

# Measuring Social Vulnerability to Natural Hazards in Beijing-Tianjin-Hebei Region, China

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**Abstract:** Social vulnerability in this study represents the differences between the capacity to cope with natural hazards and disaster losses suffered within and between places. The assessment of social vulnerability has been recognized as a critical step in understanding natural hazard risks and enhancing effective response capabilities. This article presents an initial study of the social vulnerability of the Beijing-Tianjin-Hebei (B-T-H) Region in China. The goal is to replicate and test the applicability of the United States Social Vulnerability Index (SoVI) method in a Chinese cultural context. Thirty-nine variables adapted from the SoVI were collected in relation to two aspects: socioeconomic vulnerability and built environment vulnerability. Using factor analysis, seven factors were extracted from the variable set: the structure of social development, the level of economic and government financial strength, social justice and poverty, family structure, the intensity of space development, the status of residential housing and transportation, and building structure. Factor scores were summed to get the final SoVI scores and the most and least vulnerable units were identified and mapped. The highest social vulnerability is concentrated in the northwest of the study area. The least socially vulnerable areas are mainly distributed in the Beijing, Tianjin and Shijiazhuang core urban peripheral and central city areas of the prefecture-level cities. The results show that this method is a useful tool for revealing places that have a high level of vulnerability, in other words, areas which are more likely to face significant challenges in coping with a large-scale event. These findings could provide a scientific basis for policy making and the implementation of disaster prevention and mitigation in China.

**Keywords:** natural hazards; social vulnerability; factor analysis; Beijing-Tianjin-Hebei Region

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## 1 Introduction

In the past 20 years, global warming, sea level rises and rapid urbanization have begun to show negative feedback effects; moreover, the frequency and intensity of heavy rain, storm surges and other hazardous incidents have increased significantly (IPCC, 2012; Ziegler, 2012). China is one of the countries that have been sub-

ject to the most serious losses from natural disasters. The losses, especially the economic losses, are indicative of a recent and increasing trend (Yang *et al.*, 2014), especially in China's densely populated areas, where natural hazards have had a huge impact on the regional socioeconomic development (Lin *et al.*, 2006; Yin *et al.*, 2011; 2012; 2013; 2015). Therefore, carrying out effective disaster risk assessment and management research

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has become a key priority for the current government and academia.

Risk assessment is an important tool for hazard prevention in hazard risk research, and vulnerability analysis is an important bridge between hazard and risk research that also plays a key role in hazard reduction and prevention (Lee, 2014). The impact of a natural hazard is the joint product of stress and exposure on the one hand and vulnerability on the other (Blaikie *et al.*, 1994); in other words, if a place is not vulnerable to natural hazards events, there will be no natural disaster loss. While the traditional study of physical processes can only explain who may be exposed to the natural hazards and where they may occur, it is not sufficient to understand the degree to which people at a particular location are threatened by that exposure. Natural hazards may produce significantly different impacts on people and places, often depending not only on the severity of the hazard, but also on the physical attributes and the socioeconomic characteristic of a locale. The vulnerability analysis is a new paradigm for addressing natural hazard-related issues. Currently, the concept of vulnerability is used in many fields and adopts different spatial scales. Although there have been several attempts at defining and capturing what is meant by vulnerability, the term varies among disciplines and research fields. Therefore, a better understanding of the multifaceted nature of vulnerability is a prerequisite for designing and implementing effective disaster prevention and mitigation strategies (IPCC, 2012). Presently, vulnerability can be divided into two broad categories: physical vulnerability and social vulnerability (Schmidtlein *et al.*, 2008). Physical vulnerability links vulnerability to unsafe conditions, and stresses the exposure of society to natural hazards. For example, people who live in a flood zone will have a higher physical vulnerability than those who do not live in one. Physical vulnerability provides a useful way of helping people to understand their vulnerability to natural hazards due to their occupancy of hazardous zones. But this can not explain the different disaster losses in the same city suffered by different people or different blocks as a result of the same natural hazard shocks to which there is the same physical vulnerability. The differences in disaster losses are also connected with social factors of the region. There is now a realization that natural hazard prevention and mitigation will need to address not only the hydrologi-

cal-meteorological factors, but also the economic, social and political factors influencing the wider society and underpinning the impact of hazardous events. As an important supplement to physical vulnerability research, scholars have proposed social vulnerability as a new analytical framework for natural disaster risk assessment and management research (Fuchs *et al.*, 2012; Wolf, 2012; Yoon, 2012). There are various concepts and definitions of social vulnerability. Cutter and Emrich (2006) defined social vulnerability as the limitations of a community with regard to the impact of natural disasters that influence its ability or resilience in the effort to recover from their impact. Social vulnerability is a preexisting condition for communities, irrespective of the type of hazard (Cutter and Finch, 2008). Holand and Lujala (2011) considered social vulnerability as having two distinct parts: socioeconomic vulnerability and built environment vulnerability. In this research, social vulnerability refers to the propensity or predisposition of exposed elements such as human beings and their livelihoods and assets to suffer adverse effects from the impact of hazard events.

In the last decade, a considerable body of research on social vulnerability has emerged, and many scholars have applied the paradigm of social vulnerability to natural hazards across different spatial and temporal scales (Cutter *et al.*, 2003; Cutter and Finch, 2008), in different states and regions (Lee 2014; Siagian *et al.*, 2014) and to both comprehensive natural disasters and specific disaster events (Kuhlicke *et al.*, 2011; Tate, 2012). In China, research on social vulnerability to natural hazards is at its starting point (Ge *et al.*, 2006; Chen *et al.*, 2013). In recent years, scholars have begun to discuss the paradigm of social vulnerability to hazards, and the connotations and basic research propositions of social vulnerability have been examined (Zhou, 2012). Scholars have proposed different index systems and evaluation methods for social vulnerability, and have carried out empirical studies on different areas (Shi *et al.*, 2009; Tan *et al.*, 2011; Ge *et al.*, 2013; Huang *et al.*, 2013), but these have either been restricted to specific regions or types of natural hazard. Compared with the other hazard research areas, the current research theories and methods of social vulnerability are not yet mature. In particular, the social vulnerability of China is still poorly understood.

The purpose of this study is to establish a Social

Vulnerability Index (SoVI) for natural disasters that considers the current social and economic development situation of China on a local scale in the Beijing-Tianjin-Hebei Region. This study will enrich the theory and case studies of domestic social vulnerability research, and also provide a reference basis for hazard prevention and mitigation policy for the Beijing-Tianjin-Hebei Region.

## 2 Materials and Methodology

### 2.1 Study area

In this study, 140 counties from Tangshan, Chengde, Baoding, Langfang, Zhangjiakou, Qinhuangdao, Cangzhou and Shijiazhuang in the Beijing-Tianjin-Hebei (B-T-H) Region were selected as the basic unit of analysis (Fig. 1). The B-T-H Region has an important position in Chinese economic development: it is the country's political and cultural center, and it is the economic center of the northern China. In 2012, the region accounted for 9.99% of the entire country's GDP, and for 5.4% of the national population. The B-T-H Region is also an area which faces a variety of natural hazards every year including droughts, typhoons, and earthquakes, *etc.* In the B-T-H Region, the highly concentrated population

distribution pattern and intensive high-rise buildings mean that the region faces the double stress of internal and external, and shows the typical characteristics of a regional natural disaster system such as diverse natural hazard types that frequently occur with obvious anthropic factors and the influence of man-made amplification on disasters. Once natural hazard events occur, significant disaster impacts on the region will be unavoidable. An example is the urban rainstorm that took place on 21 July 2012, in which 79 people were killed and  $1.602 \times 10^8$  person were affected by the floods at a cost of around  $1.164 \times 10^{10}$  yuan (RMB). Disaster prevention and mitigation is a very urgent task.

### 2.2 Methods

#### 2.2.1 Generic social vulnerability assessment approach

There is an argument in academia about whether the social vulnerability varies for different hazards. Some scholars strongly argue that social vulnerability differs when different natural hazards are faced; in other words, social vulnerability is hazard-dependent. Because the aetiological characteristics of hazards may affect social vulnerability, social vulnerability studies should consider the context of the type of natural hazard. For example, the quality of housing will be an important

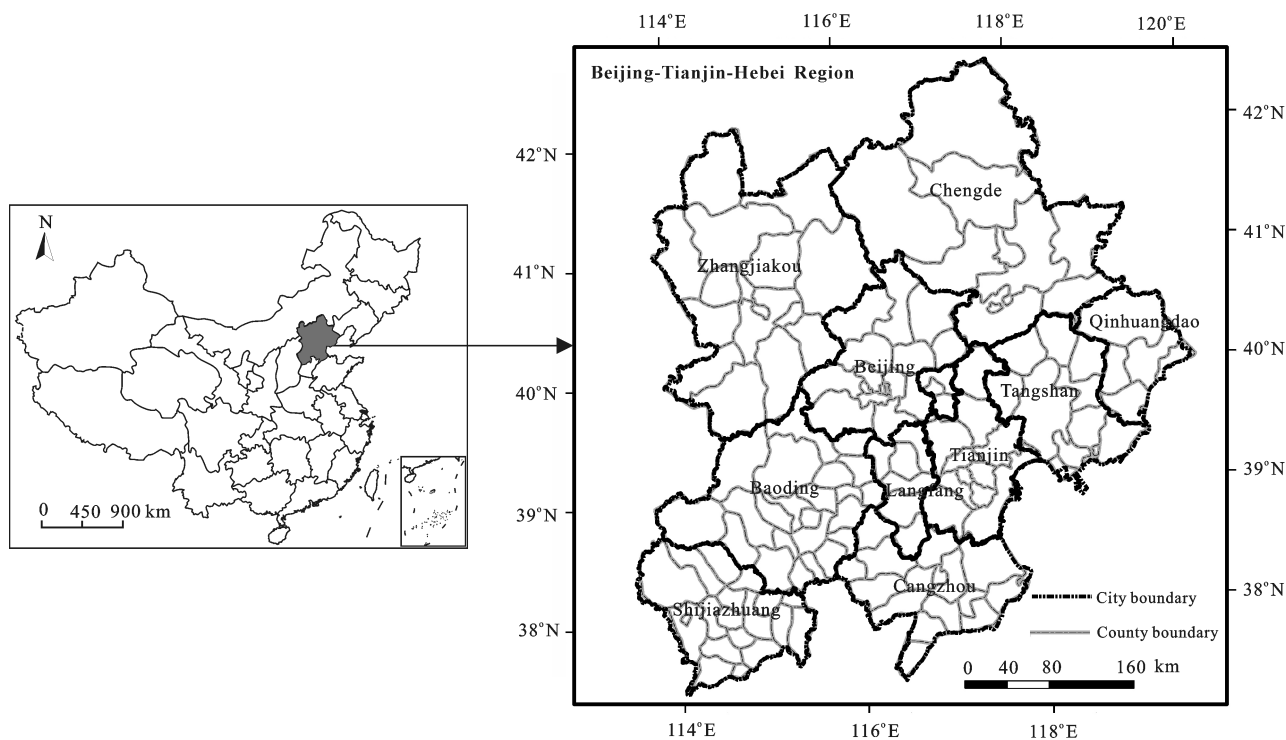


Fig. 1 Location of study area

determinant of a community's vulnerability to floods, but it is less likely to influence its vulnerability to drought (Adger, 2006). Some studies of social vulnerability to specific natural hazards have been carried out, such as to floods, heat waves, hurricanes and so on (Kuhlicke *et al.*, 2011; Tate, 2012). Although researchers have proposed different indicators aimed at specific hazards, it is easy to find that many of the selected factors are common, except for a few indicators which are strongly related to a specific hazard. In view of this, other scholars have taken a different perspective, emphasizing that the main sources of social vulnerability originate from certain specific traits in human society such as poverty, age, nationality, health status, income and other factors; moreover, these traits are not affected by the changes in the types of natural hazards, as they are vulnerable to any type of natural hazard; namely, social vulnerability is a preexisting condition of existing communities, irrespective of the type of hazard (hazard-independent). A generic social vulnerability assessment model was proposed by Cutter and Finch, 2008. In fact, generic social vulnerability has the advantage of providing an overall assessment of the social vulnerability to natural hazards in a relatively simple way by considering the circumstances of the region or people that are subject to different kinds of natural hazards, which also have complex interactions such as the effects of a natural disaster chain. Sometimes, it is not possible to be explicit about the social vulnerability to a specific hazard, but researchers can use the generic social vulnerability assessment to provide the government or the public with a holistic view of their social vulnerability to natural hazards. Thus, this paper adopts the generic social vulnerability approach.

### 2.2.2 Evaluation index system

The factors that influence social vulnerability range from the characteristics of individuals (age, race, health, income, dwelling, employment) to the attributes of whole communities or regions (population growth, urbanization, economic vitality, robustness of the built environment, quality of infrastructure). Due to its multidimensionality, there is no single measure that covers the whole spectrum of how social vulnerability may be manifested. However, Cutter *et al.* (2003) established an approach for quantifying social vulnerability. They applied a large number of measurable variables, each of which indicates a facet of communities' vulnerability to

natural hazard shocks. We used the same approach, adapted for the Beijing-Tianjin-Hebei regional context, to identify the factors that make B-T-H Region socially and economically vulnerable to natural hazards, and to calculate vulnerability index scores for each county. Using Borden *et al.*'s (2007) approach, the social vulnerability concept was considered to consist of two distinct parts: socio-economic vulnerability, which is characterized by aspects such as living conditions and population structure; and built environment vulnerability, which is measured by factors such as population density, the quality and magnitude of infrastructure, and the number of exit routes. This approach has two benefits: firstly, merging both aspects into one index may mask significant local vulnerabilities if a municipality scores highly on only one of the two; secondly, having two vulnerability indices has policy implications in that strategies to reduce vulnerability can be chosen according to the type of vulnerability that is relevant to a given region. Following scientific, comprehensive, accessible and dynamic principles, and taking into account relevant research results (Holand and Lujala, 2011; Chen *et al.*, 2013; Siagian *et al.*, 2014), the indices of social vulnerability to natural hazards were constructed, as shown in Table 1.

### 2.2.3 Analysis methods

The performance of social vulnerability in relation to natural hazards is multifaceted, and the interaction between the various factors are overlapping and layered, so social vulnerability requires various accurate descriptors, and the variables should be factors that are subject to effective, comprehensive and integrated analysis. Factor analysis is dependent on several variables that can be studied by intracorrelation matrix (or covariance matrix) relationships, and by finding several random variables which can integrate all variables. These random variables can not be measured: commonly they are referred to as 'factors'. Then, according to the correlation of the variable packet size, the correlation of variables within the same group is higher than that of variables in different groups. Factors are unrelated, and all variables can be expressed as a linear combination of common factors (Cutter *et al.*, 2003; Holand and Lujala, 2011). The purpose of factor analysis is to reduce the number of variables by using several factors to replace all the variables, which enables complex problems to be analysed. Therefore, factor analysis

**Table 1** Indicator system of social vulnerability to natural hazards

Objective	Principle	Indicator
Social vulnerability to natural hazards	Socio-economic vulnerability index (SeVI)	Urbanization level (%)
		Total retail sales of consumer goods per household (yuan (RMB))
		Beds in medical institutions per 1000 person
		Telephones per 100 household
		Per capita deposits of residents (yuan (RMB))
		Proportion of total population aged 0–14 (%)
		Demographic dependency ratio
		Proportion with tertiary education (%)
		Average years of schooling (years)
		Illiteracy rate (%)
		Proportion of employment in primary industry (%)
		Out-migration (%)
		Ratio of population without labor capacity (%)
		Proportion in rented housing (%)
		Proportion of tertiary industry (%)
		GDP per capita (yuan (RMB))
		Average wage or urban collective-owned units (yuan (RMB))
		Per capita income (yuan (RMB))
		Fiscal balance ratio (%)
		Sex ratio (%)
		Minority population proportion (%)
		Ratio of urban and rural residents receiving minimum living allowance (%)
		Proportion of low-income families (%)
		Average population size per household
		Proportion of population with disability (%)
		Natural population growth rate (%)
	Built environment vulnerability index (BEVI) model	Unit area total investment in fixed assets (yuan/km <sup>2</sup> )
		Ratio of construction land use
		Population density (people/km <sup>2</sup> )
		Serviced area per community service center
		Proportion of household buildings (%)
		Proportion of gross floor area (%)
		Industrial output (yuan/km <sup>2</sup> )
		Number of rooms per household
		Per capita housing area (m <sup>2</sup> )
		road density (km/km <sup>2</sup> )
		Per capita road length (m)
		Proportion of reinforced concrete housing (%)
		Proportion of brick structure housing (%)

can be used to present the complex social features of an area's social vulnerability to natural hazards. The calculation procedures for factor analysis are detailed in

Holand and Lujala (2011). By using the factor analysis, we can identify and interpret the underlying common factors of social vulnerability, but we are equally inter-

ested in calculating vulnerability scores for each county. For this purpose we use factor score weights created in a factor analysis process which are analogous to coefficients in multiple regression analysis. We assign a positive score when the resulting factors in question increases total vulnerability and a negative score when it decreases it. In cases in which both the high and low values have a positive effect on the overall vulnerability, the absolute value of the factor score is used. After adjustment, following Cutter *et al.* (2003), we summarize the resulting values for each municipality to attain a total vulnerability score using an additive model and attaching no weights to individual factor scores. Each score thus has an equal contribution to the overall vulnerability score.

### 3 Results and Analysis

#### 3.1 Extraction and recognition of social vulnerability factors

Using factor analysis, we extracted the main social vulnerability factors from the socioeconomic aspect and the built environment aspect, respectively (Table 2). There were four factors for the socioeconomic aspect with eigenvalues greater than 1, explaining 77.58% of the total variance; the built environment dimension had three factors with eigenvalues greater than 1, explaining 82.71% of the total variance.

##### 3.1.1 Socioeconomic aspect

Table 3 shows that Factor 1 of the socioeconomic aspect, which explains 39.88% of the variance, reflects the strongly positive effects of variables for the level of urbanization of the area, total retail sales of consumer goods per household, per capita deposits of residents, average years of schooling and housing rent proportion, while there is also a significantly positive effect for beds in medical institutions per 1000 persons and telephones per 100 households. However, the demographic dependency ratio, the proportion of the population aged 0 to 14,

the proportion of employment in primary industry and the illiteracy rate have a strongly negative effect. Overall, these indicators describe the structure of regional social development at the macro-level; thus, this factor was named the structure of social development factor, and the items contributing to this factor are indicative of a negative effect on social vulnerability and of the region's resistance: the higher the score is, the lower the social vulnerability. Factor 2, which explains 16.91% of the variance, represents significant positive effects for regional GDP per capita, the average wage or urban collective-owned units, per capita income levels, and fiscal balance ratio. This factor describes the regional power of economic and government finances and is named, the 'economic power and government financial factor', and it also has a negative effect on regional social vulnerability. Factor 3 explains 12.44% of the variance and relates to the significant impact on the ratio of urban and rural residents receiving minimum living allowance (low-income family proportion, the proportion of minorities, sex ratio). This factor can be summarized as the 'social justice and poverty factor'. This factor has a positive effect on regional social vulnerability. Factor 4 explains 8.36% of the variance, and is related to having a higher proportion of the loading on the average population size per household, the natural population growth rate and the proportion of population with disability. Thus, it can be summarized as the 'family structure factor', which has a positive effect on regional social vulnerability.

##### 3.1.2 Built environment aspect

Factor 1, which explains 46.70% of the variance in the built environment aspect, is related to a significant positive impact on the region's population density, the proportion of construction land, the proportion of the construction area, the density of fixed asset investment, serviced area per community service center and other indicators (Table 3). These indicators describe the regional development intensity, and the factor can be summa-

**Table 2** Variance contribution percentages of social vulnerability factors

Socio-economic aspect	Eigenvalue	Variance contribution rate (%)	Cumulative variance contribution rate (%)	Built environment aspect	Eigenvalue	Variance contribution rate (%)	Cumulative variance contribution rate (%)
Factor 1	10.37	39.88	39.88	Factor1	6.07	46.70	46.70
Factor 2	4.40	16.91	56.78	Factor2	3.11	23.90	70.60
Factor 3	3.23	12.44	69.22	Factor3	1.58	12.11	82.71
Factor 4	2.17	8.36	77.58				

**Table 3** Factor loadings for social vulnerability

Socio-economic aspect	Main factor				Built environment aspect	Main factor		
	Factor 1	Factor 2	Factor 3	Factor 4		Factor 1	Factor 2	Factor 3
Urbanization level	0.878				Unit area total investment in fixed assets (yuan/km <sup>2</sup> )	0.940		
Sex ratio			0.766		Ratio of construction land use	0.918		
Average population size per household				-0.846	Population density	0.969		
Proportion of tertiary industry	0.736				Serviced area per community service center	0.959		
GDP per capita		0.815			Number of rooms per household housing		0.924	
Average wage or urban collective-owned units		0.664			Per capita housing area		0.976	
Total retail sales of consumer goods per household	0.720				Proportion of reinforced concrete housing	0.559		0.630
Ratio of urban and rural residents receiving minimum living allowance			0.750		road density (km/km <sup>2</sup> )		0.932	
Proportion of low-income families			0.784		Per capita road length		0.510	
Proportion of population with disability				0.713	Proportion of household buildings	0.706		
Beds in medical institutions per 1000 persons	0.686				Proportion of gross floor area	0.972		
Telephones per 100 household	0.552				Proportion of brick structure housing			-0.872
Per capita income		0.739			Industrial output (yuan/km <sup>2</sup> )	0.833		
Fiscal balance ratio		0.696						
Per capita deposits of residents	0.766							
Proportion of total population aged 0–14	-0.826							
Demographic dependency ratio	-0.806							
Proportion with tertiary education	0.845							
Average years of schooling	0.858							
Illiteracy rate	-0.642							
Proportion of employment in primary industry	-0.750							
Minority population proportion			0.620					
Out-migration	0.844							
Ratio of population without labor capacity	-0.863							
Natural population growth rate				-0.513				
Proportion in rented housing	0.882							
Influence of social vulnerability	-	-	+	+			-	-

Notes: rotated loading, loadings of less than 0.5 are not listed. A positive sign ('+') indicates the factor has a positive effect on social vulnerability and a negative sign ('-') indicates a negative effect, while '||' means that both the high and low values have a positive effect on social vulnerability

rized as intensity of space development. This factor has a bidirectional impact on regional social vulnerability: first, due to a large population concentraion, the effect of the high intensity of human activities on the destruction of the regional natural ecosystem and the high regional spatial development intensity caused by irrational development will exacerbate regional social vulnerability; second, if the intensity of the development of the construction area is too low, and the area lacks the ef-

fective infrastructure to respond to natural disasters, this will also promote the social vulnerability of the region. Thus, a moderate strength of development and construction could reduce the social vulnerability to natural disasters. Factor 2 explains 23.90% of the variance; it is related to the variables for significant impact on the per capita housing area, the average number of household dwelling rooms, road density, per capita road length and other indicators. This factor explains the housing condi-

tions and traffic status; it is negatively correlated with social vulnerability, and is named 'residential and housing transportation factor'. Factor 3, which explains 12.11% of the variance, directly reflects the regional housing construction quality. It is named the 'building structure factor', and has a negative effect on regional social vulnerability.

### 3.2 Analysis of social vulnerability factors

#### 3.2.1 Socioeconomic aspect

##### (1) Structure of social development

Figure 2a shows that for the comprehensive structural social development factor, prefecture-level cities, urban areas of municipalities and some peri-urban areas have scores that are 0.5 times greater than the SD. However, most downtown areas have factor scores that are 1.5 times greater than the SD. This is because the downtown areas represent the core of regional socioeconomic development and their overall development levels are greater than the surrounding areas. However, some eastern areas have factor scores that are 0.5 times less than the SD. Most of these areas are plains, and the proportion employed in primary industry is higher than that in the northwestern mountainous area. In addition, the population in areas with less employment has a negative impact on this factor, and there is a remarkable consistency between the areas with a low value for this variable and the areas that have a high proportion of population with a disability. For example, the proportion of the population with a disability in Luannan County and Leting County of Tangshan, Miyun District and Pinggu District of Beijing are high. Overall, most areas have factor scores from  $-0.5$  to  $0.5$  SD, which indicates that they are at the moderate level of socioeconomic development and display an obvious distribution pattern of 'northwest higher, southeast lower'.

##### (2) Level of economic and government financial strength

In Fig. 2b, there are four areas' (Binhai New Area, Chaoyang District, Shunyi District, Manchu Autonomous County) with a factor score of 1.5 times more than SD. The economic and technological development zones of these areas are relatively more concentrated and these areas have high levels of economic activity. This factor reflects the regional government's financial status, and the factor is significantly higher in the eastern region

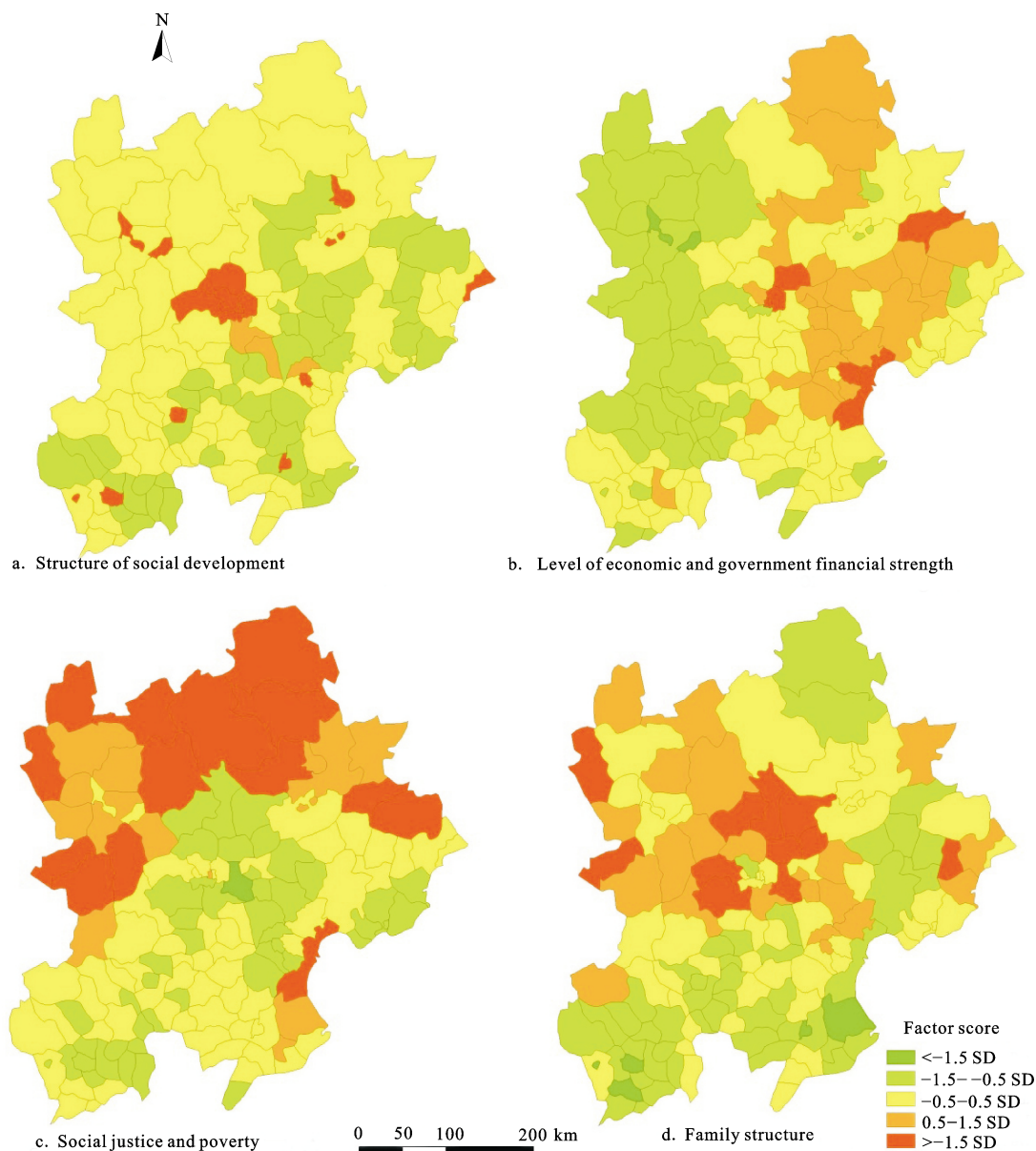
than in the western mountainous areas. This factor shows an opposite trend to the integrated social development factor, indicating that economic development can not reflect the regional development level. In the eastern more developed regions, the factor scores for the structure of social development are lower, which means that rapid economic development has not brought about a corresponding increase in the level of social development.

##### (3) Social justice and poverty

Figure 2c shows that factor scores of greater than  $0.5$  SD are mainly found in the northern part of the region, which is because the northern mountainous areas have problems of poverty and the distribution of minority concentration areas. Regarding poverty, the proportion of residents of the minimum subsistence guarantee accounted for 30% in the northern region of Kangbao, Guyuan and Chicheng of Hebei Province. In comparison, the factor scores for the central and southern areas are low; for example, the factor scores for most areas of Beijing is less than  $0.5$  SD, which means that overall poverty in the area is less prominent, but it is worth noting that the downtown factor scores are relatively high, indicating that poverty in the old town community is quite serious.

##### (4) Family structure

The family structure factor shows a pattern of 'higher in the middle, lower in the north and south'. Urbanization has developed rapidly in the middle area and, due to the influence of fast-paced social and economic development. The family structure shows a trend towards simplification of family structure with multigenerational phenomenon gradually reducing. Therefore, the reduction in natural population growth rate and smaller family size result in higher factor scores for this region. If a natural disaster occurs, this simple combination of family structure would have a higher social vulnerability because, with fewer family members, the family would face a major crisis in the event of casualties. Another reason is that family members in this situation would have less help and there would be fewer collaboration opportunities within the family; thus, they lack the ability to cope with hazards and achieve recovery afterwards. In addition, the factor for family structure has an important effect on the indicator of the regional proportion of disabled people, which is the reason why counties such as Yangyuan, Shangyi and Lulong have higher scores.



**Fig. 2** Spatial pattern of socioeconomic vulnerability in Beijing-Tianjin-Hebei Region

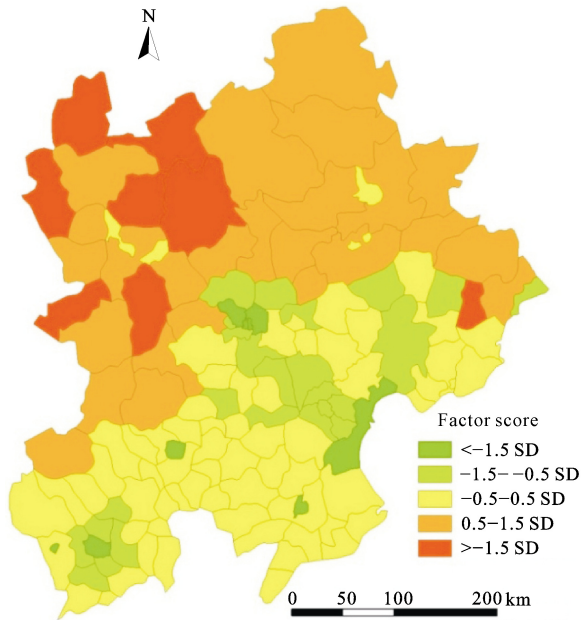
The above factors describe the characteristics of the regional socioeconomic aspect of social vulnerability. In this study, the integrated scores of the socioeconomic aspect of the B-T-H Region were obtained by using the unweighted sum method (Fig. 3). Overall, the region's socioeconomic factor scores showed a significant trend in its characteristics from northwest to southeast, which means that the social vulnerability of the northwestern mountainous area is higher than the southeastern plains. Moreover, the main low value area (less than  $-0.5$  SD) is concentrated in Beijing, Tianjin and Shijiazhuang, which have a higher level of socioeconomic development.

The region's socioeconomic vulnerability scores reveal a tendency to increase from the central city areas to the spheres of the surrounding suburban counties. The vulnerable regions with higher scores (greater than  $1.5$  SD) are mainly in the mountainous counties in Zhangjiakou City. Subject to natural conditions, these areas have low levels of socioeconomic development, which results in high social vulnerability; thus, they are key areas of natural disaster prevention and mitigation in future.

### 3.2.2 Built environmental aspect

#### (1) Intensity of space development

The score for the space development intensity factor has



**Fig. 3** Comprehensive scores for socioeconomic vulnerability in Beijing-Tianjin-Hebei Region

clearly polarized properties (Fig. 4a). The highest scores of over 1.5 times the SD is highly concentrated in the areas of Beijing, Tianjin and Shijiazhuang. These three areas have a huge population and they are industrial with higher space development intensity. On the other hand, the eastern and northern mountainous area has lower space development intensity due to its environmental constraints and economic problems. Most scores are in the middle levels, ranging from  $-0.5$  to  $0.5$ . The space development intensity is a double-edged sword when it comes to social vulnerability: areas which have high space development intensity such as Beijing, Tianjin, have increased exposure and sensitivity to natural disasters, which leads to an increase in the social vulnerability of the areas; however, less developed areas such as the northeastern region lack development, which results in the warning and rescue systems for such areas being much worse than in the developed areas. Therefore, the lack of insufficient capacity leads to higher social vulnerability.

### (2) Residential housing and transportation

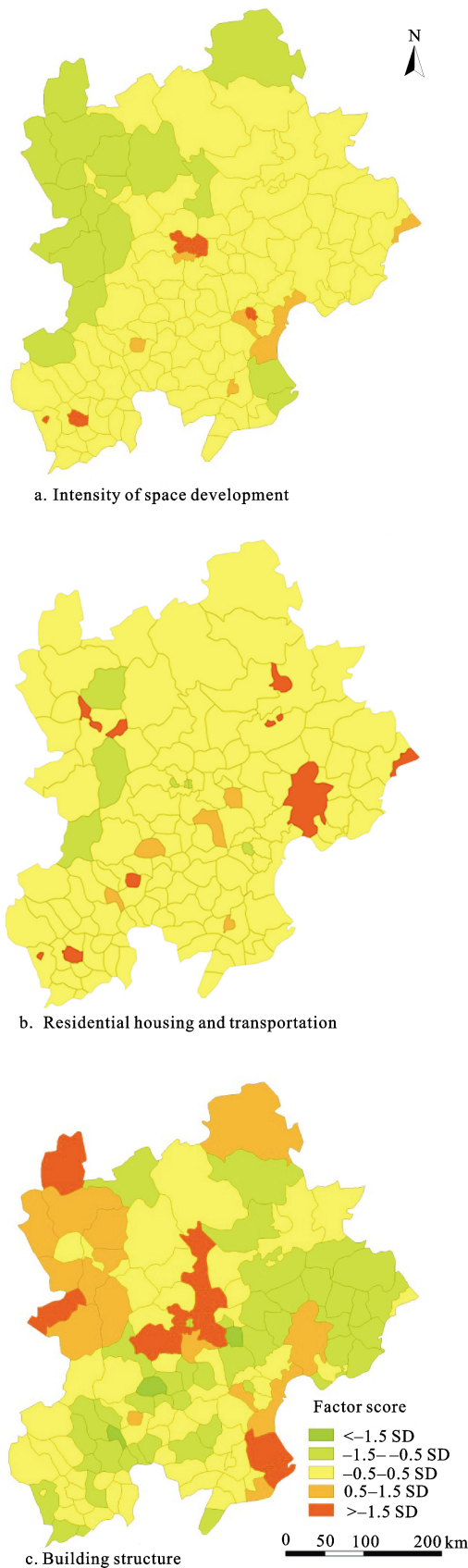
The housing and transportation factor has a clear polarizing characteristic as well, as Fig. 4 shows. Housing and transportation is better in the second-order cities areas such as Shijiazhuang, Tangshan, Zhangjiakou, and Chengde where the housing and transportation factor is greater than 1.5 SD. Conversely, the area with a high

space development intensity factor only has a housing and transportation factor of less than  $-0.5$  SD. This indicates that the housing and transportation conditions in these areas are very bad, especially in the inner city areas, where there are many old houses in adverse environmental settings. In these areas, the density of transportation is high; however, while the average transportation per person is low, the travel cost is higher, which lowers the overall score. Most places within the entire region have scores falling within the range of  $-0.5$  to  $0.5$  SD, which show that the general conditions of housing and transportation are good.

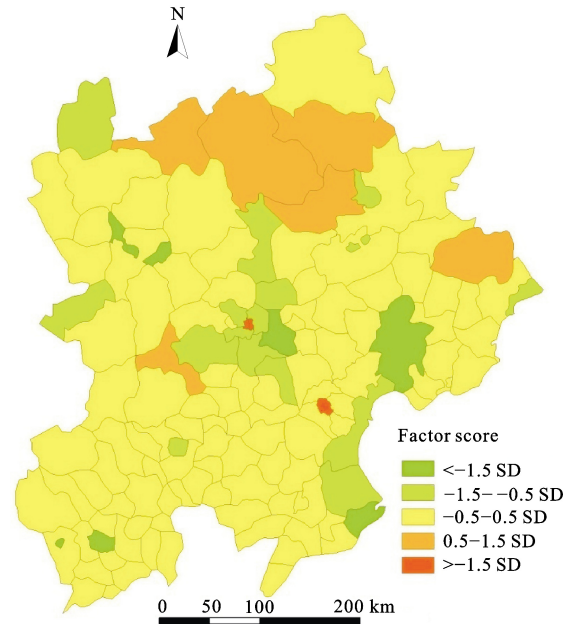
### (3) Building structure

The construction structure factor in the B-T-H Region has discrete features, and near the suburbs of Tangshan there is one focal area with low scores (factor value in the range  $-0.5$  to  $-1.5$  SD)(Fig. 5). More attention should be paid to this phenomenon because, for example, in the huge historical earthquake disaster that occurred in Tangshan in 1976 the centre of the earthquake was the city centre. After several decades of rebuilding after the earthquake, the quality of the buildings in the inner city has improved significantly. But around the city, the building quality is much lower than in Tangshan itself due to the overall lack of development. In the case of Beijing, the situation is the opposite, as it appears that construction structure quality gets better going outwards from the city centre to the outside of the city. The reason for this is that the main buildings in the city centre are old and the area includes many protected areas with large numbers of historic buildings. However, the suburbs of the city have mostly new high quality buildings. Because there are two earthquake belts sited in the B-T-H Region, it faces potentially serious natural disasters including earthquakes, as a result of which the government has to pay more attention to the construction structure quality and the prevention of earthquake disasters.

By using same method that combines socioeconomic vulnerability factors, the overall built environment vulnerability is found and its particular distribution can be analysed. In general, most of the area's environment vulnerability factors are around  $-0.5$  SD, and the overall built environment vulnerability is in the middle range. The two areas with the highest built environment vulnerability values are, firstly, the Beijing and Tianjin area, which is due to the high population and high space



**Fig. 4** Spatial pattern of built environment vulnerability in Beijing-Tianjin-Hebei Region



**Fig. 5** Comprehensive scores for built environment vulnerability in Beijing-Tianjin-Hebei Region

development intensity that results in an increased built environment vulnerability level. The second area is distributed in the mountainous region of the north, which is due to the effect of the low strength of development and the poor housing conditions compared to other places; therefore, the built environment vulnerability level in this area is high. There are also two further areas with the particularly low built environmental vulnerability factor scores: the small city around Beijing, and the Binhai New Area. These areas have high development intensity, but the housing and transportation conditions and construction quality are better than those in the city center, so the social vulnerability is lower. Other places with lower built environment vulnerability factors are distributed in the areas of the second-order cities such as Shijiazhuang.

### 3.3 Analysis of social vulnerability to natural hazards in Beijing-Tianjin-Hebei Region

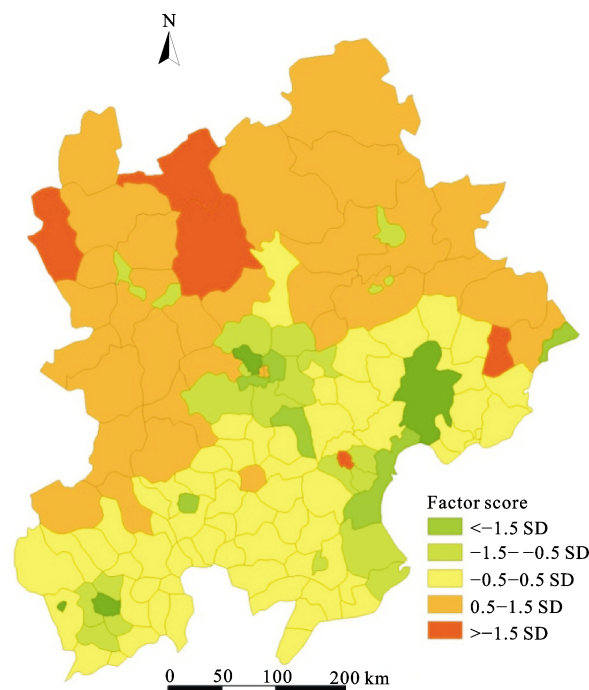
By using the mean weighted sum of the socioeconomic vulnerability and the built environment vulnerability factors, the results of the social vulnerability to natural hazards are achieved (Fig. 6). In general, the areas of social vulnerability to natural hazards are divided into a west-north and east-south structure, which fits with the region's social and economic development structure. The west-north mountainous area has had slow eco-

conomic development due to its natural conditions, and its overall social vulnerability level is higher than that of the east-south region. However, the economic development level is not proportional to the natural hazards social vulnerability. This can be illustrated by the areas around Beijing and Tianjin, which have a low level of social and economic vulnerability, but the high population and density of the economy increases the level of built environment vulnerability, which increases the area's overall level of social vulnerability to natural hazards. This indicates that highly developed areas do not necessarily have a low social vulnerability, since achieving a high efficiency of development can cause huge unfairness in terms of poverty, inequity and so on. This counteracts the positive effect of economic development, and increases social vulnerability. By comparing these factors, areas with low levels of social vulnerability are mainly distributed in the suburbs of Beijing and Tianjin, as well as other second-order cities. These areas have a relatively moderate population and economic density and, at the same time, a higher income level, good medical conditions and so on. Within their communities there are less differences, thus their overall social vulnerability is low.

Table 4 shows that, according to their level of social vulnerability to natural hazards, most areas are in the middle vulnerability levels (49.61% of areas), but the number of units with a high level of vulnerability accounts for 24.81% of areas, indicating that the region's social vulnerability is a universal phenomenon. In the current situation, the social vulnerability of these areas is not very serious, but if the social vulnerability of these areas were to deteriorate it would undoubtedly result in significant losses in these regions. So from the long-term perspective, the Beijing-Tianjin-Hebei Region faces the challenging task of reducing social vulnerability to natural hazards.

#### 4 Discussion and Conclusions

An understanding and evaluation of social vulnerability



**Fig. 6** Comprehensive scores for social vulnerability in Beijing-Tianjin-Hebei Region

to natural hazards are necessary to ensure that policy makers can develop mitigation and adaptation policies. In this study, we explored the different characteristics, types and impact factors behind social vulnerability to natural hazards at the county level of the B-T-H Region from both the socioeconomic and built environment aspects. The results indicate that the social vulnerability to natural hazards in the B-T-H Region shows a pattern of 'high in the northwestern area, low in the southeastern area'; in other words, the level of social vulnerability in the northwestern mountains is significantly higher than the southeastern plains. The areas with lower levels of social vulnerability are mainly concentrated in peripheral urban areas to city centres of the prefecture-level cities of Beijing, Tianjin and Shijiazhuang. This indicates that highly developed core city centre areas do not necessarily have a low social vulnerability, as achieving a high efficiency of development has also caused huge unfairness with poverty, inequity and so on.

**Table 4** Grades for social vulnerability to natural hazards according to SD

Grades for social vulnerability	Very weak (<-1.5 SD)	Weak (-1.5 to -0.5 SD)	Moderate (-0.5 to 0.5 SD)	Strong (0.5 to 1.5 SD)	Very strong (>1.5 SD)
The number of (a)	9	19	64	32	5
Proportion (%)	6.98	14.73	49.61	24.81	3.88

Notes: a represents unit of analysis

The mechanism explaining how these factors influence vulnerability and the associations among them are complicated and still not clear. Thus, there is an argument about the relative contributions of the variables used to define social vulnerability. Some researchers have chosen not to weight variables differentially to allow for dissimilar effects (Cutter *et al.*, 2000), while others have explored distinctive weighting schemes designed to reflect variations in importance, such as factor analysis, analytic hierarchy process and the expert scoring method (Brooks *et al.*, 2005). Some scholars have proposed a method to test the stability of the different weighting methods (Schmidtlein *et al.*, 2008). In order to test the stability and the validity of the results, we constructed a simple test. We compared three vulnerability assessment results from two methods: the weighted mean and weighted variance in the Social Vulnerability Index. The purpose of the quantitative assessment of social vulnerability to natural hazards was to decide the order of the social vulnerability level, and consequently to identify the highly vulnerable regions. Therefore, it was necessary to compare the two results using Spearman's rho. The analysis shows that the correlation coefficient is 0.717 and this is significant at the 0.01 level. Thus, the two models of social vulnerability assessment have relative consistency. This also shows that the social vulnerability system constructed by this research and the assessment methods applied in this study have relatively good robustness.

With regard to the reliability of the assessment, the frequency of natural disasters in the region was used to indirectly reflect the level of social vulnerability, due to the lack of specific data on the hazards of some counties and cities of the B-T-H Region. In general, if the area has experienced a higher frequency of natural disasters it also, to some extent, shows that the region has a high social vulnerability to natural hazards, which could then be used to indirectly verify the effectiveness of the evaluation results. The frequency of natural disasters occurring in the northeastern area of the B-T-H Region is higher than that in the southwestern area, and the situation is the same for the spatial pattern of social vulnerability. However, this information only concerns the frequency of natural disasters, whereas social vulnerability-related information is more effective in estimating losses caused by natural hazards in actual disasters; thus, the frequency of the occurrences based on the

hazard area only partially explains the pattern of social vulnerability to natural hazards, and there are also inconsistencies in the pattern. However, the regression analysis of the frequency of occurrence of the level of social vulnerability to natural hazards and regional natural hazards found that for the frequency of natural hazards, the weighted coefficient is positive; so in general, the quantitative assessment has relative reliability.

There is no doubt that the vulnerability analysis is the core of hazard risk assessment, but the state of social vulnerability is not easy to measure and observe, and a useful way of testing the effectiveness of a specific quantitative research is lacking, as discussed above. Based on an existing database, this study designed an evaluation index system for the socioeconomic and built environment aspects of social vulnerability to natural hazards. Moreover, an empirical analysis was conducted of the social vulnerability to natural hazards of the B-T-H Region by county-level administrative units. However, the index system for evaluating vulnerability is still not perfect. In this study, we only analysed social vulnerability to natural hazards in the B-T-H Region at the county level, but there are further questions to be considered and the intrinsic mechanisms of the key driving factors of social vulnerability to natural hazards should be further explored: can we make scientific predictions of social vulnerability in the future? How can community-based social vulnerability to natural hazards be assessed? Therefore, a further in-depth analysis should be considered.

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