Figure 3 Landscape of Haitong Watershed after 6.23 large-scale debris flows

(a. Taken in June 2012, Deposition dam:200m length, 100m width and 6-8m depth; b.Taken in Sept. 2013)

The parameters of the debris flow on June 23, including velocity and discharge which were obtained from the cross-section at the outlet and material components from deposit sample test, were input into a dynamic movement model of debris flow to simulate and analyze deposition process and result(Figure 4). Then hazard of debris flow was implemented using the formulae (12). The result showed that the influenced and endangered highway was about 820m, and 380m, 330m and 110m was in high-danger zone, middle-danger zone and low-- danger zone, respectively (Figure 5), and those in middle--danger zone and high--danger zone covered 86.5%. The destructed highway on site was about 860m and the total of the buried and submerged highway was about 650 m, which agreed with those from simulated model. Therefore, the models for movement simulating and risk assessment strongly benefits to prediction and prevention and reduction of risk and mitigation of debris-flow hazards.

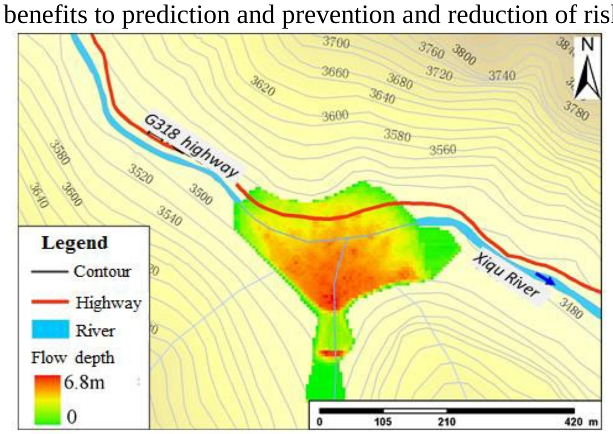

Figure 4 Dynamic simulation result of debris flow in the outlet

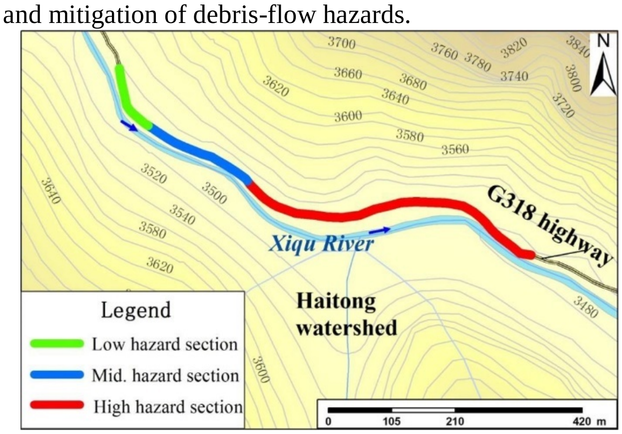

Figure 5 Risk map of debris flow in Haitong Watershed

6. Summary and Conclusions

The Sichuan-Tibet highway and railway are the main traffic trunks line in the western mountain areas of China. Unfortunately, this road has long been severely affected by debris flows. The steep terrain, numerous unconsolidated soil produced by complex lithology and hydrologic meteorological, and the high intensity rainfall are very conducive to the formation of large scale debris flow. Various types of debris flow are widely spread along the major road, which strongly affect road safety.

We have analyzed the spatial distribution, activity and hazard characteristics of debris flows. Moreover, we comprehensively analyzed the dynamic process of debris flow at a local scale, the compound effects of debris flows along riverside section and the disaster environment factors of debris flows overall scale of Sichuan-Tibet highway respectively. Accordingly, we built an applicable factor system and a comprehensive framework to quantitatively evaluate debris-flow hazard degree, and then proposed a multi-scale debris-flow hazard assessment method.

The high hazardous areas along G318 Sichuan-Tibet highway are mainly located in the canyon area of Dadu River, Jinsha River, Lanchang River, Nu River and Palongzangbu River. Referring to these areas, the debris-flow prevention project should be strengthened in road construction and land designing. Among them, the Xiq u-River section of Sichuan-Tibet highway was seriously affected by debris flow. The large-scale debris flow on June 23, 2012 at Haitong Watershed was composed by the hazard chain including flash flood, debris flow, dammed lake and outburst flood. The risk assessment based on dynamic model indicated that the high-danger zone and middle-danger zone occupied 86.5%, where were buried by debris-flow deposits or submerged by the following dammed lake, which agreed with the actual. According to the characteristics, hazards and risk of 6.23 debris flows, the protection measures, including dangerous debris-flow identification, risk assessment, rational route, highway protection, integrated control and emergency plan, were recommended to reduce highway hazards.

Acknowledgements

This work was supported by the National Nature Science Foundation of China (Grant No. 41790432)，the Research Program of China Railway Eryuan Engineering Group CO. LTD (Grant No. KYY2018015(18-20)) and the Key Research Program of Frontier Sciences of Chinese Academy of Sciences (Grant No. QYZDY-SSW-DQC006).

References

Adachi K., Tokuyama K., Nakasuji A., et al, 1977, Study on judgment of outbreak ability of debris flow: SHIN - SABO, v.33, p. 7-16.

Aldo C., Susanna P., Claudio T., et al, 2002, A procedure for landslide susceptibility zonation by the conditional analysis method: Geomorphology, v.48, p.349-364.

Carrara A., Cardinali M., Detti R., et al. , 1991, GIS techniques and statistical models in evaluating landslide hazard: Earth surface processes and landforms, v.16 , p. 427-445,doi: 10.1002/esp.3290160505.

Chen N. S., 2011, Exploration technology of debris flow: Beijing, Science Press.

Cui P., Hu K. H., Zhang J. Q., et al., 2011, Prediction of the debris flow area by combing hydrological and inundation simulation methods: Journal of Mountain Science, v.8, p. 1-9.

Dhital, M. R., 2015, Geology of the Nepal Himalaya: Regional perspective of the classic collided orogeny, USA, Springer International Publishing.

Ellen S.D., Wieczorek G. F., 1988, Landslides, Floods, and Marine Effects of the Storm of January 3-5, 1982, in the San Francisco Bay Region, California. California: US Geological Survey Professional Paper, 1434, doi:10.3133/pp1434.

Fowlie Cashman. C. M., 1957, Debris flow and road design in debris flow-affected area: Beijing, China Communications Press.

Hollingsworth R. and Kovacs. G.S., 1981, Soil slumps and debris flows: prediction and protection: Bulletin of the Association of Engineering Geologists, v.38, p.17-28.

Hu K.H. and Wei F.Q., 2005, Numerical-simulation-based Debris Flow Risk Zoning: Journal of Natural Disasters, v.14, p.10-14.

Hunger O., Morgan C.G., Van Dine D.F., et al., 1987, Debris flow defenses in British Columbia: Geological Society of America Reviews in Engineering Geology, v.7, p.201-222.

Kienholz H, 1999, Anmerkungen zur Beurteilung von Naturgefahren in den Alpen: Relief, Boden, Paläoklima, v.14, p.165-184.

Liu X. L. and Tang. C., 1995, Debris flow hazard assessment: Beijing, Science Press.

O'Brien JS, Julien PY, Fullerton WT, 1993, Two-Dimensional Water Flood and Mudflow Simulation: Journal of Hydraulic Engineering, v.119, p.244-261.

Olivier L., 1998, Example of hazard assessment and landuse planning in Switzerland for snow avalanches, floods and landslides: Bern, Swiss national hydrological and geological survey.

Ou G. Q., You Y., Lu J.,et al.,2006, A study on the scale forecast and the influence of debris flow on the water diversion project in the west line project of water diversion from upper Yangtze River into upper Yellow River: Journal of Mountain Science, v.24, p.580-584.

Rickenmann D, 2001, Methoden zur Gefahrenbeurteilung von Murgängen. In: Projekt CADNAV, Etablissement dúne methodologie de mise en euvre des cartes de dangers naturels du canton de Vaud: Switzerland, 2eme rapport intermediare, Ecole Polytechnique Federal de Lausanne.

Saito M., 1969, Forecasting time of slope failure by tertiary creep: Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering, v.2, p.677-683.

Iverson. R. M., 1997, The physics of debris flow: Review of Geophysics, v.35(3), p.245-296.

Smith T. C., 1988, A method for mapping relative susceptibility to debris flows, with an example from San Mateo County, California. In: Ellen, S.D., Wieczorek, G.F. (Eds.), Landslides, Floods, and Marine Effects of the Storm of January 3–5, 1982, in San Francisco Bay Region, California: US Geological Survey Professional Paper, 1434, p.185-194.

Takahashi T., 1980, Debris flow on prismatic open channel: Journal of the Hydraulics Division, Proc. ASCE, 106(HY3), p.381-396.

Takahashi T., Hajime N., Sato H.., 1988, Hazard assessment of debris flow alluvial fan: Annuals, DPRI, 31 (B-2), p. 655 - 676.

Chen. C.L., 1988, General solution for visoplastic of debris flow: Journal of Hydraulic Engineering, ASCE, 114(3), p. 259-282.

Water Resources Department of Sichuan Province., 1984, Storm flood Computation Handbook of small watershed in Sichuan Province: Chengdu, China, The books press of hydrological terminus in Sichuan province water resources and power authority.

Wei F.Q., Hu K.H., Lopez J.L., et al., 2006, Model and method of debris flow risk zoning based on momentum analysis: Wuhan University Journal of Natural Sciences, v.11, p. 835–839.

Zhong Z.L., Wang C.H., Xie H., et al., 1988, The catalog database and regional law of debris flow and landslide of China: Chengdu, Sichuan Science Technology Press.

Zhou B.F., Li D.J., Luo D.F., et al., 1991, Guidebook for Debris Flow Prevention and Control: Beijing, Science Press, p.87-92.