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Catastrophic Debris Flows on July 10 2013 along Min River, the Wenchuan Earthquake Seriously Stroke-area

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INTRODUCTION

After 2008, the severest catastrophic debris flows occurred on July 9~11 2013 in the most areas that were seriously stroke by the Wenchuan earthquake, and the reconstructions, highways, factories and villages were fatally destroyed and even completely ruined. In particularly, over 240 debris flows occurred on July 10 (named 7.10 debris flows) at the Wenchuan County along Min River and it's tributaries including the rivers of Caopo, Yuzixi and so on. They involved in over 90% communities of the Wenchuan County, and made 29 casualties, 22086 houses destroyed, 2065 families houses submerged, 2 reservoirs destructed and 44 factories ruined. Moreover, the G213 highway and the express highway from Yingxiu to Wenchuan were destructed in 16 sites and the traffic interrupted for 16 days and the G213 highway was interrupted until now. Moreover, the traffic from Yingxiu to Gengda was halted for over 70 days due to the fatal destruction of S303 highway, which is often interrupted by debris flows in rainfall season but by far less than 70 days. This region suffered the heaviest disastrous hazards and losses after 2008. This work aims to analyze the characteristics, hazards and causes of 7.10 catastrophic debris flows to find the problems of hazards mitigating after Wenchuan Earthquake and explore valuable measures.

1. STUDY AREA

7.10 debris flows mainly occurred along the Min River from Xuankou to Maoxian, the Yuzi River from Yingxiu to Gengda and the Caopo River basin. The G213 highway and the express highway from Dujiangyan to Wenchuan, which is parallel to the G213 highway, distribute along Min River, and the S303 highway was built along Yuzi River. This region is located at the transition areas between Sichuan Basin and Qinghai-Xizang Plateau Eastern, and dominated by mountains with the elevation difference of about 3000m, the slope gradient of over 30 ° and deep-cut valleys. The active faults of Wenchuan-Maoxian and Yingxiu-Beichuan pass through this region. The active tectonic movement results in frequent earthquakes, and the Yinxiu-Beichuan fault, triggered the Wenchuan Earthquake, passes through Yingxiu town. Granitic rocks, Sinian pyroclastic rocks and Carboniferous limestone underlay this region， and Triassic sandstones and loose Quaternary deposits are distributed in the form of terraces and alluvial fans along channels. All bedrocks is deeply fractured and heavily weathered, and covered with a layer of weathered material. The climate remarkably varies in latitudinal and vertical direction due to steep terrain， and the semitropical humid climate and the warm temperate semi-drought climate, with the mean annual rainfall of 1258.1 mm and 500~600m, cover the southern and the northern of Supodian, respectively. Rainfall, with many rainstorms, concentrates from June to Sept and account for 70~80% of the total. The favourable environmental conditions formed many landslides, rock falls and debris flows before 2008 and 19 debris flow watersheds distribute along Min River. The Wenchuan Earthquake made intensive earth surface ruptures along National Highway 213 (G213) at the epicentre, with uplift amount is 2.72 m and the shortening amount 0.38m (Dong et al. 2008), and generated massive of loose soil including the deposits of landslides, debris avalanches, rock falls and the unstable hill-slopes. Only the deposits along Min River were beyond 0.2 billion m3, and almost all watersheds along Min River have the potential of debris flow occurrence (Zhuang, et al. 2009). After May 12th, 2008, the catastrophic debris flows, on July 17, 2009, Aug. 14 , 2010 and July 3, 2011, densely occurred at the sections from Yingxiu to Chediguan and from Yingxiu to Gengda, and produced fatal damages and destruction on highways， bridges， villages and reconstructions as well as resulted in many casualties. The 7.10 catastrophic debris flows occurred in larger areas, and produced heavier hazards and losses than those before 2013.

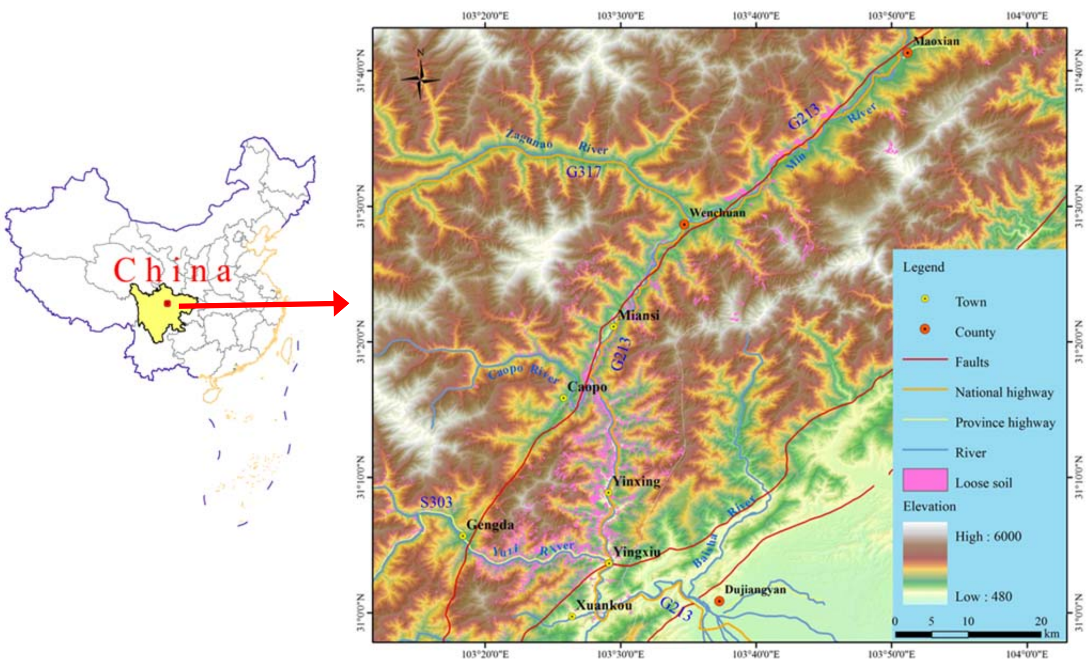

Figure.1 Location of study area

2 METHODS

Field investigation

Field investigations were carried out in July 22th ~30th, 2013 and January 11th ~18th, 2014 along Min River from Xuankou to Mao county，Yuzi River from Yingxiu to Gengda and Caopo River. The types and distribution of debris flows were identified，collected and confirmed，and large and catastrophic debris flow sites were investigated, including deposit samples collecting, cross section surveying, depositing and scouring parameters surveying, damage investigating. The 26 intact deposit samples, each about 3kg, were collected at the deposition areas to analyze solid material size components and calculate densities of debris flows. The cross sections (flow depth, section area and channel slope) and deposition fan (shape, area and deposition depth，deposition fan slope) were surveyed by a handy Laser Distance Meter to calculate the discharges and help estimate the amounts of transported sediment. Moreover, rainfall data, from 4 rainfall gauges run by Sichuan Meteorologic Bureau and 2 step-rainfall gauges for debris flow monitoring and alarming at the watersheds of Er and Jiyu of Institute of Mountain Hazards and Environment, CAS, were employed to analyze triggering conditions of debris flows.

Remote sense interpretation

The aerial images with a spatial resolution of 0.5 m, taken by Sichuan Bureau of Surveying, Mapping and Geo-information on July 14th 2013, were overlaid with the DEM of 1:10000 to interpret debris flows and their backgrounds. Moreover, the remote sense images with a spatial resolution of 4m from Google Earth, referencing to DEM data of 1: 50000, was applied to calculate geomorphic parameters of watersheds including shape, area, main channel length, channel slope gradient and provided the spatial distribution map of loose solid materials.

Formula calculated

Particle size components and density

26 debris flow deposit samples were collected, involving particle size up to 100 mm. The samples were dried and analyzed in conventional methods. Particles bigger than 0.5 mm were sorted by sieving and particles less than 0.5 mm are measured by the laser granularity meter. Then, the densities of debris flows were estimated using the formula established by Yu (2008):

$$\gamma_D = \gamma_O + P_2 P_{05}{}^{0.35} \gamma_V \qquad (1)$$

Velocity and discharge

The parameters of 12 discharge cross-sections featured by the balance between scouring and depositing and unbent channel were measured to calculate the velocity and discharge of debris flows using the Manning formulae:

$$V_C = \frac{1}{n_c} H^{\frac{2}{3}} I^{\frac{1}{2}} \qquad (2)$$

$$Q_C = A_C V_C \qquad (3)$$

Magnitude calculation

In order to exactly estimate the amount of sediment delivery and magnitude of debris flows, the data of field investigation and remote sense image interpretation, and the empirical formula were combined, optimized and employed to obtain the magnitude of debris flows. The empirical formula was showed as the equation (4) (Tang et al. 2000):

$$D_S = 0.264(\gamma_D - \gamma_W)/(\gamma_H - \gamma_W) Q_C T \qquad (4)$$

RESULTS

Debris Flows Characteristics

Low viscosity and High-density

The debris flows are characterized by low viscosity because that their dominator loose soil mainly originate not from surface weathered soil but from landslides, rock falls and debris avalanches with more sands, gravels and stones but less clay soil. The content of clay soil (<0.005mm), silt (>0.005mm and <0.5mm), and gravel (>2mm) account for 0.10%~3.56%, 0.34%~10.67% and 42.00%~77.97%, respectively, with the average of 0.71%, 2.87% and 65.73%. The flow densities ranged from 1.72t/m3 to 2.14t/m3, which were very similar to those during 2008~2012.

（2）Numerous-occurrence

Comparing with the events before 2013, the 7.10 debris flows not only appeared in hill-slopes, gullies and small watersheds, but also occurred in watersheds bigger than 5 or even 10km2 . Debris flows occurred in over 50 watersheds along the rivers of Min and Yuzi, and 22 ones were bigger than 10 km2.

（3）Large discharge and magnitude

The magnitude of debris flow varied from 1.0×105m3 to 1.26 Due to loose sediment accumulation in channels and hill-slopes,m3, with the range of sediment delivery modulus from 0. 3×104m3/km2 to 6.83×104m3/km2 and the average of 1.2×104m^3/km^2 . The peak discharges of 10 watershed were from 335m3/s to 2238 m3/s. And even some from hill-slope watersheds also transported sediment over 25×10^{4}m3 .

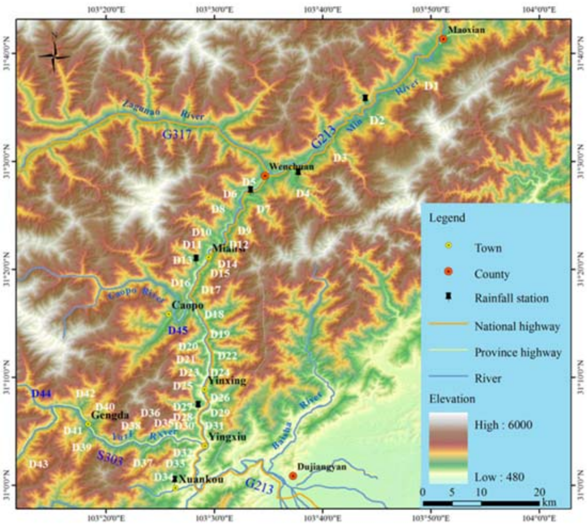

Figure.2 Distribution of debris flow

（4）Hazard chains

Large debris flows from hill-slopes, gullies and watersheds formed 3 hazard chains: (1) flash flood—hill-slopes or gullies debris flow—channeled debris flow—outburst amplifying —dammed lakes—outburst flood, (2) flash flood—hill-slope or gully —river blocking—dammed lake—outburst flood, (3) flash flood—hill-slope or gully—(watershed debris flows)—step-dammed lakes— channel rise—mega flood. The 36 dammed lakes distributed along the rivers of Min and Yuzi and resulted in river channel rising about 2~11m and 4~6m, respectively. The 36 dammed lakes was showed in the figure.3

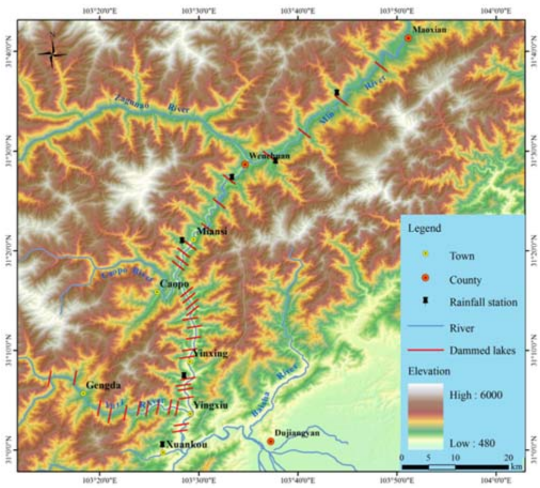

Figure.3 Distribution of dammed lakes

Debris flow hazards

Towns and villages

Towns and villages were seriously ruined by debris flows from the watersheds of Yanmen, Qipan, Cutou, Taoguan, Huaxi and Caopo River basin (Caopo town). The houses, buildings and constructions were heavily scoured, buried and silted up by debris flows, also submerged by dammed lakes and destructed by outburst flood of dammed lakes as showed in Figure.4

Highway and traffic

Debris flows interrupted the traffic from Yingxiu town to Gengda town for over 70 days, and from Yingxiu to Wenchuan for 16 days. The interruption sites of highways were 16 and 13 ones along G213 highway and S303 highway as showed in Figure.5. The heaviest damages originated from bridge collapse, highway submerging, highway embankment loss, tunnel submerging and silting up and so on (Figure.6 and Figure.7). The unexpected damages produced huge difficulties for the reconstruction of traffic, especially the G213 highway.

Figure.4 Destructed buildings and houses

(3) Factories and hydro power station

Debris flows damaged 44 factories and the most hydro power stations along the rivers of Min, Caopo and Yuzi. The factories at the Watersheds of Taoguan and Guxi were seriously silted up and even buried , and lost their functions. The hydro power stations were submerged by flash flood, silted up and buried by sediment from dammed lake upstream (Figure. 7). Moreover, the increasing river channel and the following hazards are posing more threats on many constructions along rivers.

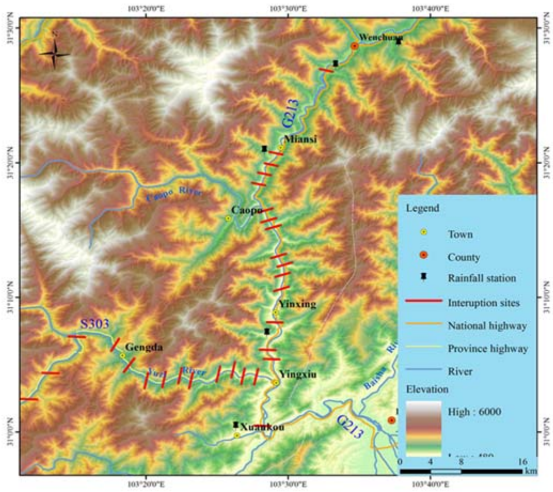

Figure.5 Traffic interruption sites

Disasters Causes

Over Control-standard Hazards

The discharge and magnitude of debris flows by far exceeded the capabilities of their control engineering works, which were designed as the standard for normal ones. Debris flows destructed most control engineering works of over 20 watersheds along the rivers of Min and Yuzi so that the huge loss was made.

Irrational Location of Reconstructions

Due to unclear understanding of location, characteristics, discharges, magnitude and hazard modes of the posted-earthquake debris flows, some dangerous areas and even high-dangerous areas were selected to build reconstruction projects and newly constructions. For example, the constructions of Taoguan watershed and Caopo river.

Low-standard reconstructions

The low resistant capabilities of reconstructions, including buildings, factories and highways, were also responsible for huge losses.

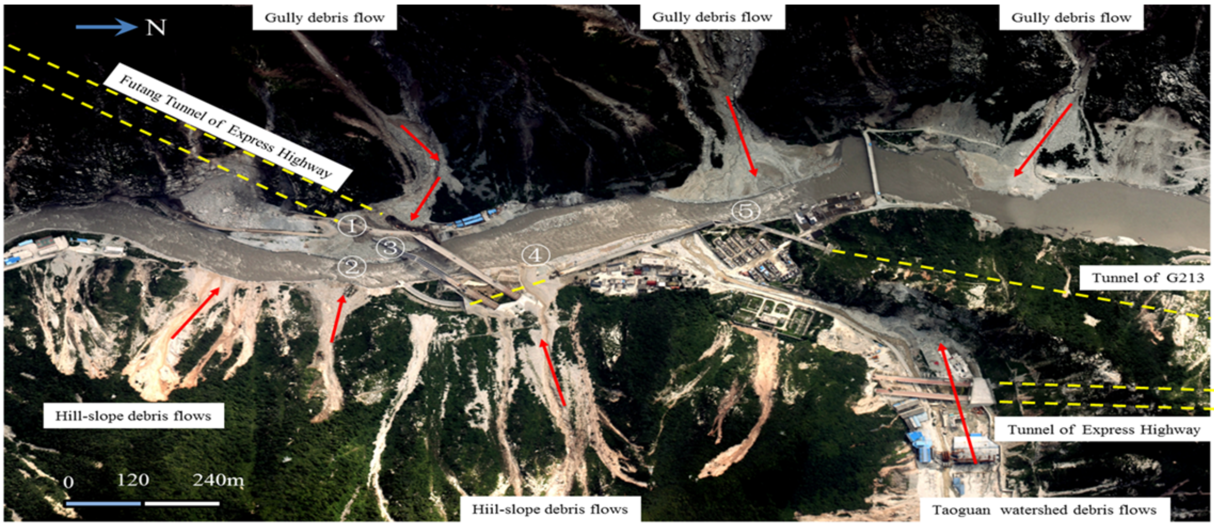

Figure.6 Destructions of highways and constructions at the Taoguan watershed outlet

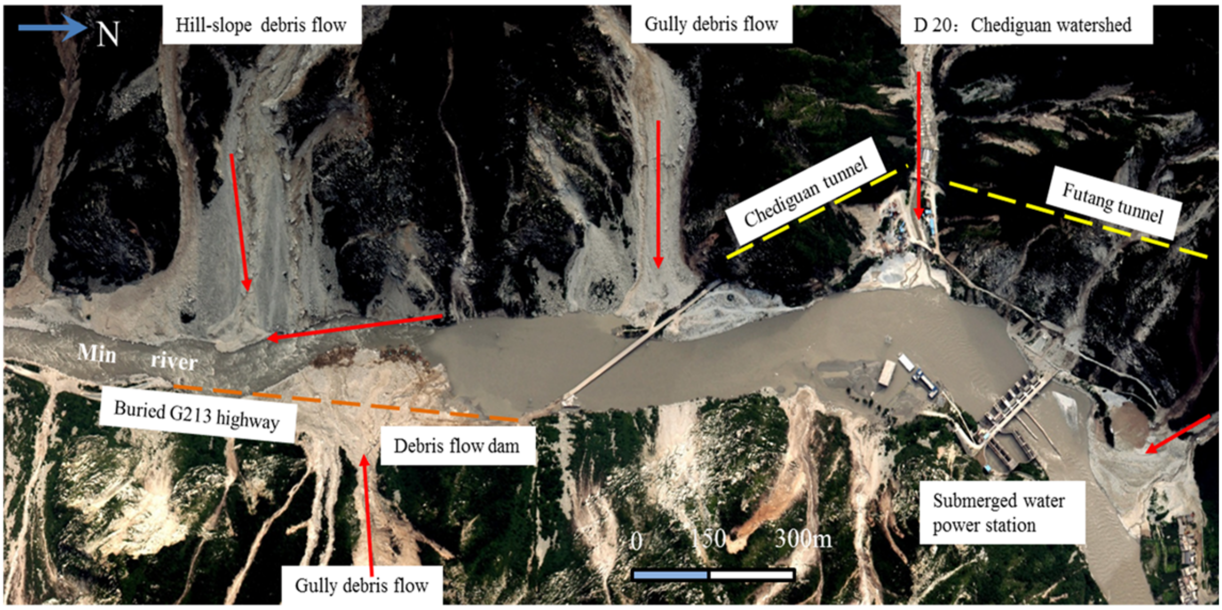

Figure.7 Destructions of highways, bridges, tunnels and hydro power stations

Prevention Problems

The mitigating of debris flow hazards in the Wenchuan county are facing unexpected difficulties after July 10th 2013 as the following: （1）explore valuable methods to to identify potential debris flow sites, especially the ones from steep hill-slopes and gullies; (2) find feasible techniques to observe, predict, control, prevent, forecast and warn debris flows according to the change of debris flow forming conditions and to protect local security and reduce losses, especially at the disastrous sites; (3) continuously develop newly techniques and measures to integrated control debris flows and protect highways and keep the traffic in security, especially that from Dujiangyan to Wenchuan; (4) seek feasible measures and solutions to be against the increasing hazards of rapid rise of river channel and to manage risk.

Mitigation measures

After July 10th 2013, debris flows will be very active in the future long term due to local environment further disturbed. Considering the characteristics and changes of debris flow events that followed the Wenchuan Earthquake and the problems of mitigating, the feasible mitigating measures for short-term and middle-long term were provided as Figure .8.

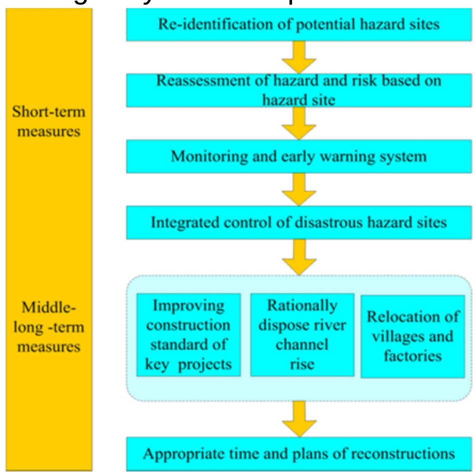

Figure.8 Suggested mitigating Measures

CONCLUSIONS

7.10 catastrophic debris flows distributed in disequilibrium along the rivers of Min, Yuzi and Caopo due to spatial variation of rainfall and loose sediment. They are characterized by the clay soil contents of 0.1~3.56%, the densities of 1.72~2.14t/m3, the velocities of 5.0~12.7m/s, the discharges of 335~2353m3/s and the sediment amounts of 0.10~1.26 million m3, and also densely occurred at 22 large watersheds with over 10 km^2. Large debris flows formed three typical hazard chains as the following: (1) flash flood—debris flows in hill-slopes or gullies—channeled debris flow—outburst amplifying—river blocking—dammed lakes—outburst flood, (2) flash flood—debris flow in hill-slope or gully—river blocking—dammed lake—outburst flood, (3) flash flood—debris flows in hill-slopes or gullies—(debris flows in watershed)—dammed lakes— channel rise—mega flood. The step-dammed lakes, including 26 ones along Min River and 10 newly ones along Yuzi River, formed and made river channel rise about 3~11m. The damages and destructions mainly originated from the burying, scouring and submerging of houses and buildings along channels, the interruption of the highways of Dujiang-Wenchuan Express, G213 and S303 induced by the burying, scouring and collapse of bases, the submerging and collapsing of bridges and the silting up of tunnel, the filling up of factories as well as the increasing hazards caused by river channel rapid rise. 7.10 catastrophic debris flows were trigged by cumulative rainfall of 210 mm and hourly rainfall of over 15 mm, the heaviest after 2008, and produced severest losses due to fatal destructions of control projects as well as the irrational location and low-resistant capabilities of reconstructions. For the mitigating of active debris flow hazards，the following measures were strongly suggested: (1) identify, predict and reassess forgone and potential hazard sites, (2) integrated control hazards to regulate discharges and magnitudes of debris flows and prevent hazard chains forming; (3) establish and improve monitoring and alarming network using typical disastrous watersheds as nodes; (4) select appropriate time and felicitous plan for reconstructions; (5) improve resistant capability of reconstructions; (6) rationally dispose river channel rapid rise for reconstructions.

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