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Social vulnerability of rural households to flood hazards in western mountainous regions of Henan province, China

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Abstract

Evaluating social vulnerability is a crucial issue in risk and disaster management. In this study, a household social vulnerability index (HSVI) to flood hazards was developed and used to assess the social vulnerability of rural households in western mountainous

- ⁵ regions of Henan province, China. Eight key indicators were indentified through interactive discussions with multidisciplinary specialists and local farmers, and their weights were determined using principle component analysis (PCA). The results showed that (1) the ratio of perennial working in other places, hazard-related training and illiteracy ratio (15+) were the most dominant factors to social vulnerability. (2) The numbers of
- ¹⁰ high, moderate and low vulnerable households were 14, 64 and 16, respectively, which accounted for 14.9, 68.1, and 17.0% of the total interviewed rural households, respectively. (3) The correlation coefficient between household social vulnerability scores and casualties in a storm flood in July 2010 was significant at 0.05 significance level (r = 0.248), which indicated that the selected indicators and their weights were valid.
- (4) Some mitigation strategies to reduce the household social vulnerability to flood hazards were proposed based on the assessment results. The results provide useful information for rural households and local governments to prepare, mitigate and response to flood hazards.

1 Introduction

²⁰ Flood hazard risk has increased over the past several decades and will continue to increase in the future, and the casualties and economic losses caused by flood disasters are following a similar and increasing trend in the world (Terry and Lisa, 2014; Walter, 2004). A number of studies indicated that regional flood disasters were caused by the interactions of flood hazards and the vulnerability of flood hazard-prone areas (Zhang
 et al., 2010; Hsieh, 2014). It is more difficult to prevent a flood hazard from becoming a flood disaster than to reduce the vulnerability of flood hazard-prone areas (Liu and





Liang, 2014). In order to effectively reduce the adverse effects of a flood disaster, it is necessary to enhance the understanding of the social vulnerability of flood hazardprone areas (Cutter et al., 2003, 2013; Zhang and You, 2014). Since Cutter developed a social vulnerability index to measure the social vulnerability to environmental hazards

- ⁵ (Cutter et al., 2003), there have been growing concerns and interest in this area (Bjarnadottir et al., 2011; Noriega and Ludwig, 2012; Zebardast, 2013; Siagian et al., 2014; Garbutt et al., 2015). For example, Noriega and Ludwig (2012) assessed the social vulnerability of local earthquake risk in Los Angeles County. Zebardast (2013) constructed a social vulnerability index to earthquake hazards using a hybrid factor analysis and an-
- ¹⁰ alytical network process model. Using the social vulnerability index approach, Siagian et al. (2014) deterimined the driving factors of social vulnerability to natural hazards in Indonesia. Garbutt et al. (2015) presented an open source vulnerability index and mapped the social vulnerability to flood hazards in Norfolk, England. All these studies provide a good understanding of the social vulnerability to natural hazards. However,
- these studies focused on contributing to theoretical research or empirical study at national or regional scales (Garbutt et al., 2015; Zhou et al., 2014; Cutter and Finch, 2008; Cutter et al., 2013). The studies at the househould level are very little. The household is the basic unit of social orgnization, and which is also one of the most improtant flood hazard-prone areas (Eakin and Bojorquez-Tapia, 2008; Ghimire et al., 2010), and more
- than six hundred million people live in a rural area in China. Therefore, understanding the social vulnerability at rural household level is crucial for both rural households and local governments to prepare, mitigate and response to natural hazards (Ghimire et al., 2010; Linnekamp et al., 2011).

The objectives of this paper were (1) to identify and prioritise key influencing factors of social vulnerability to flood hazards at household level, (2) to develop and use a household social vulnerability index to assess the household social vulnerability to flood hazards in western mountainous regions of Henan province, China, and (3) to propose some targeted mitigation strategies to reduce the household social vulnerability to flood hazards.





2 Household social vulnerability index (HSVI)

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Several methods can be used to evaluate the social vulnerability to natural hazards, such as assessment method based on historcial disaster data and scenario-based, GIS-based and index-based assessment methods (Li et al., 2008). The index-based assessment method was used here maily because (1) which can effectively reveal the spatial and temporal patterns, evolution of vulnerability to a natural hazard at different scales, and (2) the assessment results among different regions are comparable due to the use of the same assessment index system (Cutter et al., 2003; Garbutt et al., 2015). There are five steps for using index-based method to assess the househould social vulnerability to flood hazards as the follows:

- 1. Determination of assessment scales. Firstly of all, it is necessary to determine the research scales because index-based assessment method can be used at different scales with different indictors. In this study, the rural household-level was chosen.
- Selection of indictors. There are a number of factors affecting the socail vulnerability of rural households to flood hazards. In order to make the selected factors as comprehensive as possible, two methods were used in this study. One is interactive discussions with multidisciplinary specialists and local farmers (Ghimire et al., 2010), and another is obtaining indicators from the existing literature (Cutter et al., 2003; Werg et al., 2013; Linnekamp et al., 2011).
 - 3. Collection and processing of data. Two methods, participatory rural apprasial (PRA) and household survey, were used to gather the data. The PRA method was used to gather some supporting information, such as their socioeconomic status, attitutes to flood hazards. Household survey (individual interviews) was used to collect the quantitative data of social vulnerability indicators (Ghimire et al., 2010). When the data were gathered together, it is necessary to normalize them to have

When the data were gathered together, it is necessary to normalize them to have a uniform dimension. Meanwhile, some indicators have favorable impacts, while





some have unfavorable impacts on socail vulnerability to flood hazards. In order to resolve these problems, the extreme standardization was used.

Positive correlation indicators: $x'_i = (x_i - \min x_i)/(\max x_i - \min x_i)$ (1)

Negative correlation indicators $x'_i = (\max x_i - x_i)/(\max x_i - \min x_i)$

- where, x_i and x'_i are the original and standard values of indicator *i*, respectively, max x_i and min x_i are the greatest and smallest values of the selected indicators' values, respectively.
- 4. Determination of index weights. The principle component analysis (PCA) method was used to determinate the weights of each indicator. The principles, steps and advantages of using PCA to determinate index weight was detailed in Qu (2012).
- Caculation of household social vulnerability. Based on the standardized data and determined index weight, a househould social vulnerability index (HSVI) was constructed and used to study household social vulnerability to flood hazards. The HSVI can be expressed by

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$$\mathsf{HSVI} = \sum_{i=1}^{n} x_i \times w_i$$

where, HSVI is the household social vulnerability index, x_i and w_i are the standardized data and the weight value of index *i*, respectively, and *n* is the number of indicators.

3 A case study

20 3.1 Study area

Eleven villages located in the western mountainous regions of Henan province (the center regions of China) were chosen as the study area (Fig. 1). The total area of



(2)

(3)

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the 11 villages is 88.2 km², and most of which is hilly land. The area of arable land (7.2 km²) only accounts for 8.2 % of the total area. The per capita income is less than USD 250 yr⁻¹, and the poverty rate was higher than that in China (Xi, 2012). The annual mean precipitation is about 750 mm, and about 60 % of which occurs during the period
of June to September. Rainstorm can easily result in a flood because of the steep and narrow riverbeds, poor flood discharge capacity and intense human activities (Shao et al., 2013). These villages were chosen as the study area mainly becacuse (1) the conditions of nature, society and economy are very similar to most other villages' in the western mountainous regions of Henan province, and (2) it is easy to obtaine sufficient and reiable data because these villages had undergone some severe flood disasters in recent years.

3.2 Selected indictors and weights

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Based on the exisitng literature (Cutter et al., 2003; Werg et al., 2013; Linnekamp et al., 2011) and interactive discussions with multidisciplinary specialists and local farmers, eight indicators were identified to assess the social vulnerability at household level to flood hazards. The selected indicatiors and their weights, definitions, measurement methods and underlying assumptions are shown in Table 1.

The eight selected indicators can be divided into two catergories. One is the basic information of family characteristics, including family size, dependency ratio, illiteracy ratio (15+) and the ratio of perennial working in other places. Another is the ability to prepare, mitigate and response to flood disasters, including per capita income, access to hazard-related information, vehicles per capita and hazard-related training. The weight of each indicator was detemined by using PCA method and SPSS 17.0 software (Qu, 2012). Table 1 showed that the indicator with the biggest weight value (0.17) was the ratio of perennial working in other places, the indicator with the smallest weight

the ratio of perennial working in other places, the indicator with the smallest weight value (0.09) was dependency ratio, and the weight values of other indicators ranged from 0.10 to 0.14.





3.3 Data collection

A door-to-door questionnaire investigation was carried out by the author's research team during the period of 10–15 April 2014. The requirement for participants was that they could answer a questionnaire and have been affected by a flood disaster. One

⁵ hundred households were chosen according to the local officials' advice. All the 100 copies of the questionnaire were collected on the spot, and 6 copies were eliminated due to the inconsistent and incomplete answers.

3.4 Household social vulnerability assessment

According to the factors shown in Table 1, the data collected from 94 households were firstly processed by using Eqs. (1) and (2). Secondly, the household social vulnerability (HSV) scores were calculated using Eq. (3). Lastly, the HSV scores were divided into three grades using mean value (MV) and standard deviation (SD) of HSV scores. If the HSV score was greater than one SD from the MV [(HSV score) > (MV + 1SD)], the household was in the high vulnerability category, if the HSV score was lower than one

¹⁵ SD from the MV [(HSVscore) < (MV – 1SD)], the household was in the low vulnerability category, and other HSV scores [(MV – 1SD) ≤ (HSVscore) ≤ (MV + 1SD)] was in the moderate vulnerability category. In this study, the SD, MV, Max. and Min. of HSV scores were 0.11, 0.59, 0.21, and 0.87, respectively. Therefore, the ranges of low, moderate and high vulnerability category for a household were [0.21, 0.48), [0.48, 0.70], and (0.70, 0.87], respectively.

The results showed that (1) the numbers of high, moderate and low vulnerable households were 14, 64 and 16, respectively, which accounted for 14.9, 68.1 and 17.0% of the total interviewed households, respectively. (2) Seen from the spatial distributions of household social vulnerability in the 11 villages (Table 2), there were three high and a spatial distribution of household social vulnerability in the 11 villages (2).

high vulnerable villages, Manying, Shimen and Zhaozhuang. (3) Table 3 reveals that, compared with the low vulnerable households, the ratio of perennial working in other places, hazard-related training and illiteracy ratio (15+) had the greatest impacts on





moderate and high vulnerable households, and the ratios of high and moderate vulnerability scores to low vulnerability scores were greater than 2.5 and 3.3, respectively. Access to hazard-related information and per capita income had the smallest impact, while the impacts of family size and vihicles per capita were moderate (Table 3). (4) The correlation coefficient of HSV scores and casualties was valid at 0.05 significance level (r = 0.248).

4 Discussion

4.1 Key problems in using index-based assessment method

Index-based assessment method is one of the most widely used assessment methods
(Cutter et al., 2003; Garbutt et al., 2015; Cutter and Finch, 2008). But three problems, index system, index weight and index validity, should be considered before using this method. (1) There are a number of factors affecting the social vulnerability of households. On the one hand, it is difficult to describe the characterisitcs of social vulnerability if there were only few indicators, but on the other hand, if too many indicators were selected and used, there were also some problems, such as inaccessible data, complex calculation, and poor operability (Cutter et al., 2003; Murphy and Scott, 2014). It is important to make the selected indicators be in a manageable level, for which the PCA is a good method to use (Liu et al., 2013). For example, Cutter and Finch (2008) used PCA method to reduce 42 social vulnerability variables to 11 independent indicators, and studied the temporal and spatial changes in social vulnerability to natural herework were and the indicators is a problem.

hazards using the indicators. In this paper, eight indicators were selected based on existing references and interactive discussions with multidisciplinary specialists and local farmers (Table 1). Eight indicators should be a manageable level and they are easily quantified (Cutter and Finch, 2008). (2) Index weights are crucial to the accuracy
of assessment results. The methods used to determine index weight can be divided into three categories. The first category is subjective weithting method, such as Del-





phi and experts grading method. The second category is objective weighting method, such as entropy method and PCA. The third category is an integrated subjective and objective weighting method, such as analytic hierarchy process (AHP). Each of these methods has its advantages and disadvantages (Wang et al., 2012), and different in-

- ⁵ dex weight could affect the scores of assessment results. Therefore, how to determine the reasonable index weights is an imortant problem to be solved in assessment research. (3) A comparison between the assessment results and a post-event situations is a feasible method to test the validity of selected indicators and their weights. For example, Cutter tested the validity of the SoVI during Hurricane Katrina (Cutter et al.,
- ¹⁰ 2003; Cutter and Finch, 2008). In this study, we calculated the correlation coefficient between socres of household social vulnerability and the casualties of each household in a storm flood in July 2010. The results showed that the correlation coefficient was significant at 0.05 significance level (r = 0.248), which indicated that the selected social vulnerability indicators and their weights were valid.

15 4.2 How to reduce social vulnerability

There were much exciting researches on how to reduce social vulnerability, but they mainly focused on the scales of country, region and river basin. For example, based on the analysis of driving factors of social vulnerability to natural hazards in Indonesia, Siagian et al. thought that it was a good way to reduce the social vulnerability by inte-

- ²⁰ grating social vulnerability maps in early waring systems (Siagian et al., 2014). Chen et al. put forward to some sugesstions to reduce social vulnerability in the Yangtze River Delta region, such as reducing the inequal distributions of social resources, improving the empolyment rate (Chen et al., 2013). The studies at household level were little, especially to flood hazards (Chen et al., 2013; Siagian et al., 2014). In this study,
- the target strtegies to reduce the household social vulnerability to flood disasters were discussed based on the assessment results (Table 3). At first, the ratio of perennial working in other places should be reduced as soon as possible, because it was the most dominant factor to result in high vulnerability. According to the investigation, in





the 95 households, the number of people who perennial working in other places due to limited local job opportunities was 141, which accounted for 27.2% of the totle people (519), 52.4% of the population aged between 18 and 64, and 82.5% of the people aged between 18 and 49, respectively. In ordet to solve this problem, the reasons why

- the local residents preferred working in other places to staying at home needs to be understood. The most important reason was that the high cost of farming and low price of agricultural products resulted in the low income of a family. Besides, the agricultural income in these regions is not guaranteed due to the variation of climate conditions. Another important reason was that there were few companies or factories to provide
- ¹⁰ work oppotunities for local residents. Therefore, the ratio of perennial working in other places should be reduced by establishing agricultural insurance and incerasing the work opportunities to guarantee the local residents' income. And then, the disaster related knowledge and evacuation skills of the local residents should be enhanced through disaster realted trainings. Some unexpected ovservations were found during
- this survey. For example, there were 64.2% of the interviewed people thought that a flood did not occur in this region, and only 23.2% of the interviewed people often received trainings of hazard-related knowledge or evacuation skills. As a result, certain level of trainings about flood hazards should be often held in order to improved the hazard-related knowledge and evacuation skills of local residents. Finally, the literacy
- ratio should be improved. From the perspectives of communities or governments, the following measures could be effective to reduce the social vulnerability to flood disasters. (1) Preparing flood hazards mitigation plan based on risk assessment results of flood hazards. (2) Improving the accuracy of disaster monitoring and warning systems.
 (3) Establishinig specialized emergency management department and comprehensive
- rescue systems. (4) Developing an emergency plan and carrying out emergency drills and trainings.

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5 Conclusions

In order to understand the rural household social vulnerability to flood hazards, a household social vulnerability index was developd, and the household social vulnerability at the selected 11 villages were assessed. Some mitigation strategies to ⁵ reduce the household social vulnerability were proposed based on the assessment results. There are some intresting foundings. (1) Through relevant references and interactive discussions with multidisciplinary specialists and local farmers, eight key indicators were indentified and used to develope a household social vulnerability index. Their weights were determined using PCA method. The eight indicators and their weights were dependency ratio (0.09), illiteracy ratio (0.12), the ratio of perennial working in other places (0.17), per capita income (0.14), access to hazard-related information (0.12), vehicles per capita (0.10) and hazard-related training (0.14), respectively. (2) The results showed that the numbers of high, moderate and low vulnerable households were 14, 64 and 16, respectively, which accounted for 14.9, 68.1 and 17.0% of

- the total evaluated households, respectively. The correlation coefficient of HSV scores and casualties was significant at 0.05 significance level (r = 0.248), which indicated that the selected social vulnerability indicators and their weights were valid. (3) The ratio of perennial working in other places, hazard-related training and illiteracy ratio (15+) were the most dominant factors to result in higher vulnerability. Access to hazard-
- ²⁰ related information and per capita income had the smallest impact on higher vulnerability, and the impacts of family size and vihicles per capita were moderate. (4) To reduce the household social vulnerability to flood hazards. Reducing the ratio of perennial working in other places, enhncing the hazard-related knowledge and evacuation skills were effective measures and must be carried out as soon as possible.
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Table 1. Selected indicators and their weights, definitions, measurement and underlying assumptions to social vulnerability (SV).

Indicator	Weight	Definition	Measurement	Assumptions
Family size	0.13	Total number of family mem- bers	Number of family members	The more the family members, the higher the SV. Because there are more people are ex- posed to flood hazards for a big family
Dependency ratio	0.09	Number of dependents (aged 0–18 and over the age of 65) to number of working-age people (aged 19–64)	(Number of dependents/number of people aged from 19 to 64) × 100 %	The larger the ratio, the greater the burden on the average working-age people, and the higher the SV
Illiteracy ratio (15+)	0.12	Number of illiteracy (people are over the age of 15 and with inability to read and write) to the fimily size	(Number of illiteracy/family size) × 100 %	The higher the ratio, the lower the ability to access to hazard- related information and resoure- ces, the higher the SV
The ratio of perennial working in other places	0.17	Number of people (who work in other place and can not re- turn home for a long time) to family size	Number of people who work in other place/family size	The more people work in other place, the higher dependents ratio, and the higher the SV
Per capita income	0.14	The average income earnd per person in a fimily	The total family income/family size	The higher the per capita in- come, the more the accumula- tion of wealth and ability to ac- cess to hazard-related informa- tion and resources, the lower the SV
Access to hazard-related information	0.12	It mainly refers to the ability to receive disaster risk informa- tion	Number of information receiving tools, including telephone, cell- phone, TV and Internet	The more inforamtion receiving tools, the more ability to access to risk information, the lower the SV
Vehicles per capita	0.10	Total number of vehicles in a family to family size	Number of vehicles/family size	The more vehicles per capita, the more ability to evacuate from a disaster, the lower the SV
Hazard-related training	0.14	Times to take part in hazard- related training for last 5 years	No = 0; One time = 0.5; Two or more times = 1	The knowledge, attitudes and behaviours to disasters can be improved by attending training. So, the more times to attend, the lower the SV



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Village	High	Moderate	Low
Manying	33	67	0
Shimen	29	57	14
Zhaozhuang	25	67	8
Gucheng	18	73	9
Hujia	13	87	0
Xipo	11	56	33
Tantou	11	61	28
Zhifang	10	60	30
Gouyu	0	100	0
Hecun	0	83	17
Zhangjia	0	83	17

Table 2. Spatial distributions of household social vulnerability (%).



Table 3. The mean scores of low, moderate and high vulnerable households for each index $(\times 100)$.

Indicator	Low	Moderate	High	Ms/Ls	Hs/Ls
Ratio of perennial working in other places	2.03	7.19	11.4	3.54	5.62
Hazard-related training	2.19	6.45	9.5	2.95	4.34
Illiteracy ratio (15+)	2.00	5.14	6.66	2.58	3.34
Family size	6.26	8.31	11.03	1.33	1.76
Vehicles per capita	5.68	7.62	8.61	1.34	1.52
Dependency ratio	1.97	2.14	2.78	1.08	1.41
Access to hazard-related information	9.83	11.02	11.64	1.12	1.18
Per capita income	11.23	12.48	12.99	1.11	1.16

Note: Ms/Ls is the ratio of moderate vulnerability score to low vulnerability score; Hs/Ls is the ratio of high vulnerability score to low vulnerability score.

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Figure 1. Maps of study area (a) Location of Henan Province in China. (b) Location of the study area in Henan Province. (c) Investigation sites and distributions of rivers in study area.



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