Flash Flood Risk Assessment Based on FFIA in China

Changzhi Li*, Dongya Sun, Liang Guo, Hong Wang, Xiaolei Zhang, Miao Zhang
China Institute of Water Resources and Hydropower Research, Beijing, 100038
Email: lichangzhi@iwhr.com

Keywords: Flash flood, risk assessment, FFIA, China

Abstract: Reliable flood risk level information is significant to take appropriate strategies and measures for flash flood management from area to area in China that suffers heavily from flash flood disasters. A nation-wide project, called Flash Flood Investigation and Assessment (FFIA), was performed during the period of 2013-2016 for the purpose of a great improvement in flash flood management. Based on the data from FFIA on hazard, exposure and vulnerability for each watershed in mountainous area, this study performed flash flood risk assessment by steps of risk index system development, risk assessment model construct, risk component computation and flash flood risk analysis; the risk index system is consisted of three layers of general risk layer, component layer and factor layer (mainly from FFIA); and the model for flash flood risk indicates the overlying effect of hazard, exposure and vulnerability. The main conclusions include: 1) the outcomes of flash flood risk assessment agree well with the places where flash flood events occurred, 2) the protected objects at different risk levels are identified on different administrative jurisdiction levels, and 3) areas with high flash flood risk are highlighted as the Qin-Ba Mountains area, the Wuling-Xuefeng Mountains area, the Wuyi Mountains area, the Nanling Mountains, the Sichuan Basin and its surrounding area, the Yun-Gui plateau, the Yanshan-Taihang Moutains, the Loess Plateau, and the Changbai Mountains; and suggestions were presented for flash flood risk management in these areas according to local conditions of climate, geography, population and urbanization.

1 INTRODUCTION

Flash floods are highlighted by deep, fast flowing water which – combined with the short time available to respond - increases the risk to local people and property (Sene, 2013). China suffers heavily from flash floods due to much covering of mountain and hilly area, frequent high-intensity and short-duration storms, and increasing human actions.

The mountainous area covers roughly two thirds of the land area of China, and the topography is high in the west and low in the east, taking three level ladder-like steps from west to east. The first one is the Tibet Plateau with average elevation over 4,500 meters and bounded by the line of Kunlun-Qilian-Hengduan mountain ranges. The area in the east of the line along the Greater Khingan-Taihang-Wushan-Xuefeng mountain ranges, is the third step, consisting of vast plains, hills and low mountains with elevation less than 500 meters. The remaining is the second step with large basins and plateaus, and average elevations ranging from 1000 to 2000 meters (See Figure 1).

This topography in China leads much warm moist air of the Pacific to flow into the south-east areas but pretty less in the north-west inland areas. This causes great regional differences in average annual rainfall, generally, over 1,000 mm in the south-east areas and less 200 mm in the north-west inland areas. It is easy for hills or mountains to obstruct the movement of hot and wet air flow which makes a great local difference in rainfall amount. Therefore, as far flash flood event is concerned, local topography plays significant role in the formation of abrupt orographic rain with heavy rainfall on the windward side and little even no rainfall on the leeward side. Figure 2 presents the spatial distribution of rainstorm depth with 6-hour-duration and indicates a significant consistence with the land framework, which is constituted by the long and high mountain ranges (See Figure 2).

Li, C., Sun, D., Guo, L., Wang, H., Zhang, X. and Zhang, M.
Flash Flood Risk Assessment Based on FFIA in China.
In *Proceedings of the International Workshop on Environment and Geoscience (IWEG 2018)*, pages 566-575
ISBN: 978-989-758-342-1

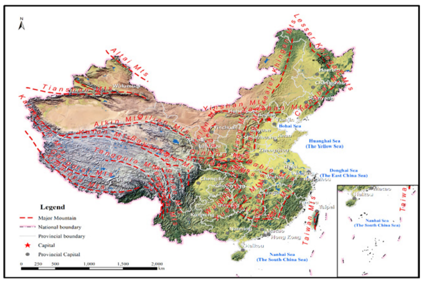

Figure 1: The ladder-like pattern of China topography.

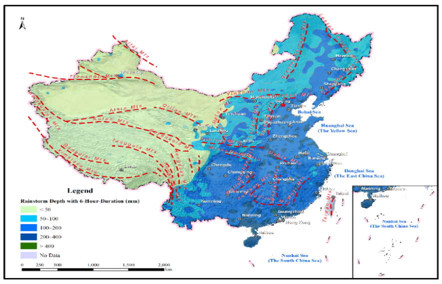

Figure 2: Rainstorm depth with 6-hour-duration in China.

In addition to this, human actions have been increasingly activated in mountain and hill areas in recent years, such as farming, leisure, entertainment, mining, tourist, and so on, which have put more and more people and properties to the threat of flash flood.

There were many records on flash flood events in China since 1950s, and these events are highlighted by unexpected occurrence, sporadic and isolated distribution in large mountain area, and huge destructive power. Flash flood hazard mostly occur in isolated or remote communities. Therefore, flash flood management has become one of the most challenges in flood management in China. According to international experiences, one of the effective strategies on flash flood mitigation is to practice risk management that can reduce flash flood risk levels and represent a guidance on strategies and countermeasures from area to area.

Many current researches regarding flood disasters consist of pregnant environment, disastrous factors, exposures and disaster prevention capacity. Flood risk is the possible consequence among interactions of hazard, exposure and vulnerability (Cheng, 2009) while the earlier concept of risk is usually the product of losses and possibility (International Union of Geological Sciences (IUGS), 1997). WMO/GWP (WMO/GWP, 2007) regarded the regional flood risk should be determined by quantizing the hazard, exposure and vulnerability while Merz and Thieken(Merz et al., 2004) thought that the aim of flood hazard appraisal is to estimate the possible inundated area and intensity of various scenarios. It is quite difficult to obtain entire data about total components of the flash flood risk and many studies focused on respective component, such as hazards estimation(Zhang et al., 2000; Zhao, 1996; Azmeri et al., 2016), exposure and vulnerability appraisal, especially, in recent years, more and more attentions were drawn to vulnerability or resilience and uncertainty at community level (Papathoma et al.,2012; Birkmann et al.,2013; Totschnig and Fuchs, 2013; Jakob et al., 2012; Sanyal and Lu, 2005; Shi et al., 2004). As for methods for risk analysis, historical approaches (Copien et al., 2008; D'Agostino, 2013; Greardo et al., 2004) were frequently used while some studies on flood hazard assessment focused mainly on small-scale region with comparative complete methods and techniques, such as hydrological and hydraulic methods and tools (Capello et al., 2016; Leticia et al., 2008; Fuchs et al., 2013). Apel H, et al (Apel et al., 2009) discussed how to choice methods to how detailed do we need to be in risk analysis. At the same time, more and more information technologies have been used to make flash flood analysis, such as RS (Remote Sensing) and GIS (Geographic Information System) (Solaimani et al., 2005; Sanyal and Lu, 2006; Lepuschitz, 2015).

The impacts of flash floods are so heavy for the socioeconomic developments and the achievement of the sustainable development goals that much attention has been paid to flash flood management. During the period of 2013-2016, a nation-wide project named Flash Flood Investigation and Assessment (FFIA) was performed to improve flash flood management (the Project). Based on the fundamental data from FFIA on hazard, exposure and vulnerability, this study aimed at supporting decision making on countermeasure for flash flood management from area to area in China. The risk conception of WMO/GWP (WMO/GWP, 2007) was adopted in this study because the authors regard this conception presents not only the expression on components of flash flood risk, but also on macro-thought of flood risk computation and guidance on flash flood management. At the same time, the literature review indicated that most studies combined exposure and vulnerability as one entity for risk analysis, but the authors found that vulnerability is, to some extent, independent on exposure in the process of data analysis. Therefore, risk assessment in this study was performed according to three risk components: hazard, exposure and vulnerability.

2 FLASH FLOOD HAZARDS INVESTIGATION AND ASSESSMENT (FFIA)

2.1 About the Project

As mentioned above, the nation-wide project FFIA focuses on flash flood risk reduction. The Project was implemented in 2,058 counties in China through the following 3 periods: 1) early preparedness period, during which many technical documents were developed, basic data and map prepared, special software kit developed for data collection and process for field work, watershed information extraction from digital elevation model (DEM), and determination on what data and information to be further acquired during the next period; 2) investigation and assessment period, during which all of the tasks were done at county level, the tasks during investigation include identification on local flash flood prone areas and communities threatened by flash floods, data collection and process on local hydrology and flash flood events, and field measurements on the local river transverse and longitudinal sections; while the tasks during assessment include computation on design storm-flood in watersheds, and estimation on the flood control capacity and rainfall thresholds for flash flood early warning for riverside communities; and 3) result summarizing period, during which data recheck and review were conducted at county, provincial and national levels, respectively; and a national fundamental database has developed for flash flood management.

2.2 Outcomes of the Project

Great progresses were made through the Project in the fundamental data for flash flood management. All of these information were summarized according to watershed scales and different administrative jurisdiction levels (county, province, and nation) for the purpose of both administrative and technical high-efficiency. In summary, fundamental information of 255,382 watersheds and 2,058 counties were included in the national database for flash flood management. For each watershed and administrative jurisdiction unit, the following data were collected: 1) the basic attributes of the watershed, such as catchment area, channel system, length and slope of each channel, landuse cover; 2) flash flood prone area; 3) the number and distribution of population, houses, household asset, monitoring and warning devices, and current flood control capacity of communities threatened by flash flood; 4) typical water-related structures potentially causing disaster, such as bridges, culverts, and weirs; 5) survey data on longitudinal and cross sections of river channel near riverside communities; and 6) historical flash flood events. Therefore, a good foundation has been laid by the Project, and more and deep understandings on flash flood disasters were obtained, such as properties of flash flood environment, hazard, exposure, vulnerability.

3 FLASH FLOOD RISK ASSESSMENT MODEL CONSTRUCTION

According to the aim of flash flood risk assessment, it is feasible to develop a simple and operable method to compute flash flood risk. The key factors for risk should be considered in the method that are of abundant flash flood information, liable to be obtained, and to be quantified. Obviously, the outcomes of the Project meet the requirements very well for choice of key factors. In this study, risk was regarded as the overlaying effect of hazard (*H*), exposure (*E*), and vulnerability (*V*). Hazard is mainly from physical factors, such as short-duration storm, and steep landform within a watershed; exposure depends from socioeconomic factors and, for instance, populations and houses in mountainous area; the vulnerability depends chiefly on susceptibility to flash flood, for example, the material and structure of houses, the capacity on flash flood monitoring and warning of a community, and the awareness of local people on flash floods. It should be pointed out that watershed is the basic geomorphic entity for flash flood risk assessment in this study. For this reason, the original values of each factor were acquired and processed according to each watershed in mountainous and hilly areas.

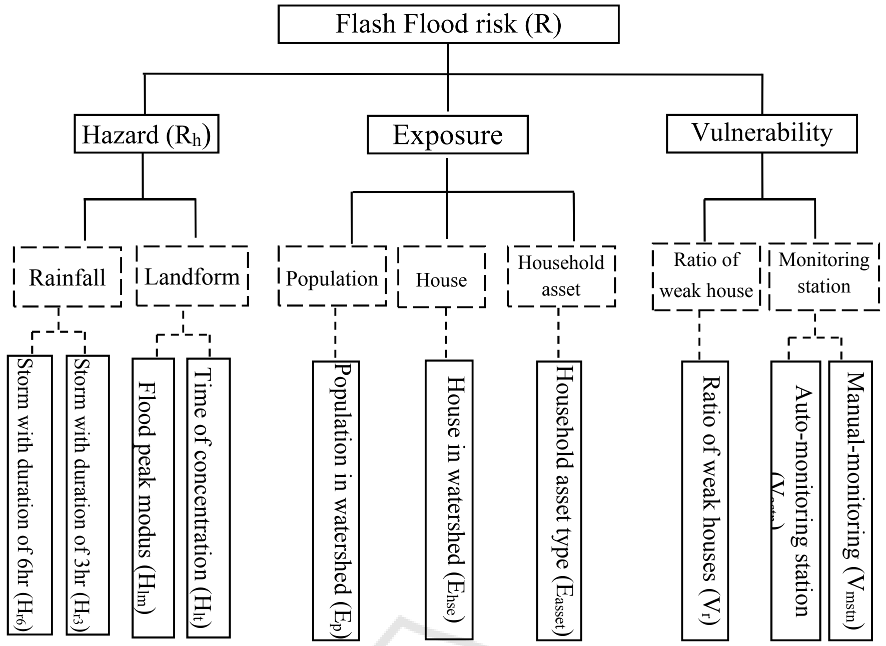

Figure 3: Flash flood risk index system.

3.1 Index System Construction

The index system for risk assessment was developed from three aspects: hazard, exposure, and vulnerability. The indexes are satisfied with the following conditions as much as possible: (1) utmost use of the data from the Project; (2) easy to be quantified; (3) the independence between factors, and (4) directly serving flash flood management.

Figure 3 presents the index system that consists of three layers of general risk layer, component layer and factor layer. Layer 1 is the general risk (R) that stands for the overlaying effect of all components of risk; layer 2 includes three components of risk: hazard (R_h), exposure (R_e) and vulnerability (R_v), all of which result from factors of risk; and layer 3 includes the factors corresponding to three components of risk, respectively.

In this study, great attention was paid to the characteristics of flash floods, such as short duration and high intensity rainstorms, high slope of channels in watersheds with small drainage area, and population and properties of local people. Moreover, the main considerations on the choice of factors at the third layer were as follows.

Hazard (R_h) refers to the hazardous degree of flash flood events, chiefly decided by the features of rainfall and landform. Larger scale and higher frequency of flash flood events are, possible heavier loss in the events. The hazard is determined by the integrated effects of pregnant environment, the disastrous factors, and disaster prevention capacity. In this study, the rainstorms with durations of 6 hours (H_{r6}) and 3 hours (H_{r3}) were selected as rainfall feature, while flood peak modus (H_{lm}) and time of concentration (H_{lt}) as landform feature, which considered the characteristics of runoff generation and surface volume in a watershed, from the point view of hydrology and hydraulics.

Exposure (R_e) means the population and houses and household assets threatened by flash flood in a watershed. Obviously, more population, houses, and household assets threatened by flash flood are, higher flash flood risk. The features of spatial and temporal distribution of population and assets are the focuses of exposure study. In this study, the population (E_p), houses (E_{hse}) and household assets (E_{asset}) were chosen to as three indexes to represent exposure. The household assets were simply estimated as the magnification of the number of households in mountain and hill area in the process of FFIA to estimate the possible losses due to flash flood.

Vulnerability (R_v) is the inner attribute of exposure and represents the fragility of exposures in same flash flood hazard. Generally, more vulnerability of exposures is, and higher flash flood risk. Vulnerability is closely related to the capacity of exposure of response to flash flood. In this study, both the ratio of weak houses (V_r) and covering scope of single auto- or manual- monitoring station (V_{astn} and V_{mstn}) are on half of vulnerability (R_v). In the process of FFIA, the houses in mountain and hill area were classified as four types and the house's capacity against flash flood increases from type IV to type III, to type II and type I, both type IV and type III belongs to weak house.

3.2 Model Descriptions

3.2.1 Risk Model

As mentioned above, flash flood risk is the overlying effect of hazard, exposure and vulnerability, as expressed by the following equation:

$$\text{Risk} = \text{H} \cap \text{E} \cap \text{V} \tag{1}$$

where, *R* is regional flood risk; *H*, *E* and *V* the elements of flood risk, hazard, exposure and vulnerability, respectively.

The risk components of hazard, exposure and vulnerability are computed as follow:

$$\text{H} = \sum_{i=1}^{m} W_i H_i = \sum_{i=1}^{m} w_i \left(\sum_{k=1}^{m'} w_{ik} H_{ik}\right) \tag{2}$$

$$\text{E} = \sum_{j=1}^{n} W_j E_j = \sum_{j=1}^{n} w_j \left(\sum_{k=1}^{n'} w_{jk} E_{jk}\right) \tag{3}$$

$$\text{V} = \sum_{k=1}^{l} W_k V_k = \sum_{k=1}^{l} w_k \left(\sum_{k'=1}^{l'} w_{kk'} V_{kk'}\right) \tag{4}$$

Where,

H, E, V —components of layer 2: hazard, exposure and vulnerability;

H_i, E_j, V_k —factors of layer 3 corresponding to components of layer 2;

m, n, l — numbers of factors of layer 3 corresponding to components of layer 2;

m', n', l' — numbers of factors of layer 3;

i, j, k, k' — intermediate variables to summarize;

W — weights of components of layer 2 and factors of layer 3.

3.2.2 Considerations on Weights

The following three considerations were taken into account:

Components of layer 2: weights for hazard, exposure and vulnerability were set as equal, 1/3, for they are all the components of risk triangle.

Factors of layer 3: as for hazard, more weight set for rainstorm with short duration that trigger flash flood, and for exposures, more weight set for population, and for vulnerability, more weight set for monitoring station, which is important for emergency evacuation.

Weight value calibration with flash flood event: trial-and-error method was used for obtaining appropriate weight values for each factor. Initial values were set to each factors for typical areas and comparison was made between the calculated results with the places where flash flood events occurred to reset the weights until a good agreement reached.

3.2.3 Considerations on Thresholds

Considerations on thresholds were performed for components of layer 2 and risk level of layer 1 as follows:

Thresholds for components of layer 2: sort descending all values of the samples, the values at 1/3, and 2/3 of samples were determined as thresholds for the corresponding to levels of high, medium, low for hazard (H), exposure (E) and vulnerability (V) (see Figure 4).

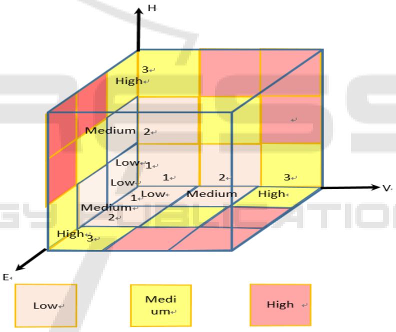

Figure 4: threshold for hazard, exposure and vulnerability.

Thresholds for risk level of layer 1: thresholds of 3 levels (high, medium, low) were taken in this study. Hazard, exposure and vulnerability levels were classified as 3 levels (high, medium, and low) and developed an overlaying effect of H-E-V Cube with 27 sub-cubes (see Figure 5). The thresholds were made according to the overlaying effect of H-E-V for the corresponding to levels of high, medium, low for sub-cubes (see table 1).

Table 1: Overlaying effect of H-E-V and flash flood risk classification.

Risk level	Number	Code of sub-cube
High	7	H1E3V3, H2E3V3, H3E1V3, H3E2V3, H3E3V1, H3E3V2, H3E3V3
Medium	13	H1E2V2, H1E2V3, H1E3V2, H2E1V2, H2E1V3, H2E2V1, H2E2V2, H2E2V3, H2E3V1, H2E3V2, H3E1V2, H3E2V1, H3E2V2
Low	7	H1E1V1, H1E1V2, H1E1V3, H1E2V1, H1E3V1, H2E1V1, H3E1V1

Table 2: demo data of flood risk index for watershed.

Watershed code	H_{r6} /mm	H_{r3} /mm	H_{lm} /$m^3/(s\cdot km^2)$	H_{lt} /hr	E_p	E_{hse}	E_{asset} /10^3 Yuan	Vr	V_{astn} /km^2	V_{mstn} /km^2
WJB3410F00000000	161	130	0.21	1.33	822	64	5,120	0.28	11	1
WJB32006L0000000	142	115	0.26	1.00	3075	260	20,800	0.51	5	*
WJB3400121Q00000	172	137	0.23	1.33	684	66	5,280	0.58	13	*
WJB3400123UM0000	166	134	0.17	1.67	506	130	10,400	0.48	24	*
WJB3400127kE0000	165	133	0.16	1.67	821	129	10,320	0.55	31	*
WJB000010111vA00	156	126	0.20	1.33	359	93	7,440	0.89	*	1
WJB31101CA000000	133	109	0.17	1.67	2000	260	20,800	0.50	*	5
WJB3110700000000	133	109	0.24	1.17	2911	78	6,240	0.50	*	9
WJB3400121h00000	169	136	0.23	1.17	1120	71	5,680	0.66	*	5
WJB3400121kED000	170	136	0.16	1.67	1301	126	10,080	0.56	*	3

(*stands for no stations in the watershed)

Table 3: weights of component and factors in the risk index system.

Component	Hazard				Exposure			Vulnerability		
Weight	1/3				1/3			1/3		
Factor	H_{r6}	H_{r3}	H_{lm}	H_{lt}	E_p	E_{hse}	E_{asset}	Vr	V_{astn}	V_{mstn}
Weight	0.45	0.15	0.25	0.15	0.55	0.35	0.10	0.30	0.35	0.35

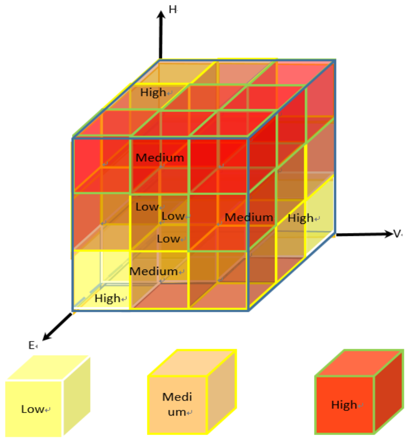

Figure 5: Overlaying effect of H-E-V Cube and risk level threshold.

4 COMPUTATION AND ANALYSIS ON FLASH FLOOD RISK

4.1 Data Acquiring and Process

The analysis on flash flood risk level in China was done based on the model described in section 3.2. And each computed entity is a watershed-level element with area equal or less than 200 km^2. There were 255,382 watersheds or entity included in the assessment. Table 2 presents some original values of sample data of flash flood risk index for watersheds.

4.2 Method and Steps

The risk analysis was performed according to the following four steps.

Step 1, index normalization. Table 2 presents that the 10 indexes are quite different in magnitude and dimensions, it is necessary to make normalization before performing flash flood risk assessment. After normalization, the absolute values of data of different indexes can be change into relative values in same magnitude and dimensionless. The following expression presents the algorithm of normalization:

$$x_i{}^* = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (5)$$

where, x_i is the value of original data, $x_i{}^*$ the normalized value of original data, and x_{max} and x_{min} the maximum and minimum of a same index, respectively.

Step 2, weights set. The initial values of weights were set referring to expert's experiences, that is, the hazard factors of rainstorms with durations of 6 hours (H_{r6}) and 3 hours (H_{r3}), flood peak modus (H_{lm}) and time of concentration (H_{lt}) were set values of 0.5, 0.1, 0.2, and 0.2; the exposure factors of population, numbers of houses and household assets were set of 0.5, 0.4 and 0.1; and the vulnerability factors of ratio of weak houses (type III- and IV) to the total houses, covering areas of single auto- or manual monitoring station were set of 0.3, 0.35 and 0.35. Then, the initial values were modified by trial-and-error method, using the flash flood events records in three typical watersheds, the Jinghe River, the Longhe River and the Yihe River (see Figure 1), which stands for south area, north area and Loess Plateau area in China. Table 3 presents the calibrated weight values of components and factors in the risk index system.

Step 3, the values of risk components computation. The contributions of H, E and V were computed according to the model developed in section 3.2. The value of flash flood risk can be computed based on formula (2), (3) and (4) as follows: first, obtaining the weighted values of each factor through values of each factor multiplying its weight; second, summarizing the values of components of layer 2 (hazard, exposure and vulnerability); third, multiplying the values of components of layer 2 and getting the values of flash flood risk in each computed entity.

Step 4, perform flash flood risk assessment and risk level classification, namely, the contributions of H, E, and V were classified as three levels of high, medium, and low, then made a risk assessment using the H-E-V Overlaying Cube to obtain the general risk levels for each watershed (refer to table 1).

5 CONCLUSIONS

The main understandings from this flash flood risk assessment are as follows:

(1) The consideration on the computed entity and weight set for risk factors was special and made the results more creditable in this study. On one hand, the basic entity for flash flood computation is watershed that the relationships among various hazard factors were taken into consideration. Flood peak modus and time of concentration were selected as factors for watershed geographic delineation for hazard component. In fact, the calculation processes of the two parameters involve the longest distance from the mouth to the origin of a river, the mean slope, landuse situation, soil type, vegetation cover, and average surface slope in the watershed, the shape of cross section of river channel. Generally, the hazard component was considered in terms of hydrology and hydraulics. On the other hand, weight set was performed by trial-and-error method using the flash flood events records in three typical watersheds, the Jinghe River, the Longhe River and the Yihe River, that made the weights in this analysis more reasonable. These consideration on entity and weight set made the results more creditable.

(2) The third layer factors in risk index system are highly representative and the approach on risk analysis are rational in this study. The outcomes of flash flood risk assessment agree well with the places where flash flood events occurred. Generally, there are about 49,000 flash flood events records since 1950 in China, about 91% of them located within the high and medium flash flood risk area in this study. The statistical results in this study indicated that the densities of flash flood events are about 19, 12 and 10 per thousand square kilometer in high, medium and low risk level area, respectively. In other words, the density in high risk level area is about twice of that in low risk level area. Therefore, the results are credible and worth of reference.

(3) The protected objects at different risk levels are identified at different scales that is significantly important for flash flood management from area to area. In general, the nation-wide areas in high, medium and low risk level reach 0.46, 1.22, and 2.17 million square kilometers, respectively; and the populations are 99 million, 184 million and 302 million, severally. These outcomes can be further refined to each watershed, then to county level, and to provincial level, which are quite helpful for

appropriate human interventions in flash flood management at different levels.

(4) The areas with high flash flood risk are highlighted in main mountainous regions. Figure 6 presents the results of flash flood risk assessment. Generally, flash flood prone areas with high and medium risk level concentrate mainly on the following nine:① the Qin-Ba Mountains area, ② the Wuling-Xuefeng Mountains area, ③ the Wuyi Mountains area, ④ the Nanling Mountains area, ⑤ the Sichuan Basin and its surrounding area, ⑥ the Yun-Gui plateau area, ⑦ the Yanshan-Taihang Moutains area, ⑧ the Loess Plateau area, and⑨ the Changbai Mountains area (see Figure 6). Therefore, more attention should be paid to these areas in flash flood management. Suggestions are presented for flash flood risk management in these areas as follow, and Table 4 demonstrates the characteristics of flash flood and general suggestions in these areas.

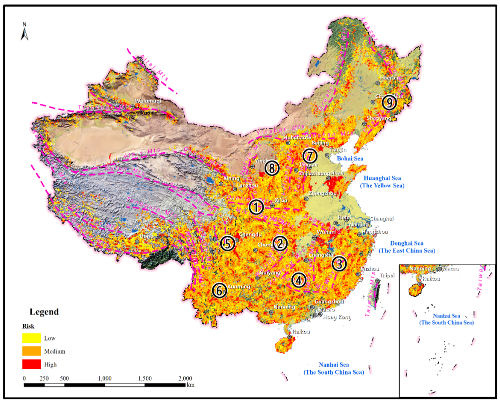

Figure 6: flash flood risk in China.

① the Qin-Ba Mountains area, ② the Wuling-Xuefeng Mountains area, ③ the Wuyi Mountains area, ④the Nanling Mountains area, ⑤the Sichuan Basin and its surrounding area, ⑥ the Yun-Gui plateau area, ⑦the Yanshan-Taihang Moutains area, ⑧ the Loess Plateau area, and ⑨ the Changbai Mountains area

Table 4. Characteristics and general suggestions in flash flood prone areas.

No.	Area	Characteristics	Province involved	Suggestions
①	Qin-Ba Mountains	abundant rainfall, frequent storms, good vegetation, highly populated, low urbanization	Shanxi, Gansu, Henan, Sichuan, Chongqing, and Hubei	I, II, III, and IV
②	Wuling-Xuefeng Mountains	abundant rainfall, frequent storms, good vegetation, highly populated, low urbanization	Hunan, Hubei, Chongqing	I, II, III, and IV
③	Wuyi Mountains	abundant rainfall, frequent storms, good vegetation, highly populated, high urbanization	Fujian, Jiangxi	I, II, III, and IV
④	Nanling Mountains	abundant rainfall, frequent storms, good vegetation, highly populated, low urbanization	Hunan, Jiangxi, Guangdong and Guangxi	I, II, III, and IV
⑤	Sichuan Basin	abundant rainfall, frequent storms, highly populated	Sichuan, Chongqing	I, II, III, and IV
⑥	Yun-Gui Plateau	abundant rainfall, frequent storms, common vegetation, highly populated	Yunnan, Guizhou	I, II, III, IV and V
⑦	Yanshan-Taihang Moutains	common rainfall, frequent storms, common vegetation, common populated	Beijing, Shaanxi,Hebei	I, II, III, IV and V
⑧	Loess Plateau	poor rainfall, frequent storms, common populated, sediment problem	Shanxi, Shaaxi, Gansu	I, II, III, IV and V
⑨	Changbai Mountains	common rainfall, good vegetation, common populated	Jilin, Liaoning	I, II, III, and IV

These areas can be classified as the following five categories according to local conditions of climate, geography, population and urbanization.

Category I is characterized by abundant rainfall, frequent storms, good vegetation cover, highly populated but low urbanized. This category include the Qin-Ba Mountains area, the Yun-Gui plateau area, the Wuling-Xuefeng Mountains area, and the Nanling Mountains area. The suggestions on intervention to flash flood hazard mitigation include macro-scale rainfall monitoring, local rainfall and water stage monitoring and warning, appropriate local structural measures, and community-based awareness and drill.

Category II is particular for abundant rainfall, frequent storms, good vegetation cover, highly populated, but highly local urbanized. This category cover the Wuyi Mountains area, and the Sichuan Basin and its surrounding area. In these areas, more attention should be paid to appropriate local structural measure arrangement in highly urbanized area besides suggestions on intervention to flash flood in the areas of Category I.

Category III is highlighted by common rainfall, frequent storms, and good vegetation cover, highly populated, but low urbanized. The Changbai Mountains area belongs to this category area. Suggestions include macro-scale rainfall monitoring, local rainfall and water stage monitoring and warning, appropriate local structural measures, and community-based awareness and drill.

Category IV is made outstanding by common rainfall, frequent storms, and common vegetation cover, highly populated and highly local urbanized. This area cover the Yanshan-Taihang Moutains area. In this area, more attention should be paid to appropriate local structural measure arrangement in those locally urbanized area, vegetation protection, and community-based awareness and drill, in addition to those common suggestions on intervention to flash flood.

Category V is made special by common rainfall, frequent storms, very poor vegetation cover, highly populated but very low urbanized. This area covers the Loess Plateau area. Strong suggestions for flash flood risk management in this area include long-term vegetation restoration, river harnessing, and appropriate landuse arrangement, community-based awareness and drill, beyond that common suggestions in other areas.

ACKNOWLEDGEMENTS

This study is financially supported by “Mechanism and model on mixing runoff generation from spatial-temporal changing sources” (No. KY1793-IWHR), and “China National flash flood prevention and control (2013-2015, 2016-2018), MWR”.

REFERENCES

Apel H, Aronica G T, Kreibich H and Thieken A H 2009 Flood risk analyses-how detailed do we need to be? *Nat Hazards* April **49(1)** 79-98

Azmeri, Hadihardaja I K and Vadiya R 2016 Identification of flash flood hazard zones in mountainous small watershed of Aceh Besar Regency, Aceh Province, Indonesia *The Egyptian Journal of Remote Sensing and Space Science* 19(1) 143-160

Birkmann J, Cardona O D and Carreo M L, et al. 2013 Framing vulnerability, risk and societal responses: the MOVE framework *Natural hazards* 67(2) 193-211

Capello M, Cutroneo L and Ferretti G, et al. 2016 Changes in the physical characteristics of the water column at the mouth of a torrent during an extreme rainfall event *Journal of Hydrology* 541 146-157

Cheng X T 2009 Flood and drought risk management evolving with progress of sciences and technologies *Water Resources and Hydropower Engineering* 40(8) 122-125

Copien C, Frank C and Becht M 2008 Natural hazards in the Bavarian Alps: a historical approach to risk assessment *Natural Hazards* 45(2) 173-181

D’Agostino V 2013 Assessment of past torrential events through historical sources (M)//Dating torrential processes on fans and cones. Springer Netherlands 131-146

Fuchs S,Keiler M and Sokratov S, et al. 2013 Spatiotemporal dynamics: the need for an innovative approach in mountain hazard risk management *Natural hazards* **68(3)** 1217-1241

Greardo B, Michel L and Mariano B,et al. 2004 Use of Systematic, Palaeoflood and Historical Data for the Improvement of Flood Risk Estimation. Review of Scientific Methods. Natural Hazards 31 623-643

International Union of Geological Sciences (IUGS), 1997 Working Group on Landslides, Committee on Risk Assessment. Quantitative risk assessment for slopes and landslides - The state of the art. Proceedings of the Landslide Risk Workshop, IUGS Working Group on Landslides, Honolulu 3-12

Jakob M, Stein D and Ulmi M 2012 Vulnerability of buildings to debris flow impact *Natural hazards* 60(2) 241-261

Lepuschitz E 2015 Geographic information systems in mountain risk and disaster management *Applied Geography* **63** 212-219

Leticia B Rodriguez, Pablo A Cello and Carlos A Vionnet, et al. 2008 Fully conservative coupling of HEC-RAS with MODFLOW to simulate stream–aquifer interactions in a drainage basin *Journal of Hydrology* 353(1) 129-142

Merz B, Kreibich H, Thieken A and Schmidtke R 2004 Estimation uncertainty of direct monetary flood damage to buildings *Nat Hazards Earth Syst Sci* 4(1) 153-163

Papathoma Khle M, Totschnig R and Keiler M, et al. 2012 A new vulnerability function for debris flow - The importance of physical vulnerability assessment in alpine areas//12th Congress Interpraevent 1033~1043

Sanyal Joy and Lu X X 2005 Remote sensing and GIS-based flood vulnerability assessment of human settlements: a case study of Gangetic West Bengal, India. Hydrologial Procese 19 3699-3716

Sanyal Joy and Lu X X 2006 GIS-based flood hazard mapping at different administrative Scales: A cale study in Gangetic West Bengal, India. Singapore *Journal of Tropical Geography* **27** 207-220

Sene K 2013 Flash Floods: Forecasting and Warning DOI 10.1007/978-94-007-5164-4_1, @Springer Science+Business Media Dordrecht

Shi P J, Wang J G and Zhou J H, et al. 2004 Integrated risk management of flood disaster in China: To balance flood disaster magnitude and vulnerability in metropolitan regions *Journal of Natural Disasters* 13(4) 1-7 (In Chinese)

Solaimani K, Mohammadi H, Ahmadi M Z and Habibnejad M 2005 Flood occurrence hazard forecasting based on geographical information system *International Journal of Environmental Science and Technology* **2(3)** 253-258

Totschnig R and Fuchs S 2013 Mountain torrents: quantifying vulnerability and assessing uncertainties *Engineering Geology* 155 31-44

WMO/GWP, 2007: Guidance on Flash Flood Management-Recent Experiences from Central and Eastern Europe. December 20-23

Zhang X N, Luo J and Chen L, et al. Zoning of Chinese flood hazard risk *Journal of Hydraulic Engineering* 2000(3) 3-9(In Chinese)

Zhao S P 1996 An elementry study on whole characteristics of mountain torrents disaster system in China and its hazard regionalization *Jounral of Natural Disasters* 3 95-101(In Chinese)