

## DEBRIS FLOW DISASTER IN THE UPPER REACHES OF THE CHANGJIANG RIVER, CHINA

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### ABSTRACT

The upper reaches of Changjiang River are the most serious regions of debris flow disasters. Nearly 50 counties and cities as well as hundreds of towns are under menaces of 6 800 gullies of debris flow. Every year debris flow claims deaths of tens to hundred and causes economic loss amounting to 120-180 million US dollars, which has lagged and limited the development in the areas. Debris flow gullies are widely distributed in the Upper Changjiang, which stretches eastwards across two geomorphologic transition zones in China: 1) the transition zone from the Qinghai-Xizang Plateau, down to the Yunnan-Guizhou Plateau, where develop rainy and glacial debris flows; and 2) the transition zone from the Yunnan-Guizhou Plateau to the area of middle mountains and hills, where dominate the rainy debris flows. The concentration in the first zone mainly depends on the more favorable conditions compared to the second: such as the higher altitude, greater relief, and more concentrated precipitation. Hundreds or thousands of debris flows occur here each year. Coarse grains are playing the dominating roles, e.g. pebbles of more than 20 mm in diameter counts for 49.8% (weight percent) in average.

**KEY WORDS:** debris flow; debris-flow disasters and features; the upper reaches of Changjiang; China

### INTRODUCTION

Changjiang (Yangtze) has a drainage area of  $18 \times 10^5$  km<sup>2</sup>, 56% of which expands over 71% of

the total length, 4500km upper to Yichang, the Upper Reaches of the river. The Upper Reaches is locate in 24°28' - 35°50' N, 90°30' - 111°20' E and its drainage area is  $100.5 \times 10^4$  km<sup>2</sup>.

Debris flows in the areas are severely active, chiefly due to the complexity of geology, abundance of faults, recurrences of earthquakes, deterioration of eco-environment; and more directly, to the concentrated precipitation of typical mason climate as well as to the irrational activities of human in constructions (e.g. wanton clearance of forest and cultivation on precipitous slope) (TANG *et alii*, 1993; CHENG 1999; SHI *et alii*, 1999).

### DISASTERS OF DEBRIS FLOWS

In the last decade, debris flows have caused loss of 120-180 million dollars in the area, killed tens or hundreds each year. Historic record indicates that there were 17 events that killed more than one hundred persons between 1753-1997 (Figure 1). Damages are mainly caused to towns and villages, to factories and mines, and to other constructions.

### DAMAGE TO TOWNS AND VILLAGES

Towns and villages are commonly located on debris-flow fans in mountains because of the scarcity of land (Photo 1). About 50 counties are under the menace of debris flow, distributing in Sichuan, Yunnan, Qinghai, Gansu, Hubei, and Chongqing, and most counties had suffered from the disasters. For instance,



Fig. 1 - Map of hazard points of more than 100 people killed in one debris flow occurrence in the upper reaches of Changjiang River

a debris flow hit Badong County, Hubei, on August 8, 1991, killed and injured 58 persons, destroyed 1 394 houses, buried 70 warehouses, closed 43 factories and 110 shops. It brought about 6 million dollars of loss. In each county of Wudu, Xichang, Hanyuan, and Nanping, more than 10 debris flows occurred in the last 200 years. As to the villages and towns, they are more frequent victims. From 1950-1990, in 7 counties (Yibin, Pingshan, Leibo, Jinyang, Ningnan, Huidong, and Huili) of Sichuan, there had been fifty-two sites of severe disaster where debris flows caused death of 171 and loss of 5 million dollars (ZHANG *et alii*, 1995). On July 12, 2003, debris flow in Qionghangou gully in the upper Dadu, Danba county, caused 51 death and missing, and brought damage to more than 5000 people.

#### DAMAGE TO FACTORIES AND MINES

There are 20 large and medium mine fields under the threat of debris flows in Sichuan, Yunnan, and Guizhou. On May 27, 1984, a debris flow hit Yinmin copper mine, killed 120 people, destroyed almost all the facilities, closed the mine, the school and the market for half a month, resulted in a loss of 1.5 million dollars (TIAN, 1986). As another case, 34 deaths and 29 injuries were claimed by a debris flow in Yimen mine, Huili, Sichuan, on May 31, 1990, which devastatingly destroyed the factories and buildings and caused a loss of 500 thousand dollars.

Railway lines in the area, especially the major Chengdu-Kunming line (the CK line), Chengdu-Baoji line, and the branch Kunming-Dongchuan line are famous for their disasters of debris flows.



Fig. 3 - Debris flow blocks river course, harm traffic and farmland in Dongchuan, Yunnan

There are 511 debris-flow gullies along the CK line. Since July 1, 1970 when the whole line joined up, there have been 18 stations buried by debris flows that overturned 3 trains, washed out 2 bridges, and killed more than 370 persons. Along the 627km of Chengdu-Baoji railroad there are 159 debris flow gullies, and 134 debris flows occurred in 1981, which buried seven station and blocked the traffic for more than 60 days. To be compounded, the Dongchuan branch railway has 86 debris flow gullies within 50 km in the south, which have frequently destructed bridges and tunnels since it operated in 1964 and finally broken the line in late 1980s (Photo 3).

Highways are also often blocked in rainy seasons by debris flows in the area. For example, debris flow in the Harmu gully in Lixian, Sichuan caused a month of suspension of the No. 213 national line from Lixian to Wenchuan in 1989 (XIE *et alii*, 1994). Recently, a 400m road in Songpan was inundated by water

dammed by debris flow in Minjiang River. Statistics indicates that some 2 000 thousand dollars had been cost in reconstructing the destroyed lines only in 1986.

Navigation is also blocked by debris flows. For instance, 99 debris flows have formed beaches in the center of the river, which have so far suspended the navigation in the upper stream from the Xinshi town (near the county of Leibo).

#### *DAMAGE TO AGRICULTURE*

Debris flows destroy agriculture generally by inundation, washing, siltation and impact. For example, in Qiaojia, Yunnan, 171 ha farmlands were buried by a debris flow on August 24, 1980, lost ripening rice and sugar-cane of about 2800 t. Moreover, an event on May 6, 1989 buried 134 ha lands of sugar-cane, destroyed water-conservancy systems including 13 drainage channels and a 1800 m dam, and brought about damages in monetary of 200 thousand dollars to 17 villages with more than 4 000 habitants.

#### *DAMAGE TO LIVING CONDITIONS*

The high mountains and precipitous slopes in the upper Changjiang and at the same time threatened by debris flows that would once and forever destroy the cultivated lands and limit cultivation of land. For instance, in June and July in 1981, debris flows in Laoshugou of Qiaojia washed and buried farmlands of 24 ha, and forced 14 families to relocate.

#### *DAMAGE TO HYDROPOWER ENGINEERING*

Water power available in the upper Changjiang amounts to  $1.7 \times 10^8$  kw, 45% the total in China. But the utilization is constantly under the menace of debris flows. There are 146 and 271 debris-flow gullies in the area of Ertan Hydroelectric Power Station and the Three Gorges. Debris flows reduce the reservoir capacity and adjustability of power production due to siltation of sediments. For example, the Gongzui Power Station in the lower Daduhe River had an average sediments yield of  $3.5 \times 10^7$  t/yr in 1971-1990, but an annual yield of  $10^8$  t in 1989 when the summer witnessed debris flows on the eastern slope of Mt. Gongga. Entrance of sediments cut operating life of station, as confirmed by so many small scale stations. For examples, 23 out of 32 stations in Maoxian County of Sichuan were devastatingly destroyed by debris flows in July, 1981.

#### *DAMAGE TO RIVERS*

Debris flows carry large quantity of sediment into main streams lift the water level and enforce the destructive power. The Xiaojiang basin is one of the most serious areas of debris flow, it extends 139 km northwards and has 123 tributaries along both sides, of which 107 gullies are concentrated within 90km and form 78 fans in the lower river (DU *et alii*, 1987). Some gullies are active in their fans making at the mouths as typically shown by the Dabaini gully who had in the past 30 years extended its fan area from 0.52 km<sup>2</sup> to 1.43 km<sup>2</sup>, lifted depth of 20.7 m, accumulated volume of  $2.4 \times 10^7$  m<sup>3</sup>. Another case is the famous Jiangjia gully, having its fan area up to 2.6 km<sup>2</sup> with radius of 1.6km on average, top depth of 100m, and volume of  $7.4 \times 10^7$  m<sup>3</sup> (WU *et alii*, 1990). As a result, the Xiaojiang is constantly in course of bed uprising and stream winding, compounded by flood inundating in rainy season and sand devastating in drought (Photo 3).

#### **CHARACTERISTICS OF DEBRIS FLOW QUANTITY AND TYPE**

There have been 6 800 gullies of debris flow recorded in the upper Changjiang; and the special physical location and great relief and differentiation in rocks determine the diversity and intensity of debris flows (XIE *et alii*, 1994), Table 1 indicates a complete set of debris flow type only with the exception of volcanic case.

#### *DISTRIBUTION*

The upper Changjiang transverses two geomorphologic zones: 1. transition zone from the Qinghai-Tibet Plateau of more than 4 000m a.l.t. down to the Yunnan-Guizhou Plateau of 1000-2000 m a.l.t, including regions of Hengduan Mountains, mountain areas around the Sichuan Basin and in the south of Gansu, where develop rainy and glacial debris flows that are especially active in northeastern Yunnan, western Sichuan, and southern Gansu; and 2. transition zone from the second terrace to the areas east to the Wu Mountains of 500m a.l.t., covering regions of Mts. Dalou, Wu, and Daba, where develop debris flows in 920 gullies and slopes. Great relief is responsible for the distribution. In particular, the concentration of debris flow in the first zone is mainly dependent upon the facilitating conditions.

The area is near the collision zones of Indian and Ore-Asian plates where the tectonic actions are strong with deep and large faults and frequent earthquakes.

Group indication	Type	Example (corresponding to type)
Geomorphologic condition	Gully- and slope-debris flow	Shiyang in Dongchuan, Yangjia in Fengjie
Solid composition	Mud- and rock- debris flow	Buzuwan by C.K line, Donghe in Xichang
Fluid property	Viscous, sub-viscous, and dilute debris flow	Huoshao in Wudu, Caogou in Leshan, Masixi in Ebian
Water condition	Rainy, glacial, and lake-broken debris flow	Shiwo in Fengxian, Wachang in Kangding, Baipingtang in Cangxi
Solid source	Landslide-, channel-erosion-, slope-erosion- debris flow	Xikou in Huaying, Yonglang in Dechang, Liucun in Fengxian, Railroad station 1 in Dechang
Frequency	High-, moderate-, and low-frequency debris flow	Dabaini and Daduo in Dongchuan, Taoguan in Maoxian
Human activity	Natural and man-induced debris flow	Liziyida in Ganluo, Yanjing in Mianning
Scale	Extreme-, large-, moderate-, and small-scale debris flow	Qipingsi in Nanjiang, Caijia in Dechang, Santanzhongqiao in Panzhuhua, Long in Leshan
Evolution stage of gully	Developing, active, decline, terminating	Railroad station 1 in Xide, Jiangjiagou in Dongchuan, Xiaojie in Miyi

Tab. 1 - Debris flow types in the upper Changjiang

This results in slope instability and erosion as the causes of debris flows. Along the faults develop rivers of Baqu-Benzilan of Jinshajiang, Anninghe, Xi-anshuihe, Longchuanjiang, Zemuhe, Xiaojiang, and Bailongjiang, where debris flows are concentrated with 12 gullies per 10km, and occur in frequency as high as 6-28 cases a year in Jiangjiagou gully (DU *et alii*, 1987).

Most debris flows develop in valleys smaller than 4 km<sup>2</sup>, counting for 72.7% of the total, as revealed by a statistic conducted in the CK line with 366 debris flows within the Sichuan (Chengdu Institute of Mountain CAS 1990). And in 6 counties in the lower Jinsha, gullies smaller than 10 km<sup>2</sup> count for 67.3% out of 346; and for the Reservoir of Sanxia, 70.1% out of 271 gullies are smaller than 5 km<sup>2</sup> (DU *et alii*, 1990) Along the Chengdu-Baoji railroad, 74% gullies are below 2 km<sup>2</sup>.

The upper Changjiang spans 11°22' of latitude and has a relief between 2 500-3 500 m, accompanied by the striking horizontal and vertical zonality of alpine climate which are not concerned with the development of debris flows.

### FREQUENCY

Debris flow is frequent in the study area. In every year occur hundreds or thousands of occurrences. Some are recurrent, such as Daqiaohe, Dabaini, Xi-aobaini, Jiangjiagou, in Dongchuan, Yunnan, and Huishaoqou, Beiyugou, Liuwangou, in Wudu, Gansu, and Xiahuangtian in Miyi, Sichuan. For instance, be-

tween 1965-1994 (with a data loss of 1986), Jiangjiagou gully had a record of 362 occurrences (WU *et alii*, 1990; ZHANG & XIONG 1997), especially with the extreme recurrences of 28 in a year (Rapp, A *et alii*, 1991). Liuwangou gully has 11 occurrences in annual average, and Huoshaogou, 3-4(Lanzhou Institute of Glaciology and Gocryology, CAS, and Institute of Communication Science, Gansu 1982).

### TRANSPORTATION CAPACITY

Debris flows are of great power in carrying large quantity of sediment and blocks from the source areas to the deposition areas or into the main rivers (Table 2). Deposits of debris flows are characterized by the poor-sorted and large-ranged particles, covering a radius domain of magnitude 10<sup>7</sup>. The biggest boulder measured in debris flows in the area of Dadu river is of 10 m×6 m×4 m. Coarse grains are playing the dominating roles, e.g. pebbles of more than 20 mm in diameter counts for 49.8% (weight percent) in average, as confirmed by 69 samples chosen out from Niurihe (a tributary of Dadu River), Anninghe and the tributary Sunshuihe, and Yalongjiang, as well as other tributaries of Jinsha (Table 3).

### SCOUR AND SILT

Intensive scour and silt are major effects of debris flows and also the most active agents sculpturing landform. A debris flow in August 1981 scoured the

Gully	Location	Drainage area (km <sup>2</sup> )	Sediment (10 <sup>3</sup> m <sup>3</sup> )	Duration (hour)	Occurring date
Hanluogou	Mianning,Sichuan	3.22	10.0	0.1	May 14, 1972
Shi'aozigou	Dangchang,Gansu	13.56	50.0	7.0	July 25, 1976
Dadegou	Dongchuan,Yunnan	14.30	132.5	1.0	June 30, 1981
Liziyidagou	Ganluo,Sichuan	24.32	84.0	1.0	July 9, 1981
Lieguluoduo	Ganluo,Sichuan	38.24	20.0	0.5	July 1, 1984
Jiangjiagou	Dongchuan, Yunnan	41.70	110.8	7.2	July 13, 1991

Tab. 2 - Sediment transportation of several debris flows

River basin	Diameter of rain (%)				Samples
	>20mm (%)	20-2mm	2-0.06mm (%)	0.05mm (%)	
Sunshuihe River	47.5	26.3	18.3	8.0	36
Niurihe River	43.6	22.0	24.3	10.2	11
Anminghe River	43.9	32.0	19.0	5.0	13
Lower Yalongjing River	64.8	13.0	20.0	2.2	1
Lower Jinshajing River	53.0	24.6	15.5	6.9	6
Lower Daduhe River	45.8	18.7	23.3	12.2	1
Upper Minjiang River	54.3	22.5	18.5	4.7	1

Tab. 3 - Grains consists in debris-flow samples (in percentage of weight)

channel down to 7-13 m. And a landslide-turned debris flow on September 14, 1974 in Baimeiya, Nanjiang, Sichuan, swept its way of 4 900 m from the landslide ( in volume of  $7 \times 10^6 \text{ m}^3$ ) to deposit ( in a fan of  $107 \text{ m}^3$ ) in less than 5 minutes. It eroded the bedrock channel up to more than 10m, formed a fan of  $2.5 \times 10^5 \text{ m}^2$ , caused a 50-60 m thick siltation in the base of Qipingsi gully. Besides, it blocked Banqiao gully and dammed  $1.3 \times 10^5 \text{ m}^3$  of water. An action in several minutes, and an effect of great change, one can feel with it at this case. As for Jangjiagou, debris flows had blocked Xiaojiang 16 times from 1919 to 1968. The 1968 blockage lasted as long as 3 months, lifting water level by 10m, inundating farm lands and villages along.

**CONTROL OF DEBRIS FLOW**

Since 1949, measures preventing and controlling of debris flow have been adopted in the upper reaches of Changjiang. Measures including engineering structures, plantation, prediction and warning, as well as danger degree division have reduced losses to a certain extent (Photo 4).

Debris flow lags and limits economic development in mountainous areas in the upper reaches of Changjiang. Further studies on theory and control measurements are urgent.



Fig. 4 - Check dam for prevention debris flow in Heishui, Sichuan

Debris flow is one of the most vital agents of geology, especially in destroying environment and accelerating landform change as well as affecting human activities through erosion, siltation, scouring, transportation and deposition. Debris flows in this area present a variety of appearances and provide a stage for practice of various control measurements.

**CONCLUSION AND ACKNOWLEDGMENTS**

This study is supported by Chinese Ministry of Water Conservation Special Fund for Public Welfare Industry Project.

The monitoring and prevention for dam-break flood by landslide and debris flow in the upper Minjiang River.

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