Study on hazard assessment of mountainous flood in riverside country- a case study in Xinshan, Hubei, China

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Abstract. Mountainous riverside countries have already become the weaknesses of flood disaster control infrastructure in China, so flood calculation based on hydraulics models plays a key role in urban flood monitoring, warning and prevention. In order to validate the availability of a proposed one-dimension hydraulics flood model, the paper selects Xinshan County, Hubei Province, China as a typical study area. Considering the river distribution system and flood source analysis in Xinshan County, its flood scale and calculation scheme are then proposed. On the basis of HEC-RAS software, the one-dimension hydraulics model is constructed, which is applied to calculating the river flood evolutions and diffusing embankment processes with the designed flood probability of 0.01, 0.02, 0.05, 0.10, and 0.20 respectively. The comprehensive flood process information (such as diffuse area, diffuse duration and water depth) is also retrieved, which is used to calculate flood hazard and map flood hazard distribution. Calculation results reveal that the main parts of Gufu River basically meet the flood prevention standard of 0.05 (probability) in Xinshan County, while the intersection of Gufu River and Wangjia River has lower flood prevention ability than its flood prevention standard, which are basically consistent with local reality and flood estimation. Moreover, this fact proves that the proposed one-dimension hydraulics flood model is effective.

1. Introduction

Due to their high frequency and great destructive power, flood often cause great disasters and poses great threats to local people's lives and property[1, 2]. China is one of the countries with the most serious flood menaces in the world. Since 1949, more than 270,000 people died in flood disasters, of which more than 190,000 were affected by mountainous flood[3].

Flood prevention has been highly valued by the Chinese government. At present, flood control infrastructures in major rivers and important cities have basically accomplished, but the prevention of mountainous flood disasters in small and medium-sized rivers and riverside countries becomes the bottleneck problem. The Chinese Ministry of Water Resources has already set up an important project for the prevention and control of mountainous flood disaster in small rivers and riverside countries. Through the on-the-spot investigation via remote sensing and in-situ observation, the basic information of mountainous flood disasters, such as flood source, river section and nearby village residents, is collected and assembled in local and national flood databases. Designed flood scales and its affecting areas are calculated and drafted in flood risk maps, which might provide basic materials for mountainous flood monitoring, early warning, and prevention[4].

Many scholars have already carried out the mountainous flood calculation along the rivers with the combination of numerical simulation and field observation. Xue[5] introduced the HEC-RAS model to
calculate the maximum flood peak flow in the Shangjiahe section of the Hanjiang River, and the model results were basically consistent with the measured flow. Considering the watershed area, river slope, river channel and other factors, Li[6] constructed the complex correlation formula to simulate flood in the special small basin. Yuan[7] established a two-dimensional hydrodynamic coupling mathematical model to calculate the flood diffusion process, and to simulate the flood evolution along the rivers and nearby villages, reflecting the water-blocking of special boundaries such as roads and irrigation canals. Rai[8] designed a two-dimensional coupled hydraulic model to calculate flood process without the in-situ observation, and compared the model results with in-situ observation to verify the availability of the model. Shen[9] used the TUFLOW software to construct regional flood models, and carried out in-depth analysis of urban flood diffusion, submerged water depth and submerged area. In conclusion, most of the above studies focus on the flood calculation in small or special river sections, while the comprehensive assessment of mountainous flood disasters regarding riverside countries is still rare, which requires to be deeply explored.

2. Research area
Xinshan County is in the canyon basin formed by the erosion of rivers. The country locates at the western part of Hubei Province, which is north to the Xiling Gorge of the Yangtze River. The downstream exit section is narrow, so the floods caused by torrential rain occurs frequently. Xinshan County has the representativeness of riverside towns which is prone to mountainous flood disaster in Central China, so it is selected as the typical study area.

There are two main rivers in Xinshan Country. The biggest river is the Gufu River. This river locates at the upper reaches of Xiangxi River, which originates from Shenlongjia mountain. It passes through Xinshan County from north to south, and forms a big reservoir not far from the Gufu Town. Its rain collecting area is about 1134.7 km², the main river stream is about 68 km long, which has the rain collecting area of about 1134.7 km² and the slope of approximately 2%. Wangjiahe River is the second big river passing through Xinshan County, which flows into the Gufu River at Gufu Town. The main river stream is 19.9 km long, which has the rain collecting area of about 135.7 km² and the slope of approximately 3.24%. The river distribution systems in Xinshan County is shown in Fig. 1.

Figure 1. The rivers (blue line) and flood calculation border (red line) in Xinshan County
3. Methology

3.1. Flood calculation scheme
Considering that the flood prevention standards of the levee in Gufu Town is 0.05 (probability), the flood calculation scheme is proposed (Table 1). The flood calculation of Gufu River is designed to four scales: 0.1(probability, approximately once a 10 years), 0.05(probability, approximately once a 20 years), 0.02(probability, approximately once a 50 years), and 0.01(probability, approximately once a 100 years). And the flood calculation of Wangjia River is designed to five scales: 0.05(probability, approximately once a 20 years), 0.1(probability, approximately once a 10 years), 0.05(probability, approximately once a 20 years), 0.02(probability, approximately once a 50 years), and 0.01 (probability, approximately once a 100 years).

Table 1. Flood calculation scheme in Xinshan County

| Rivers     | Flood scale                                                                 |
|------------|-----------------------------------------------------------------------------|
| Gufu River | 0.01 Once a 100 years in the Gufu River after Gudongkou Reservoir, together with the corresponding flood in the Wangjia River |
|           | 0.02 Once a 50 years in the Gufu River after Gudongkou Reservoir, together with the corresponding flood in the Wangjia River |
|           | 0.05 Once a 20 years in the Gufu River after Gudongkou Reservoir, together with the corresponding flood in the Wangjia River |
|           | 0.1 Once a 10 years in the Gufu River after Gudongkou Reservoir, together with the corresponding flood in the Wangjia River |
| Wangjia River | 0.01 Once a 100 years in the Wangjia River, together with the flood once a 20 years in the Gufu River |
|            | 0.02 Once a 50 years in the Wangjia River, together with the flood once a 20 years in the Gufu River |
|            | 0.05 Once a 20 years in the Wangjia River, together with the flood once a 20 years in the Gufu River |
|            | 0.1 Once a 10 years in the Wangjia River, together with the flood once a 20 years in the Gufu River |
|            | 0.2 Once a 5 years in the Wangjia River, together with the flood once a 20 years in the Gufu River |

3.2. Flood simulation model
The one-dimensional hydraulic method is proposed. According to the topographical, hydrological, and river section observation datasets of Xinshan County, the flood range, water depth, and submergence area of the Gufu River and Wangjia River is calculated by this one-dimensional model, which is established by Saint-Venant equations on the basis of HECRAS software.

- **Calculation range.** As shown in Figure 1, the red line represents river system in the calculation range. When calculating the main stream of the Gufu River, the upstream starts from the dam site of the Gudongkou Reservoir and the downstream is at the Maicang Bridge. Meanwhile, when calculating the Wangjia River tributary, the upper boundary comes from the upper 800m end of the Qinghong Hotel. The lower boundary is the intersection of Wangjia River and Gufu River. The blue line represents the one-dimensional hydrodynamic model range of the river.

- **One-dimensional model.** According to the river section observation of the calculation range, the HECRAS software is introduced to establish the one-dimensional model. And the initial settings, the boundary parameters, the calculation steps and the output datasets are comprehensively determined. After the model completion, the calibration and rationality analysis is carried out, and the availability of flood calculation is also determined.

- **Model boundaries.** When calculating the Gufu River, the upper boundary conditions is flood process line for each designed frequencies after the regulation of the Gudongkou Reservoir, while encountering the corresponding flood process line of the Wangjia River. The lower boundary condition is the most downstream section of the river channel. When calculating Wangjia River, the upper boundary condition is taken from the typical frequency flood process line at 800 meters on the Qinghong Hotel, and the lower boundary is taken from the fixed flood process line(approximately once a 20 years) of the Gufu River.
3.3. Model parameter setting

- Roughness coefficients. According to the Chinese manual of hydraulic calculation [12], the roughness coefficient is selected as follows: the river channel is 0.03–0.035, the water-passing house is 0.15, the village is 0.07, the forest is 0.065, the paddy field is 0.05, and the open space is 0.035.
- Calculation parameters. The full calculation duration of each scheme is 40h, the peak value of the flood peak appears at approximately 10-15h, the calculation time step is 5s, and the output time interval is 30m.

4. Result and analysis

4.1. Designed flood process

The flood process of the Gufu River at the site of the Gudongkou dam. The flood process of the Gufu River in the study area is regulated by the Gudongkou Reservoir. Based on the “Preliminary design report of the Gudongkou (I) water conservancy and hydropower project” and the reservoir flood control regulation rules, the designed flood process at the Gudongkou dam is shown in Fig. 2.

- Designed flood process of Wangjia River. Because there is no hydrological and flood measurements in the Wangjia River, and the rain collecting area is less than 1000 square kilometres, so it is available to use the fast flood algorithm [10]. The designed flood calculations are shown in Fig. 3.

4.2. Flood information retrieval

- Flood submerged area. As shown in Table 2, under typical flood conditions (0.01-0.2, probability), the main flood submerged area in Xinshan County are concentrated in Hanxikou, Dengjiaba, Xinshan County People's Hospital and Beidouping. The total area of the flood submerged area is approximately 0.75 km².
- The water depth. Takes a typical flood process (approximately once a 100 years) as an example. As shown in Fig. 4, the flood submerged area of the Gufu River is mainly concentrated in the Dengjiaba, Xinshan County People's Hospital and Beidouping area. The average water depth of flood submerged area is more than 1.0m. Moreover, the flooding of the Wangjia River is mainly concentrated in the area of Hanxikou and Dengjiaba, the average water depth is about 0.3-1.0m.

| Frequency /% | Submerged area / km² | Submerged area of different water depth / km² |
|--------------|----------------------|---------------------------------------------|
|              |                      | 0.05-0.3 | 0.3-0.5 | 0.5-1.0 | 1.0-2.0 | >=2.0 |
| 20           | 0.08                 | 0.01     | 0.01    | 0.02    | 0.02    | 0.02  |
| 10           | 0.53                 | 0.05     | 0.04    | 0.11    | 0.16    | 0.17  |
| 5            | 0.58                 | 0.04     | 0.05    | 0.12    | 0.18    | 0.19  |
4.3. Flood hazard assessment

According to the “Technical Requirements for Analysis and Evaluation of Mountain Flood Disasters” [10] edited by the Chinese Ministry of Water Resources, the river section with the current flood control capacity less than once a 10 years is defined as extremely high-risk area (EHR), with the current flood control capacity more than flood once a 20 years is defined as risky area (R), and the river section between the encounters is high-risk area (HR).

From the Gudongkou Reservoir flood discharge tunnel to the Xinshan County People's Hospital river section of Gufu River, the 4-8 meter water levee is built which can prevent typical flood (approximately once a 20 years). After the flood regulation of the Gudongkou Reservoir, the current flood control capacity of the river section is greater than typical flood(approximately once a 20 years, R zone), which is actually able to prevent greater flood. The Wangjia River from Hanxikou to Dengjiaba is basically a original riverbed, the actual flood control status is less than typical flood(approximately once a 10 years, EHR zone). Moreover, 4-8m water levee is built along Gufu River from Xinshan County People's Hospital to Maicang Bridge section. Although it is usually affected by flood in the Wangjia River, actual flood control capacity is greater than 20 years (R zone).
5. Conclusions
It is of great significance for monitoring, early warning, defence and engineering management of mountain flood disasters in riverside countries. A one-dimension hydraulics model is proposed in the paper for flood simulations and risk analysis. According to the river distribution, meteorology, flood, topography and geomorphology of Xinshan County, a flood calculation scheme is proposed. Based on HEC-RAS software, the designed flood process is calculated, and the flood related information (such as flood submerged depth and submerged area) is retrieved with the combination of GIS and flood simulation for risk assessment. The results show that the main river sections of the main stream of the Gufu River meet the flood control standards of 20 years, and the current flood control capacity of the river section of the Wangjia River is lower, which are basically consistent with the Xinshan County Flood Control Emergency Plan[11]. Moreover, this fact proves that the proposed one-dimension hydraulics flood model is effective.

The future work is to conduct in-depth flood investigation and analyze the flood hazard to urban important units, such as government administration, enterprises, institutions, schools and hospitals. Collecting all flood dangerous materials, the comprehensive flood risk map is drafted to provide flood related information to urban important units and local people, which will extent the availability of our flood simulation results in flood disasters prevention and relief.

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