IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

The mountain torrent disasters and its effect on sediment transport after the Wenchuan earthquake

To cite this article: H R Ding *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **344** 012159

IOP Conf. Series: Earth and Environmental Science **344** (2019) 012159 doi:10.1088/1755-1315/344/1/012159

The mountain torrent disasters and its effect on sediment transport after the Wenchuan earthquake

H R Ding[1,2], Y Li[3,5], S J Ni[1], C J Shao[3], Z M Shi[1], L Yan[3], L Q Lv[3], T Ni[4], R H Gong[4], L Shi[4] and Y X Liu[4]

[1]School of Earth Science, Chengdu University of Technology, Chengdu, Sichuan Province, 610059, China
[2]State Key Laboratory of Geohazard Prevention and Geoenvironment Protection Chengdu University of Technology, Chengdu, Sichuan Province, 610059, China
[3]School of Energy, Chengdu University of Technology, Chengdu, Sichuan Province, 610059, China
[4]College of Environment and Civil Engineering, Chengdu University of Technology, Chengdu, Sichuan Province, 610059, China

E-mail: liy@cdut.edu.cn

Abstract. By analyzing the formation causes of the mountain torrent disasters as well as the distribution characteristics of rainstorm in Longmen Mountain area, and citing the typical post-seismic the mountain torrent disasters within 2008~2013 after the Wenchuan earthquake in the area as example, the character of post-seismic floods, the spatial distribution of the devasting post-seismic debris flows, the critical rainfall to trigger the mountain torrent disasters and so on are explored. Besides, the sediment before and after the Wenchuan earthquake of the Minjiang watershed are compared. The conclusions are as following: (1) The time of the post-seismic flash floods and debris flows after the Wenchuan earthquake are centered from July to September, which is consistent with the rainfall of the area. (2) Rather than the debris flows are triggered when the rainfall intensity reached the critical rainfall intensity, those are closely linked with the pre-accumulated rainfall. That is to say, the more pre-accumulated rainfall, the more probability of the debris flows. (3) After the Wenchuan earthquake, the total sediment increases 13.8%~70%. But the increasing range is varied from year to year. In the year when the debris flow occurred, the sediment shall increase drastically.

1. Introduction

Debris flow is one kind of special flows which is caused by flash flood, snowstorm, or other natural disaster in a mountainous area with deep gullies and steep terrain. In the paper, the post-seismic debris flow means the debris flow caused by flash flood after the Wenchuan earthquake [1]. It is the superposition effect of the earthquake and the results of the storm, mainly occurred in the process of a sudden rainstorm after the earthquake or the outburst of the earthquake barrier lake. It has the characters of sudden, high flow rate, large flow, large material capacity and destructive power.

On May 12, 2008 14:28 Wenchuan 8.0 strong earthquake triggered a large number of collapse, landslide and other geological disasters, which are rare in the world due to their large number, wide distribution, complex type and huge damage [2]. After the Wenchuan earthquake, the flash flood and debris flow disasters occurred frequently in Longmen Mountain area, especially during the flood season from July to September, 2008-2013. Through a large number of field research work, experts and scholars have done a lot of research work in terms of the formation conditions, the dynamic mechanism, the characteristics and causes of flash flood and debris flow disaster, and obtained a large number of research results. However, the previous studies on the relationship among heavy rainfall, flash flood and sediment transport are not in-depth enough. In fact, co-seismic landslides, the erosion, sediment transport and diffusion, and sedimentation caused by the post-seismic flash flood are important factors to affect the surface erosion and geomorphic growth of mountains [3,4]. The co-seismic landslides, post-earthquake flash floods and debris flows can bring a large amount of sediment input to the basin, which results in a huge increase in sediment transport. The increase range of sediment transport is 2-10 times, and the erosion rate can reach 0.2-7 mm/a [5]. Predecessors have long been put forward in the study that the debris flow caused by post-seismic flood should be studied, because of the pernicious characters of the sudden outbreak, large inertia, high velocity, a strong momentum, and carrying heavy loads of sediment into the river. If serious, it can jam the river and form the barrier lake, whose burst can cause the secondary disasters for upstream and downstream. Even the part jams can change river regime, sediment conditions and water flow. After the Wenchuan earthquake, large amount of the debris and sediment caused by landslide and sediments are still preserved in the riverbed, whose transmission process in the river system will have an important impact on the water conservancy projects and agricultural irrigation in the basin and downstream areas. Therefore, it is of great theoretical and practical significance to study the effect of flash flood, debris flows and their effects on sediment transport after Wenchuan earthquake for the post-disaster reconstruction in Wenchuan earthquake area and the water conservancy construction, water and soil conservation, and secondary disaster prevention and control in the Minjiang, Tuojiang and Fujiang river basins and their downstream areas in Longmenshan area.

2. Background

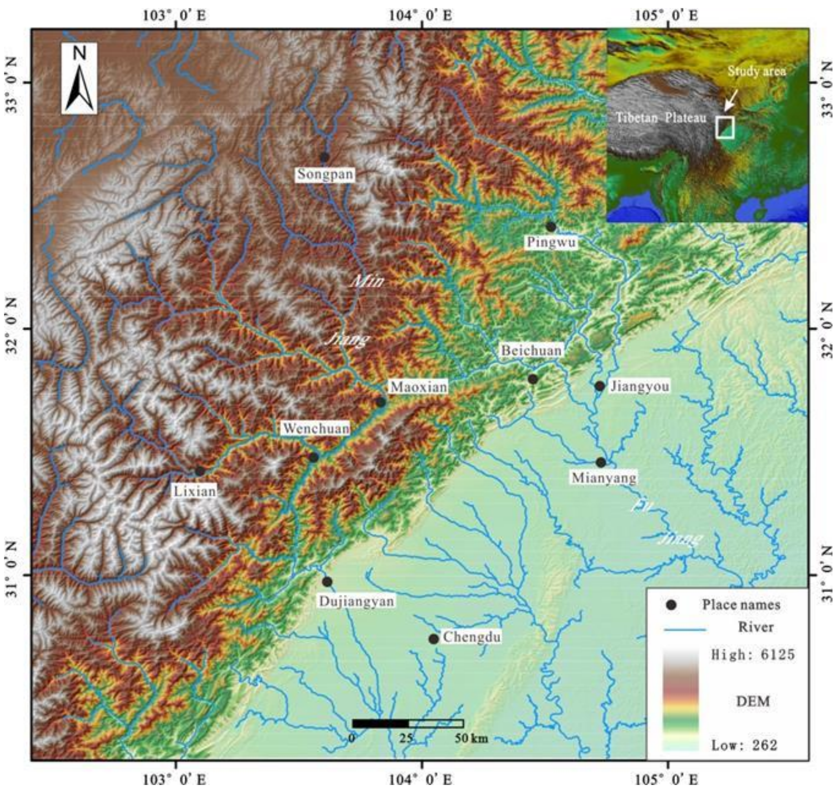

Figure 1. Geomorphologic and water system map of Longmen Mountain area.

Longmen mountain area is located in the abrupt change zone of geology, landform and climate in western China, which is the birthplace of Jialing River, Minjiang River, Fuljiang River, Tuo River, Dadu River and Qingyi River (figure 1). The main type of river system in the area is transverse river, whose flow direction is nearly vertical to Longmen Mountain. The river in the area can be divided into two kinds [5]. The first kind is through type rivers (the middle and southern of the upper reaches of Minjiang river, fu river and Jialing river, etc.), which originated in the west of Longmen Mountain. The Minshan, and Longmen Mountain act as watershed. Those rivers are composed of east-west sections and north-south sections, cross Longmen Mountain, and enter Sichuan basin. The second type is the piedmont rivers of Longmen Mountain, which originated in the east range of Longmen Mountain and consist of only east-west transverse river sections. Those cut through the piedmont area of Longmen Mountain (such as the north upper reaches of the Minjiang river) and enter the Sichuan basin (figure 1).

3. The main factors to form the mountain torrent disasters in the area

Longmen Mountain is located in the eastern edge of Qinghai-tibet plateau. Rainfall is mainly controlled by the east Asian monsoon. From July to September, east Asian monsoon airflow passes through the Longmen Mountains from southeast to northwest. On the windward side of the eastern side of the Longmen Mountains, the enhanced precipitation under the influence of the terrain reaches 1600~2000 m/a, which is significantly. Heavy rainfall will inevitably lead to a large number of landslides and rapid mass loss of Longmen Mountain. While on the leeward side of the western Longmen Mountains, the precipitation is greatly reduced, which result in arid grasslands and deserts, and the erosion is significantly reduced. Those are beneficial to the formation of the Qinghai-tibet plateau on the west (behind) of the Longmen Mountains.

4. Distribution character of rain storm in the area

The distribution of rainfall in the Longmenshan area, which is on the eastern edge of the Qinghai-tibet plateau is mainly affected by the warm and humid air flow from the southeast. The ease slope of the mountain is windward slope with abundant rainfall. It is one of the rainstorm centers in Sichuan province and known as Lutoushan rainstorm area. The warm and humid airflow of the southeast monsoon is blocked by the Longmen Mountain, and the precipitation is formed by the uplift of the airflow. The rainstorm center is formed in the mountain front area, while the Minjiang river valley area, located on the west lee slope, has a dry climate and a rainless area.

5. Rainfall character in the area after the Wenchuan earthquake

It can be seen from table 1 that: (1) the annual average rainfall of the region where the flash flood and debris flow disaster occurred is large. (2) Comparing the critical rainfall intensity and maximum 1 h precipitation, the higher the previous accumulative rainfall, the easier to trig debris flow. (3) Because the cumulative rainfall increase rapidly near the maximum rainfall intensity, flash floods and debris flows outburst suddenly within short period. And most of the flash floods and debris flows occur at the maximum or near the maximum rainfall intensity.

Table 1. Rainfall parameters of typical debris flows after the Wenchuan earthquake [6-9].

No.	Gully Name	Location	Water Basin	Time	Critical Rainfall Intensity (mm/h)	Average Annual Rainfall (mm)	The Accumulated Rainfall (mm)	The maximum Rainfall Intensity (mm/h)	Fault
1	Hongcun	Wenchuan	Minjiang	2010/8/14	16.4	1253.1	171	36.5	Yingxiu-Baichuan
2	Taipingyi	Wenchuan	Minjiang	2010/8/14	16.4	1190.9	126.1	32.2	Yingxiu-Baichuan
3	Xiaojia	Wenchuan	Minjiang	2010/8/14	16.5	1253.1	163	32	Yingxiu-Baichuan
4	Niujuan	Wenchuan	Minjiang	2010/8/14	16.4	1253.1	40.2	27.6	Yingxiu-Baichuan
5	Gaojia	Wenchuan	Minjiang	2011/7/3	22.5	932.6	213.1	/	Yingxiu-Baichuan

6	Guxi	Wenchuan	Minjiang	2013/7/10	17.1	1200	210.2	24.1	Yingxiu-Baichuan
7	Zhutou	Wenchuan	Minjiang	2013/7/10	18.6	1222	148.1	18.6	Yingxiu-Baichuan
8	Taoguan	Wenchuan	Minjiang	2013/7/10	/	1253.1	67.3	20	Yingxiu-Baichuan
9	Yangling	Wenchuan	Minjiang	2013/7/11	/	1253.1	67.3	20	Yingxiu-Baichuan
10	Zoumaling	Qingping	Mianyuan	2010/8/13	38	1086.4	166	70	Yingxiu-Baichuan
11	Wenjia	Qingping	Mianyuan	2010/8/13	38.7	1086.4	137.6	49.8	Yingxiu-Baichuan
12	Xiaogangjian	Qingping	Mianyuan	2011/7/4	46.4	1086.4	136.5	46.4	Yingxiu-Baichuan
13	Yongjia	Qingping	Mianyuan	2012/8/18	16.3	1086.4	171.2	49.8	Yingxiu-Baichuan
14	Huashiban	Beichuan	Subaohe	2008/9/24	53.1	1399	72.8	57.2	Yingxiu-Baichuan
15	Xishanpo	Beichuan	Subaohe	2008/9/24	41	1399	272.7	62.1	Yingxiu-Baichuan
16	Weijia	Beichuan	Subaohe	2008/9/24	41	1399	231.7	61	Yingxiu-Baichuan
17	Chafangcun	Beichuan	Subaohe	2008/9/24	41. 8	1399	163.1	61	Yingxiu-Baichuan
18	Dagan	Dujiangyan	Longxi	2009/7/17	/	1225.7	/	134	Yingxiu-Baichuan
19	Bayi	Dujiangyan	Longxi	2010/8/13	21.1	1134.8	96.1	75	Yingxiu-Baichuan
20	Maliu	Dujiangyan	Longxi	2010/8/13		1134.8	150	75	Yingxiu-Baichuan
21	Maliu	Dujiangyan	Longxi	2010/8/18	69	1134.8		69	Yingxiu-Baichuan
22	Gaojiazi	Pengzhou	Baishui	2012/8/18	72	1450	247	65	Yingxiu-Baichuan
23	Yinchang	Pengzhou	Baishui	2012/8/19	41	1450	227.1	70.3	Yingxiu-Baichuan

6. Sediment transport comparison before and after the Wenchuan earthquake in the upper reaches of Minjiang River

After the Wenchuan earthquake, the author has repeatedly field trips to the earthquake zone. Along the way, it was found that a large amount of loose debris caused by the earthquake accumulated in the valleys. When heavy rain, the debris shall be carried into the river in the form of debris flow, which leads to the river water become muddy and high sediment, far higher than that before the Wenchuan earthquake. Taking the upper minjiang river basin as an example, the effects of rainstorm and flood on sediment transport before and after the Wenchuan earthquake shall be compared.

Table 2. Correlation between precipitation and sediment Discharge in Minjiang river basin before and after the Wenchuan earthquake.

Year	Runoff (108m^3)	Annual Sediment Discharge (104t)		
		Minjiang Hydrometric Station Y=5.7595X-4.3183	Zipingpu Hydrometric Station Y=5.9823X-79.498	Dujiangyan Hydrometric Station Y=0.3487X+424.23
2000	110.46	632.45	581.9	642.93
2001	115.39	660.21	610.74	695.97
2002	106.54	609.29	557.86	600.71
2003	118.31	677.03	628.21	727.39
2004	112.73	644.95	594.89	667.34
2005	121.05	692.87	644.66	756.92
2006	109.07	606.6	572.99	628.00
2007	118.65	679.05	630.28	730.98
2008	129.75	965.87	905.71	1105.63
2009	117.19	871.85	808.05	929.92
2010	172.62	1286.85	1239.19	1705.54

According to the analysis of relationship between monthly precipitation and monthly sediment discharge in Dujiangyan from 2000 to 2010, the annual precipitation and annual sediment transport in Dujiangyan are significantly correlated with the correlation coefficient R=0.9707 and the correlation equation is Y=0.3487X+424.23. Based on this, the annual sediment discharge volume in the upper reaches of Minjiang River from 2000 to 2010 was calculated in this paper (table 2).

Table 2 shows that, according to the correlation equations between precipitation and sediment discharge established by Dujiangyan hydrometric station, the calculated annual sediment discharge is greater than the measured values. The main reason is that Dujiangyan is located in the heavy rain zone of Longmen Mountain areas, and the annual precipitation of the zone is greater than the average annual precipitation values of the whole area. Because the precipitation and sediment discharge are high correlated, the calculated sediment discharge value is greater than the measured values. While the calculated annual sediment discharge values are with little difference from the measured values according to the correlation equations between precipitation and sediment discharge established by Zipingpu hydrometric station and Minjiang hydrometric station. And the calculated sediment discharge value according to the correlation equations established by Zipingpu hydrometric station is slightly less than that calculated according to the correlation equations established by Minjiang hydrometric station. Based on comprehensive consideration, it is considered that the calculated value according to correlation equations established by Zipingpu hydrometric station is close to the measured value.

As can be clearly seen from figure 2, the annual sediment discharge volume of Zipingpu in 2007 was 6.3028 million t. And that in 2008 was 9.0571 million t, which was 27.56% higher than the average annual sediment discharge volume (7.1 million t) before the earthquake. The annual sediment discharge volume in 2009 was 8.0805 million t, 13.8% higher than that before the earthquake.

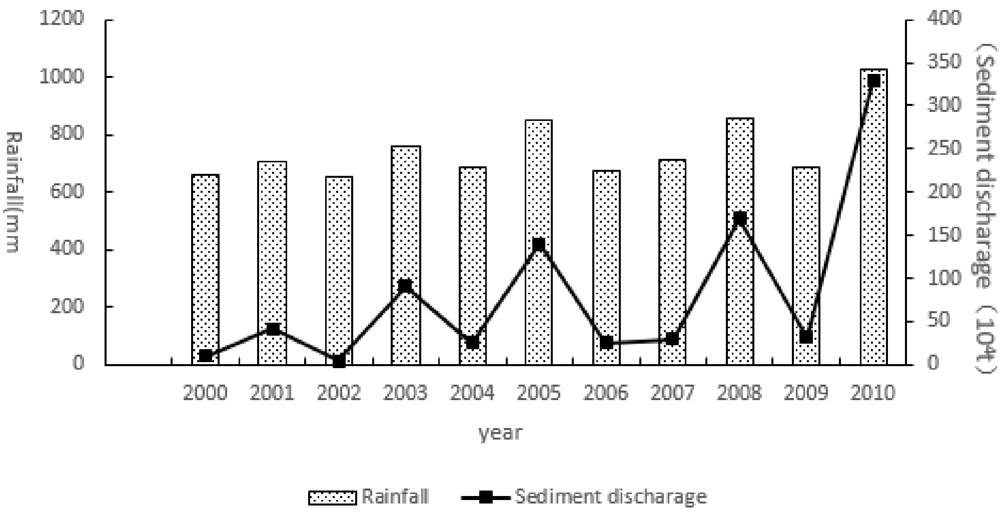

Figure 2. Rainfall, Sediment discharge comparison before and after the Wenchuan earthquake in the upper reaches of Minjiang River.

In 2008 and 2009, there were no floods or debris flows in the upper Minjiang river basin, but the sediment discharge volume increased by about 30% compared with the annual average. In 2010, the annual sediment discharge at Zipingpu was 12.3919 million tons, which was 1.75 times of the annual average before the earthquake. The significant increase in sediment discharge is mainly due to the devastating floods and debris flows on August 13 and August 18 in the basin in 2010, and large amounts of loose solid debris were transported to the river in the form of debris flows. In 2010, the annual precipitation reached 2545.8 mm, much higher than the average multi-years rainfall before the earthquake. Only in August 2010, the sediment discharge volume in Zipingpu accounted for 58.55% of the total sediment discharge in the year. It can be seen that after the Wenchuan earthquake, the sediment discharge in the upper reaches of Minjiang River increased by 13.8%-70% on the whole, and the increase rate of sediment discharge was also in the process of change. Only in the years in which rainstorm and debris flows occurred, the sediment discharge volume increase sharply. In addition, the sediment discharge volume does not increase uniformly in each month, but increases greatly in the month when rainstorm debris flow occurs. Therefore, after the Wenchuan earthquake, as long as there is no rainstorm or debris flow disaster, there will not be a huge increase in the amount of sediment discharge volume in the river.

7. Conclusion

The enlightenment of Wenchuan earthquake is that the landscape of the mountain shall be changed in a very short period of time because of the earthquake tectonic process, while it often takes decades to hundreds of years for river system to adjust the disturbed balance. Therefore, climate change on a time scale of several decades to several hundred years in relation to the erosion of the entire mountain can lead to scour - cut landforms. In particular, the heavy rainfall caused by the unique topography of Longmen Mountain increases the erosion and produces a huge amount of landslides and debris flows, which slow down the growth rate of Longmen Mountain.

Acknowledgment

This study was sponsored by the Natural Science Foundation of China (Grant NO. 41602306, 41741003); Key national research and development projects in the 13th five-years plan (2017YFC1501000), Sichuan science and technology department project (2017JY0140), Earthquake science and technology special project of Sichuan earthquake administration (LY1910); Sichuan science and technology department project (2018124). We are grateful to the data provided by the bureau of hydrology and water resources survey in Sichuan Province.

References

[1] Ding H R, Li Y, Zhao G H *et al* 2013 Analysis of flash flood formation character and cause in the upper reaches of Minjiang River after Wenchuan earthquake *J. Catastrophol.* **28** 14-9
[2] Huang R Q and Li W L 2008 Research on development and distribution rules of geohazareds induced by Wenchuan earthquake on 12th May, 2008 *Chinese Journal of Rock Mechanics and Engineering* **27** 2585-92
[3] Li Y, Li B, Zhou R J *et al* 2007 The quantitative correlation between denudation volume and sedimentary flux in the denudation-accumulation system: Examples from Minjiang River drainage system *Acta Geologica Sinica* **18** 332-43
[4] Parker R N, Densmore A L, Rosser N J *et al* 2011 Mass wasting triggered by the 2008 Wenchuan earthquake is greater than orogenic growth *Nat. Geosci.* **4** 449-52
[5] Bruce D M, Donald L T, Fausto G *et al* 2004 Landslides, earthquakes, and erosion *Earth and Planetary Science Letters* **229** 45-59
[6] Li Y and Huang R S 2009 Basic features and research progresses of Wenchuan Ms 8.0 earthquake *J. Sichuan Univ. (Eng. Sci. Ed.)* **41** 7-26
[7] Yang F R, Zhou H W, Huo M *et al* 2016 Rainfall induced debris flow characteristics and mechanisms of plagues after the outbreak of the earthquake in Wenchuan *China Rural Water and Hydropower* **12** 38-42
[8] Yu T B, Ren G M, Wang M *et al* 2014 Preliminary investigation on zonal control pattern of debris flow in Shengou small watershed in Dongchuan, Yunnan Province *The Chinese Journal of Geological Hazard and Control* **25** 9-13
[9] Chang M, Dou X Y, Fan X M *et al* 2018 Critical rainfall patterns for rainfall-induced debris flows in the Wenchuan earthquake area *Geoscience* **32** 623-30