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Initial Evaluation of Provincial-Level Environmental Risks from the Perspective of Human Settlements

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Abstract: This study introduces risk theory of environmental science into human settlement science using 2004–2013 statistics, remote sensing data, and thematic maps. The entropy weight method and risk-index model are both used to study the characteristics of the time course and spatial pattern of human settlement risk in 31 provincial regions in China. In addition, influential mechanisms of vulnerability, functionality, stress, and adaptability on environmental risks are analyzed. Three primary results are obtained. First, for temporal characteristics, environmental risks of human settlements increased significantly from 2003 to 2012. The year 2006 marked both a sudden change and the cut-off point after which human settlements in China experienced qualitative changes and new risks. Second, for spatial characteristics, the risk index of human settlements decreased gradually from the southwestern to the northeastern, northwestern, and northern parts of China. The risk index of human settlement spaces differed significantly, with obvious block aggregation of spatial-distribution characteristics. Third, for relevant factor characteristics, between 2003 and 2012, the temporal change in vulnerability is relatively stable, with a slight increase in functionality and a slight decrease in adaptability. Spatially, Qinghai, Tibet, southwestern China, Guangdong, Guangxi, Beijing, and Tianjin had relatively high vulnerability in human settlements; Beijing, Tianjin, Jiangsu, and Zhejiang had the best functionality; Hunan and Sichuan had relatively high stress; and Guangdong, Jiangsu, and Zhejiang had relatively stronger adaptability. Further consideration and discussion are required on the environmental risks for different social groups and at different geographical scales, as well as on the uncertainty and long-term features of environmental risks in addition to environmental justice issues.

Keywords: human settlement perspective; environmental risk; risk index model; entropy weight method; provincial regions

1. Introduction

With rapidly advancing new urbanization, the tendency of industry relocation has become increasingly evident and many regions are developing their economies at heavy cost to the environment. Severe polarization has developed between advantaged and disadvantaged groups in society with regard to their environmental rights and interests, risks, and even their capacity for self-rescue. There is different focus of policies for social development, marking significant differences in environmental risks among generations. Against a background of ecological civilization, it is timeous to provide a normative standardized theoretical framework and to carry out empirical research on environmental risks from the perspective of human settlements with a focus on different periods, spaces, and groups.

The environmental risk assessment has a long history. Environmental risk assessment in the US consists of three main stages [1]: health risk assessment, accident risk assessment, and ecological risk assessment. The UK has proposed "Guidelines for Strategic Environment Assessments" to counter environmental risks [2]. Canada's environmental risk assessment system is composed of government management guidelines and assessment process guidelines from non-administrative organizations [3]. However, the present environmental risks are not limited to such fields as environmental toxicology, ecotoxicology, environmental pollution, and disruption of environment geology. There are many newly emerging topics, such as ecological risk assessment of elevated carbon dioxide levels in the marine environment [4], ecological risk assessment of heavy metal-polluted lakes (Morocco) [5], ecological risk assessment of rivers influenced by heavy use of antibiotics for aquaculture (Vietnam) [6], environmental risk assessment from the perspective of public health (Brazil) [7], risk assessment of indoor environments exposed to risks (Korea) [8], risk assessment of cumulative chemical exposure in urban environments (Holland) [9], environmental risk assessment based on mercury exposure (France) [10], risk assessment of the presence of pharmaceutical residues in water resources (France) [11], and medical waste and environmental health risk assessment (Mauritius) [12]. Approaches to environmental risk assessment are either qualitative or quantitative. The former includes safety checklists and fault tree analysis [13]; the latter includes a probability risk assessment method, damage scope assessment method, and risk index method [14]. However, these methods cannot deal with such issues as spatial and temporal uncertainties of environmental risks, and precise positioning and proximity of environmental risk sources. In the future, geographic information systems (GIS) and remote-sensing technology will be needed to cope with environmental risks intuitively, timeously, and accurately.

The problem of environmental risks in China is persistent and continuously deteriorating. Academic discussions and research on this issue vary and include the processes of regional environmental system risks [15], problems and solutions of the uncertainty in environmental risk assessment [16], soil environmental risks in mining areas and farmlands [17,18] study of water environmental risks in rivers, lakes, and urban drinking water source areas [19–21], assessment and study of natural ecological environment [22], assessment and study of the environmental risks in the petrochemical industry [23,24], and environmental risk assessment of transgenic crops and antiviral engineering [25,26]. In recent years, new progresses of environmental risk are concentrated on the following areas: the application of remote sensing and GIS technologies in environmental risks [27,28], the problems and countermeasures of trans-boundary environmental risk management [29], the environmental risk assessment of suburban agriculture based on relative risk model [30] and the evolutionary mechanism and coping method of transforming environmental risks to social risks [31].

In summary, a foundation and experience have accumulated in related theories and empirical studies about the connotations, denotation, research contents, assessment procedure, and method of current domestic and international environmental risk assessments. These studies have high theoretical and practical significance in the prevention and management of certain emerging single-element and original environmental risks. On the other hand, comprehensive studies beyond a single discipline, about the uncertainty, non-accidental factors, and sociality of environmental risks, are lacking. As a multi-disciplinary and integrated subject group, the science of human settlements includes not only physical sciences but also social sciences, and is a new subject that covers technological sciences. It can transcend the limitations of individual elements and disciplines, and allow comprehensive study on environmental risks, while utilizing technologies like GIS to study non-accidental and secondary environmental risks caused by human factors. Current studies mostly center on aspects including the theoretical framework of human settlements [32–34], definition of geographical scale [35–42], content assessment [43–45], division into components [46], method and technology [47,48], as well as correlation between human settlements and other disciplines [49,50]. However, until now, there have been few studies on the environmental risks of human settlements. Therefore, this study introduces risk theory of environmental science to human settlement science based on related social, economic, environmental, and graphical data from 2004 to 2013. It studies the time course, spatial pattern, and influential mechanisms in 31 provincial regions of China from the following four aspects: vulnerability and functionality of human settlement environment, and stress and adaptability of human settlement activities.

2. Data and Method

2.1. Data Sources

The socioeconomic statistical data used in this study were sourced from the *China Statistical Yearbook* [51], *China Environmental State Bulletin* [52], *China City Statistical Yearbook* [53], and *China Population Census Data* [54,55] published between 2004 and 2013, as well as statistical yearbooks, environmental quality bulletins, and national economy and social development statistical bulletins from various provinces, autonomous regions, and municipalities over the same period. The graphical data were sourced from the remote sensing interpretation data of this period. In addition, corresponding thematic maps, such as the *China Natural Disaster Risk Atlas* and *China Natural Disaster System Atlas*, were collected. Owing to changes of administrative region divisions and statistical specification, some data were corrected and adjusted according to statistical science.

2.2. Index System

Human settlements are complex macro systems. Because of differences in natural geographical environment caused by “regionality”, human settlement risks present differences in spatial patterns. Similarly, owing to different economic environments caused by the interference and stimulation of human activities from differing social progress, human settlement risks exhibit differentiation over time.

By referring to the Technical Guidelines for Environmental Risk Assessment on Construction Projects (HJ/169-2004), Evaluation Index System for China Human Settlements Award (Ministry of Housing and Urban–Rural Development, 2016), The Environment Impact Assessment Act of China, Management Regulations for Environmental Protection from Construction Projects, and Technical Guidelines for Environment Impact Evaluation [56–58], as well as previous research results [59,60], this study designed a human settlement risk evaluation system based on such principles as systematicness, the comprehensiveness and openness of human settlements, and the irreplaceability and operability of indicators. The system altogether has four criteria, namely, vulnerability, functionality, stress, and adaptability. Vulnerability is composed of natural geographical factors and socioeconomic factors. Functionality is presented mainly in social and ecological functions of human settlements. Stress refers to the stress caused by nature itself and the external interference from human activities on human settlements. Adaptability means the response of human activities to human settlements. Altogether, the system is composed of 37 indicators (Table 1).

Table 1. Evaluation index system of human settlement risks.

Object	Criterion	Index Type	Index
Human settlement risks	Vulnerability	Social conditions	Non-agricultural composition (regional total output value = 100); regional production index (previous year = 100); comparison of urban and rural consumption levels (rural resident = 1); residence consumer price index (CPI); regional total output value per capita (yuan); year-end urban population proportion (%); natural population growth rate (%)
		Natural conditions	Water resource quantity per capita (cubic meter per person); annual average temperature (°C); annual relative humidity (%); sunshine duration (h)

Table 1. *Cont.*

Object	Criterion	Index Type	Index
Human settlement risks	Functionality	Social functions	Public transportation (vehicles per 10,000 people); urban road area per capita (m^2); number of public toilets per 10,000 people; student–teacher ratio in general colleges (teacher = 1); average number of undergraduate students per 100,000 people
		Ecological functions	Green area per capita (m^2); natural reserve–administrative region ratio (%); wetland–administrative region ratio (%); green coverage ratio in built-up areas (%); forest coverage rate (%)
	Stress	Social stresses	Urban population density (people per square kilometer); total dependency ratio of population (%); urban registered unemployment rate (%); gender ratio (female = 100)
		Environmental stresses	Sulfur dioxide emissions (10,000 tons); smoke (dust) emissions (10,000 tons); total wastewater discharge (10,000 tons); amount of household waste cleared (10,000 tons); number of unexpected environmental accidents; number of geological disasters
	Adaptability	Human responses	Innocent treatment ratio of household waste (%); completed investment in industrial pollution treatment (10,000 yuan); number of completed pollution treatment projects within the year; innocent treatment capacity (tons per day); total afforestation area (ha); environmental investment ratio (%)

2.3. Research Method

Risk evaluation was applied first to evaluations of natural disaster risks and environmental risks. The introduction of a risk index model to human settlements science can be explained as follows: under the influence of natural geographical factors and external human settlement activities, human settlements exhibit different carrying capacities and feedback mechanisms in different regions, at different periods, and with different social groups. Hence, this results in human settlement risk. Thus, the value and sequential variation of risk indexes can be applied to describe the risk of human settlements. Generally, the bigger the risk index of a region and a period, the more risk that the human settlements of this region and period have to bear compared with the other temporal and special scales. The calculation model is:

$$R = V \times F \times S / A \quad (1)$$

In this expression, R is the risk index of human settlements (Risky); V is the vulnerability index of human settlements; F is the function index of human settlements; S is the stress index of human settlements; and A is the adaptability index of human settlements. V, F, S and A are calculated through the entropy weight method [61,62] as follows.

(1) Primitive matrix: $X = \left\{ x_{ij} \right\}_{m \times n}$ $(0 \leq i \leq m, 0 \leq j \leq n)$, then x_{ij} is the value of the jth value in the ith province.
(2) Standardized treatment of data: $X'_{ij} = (x_{ij} - \overline{x}_j)/\sigma_j$. In this expression, $\overline{x}_j$ is the average of the jth index values and σ_j is the standard deviation of the jth index values.
(3) Calculate the weight of the jth index in the ith province: $p_{ij} = X'_{ij} / \sum\limits_{i=1}^{m} X'_{ij}$.
(4) The entropy value of indicator: $e_j = -k \sum\limits_{i=a}^{m} (p_{ij} \ln p_{ij})$, $k = 1/\ln m$, $e_j \in [0,1]$.
(5) Difference coefficient: $g_j = 1 - e_j$.

(6) Calculate the weight of the jth index: $w_j = g_j / \sum_{j=1}^{n} g_j$.

(7) Calculate the score of human settlement indexes (V, F, S and A): $P = \sum_{j=1}^{n} w_j \times p_{ij}$.

In the expression, P is the score of human settlement indexes (V, F, S and A); w_j is the weight of the jth index worked out by the index's information entropy; and p_{ij} is the normalized values of the index's original values of human settlements.

3. Results and Analysis

3.1. Temporal Characteristics Analysis of Human Settlement Risks

(1) Stage division of human settlement risks

A sequential cluster method was adopted to analyze the indexes of human settlement risks from 2003 to 2012. The corresponding years of the max–min method's breaking points were defined as the years in which sudden change in human settlement risks occur. Based on the high and low jump points of the indexes, this study conducted a division for human settlement risks, as shown in Figure 1. The annual averages of the divisions of risk indexes were for 2003–2004, 2004–2006, 2006–2010, 2010–2011 and 2011–2012, and the change rates of the divisions of risk indexes were for 2003–2004, 2004–2005, 2005–2007, 2007–2009, 2009–2010, 2010–2011 and 2011–2012. According to Figure 1, the maximum jump points of the annual averages of human settlements risk indexes occurred in 2004, 2010, and 2012; the minimum jump points occurred in 2006 and 2011. The maximum jump points of environmental change rates occurred in 2007 and 2012, with increasing rates of human settlements risk of 0.36 and 0.26, respectively; the minimum jump points occurred in 2005 and 2011, with decreasing rates of human settlements risk of 0.19. The results showed that from 2003 to 2012, human settlements risk indexes mainly presented a salutatory uptrend, which means the bigger the risk that human settlements had to bear, the more obvious was the uptrend, especially after 2006. Hence, 2006 can be regarded as the cut-off point, after which human settlements in China experienced a qualitative change and were faced with a new set of problems associated with risks.

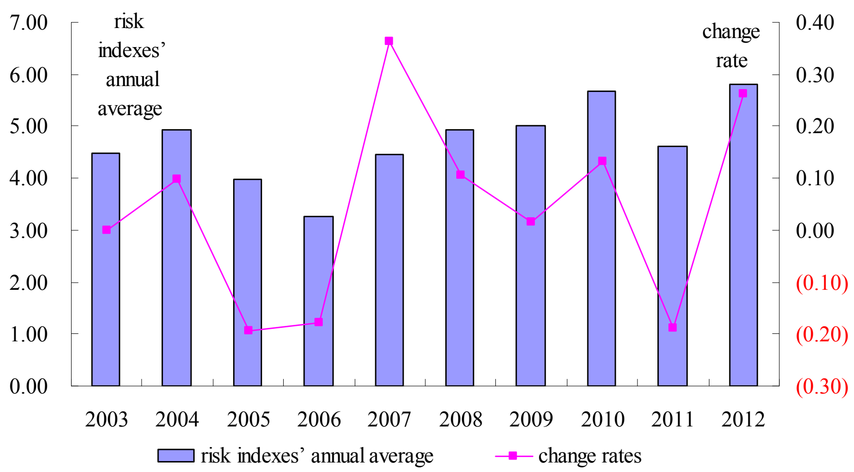


Figure 1. Stage division of China's human settlement risks.

By integrating the analysis of sequential cluster and jump points, it could be found that the change rates of human settlement risks in 2005 and 2007 were especially high, with an absolute value of 0.55. A significant change point of China's human settlement risk indexes occurred in 2006. Before then, human settlement risks showed a downtrend, while after 2006, the risk tendency of human settlements was clearly upward. The analysis showed that in 2006, indicators among the functionality of human settlements, including urban population density and number of geological disasters, underwent changes. In 2006, China's average urban population density was 2829.98 people/square kilometer, which is significantly higher than the average for 2003 to 2005 (1453.06 people/square kilometer). After 2006, this figure was consistently higher than 2600 people/square kilometer. Similarly, the number of geological disaster occurrences increased consistently after 2006, which led to a continuous increase of the human settlement risk indexes, and thus, worsening of human settlements.

(2) Sudden change analysis of human settlement risks

This study carried out anomaly standardization on the standard deviation of human settlement risk indexes (Figure 2). The results show that China's human settlement risk indexes exhibited a decline in the early stage (2003–2006), a rise in the middle stage (2006–2010), and a decline in the later stage (2010–2012), indicating that China's inter-annual human settlement risk indexes have been fluctuating.

For the standard deviation analysis of human settlements, the first stage showed a fluctuating downward trend, reaching its trough in 2006 with a minimum of 2.94; the second stage showed a fluctuating uptrend, reaching its peak in 2010 with a maximum of 5.79; and the third stage showed a downward trend as well, although its minimum was 3.58, higher than that of the first stage. For analysis of human settlements' anomaly standard value, the first stage showed an uptrend followed by a downward trend with an obvious fluctuation. In 2006, it reached a trough with a minimum of −1.45. The second stage showed a fluctuating uptrend, reaching its peak in 2010 with a value of 0.95. The third stage showed a downward trend followed by an uptrend. This fluctuation was strong and presented a "V" tendency. In 2012, the anomaly standard value reached its maximum of 1.10.

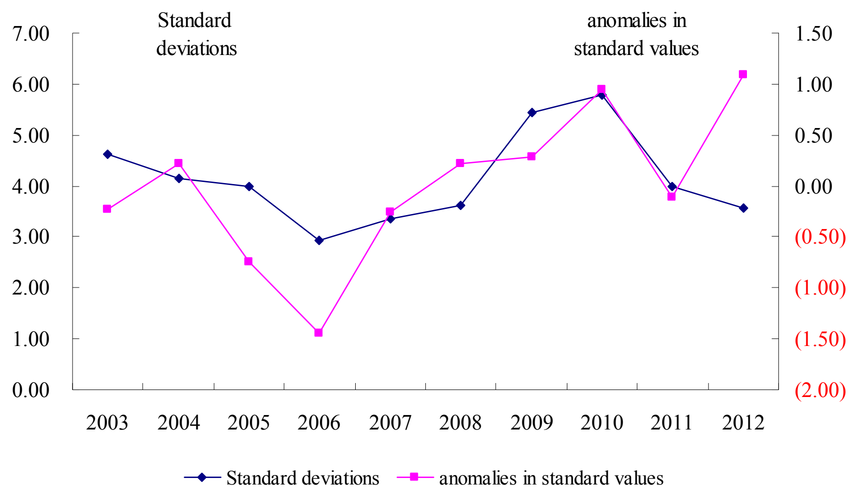


Figure 2. Standard deviation and anomaly standard variation of China's human settlement risks.

Thus, China's human settlement risk indexes showed an uptrend with big inter-annual fluctuation and obvious phase characteristics. According to the mutual variation property of standard deviation and anomaly standard value, 2006 was confirmed to be the sudden change year for China's human settlements.

3.2. Spatial Characteristics Analysis of Human Settlement Risks

(1) Geographical division characteristics of human settlement risks

From China's geographical division (Figures 3 and 4), the general feature of China's human settlements' risk indexes was that they decreased progressively from the southwest to the northeast, northwest, and north of China. Specifically, the human settlement risk index of the southwest ranked first nationwide at 6.56; those of eastern, southeastern, and central China were ranked second, third, and fourth at 5.59, 4.89, and 4.85, respectively, which were above the national level of 4.66. Moreover, those of northeastern, northwestern, and northern China were ranked fifth, sixth, and seventh at 4.28, 3.81, and 2.64, respectively, which were below the national level.

(2) Spatial distribution characteristics of human settlement risks

This study applied the ArcGIS natural division method to divide the human settlement risk indexes of 31 provinces from 2003 to 2012 into five region types (Table 2 and Figure 4). Comprehensive studies have found that China's human settlements risk has prominent spatial differences with different area types presenting obvious spatial distribution characteristics of block aggregation in the nationwide geographical scale.

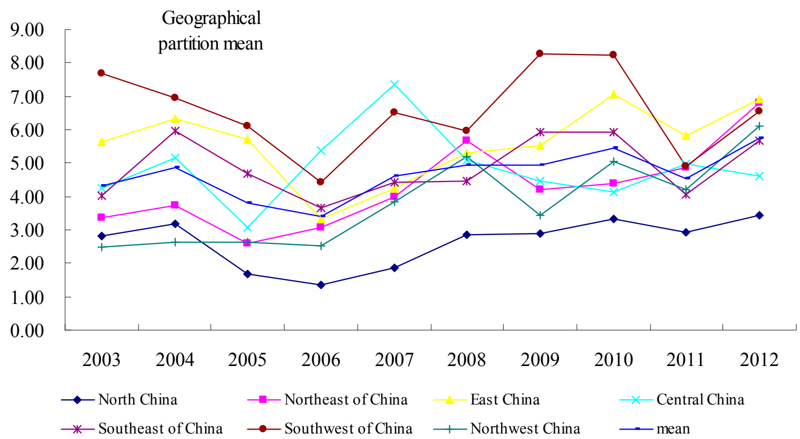
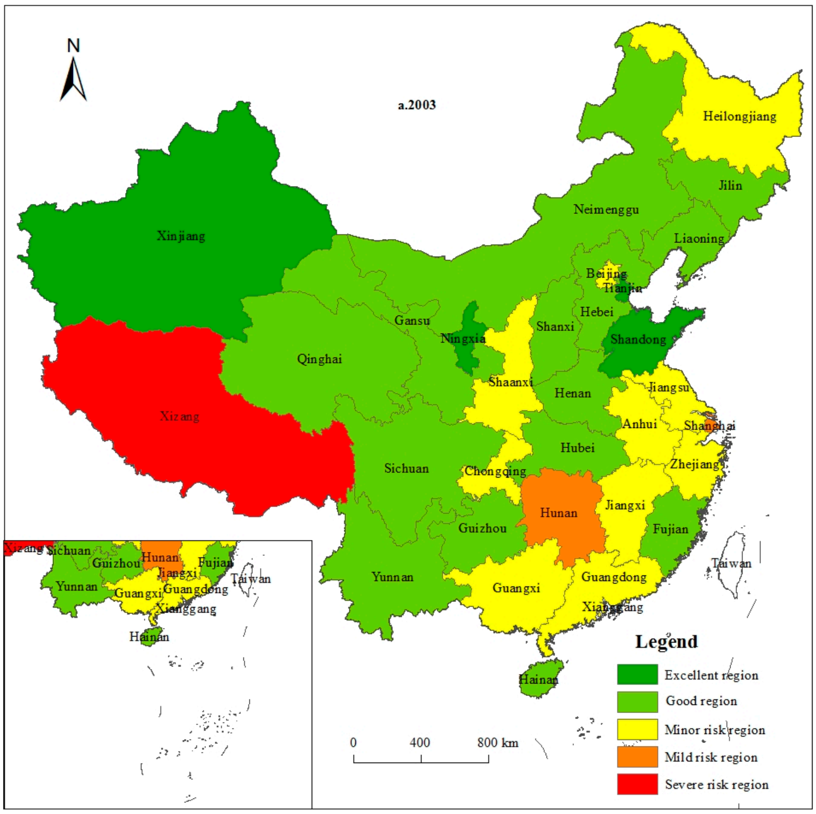


Figure 3. Geographical partition characteristics of China's human settlement risks.



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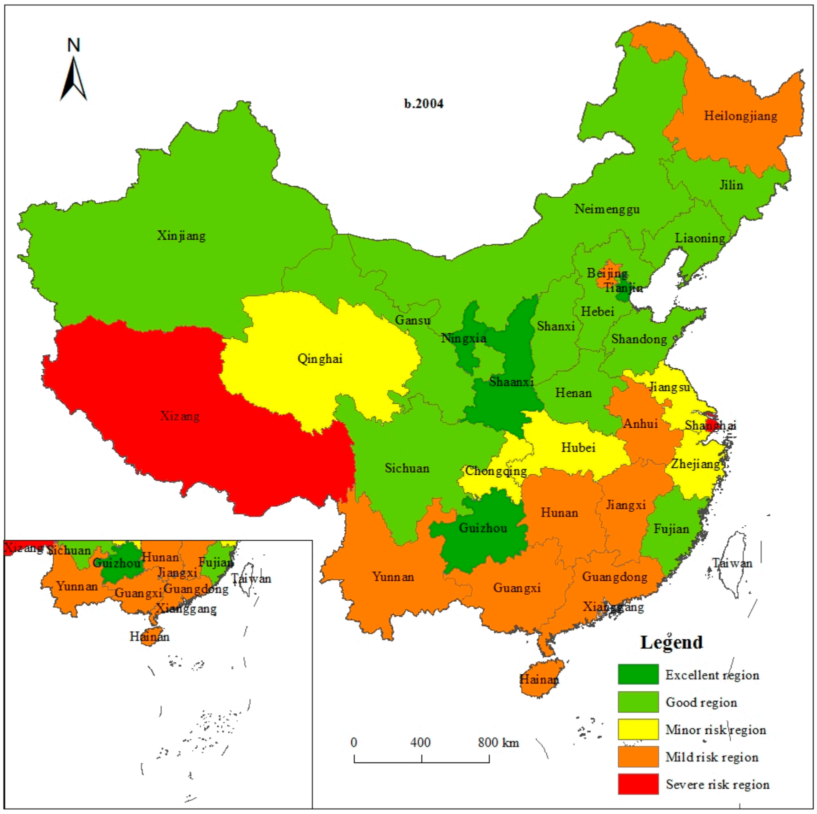

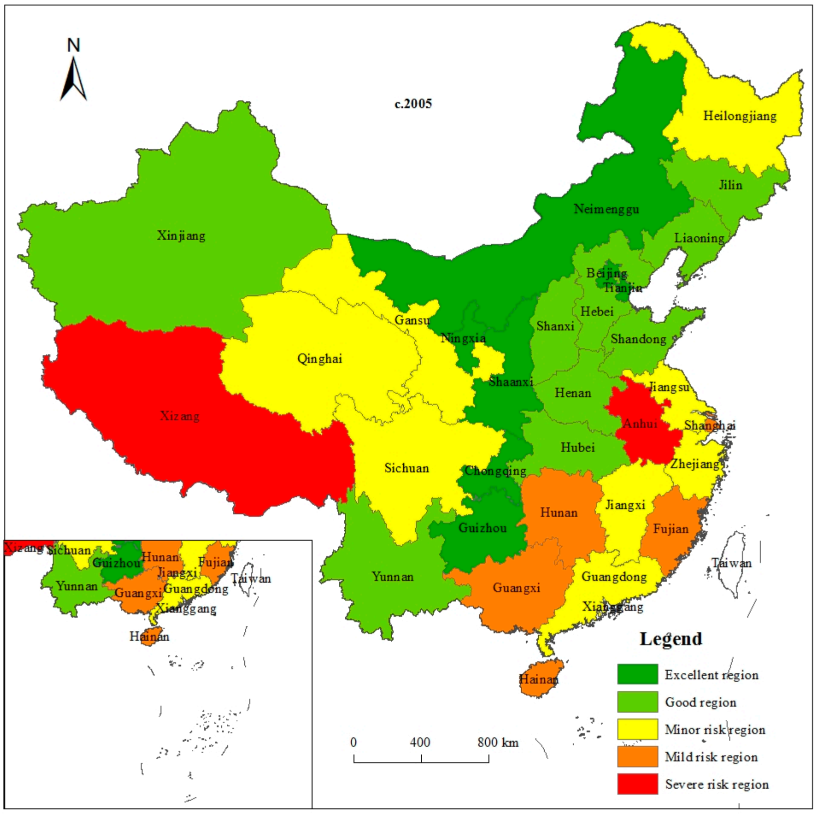

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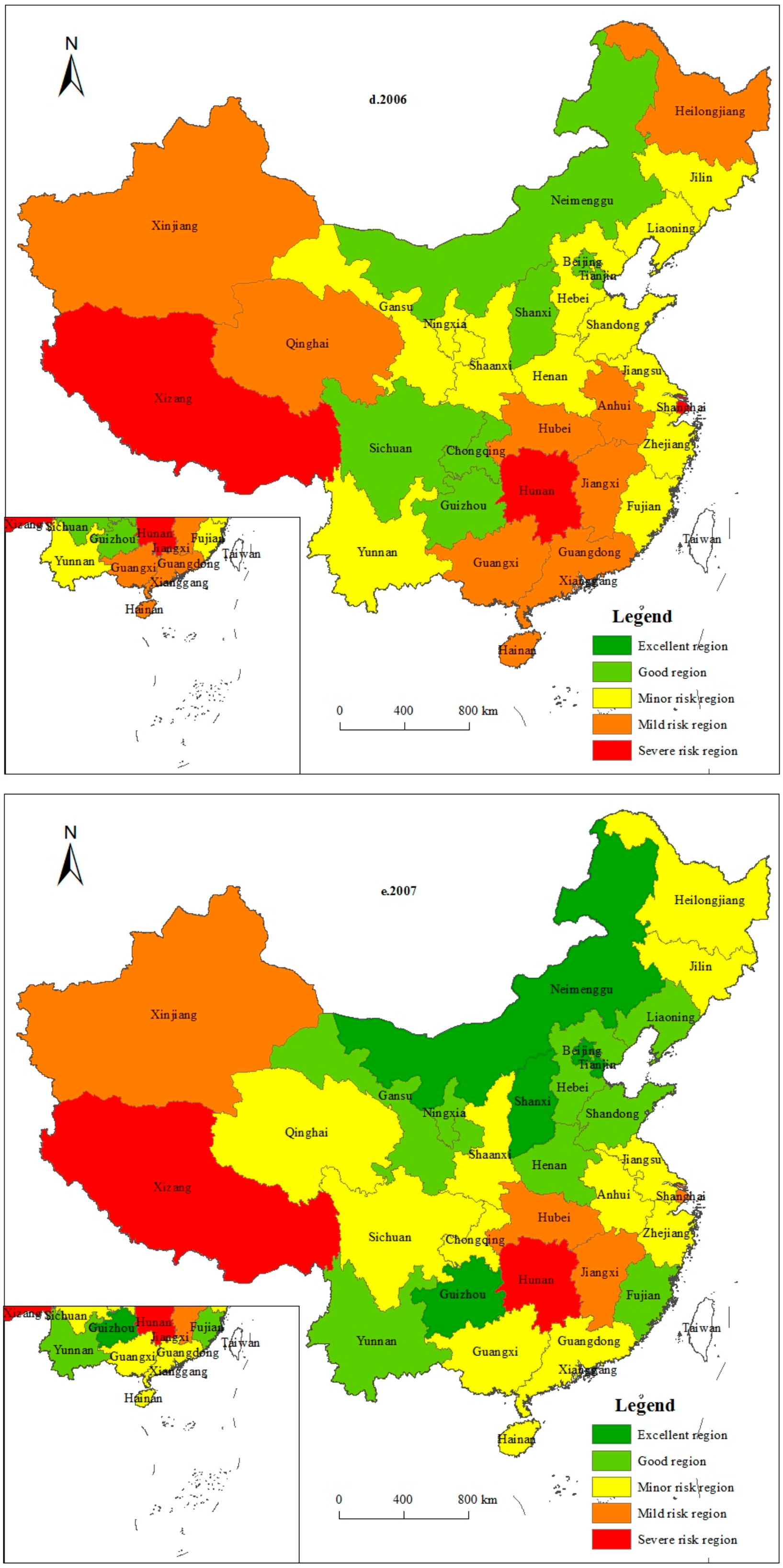

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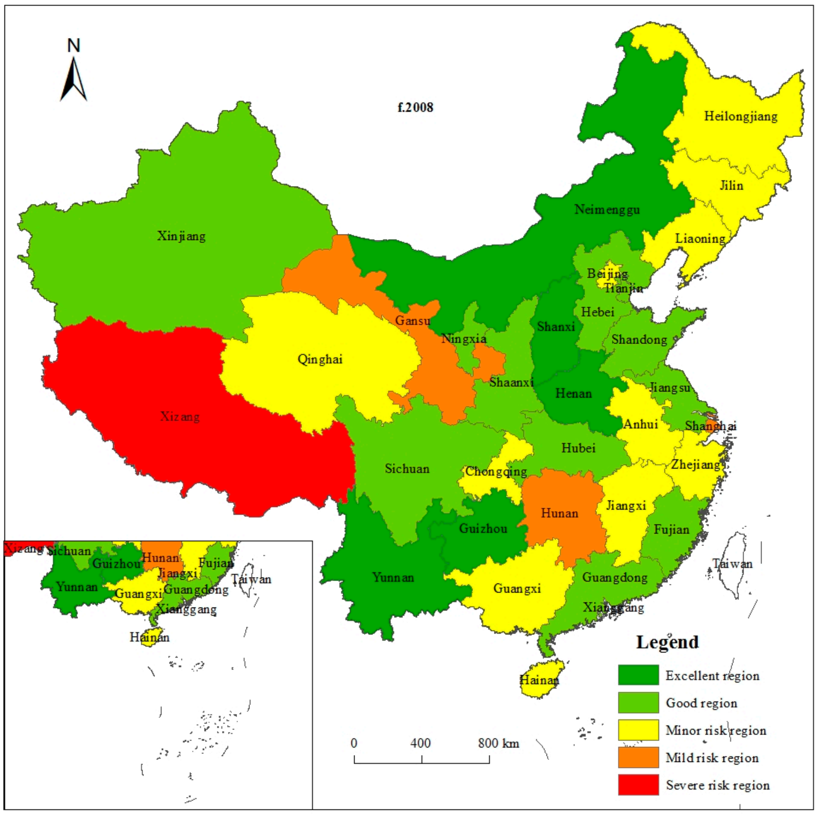

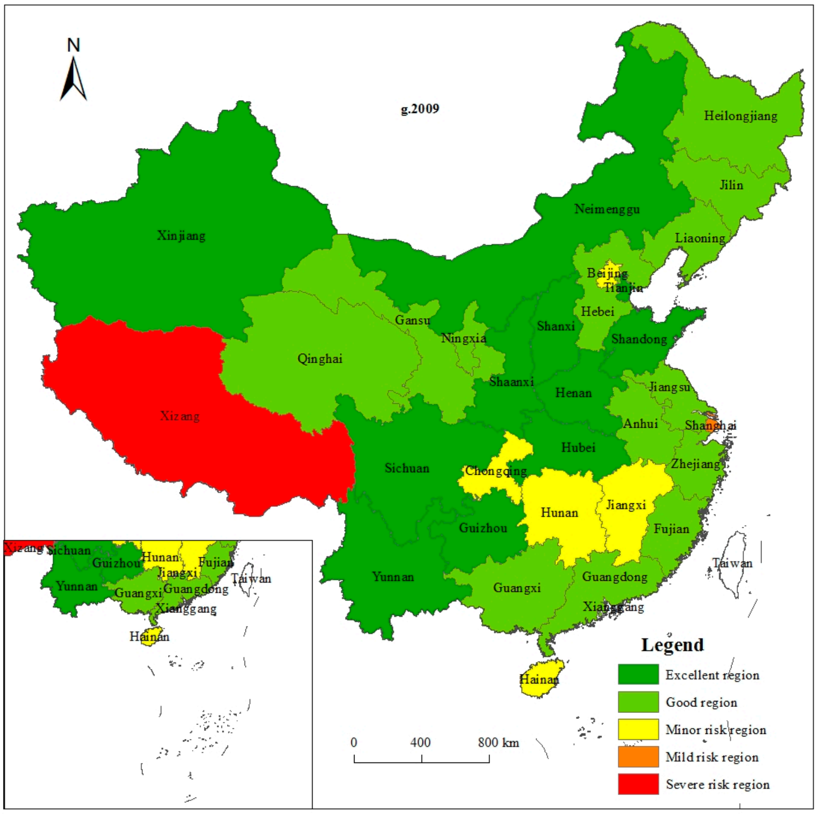

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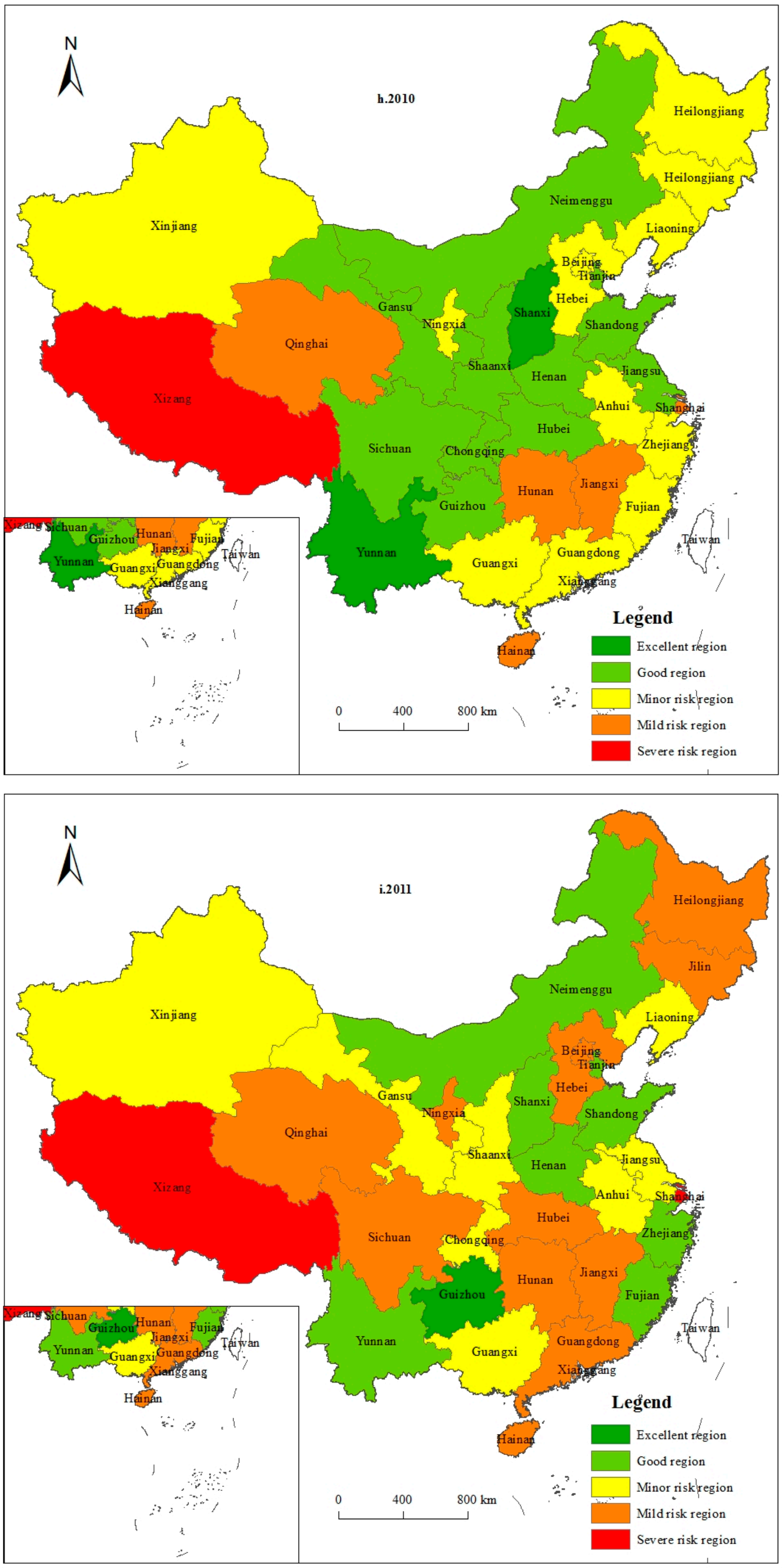

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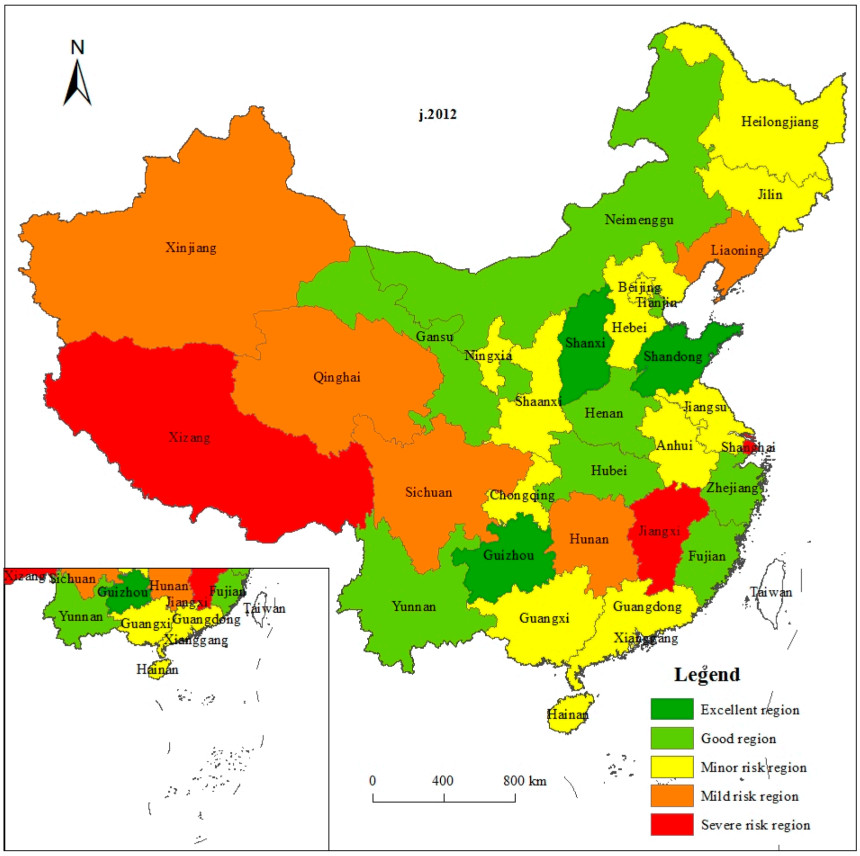


Figure 4. Temporal and spatial patterns of China's human settlement risks. (**a**–**j**) are the spatial distribution of China's human settlement risk (2003–2012).

Table 2. Region-type division of China's human settlement risks.

Year	Excellent Region		Good Region		Minor Risk Region		Mild Risk Region		Severe Risk Region	
	Score	Number	Score	Number	Score	Number	Score	Number	Score	Number
2003	1.65	4	2.52	14	4.80	10	12.27	2	24.91	1
2004	1.68	4	2.76	11	4.31	5	6.23	9	19.10	2
2005	1.49	7	2.18	9	3.73	8	5.62	5	17.62	2
2006	0.96	1	1.26	6	2.26	12	3.71	9	10.76	3
2007	1.61	5	2.83	8	4.34	12	5.91	4	15.87	2
2008	1.59	5	3.23	11	5.40	11	10.23	3	19.41	1
2009	2.01	11	3.88	13	7.35	5	15.38	1	30.52	1
2010	1.42	2	2.90	11	4.42	12	11.37	5	31.13	1
2011	1.38	1	2.13	8	3.43	8	5.03	12	18.19	2
2012	2.10	3	3.20	7	5.28	13	8.10	5	14.16	3

Table 2 and Figure 4 show that the spatial distribution of China's human settlement risk-type regions had the following characteristics: (1) Provinces with good human settlements accounted for a large proportion of 31.61%. These mainly consisted of the 12 provincial administrative geographical units of Tianjin, Hebei, Liaoning, Fujian, Shandong, Henan, and Hubei provinces in central and eastern China, and Inner Mongolia, Sichuan, Gansu, Ningxia, and Xinjiang provinces in western China. Areas of this type were quite dispersive and mainly presented a sporadic block aggregation distribution; (2) Provinces of minor risk areas accounted for 30.97% and ranked second. This type mainly included 11 provincial administrative geographical units and showed obvious block concentration characteristics. It was composed of three major sections, namely, Jilin and Heilongjiang provinces in northeastern China, Jiangsu, Zhejiang, and Anhui provinces in eastern China, and Guangdong and Guangxi provinces in southern China. The other provinces of this type were dispersive and mainly consisted of Beijing, Shaanxi, Qinghai, and Chongqing provinces; (3) Provinces of mild risk to human settlements accounted for 17.74% and ranked third. They mainly included the four provincial administrative geographical units of Hunan, Jiangxi, Shanghai, and Hainan, with a spatial characteristic of small block distribution; (4) Provinces of excellent human settlements accounted for 13.87% and ranked fourth. They mainly included the three provincial administrative geographical units of Shanxi, Guizhou, and Yunnan, with dispersive spatial distribution; (5) Provinces of severe human settlement risk accounted for 5.81% and ranked fifth. They mainly included Tibet Autonomous Region with severe human settlements risk conditions.

(3) Longitudinal and latitudinal change characteristics of human settlement risks

Latitudinal change. According to the latitudinal situation of China's human settlement risks (Figure 5), the overall latitudinal distribution characteristic of China's human settlement risk index decreased progressively on both sides from 30°N. At 30°N was the area of the highest human settlement risk index, with a maximum of 8.69 and an average of 7.23. At 40°N was the area of the lowest human settlement risks with a minimum of 1.90 and an average of 3.21.

Longitudinal change. According to the longitudinal distribution curve of China's human settlement risks (Figure 6), from 2003 to 2012, China's human settlement risk regions shifted from 90°E to three other longitudes. At 90°E was the area of the highest human settlement risk indexes with a maximum of 15.25, whereas 110°E had the lowest human settlements risk indexes with an average of 3.19.

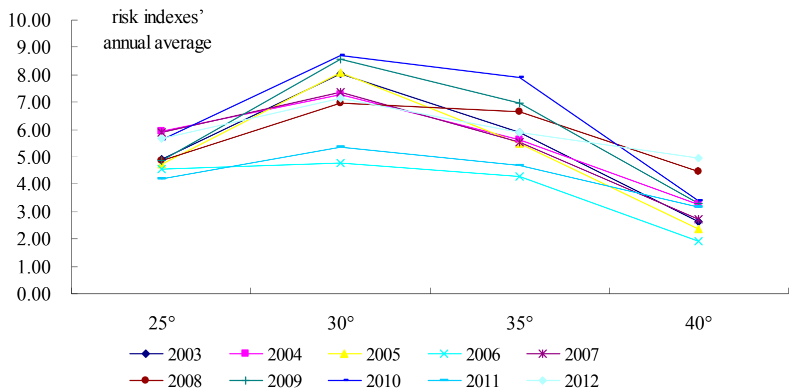


Figure 5. Latitudinal change characteristics of China's human settlement risks.

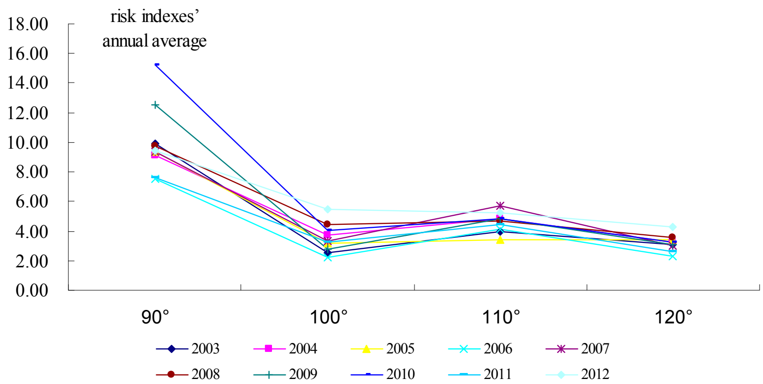


Figure 6. Longitudinal change characteristics of China's human settlement risks.

Thus, it can be seen that China's latitudinal human settlements risk index could be ordered as 30° (7.23) > 35° (5.90) > 25° (5.13) > 40° (3.21), with its overall distribution characteristics decreasing progressively on both sides from 30°N. The longitudinal human settlement risk index could be ordered as 90° (9.98) > 110° (4.61) > 100° (3.50) > 120° (3.19), with its overall distribution characteristic shifting from 90°E to three other longitudes. In other words, there is a decreasing tendency from western China to mid-eastern China.

3.3. Relevant Factor Analysis of Human Settlement Risks

(1) *Vulnerability*. The spatial and temporal patterns of the relevant factors of China's human settlements risk (Figures 7 and 8) show that during 2003–2012, the vulnerability of human settlements was stable and without obvious fluctuation. Its values were between 2.01 and 2.37 with an overall value change range of 0.36.

Spatial distribution (Figure 8a) showed that the vulnerability of China's human settlements was distributed in a scattered fashion but with obvious aggregation in three blocks, namely Tibet and southwestern China, Guangdong and Guangxi region, and Beijing and Tianjin region. According to *The National Major Function Oriented Zoning* and *The National Ecological Function Zoning*, the Tibetan area, the forest ecological function region on the edge of the southeastern Tibetan Plateau in southwestern China, Sanjiangyuan Grassland meadow wetland ecological function area, and Ruoergai meadow wetland ecological function area had severe natural geographical environments with complex topographical structures and frequent occurrences of primary disasters. Thus, their human settlements were quite vulnerable. Guangdong, Guangxi, and Hainan areas partially overlapped with ecological function areas for biodiversity at Nanling mountainous forest and the ecological function area at the rainforest in the central mountainous area of Hainan Island. They suffered from frequent occurrences of primary disasters and environmental pollution caused by human activities. Thus, their human settlements were quite vulnerable as well. The meadow ecological function area in the Hulunbeir Grassland of Inner Mongolia, Khorchin meadow ecological function area, and Beilu Grassland meadow ecological function area in Yinshan Mountains were very vulnerable. Human settlements in areas with high population density and exhaust emissions from motor vehicles, like Beijing and Tianjin, also had high vulnerability.

(2) *Functionality*. According to Figure 7, from the perspective of temporal characteristics, functionality of human settlements from 2003 to 2012 had an overall small uptrend tendency. The changes in values increased from 2.58 in 2003 to 3.09 in 2012, but the overall fluctuation range was not large, with a maximum variation range of 0.51.

In terms of spatial patterns (Figure 8b), the functionality of human settlements in eastern China was better than that in central China, which was better than that in western China. According to *National Major Function Oriented Zoning*, Beijing, Tianjin, Jiangsu, Zhejiang, and other lower reaches of the Yangtze River were parts of state-level optimized development areas with more developed economies, complete urban infrastructure, higher education level per capita, higher environmental protection investment, larger green park areas per capita, and higher plantation coverage rate. Therefore, their functionalities in human settlements evidently were higher. Guizhou is part of an ecological function zone to protect against Guizhou-Yunnan karst rocky desertification and Gansu is part of an important water-supply ecological function area of the Yellow River. The scale development of these regions has been very restricted. Meanwhile, Shanxi and Henan were found to be heavily populated. Education, sanitation, and medical resources in these provinces were relatively poor. In addition, excessive resource development, low forest coverage rate, and significantly decreased protected natural area led to seriously deteriorated environments and low functionality of human settlements.

(3) *Stress*. According to Figure 7, from the perspective of temporal characteristics, the overall fluctuation in the stress of human settlements was relatively intense and presented evident stage characteristics. The overall curve was similar to a "W" shape, with the largest change value of 0.73.

With regard to spatial patterns (Figure 8c), there were no evident block aggregation characteristics in the overall spatial pattern of the stress of human settlements in China. However, the stress of Hunan and Sichuan was higher than that of other provinces in China. In particular, the stress of Hunan was eight times higher than that of the lowest province, because there were 1041 emerging environmental incidents in total in Hunan from 2003 to 2007, which was significantly higher compared to other provinces. Geological disasters occurred in 119,571 places in Hunan, while 25,404 such disasters occurred in Sichuan. Therefore, the stress of human settlements in these regions was relatively high.

(4) *Adaptability*. According to Figure 7, from a perspective of temporal characteristics, the adaptability values were relatively high and were significantly higher than those of vulnerability, functionality, and stress. The overall change of adaptability was relatively stable, presenting a slight decreasing tendency, and its value changes decreased from 3.11 in 2003 to 3.02 in 2012.

In terms of spatial patterns (Figure 8d), the overall adaptability of human settlements in eastern China was better than that of central China, which was better than that of western China, except for Sichuan. Guangzhou, Jiangsu, and Zhejiang in eastern China had relatively strong economies, and they invested more in environmental protection and non-pollution treatments of solid waste. Therefore, the adaptability of human settlements in these regions was relatively high. Because the government had carried out ecological environmental management in mining areas in previous years in Shanxi, Shaanxi, and Inner Mongolia, and investment proportions in industrial pollution control projects and environmental protection had increased significantly, the adaptability of human settlements also improved significantly. By initiating projects in Sichuan and Yunnan, like enlarging forest areas and ecological restoration and protection, the adaptability of human settlements has improved consistently.

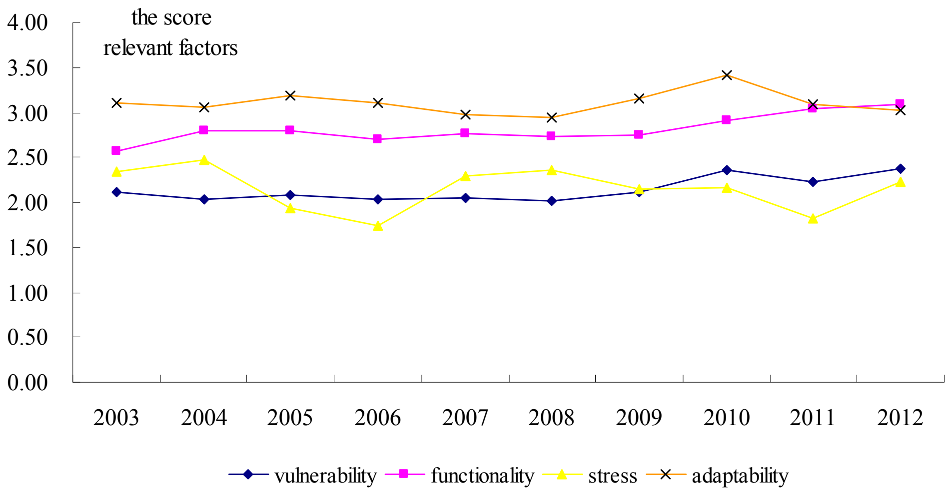
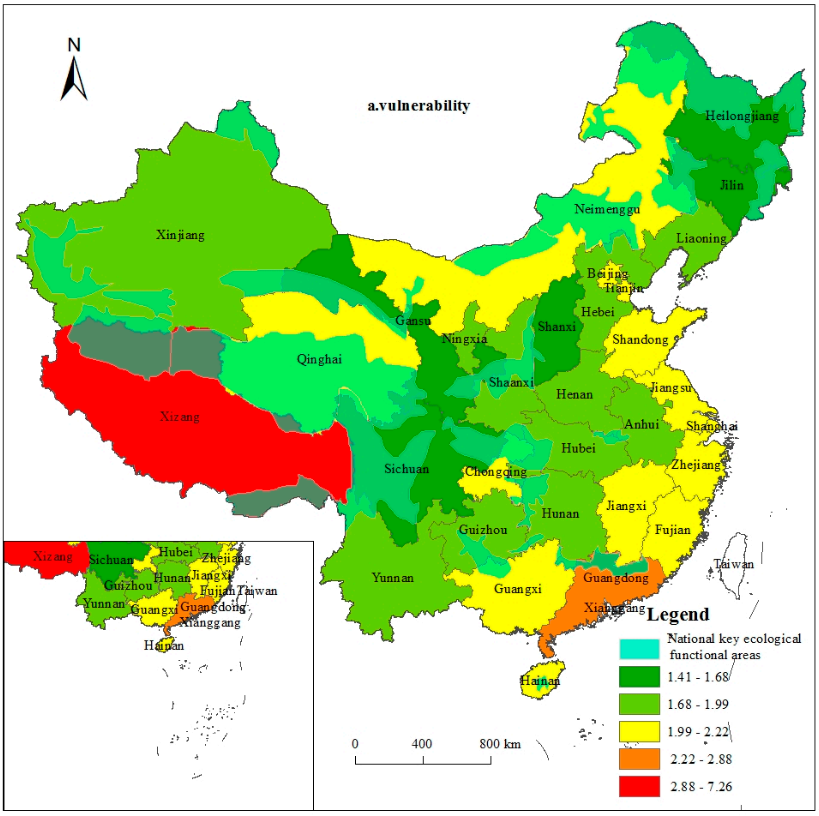


Figure 7. Sequential changes of relevant factors of China's human settlement risks.



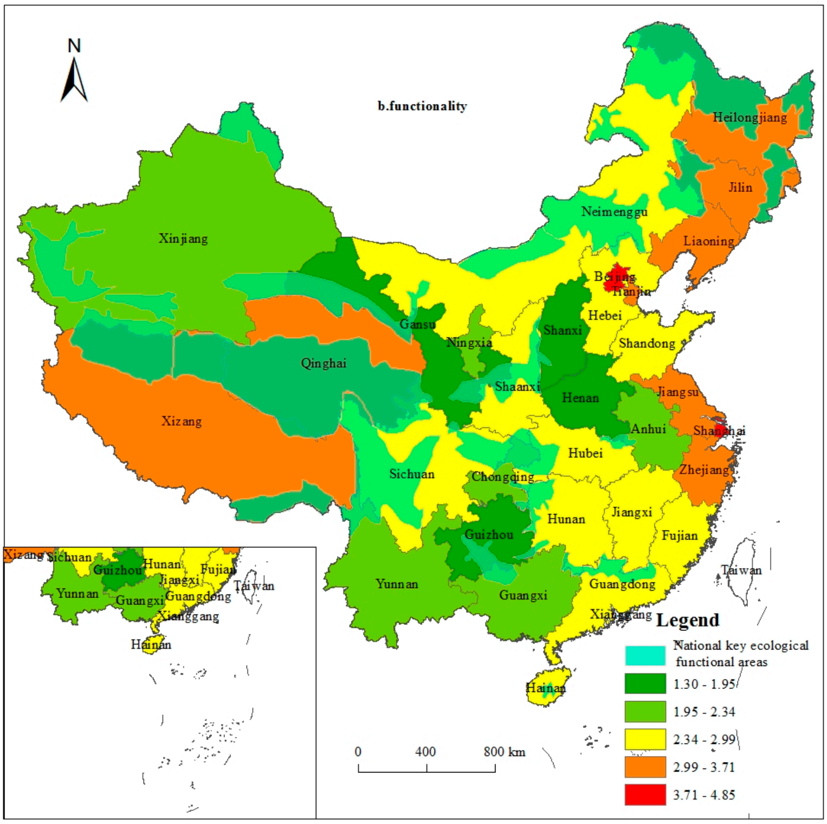


Figure 8. *Cont.*

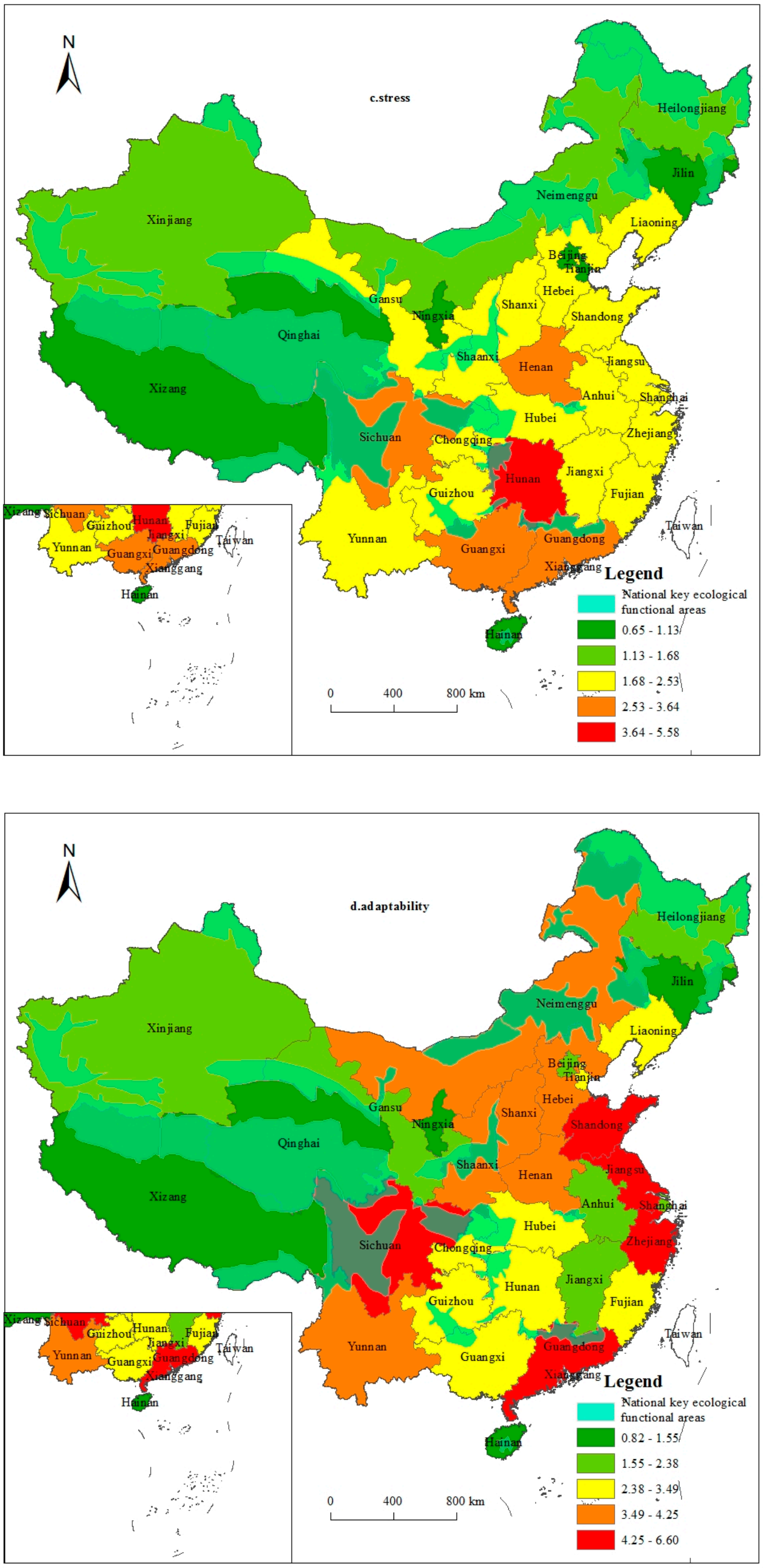


Figure 8. Spatial pattern diagrams of relevant factors for human settlement risks in key national ecological functional areas. (**a**–**d**) are as follows: Vulnerability, Functionality, Stress, Adaptability.

4. Discussion and Conclusions

This study introduced risk theory of environmental science into human settlements science using 2004–2013 statistical data and interpreted data from remote-sensing images, and thematic maps. In addition, it analyzed the time course and spatial pattern characteristics of human settlement risk indexes in 31 provincial regions in China by utilizing an entropy weight method and a risk index model. The human settlements risk mechanism was analyzed from the four aspects of vulnerability, functionality, stress, and adaptability. The results are as follows.

(1) With regard to temporal characteristics, environmental risks of human settlements in China showed a fluctuating uptrend from 2003 to 2012. The year 2006 marked both a sudden change and a cut-off point when the standard deviations of human settlements reached a trough of 2.94, and the anomalies in standard values also reached a trough of -1.45. After 2006, the uptrend of human settlement risk in China became more obvious, indicating qualitative changes and new risks.

(2) In terms of overall spatial characteristics, the risk indexes of human settlements in China gradually decreased from southwestern to northeastern, northwestern, and northern China. Special differences in the risk indexes of human settlements were significant, with obvious block aggregation of spatial-distribution characteristics among regions of different types at the national scale. In the latitudinal distribution, the risk decreased progressively on the two sides at 30°N. The longitudinal distribution shifted from 90°E to the three longitudes in the middle and eastern parts of China.

(3) With regard to relevant factor characteristics, from 2003 to 2012, the temporal change in vulnerability was relatively stable and fluctuation was not very obvious, with values from 2.03 to 2.37 and an overall range of change of 0.34. A slight increase in functionality was observed, with values increasing from 2.58 in 2003 to 3.09 in 2012. However, the overall fluctuation range was not large and the largest change in values was 0.51. The overall fluctuation in stress of human settlements was relatively large; it presented evident stage characteristics and had a near "W"-shaped characteristic, with the largest variation range of 0.73. The adaptability values were higher than those of vulnerability, functionality, and stress. The overall adaptability change was relatively stable although a slight decrease was observed from 3.11 in 2003 to 3.02 in 2012. Spatially, vulnerability was distributed dispersedly but the block aggregation characteristics were evident. There were three blocks: first, Qinghai, Tibet, and southwestern China; second, Guangdong and Guangxi; and third, Beijing and Tianjin. The Beijing and Tianjin region and the Jiangsu and Zhejiang region had the best functionality. Hunan and Sichuan had relatively high stress. Shandong, Jiangsu, Zhejiang, Guangdong, and Sichuan had relatively strong adaptability in human settlements.

Using human settlements science, this study investigated the effect mechanism, including time course, spatial pattern, and relevant factor characteristics, of human settlement risk in China. However, there are still some problems requiring further discussion. First, a study on the geographical scales of human settlement risk is required. China covers almost 50° latitude from south to north, and nearly 63° longitude from east to west, crossing five temperature zones and five geographical types. Natural geographical elements remain the leading factors that fundamentally restrict human settlement risk on different geographical scales. Since the range and intensity of human activities on various geographical scales differ, human settlement risk require further investigation at micro-geographical scales. Second, studies on human settlement risk in different populations (classes) are required. Environmental rights, environmental risk exposure, and the capacity to avoid environmental risks among different social groups will become important research topics in geography, human settlement sciences, and even ecological civilization construction. Third, as the environment in China has become bleaker and new pollutants have emerged one after another, the uncertainty and non-emergency of environmental risks, as well as environmental justice require further discussion and analysis.

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