Int. J. Disaster Risk Sci. 2013, 4 (4): 169–181
doi:10.1007/s13753-013-0018-6

ARTICLE

Measuring Social Vulnerability to Natural Hazards in the Yangtze River Delta Region, China

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Abstract Social vulnerability emphasizes the different burdens of disaster losses within and between places. Although China continuously experiences devastating natural disasters, there is a paucity of research specifically addressing the multidimensional nature of social vulnerability. This article presents an initial study on the social vulnerability of the Yangtze River Delta region in China. The goal is to replicate and test the applicability of the place-based Social Vulnerability Index (SoVI®) developed for the United States in a Chinese cultural context. Twenty-nine variables adapted from SoVI® were collected for each of the 134 analysis units in the study area. Using principal components analysis, six factors were identified from the variable set: employment and poverty, education, poor housing quality, minorities, family size, and housing size—factors similar to those identified for the United States. Factor scores were summed to get the final SoVI® scores and the most and least vulnerable study units were identified and mapped. The highest social vulnerability is concentrated in the southern portions of the study area—Jingning, Suichang, Yunhe, Lanxi, Pan'an, and Shengsi. The least socially vulnerable areas are concentrated southwest, west, and northwest of Shanghai. Limitations of replication are discussed along with policy-relevant suggestions for vulnerability reduction and risk mitigation in China.

Keywords China, natural hazards, social vulnerability index, Yangtze River Delta

1 Introduction

Disaster losses result not only from the magnitude and duration of natural events, but also from the inability of people and society to self-protect their lives, livelihoods, and property. Vulnerability gained popularity and has been widely used in various research fields such as disaster risk, sustainable development, and climate change (Blaikie et al. 1994; Cutter 1996; Alexander 1997; Tobin and Montz 1997; Mileti 1999; White, Kates, and Burton 2001; Cardona 2003; Birkmann 2006b).

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By adopting the human-centered vulnerability concept, the "social vulnerability paradigm" (Hewitt 1983; 1997; Blaikie et al. 1994; Cutter, Boruff, and Shirley 2003) stresses that vulnerability is socially constructed and exhibits with stratification and inequality among different groups of people and different places. Consequently, vulnerability reduction requires understanding the underlying social, economic, and political context and then addressing the factors that increase risk and vulnerability.

Much of the vulnerability research uses case study and qualitative assessments of the root causes of vulnerability to different hazards in various countries and world regions (Fordham 1999; Laska and Morrow 2006; Few and Pham 2010; Zou and Wei 2010; Mallick, Rahaman, and Vogt 2011). However, there is continuing interest in empirically measuring vulnerability (Cutter, Boruff, and Shirley 2003; Armas 2008; Myers, Slack, and Singelmann 2008; Mendes 2009), especially social vulnerability. Social vulnerability is a pre-existing condition of the population that influences its ability to prepare for, respond to, and recover from hazard events. Among the most recognized is the Social Vulnerability Index (or SoVI®) (Cutter, Boruff, and Singelmann 2003). The Social Vulnerability Index (SoVI®) quantifies social vulnerability making it possible to compare place-based social vulnerability as well as identify the most important drivers across the territories of the United States and over time (Tierney 2006; Cutter and Finch 2008). Debates on whether social vulnerability can be quantified or not, which indicators should be included in the social vulnerability assessment, and what types of results can best represent the magnitude of social vulnerability are ongoing (Birkmann 2006a; Montz and Tobin 2011). In addition, the SoVI® method itself has gone through continuous evolution with the deeper understanding of the nature and drivers of social vulnerability (Cutter and Morath 2014). However, the SoVI® method has been widely accepted and adapted to other different contexts (for example, Boruff and Cutter 2007; Mendes 2009; Holand and Lujala 2013).

There is little evidence of empirical assessments of social vulnerability in China, due to inadequacy of and limitations on available social data for analysis and mapping largely based on historical, cultural, and social reasons. First, the belief that disasters are caused by extreme natural hazards rather than human actions is still popular in Chinese society due to a long-term experience of suffering, especially for peasants whose livelihoods are heavily dependent on the natural environment. The view of disasters as acts of God, not acts of people, dominates both popular and academic understanding. Academic disaster research in China has mostly focused on the physical aspects, such as engineering-related studies and probabilistic modeling of the hazards (for example, Chen, Chen, and Chen 2001; Wu et al. 2013). When vulnerability or social vulnerability is discussed, the focus is solely on exposure or, if referring to sensitivity, is represented by only a few variables that do not provide a detailed explanation of its meaning in reality. For example, Wei et al. (2004), Li and Li (2011), Huang et al. (2012), and Zeng et al. (2012) use different conceptual frameworks of vulnerability and thus different sets of indicators to measure it. Zeng et al. (2012) is one of the few empirically based social vulnerability studies, using only three indicators—population density, age structure, and distance to hospital—to measure social vulnerability. The most relevant research for this present study is Ge et al. (2013). They provided a temporally based social vulnerability index for the Yangtze River Delta. In their formulation, nine variables were included in the index and they used a different statistical method for creating it: the projection pursuit cluster. The primary weakness of the article is its reliance on GDP as the measure of socioeconomic status. In fact two of the nine variables are called socioeconomic status (one is measured as regional per capita GDP; the other as GDP per square kilometer). In this respect, many of the underlying drivers of social vulnerability (age, ethnicity, occupation, employment) are absent from this previous work. Our analysis includes these important indicators of social vulnerability and advances their understanding within the Chinese context.

Second, China has gone through a series of radical social, political, and economic changes during the last six decades. These changes are ongoing, making it more difficult to analyze and measure social vulnerability because the political economy of Chinese society has changed so dramatically. Rapid central government policy changes coupled with the great disparities between wealthy coastal regions and underdeveloped inland regions, and between urban and rural areas as well as between different provinces make contextualizing social vulnerability perhaps more complicated in China (Fan, Ranbar, and Zhang 2009; Sheng 2011). Even with these radical changes, social vulnerability reduction has been rarely incorporated into risk mitigation and regional development planning in China. Essentially, it is still the hazard and not the affected people that are being addressed in mitigation and risk attenuation discussions.

This article provides an empirical analysis of the spatial distribution of social vulnerability and its underlying social, economic, and political causes on a local scale in the Yangtze River Delta (YRD) region. This region is one of the most urbanized, rapidly growing, and developed coastal regions in China.

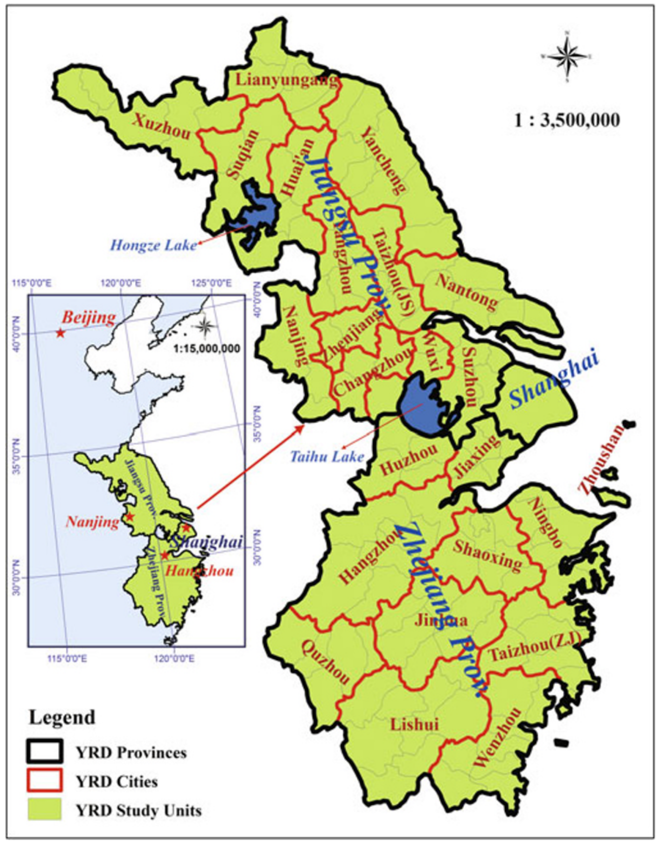

Figure 1. Yangtze River Delta, China: location and cities
Source: Adapted from administrative boundary data provided by the National Administration of Surveying, Mapping and Geoinformation of China.

2 The Yangtze River Delta Region

The Yangtze River Delta (YRD) economic region, broadly defined as the whole area of the 25 cities in east central China, is the wealthiest region in China. It contains the economically powerful Shanghai Municipality, one of the four municipalities directly administered by the central government in China. The region also includes the 13 cities of Jiangsu Province and the 11 cities in Zhejiang Province (Figure 1).

2.1 Physical Environment

The whole region accommodates more than 156 million people and covers approximately 213,000 km^2 of land. Most of the region (60%) is below 50 m in elevation. The northern part, Jiangsu Province, is located in the low-lying Taihu Lake plain, while the southern region, Zhejiang Province has hilly and mountainous terrain, with the highest peak of Fengyang Mountain (about 1,900 m in elevation) in Longquan City of Lishui. Shanghai is completely flat with an average elevation of 4 m.

The water network in this region is very dense and developed. The Yangtze River enters the region near Nanjing, flows north through Zhenjiang, then turns south draining into the

East China Sea at Shanghai. Smaller regional rivers and tributaries dot the basin. Taihu Lake formed by a meteor-impact crater is located on the border of Jiangsu and Zhejiang Provinces and is the third largest freshwater lake in China. The longest freshwater canal in the world—the Grand Canal—starts at Hangzhou and passes through the study region on its way north to Beijing. The presence of a dense hydrological system provides not only abundant resources but also convenient water transportation for both domestic and international goods.

The YRD is prone to flooding, and many farms and crops require annual or semiannual flooding for optimal production. The East Asian rainy season, commonly known as the "plum rain," usually appears and persists during mid-June and early-July, before the arrival of the hot summer. Tropical cyclones (June to September) add to the flooding potential, especially when the plum rain meets with the tropical cyclones. For example, in 1954 catastrophic flooding in the Taihu Lake Basin was caused by an unusual long period of plum rain (lasted about 60 days). It inundated about 5,800 km^2 farmland, induced flash floods in some mountainous areas in Zhejiang Province, and resulted in an economic loss of about 0.6 billion Chinese yuan (about 96.8 million US dollars at present price) (Weather China 2009).

In addition to flooding, the region is prone to drought, storm surges, landslides, and winter storms. Hazards frequently affect this area and cause significant casualties and economic losses as well as social disruptions (Wen and Xi 2006; Wen and Xu 2006; Wen and Bian 2008). Drought in the YRD usually happens in summer after the plum rain season, when the subtropical high-pressure zone moves northwards and stagnates over the lower and middle Yangtze River. After that, the typhoon season begins with heavy rainfall and strong wind over the whole region, inducing storm surges along the coastline and landslides in the northern mountainous areas of the YRD.

2.2 Socioeconomic Environment

Due to the excellent location and superior transportation system, the YRD enjoys unparalleled prosperity as the largest economic zone in China. In 2010, GDP created by the YRD was about 21 percent of the national GDP, although the region has only 12 percent of national population and 2 percent of the country's land area. In 2010, per capita disposable incomes for most of the cities except Suqian, Lianyungang, Huai'an, Xuzhou, and Yancheng were higher than the national level, while rural residents of all the cities in the YRD enjoy higher-than-national-average per capita net income.

The YRD region is dominated by secondary (industrial) and tertiary (commerce and finance) economic activities, each respectively contributing 51 percent and 45 percent of the region's total GDP in 2010. High-tech industries such as electronic information and pharmaceutical manufacturing, and the more traditional industries such as textiles, communications equipment manufacturing, and computers and other electronic equipment manufacturing are highly developed and capitalized in the region.

As an international center for commerce and finance, Shanghai ranks first in terms of the ratio of GDP created by the tertiary industry, 57 percent, followed by the two provincial capitals—Nanjing (52%) and Hangzhou (49%). The four cities in the northwestern corner of Jiangsu Province—Suqian, Yancheng, Lianyungang, and Huai'an—have the highest ratios of GDP contribution from primary industry, between 14 and 17 percent.

The economic development in the YRD is attracting people from all over the country to live and work. The total population reached 156 million at the end of year 2010. A large portion of population in YRD is concentrated in those most developed cities including Shanghai (15% of the total population in YRD), Suzhou (7%), Hangzhou (6%), Nanjing (5%), and Ningbo (5%). Zhoushan, the smallest city (in area), only has 0.7 percent of the total population.

2.3 Urban/Rural Divisions

As a traditional agricultural country, China has had an urban-rural division issue since its establishment. This dichotomy still exists even in the wealthy YRD region, with the stark disparities between urban and rural areas reflected in many dimensions—income, education resources, infrastructure, public services, employment opportunity, and access to medical services (Shi 1993; Henderson, Quigley, and Lim 2009; Sheng 2011). In 2010, the ratios of per capita disposable income of urban residents to per capita net income of rural residents in all the cities of the YRD are above 1.8; for Lishui, it even reached 3.2. The presence of the household registration system (*hukou*) is the main reason for disparities between urban and rural places. In essence, *hukou* is a discriminatory system that has restricted the mass movement of rural residents to cities and enforced a kind of economic apartheid since 1950s. By registering where people were born, rural residents held an agricultural *hukou* and were limited to work on their land with limited resources. Urban residents who have a nonagricultural *hukou* can fully enjoy the social services tied to their *hukou*, such as health care, education, job opportunities, pensions, and many others. The *hukou* system establishes a barrier between rural and urban areas, creating disparities. Since the reform and opening-up in 1978, millions of farmers have left their hometowns to seek jobs in cities. However, these migrant workers are not eligible for the same benefits as registered residents of the cities. They have no access to subsidized medical care and financial subsidies, and are usually lower-paid; their children are also unable to enjoy the free education in the cities.

Mass migration of rural population to urban areas for employment and better living standards leads to the further overcrowding of city spaces and consequent social problems. Population densities in city districts are generally much higher than in the surrounding counties. The average population density of city districts is twice that of the counties in the YRD in 2010—1,400 compared to 600 persons/km^2. The changes in the total resident population between 2000 and 2010 also indicate the urban/rural divide. While resident population in all the city districts has increased, in 57 counties it has decreased, in some cases as much as 30 percent, implying an inflow of population from rural to urban areas.

China's one-child policy, implemented in the late 1970s, continues to influence the demographic features of the YRD, despite recent changes in the policy. The average family size of the YRD in 2010 was 2.8; it was 3.1 in 2000. The decline in family size means that when the younger generation leaves home to study or work elsewhere (generally from rural to urban areas), the empty nest elderly are left behind—reducing family size from three to two. In the developed coastal regions, family size is also less than three persons due to the large influx of single young people flowing into these regions seeking better economic opportunities.

The physical, socioeconomic, and urban and rural land use patterns interact to produce disaster risks. The concentration of people and property, especially in the most developed areas, adds to the risk exposure, while the inequality between the rural and urban areas and the populations who live there adds to the vulnerability.

3 Data and Method

The administrative division of China consists of three levels according to the constitution, but in reality, there are five practical levels of local government: province, prefecture, county, township, and village (Figure 2). Of the 25 cities in the YRD, Shanghai is a provincial-level municipality, and the others are prefectural-level cities. Each of them governs several city districts, counties, or county-level cities. For example, Shanghai governs 17 city districts and one county, and Hangzhou governs eight city districts, two counties, and three county-level cities. City districts are the condensed central part of cities, highly urbanized and populous; counties and county-level cities govern urbanized towns and rural townships. For our study, considering the administrative structure, availability of demographic data, and statistical requirement of the SoVI® model, the county level is the most appropriate level of analysis. In this article, we combine the city districts for each city into one study unit because data on residents' income and medical service are not available for most of the individual city districts, but for city districts as a whole. Since indicators of socioeconomic status and access to medical service are very important in the SoVI® model, combining city districts into an integral city district region (still called "city district" for short) is a reasonable solution.

Finally, we obtained 134 study units (SU) including 25 city districts and 109 counties (including counties and county-level cities). Table 1 lists the name and number of SUs of each city.

3.1 Data Collection and Preprocessing

This article replicates the SoVI® study, but customizes the variables used in the original construction to conform to the Chinese context. Public data availability usually plays a significant role in this kind of place-based research, and the types of socioeconomic data vary from place to place. Differences in the historical background, social structure, and economic conditions between countries complicate a simple translation of the SoVI® variables and necessitate some adaptation to the country context. Thus, the selection of proxy indicators that correspond to the broader dimensions of social

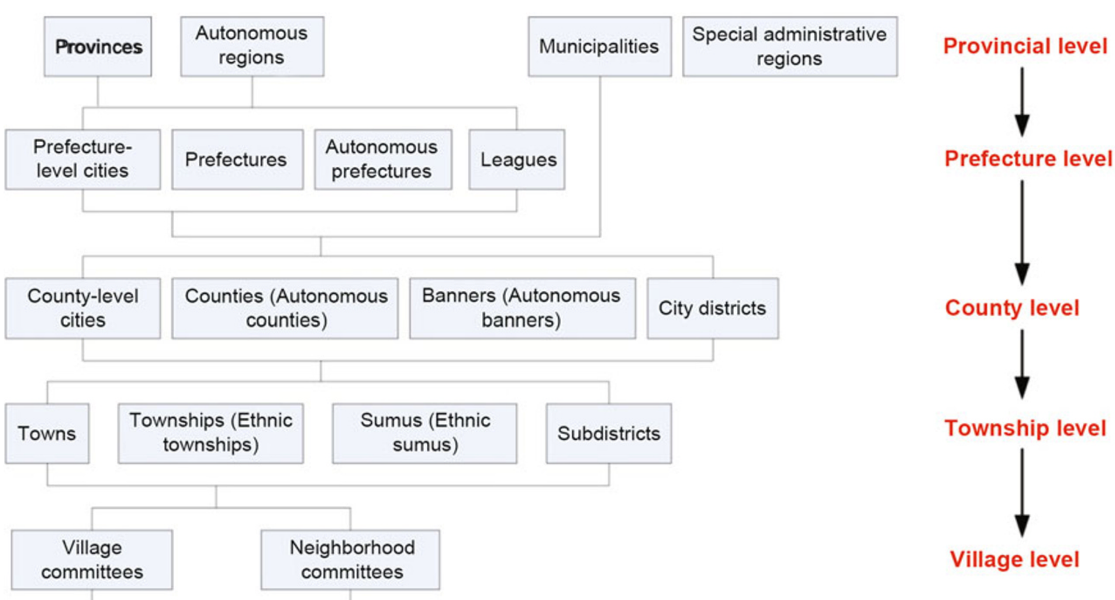

Figure 2. The five-level administrative division system in China
Source: Adapted from http://bantu.tianditu.com/article/view/id/188.

Table 1. General information about the 134 study units in the Yangtze River Delta

Provinces	No.	Cities	Names of Study Units	Number of Study Units
Shanghai	1	Shanghai	Shanghai_Ub†, Chongming	2
Jiangsu Province	2	Nanjing	Nanjing_Ub, Lishui,Gaochun	3
	3	Wuxi	Wuxi_Ub, Jiangyin, Yixing	3
	4	Xuzhou	Xuzhou_Ub, Pizhou, Xinyi, Suining, Peixian, Fengxian	6
	5	Changzhou	Changzhou_Ub, Liyang, Jintan	3
	6	Suzhou	Suzhou_Ub, Changshu, Zhangjiagang, Kunshan, Wujiang, Taichang	6
	7	Nantong	Nantong_Ub, Hai'an, Rudong, Qidong, Rugao, Haimen	6
	8	Lianyungang	Lianyungang_Ub, Ganyu, Guanyun, Donghai, Guannan	5
	9	Huai'an	Huai'an_Ub, Jinhu, Xuchi, Lianshui, Hongze	5
	10	Yancheng	Yancheng_Ub, Jianhu, Sheyang, Funing, Binhai, Xiangshui, Donghai, Dafeng	8
	11	Yangzhou	Yangzhou_Ub, Baoying, Yizheng, Gaoyou, Jiangdu	5
	12	Zhenjiang	Zhenjiang_Ub, Danyang, Yangzhong, Jurong	4
	13	Taizhou(JS)	Taizhou(JS)_Ub, Xinghua, Jingjiang, Taixing, Jiangyan	5
	14	Suqian	Suqian_Ub, Siyang, Sihong, Shuyang	4
Zhejiang Province	15	Hangzhou	Hangzhou_Ub, Tonglu, Chun'an, Jiande, Fuyang, Lin'an	6
	16	Wenzhou	Wenzhou_Ub, Rui'an, Leqing, Dongtou, Yongjia, Pingyang, Cangnan, Wencheng, Taishun	9
	17	Ningbo	Ningbo_Ub, Yuyao, Cixi, Fenghua, Xiangshan, Ninghai	6
	18	Jiaxing	Jiaxing_Ub, Pinghu, Haining, Tongxiang, Jiashan, Haiyan	6
	19	Huzhou	Huzhou_Ub, Deqing, Changxing, Anji	4
	20	Shaoxing	Shaoxing_Ub, Shaoxing, Shangyu, Shengzhou, Xinchang, Zhuji	6
	21	Jinhua	Jinhua_Ub, Lanxi, Yiwu, Dongyang, Yongkang, Pujiang, Wuyi, Pan'an	8
	22	Quzhou	Quzhou_Ub, Longyou, Changshan, Kaihua, Jiangshan	5
	23	Zhoushan	Zhoushan_Ub, Daishan, Shengsi	3
	24	Taizhou(ZJ)	Taizhou(ZJ)_Ub, Yuhuan, Sanmen, Tiantai, Xianju, Wenling, Linhai	7
	25	Lishui	Lishui_Ub, Qingtian, Jinyun, Suichang, Songyang, Yunhe, Qingyuan, Jingning, Longquan	9

Note: † We use "_Ub" after the city names to represent the city districts, which are mostly urban areas.

vulnerability—socioeconomic status, gender, education, and so on—becomes important. In this study, the dimensions of vulnerability identified by Cutter, Boruff, and Shirley (2003) guided the variable selection along with housing conditions. While not an exact replica (largely because of data inconsistencies, comparability, and availability), using the broad components coupled with the faithful replication of the methodology does insure a robust test of the SoVI® adjusted for a different cultural context.

Data come from the sixth national population census in 2010 (2010 census) (Population Census Office of the State Council and Department of Population and Employment Statistics of the National Bureau of Statistics of China 2012), 2010 statistical yearbooks of each city published by the cities' Statistical Bureaus, as well as the 2010 China Civil Affairs Statistical Yearbook (Ministry of Civil Affairs of the People's Republic of China 2011). After a correlation analysis and the removal of highly correlated variables, 29 variables (Table 2) were collected as proxies for each of the 134 study units in the YRD.

Where there are incomplete (missing) data, we employed substitution strategies based on available data (Table 3). Generally, the mean values for larger enumeration units (counties or provinces) substituted for the missing values so as not to change the mean and standard deviation of the data. In the case of urban income, the mean value for all city districts substituted for missing districts in Nanjing, while the aggregate citywide value of urban income was used in the other cities with missing data (for example, Wuxi, Shanghai, Changzhou) (Table 3).

As this article is a replication of the SoVI® methodology, the customization of variables for the Chinese context is an important task. The rationale for selecting variables can be found in Cutter, Boruff, and Shirley (2003). Due to space limitations, only a brief explanation of the customization of the SoVI® variables in the regional context is given. Not all of these variables show variability within each study unit, but when aggregated to the entire region, the geographical differences among study units become clear.

Socioeconomic status: Income is usually the best indicator for the socioeconomic status of residents. Corresponding to the dual system of rural and urban areas in China, income levels of rural residents and urban residents were measured separately in statistical yearbooks using two different indicators: per capita disposable income for urban residents and per capita net income for rural residents. The two indicators, obtained with different methods of sampling, investigation, and calculation, are not directly comparable. However, due to a high correlation between them (the Pearson correlation coefficient is 0.91), only the former, denoted as UBINCM, remains in our study.

Gender: As demonstrated in the literature, females are more vulnerable in disasters than males due to their biological characteristics, psychological features, and social roles within society. Thus, the percentage of females is taken into account.

Table 2. Vulnerability concepts and variables used for the Yangtze River Delta SoVI®

Concept	No.	Name	Description
Socioeconomic status	1	UBINCM	Per capita disposable income of urban residents, 2010 statistical yearbooks
Gender	2	QFEMALE	Percentage of female resident population, 2010 census
Race & Ethnicity	3	QMINOR	Percentage of minority population (non-Han groups in China), 2010 census
Age	4	MEDAGE	Median age, 2010 census
Employment loss	5	QUNEMP	Unemployment rate of population 15 years or older, 2010 census
Rural/Urban	6	POPDEN	Resident population density, 2010 census
	7	QUBRESD	Percentage of urban residents, 2010 census
	8	QNONAGRI	Percentage of population with non-agricultural *hukou*, 2010 census
Renters	9	QRENT	Percentage of households that live in rented houses, 2010 census
Occupation	10	QAGREMP	Percentage of laborers working in primary sector industries and mining, 2010 census
	11	QMANFEMP	Percentage of laborers working in secondary sector industries, 2010 census
	12	QSEVEMP	Percentage of laborers working in tertiary sector industries, 2010 census
Family structure	13	PPUNIT	Average number of people per household, 2010 census
Education	14	QCOLLEGE	Percentage of population 25 years and older with college diploma, 2010 census
	15	QHISCH	Percentage of population 20 years and older with high school diploma, 2010 census
	16	QILLIT	Illiteracy rate of population 15 years or older, 2010 census
Population change	17	POPCH	Growth rate of resident population (2000–2010), 2010 census
Housing conditions	18	PHROOM	Average number of occupied rooms per household, 2010 census
	19	PPHAREA	Per capita building area, 2010 census
	20	QNOPIPWT	Percentage of households without piped water in their houses, 2010 census
	21	QNOKITCH	Percentage of households without a kitchen in their houses, 2010 census
	22	QNOTOILET	Percentage of households without a toilet in their houses, 2010 census
	23	QNOBATH	Percentage of households without a bath in their houses, 2010 census
Medical service	24	HPBED	Number of beds in health care institutions per 1,000 resident population, 2010 statistical yearbooks
	25	MEDTECH	Number of medical technical personnel per 1,000 resident population, 2010 statistical yearbooks
Social dependency	26	QPOPUD5	Percentage of population with age <5, 2010 census
	27	QPOPAB65	Percentage of population with age >65, 2010 census
	28	QDEPEND	Population dependency ratio (the ratio of the total population above 65 years old and below 15 years old to the total population between 15 and 65 years old), 2010 census
Special needs population	29	QSUBSIST	Percentage of residents covered by subsistence allowances from the government, 2010 China Civil Affairs Statistical Yearbook

Table 3. Incomplete data and substitution method

Variable	Study Units	Substitution Method
UBINCM	Nanjing_Ub	The average of all the city districts' values
	Wuxi_Ub, Shanghai_Ub, Changzhou_Ub, Yangzhou_Ub, Taizhou(JS)_Ub, Hangzhou_Ub, Xuzhou_Ub, Lianyungang_Ub, Huai'an_Ub, Yancheng_Ub, Suqian_Ub	The value of each city
HPBED	Wenzhou_Ub, Dongtou, Yongjia, Pingyang, Cangnan, Wencheng, Taishun, Rui'an, Leqing, Huzhou_Ub, Deqing, Changxing, Anji, Quzhou_Ub, Changshan, Kaihua, Longyou, Jiangshan, Zhoushan_Ub, Daishan, Shengsi	The mean of Zhejiang Province
MEDTECH	Wenzhou_Ub, Dongtou, Yongjia, Pingyang, Cangnan, Wencheng, Taishun, Rui'an, Leqing, Quzhou_Ub, Changshan, Kaihua, Longyou, Jiangshan, Zhoushan_Ub, Daishan, Shengsi	The mean of Zhejiang Province

Race & Ethnicity: China is a multi-ethnic country, with 56 recognized ethnic groups. While Han is the majority, minority groups make up about 8.4 percent of the national population. Compared to Han Chinese, most minorities live in a disadvantageous condition with low income, little education, and few employment opportunities. Thus, the percentage of minorities is included as an important variable.

Age: Median age is a popular indicator for age structure and tendency of a population. The median age in China climbed from 29.0 in 2000 to 35.2 in 2010, according to the fifth and sixth national population census data, indicating a rapid aging process of Chinese population partly influenced by the one-child policy.

Employment loss: The unemployment rate indicates the economic health and vitality of a region. Unemployed people are vulnerable because of inadequate income and resources to support themselves and recover from disasters. The more unemployed people in a society, the more unstable the society is as more problems may emerge under these adverse circumstances.

Rural/Urban: As mentioned in section 2.3, the urban/rural division is prominent in China. This residential distinction is significantly impacted by the *hukou* system. Three indicators represent the concept of Urban/Rural: population density, percentage of urban residents, and percentage of population with a nonagricultural *hukou*. Population density is generally higher in highly urbanized regions than in rural areas. As people living in urban areas may not be nonagricultural residents who are permitted to receive local welfare support, both urban resident and population with nonagricultural *hukou* variables are included.

Renters: Renters are a group of vulnerable people and they may suffer more from natural disasters. The ratio of renters is larger in big cities, where migrant workers gather for jobs. If affected by natural disasters, they may find problem in paying for rent or finding a new place to live. Thus, this variable is included.

Occupation: Different occupations require different education levels and skills and produce different levels of income. People employed in a tertiary industry generally are paid higher than those employed in primary and secondary industries. People work in the primary activities such as farming and mining are the most vulnerable because of their dependency on natural conditions such as weather and other hydrological and geological situations.

Family structure: Family size is an important element of family structure. Under the influence of the one-child policy, family sizes are decreasing. More and more families are composed of three persons—father, mother, and child. With the outflow of young people from home to work and study in other places, those "empty nest elderly" are very vulnerable when confronted by natural hazards. Single mother-headed families are another group of vulnerable people.

Education: Education levels are important variables that can imply the residents' income, quality of life, job opportunities, and so on. The average education level of a society can indicate its development potential. More education means a greater capacity to respond to, cope with, and recover from natural disasters.

Population change: The population change rate indicates the speed of population growth and regional development. Fast-growing population may trigger unbalances between population and resources. In China, the natural growth of population has been declining thanks to the one-child policy, but the speed of growth in some urban areas is prominent with the increasing urbanization process.

Housing conditions: Housing conditions reflect the residential property concept, as they are more reflective of average living conditions in the study units. The quality of residential environments includes the average number of occupied rooms, per capita building area, and percentage of households without piped water, kitchen, toilet, and bath.

Medical service: Access to medical service is important after disasters. Effective disaster response needs adequate hospital beds and medical technical personnel once there are casualties.

Social dependency: Children under six years of age and elderly above 65 are two vulnerable groups in disasters. Population dependency ratio—the ratio of nonworking-age population to working-age population indicates the pressure on the economically productive, working population in society.

Special needs population: In China, households whose per capita monthly incomes are lower than certain local standards[i] receive subsistence allowances from the local government. This group of residents is in an economically disadvantageous situation and is included as a special needs population in our study.

3.2 Application of Principal Component Analysis

Principal Component Analysis (PCA) is the primary statistical procedure for constructing the SoVI® following the Cutter, Boruff, and Shirley (2003) methodology. The variables reflect certain social and economic characteristics that influence social vulnerability. However, the intersection of the variables is equally important given the multidimensional nature of social vulnerability. The PCA method captures this multi-dimensionality by transforming the raw dataset to a new set of independent variables (principal components). Each component can explain a proportion of the total variance of the dataset, and the larger variance a component can explain, the more information it contains. More importantly, PCA enables a few components to represent the dimensional data, and makes it easier to identify the underlying factors (see Abdi and Williams 2010; Jolliffe 2005).

The PCA was performed with the SPSS software. We used the varimax rotation in the PCA because it minimizes the number of components and maximizes the sum of variances they represent, and the Kaiser criterion (only keeping the components with eigenvalues equal to or greater than 1.0 as the principal components) as the factor selection method. Once produced, the factors are examined manually as to whether they increase (+) or decrease (−) vulnerability and they are assigned a cardinality on that basis. The index is produced by summing all the factors using equal weighting, again following the Cutter, Boruff, and Shirley (2003) approach. They used equal weights as there is no theoretical justification for assuming that one factor has more significance in contributing to social vulnerability than the other (Cutter, Boruff, and Shirley 2003). The following section presents the components and SoVI® scores.

4 Results

After performing the PCA in SPSS, six components with eigenvalues greater than 1.0 were extracted, and then named to indicate the latent variable based on the variable loadings in each component and expert judgment. The SoVI® in the YRD region was calculated, and the drivers for the spatial variability were analyzed as follows.

4.1 SoVI® Factors

Six principal components explain 80.1 percent of the variance among all SUs. The six factors are named as Employment and Poverty; Education; Poor Housing Quality; Minorities;

Family Size, and Housing Size. Each factor has a sign denoting the positive or negative effect on social vulnerability based on the dominant variables on each component. Those variables with the largest absolute loadings (greater than or equal to 0.5) are identified as the main drivers in the corresponding factor (Table 4).

The first factor, Employment and Poverty, contributes 24.1 percent of the total variance. This factor is dominated by the indicators that imply a high percentage of employees in the primary industry, a socially dependent population, a low percentage of employees in secondary/manufacturing industry, lower income, less renters, and lower population change and density. Overall, the first factor identifies a group of poorer study units mainly engaged in agricultural employment. Lower nonagricultural employment and poverty contribute to a higher social vulnerability, and thus this factor receives a positive sign.

The second factor, Education, contributes 20.1 percent of the total variance. It identifies a group of study units with residents having a higher level of education, indicated directly by the positively loaded variables—percent of residents completing college and high school. This is also indirectly indicated by other drivers—people who are nonagricultural residents, work in urban areas in tertiary industries, and as medical technical personnel, all of which occupational categories have relatively high educational levels. Despite the positively loaded high unemployment ratio and population density, this factor reduces social vulnerability, so a negative sign is attributed to the component.

The third factor, Poor Housing Quality, represents 12.6 percent of the total variance. The percentage of households without basic facilities, such as a bath, toilet, piped water, and a kitchen, is high according to the positively loaded variables on this factor. At the same time, the factor has high percentages of children that loads positively on this component. All of these increase social vulnerability, so a positive sign is assigned.

The fourth factor Minorities explains 8.6 percent of the total variance. This factor illustrates places with a large percentage of ethnic minorities, illiteracy, unemployment, and male residents. Overall, it increases social vulnerability (positive cardinality).

The Family Size factor highlights the number of people per household and percentage of children (below 5 years of age) along with median age and percentage of the elderly (above 65 years of age). It contributes 8.5 percent of the total variance and indicates smaller-sized families with elderly people. A positive sign is assigned to the factor identifying places with smaller households with elderly populations.

The sixth factor is Housing Size and contributes 6.2 percent of the total variance. This factor shows good housing conditions in terms of more rooms and building area occupied by each household. A negative sign is assigned to it.

Finally, the SoVI® scores are computed using the formula: SoVI® = Factor 1 – Factor 2 + Factor 3 + Factor 4 + Factor 5 – Factor 6.

4.2 Geographic Variability in Drivers of Social Vulnerability

Once computed, the SoVI® scores are mapped using standard deviations from the mean to show the spatial variability across the region (Figure 3). The overall SoVI® scores range from −5.51 (low social vulnerability) to 7.37 (high social vulnerability) with a mean social vulnerability score of 0.01 and standard deviation (SD) of 2.44. Study units with SoVI® scores greater than 1.5 SDs are labeled as most vulnerable. Only six counties (4% of all study units) are classified into this category. The highest social vulnerability appears in Jingning of Lishui, followed by Pan'an of Jinhua, Shengsi of Zhoushan, Lanxi of Jinhua, Suichang and Yunhe of Lishui (Figure 3). However, the high social vulnerability is driven by different factors in each study unit. Higher scores on the fourth factor, Minorities, lead to the high SoVI® scores of Jingning, Suichang, and Yunhe of Lishui as well as Lanxi of Jinhua. For Pan'an and Shengsi, the high score of the Family Size factor is the main driver for the high SoVI® score.

The 11 study units (8.21%) labeled as least vulnerable (more than −1.5 SD below the mean) include Zhangjiagang of Suzhou, Jingjiang of Taizhou(JS), Yangzhong of Zhenjiang, Yangzhou_Ub, Kunshan of Suzhou, Taizhou(JS)_Ub, Suzhou_Ub, Tongxiang of Jiaxing, Lianyungang_Ub, Changshu of Suzhou, and Hangzhou_Ub. Zhangjiagang is ranked lowest in SoVI® due to its good housing quality, low

Table 4. SoVI® factors of the Yangtze River Delta, China

No.	Name	Sign	No. of Drivers	Drivers (Loadings)
1	Employment and Poverty	+	9	QMANFEMP(−0.91), UBINCM(−0.86), QAGREMP(0.84), QRENT(−0.83), POPCH(−0.78), QDEPEND(0.78), QSUBSIST(0.7), QPOPAB65(0.57), POPDEN(−0.55)
2	Education	−	9	QCOLLEGE(0.90), QHISCH(0.86), QNONAGRI(0.84), QSEVEMP(0.77), HPBED(0.76), QUBRESD(0.71), MEDTECH(0.67), QUNEMP(0.57), POPDEN(0.53)
3	Poor housing quality	+	6	QNOKITCH(0.83), QNOBATH(0.79), QNOTOILET(0.75), QNOPIPWT(0.7), QPOPUD5(0.6), MEDAGE(−0.55)
4	Minorities	+	4	QFEMALE(−0.76), QMINOR(0.76), QILLIT(0.53), QUNEMP(0.52)
5	Family size	+	4	PPUNIT(−0.79), MEDAGE(0.69), QPOPAB65(0.51), QPOPUD5(−0.52)
6	Housing size	−	2	PPHAREA(0.78), PHROOM(0.70)

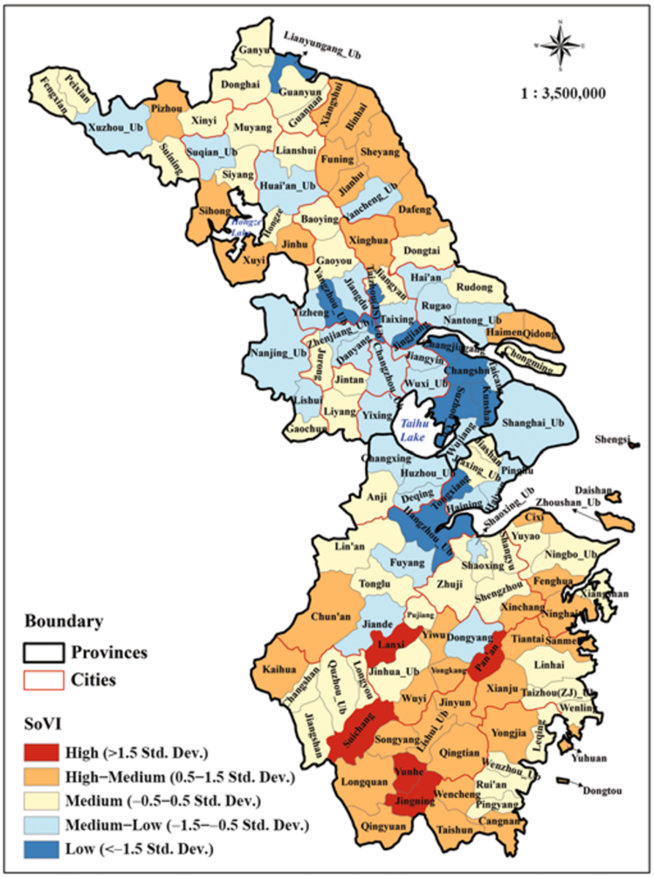

Figure 3. Spatial distribution of SoVI® in the Yangtze River Delta region

agricultural employment and poverty, small family size, and large housing size. The lower vulnerability of Jingjiang and Yangzhong is explained by large housing size and good housing quality. For Yangzhou_Ub, Taizhou(JS)_Ub, Suzhou_Ub, Lianyungang_Ub, and Hangzhou_Ub, their higher education level is the main contributor to their low social vulnerability. For Kunshan and Changshu, low agricultural employment and poverty make social vulnerability low. For Tongxiang, large housing size is the main reason.

Around 29 percent of the study units fall into the medium-high level of vulnerability (0.50–1.5 Std. Dev.). Most of these are counties with high minority scores as well as low scores for housing size. These study units are located mainly in Lishui, Yancheng, Wenzhou, Taizhou(ZJ), and Ningbo. Zhoushan_Ub and Lishui_Ub are the two only city districts that have medium-high levels of social vulnerability, driven by their smaller housing size and high minority scores. Thirty-five percent of the study units fall into the medium (−0.5–0.5 Std. Dev.) level vulnerability category. Most of these places are counties located in Lianyungang, Quzhou, Shaoxing, Wenzhou, Xuzhou, Ningbo, and Taizhou(ZJ), as well six city districts including Wenzhou_Ub, Ningbo_Ub, Jinhua_Ub, Taizhou(ZJ)_Ub, Quzhou_Ub, and Jiaxing_Ub. Medium to low social vulnerability (−1.5– −0.5 Std. Dev.) is attributed to 23 percent of our study units, mainly located in Huzhou, Jiaxing, Nantong, Wuxi, Hangzhou, Nanjing, Suzhou, Yangzhou, and Zhenjiang. Twelve city districts belong to this medium-low social vulnerability group, such as Shanghai_Ub, Nanjing_Ub, and Wuxi_Ub.

5 Discussion

The most vulnerable study units are located at the geographic ends of the YRD, especially in the southern end—counties in Lishui, Yancheng, Jinhua, Wenzhou, Taizhou(ZJ), Ningbo, and Zhoushan (Figure 3). Three factors, minorities, small housing size, and small family size drive this geographical pattern. The least vulnerable study units are mainly located in the middle part of the YRD, the region around Shanghai. Low agricultural employment and poverty, high education level, and good housing quality contribute jointly to their low vulnerability.

The geographic distribution of social vulnerability is a reflection of the historical legacy of development patterns in China. The patterns of urbanization and industrialization created two separate societies—a rural agrarian society with lower wages and educational levels, and the more affluent and educated urban society. These inequalities were aggravated by the social revolutions during the 1950s and the late 1970s (reforms to promote economic growth) (Whyte 2010). The remnants of the historical inequality are apparent in the contemporary patterns of social vulnerability in the YRD region. Despite governmental efforts to rectify urban-rural and coastal-inland disparities, the *hukou* system remains as one of the main obstacles for reducing the rural-urban inequality gap.

There are considerable spatial variabilities in the individual factors contributing to social vulnerability. The results also reveal that most city districts rank low in terms of SoVI® scores, with none of them in the most vulnerable group, and two of them in the high-medium group. In China, highly urbanized areas are generally much less vulnerable than rural areas. Social resources like education opportunities, medical services, government financial aids, and job opportunities are distributed unequally between urban and rural areas. For example, the study units with the highest scores on education (Figure 4) are city districts—Nanjing_Ub, Lianyungang_Ub, Shanghai_Ub, and Hangzhou_Ub. However, these same places exhibit other dimensions of vulnerability. For example, Shanghai_Ub, the city district of Shanghai Municipality, ranks low on the factor housing size due to its high population density and limited housing spaces, while Ningbo_Ub has high loadings on the poor housing quality factor due to its inadequate housing facilities.

The employment and poverty factor shows a clear pattern with highest values at the two ends and lowest values in the middle of the region (Figure 4 (a)). Study units in Wenzhou, Lishui, Quzhou, Suqian, Yancheng, Xuzhou, and Lianyungang have low income, a high percentage of employees in

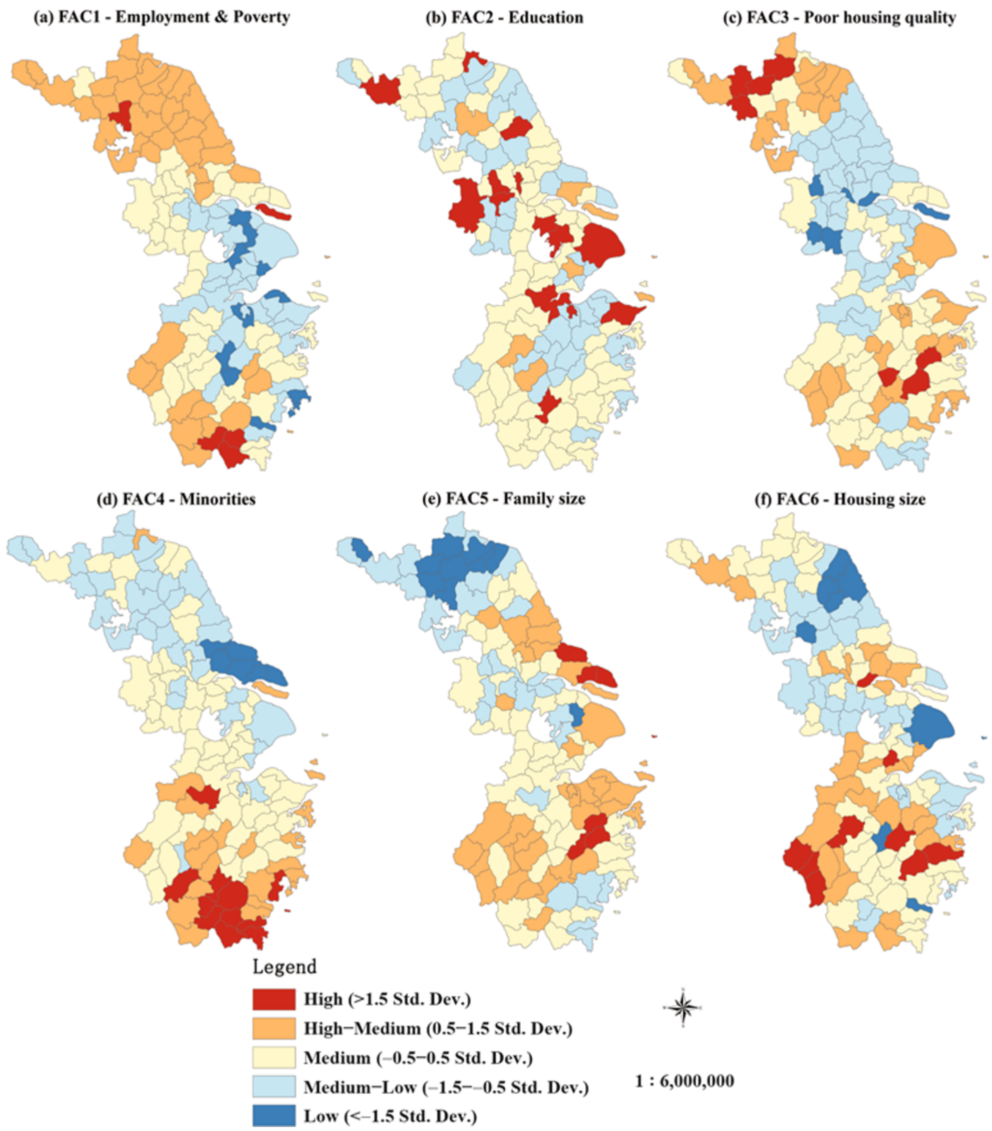

Figure 4. The maps of principal components of the social vulnerability in the Yangtze River Delta

primary industry, a low percentage in manufacturing industry, a low ratio of population change, as well as a high population dependency ratio. In contrast, study units in the municipalities of Suzhou, Wuxi, Shanghai, Jiaxing, Ningbo, Shaoxing, and Jinhua are under the opposite conditions. This pattern reflects an unbalanced development within the YRD region.

The education factor indicates an apparent disparity in education levels between residents in the most developed study units (city districts) and less developed study units (Figure 4 (b)). Almost all of the city districts except Taizhou(ZJ)_Ub and Huzhou_Ub, especially Nanjing_Ub, Lianyungang_Ub, Shanghai_Ub, and Hangzhou_Ub, rank at the top on this factor. These city districts feature high percentages of college and high school graduates, high percentages of employees in tertiary industry, and good medical service access, as well as a high percentage of urban residents and non-agricultural residents. Besides, Shengsi in Zhoushan, Chongming of Shanghai, and Jiande in Hangzhou have high factor scores because of high percentage of employees in the tertiary industry, higher per capita beds in health care institutions, and per capita medical technical personnel respectively.

Housing quality in the south of YRD is less adequate than the north (Figure 4 (c)). Study units in Zhejiang Province have high scores on the factor poor housing quality except some study units in Hangzhou, Wenzhou, Huzhou, and Jiaxing. It demonstrates that in mountainous Zhejiang, houses are not adequately equipped with facilities despite a large number of residents living in such houses. In most study units of Xuzhou and Lianyungang as well as Shanghai_Ub, the same conditions also exist.

The fourth factor, minorities, shows high values mainly in the southern end of the YRD—Lishui, Wenzhou, Jinhua, and Hangzhou (Figure 4 (d)). This has partly resulted from the gathering of the ethnic minority—the *She* people—in this area. Zhejiang Province is one of the main habitations of the *She* people, who moved into and settled in Zhejiang during Ming and Qing Dynasties. Jingning County in Lishui is the only autonomous county for the *She* people in China. This part of the region has a high illiteracy rate due to the underdeveloped education system in the mountainous area. Besides, this southern part has a low percentage of females (mostly below 50%), while the northern part, especially in Nantong and Yangzhou has a high percentage of females (up to 55% in Haimen of Nantong).

The family size factor shows high values in the study units with a small family size and high percentage of elderly people (Figure 4 (e)). Affected by the one-child policy in China, family size has been declining. Of the 134 study units, 100 (75%) have a lower-than-three persons average family sizes, with the lowest values located in the study units in Nantong, Shanghai, Zhoushan, Jinhua, and Lishui. The study units at the northwestern corner—Suqian, Lianyungang, Xuzhou, and Huai'an—have larger family sizes and higher percentages of children compared to other study units. The study units with high percentages of elderly are concentrated in Nantong, Taizhou(JS), Yangzhou, Quzhou, and Lishui. Study units with high factor scores are in Nantong, Zhoushan, Shaoxing, Taizhou(ZJ), Jinhua, and Lishui. However, the high median ages in the whole YRD (from 33 to 46 years) indicate an overall aging population.

Larger housing size, the last factor, including more rooms and building areas (indicating less crowding), are concentrated in the southern part of the YRD, especially in Quzhou, Taizhou(ZJ), and Hangzhou (Figure 4(f)). In contrast, in Yancheng, Shanghai, and Zhoushan housing space is very limited for the residents.

Examining the relative levels of social vulnerability assists in making mitigation decisions about natural disaster risks. Mapping social vulnerability provides a way to communicate which areas are more susceptible to the impacts of disasters. For example, based on this regional assessment, special attention should be focused on the most vulnerable study units we examined including Jingning, Suichang, and Yunhe of Lishui, Pan'an and Lanxi of Jinhua, as well as Shengsi of Zhoushan. Furthermore, the identification of the underlying drivers of the social vulnerability suggests the utility of social vulnerability as a spatial planning tool for all facets of emergency management—preparedness, response, recovery, and mitigation (Mendes 2009). Given that social vulnerability is a dynamic concept, regular assessments are needed to capture the rapid social economic changes in this area, which amplifies or attenuates the social vulnerability of counties, city districts, towns, and villages.

6 Conclusions

This article provides an assessment of social vulnerability in the YRD region by applying the SoVI® method, modified to reflect the Chinese social and cultural context. It is evident that some specific historical, social, and economic factors in the study area have a great influence on social vulnerability, notably the household registration system, the one-child policy, the rapid urbanization process, and the aging of the population. Indeed, these factors become the main sources of social and spatial inequality, and consequently create the unevenly distributed social vulnerability and disaster risks.

Overall, this replication of SoVI® for the Yangtze River Delta region has captured the major dimensions of social vulnerability, showing that the SoVI® algorithm has a good applicability in the context of other countries. The spatial patterns of SoVI® factor scores reflect the local demographic and economic conditions that influence social vulnerability to natural hazards in the YRD region. The visualization of SoVI® and all the SoVI® factors through mapping provides a good foundation for understanding the spatial variation in social vulnerability across the region.

This project also identified the driving factors contributing to the overall vulnerability, providing a benchmark reference for decision makers on where vulnerability reduction could occur. By gradually bridging the gap between rural and urban areas in income, education resources, medical service levels and so forth, overall societal vulnerability is likely to be reduced.

This study also reveals the importance of integrating social vulnerability and disaster risk mitigation with sustainable development. How people live and society develops affect the overall loss potential from disasters. Realizing this, more attempts should be made to develop social vulnerability metrics and put theories and metrics into practice. This particular case study has contributed towards this goal, particularly for China, but also for other countries. The replication has also demonstrated the utility of SoVI® in measuring social vulnerability in other world regions.

Use of the SoVI® analysis in the YRD also has limitations. The major problem lies in data availability and quality. For example, the combination of city districts into one study unit prevents the investigation of differences among city districts, reduces the spatial resolution of analysis, and makes the scale of analysis close to but not equal to county-level. It is necessary to implement a county-level SoVI® assessment if relevant data (on income and medical service) become available in the future regarding the rapid development of urban areas. Data availability also determines the variable selection process. In our study, the number of variables is sufficient to conduct a principal component analysis; the variable set is also well constructed to reflect the multiple dimensions of social vulnerability. But missing data still exist, and data comparability cannot be guaranteed when they come from different sources. Despite our efforts in data compilation, bias may still exist due to data limitations, which can be reduced by employing better data in future studies.

The Yangtze River Delta can be seen as a representative of coastal developed regions in China, and the methods employed in this study can be applied to other regions and the results compared. To remove the data obstacle, central and local governments would have to collect and provide consistent socioeconomic statistics. It would contribute greatly to social vulnerability research if the governments collected disaster victims' characteristics, such as gender, age, occupation, and so on after each disaster.

Further work needs to be done to develop a social vulnerability assessment framework adapted to a Chinese background. This means that the relationships between various elements in Chinese society and of social vulnerability to natural hazards need to be investigated and built. Only in this way can place-based social vulnerability be enriched by comparative examples, and China can find unique and appropriate approaches to reduce its disaster risks.

Acknowledgments

This research was supported jointly by the National Key Basic Research Program of China (973 program) (Grant No. 2012CB955404), the Foundation for Innovative Research Groups of the National Natural Science Foundation of China (Grant No. 41321001), and the Integrated Research on Disaster Risk's (IRDR) International Centre of Excellence (ICoE) in Vulnerability and Resilience Metrics, at the University of South Carolina. The authors would like to express our great appreciation to Ronnie Schumann, Kevin Ash, Robert Gottlieb, and Gregg Bowser in the Hazard and Vulnerability Research Institute, University of South Carolina, for giving valuable advice on the writing of the manuscript and providing technical guidance as well as provoking thoughts during the development of the research work. The authors also wish to thank Dr. Saini Yang and Yongchang Meng in the Academy of Disaster Reduction and Emergency Management, Beijing Normal University for their great help in data collection.

Note

i The standards range from 150–350 Chinese yuan, about USD 25–58 per person per month in different cities for year 2007, according to the Ministry of Civil Affairs of the People's Republic of China (http://dbs.mca.gov.cn/article/dbbz/200801/20080100011256.shtml).

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