast the rainstorm debris flow, in which the main parameters included the 10 minutes rainfall intensity with short duration rainstorm, the 60 minutes rainfall intensity and the 24 hours rainfall, was set up based on the monitoring data from 64 debris flow hazards in Ganluo forecast testing zone of Chengdu-Kunming railway from 1989 to 1990. Then the model was testified by 75 debris flow hazards happened along the railways distributed in southwest, northwest, and northeast of China since 1960, the results indicated that the discriminative model is with a certain degree of representation and accuracy.

Tan et al. (2000) discussed the four basic principles of the forecast of rainstorm debris flow, the phenomenon predictability principle, the genetic classification principle, the discriminant factor simplification principle and the forecast decision respective principle. Then the forecast model was classified. The long-term trend prediction model and the state predicting model of frequency were set up based on the superposition of periods of activity and precipitation and the combination of frequency of yearly activity and precipitation gradation respectively.

The debris flow could be forecasted by the rainfall, which was not only the theoretical issue but also the methodological issue. The study of the monitoring data (Chen, 1985, 1990; Jing, 1986; Wu et al., 1990; Tan et al., 1992; Yin, 1992; Tan et al., 1994) showed that it still followed some rules to predict and forecast the debris flow through the natural phenomenon. Such as debris flow have the following characteristics: the significant regional and geographical differences for its development regional distribution, the significant periodicity and stage activity in time series, the popular collective and regional hazard severity in the process of hazard evolution. The main factors of rainstorm triggered debris flow were the characteristics and rainfall during the raining including rainfall type, quantum and intensity. The rainfall threshold of rainstorm triggered debris flow was obtained by study the long-term observation or the influenced factors in region including the historical hazard, geomorphology, geology, vegetation, etc., then the simplified discriminant model between the debris flow and rainfall, which was helpful to operation and forecast analysis. The forecast of debris flow was based on the regional average forecast information of rainfall in a year, quarter, month, day or hour. At present for the meteorological department, it just provided the rainfall ranges or levels in some region with a certain period. For example, it forecast the rainfall level was R_L-R_H (mm) in some region with 24 hours, the rainfall level was R_L'- R_H'(mm) in local region, which meant the low limit value for the rainfall was R_L (mm) and its upper limit was R_H’(mm). It supposed that the region discount coefficient of some certain region with the rainfall level of R_L-R_H and R_L'- R_H' was K_1 and K_2 respectively, and they were satisfied with the following equations (1):

$$\begin{gathered} R_L < R_H \le R_L' < R_H' \\ 0 < K_1(K_2) < 1 \qquad (1) \\ K_1 > K_2 \end{gathered}$$

Then the average rainfall in this region was deduced by the rainfall forecast registration (2):

$$R_m = (R_L + R_H) \times K_1 + (R_L' + R_H') \times K_2 \qquad (2)$$

It supposed that the rainfall threshold of debris flow in the forecast region was R_a.

When R_m was less than R_a, the debris flow was less likely to happen,

When R_m was no less than R_a, the debris flow was likely to happen,

When R_H' was no more than R_a, the debris flow wasn’t likely to happen,

When R_L was no less than R_a, the debris flow was inevitable to happen.

Therefore, the debris flow prediction was deduced by the rainfall forecast. Its timelines and reliability was the core for the debris flow forecast decision basis. To make the accurate forecast, it was important for the successful forecast to obtain the threshold rainfall R_a which triggered the debris flow by the long-term observation. The rainfall thresholds in different regions are showing in **Table.1**. It showed that the rainfall threshold to trigger the debris flow was 70.0mm in Fujian province with the rainfall more than 1200.0mm per year. But there was not strictly relationship between the debris flow scale and the rainstorm level, because it happened frequently that there was the heavy rainfall but the debris flow was small, there was the small rainfall but the debris flow was large. In a word, the rainfall threshold was just the preliminary value for the discriminant of debris flows happen in some region, it should be considered other factors such as geomorphology and terrain, soil, deposit state, et al.

Table.1 Rainfall threshold in different regions (Tan, 1994)

Annual rainfall	$H_{24(D)}$	$H_{1(D)}$	$H_{1/6(D)}$	$H_{o(D)}$	Different regions
>1200	100	40	12	70	Zhejiang, Fujian, Taiwan, Guangdong, Guangxi, Jiangxi, Hunan, Hubei, Anhui, Henan, Beijing suburb, east of Liaoning, west of Yunnan, southeast of Tibet, etc..
1200-800	60	20	10	35	Sichuan, Guizhou, east of Yunnan, south of Shaanxi, Henan, east of Shandong, west of Hebei, Jilin, Heilongjiang, west of Liaoning, etc..
800-400	30	15	6	20	North of Shaanxi, part of Xinjiang, Inner Mongolia, Ningxia, Shanxi, Gansu, northwest of Sichuan, Tibet, etc..
<400	25	15	5	15	Tibet, Xinjiang, Qinghai, west of Yellow River in Gansu and Ningxia

$H_{24(D)}$——rainfall threshold in 24 hours to trigger the debris flow possibly
$H_{1(D)}$ ——rainfall threshold in an hour to trigger the debris flow possibly
$H_{1/6(D)}$——rainfall threshold in 10 minutes to trigger the debris flow possibly
$H_{o\ (D)}$——rainfall threshold to trigger debris flow in region

2.2 The relationship analysis between landslide and debris flow triggered by rainfall in heap leaching field

The risk assessment of debris flow in the slag disposal pit was a complicated system engineering, which depended on the following factors: geomorphology and terrain factor, provenance factor, meteorological and hydrological vegetation factor, geological condition factor, human activity factor, effect factor, etc. After quantization, it was analyzed comprehensively by using multi factors. During the quantization, the three basic conditions of debris flow was the direct evaluation factors including the natural environmental condition, development situation and forming factor of debris flow, then the evaluation index system of debris flow was set up.

For the geomorphology and terrain factor, it includes:

(1) The basin relative height difference. It was the difference between the highest elevation in basin and the lowest elevation in gully, which was measured from the topographic map,

(2) The hill slope of gully banks. It was the average gradient both sides of gully that was reflected from the rainfall collecting capacity of slope and measured from the topographic map,

(3) The longitudinal gradient of groove bed. It was the average gradient of main gully above gully mouth, which was calculated by the weighted average in the segmented statistics; it thought that it was dangerous very much when the longitudinal gradient of groove bed was no less than 50%,

(4) The length of gully, which was from the gully mouth to the watershed.

For the provenance factor, it includes:

(1) The gully blocking level. There were three levels with mild, moderate and severe, which was obtained by in situ investigation. It had the obvious flowing phenomenon when the debris flow happened in the severe blocking level of gully that increased the risk of debris flow,

(2) The soil reserve of mining disposal or slag disposal pit. It was the reserve of mixture with disposal soil, stone and sands from the underground mine and open quarry in the gully region, obtained by in situ investigation.

(3) The loose natural material reserve. It included the total reserve of loose debris, slope sediments and riverbed alluvial deposits in the gully region, obtained by in situ investigation and estimation.

(4) The landslide volume. It included the whole landslide volume in the gully region, obtained by in situ investigation and estimation.

(5) The collapse volume. It included the whole collapse volume in the gully region, obtained by in situ investigation and estimation.

(6) The reserve of loose solid material in unit area. It was the ratio between the whole volume of loose solid material and the collecting water area in the gully, which reflected the seriousness degree of loose landslide deposits.

For the meteorological and hydrological vegetation factor, it included the rainfall data and vegetation coverage ratio of fixed point meteorology and rainfall observation station in detail. The more the rainfall, the more possibility and the larger scale the debris flow. The vegetation coverage ratio was the coverage ratio of Trees, Shrub, Grasses, etc.

The rainstorm was the direct dynamic factor for the debris flow and also the trigger factor for the rainstorm triggered debris flow and collapse. During the raining, the rain was permeated into the soil of slag disposal pit, hence its strength was changed to poor, as a result, there was the chain disaster process such as the landslide and the debris flow both triggered by the rainfall. During the process of debris flow triggered by the rainfall, there was the rainfall threshold, once it was to the rainfall threshold; the stable state of loose deposit was broken. Therefore, the rainfall statistics was the main method for qualitative prediction of debris flow. By statistical analysis of the rainfall and debris flow, the rainfall forecast value was suggested for the loose deposit in Shanghang, Fujian province when the debris flow happened.

The monitoring data (Tan et al., 1981; Cui et al., 1997) showed that there was at least one rainfall center or more for every rainstorm in every region, in which there was one main rainfall center and several non-main rainfall centers. Because of the more rainfall and intensive strength of the rainfall center, it was the center for the occurrence of debris flow and landslide. For example, in the debris flow happening center of Ya’an and Wanxian county of Sichuan province, the day rainfall threshold was between 100.0mm and 200.0mm. In the debris flow occurrence center of Miyun county of Beijing, it had the same the day rainfall threshold. In the debris flow happening center of Helanshan mountain region of Ningxia, Dongshenxian county of Inner Mongolia, the day rainfall threshold was about 100.0mm. In the debris flow happening center of Panxi region of Sichuan province, the day rainfall threshold was between 50.0mm and 70.0mm, which was smaller than that of the above region. From the above examples, there was the triggered rainfall threshold in different regions when the debris flow happened. But the value of triggered rainfall threshold in different regions was different due to the difference of geography, geology, climate, etc. That was to say, during the rainstorm in some region, once the rainfall and strength of rainstorm was over the triggered rainfall threshold, the most of debris flow gullies and many landslide was unstable that indicated the concentrated happen of the landslide and debris flow

Study showed that if the regional rainstorm in the rainbelt was larger, the region of debris flow and landslide was wider and the number of hazards was larger, the lower limit of minimum rainfall was lower. On the other hand, if the entire regional rainstorm in the rainbelt, the region of debris flow and landslide and the number of hazards was small, the lower limit of minimum rainfall was higher. For the large regional rainstorm, it was influenced by the whole weather system, and then there was the regional rainfall process with long duration, the rainfall in early or late period was more, the water content of soil was higher, therefore the lower limit of triggered rainfall threshold was lower, vice versa. The relationship between the daily rainfall and debris flow on July 8th, 1985 was shown in **Fig.1**.

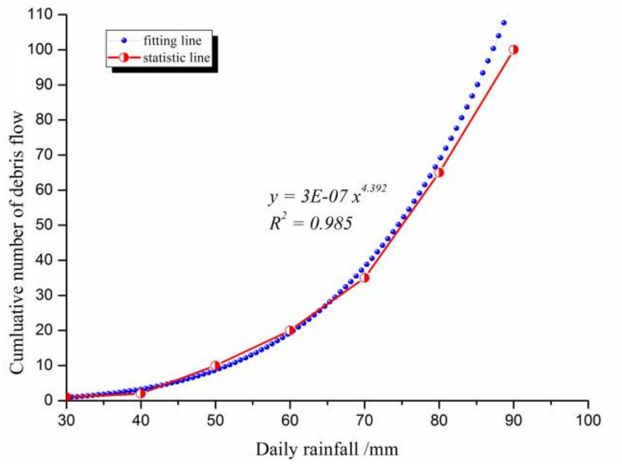


Fig.1 Relationship between cumulative number of debris flow and daily rainfall in Panxi on July 8th, 1985

Fig.1 showed that the cumulative density of debris flow increased exponentially with the increasing of rainstorm, once the daily rainstorm was larger than the 75.0mm ~80.0mm, the curve had the linear increasing tendency, but when the daily rainstorm was lower than 70.0mm, the curve had the slow change tendency. The fitting relations between daily rainfall and debris flow was $y=3E\text{-}07x^{4.392}$. From the fitting relations, it showed that there was the rainfall threshold between the rainstorms triggered debris flow gullies and the rainstorm. When the rainfall was larger than the rainfall threshold, the quantity and density of debris flow increased rapidly with the increasing of rainstorm level, but when it was lower than 30.0mm, there was no debris flow to happen.

It was the rainfall that increased the water content of soil in the loose deposits and decreased its strength and the stability of slope, particularly the soil strength couldn’t keep the stability of slope, which was the rainfall threshold. When the rainfall was lower than that, the debris flow or rainstorm landslide was less likely to happen, when the rainfall was more than it, the debris flow or rainstorm landslide was likely to happen. The value of minimum rainfall was related to the antecedent precipitation and different with the difference of regions. Then the regional minimum rainfall threshold was suggested. The regional minimum rainfall threshold was the rainfall threshold that resulted in the occurrence of debris flow in the most of debris flow gullies in this region or the occurrence of most landslides in this region, which was obtained by a lot of statistic information. For example, there were the daily rainfall and the total effective rainfall information of 272 cases of debris flow and 46 cases of landslides monitored in Panxi region, the rainfall in the early 14 days was calculated by following equation(3):

$$R_t = \sum_{i=1}^{14} a_t P_t \qquad (3)$$

In equation,

Pt---- rainfall in t days (mm),

$a_t = (0.5)^{t/T}$ ----rainfall attenuation coefficient

t---- Days, (day)

T---- days of half life

The total effective rainfall was the above calculated value with the rainfall on the day. The relationships among the debris flow or landslide and the daily rainfall, the total effective rainfall in Panxi region are as show in **Fig.2**. It showed that all of the points distributed below the line with 45° at coordinates, which indicated that there was some rainfall in early before the day of debris flow and landslide's occurrence. It also showed that most of the points distributed below and close to the line with 45° at coordinates, which indicated that the antecedent precipitation account for a substantial proportion before the day of debris flow and landslide's occurrence.

$$R_t = T_t + R_{day} \qquad （4）$$

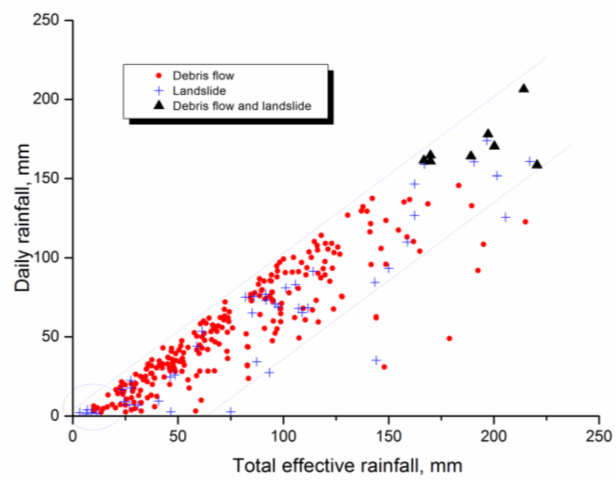


Fig.2 Relationship between debris flow & landslide and the daily rainfall, the total effective rainfall

In **Fig.2**, there were a few points distributing at the total effective rainfall with 10.0mm or 20.0mm, it was probable because the local rainstorm in mountain triggered the debris flow & landslide. But in the meteorological station, it was the regional average rainfall not the local rainstorm that was monitored; furthermore the local rainstorm happened far away from the meteorological station, which had the poor representation as the condition of rainfall threshold on the day of occurrence of debris flow & landslide. Therefore, the regional minimum rainfall threshold in Panxi region, which triggered the debris flow & landslide to happen, was about 25.0mm ~30.0mm.

There was the important relationship between the occurrence of debris flow and the antecedent precipitation, the rainfall on the day and the triggered rainfall threshold, therefore, the antecedent precipitation, the rainfall on the day and the triggered rainfall threshold were the basis for the prediction and forecast of rainstorm triggered debris flow. The antecedent precipitation and the rainfall on the day was measured by the self-recording rain gauge and the remote recording rain gauge, the antecedent precipitation dissipated gradually with the increasing of days and it was calculated by the following equation:

$$P_{a0} = P_1K + P_2K^2 + P_3K^3 + P_4K^4 + \cdots\cdots + P_nK^n \qquad (5)$$

Where,

P_{a0} is the antecedent precipitation of the debris flow occurrence,

P_1, P_2, P_3…P_n is the rainfall before the day before the outbreak of debris flow, the first two day of debris flow, the first three day of debris flow, the first n day of debris flow

K is reduction coefficient. It was obtained by latitude, sunshine, potential evaporation and infiltration capacity of the solid substance, generally it was 0.8. For one rainfall, it dissipated at about 20 days; therefore the maximum n was 20.

The rainfall threshold as show in **Table.2** when the debris flow was triggered by the hazard-inducing rainfall in mountain region of China, was statistical analyzed comprehensively (Cui et al., 2000). When it was lower than the rainfall threshold, the debris flow was less likely to happen, but once it was more than the rainfall threshold, the debris flow was likely to happen. At present, the prediction of debris flow to happen in advance had been achieved by taking full advantages of the triggered rainfall threshold

Table.2 The rainfall threshold of the debris flow triggered by the hazard-inducing rainfall in mountain region of China (Cui et al., 2000)

Region	**Tianshan mountains**	**Xiqin area of Qilianshan mountain**	**Gangdisi mountains**	**Shaluli area Nien-ch'ing-t'ang-ku-la Mountains**	**Minshan mountains**	**Ailao area of Gaoligong mountain**	**Quhaoshan mountains**
Daily rainfall /mm	25～50	25～200	25～50	30～100	35～300	50～200	50～200
hourly rainfall /mm	20	20	20	25	30	30	30
Region	**Helanshan mountains**	**Liupanshan mountains**	**Lvliangmountains & Huoyanshan mountains**	**Daba mountains & Qinling mountains**	**Daxing’anling mountains**	**Xiaoxing’anling mountains**	**Longgan mountains & Taihang**
Daily rainfall /mm	100～300	100～300	100～300	100～300	100～200	200～300	200～300
Hourly rainfall /mm	30	30	40	40	40	40	50
Region	**Qainshan area of Beilaotu**	**Zhongtiao-shan area of Wutaishan**	**Daloushan mountains**	**Wudangshan area of Dabieshan mountains**	**Mu’ao area of Xufengshan mountains**	**Wuyishan mountains, Alishan mountains,Mounta**	**Laoshan area of Qinshan**
Daily rainfall /mm	100～300	100～300	100～300	100～300	150～300	200～300	200～300
Hourly rainfall /mm	50	50	50	50	50	60	60

3. CHARACTERISTICS OF HAZARDS AND RAINFALL IN STUDY AREA

3.1 The rainfall characteristics of slag disposal pit

The study area was located at Shanghang County, Longyan City, Fujian Province, China, as was shown in **Fig.3**. According to the distribution of monitoring stations of hydrological and rainfall in Longyan city of Fujian province and the location of gold-copper deposit, the Shanghang monitoring station of hydrological and rainfall was chosen, which is the nearest one to the gold-copper deposit. The annual rainfall statistics both of Shanghang monitoring station and gold-copper deposit was analyzed. The rainfall bar chart of Shanghang County for 70 years from 1939 to 2008 was shown in **Fig.4**, the annual rainfall bar chart of Zijinshan monitoring station from 1988 to 2010 was shown in **Fig.5**, the monthly rainfall statistics in different years was shown in **Fig.6**.

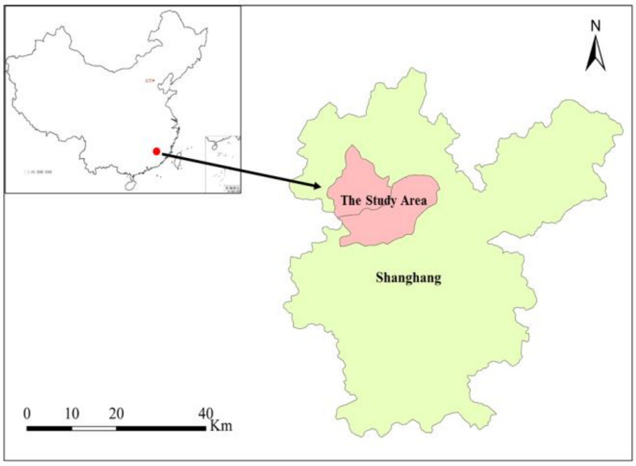


Fig.3 Location of the study area (Shanghang County, Longyan City, Fujian Province, China)

Fig.4 showed that the minimum rainfall was 860.5mm in 1943, which belonged to the extreme lowest flow year, the maximum rainfall was 2437.3mm in 1959, belonged to the high flow year, and the average rainfall was 1581.2mm for 70 years. **Fig.5** showed that the minimum rainfall was 1048.5mm in 1991, which belonged to the low flow year, the maximum rainfall was 2118.6mm in 1997, belonged to the high flow year, and the average rainfall was 1841.8mm from 1988 to 2010. **Fig.6** showed that they were abundant rainfall months including May, June and August, in which there was the frequency of debris flow hazards triggered by heavy rainfall.

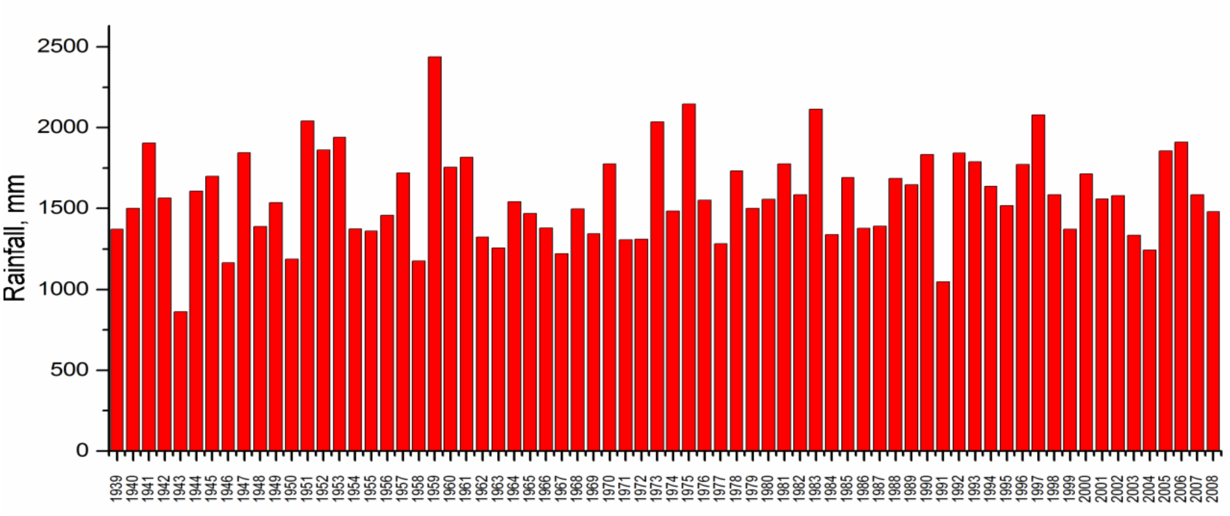


Fig.4 Rainfall bar chart of Shanghang county for 70 years from 1939 to 2008

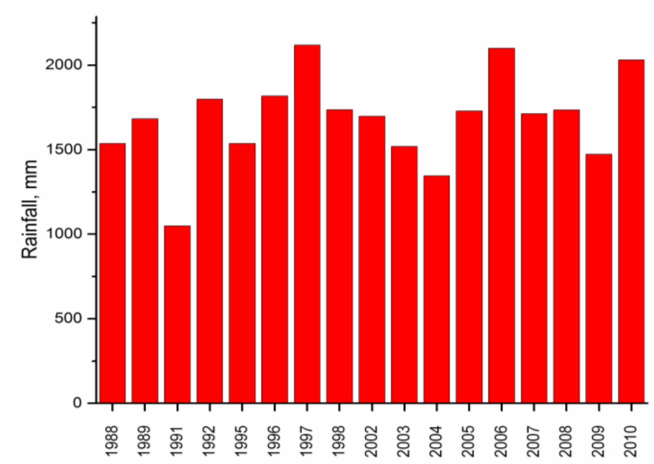


Fig.5 Rainfall bar chart of Zhijinshan monitoring station from 1988 to 2010

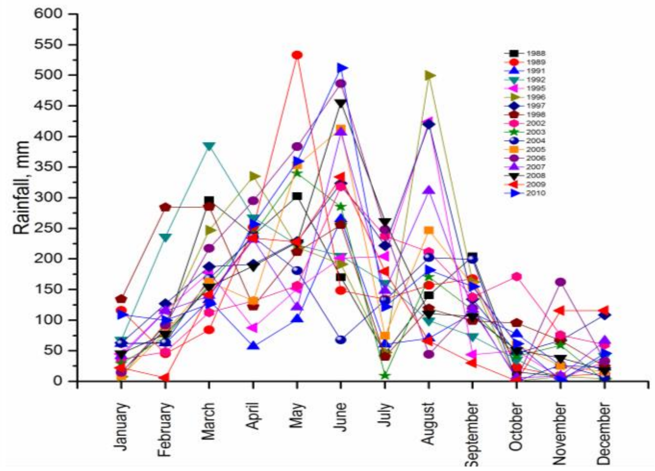


Fig.6 Rainfall statistics of Zijinshan monitoring station in different years from 1988 to 2010

According to records(Gao et al., 2010), from August 25th to 28th, 2000 it was the rainfall with 342.0mm, on April 3rd, 2003 it was the rainfall with 107.0mm, from May 16th to 17th, 2003 it was the rainfall with 170.0mm, the above rainfall resulted in the serious collapse of slope. On May 22th, 2010, from 10:10 p.m to 11:30 p.m, the rainfall was 75.3mm, which meant the rainfall was 56.5mm/h and the rainfall intensity was 0.94mm/min. The rain continued to the 1:00 a.m on 23rd with the rainfall of 32.1mm and the maximum rainfall was 62.0mm. This heavy rainfall resulted in the serious collapse because the water eroded the road surface due to (1) the small temporary pipe of drainage ditches beside the roads of Dalongli and (2) the broken drainage pipe of Yanzigou. The total economic loss was about ¥700,000 yuan. The above rainfall statistics showed that they were the rich rainfall regions for Shanghang & Zijinshan, particularly it was the heavy rainfall from March to June and August in every year, which indicated that it had the condition for the debris flow triggered by rainfall. It found that the debris flow in Fujian province was controlled by the heavy rainfall (Gao et al., 2008), the amount of valley shaped debris flow hazards was about 82.0% of total debris flow hazards, the amount of slope shaped debris flow hazard was about 18.0% of total debris flow hazards (Liu et al.,2008, Gao et al., 2010).

3.2 The characteristics of geological hazards in study area

According to the geological investigation in Fujian province, during 2002-2010, the total number of geological hazards was 9513, in which the number of landslide, collapse, unstable slope and surface collapse was 5816, 1888, 1591, 103 and 115 respectively. The main geological hazard was the landslide with 61.1% of total geological hazards, the collapse was 19.9%, the unstable slope was 16.7%, the surface collapse was 1.2% and the debris flow was 1.0%. Among all these geological hazards, only 6.0% was relative stable, 17.0% was basic stable, and nearly 76.0% was unstable. The slope disaster was the main geological hazard, if the unstable slope was the potential landslide or collapse; the slope collapse was 98.0% of all geological hazards.

3.3 The relationship of rainfall and geological hazards in study area

The rainfall was the main cause of geological hazards, but the occurrence probability of geological hazards was different because of the sensitivity of the geological environment though of the same intensity rainfall. The relationship between geological disaster and rainfall was analyzed based on the division of environmental sensitive region in Fujian province (Huang et al., 2003, 2005, 2011). The division showed that the occurrence probability of geological hazards was 50.0%, 55.0% and 70.0% in the low sensitive, moderate sensitive and high sensitive region under the same condition of 200.0 mm rainfall respectively. The prediction model of geological hazards was set up based on the relationship between the geological hazards and the rainfall, geological environment, which was the main basis of weather forecast of geological hazards. From the above discuss, the debris flow with landslide collapse had the characteristic with chain hazard process, particularly in the mountains. Therefore, there was the comprehensive analysis with consideration of the rainfall on the day, the antecedent precipitation when the landslide collapsed, based on the hazard analysis between the debris flow with landslide collapse and the daily rainfall from 2002 to 2010. The antecedent precipitation was calculated by the following equation (6) when the debris flow happened. The hazard analysis between the debris flow with landslide collapse and the daily rainfall from 2002 to 2010 was shown in **Table.3.**

$$P_{a0} = P_1K + P_2K^2 + P_3K^3 + P_4K^4 + \cdots\cdots + P_nK^n \quad (6)$$

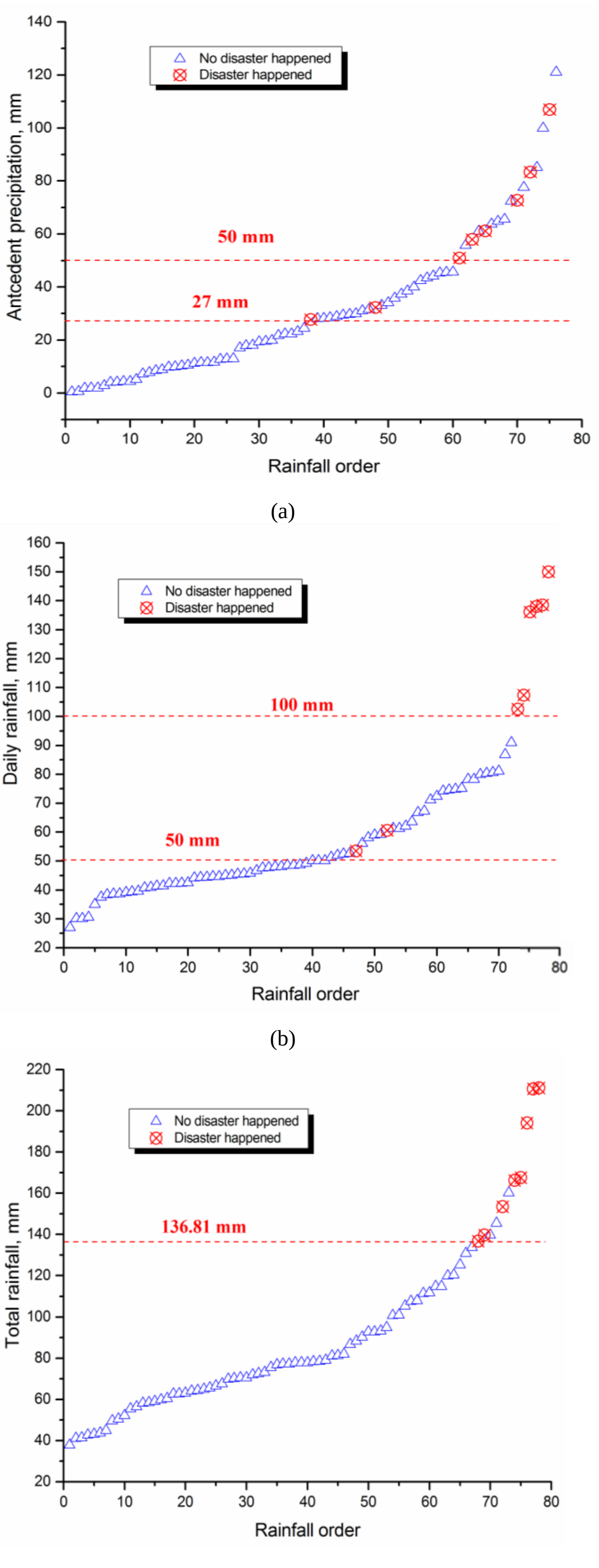
In equation (6), all indices were the same as the equation (5).

And the relationships between geological hazards and the rainfall characteristics were shown in **Fig. 7**.

Table.3 Statistics of rainfall index when debris flow with landslide collapse

Rainstorm date	The antecedent precipitation P_{a0}		Rainfall on the day （P_t） /mm	Total rainfall /mm	Whether hazard happened
	Count day	P_{a0} /mm			
2002.3.16	11	1.9	48.6	50.5	no
2002.3.24	11	10.5	30.6	41.1	no
2002.4.10	5	28.3	50.2	78.5	no
2002.5.15	7	19.4	45.0	64.4	no
2002.5.23	13	19.4	39.6	59.0	no
2002.6.11	3	4.0	51.3	55.3	no
2002.6.12	4	44.2	67.2	111.4	no
2002.6.14	6	85.1	45.8	130.9	no
2002.6.18	9	77.6	62.1	139.7	no
2002.7.22	13	28.5	48.7	77.2	no
2002.7.30	15	43.4	27.0	70.4	no
2002.8.9	6	29.7	42.3	72.0	no
2002.8.10	12	13.0	30.1	43.1	no
2003.3.3	3	7.7	30.1	37.8	no
2003.4.12	6	42.5	72.4	114.9	no
2003.5.7	5	8.4	58.1	66.5	no
2003.5.17	14	61.1	150.0	211.1	yes
2003.6.6	1	4.4	71.1	75.5	no
2003.6.27	20	22.3	37.5	59.8	no
2003.9.21	20	11.5	46.7	58.2	no
2003.10.22	0	0.0	41.3	41.3	no
2003.11.8	1	7.2	42.5	49.7	no
2004.3.8	17	1.8	61.3	63.1	no
2004.5.13	12	12.7	50.1	62.8	no
2004.7.8	3	18.0	74.8	92.8	no
2004.8.20	19	9.8	91.0	100.8	no
2005.3.29	20	11.2	49.2	60.4	no
2005.5.9	6	22.3	59.0	81.3	no
2005.6.2	10	19.8	59.2	79.0	no
2005.6.12	4	4.4	52.0	56.4	no
2005.6.23	13	100.0	45.5	145.5	no
2005.8.14	8	27.7	138.6	166.3	yes
2005.9.3	1	11.6	81.1	92.7	no
2006.4.6	6	4.1	40.8	44.9	no
2006.4.27	21	38.5	86.8	125.3	no
2006.5.17	15	12.9	45.6	58.5	no
2006.6.8	18	72.7	138.0	210.7	yes
2006.6.17	8	40.0	80.3	120.3	no
2006.7.15	11	33.1	74.6	107.7	no
2006.11.26	10	24.4	52.7	77.1	no
2007.4.24	9	45.6	47.6	93.2	no
2007.5.29	13	17.9	44.7	62.6	no
2007.6.8	7	61.0	44.4	105.4	no
2007.6.13	12	72.4	61.3	133.7	no

2007.7.13	12	1.9	63.6	65.5	no
2007.8.14	5	21.7	48.0	69.7	no
2007.8.15	6	55.8	45.1	100.9	no
2007.9.3	15	37.3	44.7	82.0	no
2007.9.4	16	65.6	42.4	108.0	no
2008.2.1	7	17.1	35.0	52.1	no
2008.4.20	10	10.2	80.0	90.2	no
2008.5.28	10	31.0	39.4	70.4	no
2007.8.15	6	55.8	45.1	100.9	no
2007.9.3	15	37.3	44.7	82.0	no
2007.9.4	16	65.6	42.4	108.0	no
2008.2.1	7	17.1	35.0	52.1	no
2008.4.20	10	10.2	80.0	90.2	no
2008.5.28	10	31.0	39.4	70.4	no
2008.5.30	12	121.1	39.1	160.2	no
2008.6.12	19	51.0	102.5	153.5	yes
2008.6.18	5	28.8	44.2	73.0	no
2008.6.27	2	2.8	75.1	77.9	no
2008.6.30	5	45.7	74.2	119.9	no
2008.7.29	1	0.5	80.6	81.1	no
2008.7.30	1	64.8	50.1	114.9	no
2009.4.25	13	28.1	66.8	94.9	no
2009.5.20	7	29.4	48.5	77.9	no
2009.6.11	1	8.8	56.1	64.9	no
2009.6.14	4	45.3	41.4	86.7	no
2009.6.24	14	63.7	48.1	111.8	no
2009.7.3	1	0.6	42.2	42.8	no
2009.7.4	2	34.1	38.4	72.5	no
2009.11.13	5	23.2	44.3	67.5	no
2010.4.8	6	35.9	40.9	76.8	no
2010.4.13	11	31.5	38.7	70.2	no
2010.5.6	1	11.5	52.5	64.0	no
2010.5.23	18	32.3	107.4	139.7	yes
2010.6.15	6	57.9	136.2	194.1	yes
2010.7.26	5	29.9	47.8	77.7	no
2010.8.10	0	0.0	78.3	78.3	no
2010.8.10	6	9.9	78.3	88.2	no
2010.8.25	3	5.1	38.6	43.7	no
2010.6.25	16	83.3	53.5	136.8	yes
2007.6.14	13	107.0	60.6	167.6	yes



(a)

(b)

(c)

Fig. 7 Relationship between geological hazards and critical rainfall from 2002 to 2010: (a) antecedent precipitation; (b) daily rainfall; (c) total rainfall

4. RESULTS

According to the **Table.3**, the relationship between the debris flow with landslide collapse and the antecedent precipitation, the rainfall on the day, the total rainfall respectively was shown from **Fig.7 (a)** to **Fig.7 (c)**. From **Fig.7 (a)** to **Fig.7 (c)**, there were four hazards on the condition that (1) the antecedent precipitation was lower 50.0mm, (2) the rainfall on the day was lower 100.0mm. The antecedent precipitation of 27.7 mm, 32.3mm, 60.6mm and 53.5mm was on August 14th, 2005, on May 23rd, 2010, on June 14th, 2007, on June 25th, 2010 respectively. If it was satisfied with the one of the following conditions, the risk of debris flow with landslide collapse was higher, when the antecedent precipitation was more than 50.0mm, the rainfall on the day was more than 100.0mm or the total rainfall was more than 137.0mm. When the antecedent precipitation was more than 50.0mm, the risk probability of debris flow with landslide collapse was 37.5%. When the rainfall on the day was more than 100.0mm, the risk probability of debris flow with landslide collapse was nearly 100.0%. When the total rainfall was 136.0mm, the risk probability of debris flow with landslide collapse was 72.7%. There were two hazards when the antecedent precipitation was less than 50.0mm, but the rainfall on the day was 138.6mm and 107.4mm, the total rainfall was 166.3mm and 139.7mm. There were two hazards when the rainfall on the day was less than 100.0mm, but the antecedent was 107.0mm and 83.3mm, the total rainfall was 167.6mm and 136.8mm.

The results indicated that there was high risk for the debris flow with landslide collapse when either the daily rainfall was more than 100.0 mm, or the total rainfall was more than 136.0mm in the gold-copper deposit and the Shanghang region. At the same time, although there was few risk for the debris flow when the daily rainfall was between 50.0~100.0mm, if the soil was saturated or nearly saturated because of the continuous antecedent precipitation, debris flow hazards would occur even the daily rainfall was only 50.0mm. In addition, it was prone to trigger debris flow hazards when the daily heavy rainfall was more than 100.0mm or the torrential rainfall in 3 days was between 250.0~300.0mm. At last, once the continuous heavy rainfall reached to 300.0mm, it was the frequent period of debris flow and usually generated to large scale and clusters of debris flow.

5. CONCLUSION

The analysis of the nearly 80 heavy rainfalls and related hazards from 2002 to 2010 indicated that there was high risk for the debris flow with landslide collapse when the daily rainfall was more than 100.0mm; or the total rainfall was more than 136.0mm in the gold-copper deposit and the Shanghang region.

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