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Post-Seismic Floods after the 2008 Wenchuan (Ms8.0) Earthquake in the Minjiang River, Sichuan, China

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On May 12, 2008, devastating Wenchuan (Ms8.0) earthquake occurred in Longmen Shan area, Sichuan Province, China, which had the character of high magnitude, long rupture zone, severe damage, strong and frequent aftershocks. The earthquake triggered a large number of collapse, landslide, dammed lake and other secondary disasters. On September 24, 2008, after four months of the Wenchuan earthquake, Beichuan County was attacked by heavy rainfall, which triggered a largescale debris flow and killed more than 40 persons, thousands of acres of fertile land and houses were washed away or buried. On August 13, 2010 and August 17, 2012, heavy rainfall triggered severe group-occurring postseismic floods in the upper reaches of Minjiang river, and caused huge losses of people's lives and property. Within the 5 years after Wenchuan earthquake, floods disaster occurred in 3 years and triggered a significant hazard to the post-disaster reconstruction again. So post-seismic flood has become one of the most important natural disasters in Sichuan.Based on "8.13" and "8.18" devastating floods in 2010 in the upper reaches of Minjiang River, this paper attempts to analysis the relationship among rainfall, runoff and flood, and study on control factors and the mechanism of the post-seismic flood.

There are many floods and mudflow occureed after Wenchuan Earthquake in Longmen Shan region(Fig.1-2). Here we just summarize the floods after the Wenchuan earthquake in the upper reaches of Minjiang River. On " 8.13 "and " 8.18 " of 2010,heavy rainfall attacked Yingxiu town in the upper reaches of Minjiang River, and triggered a mass of flood disaster in Yingxiu town. According to data of Yingxiu meteorological station, on August 12, 2010 the total rainfall in Yingxiu town was 19.9mm; on August 13 the cumulative rainfall was 126.8mm, maximum hourly rainfall intensity was 32.2mm/h; on August 14 cumulative rainfall was 23.4mm. The total rainfall amounted to 162.1mm, and the maximum hourly rainfall intensity was 16.4mm/h. So flush flood and debris flow is outbreak in Hongcungou, where debris flow destroyed roads and houses, blocked the 120m-wide river channel, and the barrier lake was formed with the average 7m-high barrier dam. When the huge barrier body was broken down, breakout of the powerful flood destroyed the Road 213 and the Du-wen expressway. Because the barrier dam blocked the left river course, the river course was changed, which lead the flood to rush into Yingxiu town where just has been reconstructed after the Wenchuan earthquake.

On August 13, 2010 ,heavy rainfall attacked Longchi town in Dujiangyan. According to Precipitation data at Chaguan meteorological station, total rainfall was 156.9mm, maximum hourly rain intensity was 75 mm/h from August 13 to August 14. At 16: 00, large-scale debris flow formed. At 17: 40 debris flow changed into flood flow. While in the "8.18" heavy rainfall, the total rainfall was 252.2mm, and maximum hourly rain intensity was 69 mm/h from August 18 to August 19. At 20: 00 flush flood and debris flow formed. This post-seismic flood trapped nearly 800 person, 1 was killed, 12 were missing, 137 houses were collapsed or destroyed.

Here we summarize mechanism of post-seismic floods in the Minjiang river as follow:

(1)The heavy rainfall is controlled by the rographicallyenhanced precipitation

The upper reaches zone of Minjiang River is a typical mountainous river basin where mountains are high and steep. The distribution of precipitation is mainly affected by warm air of the southeast monsoon and relief. Because the east side of Longmen mountain is windward, so the warm air of the southeast monsoon shall be lift due to

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barrier of Longmen mountain and the orographicallyenhanced precipitation shall be formed. So the rainfall center shall be formed at piedmont region of Longmen Mountain. Therefore, heavy rain occurs frequently in the upper reaches of Minjiang River, which causes the storm floods with high frequency, large magnitude, and serious disaster.

(2) Wenchuan earthquakes provides the conditions for the development of post seismic flood

In the region, the strong rainstorm area roughly coincides with Yingxiu- Beichuan fault zone. Wenchuan earthquake on May 12, 2008 induced a significant collapse and landslide, which provides important solids source for formation of debris flow. So the occurrence of strong rainstorm can easily trigger debris flow and post seismic flood. The Wenchuan earthquake of 2008 caused the collapse, landslide, debris flow and other secondary disasters, which leaded to serious damage of forest in the area. According to preliminary estimation, in the zone, forest is 89326.31hm². The decreasing damaged vegetation coverage rate is more than 20% in core area of the earthquake. The flood is inverse proportional with vegetation cover, that is to say, the decreasing vegetation coverage rate is a direct impact on the increasing frequency of flood.In addition, after the Wenchuan earthquake, the soil erosion is significantly greater than that before earthquake. The average soil erosion modulus before the earthquake is 3703t/ (km² a) while that increases to the 4 604t/ (km^2 a) after the earthquake, where the soil erosion intensity amplitude is amount to 25%. The average annual amount of soil erosion is 4.98 \times 10^{8} t before the earthquake while that is 6.87×10^{8} t after the earthquake. So because of the increase of soil erosion, flood sediment concentration increase. These data suggest that, Wenchuan earthquake caused a decline in the efficiency of conservation of forest and soil erosion, so most of precipitation shall form the runoff, which increases the maximum flow, flood peak, and the flood sediment concentration.

(3) Heavy rainfall is the trigger to post seismic floods

There were no flood occurred in the upper reaches of Minjiang River in 2009 and 2008 after Wenchuan Earthquake, which leads some people think that the post seismic flood shall not occur. The reason is that in the period from 2008 to 2009, precipitation is within 834.8-1222.4mm, which belongs to the relatively dry years. But in 2010, serious flood attacked the Longmen Shan area. The rainfall is 2545.8mm, and the rainfall is concentrated especially in August.The precipitation is 507.2mm, which

is 239mm more than the average annual precipitation. Due to this heavy rainfall, a large amount of loose material caused by the Wenchuan earthquake can be transported into the river, and lead outbreak of the post seismic flood. Therefore, heavy rainfall is trigger to cause post seismic floods. So the post seismic floods after the Wenchuan earthquake are developed as following process: heavy rainfall triggers accumulation and loose material in the ravine to move, and debris flow is formed, which blocks the river and barrier lake is formed. When barrier lake is outburst, post-seismic flood shall be formed, which causes a number of casualties, and bring a lot of new difficulties to the post-disaster reconstruction.After the Wenchuan earthquake, the strong rainstorm weather becomes more popular, especially in the main flood season, such as the 2010 " 8.13 ", " 8.18 " heavy rainfall. Due to the high concentration of rainfall on region and time, so the rainfall intensity is very high, which lead to serious post seismic flood disaster. After the Wenchuan earthquake, criterion of rainfall caused floods also has been reduced significantly. The criterion of rainfall caused floods was 80-100mm, and rainfall intensity was 30-50mm/h before the Earthquake in Longmen mountain area, while after the earthquake, that is just 16.4mm/h, which was reduced by 45%- 67% than that before the Wenchuan earthquake. Besides after the Wenchuan earthquake, flood volume and frequency increases in the upper reaches of Minjiang River.

Some conclusions are summarized as following: (1) The Wenchuan Earthquake provides the essential conditions for the post seismic floods. The upper reaches of Minjiang River just located at epicenter of the Wenchuan Earthquake, where shows the post-seismic disaster chain: earthquake-collapse-landslide-debris flows-floods. (2) The heavy rainfall controlled by the orographically-enhanced precipitation is one important factor inducing post seismic flood. (3) The flood volume and frequency increase after the earthquake, so next 5 to 10 years will be the crest time of post seismic flood in the area.

Key words: Wenchuan earthquake, Minjiang River, heavy rainfall, post-seismic floods,orographicallyenhanced precipitation,Sichuan,China

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