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The regionalization of urban natural disasters in China

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Abstract An integrated urbanization level (CL) index and an integrated natural disaster intensity (QC) index were developed on the basis of Disaster System Theory and China Natural Disaster Database for integrated urban disaster risk assessment. Integrated quantitative assessments of the urban socio-economic system and the intensity of hazards in China were carried out by the Model-Tupu (map series) and inter-feedback process using digital map technology. On the basis of this assessment, China can be regionalized into three regions, namely, coastal urban disaster region, eastern urban disaster region and western urban disaster region, 15 sub-regions and 22 units. These results can provide a scientific basis for determining a city's disaster risk management and natural disaster relief regionalization in China.

Keywords Integrated natural disaster intensity · Integrated urbanization level · Natural disaster regionalization · Urban disasters in China

1 Introduction

The implementation of the Reform and Opening Strategy by the Chinese government has resulted in China, which is characterized as a developing country, experiencing an accelerated rate of urbanization in association with rapid

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economic development. Within as little as 26 years—from 1978 to 2004—the urbanization level of China has increased from 18 to 41.7% (Shi 2005). According to the ''Urban Development Report of China'' (2003–2004), the urbanization level in China will increase to approximately 75% by the middle of the 21st century; this means that migration from the country to cities will occur at a mean annual rate of approximately 10–12 million people per year (China Association of Mayors 2005). However, most cities in China are located in regions that are extremely vulnerable to a wide range of natural hazards; for example, 60% of Chinese cities currently have flood control standards that are below the national standard (Wang et al. 2004), and 54% of middle- and large-scale cities with more than 500,000 inhabitants are located in earthquake-prone regions (hazard of an earthquake of a magnitude greater than VII; Xu et al. 2004). The risks of these natural hazards in the cities are increasing simultaneously with rapid urbanization. Consequently, regionalization of urban natural disaster provides not only an important knowledge base for disaster risk management but also for urban disaster mitigation, resilience building and sustainable development.

The regionalization of natural disasters generally emphasizes the public emergency response to a single type of disaster (such as flood, landslide, earthquake or drought), (Fotheringham et al. 1995; Rose et al. 2004; Terlien et al. 1995; Wells 1996). However, various researchers have attempted a more integrated approach. Blaikie et al. (1994) proposed a ''Pressure-Release'' model by combining hazards and vulnerabilities to determine risks. Using multiple regression analysis, Chung et al. (1995) drew landslide disaster prediction maps for future time periods (1960–1980) using 40 data indices of the region for the period before 1960. Chinese scholars have also successively conducted research into integrated natural disaster regionalization. Zhang et al. (1992) regionalized China into 45 combinations of typical sub-regions and seven regions according to similarities and differences in terms of the main natural disasters of each typical region. Ma et al. (1994) regionalized China into four disaster regions and 12 sub-regions based on geotectonics and the physiognomy situation of China, while Zhang et al. (1995) regionalized China into six natural disaster regions, 26 natural disaster sub-regions and 93 natural disaster units with the support of the China natural disaster database. Wang and Shi (2000) formed basic spatial units of natural disasters in China by combining the pixels using a bottom-up approach, which were formed by overlapping physical geographical map series and disaster map series. Based on these spatial units, they regionalized China into five regions, 23 sub-regions and 110 units using top-down approaches and subsequently obtained integrated regionalization plans for agricultural natural disasters in China.

The regionalization map of urban natural disaster reported here was based on the basis of the disaster system theory (Shi 1991). The Digital-Tupu method, which combines quantitative and qualitative analysis, was used, assuming urbanization level and integrated intensity of a natural disaster as indices. Although the urban administrative division was chosen as the smallest spatial unit in this research, the integrality of county boundaries and the spatial neighboring relationship between urban agglomerations have been adequately taken into consideration. The result of this research can provide planning strategies for cities in terms of sustainable development and the scientific basis for disaster-reduction policies and relief regionalization.

2 Data

The data used in this paper comes from the China natural disaster database, China urban socioeconomic database and China administrative division map for regional mapping analysis (Table 1). These databases were constructed by the Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education of China, Beijing Normal University. As data sources covering Taiwan Province are inaccessible, the assessment of urban disaster risk in Taiwan is beyond the scope of this paper, and will only be possible in the future when data sharing networks between the Mainland and Taiwan are established.

3 Method

3.1 Regionalization flow

Regionalization is this article is based on the following five principles: (1) emphasis is put on the combination of integrated urbanization level and main natural disaster intensity; (2) precinct of the city is the basic spatial unit for assessment and regionalization of urbanization level; (3) the risks of structural damage are selected for the assessment and regionalization of hazard intensity; (4) both microscopic and macroscopic issues are taken into consideration, such that the east–west differentiation of economy and population are considered to be the primary issue, while urban agglomerations and important traffic corridors are considered to be the subordinate ones; (5) as semi-quantitative and semi-qualitative methods are used in this paper, the regionalization process is not fully digital; thus, prior knowledge has to be employed because digital numbers cannot cover the whole regionalization process.

According to these principles, the process of regionalization of urban natural disasters in China is as illustrated in Fig. 1.

3.2 Index system

The index system consists of two parts: the first describes the integrated urbanization level (CL), and the second describes the integrated urban natural disaster intensity (QC).

The integrated urbanization level consists of indices reflecting urban populations and urban land uses. The former includes the city non-agricultural population (CP) and urban population density (CD); the latter includes city built-up areas (CB), the land integrated transportation capability index (LM) and the urban light index[1] (DT) (Zhuo et al. 2003) (Table 2).

The index system of urban natural disasters in China considers floods, earthquakes, landslides and debris flows, typhoons and sandstorms to be the main hazards in terms of inflicting the largest structural damage to cities and disrupting transportation. Since different hazards have different quantitative indices and

[1] Urban light index is a man-made index representing the spatial distribution and intensity of nighttime lights based on DMSP/OLS data. It provides researchers with an image of lights from settlements at nighttime—as viewed from space. It is believed that the urban light index can be used to demonstrate urbanization level as, generally, large cities are always more densely and intensely lit up at night in comparison to less urbanized areas.

Table 1 Data sources of urban natural disasters in China

Data type	Content	Areas covered	Period	Origin of data
Statistic data of cities in China	City non-agricultural population, city total population, built-up area, land area, GDP	663 cities in China (no data on Taiwan)	2000	China Statistical Yearbook 2001 (China Statistics Press, Beijing)
Natural disaster reduction data in China	Time, place, cause, impact of disasters and the name of reporting journal	Cities and counties in China (no data on Taiwan)	1991~2000	Natural disaster reduction in China
Statistic data at the county level	Total population, land area and GDP	Counties in China (no data on Taiwan)	2000	Social and economic Statistical yearbook of county (city) of China 2001 (China Statistics Press, Beijing)
Maps	Railways, highways, first class roads, province roads	Provinces, cities and districts in China	2000	1:4,500,000 transportation map of China
Remote sensing images	Light index	Provinces, cities and districts in China	1998	DMSP/OLS night average light intensity images in China
Newspaper data for natural disaster in China	Name of the newspaper, published time and place; hazard, affected areas, disaster losses	Provinces, cities and districts in China (no data on Taiwan)	1949~2000	Newspapers from provinces, cities and districts in China
Administrative division map in China	Administrative district boundary: national boundary, province (city or region) boundary, districts boundary and county boundary.	Provinces, cities and districts in China	2000	Administrative Regionalization Brochure 2001 of P. R. China

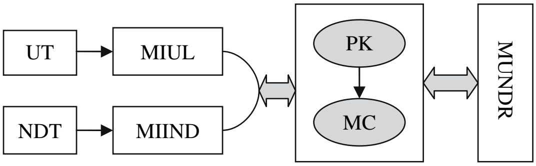

Fig. 1 Urban natural disaster in China regionalization process. *MC* Model construction, *MIIND* map of integrated intensity of natural disaster, *MIUL* map of integrated urbanization level, *MUNDR* map of urban natural disaster region, *NDT* natural disaster Tupu, *PK* prior knowledge, *UT* urbanization Tupu

Table 2 Assessment index system for integrated urbanization level (CL) in China

Urbanization level index	Code	Original data type	Year	Evaluating method
Urban non-agricultural population	CP	Statistic data of 663 cities	2000	Cities are evaluated with true value, while counties are evaluated with "0"
Urban population density	CD			
Built-up area of cities	CB			
Land integrated transportation capability index[a]	LM	Digitized transportation vector map of China (1:4,500,000)	2000	Calculated by counties
Light Index of Cities	DT	DMSP/OLS raster images	1998	Calculated by counties

[a] Land integrated transportation capability index (LM) = [(Length of railways + highways + first class roads + province roads) × buffer area of the road]/unit area. The larger the value is, the stronger the transportation capability could be

dimensions, their intensities are classified independently according to their own regional differentiation revealed by a series of disaster maps (Shi 2003). Each class of each hazard was given a score within the same range (1–7); scores are based on the evaluation of experts (Table 3) and can therefore be used in calculation equations. It is not the absolute values that are rigorous, but the relevant relationship among them as this relationship is needed to demonstrate the spatial differentiations of these natural hazards.

3.3 Assessment and regionalization of integrated urbanization level in China

Due to differences in the urbanization level index dimensions (Table 2), we applied an autocorrelation method (Haining 1990) in our assessment of integrated urbanization level in China. The weights of the indices of urbanization level—CP, CD, CB, LM and DT—are 0.206, 0.195, 0.212, 0.170 and 0.217, respectively, throughout the calculations reported herein. As such, we obtained an integrated urbanization level of each spatial unit and the regionalized map. Maintaining the county integrality in this map of integrated urbanization level index (CL), we divided the integrated urbanization level in China into five levels: strong urbanization, high urbanization, middle urbanization, low urbanization and weak urbanization (Fig. 2).

Table 3 Index system of main urban natural hazards

Hazard	Code	Spatial reference	Index (Code)	Meaning and arithmetic	Classification and evaluation	
Earthquake	D1	Point location	Earthquake magnitude (M_S)	According to Richter magnitude	>6 4~6 <4	7 4 1
Flood	W1	County	Flood frequency (w1_pc)	Mean annual flood times (1949–2000)	>0.15 0.05~0.15 <0.05	7 4 1
Landslide and debris flow	D2	Point location	Point density (d2_md)	The point location density of landslide and debris flow in the district (1949–2000)	dense area sparse area few or no	7 4 1
Typhoon	T	County	Typhoon times (t1_zc)	The total times of typhoon happened (1949–2000)	>28 13~28 1~13 <1	7 5 3 1
Sandstorm	S1	Point position	Sandstorm frequency (s1_pc)	Mean annual sandstorm times (1951–1998)	>15 5~15 1~5 <1	7 5 3 1

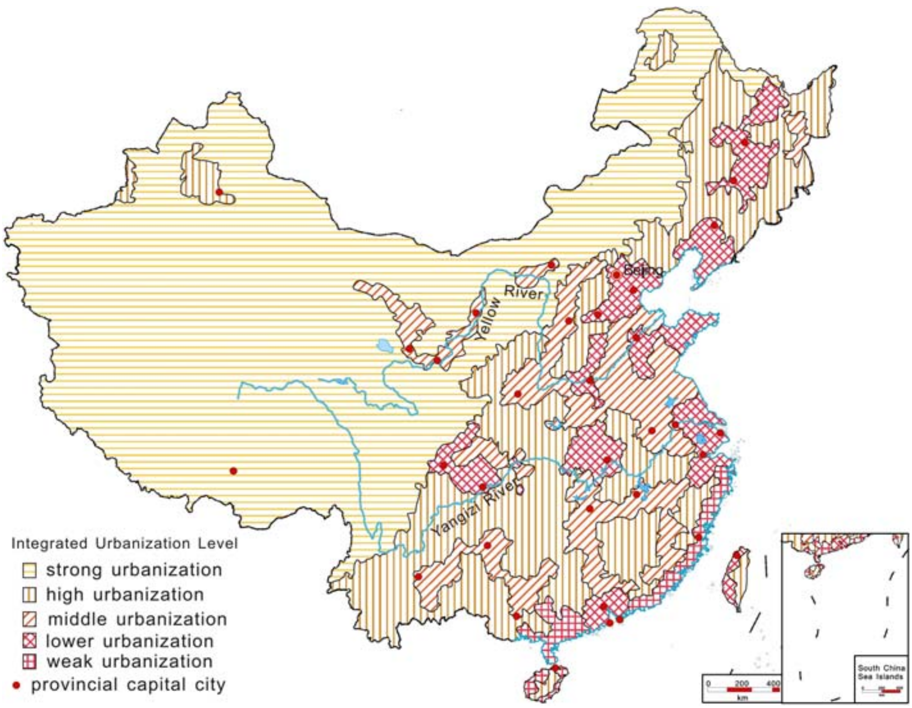

Fig. 2 The regional assessment of integrated urbanization level in China

3.4 Urban natural disaster intensity regionalization and assessment

On the basis of the five ratio classification maps for the five disaster types indices, regional maps of the intensity of the five hazards mentioned above (flood, earthquake, landslide and debris flow, typhoon and sand storm) were separately compiled according to the score of disaster intensity – following unification dimensions and characteristics of the environment. These five maps were then overlaid together, and the major urban natural hazard type-intensity map (L-Q) in China was obtained. Based on the map (L-Q), the integrated quantitative assessment for natural disaster intensity was conducted in following steps.

First, values were assigned to the intensity of regional disasters for use in subsequent calculations (Table 3). Weights were then assigned to five disasters: flood disaster = 0.4, earthquake = 0.2, landslide and debris flow = 0.2, typhoon = 0.1 and sandstorm = 0.1. These weights were not given arbitrarily but just the approximate proportions of the direct economic losses that result from these five disasters, as mined from statistical data from Ministry of Civil Affairs. That is to say, flooding is the first serious disaster in China, inducing mean annual losses that account for approximately 40% of the total mean annual disaster losses; the second serious disaster is earthquake, and so on. Thus, the urban integrated natural disaster intensity (QC) was calculated using the following equation.

$$\mathrm{QC} = qdW1 \times 0.4 + qdD1 \times 0.2 + qdT \times 0.2 + qdD2 \times 0.1 + qdS \times 0.1$$

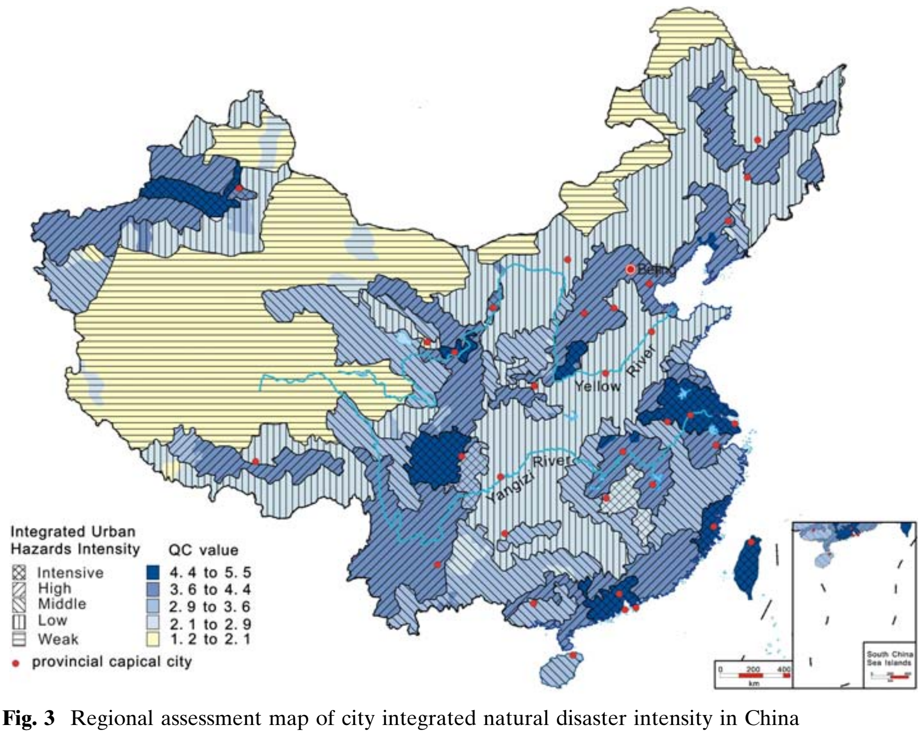

Fig. 3 Regional assessment map of city integrated natural disaster intensity in China

where, $qdW1$ is flood intensity; $qdD1$ is earthquake intensity; $qdT1$ is typhoon intensity; $qdD2$ is landslide and debris flow intensity; $qdS1$ is sandstorm intensity.

In this manner, the assessment map of integrated urban natural hazard intensity in China was compiled (Fig. 3). The integrated natural hazards intensity can be divided into five grades: strong, high, middle, low and weak.

4 Results

In order to reflect urban natural disaster intensity and integrated urbanization level, this paper established an urban natural disaster intensity (QC) and urbanization level integrated index (CL) based on the calculations reported above, where Q is the city integrated natural disaster intensity, denoted on a scale of 1 to 4, which represents the range of QC in the county unit, and L is integrated urbanization level, also denoted on a scale of 1 to 4, which represents the range of CL in the county unit. Finally, indices of all county units in China were combined into 16 kinds (4×4) of QL (Table 4).

Table 4 Integrated index (QL) of urban natural disaster intensity (QC) and urbanization level (CL)

Index grade (QL)	QC range	CL range
1	<2.5	<0.5
2	2.5~3.5	0.5~2.0
3	3.5~4.5	2.0~8.0
4	>4.5	>8.0

Fig. 4 The regionalization of urban natural disaster in China

Table 5 Regional characteristics of the urban natural disaster regionalization in China

ID	Sub-regions' name	Area (km^2)	CL	Main urban hazards (by intensity)			QC	QL
I1	High urbanized disaster region of the Bohai Surrounding area	25.7	7.21	F	E	T	2.73	23
I2	Middle urbanized disaster region of the north Jiangsu area	5.4	3.93	T	F	E	2.91	23
I3	Strong urbanized disaster region of the Yangtze River Delta	7.8	10.80	F	T	E	3.34	24
I4	High urbanized disaster region of Zhejiang and Fujian	7.6	5.87	T	F	E	3.49	23
I5	High urbanized disaster region of the Zhujiang delta	4.1	13.16	F	T	E	3.73	34
I6	High urbanized disaster region of the Lei-Qiong area	6.6	4.52	T	F	E	3.13	23
I7	High urbanized disaster region of Taiwan	3.6	8.35	E	T	F	4.00	34
II1	High urbanized disaster region of Northeastern China	66.0	3.78	F	S	T	2.47	13
II2	Middle-high urbanized disaster region of North China	48.7	4.32	F	E	S	2.78	23
II3	Middle-high urbanized disaster region of Southeastern China	83.0	3.76	F	T	L	2.58	23
II4	Low-middle urbanized disaster region of Southwestern China	136.2	2.18	F	L	E	2.74	23
III1	Low urbanized disaster region Hohhot-Baotou area	7.7	4.18	S	F	E	2.51	23
III2	Low-middle urbanized disaster region of Hexi corridor	13.5	3.85	S	E	F	4.05	33
III3	Low-middle urbanized disaster region of Northern Tianshan piedmont	15.4	3.81	E	S	F	3.63	33
III4	Weak urbanized disaster region of Northwest-Qinghai & Tibet	517.7	0.78	E	S	F	2.88	22

F, Floods; E, earthquakes; T, typhoons; S, sandstorms; L, landslides and debris flow

Based on regional differences in 16 kinds of QL above, three regions were defined by macroscopically considering regional differences between economic development levels of eastern, middle and western China. Fifteen sub-regions were defined to show the similarities in the combination of disaster types. Twenty units were defined by specifically dividing the eastern region to show high areas of high urban agglomeration and integrated indexes (Fig. 4, Table 5).

5 Conclusions and discussion

This paper employed an integrated method in which the Integrated Urbanized Level (CL) Index and Integrated Natural Disaster Intensity (QC) Index, representing the urban socioeconomic system and the risk of natural hazards, respectively, were used to reveal the regional differentiation of urban natural disasters of China. Based on a Model-Tupu and inter-feedback process and according to regionalization principles, these regional differentiations of urban natural disasters were regionalized into three regions, namely the coastal urban disaster region, eastern urban disaster region and western urban disaster region, 15 sub-regions and 22 units.

Urban natural disasters regionalization in China primarily indicates the difference between the western and eastern parts of the country, where the spatial distribution of population and economy plays a more important role. Based on this regional perspective, the major natural disasters have occurred in the eastern and coastal areas of China, particularly along the southeast coast, whereas the occurrence of natural disasters was much less frequent in the western area. According to east–west differentiation, the risk of urban natural disasters in China shows a secondary north–south spatial differentiation. This is mainly due to the spatial differentiation of natural hazards, which is determined by the characteristics of Chinese physical geography which, in turn, is mainly affected by latitudinal zonality.

The results of this study can be helpful in the planning for national disaster mitigation and spatial development. On the one hand, this regionalization map shows the most disaster-prone areas and hotspots in China, which can be of use to disaster mitigation-related authorities; for example, the coastal region of China is both the most highly developed area as well as the area most vulnerable to the effects of natural hazards area. The implication, therefore, is that this coastal region should be given priority for disaster mitigation and resilience building. On the other hand, this regionalization map is essential for good regional development planning. If we accept the consequences of the regionalization map, regional and urban development at the national scale should avoid the high risk area as much as possible, while at the regional scale the government should adjust its industry structure to adapt to various regional disaster features; in addition, industries already established in the high risk area should be prepared to increase their disaster coping capacity; i.e., to reduce their vulnerability.

The regionalization of urban natural disasters is a relatively complicated process because a disaster is a complex and coupled human-environment system. The researchpresented herein has tried to find a solution that will integrate these factors and in doing so provides a number of insights. However, several aspects still require further study in the future, namely, how to take into consideration resilience and adaptability of urban socioeconomic system in the integrating process, how to quantify assess disaster risks with more reasonable and scientific approaches and weights, among others.

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