Submerged area of typical torrential flood and debris-flow disasters in Mengzong Gully, China

Ai-Di Huo\(^{a,b,c}\), Wen-Ke Guan\(^{d}\), Jian Dang\(^{a}\), Tian-Zhong Wu\(^{d}\), Hainiken Shantai\(^{d}\), Wei Wang\(^{e}\) and Michael W. Van Liew\(^{f}\)

\(^{a}\)School of Environment Science and Engineering, Department of Hydrology and Water Resources, Chang’an University, Xi’an 710054, China; \(^{b}\)State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, Institute of Water Resources and Hydropower Research, Beijing 100038, China; \(^{c}\)Key Laboratory of Subsurface Hydrology and Ecological Effect in Arid Region of Ministry of Education, Chang’an University, Xi’an 710054, China; \(^{d}\)Afforestation Desert Control Research Institute, Xinjiang Academy of Forestry, Urumqi 830000, China; \(^{e}\)Northwest Institute of Forest Inventory, Planning and Design, Xi’an 710048, China; \(^{f}\)School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE 68583-0726, USA

**ABSTRACT**

The torrential flooding and debris flow disasters associated with global climate change pose not only serious threat to individual lives and property, but also impact economic development. Accurately simulating flood scenarios can help to reduce the losses caused by torrential flooding and debris flow by making early warning, evacuation planning, and risk analysis possible. In this study, HEC-RAS software and HEC-GeoRAS module were employed in GIS (geographic information system) to simulate the flood overtopping in the Mengzong Gully of Batang River in flood scenarios occurring once in 20, 50, and 100 years, respectively. The simulated floods provided valuable information including scope and depth of submersion via 2D visualization.

**KEYWORDS**

HEC-RAS; HEC-GeoRAS; torrential flood and debris flow inundation scenarios; Mengzong Gully

### 1. Introduction

Among the many types of natural disasters, torrential flooding is relatively common and has far-reaching impact on human society even in developed countries possessing high-tech disaster response capability (Ye et al. 1999). Alongside the rapid expansion of cities and towns associated with fast-growing populations and economies — particularly in developing countries such as China — the effects of flood disasters have increased exponentially, and are much more severe in terms of damage and loss than in previous decades (Ye et al. 1999). Apart from the necessary, basic construction (e.g. levees) implemented to minimize flood damage, it is also imperative to create and maintain a national system to provide both risk assessment and early warning for flood disasters to mitigate their potential damage. Within these systems, accurately simulating overtopping in potential submerged areas is key component (Xiu et al. 2011).

Yushu County, which is situated in a high elevation area, is located at the source of the Yangtze River. Yushu serves as a regional economic center for the surrounding area, as well (Xu et al. 2012). Due to its unique and important role, the population has boomed and construction has expanded to meet the increased demand; naturally, a medium- or large-size flood disaster could cause severe loss of lives and property in this area.

**CONTACT** Ai-Di Huo huaidi@163.com

© 2016 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Map-to-Map methodology has proven successful at predicting flood severity at the local basin scale, but until now has not been applied to any high elevation area nor regional scale model. As the first of a series of studies that focused on regional scale flood forecasts, we extended map-to-map technology to the entire Mengzong Gully basin. The primary goals of this project included: (1) employing HES-RAS software and the HES-GeoRAS module in GIS to simulate flood overtopping inundation in Mengzong Gully, and (2) analysing rainfall-runoff characteristics of the basin and assessing current infiltration methods for describing basin characteristics. We attempted to create a floodplain output that will enable researchers to efficiently and accurately model rainfall-runoff relations, and hope our results contribute to Yushu residents’ ability to respond quickly to flooding events.

2. Materials and methods

2.1. Study area and DEM data-sets

The study area is in Yushu County, Qinghai Province, China, approximately between 96°20′32.9″E and 97°10′8.9″E, and 32°52′6.7″N and 33°19′47.9″N (Figure 1). Yushu County is located in the southern high plateau across the Yangtze River and Lancang River basin, two river networks which cover the entire county. The area exhibits a typical Tibetan continental climate, with annual average temperature of 2.9 °C and annual precipitation of 487 mm. The average elevation of the Yushu region is around 4000 m. The population is about 80,000 in Yushu County in 2005.

The Mengzong Gully is located in Yushu County in the south-western part of the Xihang village of Jiegu, at 4000 m altitude (Figure 1). It sits in the middle of the Batang River valley beside the left bank. It is 7 km long from north to south, 2.4 km wide between west and east, and has a total area

![Figure 1. The location of study area in Qinghai province, north-west China.](image-url)
of 12.1 km². Mengzong Gully is characterized by massive slack soils and fissured rock. On the morning of 14 April 2010, two earthquakes hit Yushu County with a magnitude of 7.1 with the epicentre located near the county. As of 17:00 pm on 25 April, the Yushu earthquake had killed 2220 people and another 84 were unaccounted for; parts of the valley slope crumbled and blocked the flow of flood waters and debris. The large, muddy mass of sand and detritus at the hillside was the main source of debris transported into the area by flooding. In short, the topographical and geographical conditions of the area show the potential for torrential flooding and debris flow, which continues to threaten the lives and livelihood of Xihang, Jiegu residents, and others inhabiting Yushu County.

The digital elevation model (DEM) used in this study was obtained from the international scientific data service platform (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp). Its spatial resolution is 30 m. The river network was extracted from the DEM via the spatial analysis function in ArcGIS software. To apply the model, the TIN-based DEM was converted into raster coverages at 30 m resolution in GIS software. Dynamic simulations commenced on 1 August and continued until the 20 August representing 20 days (or 480 h) of real flow data.

2.2. HEC-RAS and HEC-GeoRAS

The hydraulic model is based on HEC’s River Analysis System (HEC-RAS), version 4.1 (Brunner 1995). HEC-RAS was developed by the Hydrologic Engineering Center, and was able to model the one-dimensional steady flow, unsteady flow, and river hydrologic calculation analysis (Brunner 1995; Xu et al. 2011). In this paper, we used the 4.1 version of HEC-RAS for inundation simulation based on the steady flow calculation (Xu et al. 2011).

HEC-GeoRAS developed by HEC and ESRI, plays a role as specific software of GIS dealing with the geometry data of HEC-RAS. It was the medium relating HEC-RAS and GIS. The river geometry, feature of the cross sections and dykes, were extracted by HEC-GeoRAS for pretreatment. The results of the treatment were then loaded into HEC-RAS for hydrologic analysis, and the results of HEC-RAS were in turn loaded into GIS for the flood simulation to obtain the inundation area and water depth (Cai et al. 2005).

Water surface profile data and velocity data exported from HEC-RAS simulations can be processed with HEC-GeoRAS for the purposes of GIS analysis for floodplain mapping, flood damage computations, ecosystem restoration, and flood warning response, and preparedness. We developed the proposed torrential flood and debris-flow model by integrating GIS with the HEC-RAS river hydraulic model and HEC-GeoRAS model. Numerous studies have shown that these models provide accurate and useful flood prediction results (Anderson et al. 2002). The Map-to-Map tool was modified to meet the specific needs of this study, including accommodations for unsteady flow and the incorporation of dissimilar precipitation products. As mentioned above, we tested the utility of the prototype Map to Map in terms of regional-scale flood investigations. The basic step-wise process to obtain flood prediction information is as follows (Ackerman et al., 2000; Ackerman, 2009):

1. import the DEM into GIS after HEC-GeoRAS pretreatment (in our case, creating the river centreline, river bank line, flow path, and land use layer),
2. import the GIS output into HEC-RAS to construct the geometric data, including flow direction, river network shape, cross sections, and the Manning coefficients of different land use types (e.g. hydrologic structures, embankments, dams, bridges, weirs, orifices) as necessary, and
3. set the boundary conditions (steady flow and unsteady flow) to run the HEC-RAS and obtain water depth and velocity information for different cross sections. Import the former output of HEC-RAS into HEC-GeoRAS to realize the inundation scope and water depth on the GIS platform.
2.3. Simulation

HEC-RAS was run to simulate the flood inundation after setting the boundary and initial conditions. The roughness value of the study area, the simulation start time, the time period for output simulation, the parameters of four-point implicit difference, the number of iterations, and the permissible error were set prior to simulation in the HEC-RAS interface.

We developed a flood simulation specifically for Mengzong Gully in Yushu County using HEC-RAS and HEC-GeoRAS in GIS. The various numbers in figure 2 indicate different reaches: number 1 indicates the upper reach of the Batang River, number 2 indicates the middle reach of the Batang River, number 3 indicates the lower reach of the Batang River, number 4 indicates the Mengzong Gully, and number 5 indicates the Zhaqu River. The arrow in figure 2 marks the flow direction, the blue line represents each reach, the red line indicates the area out of the floodplain at both sides of the river, and the green line indicates the cross section of each reach.

Figure 2. The layout of river network cross-sections Yushu reach of Tongtian River.
3. Analysis and results

HEC-RAS simulation data for the study area were imported to the topographic map (DEM) with the GeoRAS module in ArcGIS software. The submerged schematic was then calculated under different flood periods as shown in figure 3.

From the inundation results under different recurrence periods, as shown in figure 3 and table 1, it is clear that flood and debris-flow disasters indeed seriously endanger residents in the Mengzong Gully and surrounding delta where there is low elevation and high flood depth. From figure 3, the area submerged by flooding and debris flow under the recurrence period of 100 years is larger than that of the 50-year period by 11,577 m², and larger than that of the 20-year period by 16,259 m². Appropriate measures absolutely should be taken to protect the residents of this area and their property. Because torrential flood disaster duration is very short, and due to soil permeability in the area, any flooding due to hydrograms or river discharge was considered negligible.

Calibrating the model with appropriate data is a crucial step in the creation of a reliable basin representation. On 8 August 2013, we conducted a field investigation which showed that the highest water level trace at the scene in situ was close to the simulated water level, suggesting that the simulation results are reasonable. A comparison between the observed flooding and predicted (i.e. simulated) flooding locations is shown in figure 4.

We found that HES-RAS software and the HES-GeoRAS module can be employed in a GIS context to simulate flood overtopping inundation and debris-flow accurately in Mengzong Gully. The methodology we used in this study can be employed to create a floodplain output which can assist residents in the study area and similar areas to respond quickly to potential flood events and thus reduce the impact of economic loss due to flooding (Huo & Li 2013).

Specific measures that can be taken to protect the residents and property threatened by flood and debris-flow disasters in Mengzong Gully include: (1) heightening protection at the embankment, (2) dredging the river channel to ensure floodwaters flow through the area safely, (3) improving the flood division gate according to the discharge at each reach, (4) constructing reservoirs with adequate capacity, and (5) using concrete on the river bank revetments to protect against erosion damage and wave impairment.

| Time               | Area /m² | Increase /m² |
|--------------------|----------|--------------|
| A flood in 20 years| 410,190  | 0            |
| A flood in 50 years| 426,449  | 16,259       |
| A flood in 100 years| 438,026 | 11,577       |
4. Conclusions

This paper contributes to the development of an innovative, integrated methodology for predicting flood and debris-flow hazards in high-elevation (>4000 m) and large-scale areas. The proposed model can be incorporated into both high-elevation regional hydrological studies and/or a regional alert system for hazard mitigation by simulating the submersion scope and water depth of flood events in the GIS platform. Our most notable conclusions can be summarized as follows.

(1) Mengzong Gully, Yushu County, Qinghai province was used as an example to conduct HEC-RAS simulations of different flood discharges with HEC-GeoRAS. The three-dimensional inundation results with the recurrence period of 20, 50, and 100 years were successfully checked in the HEC-RAS interface.

(2) There is considerable potential for a severe and disastrous flooding event in the study area. As all areas of Yushu Country should take preventative measures to mitigate potential flood and debris-flow damage, particularly as the area’s economy continues to develop and the infiltration capacity of the terrain continues to decrease.

(3) The HEC-RAS submersion simulation is simple, convenient, accurate, and manoeuvrable. Combining GIS with HEC-GeoRAS creates 2D inundation visualizations that can be accessed by managers involved in flood preparedness as well as other officials responsible for city planning and assessment.

Figure 4. Comparison between observed flooding and the simulated locations.
HEC-RAS and HEC-GeoRAS are not only able to accurately simulate flood disasters, but can also be used to simulate levee breaches, dams, and other structures to assist in planning other protective measures.

Acknowledgements

The authors thank Professor Yudong Lu from School of Environmental Science & Engineering and Yuxiang Cheng from college of Geology Engineering and Geomantic for their remarkable ideas to improve the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

We would like to thank the Science and Technology Support Project of the Tarim Populus National Nature Region in Xinjiang [2015XJ-001]; the project of Open Research Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research [grant number IWHR-SKL-201510]; and the Project of Science and Technology of Social Development in Shaanxi Province [grant number 2016SF-411].

References

Ackerman C. 2009. HEC-GeoRAS user’s manual. Computer program documentation. Davis (CA): USACE Hydrologic Engineering Center Press; p. 55.

Ackerman CT, Evans TA, Brunner GW. 2000. HEC-GeoRAS: linking GIS to hydraulic analysis using ARC/INFO and HEC-RAS. New York (NY): Hydrologic and Hydraulic Modeling Support with Geographic Information Systems ESRI Press.

Anderson M, Chen Z-Q, Kavvas M, Feldman A. 2002. Coupling HEC-HMS with atmospheric models for prediction of watershed runoff. J Hydrol Eng. 7:312–318.

Brunner GW. 1995. HEC-RAS river analysis system. Hydraul Ref Man. Version 1.0. DTIC Document. 1:5–15.

Cai X, Dong Z, Zhang Y. 2005. [HEC series water application]. Zhejiang Water Conservancy Sci Technol. June—July; 6:20–29. Chinese.

Huo A, Li H. 2013. Assessment of climate change impact on the stream-flow in a typical debris flow watershed of Jianzhuangcuan catchment in Shaanxi Province, China. Environ Earth Sci. 69:1931–1938.

Xu C, Xu X, Lee YH, Tan X, Yu G, Dai F. 2012. The 2010 Yushu earthquake triggered landslide hazard mapping using GIS and weight of evidence modeling. Environ Earth Sci. 66:1603–1616.

Xu W, Liu M, Yang J, Li C, Shang X. 2011. Huainan period of flooding— flood risk analysis based on the HEC — RAS [in Chinese]. Proc Natl Acad Sci Yangtze River. 28:13–18.

Ye Y. 1999. Urban disaster prevention projects [in Chinese]. Beijing: Metallurgical Industry Press.