Social vulnerability to floods: a case study of Huaihe River Basin

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Abstract Since ancient times, floods occurred frequently in Huaihe River with significant casualties and economic losses. In developing measures for disaster prevention or emergency response for disaster relief, the study of social vulnerability to floods in Huaihe River Basin should be strengthened. Based on the latest socioeconomic data, the index system of social vulnerability to floods was constructed from three dimensions: population, economy, and flood prevention. Sensitive indexes were identified from the original indexes by principal component analysis, and the social vulnerability index for floods was calculated for Huaihe River Basin. The results described the characteristics of the spatial distribution. It also demonstrated that vulnerability manifests itself as a regional phenomenon, with significant changes from city to city across the Huaihe River Basin. Understanding the impacts of changes in vulnerability was crucial in developing measures to prevent floods.

Keywords Huaihe River · Floods · Social vulnerability

1 Introduction

In history, floods occurred frequently in Huaihe River Basin. The river is known as the saying "the heavy rain bring a big disaster, the drizzle bring a small disaster." Huaihe River Basin is located at the junction of temperate and subtropical, and the variability of precipitation is interannual. From 246 BC to 1948, there were about 979 disasters occurred

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during the 2,194 years. Since the Yellow river's flooding into the Huaihe River in 1194, it influenced the lower reaches and caused 594 floods from 1194 to 1948 (Huaihe River Commission, Ministry of Water Resources 2007). Huaihe River Basin was historically the worst place affected by flood disasters. The severity of the floods in the basin ranks first among the seven rivers in our country. Thus, the special characteristics of flood highlight the need to pay more attention to govern Huaihe River.

Since the past ten years, Huaihe River Basin has been threatened by floods for several times of which the well-known basin-wide floods of 1991, 2003, and 2007 were historically the most destructive events on record. Losses caused by the three wide floods is displayed in Table 1, and we can see that the data in 2003 have increased by one order as compared with those in 1991, while they have decreased by one order as compared with the data in 2007. The data indicate that social vulnerability to floods is largely reduced with the development of society, resilience as well as mitigation capability, but judged from the tremendous losses including millions of evacuations and billions of economy loss, social vulnerability in Huaihe River Basin is still significant. The imbalanced development of social economy gives rise to the spatial differences of vulnerability in Huaihe Basin.

The frequent occurrence of disasters is the combined result of work for hazards and vulnerability. Analyzing the impact factors and forming mechanism of natural hazards can contribute to deal with disasters, but the floods still occurred frequently for the neglect of vulnerability.

Vulnerability comes from the Latin, which means something is easily injured. In 1970s, engineering and technical staff studied the vulnerability first, as time goes by, vulnerability was subsequently expanded to evaluate humans, buildings, and infrastructure when they face the sensitivity of disaster events. In 1975, Gilbert FW expanded the meaning of disaster prevention and mitigation from engineering measures to the defense of human behavior for the first time and emphasized the socioeconomic factors that arise from the hazards. The concept of social vulnerability includes two meanings: First, it emphasizes the potential factors that construct vulnerability, includes the pre-disaster social structure, social status, particular social groups or other institutional forces, and other factors, the more social capital, the lower vulnerability. Second, it emphasizes a kind of vulnerability reflected by the adaptation of hazard and disaster response capacity, which shows the properties of vulnerability during the process of disaster response or recovery (Shi et al. 2011).

The concept of social vulnerability was proposed by Cutter et al. (2003), and the social vulnerability index was created as well. In this study, the social vulnerability index based on the principal component analysis was optimized, and the regional differences in social vulnerability of the United States were described and analyzed. The indexes that contribute to the overall score were often different for each county, underscoring the interactive

Table 1 Losses caused by the last three wide floods in Huaihe River Basin

Year	Damage area Million mu	Inundated area Million mu	Damage-suffering population Million person	Dead population Person	Collapsed building Million	Economic losses Billion Yuan
1991	8,274	6,024	5,423	572	200	339
2003	5,570	3,886	3,728	29	74	285
2007	3,370	1,304	2,042	0	7.1	120

nature of social vulnerability—some components increase vulnerability and others moderate the effects (Cutter et al. 2003). Subsequently, the approach of social vulnerability is gradually accepted. Currently, social vulnerability indexes are usually built in two ways (Yook 2012): one is the deductive method, based on the concepts or principles of social vulnerability, and the indexes constructed in this method are qualitative, but hard to be quantified. The other is inductive approach, based on the population data and socioeconomic data. This method selects sensitive indicators, but independent from a large number of social vulnerability indexes with mathematical methods. It has been widely used for overcoming the drawbacks of the deductive method. In fact, scholars build social vulnerability index from a macro-level usually based on statistical data, such as socioeconomic data at the county level used by Mathew et al. (2008), census data of the United States used by Barry et al. (2011), the data from the data center of Orleans community exploited by Candice et al. (2008), and the social vulnerability indicators created by Ge et al. (2005) are derived from the "Hunan Statistical Yearbook" and "Changsha Statistical Yearbook."

The existing research tends to explore the relationship between social vulnerability to floods with other factors, such as urbanization. While, some scholars worked on the assessment of social vulnerability, but they lack the method to construct social vulnerability index system. In this study, Huaihe River Basin is the subject in our research. We applied a comprehensive analysis of the vulnerability among the 28 cities in the basin in terms of population vulnerability (PoVL), economic vulnerability (EcVL), and flood prevention vulnerability (FPVL). We discussed the difference of spatial distribution in order to determine the recipient regional and recipient populations, improved the measures to avoid floods, and provided a reasonable program to optimize resources. It can provide theoretical grounding for the government decision-making.

2 Social vulnerability index for floods

Social vulnerability varies with socioeconomic factors, so it is diverse in different historical period. When we study social vulnerability, latest socioeconomic data should be used in order to objectively reflect the current social vulnerability.

In this study, the Huaihe River Basin was selected as study area, and social vulnerability index system was created from three aspects, i.e., population, economy, and flood prevention, according to Cutter's place-hazard model and theory of emergency management cycle. The data of the 28 cities were obtained from "the sixth nationwide population census" and "Statistical Yearbook." Since these factors have changed greatly in recent years, all data were obtained from the information of 2011. Thirty-six factors were contained in the index system, which included 13 population indexes, 10 economic indexes, and 13 flood prevention indexes, and the contents of specific indexes are given in Table 2.

Population indexes are an important part of social vulnerability index, which can determine the degree of social vulnerability directly by the indexes such as age, sex ratio, education, and income. For example, in the flood emergency evacuation, the young adults have enough physical ability to escape, while women and children cannot evacuate in time for the lack of adequate physical strength, and thus, they have a higher vulnerability.

Economic indexes are the key factor to influence EcVL, which include household income levels and regional economic conditions. Economically developed regions are able to bear the loss and be fast recovery from losses through insurance, social safety nets, and welfare policies (Susan et al. 2003).

Table 2 Social vulnerability index system to floods

Category	Variable	Number
Population	Average number per house (one), resident male population ratio (%), resident female population ratio (%), resident population proportion <14 years old (%), resident population between the age of 5 ∼ 65 (%), resident population proportion over 65 (%), population density (person/km^2), college degree or above population ratio (%), high school (college) resident population ratio (%), junior resident population ratio (%), primary school resident population ratio (%), illiterate population ratio aged 15 or above (%), and urban population ratio (%).	13
Economy	Per capita disposable income of urban residents (Yuan), average net rural per capita income (Yuan), savings deposits of urban and rural residents per capita (Yuan), per capita income of local government budgets (ten thousand Yuan), per capita local government budget expenditure (ten thousand Yuan), per capita agricultural output (ten thousand Yuan), per capita GDP (ten thousand Yuan), number of schools (one), annual consumption of urban households living expenses (ten thousand Yuan), and rural households consumption expenditures of residence (ten thousand Yuan).	10
Flood prevention	Number of farm vehicles per ten thousand people (one), number of cars and motorcycles ownership per ten thousand people (one), highway mileage per square kilometer (/km^2), number of mobile phone users per ten thousand people (one), broadcasting coverage (%), number of Internet users per ten thousand people (%), number of hospital institutions per capita (one), number of health workers per ten thousand (one), number of hospital beds per ten thousand (one), number of township per ten thousand (one), number of people resident committees per ten thousand (one), per capita living area of urban (m^2), and rural per capita use of housing area of rural (m^2).	13

Vulnerability of flood prevention among areas is largely based on transportation, communication, medical treatment, and other aspects of these places. Convenient traffic and clear road conditions are guarantee of flood prevention. Timely delivery of the warning information and emergency notification depend on complete communication equipment; what's more, good health conditions are effective protection to reduce regional vulnerability.

3 Study area and methodology

3.1 Study area

Huaihe River Basin is located in eastern China between Yangtze River Basin and Yellow River Basin. In the basin, the longitude is 111°55′E ∼ 121°25′E and the latitude is 30°55′N ∼ 36°36′N with the land area 270 × 10^3 km^2. Population of the area is 167 millions, the highest population density among the seven river basins. This profile starts from Tongbaishan, Funiushan in the west and Yellow Sea at its east end, south to the Dabie Mountain, Jianghuai Hill, Tongyang Canal and the demarcation line of south Rutai Canal between the Yangtze River, north of Yellow River and Mount Tai as the boundary, adjacent to Yellow River Basin. Huaihe River Basin includes 28 cities which come from Henan Province, Anhui Province, Shandong Province, and Jiangsu Province from west to east.

3.2 Methodology

3.2.1 Principal component analysis

As the original indexes present serious information overlapping along with strong correlation between each other, which brings difficulty to quantitative research, we need to filter out the key indexes. Use of principal component analysis to reduce the complexity of multidimensional data has been employed in previous studied of this nature. For example, Clark et al. (1998) used PCA on the social vulnerability index for processing, while the similar method was used for dimension reduction in indexes by Ivar et al. (2011). Mathew et al. (2008) screened out 11 typical sensitive indexes from 42 social vulnerability indexes with the method of PCA. Clark et al. (1998), Barry et al. (2011), and Cutter et al. (2003) use the same way to reveal sensitive indexes of social vulnerability. Often referred to as the Kaiser' criterion, this is a standard variable reduction method for use with PCA.

Principal component analysis is given of a set of related variables by linear transformation into another group of unrelated variables, which present a kind of descending order according to the variance. By this way, most indexes can be explained with as few indexes as possible, and the purpose of the dimension reduction can be achieved by the conversion of a high correlation to each other independent of the index. We reduce the number of dimensions by working with only those provisional indexes whose eigenvalues from the PCA are larger than 1.0, provided that we could clearly identify each component. Since the original indexes are standardized to have variances equal to 1.0, components with indexes >1 represent factors with larger variances and hence greater explainable variability than any of the original indexes. Unfortunately, indexes identified in this manner can be difficult to interpret. To avoid this pitfall, we use the method of varimax orthogonal rotation to drive variables to highly correlate with as few indexes as possible.

3.2.2 Extreme standardization

In order to eliminate the impact of the dimension, actual data with different dimensions must be standardized; in our case, the selection is extreme standardization. According to the influence that indexes have on vulnerability to disasters, all indexes are divided into positive and negative indexes. As the index values increase the vulnerability reduced called positive indexes, on the contrary, as the index values increase vulnerability enhanced called positive indexes. As the order of different evaluation indexes is not the same, we need to standardize the raw data processing. Extreme standardization is the best choice for normalized index variables plotted in range of [0–1].

For the positive indexes:

$$x_{\overline{ij}} = (a_{\overline{ij}} - \min a_i)/(\max a_i - \min a_i) \tag{1}$$

$x_{\overline{ij}}$ is the standardized indexes, and max a_i is the maximum value of the ith row in matrix A

For the negative indexes:

$$x_{ij} = (\max a_i - a_{\overline{ij}})/(\max a_i - \min a_i) \tag{2}$$

$x_{\overline{ij}}$ is the standardized indexes, and max a_i is the maximum value of the ith row in matrix A

3.2.3 Vulnerability index calculation

Since our social vulnerability indexes are processed through principal component analysis, the indexes are independent. The correlation between the different indexes is weak, which means that the selected indexes can cover the meaning of different types of vulnerabilities. In addition, the research model of social vulnerability is still in the stage of exploration, there is no fixed pattern. Social vulnerability indexes are complex, and the weights of the indexes are equal in terms of their overall contribution to location-based vulnerability. Compared to other research methods, the simple average method can reflect the characteristics of vulnerability indexes, as well as the intuitive features of the data. This method has the advantages of easy operation, distinct comparison. Since the data we used come from the Statistical Yearbook and are stable, this method can effectively reflect the characteristics of the vulnerability of the region.

We then standardized the data and calculated the arithmetic average so as to measure the social vulnerability:

$$v = \frac{1}{n} \sum_{i=1}^{n} x_{ij} \tag{3}$$

where n represents the number of indexes, $x_{\overline{ij}}$ represents a standardized index, and v means the value of the vulnerability.

4 Results

4.1 Sensitivity analysis of the social vulnerability index to floods

Indexes of social vulnerability to floods can be divided into three subgroups according to the characteristic they represented: population, economy, and flood prevention. They reflected the carrier for flood vulnerability from different perspectives and combined to form an overall place vulnerability index. We standardized the data for each component of vulnerability by calculating standardized variants for each index with 0–1 standardized methods. Principal component analysis was then applied to the standardized indexes within each component. The aim, in all cases, was to reduce the larger number of indexes (Table 2) into as parsimonious a set of dimensions as possible that could still explain a large % of variation in the data. We found this to be typically between 70 and 80 % of total explainable variability. Table 3 reflects the social vulnerability index after initial preprocessing by principal component analysis. In original indexes, population indexes reduced from 13 to 3, economy indexes reduced from 10 to 3, and flood prevention indexes reduced from 13 to 5.

The statistical data of the 28 cities in Huaihe River Basin are calculated by using principal component analysis with SPSS 19.0, and three component indexes are generated from PoVL for the principal component value >1 and explained 71.692 % of the variability. The three indexes, college degree population ratio, female resident population ratio, junior resident population ratio, combined to form an overall population vulnerability index.

The EcVL index measures the contribution to vulnerability from the economic income level and their impacts. In the course of principal component analysis, according to the principal that main component value should be >1, the first three component factors are

Table 3 Sensitive indexes of population, economy, and flood prevention

Principal component	Component interpretation	Vulnerability proportionality	% Variance explained
Sensitive indexes of population			
1	College degree or above population ratio	Positive	30.363
2	Resident female population ratio	Negative	23.531
3	Junior resident population ratio	Negative	17.798
	Total variance explained		71.692
Sensitive indexes of economy			
1	Per capita income of local government budgets	Positive	46.529
2	Annual consumption of urban households living expenses	Positive	14.339
3	Per capita agricultural output	Positive	11.798
	Total variance explained		72.666
Sensitive indexes of flood prevention			
1	Number of health workers per ten thousand	Positive	28.109
2	Number of people resident committees per ten thousand	Positive	15.944
3	Number of farm vehicles per ten thousand people	Positive	12.214
4	Number of cars and motorcycles ownership per ten thousand people	Positive	9.9910
5	Highway mileage per square kilometer	Positive	8.4700
	Total variance explained		74.728

generated and explained 72.67 % of the variability, which already covered most information of the original variables. The sensitive indexes corresponding to the three principal components are per capita income of local government budgets, annual consumption of urban households living expenses, and per capita agricultural output.

The four indexes in flood prevention index system have an impact on social vulnerability from the medical, transportation, communication and other aspects with the cumulative contribution rate of 77.4 %. The indexes, such as number of cars and motorcycles ownership per ten thousand people and road density, show the importance of the unobstructed emergency, while perfect emergency refuge facilities as well as the good traffic conditions will directly affect the flow of casualty degree. Post-disaster medical relief can contribute to the vulnerability reduction from the aspect of "salvage."

4.2 Spatial variation of vulnerability

4.2.1 Spatial distribution of population vulnerability

In general, cities in the western basin have moderate to high levels of PoVL, while those in the eastern half exhibit relatively low levels of PoVL (Fig. 1). The exceptions to this trend are Zhengzhou and Huainan with the score below 0.5. In west region, the vulnerability in the middle is higher than those of the sides.

4.2.2 Spatial distribution of economic vulnerability

The EcVL of flood hazards shows a distinctively eastern bias in its geographic distribution. This is not unexpected given the rapid economic development in these areas, especially for

the cities of Yancheng, Taizhou, and Bengbu, EcVL are lower than 0.4. The most vulnerable cities focus on the eastern region, which form a semi-ring.

4.2.3 Spatial distribution of flood prevention vulnerability

Cities in the northwest of the basin have moderate to high levels of FPVL, while those in the southeastern half exhibit relatively low levels of social vulnerability to flood prevention. These regional differences are largely due to health care conditions, transportation, communication, emergency coordination, and other factors (Figs. 2, 3, 4).

4.2.4 Spatial distribution of social vulnerability to floods

Comprehensive social vulnerability is a combination of PoVL, EcVL as well as FPVL, and we can combine the three subcomponent indexes into a single index of comprehensive vulnerability. As the three subcomponents have a nonlinear effect on the location-based vulnerability, their weights can be considered equally in terms of their overall contributions to the comprehensive social vulnerability. Then, we can calculate the final SoVI with a simple average method, SoVI = 1/3 (PoVL + EcVL + FPVL).

Table 4 reflects the comprehensive situation of social vulnerability to floods. We can see from the table that Zhengzhou is the least vulnerability city among the 28 cities, which is largely due to the capital city status. In terms of economy, transportation, education, and health care conditions, Zhengzhou always stays in the leading level, along with the position of major transportation hub of the country. The city came to the top as the least vulnerable. Yancheng and Jining come second and third with the vulnerability score lower than 0.6. The PoVL of Fuyang is the highest among the 28 cities. It also scores high on the other two indexes, leading to its top ranking on comprehensive vulnerability. This indicates that the level of education and personnel quality in Fuyang need to be improved.

The pattern of comprehensive vulnerability is a little different from that of the other indexes. Higher values occur more often in the southwestern, while lower vulnerability values are concentrated in the northeast cities (Fig. 5). It gradually decreases from the center to periphery.

5 Discussions

Population vulnerability largely depends on the gender and population quality. In Huaihe River Basin, Zhengzhou is the only provincial capital city among the 28 cities; although the city has the highest population density, the rich educational resources lead to high quality and cultural level in population, which mainly reflected in the 18.94 % of the college population which is twice as many as the second. The illiteracy rate of Zhengzhou is the lowest in 28 cities with the value of 2.14 %. From the perspective of gender distribution, the male resident population in the city is as high as 51.26 % for a large number of migrant workers flew in. All these indexes combined to contribute Zhengzhou to be the lowest in the PoVL. Fuyang, Shangqiu as well as other six cities have a high ranking on PoVL. This is largely due to high population density in these areas, especially in Fuyang city, where the population density is up to 1,035 people/sq km, while male population accounted for only 49.15 %. In addition, the low quality of population largely defines the high social vulnerability of Fuyang, for just 2.95 % of the population is above the junior college level.
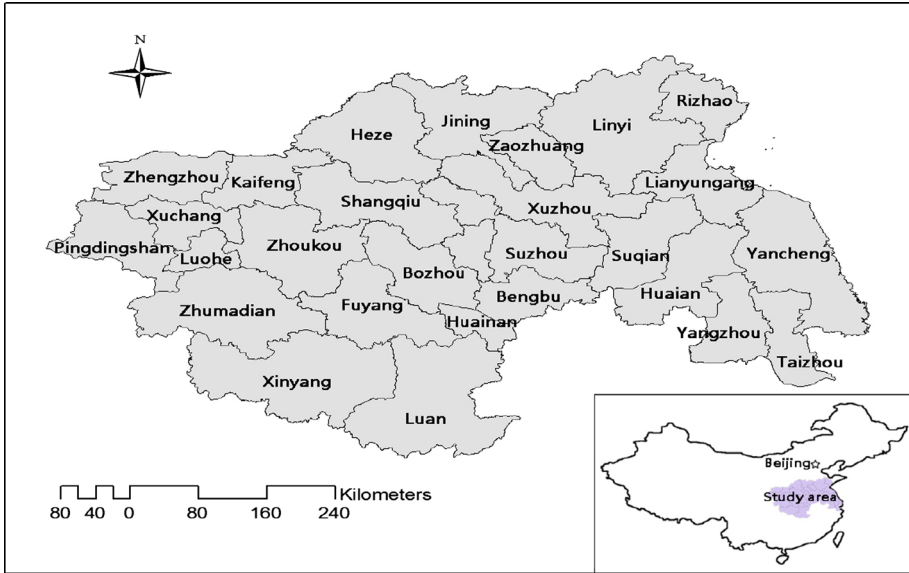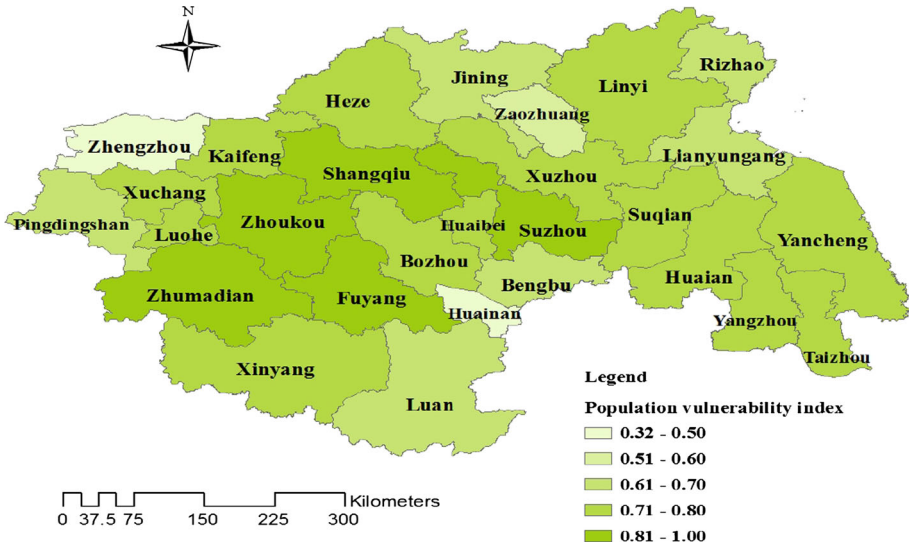
Fig. 1 Huaihe River Basin

Fig. 2 Spatial distribution of population vulnerability in Huaihe River Basin

Yancheng, Taizhou, and Bengbu are among the lowest economic vulnerable cities. In these three areas, local government budget revenues are all in the leading position, with middle size population, so per capita income of local government budgets higher than other cities. In addition, the high level of annual consumption of urban households living can also contribute to the EcVL. Such as Bengbu, which take measures to improve the living
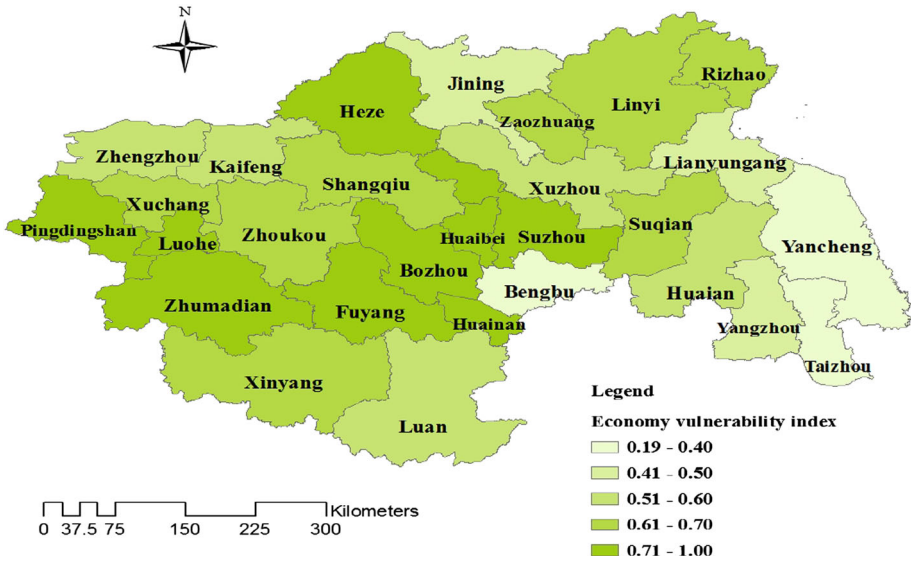
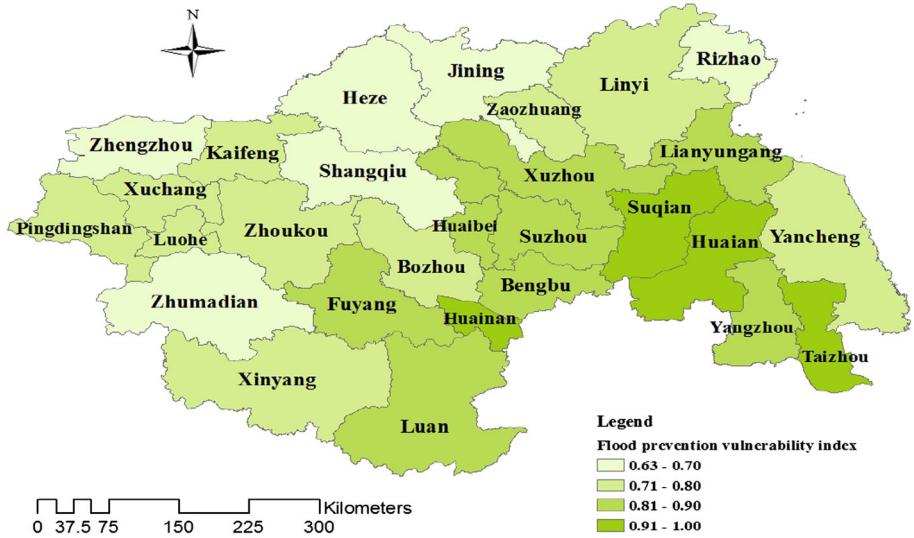**Fig. 3** Spatial distribution of economic vulnerability in Huaihe River Basin

Fig. 4 Spatial distribution of flood prevention vulnerability in Huaihe River Basin

environment for the concern of housing quality, the average expenses of households living in the area is up to 15.54 million Yuan, in the highest rank of all the cities. The above combination of indexes determines that EcVL of Yancheng, Taizhou, and Bengbu are lower than other cities. Huaian and Huaibei are among the most vulnerable cities based on the economy index, where the economy grows relatively slowly, resulting in 760 Yuan of per capita income in Huaian, and 1,399 Yuan in Huaibei. The situation of agricultural

Table 4 Social vulnerability index for floods in Huaihe River Basin

City	SoVI	PoVL	EcVL	FPVL
Fuyang	0.835	0.9	0.752	0.853
Suzhou	0.811	0.812	0.791	0.831
Huaibei	0.806	0.754	0.831	0.834
Suqian	0.778	0.798	0.614	0.922
Zhoukou	0.757	0.86	0.635	0.777
Shangqiu	0.739	0.861	0.659	0.697
Bozhou	0.739	0.735	0.765	0.716
Pingdingshan	0.736	0.661	0.805	0.741
Luohe	0.736	0.713	0.740	0.754
Zumadian	0.736	0.828	0.724	0.655
Huaian	0.731	0.776	0.505	0.911
Xinyang	0.725	0.75	0.647	0.778
Liuan	0.723	0.698	0.597	0.876
Huainan	0.720	0.356	0.893	0.911
Yangzhou	0.711	0.761	0.477	0.895
Xuchang	0.709	0.724	0.644	0.758
Heze	0.707	0.751	0.733	0.638
Linyi	0.704	0.707	0.631	0.773
Kaifeng	0.699	0.719	0.581	0.798
Xuzhou	0.680	0.721	0.507	0.811
Taizhou	0.651	0.746	0.296	0.912
Rizhao	0.647	0.666	0.603	0.672
Lianyungang	0.646	0.667	0.450	0.820
Zaozhuang	0.636	0.53	0.673	0.705
Bengbu	0.632	0.645	0.384	0.866
Jining	0.585	0.676	0.454	0.625
Yancheng	0.572	0.729	0.194	0.791
Zhengzhou	0.502	0.318	0.545	0.643

income is an another factor that impacted EcVL. In the case of Huainan, the index per capita agricultural income is the lowest in the 28 cities with the value of 591 Yuan, leading to its top ranking on EcVL.

The transportation component largely defines the low FPVL of Heze, for the number of transportation equipment per capita is in the first place among 28 cities. Neighborhood as a grassroot organization has played an important role in flood prevention. In Jining City, the number of neighborhood as an average of 8.13 explains the position of the area among the least socially vulnerable cities. Moreover, good traffic conditions and wide range of grassroot organizations also enhance the ability to withstand floods in the two regions. As the only capital city among the 28 cities, Zhengzhou has abundant medical resources, it can be seen from several data, such as the number of medical institution owned by million people is 1,347, the number of hospital beds is 47,094, and the number of health workers is 49,519. Good medical condition improves the ability to control the regional flood.

For the places such as Taizhou and Huainan, the local vulnerability is more of a function of very high scores on the flood prevention index. The primary driver is the transport
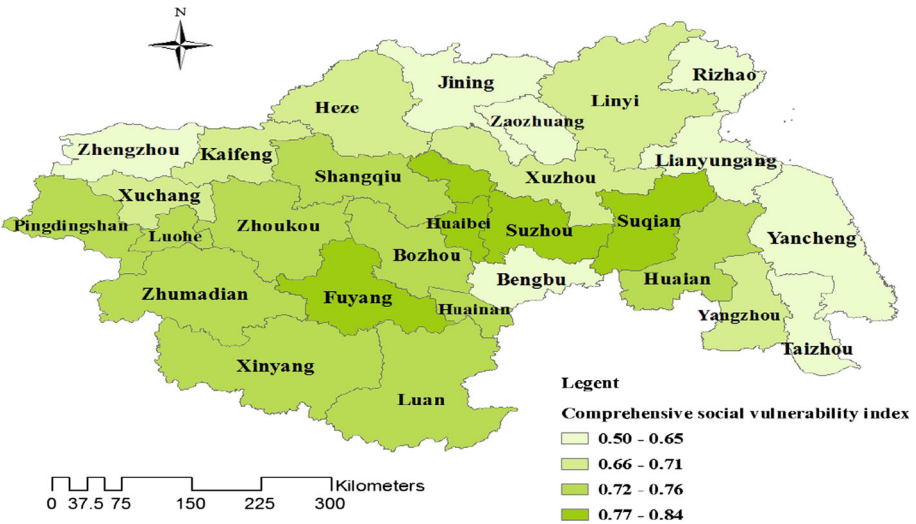
Fig. 5 Spatial distribution of social vulnerability to floods

condition, especially the ownership of vehicles. In Taizhou City, the number of farm vehicles owned by per million people is 17.1, and ownership of cars and motorcycles per capita is 490.62, which is far below the average level of the Huaihe River Basin.

Social vulnerability is a combination of the three subgroups, reflecting a city's comprehensive ability when facing floods. In the case of Jining, for example, the low ranking on social vulnerability is a function of extremely low values on all three indexes. For the other cities, such as Yancheng, the social vulnerability is more of a function of very low scores on the economy index. This suggests that cities have distinctive PoVL and FPVL, but the comprehensive and complex nature overshadows the overall vulnerability results.

It can be seen from the figure above, Fuyang is the most vulnerable cities in Huaihe River Basin. This is mainly the results of the high level of EcVL and FPVL, especially for the highest ranking of PoVL. While Huainan is the most vulnerable cities in terms of economy, the value of flood prevention is much higher than average, but PoVL in the area is very low, resulting in its comprehensive vulnerability index located in section 14 of the 28 cities, which illustrates that unilateral prominent vulnerability can affect the overall pattern. The highest score of vulnerability to flood prevention goes to Suqian City, compared with the comprehensive vulnerability which is located in the middle. It shows that local vulnerability reflects the comprehensive trends of all the factors, maybe obscuring the effects of individual index.

Social vulnerability of Huaihe River Basin from a macro-level was studied based on municipal statistical data. In the cases of other studies, for instance, Cutter's research on social vulnerability to environmental hazards, or Kevin's article of American urban environment vulnerability to disasters, all largely depends on city statistics. This phenomenon is mainly because that among the local Statistical Yearbooks in China, only those above county level can have continuous publication and public offerings, while the city-level data cannot be publicly printed. Therefore, we cannot use city-level data to study the social vulnerability in Huaihe River Basin. Since the basin has a large area, using municipal data can still reflected the characteristics of social vulnerability in the basin objectively.

Statistical Yearbook often reflected the overall average condition of a specific region. Therefore, when study social vulnerability to floods based on the information from Statistical Yearbook, the results can present an overall characteristic of social vulnerability, instead of a particular time frame. For example, summer is a flood-prone season for Huaihe River, while a large number of rural labor migrating into city is also occurred in this period. Young adults migrant and the elders stay at home. These details cannot be accurately captured in the Statistical Yearbook. The index such as car ownership would not reflect the use of cars, for some people, since fuel costs may prevent vehicle use. Idleness of vehicles may lead to the lack of escaping instruments. In future study, we can conduct a research on relevant information if we want to get the detail of the social vulnerability. Maybe it is possible to select one or several locations to distribute surveys, but if we want to complete a comprehensive research of the 189 cities of the whole Huaihe River Basin, it is nearly impossible.

6 Conclusions

In our research, we concluded the diverse geographic patterns and dominant driving forces of vulnerability between cities in Huaihe River Basin. Through a comparative analysis, we discussed the different characteristics of the cities from three types of vulnerabilities. Further, we gained insights into the different factors producing the vulnerability for multiple cities. Our work helps to reduce vulnerability and strengthen its resilience in the face of future natural hazards and disasters.

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