III. Factors Causing Landslides

Landslides are the result of the comprehensive interaction of geologic and geographical environments. A number of variables have been shown to influence landslide processes in the areas that have been studied in China.

- Geologic conditions; including rock and soil types, their strength, and structures.
- Slope angle; this can vary greatly with different material types.
- Amount, duration, and intensity of rainfall.
- Melting snow or ice.
- Effects of earthquakes.
- Effects of deforestation.
- Man's activities.

Among these factors, earthquakes and rainstorms constitute two of the most important landslide-inducing agents.

Earthquakes and Landslides

China is subjected to a lot of earthquakes. It is recognized that a significant number of landslides occur only when earthquake magnitudes are greater than six (M=6.0). At least 656 earthquakes with magnitudes greater than six (M=6.0) took place from 780 B.C. to 1976 A.D. (Feng and Guo 1985).

The two most seismically active provinces in China are Sichuan and Yunnan, and earthquakes usually cause many large-scale rockslides and rockfalls in their mountain areas; some of which block rivers and form lakes. Landslides and avalanches were widespread during the earthquakes listed in Table 9.

Another seismically sensitive region is the Loess Plateau, (Northern China) where thousands of earthquakes have been recorded. Many of them have triggered large, disastrous landslides, and some of these are described below.

The earthquake in Hontong County (September 17, 1303, M = 8.0), in Shanxi Province, triggered landslides on Xunbao Mountain. The largest of the slip bodies had a length of about 1,600m and it was 1,400m wide.

The Tianshui Earthquake (July 21, 1654, M = 8.0) in Gansu Province triggered 59 huge loess landslides. The longest of these extended for more than 500m. Among them, the Luojiapao Landslide was the biggest, and it was 4.5 km long and 2 km wide.

The Tongwei Earthquake (June 19, 1718, M = 7.5) in Gansu Province, triggered 337 large landslides which were all over 500m long. Among them, the Yongning Town Slide was 8 km long, 3 km wide, and 7 km^2 in area; its sliding distance extended over five kilometres, burying Yongning Town and killing 2,000 inhabitants.

Within recorded time, the greatest earthquake has been one that occurred in Haiyuan on December 16, 1920 (M = 8.5). It triggered 675 loess landslides that killed at least 100,000 people; accounting for half of the 200,000 deaths caused by this event (Close and McCormick 1922). The Dangjiaca Landslide in Siji County slipped northwards 2,300m and then turned southeast at right angles, moved forwards about 950m to dam a river, and formed a lake 5 km long and 380m wide. In the Siji-Jingning Region, more than 40 lakes were created by large landslides and 27 out of the 40 lakes still exist.

Historical records in China show that numerous earthquakes have produced thousands of landslides, but it is only in the last 30 years that intensive investigations of these slope failures have been carried out (Li 1979a; Li 1979b; and Zhu 1989).

Between 1973-1978, a study was made of the landslides triggered by earthquakes, and it was found that there is a direct correlation between earthquake magnitude (M) and the total area (S) where seismogenic landslides and collapses might develop. It has been

Table 9: Some Historic Earthquakes of Southwest China and Their Effects

Date	Approximate Epicentre	Magnitude	Effects
February 26, 1713	Xundin (Yunnan)	6.5	Ground fissures, many slumps, and shallow slides in upper watershed of Xiao River.
August 2 1733	Dongchuan (Yunnan)	6.75	Fault rupture 100 km long. Many landslides; one large landslide buried a village on the Daqiao River, killing 40 people.
October 10 1786	Kangding-Luding (Sichuan)	7.5	Many landslides in the Dadu River and its tributaries. One huge landslide dammed the Dadu River for 10 days, causing a big flood downstream.
September 6 1833	Songming (Yunnan)	8	Ground fissures, liquefaction (sand boils), many landslides, and reactivated ancient landslides in upper and middle watersheds of Xiao River.
June 10 1856	Qianjiang	6	Many huge landslides and falls, one huge landslide dammed the Qianjiang River, forming a lake 10 km long which still remains.
April 11 1870	Batang (Sichuan)	7.5	Many major landslides and rock avalanches in the Jinsha River Valley dammed the river.
February 6 1973	Luhuo (Sichuan)	7.6	More than 200 landslides; 20 km highway destroyed by landslides and rock falls.
May 11, 1974	Zhaotong (Yunnan)	7.1	Extensive rock falls, slumps, and slides.
May 29, 1976	Longling (Yunnan)	7.4	Extensive shallow slides and slumps in weathered granite rocks.
August 16	Songpan (Sichuan)	7.2	170 landslides; three landslide-dammed lakes formed.

Source : Collated by author from historical and technical records,

calculated by using the standard least-squares method as applied to the logarithmic data values (S in km^2). The equations of the correlation can be given as :

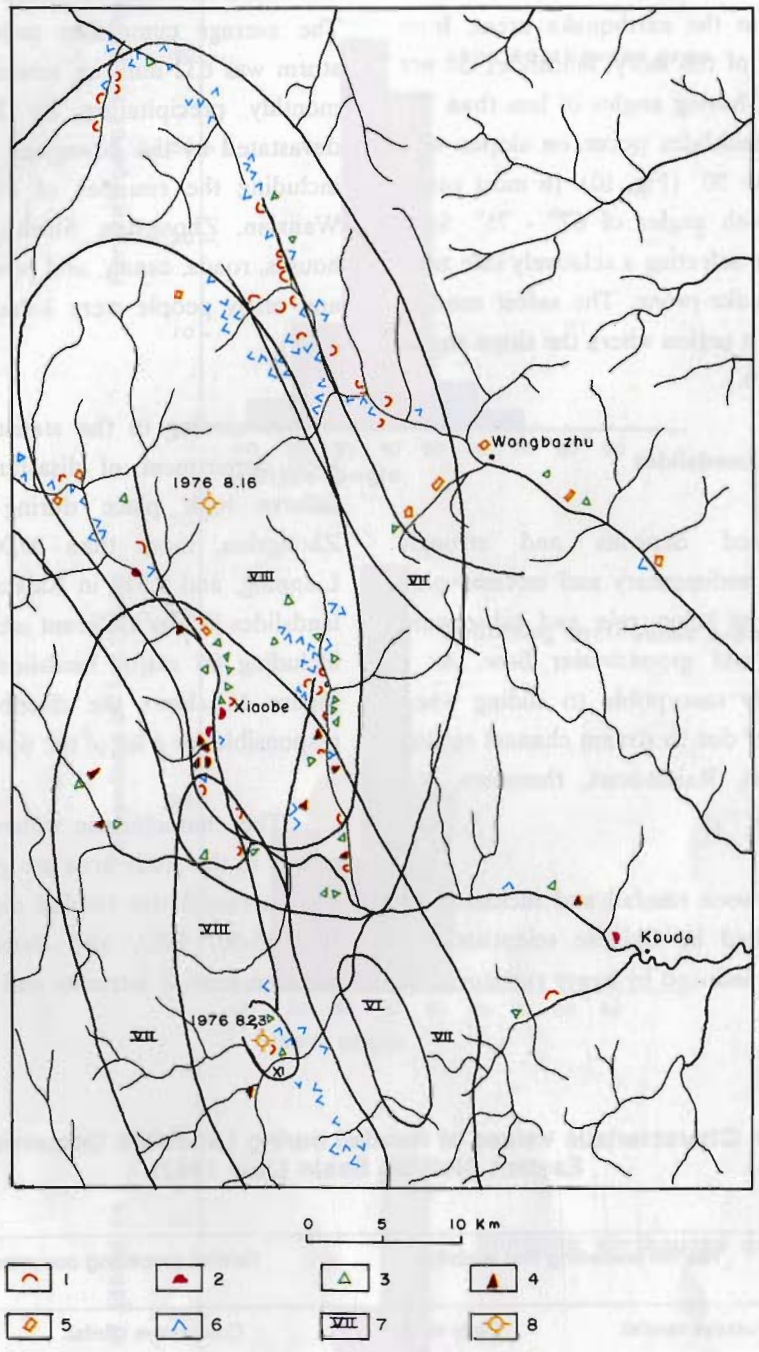
$$\log S = 0.9246\ M - 3.1089 \quad (1)$$
$$\log S = 1.0719\ M - 3.5899 \quad (2)$$

Equation (1) is applicable to mountain areas of Southwest China and equation (2) to North China (Li 1979a).

Apart from earthquake characteristics themselves (i.e., seismic accelerations, continuous time of shock, focal depths, and angle and direction of the approach of seismic waves), environmental factors, such as landform and drainage, play an important role in the formation of landslides triggered by earthquakes.

Geologic influences are reflected in both geologic structure and lithologic character. The landslides triggered by the Songpan Earthquake (August 16, 1976, M = 7.2), in the northwest of Sichuan Province, can be taken as an example. The earthquake induced more than 170 slumps, slides, and falls that occurred predominantly along the active tectonic faults in the strong seismic region (Fig. 9). On slopes consisting of loosened limestone and igneous rocks, the falls occurred readily, but, on the slopes consisting of claystone, shale, and phyllite, the falls were few in number.

Figure 9: Map Showing the Distribution of Landslides Induced by the Songpang Earthquake in 1976



Source : Li 1979b.

Notes:

1. Slide.
2. Ancient Slide.
3. Major Fall.
4. Ancient Fall Deposit.
5. Failed Larger Stone.
6. Shallow Slide.
7. Earthquake Intensity.
8. Earthquake Epicentre.

The types of slope and slope angles have a great influence upon the frequency of landslides and falls. Straight slopes seldom have landslides and falls, but they are common on convex, concave, and complex slopes, occurring mostly near the turning points of slopes. The statistical data gathered in the earthquake areas, from 1973 to 1976, tell us part of the story: landslides do not generally occur on slopes having angles of less than 25° and 90 per cent of all landslides occur on slopes with angles ranging from 30° to 50° (Fig. 10). In most cases, falls happen on slopes with angles of 67° - 75°. Such figures are of great help in selecting a relatively safe zone in an area that is earthquake-prone. The safest zone in any mountain area falls in a region where the slope angles are less than 25° (Li 1979 b.).

Monsoon Rainstorm and Landslides

Loose unconsolidated deposits and strongly weathered and fractured sedimentary and metamorphic rocks become saturated by heavy rain and subsequent excessive surface water and groundwater flow. As a result, they are especially susceptible to sliding when slopes are too steep, either due to stream channel cutting or man-made excavations. Rainstorms, therefore, are frequent landslide triggers.

The relationship between rainfall and incidence of landslides has been studied by Chinese scientists. An investigation of landslides induced by heavy rainstorm, in the eastern part of Sichuan Basin, about 240 km NNW of Chengdu, in 1982, can be cited as an example.

From 15-30 July, 1982, the eastern part of the Sichuan Basin was subjected to a continous rainstorm. The average cumulative precipitation from that single storm was 632 mm; an amount that exceeded the mean monthly precipitation by 340 per cent. The area devastated by the downpour covered about 21,000 km^2; including the counties of Fengjie, Kaixian, Liangping, Wanxian, Zhongxian, Shizhu, and Fengdu. Farmlands, houses, roads, canals, and power stations were destroyed, and many people were killed by landslides (Li and Li 1985).

According to the statistical data collected by the local department of disaster prevention, 81,199 slope failures took place during this event : 29,930 in Zhongxian, more than 20,00 in Yunyang, 11,100 in Lianping, and 8,517 in Kaixian. Three hundred and ten landslides in four different areas throughout the counties, including 85 major landslides, were studied in detail. Figure 11 shows the distribution of larger landslides responsible for a lot of the damage.

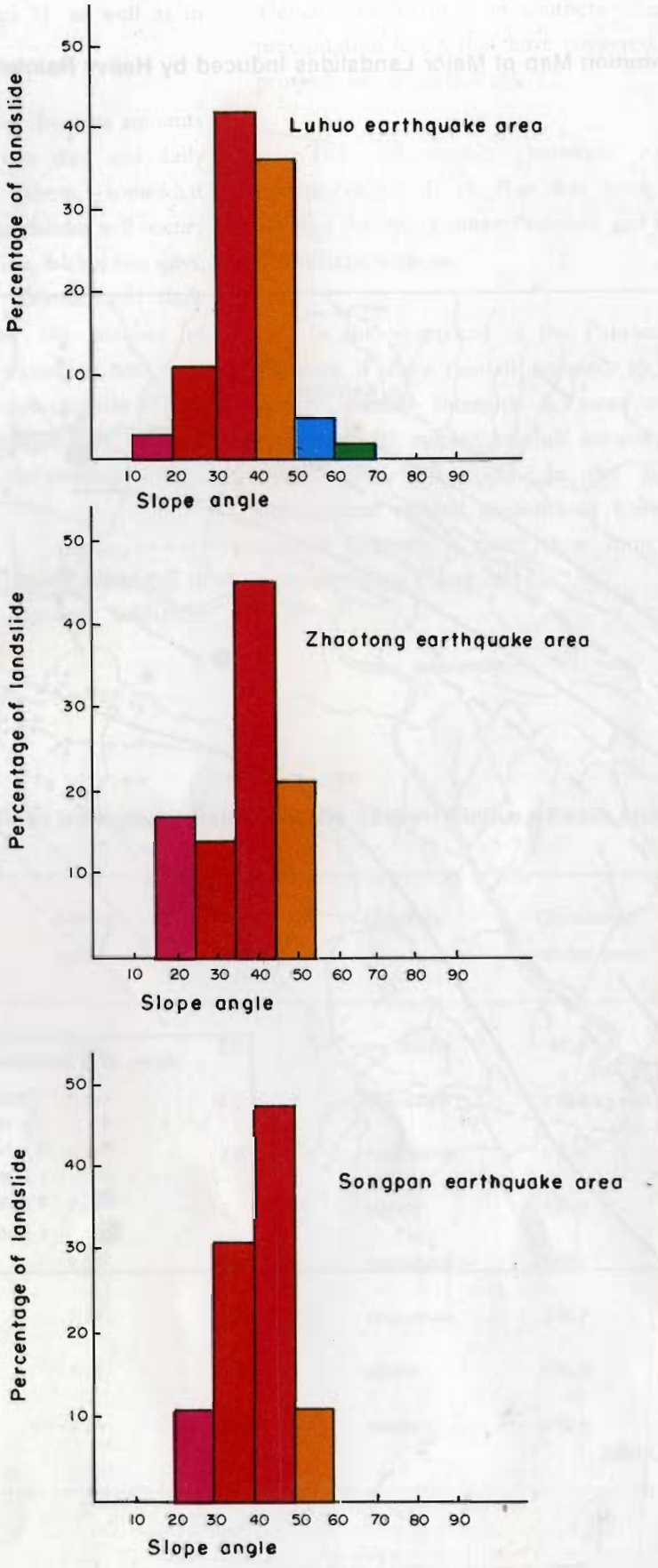
The characteristic values of precipitation for each county in the study area are given in Table 10. Figure 12 gives a cumulative rainfall diagram for the period from July 15-30, 1982, and demonstrates the relationship between rainfall intensity and landslide frequency. Table

Table 10: Characteristic Values of Rainfall during Landslide Occurrence in the Eastern Sichuan Basin (July 1982)

Location	Rainfall preceding first landslide		Rainfall preceding occurrence of numerous landslides	
	Cumulative rainfall (mm)	Daily rainfall (mm)	Cumulative rainfall (mm)	Daily rainfall (mm)
Zhongxian	139.0	139.0	289.7	138.2
Yunyang		277.7	205.6	
Kaixian	53.4	51.4	280.8	153.8
Liangping	177.0	177.0	279.3	102.3
Fengdu	99.0	88.0		
Fengjie	113.7	47.9	218.9	10.1

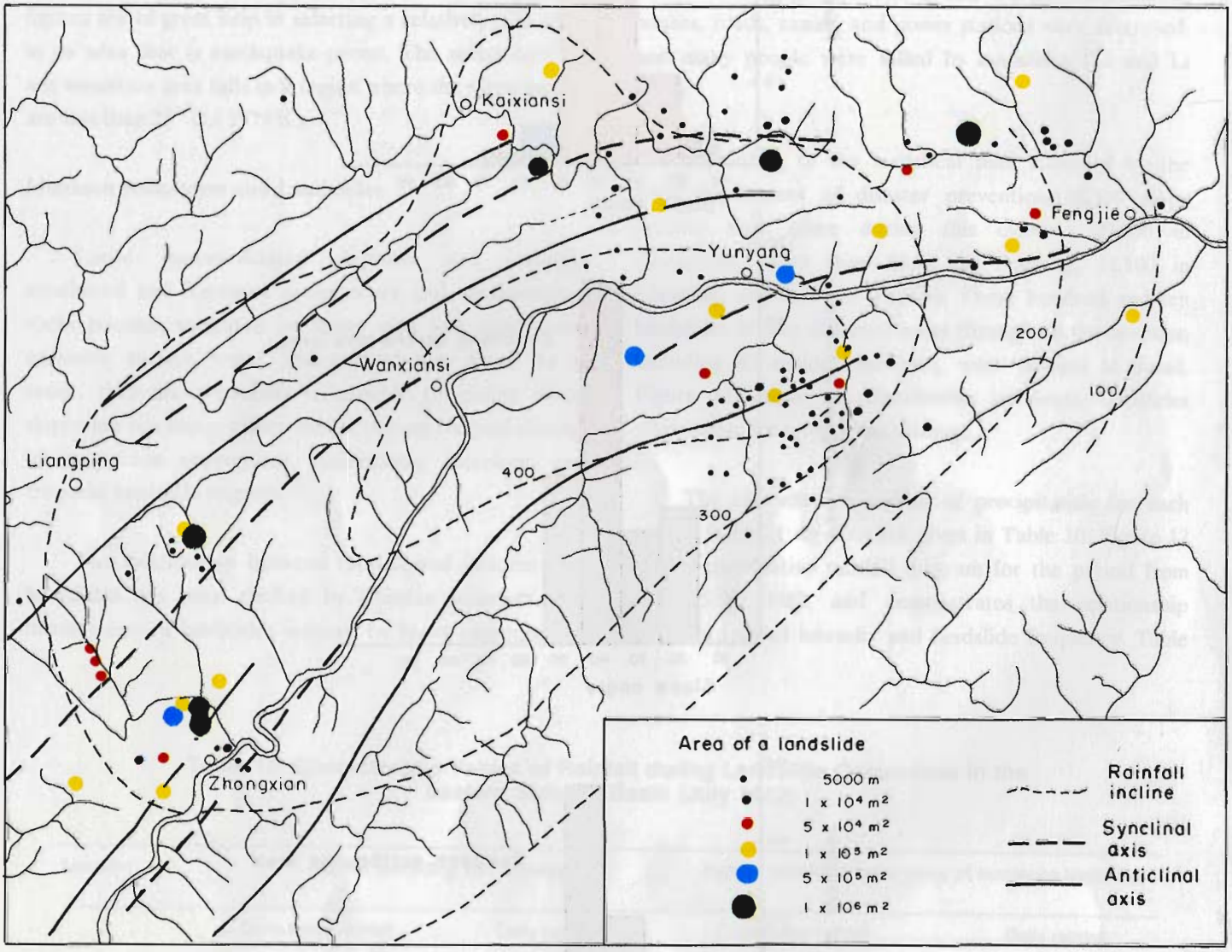
Source: Li and Li 1985

Figure 10: Relationship between Percentage of Earthquake-Induced Landslides and Slope Angle



Source : Li 1979a.

Figure 11: Distribution Map of Major Landslides Induced by Heavy Rainfall in Eastern Sichuan (July 1982)



Source: Li and Li 1985.

11 records typical examples of landslides induced by rainfall during this event.

From the data in Tables 10 and 11, as well as in Figure 12, Li and Li (1985) inferred :

- that if cumulative precipitation of the area amounts to from 50mm to 100mm in one day, and daily precipitation is more than 50mm, somewhat small-scale and shallow debris landslides will occur;
- that when cumulative precipitation, within two days, amounts to from 150mm to 200mm, and daily precipitation is about 100mm, the number of landslides will increase with precipitation; and
- that when cumulative precipitation exceeds 250mm in two days, and has an average intensity of more than 8mm per hour in one day, the number of large landslides increases abruptly.

Heavy rainfall also frequently triggers landslides in the Loess Plateau Area. In 1978, several landslides occurred in succession during the rainy season in Tianshui, Gansu Province. In 1984, during the rainy season, more than 1,000 landslides occurred in Wudu and Tianchui Prefectures, in southern Gansu. Some of the precipitation levels that have triggered landslides in this province are given in Table 12.

The relationship between rainfall and the occurrence of debris flow has been observed in the Jiangjia Ravine, Yunnan Province and the mountain area of Western Sichuan.

In the watershed of the Pabone Valley, Western Sichuan, if daily rainfall amounts to 30mm, maximum hourly rainfall intensity is more than 10mm, and maximum 10 minute rainfall intensity is above 5mm, debris flow will occur. In the Jiangia Ravine, if antecendent rainfall amounts to 10mm and 10 minute rainfall intensity is more than 2mm, debris flow will certainly occur (Tang and Li).

Table 11: Typical Landslides Induced by Rainfall in the Eastern Sichuan Basin (July 1982)

Name of Landslide	Location	Month day	Volume (10^6 m^3)	Lithology	Cumulative rainfall (mm)	Daily rainfall (mm)
Nanzhuba	Fengdu	7.16	0.7	mudstone	90.0	88.0
Shankou	Zhougxian	7.17	18.0	mudstone	310.8	171.8
Yijian	Zhougxian	7.17	2.8	mudstone	310.8	171.8
Jipazi	Yunyang	7.18	13	debris	331.0	164.1
Tianbo	Yunyang	7.17	6.2	mudstone	283.0	101.6
Geling	Yunyang	7.17	9.5	mudstone	345.7	94.9
Baigou	Fengjie	7.16	1.2	debris	138.3	58.5
Guadouzai	Liangping	7.28	5.62	debris	210.5	83.2

Source : Li and Li 1985

Table 12: Precipitation Levels Preceding Landslides in Gansu Province

Location	Day, Month, Year	Lithology	Cumulative Rainfall (10 days prior to landslide)	Maximum Daily Rainfall within the month (mm)
Tianshui	21.7.1978	Loess	82.9	200.00
Huixian	21.8.1981	Mudstone	284.0	120.00
Tianshui	3.8.1984	Loess	63.1	52.7

Source: Li and Liu 1987

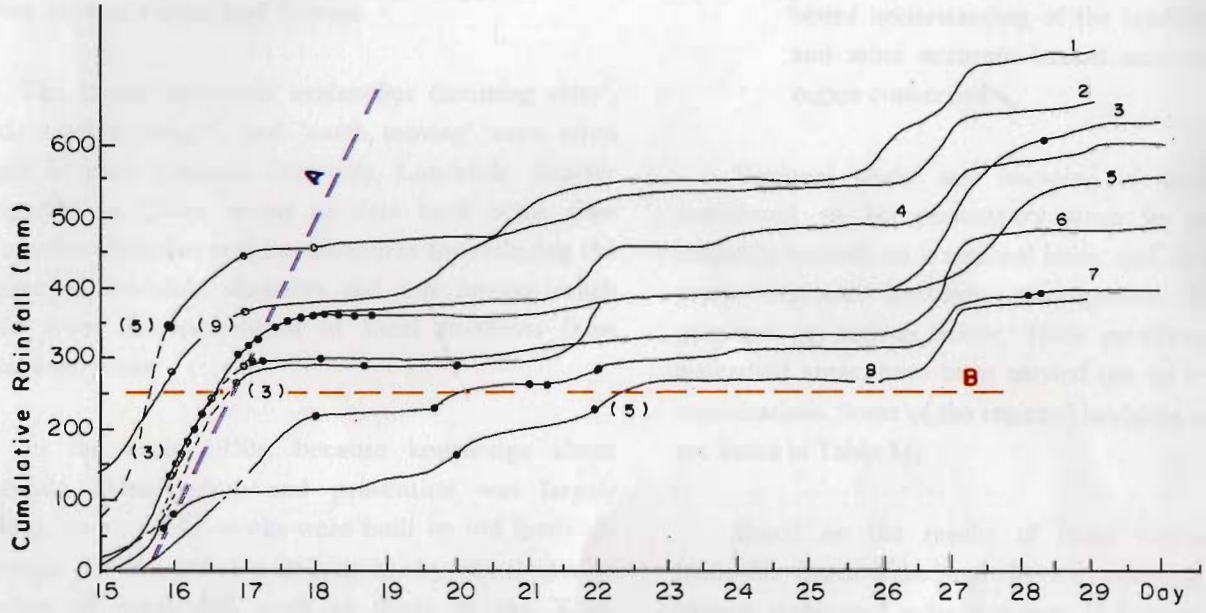
Using the data mentioned above and other statistical data, Li and Liu (1987) calculated the threshold precipitation levels that were critical in triggering landslides in different rock types in China (Table 13).

Table 13: Rainfall Thresholds for Rainfall-Triggered Landslides in Different Rock Types in China

Types of Landslide	Rainfall Intensity (mm/h)	Daily Rainfall (mm)	Cumulative Rainfall (mm) for 1 - 2 days
Small landslide of debris and loess	6.0	50.0	50 - 100.0
Medium landslide of debris and loess and fractured rocks	10.0	120.0	150.0 - 200.0
Large landslide of debris and bedrock	15.0	150.0	250.0

Source: Li and Liu 1987

Figure 12 :Cumulative Rainfall Diagram for the Eastern Sichuan Basin Based on Rainfall Records of Local Meteorological Stations (July 15-30, 1982).



Source: Li and Li 1985.

Notes :

A. Intensity of rainfall exceeding 8.5 mm/h., triggering numerous landslides.

B. Cumulative precipitation of more than 250 mm in two days, triggering numerous landslides; the individual landslide numeral in brackets is the number of landslides induced.

1. Kaixian
2. Lianghe.
3. Fengjie
4. Zhimation