Xichang, China

Risk assessment and cartography of flash floods

Yongshun Han, Peng Huang, and Longwei Li, Institute of Natural Hazards Prevention, Hunan University of Science and Technology; Arun Bhakta Shrestha, and Sagar Ratna Bajracharya, ICIMOD

Risk maps developed for the city of Xichang in China reveal that property valued at more than USD 1 billion could be damaged in the event of a flash flood. These maps have been used to inform land use planning, policy makers and communities, for example, to avoid construction in at risk areas.

Introduction

Xichang is the capital of Liangshan Yi Autonomous Prefecture, Sichuan Province, in southwest China. In 2010, the permanent residential population of Xichang was 666,200, including six sub-districts, 37 towns and countryside residents. There are three sub-district offices in the study area, Changan, Xincun, and Changning, and four administrative villages. In the upstream portion of the West River in Xide County, there is one township, five administrative villages, and 15 groups. The Yi are the dominant population group in Liangshan Yi and Xichang. At the end of 2009, the urban population of Xichang was about 356,300 people (composed of people from 28 ethnic groups, with 18.77 per cent of the population belonging to minority ethnic groups); the built-up area covered 35.51 km^2; there were 108 km of city roads; and the rate of urbanization was 53.4 per cent.

The West River is a very hazardous river running through Xichang and Xide County belonging to the Jinshajiang River system (E102°14′27″ to 102°30′24″ and N27°48′28″ to 28°05′45″). The West River watershed is rich in natural resources, making it one of the more economically developed areas with industrial and mining establishments, as well as one of the densest populated areas in the Panxi region of Sichuan.

Precipitation in the study area mainly falls between June and October; the rainfall in these five months accounts for 85–92 per cent of the annual rainfall. The mean annual rainfall is around 1,013 mm and mean annual evaporation is 1,945 mm – the difference being 932 mm. The index of aridity is 1.38. Rainfall tends to increase by about 30 mm with every 100 m in altitude.

Ordinary hazardous floods occur frequently (every year), with serious floods occurring every three to four years and flash floods occurring occasionally compared to riverine floods. The area's unique hydro-meteorological conditions, terrain, and unsustainable human activities aggravate soil erosion in the West River watershed, contributing to the frequency and severity of flash floods, which seriously endanger communities in the watershed. According to incomplete statistics dating back to the 1990s, no less than 24 flash floods have occurred in the West River watershed, destroying towns and bridges, endangering people and livestock, doing great harm to the regional economy, and resulting in loss of life and property. These calamities have even affected Xichang.

Accordingly, this study was conducted to:

- summarize the flood prevention measures that have been taken in the study area and local experiences in relation to this;
- train and educate key stakeholders and generally raise community awareness about flash flood hazards;
- establish a forecasting system and make a scientific assessment of flash flood hazards in the West River basin; and
- produce an atlas of the study area containing baseline maps and thematic maps including risk assessment maps.

Methodology

Various forms of data, including spatial data, thematic data, socioeconomic data, attribute data, and statistics, were collected for the study, and a review of the relevant literature conducted. Spatial data were collected (and purchased) from many sources including national centres for basic geo-information, relevant databases and websites, the national science data library, and by digitalizing existing maps. Field investigations, interviews, and consultations (via regular correspondence and email), as well as survey questionnaires, were conducted to collect thematic data on flash floods, socioeconomic data on the study area, and attribute data on geographic entities. Internet searches of government websites, government yearbooks and communiqués, and various literature and reports revealed relevant statistics.

In addition to these secondary sources of data, firsthand data on flash flood forecasting and risk cartography were collected through field surveys, observation, experiments, and by inviting manuscripts from peer experts. Local knowledge and practices, and the outcomes and findings of such practices, were documented from interviews with locals.

Thematic data on flash floods and land use were used for flash flood forecasting, risk assessment, and cartography. Regional flash floods and land coverage were surveyed using remote sensing interpretation with high-resolution and multi-periodical images. Loss and damage caused by particular flash flood events was determined through field investigations, interviews, visits, and a literature review.

Outcomes

The study piloted and set up 24 mathematic models including five data processing models, three flash flood forecasting models, and 16 flash risk assessment models. Seventeen methods were studied and improved, mainly including data encoding, transforming and standardizing methods, and flash flood risk mapping methods.

The project had five major outcomes:

- databases and basic information management system
- flash flood forecasting and risk assessment
- flash flood risk maps
- capability building
- tool kits

Databases and information management system

A number of comprehensive databases (including a spatial database, attribute database, thematic database, meta database, model database, and multi-media database) were piloted and scaled up in the study area (as well as in the Wenchuan earthquake-affected areas and Hunan Province). Nine kinds of databases were established with more than 800 data tables for storing and managing various and massive data and materials. For this, data were collected, compiled, processed, standardized, and encoded.

Using these databases and WebGIS technology, a basic information management system for data sharing and knowledge dissemination was developed and applied. This system has eight main functions: basic science education, data gathering, data access, data management, data querying, statistical analysis, thematic mapping, and information dissemination. The basic information management system made the other activities of the project easier and more effective, and enabled information sharing and knowledge dissemination to take place.

Flash flood forecasting

Forecasting is an effective non-structural way to prevent and mitigate flash floods, but its feasibility and effectiveness depend on data integrity and precision, the forecasting model used, and the technique and methods adopted. In this study, flash flood forecasting was carried out through the following activities:

Forecasting data: Forecasting requires real-time data and precise meteorology and hydrology data. This data must be processed quickly and the successive information fed back into the forecasting model and system. In this study, real-time forecasting data were gathered from a numerical meteorological Doppler radar set up just in the study area. The accepted radar data were transformed into a '*.txt' format through a system developed for the study and then stored in a database.

In the remote and isolated mountain areas of the study area, the high precision and integrity of radar data were poor. In order to resolve this problem and provide integrated and precise data, seven field meteorological and hydrological observation stations were set up in the study area with the capacity to gather meteorological data once every 1.5 minutes and transmit the data wirelessly to the data centre. In addition, the internal interpolation model for meteorological data were researched and established using the Kriging technique according to topographic conditions and meteorological variation with altitude.

Forecasting model: A scientific and feasible model is the key to flash flood forecasting. A new matrix formula was developed to assess the probability of flash flood in the study area. The model consisted of three steps to determine the matter-element assemblage for the grade of flash flood probability.

Forecasting technique: On the basis of forecasting data collection and processing and using the established forecasting model, a real-time flash flood forecasting system was developed and applied to the project through GIS, the database, remote sensing, programming, and communication technologies. This warning system consisted of infrared cameras, vibration sensors, a wireless signal projector, and solar cells. The system can gather the motion parameters and wirelessly transmit warning signals to local residents.

Flash flood risk assessment

The flash flood risk assessment consisted of a hazard assessment, vulnerability assessment, and loss and damage evaluation (Figure 29). The flash flood hazard and vulnerability assessments were briefly expounded as follows:

Flash flood hazard assessment: A flash flood hazard assessment was conducted to calculate the range, depth, duration, and degree of flash flood inundation by simulating the hydrological processes of a given frequency flash flood. Using a GIS technique and hydrological and topographic data, a back-propagation (BP) neural network time-sequence model was set up and applied in the study (Formulas 1 to 3).

Step 1: The stream network was extracted and created using GIS-based hydrological analysis. The process included processing DEM (digital elevation model) in a grid format/small geo-cell, determining the flow direction of each geo-cell, calculating the flow accumulation, identifying the corresponding sink, filling up the relevant sink, delineating the watershed, and creating stream networks at various levels.

Figure 29: **Procedure used for flash flood risk assessment**

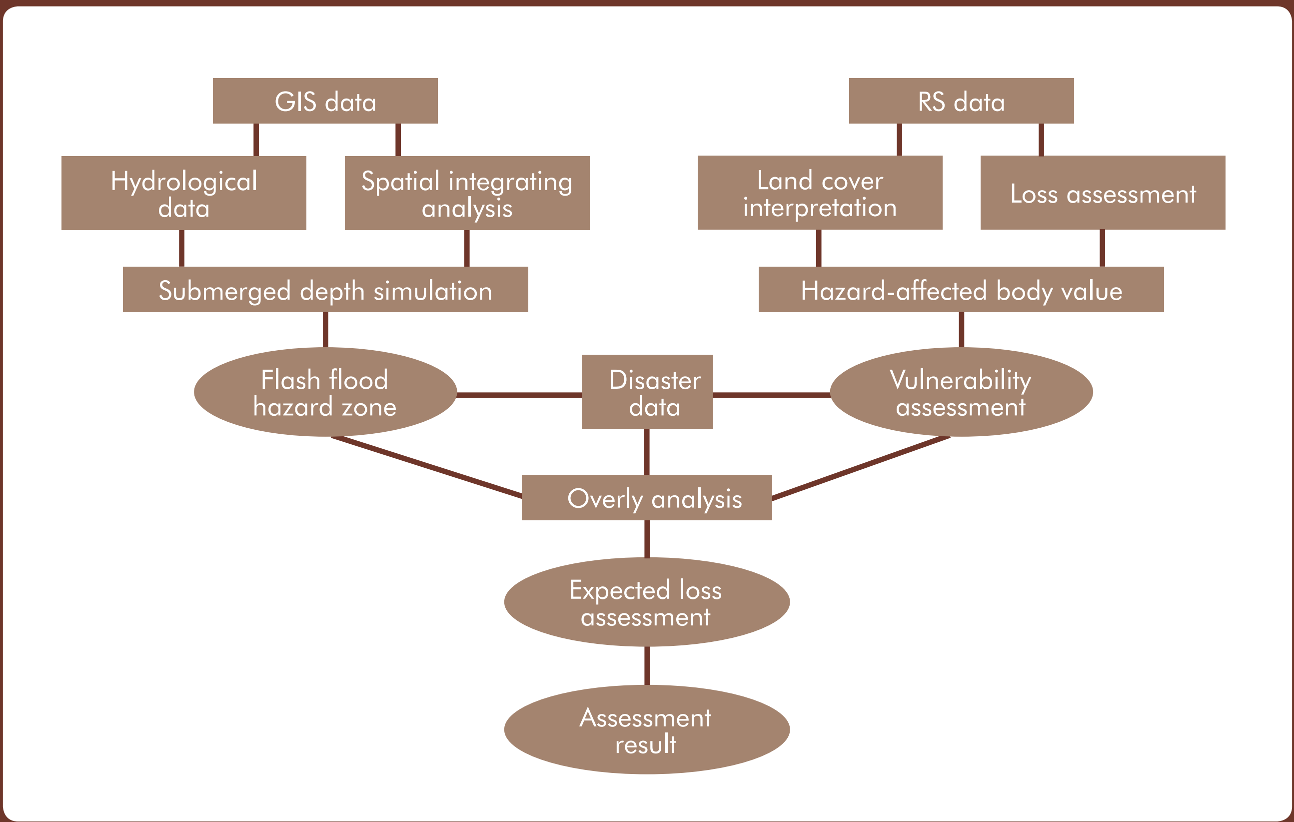
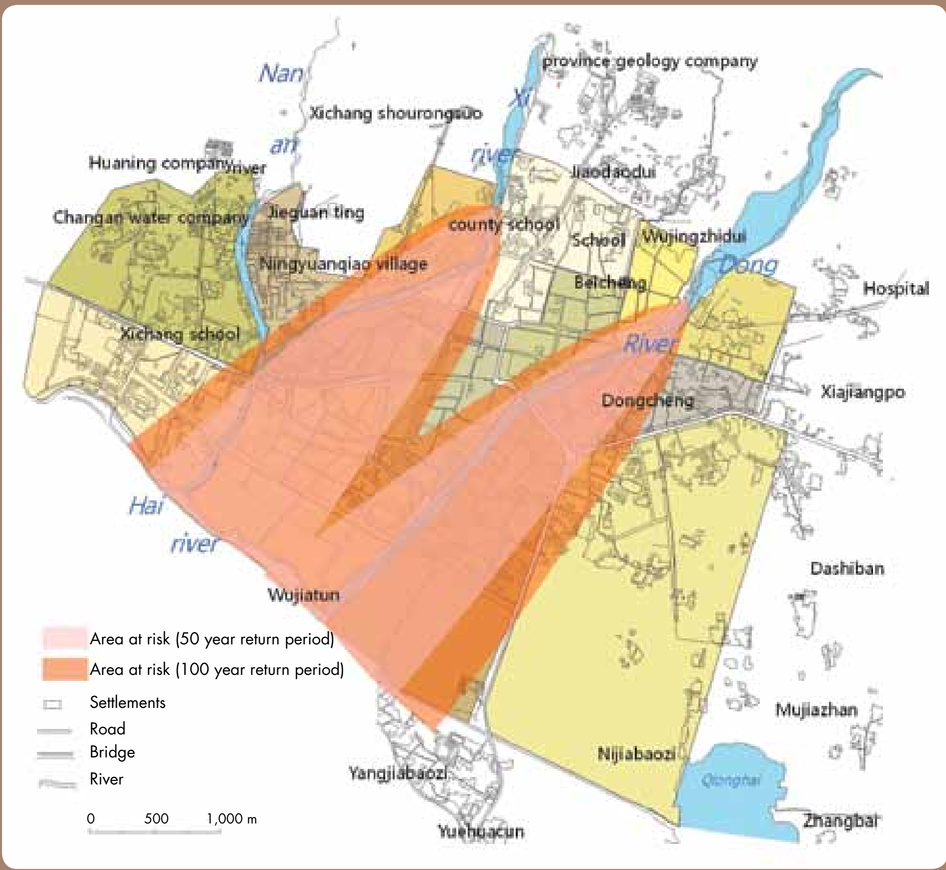


Figure 30: **Simulation and hazard assessment of flash flood of different frequencies**



Step 2: The maximum design discharge of each drainage outlet was calculated using the formula

$$Q = 0.278\psi iF = 0.278\psi \frac{S}{\tau^n} F$$

where Q is the maximum design discharge of a drainage outlet, ψ is the runoff coefficient of the flood peak, i is the maximum rainfall intensity, F is the drainage area, S is the rainstorm parameter from the Department of Water and Resources, and τ is the concentration time of drainage.

Step 3: The water level of the relevant geo-cell was calculated using the formula

$$H(x,y) = h_w(x,y)-h_g(x,y) \quad [h_w(x,y)>h_g(x,y)]$$

where (x,y) are the geographic coordinates, $H(x,y)$ is the inundated depth at coordinates (x,y), $h_w(x,y)$ is the water level at coordinates (x,y), and $h_g(x,y)$ is the elevation at coordinates (x,y).

Step 4: The inundated range/area was calculated using the formula

$$Q = \sum_{i=1}^{n} H(x,y) \times A_i$$

where Q is the maximum design discharge of drainage outlet, $H(x,y)$ is the inundated depth at coordinates (x,y), A_i is the corresponding range/area inundated, and n is the number of assessing units.

Step 5: A simulation and hazard assessment of flash flood was conducted through the BP neural network time-sequence model (Figure 30).

Flash flood vulnerability assessment: The vulnerability assessment focused on the socioeconomic attributes of flash floods, with population, estate cost, resource value, environmental value, and production value as the basic risk elements.

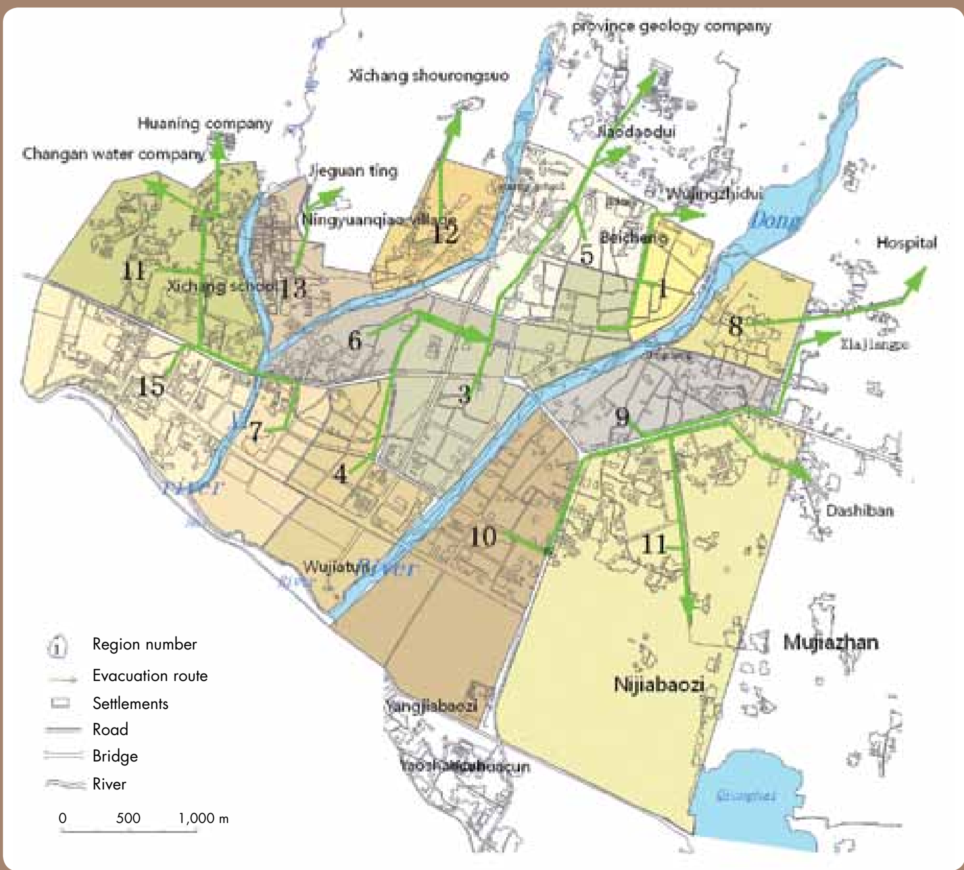
Flash flood risk mapping

In order to summarize the findings of the flash flood risk assessment and contribute to flash flood risk management, the procedures and standards, including map design and compilation, data format and processing, and thematic expression, of flash flood risk mapping were set up and formulated. Consequently, a series of practical flash flood risk maps (51 sheets in

Table 11: **Flash flood risk maps produced by the study**

Map group	Sheets	Main maps	Remarks
Flash flood-inducing environment	14	Topography, slope, altitude, aspect, geo-structure, stratum, lithology, temperature, rainfall, land use, water system, residential areas, roads, administrative divisions, etc.	These maps give information on the natural background to flash-flood formation and provide fundamental data support for the layout of control stations and networks, flash flood monitoring, forecasting, warning, risk assessment and management, and capacity building, among other things.
Flash flood investigation	12	Remote sensing images, flash flood, disaster loss and damage, population, economy, etc.	These maps focus on the danger posed by flash floods including potential socioeconomic loss and risk to resources, assets and other hazard-affected entities and provide fundamental data support for vulnerability assessment and flash flood risk management.
Flash flood prevention and control measures	7	Flash flood control engineering, soil and water conservation engineering	These maps contain information on structural and non-structural measures for flash flood prevention and control.
Monitoring and forecasting	4	Meteorological monitoring, hydrologic monitoring, flash flood monitoring, warning system, forecasting system	These maps focus on the principles, content, methodology, and technology involved in comprehensive flash flood monitoring and forecasting and reflect the achievements of the project.
Risk management	8	Framework of flash-flood risk management, flash-flood risk assessment	These maps establish the framework for flash flood risk management; they contain the flash flood risk assessments and mapping.
Capacity building	3	Flash flood awareness raising, education, training, drills, emergency response, health prevention, etc.	These maps look at the impact of capacity building on flash floods in the study area.
Information-sharing and knowledge-dissemination	3	Comprehensive databases, information-sharing and knowledge-dissemination platform, online release and interaction	These maps are designed for regional information sharing and knowledge dissemination on flash floods; they show the application and impact of the project on flash flood prevention and mitigation.

Figure 31: **The evacuation map for 50-year frequency flash flood in Xichang**



seven map groups) were made using GIS, CorelDraw, and PhotoShop (Table 11; Figure 31).

Capacity building and tool kits

Flash flood capacity building training was conducted for more than 3,700 stakeholders in the study area. Stakeholders include communities, residents, students, volunteers, and representatives of local governments, enterprises, organizations (commercial and non-governmental), and the armed forces. Capacity building activities included the distribution of booklets and posters; lectures; expert consultations; knowledge contests; curriculum teaching; workshops; local TV promotions; slide shows; programmes for students; and training and drills. These activities raised flood risk awareness and strengthened the response capacity of communities and stakeholders in the study area. Community-based preparedness and people's participation in flash flood prevention and mitigation was promoted and the risk management of flash floods in Xichang was improved with the participation of stakeholders and volunteers. In addition to this, tool kits were compiled and distributed among communities in the study area containing more than 4,000 popular science booklets and many emergency bags.

Results

In addition to the five outcomes, the project contributed to:

- **Community resilience:** The project contributed to community resilience for flash floods by using learning from past flash flood experiences and reducing vulnerability through flood forecasting, risk assessment and risk mapping. Risk assessment and mapping were also used to inform industrial arrangements and land use planning. The project also helped encouraged special agricultural practice such as changes to cropping patterns and stall-feeding of livestock to discourage pasture degradation; improved forest areas and developed commercial forestry; encouraged the exporting of services; used local labour for local construction; made proper use of local resources; and strengthened linkages and partnerships for external support and relief.
- **Reducing vulnerabilities:** By complementing existing structural measures with non-structural measures such as flash flood forecasting, risk assessment, and awareness raising, and by building response capacity at the community level, the project reduced vulnerability to flash floods in the study area.
- **Flash flood risk management:** The project raised the capacity of stakeholders in flash flood risk management in the study area through capacity building activities; by piloting and using relevant models, methods, and information systems for flash flood forecasting; and through risk assessment and the maps produced by the study.

Lessons Learnt

- **Language and cultural differences must be considered in project activities or they can become obstacles to effective flash flood risk management**. The Yi people in the study area do not readily learn other cultures and languages, posing a significant obstacle to communication, education, and training, and making it difficult to implement capacity building and flash flood risk management in some Yi areas.
- **Monitoring instruments and effective processing methods for hydrological and meteorological data are essential preliminary steps in flash flood risk management**. Only one Doppler radar and seven field observation stations were established in the study area meaning that some areas are not covered. Meteorological data for some blind areas were interpolated using only linear function and according to experience and the relationship of precipitation to topography and climate. This affects the precision of flash flood forecasting and risk assessment models.
- **Structural measures should not be overlooked and are necessary to support non-structural measures.** Structural engineering measures for flash floods were lacking and most of existing structural engineering measures in the study area were in disrepair. Unfortunately, there are no structural engineering measures in most of the remote and isolated mountain zones in the study area.

Recommendations

- Combine indigenous knowledge and local practices with up-to-date science and techniques for more effective flash flood risk management and to build resilience at the community level.
- Implement structural measures in key units and zones.
- Implement effective and feasible flash flood forecasting and risk assessment systems; this requires reinforcing not only meteorological and hydrological observations at national and local levels, but developing or improving relevant flash flood forecasting and assessment models.
- Enhance the participatory and positive scope of minority groups in flash flood risk management through training, by expanding employment, and by harmonizing them with other groups in all respects.