Case Study Paper

Comprehensive Evaluation and Dynamic Evolution Analysis of Shanghai's Urban Vulnerability

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Abstract

Urban vulnerability refers to the ability of a city to resist internal and external natural and human factors. With global environmental changes and urbanization continuing at pace, the urban planning and development strategies of cities, especially mega-cities, are facing comprehensive and unprecedented issues. This paper takes Shanghai, one of the largest mega-cities worldwide and the global cities in China, as an example, using the comprehensive evaluation index method which includes natural resource vulnerability, eco-environment vulnerability, economic vulnerability and social vulnerability, to build a comprehensive vulnerability index evaluation system of the city. Through the dynamic evolution analysis conductive to a deeper understanding of the changing laws of urban vulnerability, explore the persistence and transformation mechanism of urban functions after perturbations, and realize the sustainable development of cities, the paper found that: firstly, during 2002 -2017, the comprehensive urban vulnerability index of Shanghai has been declining, among which the decline rate was large during the years of 2004 -2006 and 2010-2012, which was the result of urban events promoting urban construction. Secondly, Shanghai has changed from an absolute dominant eco-environment vulnerability to a more balanced vulnerability, indicating that cities have greater resistance, adaptation and transformation capabilities to multiple perturbations including natural resource, ecological environment, economic and social development. Thirdly, Shanghai's eco-environment vulnerability has continued to decline in recent years, but it is still the dominant factor of the urban vulnerability. Fourthly, as Shanghai has been facing an increase in migrant population and huge arable land pressure, the contribution rate of natural resource vulnerability continues to be high and has increased in recent years. Facing the changing environment and risks, we must plan for resilience, and build, evolve and secure quality of life for dwellers.

Keywords

Urban vulnerability, evolutionary research, Shanghai

Shanghai's new round of master plan puts forward the vision of "Striving for the Excellent Global City". Under the background of a new historical starting point and adapting to the new development trend, Shanghai is also faced with many challenges such as sustained population growth, environmental resource constraints, and urban functional transformation. The combination of endogenous contradictions and external adverse effects of urban development leads to the vulnerability of cities in resource utilization, ecological environment, economic construction and social development.

In order to evaluate the urban development of Shanghai in the past ten years more comprehensively and intuitively, this paper makes a longitudinal study of the evolution characteristics of Shanghai's urban comprehensive vulnerability in the past 15 years based on statistics from 2002 to 2017. The paper deeply studies the development status and vulnerability evolution characteristics of Shanghai in the last stage, in order to effectively regulate and control the urban vulnerability and provide some inspiration for Shanghai to move towards sustainable development.

1. Introduction

The term "vulnerability" came from the field of natural disaster research (Turner et al., 2003), and then it was widely used in ecology, economics, geography, sociology and other disciplines (Fang and Wang, 2015). Urban vulnerability refers to the ability of cities to resist the interference of internal and external natural and human factors such as ecological, economic and social development. When this anti-interference ability is lower than a critical threshold, the city will enter a vulnerable state (Wang and Fang, 2014). Currently, researches on urban vulnerability in China mainly focuses on the assessment and classification of eco-environment vulnerability and the vulnerability assessment of disaster-prone cities (Zhang et al., 2016). In recent years, researches on the issue have changed from a single system to a diversified ones. For example, Fang and other scholars evaluate the comprehensive vulnerability of cities from multiple subsystems (Fang and Wang, 2015).

Based on previous relevant studies on urban vulnerability by domestic and foreign scholars, the influencing factors of urban vulnerability can be divided into two categories: natural conditions and human activities. Urban vulnerability includes four elements: resource vulnerability, eco-environment vulnerability, economic vulnerability and social vulnerability. Considering the reliability and validity of the data, this paper chooses the period from 2002 to 2017 to conduct a diachronic study on the comprehensive vulnerability of Shanghai city from four aspects: resources, ecology, economy and society.

2. Urban Vulnerability Assessment Method and Evaluation System Construction

2.1. Construction of Evaluation Index System

Based on assessment systems constructed by Fang and Wang (2015), this paper constructs the urban comprehensive vulnerability evaluation system according to the principles of non-collinearity and accessibility of index data (Fig. 1).

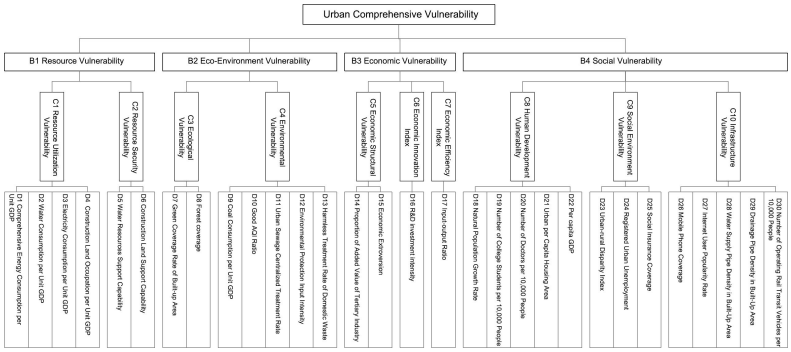


Figure 1 Urban Comprehensive Vulnerability Assessment System

Source: Self-organized, summarized and made

The target level is divided into four sub-elements including urban resources, ecology, economy and social vulnerability. The whole system contains 30 third-level indicators and 10 second-level indicators.

2.2. Identification of Typical Indicators and Determination of Weight Coefficient

2.2.1. Quantitative Identification and Explanation of Typical Indicators

(1) Water resources support capacity. The study measure the urban water resources support capacity by the ratio of urban available water resources to actual urban water demand (Fang and Wang, 2011). The calculation method is as follows:

$$WPSI_{\mathrm{i}} = \frac{DWS_i \times T}{YTWS_i} \qquad (1)$$

where: $WRSI_i$ refers to the water resources support capacity. $DWSi$ is the daily water supply of urban tap water. T is the number of days in a year. $YTWS_{\mathrm{i}}$ is the total water consumption of the city and is calculated according to the total water supply in the Statistical Yearbook of Urban Construction over the years. The closer the index is to 1, the higher the water resources support capacity of the city is. When the index value equals 1, it indicates that the current water production capacity of the city does not destroy the ecological balance, but also meet the needs of urbanization development (Fang and Wang, 2015).

(2) Construction land support capacity. According to the National Land Use Change Survey Report and related research, the per capita arable land area in cities is taken

as the basis for estimating the underlying conditions of land[1]. And the actual per capita construction land area and the healthy per capita construction land area are taken as the basis for evaluating the development potential of regional construction land①. The calculation method is as follows:

$$LCSI_{\mathrm{i}} = \frac{1}{2}\left(\frac{PAA_i}{HPAA_i} + \frac{PCA_i}{HPCA_i}\right) \quad (2)$$

where: $LCSIi$ is the construction land support capacity. $PAAi$ is the per capita cultivated land area (calculated by permanent population), and $HPAAi$ is the minimum per capita cultivated land area needed[2]. PCA_{i} is the area of construction land per capita (calculated by urban population). $HPCA$ is healthy per capita construction land area (calculated by living, service facilities, road traffic, green space and other construction land standards closely related to per capita land use indicators, this paper determines that the healthy per capita construction land area in Shanghai is 140 sqm). When the construction support capacity index is 1, it means that the city has enough development space (Fang and Wang, 2015).

(3) Coal consumption per 10,000 yuan GDP. Because carbon emission data per unit output value is difficult to obtain, and coal consumption accounts for more than half of the major energy products in Shanghai, coal consumption per 10,000 yuan GDP is used as an indicator to measure urban environmental vulnerability.

(4) Economic extroversion. That is, the degree of dependence on foreign trade, which is used to measure the degree of close economic ties, openness and dependence on foreign trade between Shanghai and other countries. This index is quantified by the ratio of total urban exports to GDP.

(5) Input-output ratio. The input-output ratio of government finance is taken as the basis to measure urban economic efficiency. This paper adopts a quantitative method to calculate the ratio of general budget revenue to expenditure of local finance.

(6) Urban per capita housing construction area. Taking urban per capita housing area as an index to measure urban human development, this paper takes per capita

[1] The index of construction land security in this paper only reflects the development support and potential status of urban construction land, and is different from the rationality of construction land allocation. According to the relevant research, if the current situation of construction land is relatively healthy per capita construction land area exceeds the standard, although the urban land security capacity is strong, but the land use efficiency is low. Such land allocation is unreasonable.

[2] The smallest per capita cultivated land area in Shanghai in 2004 was 0.045 hectares according to relevant study (Zhu and Zhang, 2007). Statistics show that the per capita cultivated land area of China is 0.09 hectares in 1998-2007 and 0.08 hectares in 2008-2017, respectively. In this paper, the minimum per capita cultivated land area is 0.04 hectares per person.

housing construction area as an index. Before 2007, the index was converted into per capita housing area, with a conversion rate of 51%[3].

(7) Urban-rural disparity index. It is the ratio of disposable income of town residents to per capita net income of rural residents. The closer the index is to 1, the smaller the income gap between urban and rural areas is, the higher the sharing level of urban and rural development results is.

(8) The registered urban unemployment rate. This paper calculates the indicator by the ratio of registered unemployment in cities and towns to the sum of registered unemployment in cities and towns. Due to the change of statistical methods, the unemployment rate of urban survey is taken as the index after 2011.

(9) Social insurance coverage. The index refers to the proportion of urban and rural insured persons in the permanent population, which is based on the permanent population and takes into account both urban and rural conditions. Because of the great changes in China's urban and rural social insurance system, the number of people who have basic medical insurance in urban enterprises and institutions (including retirees, individual businesses and freelancers) as well as the basic medical insurance for urban workers, basic old-age insurance for urban workers, social old-age insurance for urban residents, rural cooperative medical insurance, new rural social old-age insurance and the basic medical insurance for urban and rural residents and other types of insurance data are calculated in this study. The selection and calculation of indicators should not overlap or omit as much as possible.

2.2.2. Determination of Weight Coefficient

The weights of urban vulnerability index and related indexes are calculated by analytic hierarchy process (AHP). The impact and mechanism of each index on urban vulnerability are different. The index system of urban comprehensive vulnerability measurement and its related values, index properties and the corresponding data sources are shown in Table 1 below.

Table 1 Table of Comprehensive Measurement Index System of Urban Vulnerability

Target Level	Weight	Principal Level	Divided Weight	Indicator Layer	Unit	Property	Data Source
B1 Resource Vulnerability	0.2	C1 Resource Utilization Vulnerability	0.45	D1 Comprehensive Energy Consumption per Unit GDP	Tons of standard coal / 10,000 yuan	+	"2017 Shanghai Statistical Yearbook"
				D2 Water Consumption per Unit GDP	m³/10,000 yuan	+	calculated according to the Statistics Yearbooks
				D3 Electricity Consumption per Unit GDP	kWh/10,000 yuan	+	calculated according to the Statistics Yearbooks
				D4 Construction Land Occupation per Unit GDP	k ㎡/10,000 yuan	+	calculated according to relevant data
		C2 Resource	0.55	D5 Water Resources Support Capability	—	-	calculated according to relevant data

[3] This value is calculated based on the data of the "Shanghai Statistical Bulletin on National Economic and Social Development" in 2008 and following years.

		Security Vulnerability		**D6** Construction Land Support Capability	—	-	calculated according to relevant data
B2 Eco-Environment Vulnerability	0.3	**C3** Ecological Vulnerability	0.36	**D7** Green Coverage Rate of Built-up Area	%	-	"Shanghai Statistical Yearbooks"
				D8 Forest coverage	%	-	National Data& "Shanghai Statistical Yearbooks"
		C4 Environmental Vulnerability	0.64	**D9** Coal Consumption per Unit GDP	Tons / 10,000 yuan	+	calculated according to relevant data
				D10 Good AQI Ratio	%	-	"Shanghai Municipal Environmental Status Bulletin"
				D11 Urban Sewage Centralized Treatment Rate	%	-	"Urban Construction Statistical Yearbooks"
				D12 Environmental Protection Input Intensity	%	-	"Shanghai Statistical Yearbooks"
				D13 Harmless Treatment Rate of Domestic Waste	%	-	"Urban Construction Statistical Yearbooks"
B3 Economic Vulnerability	0.2	**C5** Economic Structural Vulnerability	0.33	**D14** Proportion of Added Value of Tertiary Industry	%	-	"Shanghai Statistical Bulletin on National Economic and Social Development"
				D15 Economic Extroversion	%	-	"2017 Shanghai Statistical Yearbook"
		C6 Economic Innovation Index	0.37	**D16** R&D investment intensity	%	-	"Statistical bulletin on national science and technology funding"
		C7 Economic Efficiency Index	0.30	**D17** Input-output Ratio	%	-	calculated according to the National Data
B4 Social Vulnerability	0.3	**C8** Human Development Vulnerability	0.37	**D18** Natural Population Growth Rate	‰	-	National Data
				D19 Number of College Students per 10,000 People	people	-	"2017 Shanghai Statistical Yearbook"
				D20 Number of Doctors per 10,000 People	people	-	"2017 Shanghai Statistical Yearbook"
				D21 Urban per Capita Housing Area	㎡	-	calculated according to "Shanghai Statistical Bulletin on National Economic and Social Development"
				D22 Per capita GDP	10,000 dollars	-	"2017 Shanghai Statistical Yearbook"
		C9 Social Environment Vulnerability	0.33	**D23** Urban-rural Disparity Index	—	+	calculated according to "Urban Statistical Yearbook of China"
				D24 Registered Urban Unemployment	%	+	"Urban Statistical Yearbook of China"
				D25 Social Insurance Coverage	%	-	calculated according to "Shanghai Statistical Bulletin on National Economic and Social Development"
		C10 Infrastructure Vulnerability	0.30	**D26** Mobile Phone Coverage	%	-	calculated according to "Shanghai Statistical Bulletin on National Economic and Social Development"
				D27 Internet User Popularity Rate	%	-	calculated according to "Shanghai Statistical Bulletin on National Economic and Social Development" & National Data
				D28 Water Supply Pipe Density in Built-Up Area	km/k ㎡	-	"Urban Construction Statistical Yearbooks"
				D29 Drainage Pipe Density in Built-Up Area	km/k ㎡	-	"Urban Construction Statistical Yearbooks"
				D30 Number of Operating Rail Transit Vehicles per 10,000 People	vehicle	-	"Urban Construction Statistical Yearbooks"

Source: Self-organized, summarized and made according to relevant information

Note: The process data of the number of permanent resident population, gross regional product, city total annual water supply , city annual electricity consumption, year-end total construction land area, daily water supply capacity of municipal tap water, year-end cultivated land area, city annual coal consumption, general budget revenue and expenditure of local finance, disposable income of urban residents, per capita net income of rural residents, number of basic medical insurance for urban and rural residents, number of basic medical insurance for workers and staff, year-end number of railway vehicles et al. are from the "Urban Construction Statistical Yearbooks",

"Shanghai Statistical Yearbooks", "Shanghai Statistical Bulletin on National Economic and Social Development" and the website of the National Bureau of Statistics.

2.3. Data Processing and Analysis Method

(1) Data standardization

The original data from the statistical yearbook are standardized to eliminate the influence of dimensional differences among different indicators. Thirty-one indicators in the evaluation system can be divided into positive and negative categories according to their impact mechanism on urban vulnerability, which are explained and dealt with as follows:：

Positive evaluation index: The larger the value, the greater the vulnerability. The processing method is as follows:

$$X_i = \frac{x_i - \min\{x_i\}}{\left|\max\{x_i\} - \min\{x_i\}\right|} \tag{3}$$

Negative evaluation indicator: The larger the value, the smaller the vulnerability. The processing method is as follows:

$$X_i = \frac{\max\{x_i\} - x_i}{\left|\max\{x_i\} - \min\{x_i\}\right|} \tag{4}$$

where: Xi represents the dimensionless index of 30 indicators x_i ; $\max\ \{x_i\}$ and $\min\ \{x_i\}$ are the maximum and minimum values of the evaluation index in the study period.

(2) Sub-index measurement (Layer C)

The sub-index vulnerability indexes (Layer C) refer to the indexes in the Indicator layer. The calculation formula is as follows:

$$UVI_e = \left(\sum_{i=1}^{n} x_i\right) / n \tag{5}$$

where: X_i is the standardized value of individual indicators; n is the number of individual indicators contained in each sub-factor vulnerability index; UVI_e represents the sub-index of urban vulnerability, including 10 sub-indexes such as resource-utilization vulnerability index, eco-environment vulnerability index, environmental vulnerability index, economic structure index and human development index.

(3) Sub-factor measurement (Layer B)

The urban sub-factor vulnerability indexes (layer B) are indexes in the Principal level. The index is calculated by weighting method and the formula is as follows.

$$UVI_s = \sum_{i=1}^{m} (UVI_e)_i W_i \tag{6}$$

where: UVI_e represents the vulnerability index of each sub-index. m is the number of sub-factor vulnerability indexes. W_i is the weight of each index at the Principal level. UVI_s refers the urban sub-factor vulnerability indexes including resource vulnerability index, eco-environment vulnerability index, economic vulnerability index and social vulnerability index.

(4) Comprehensive vulnerability measurement

The urban comprehensive vulnerability index is calculated by weighting the sub-factor vulnerability indexes. The calculation formula is as follows:

$$UVI = Q_1 \times UVI_{s1} + Q_2 \times UVI_{s2} + Q_3 \times UVI_{s3} + Q_4 \times UVI_{s4} \quad (7)$$

where: UVI_{si} refers the sub-factor vulnerability indexes. Q_i is the corresponding weigh. UVI is the urban comprehensive vulnerability index.

3. Evolution Characteristics of Sub-factor Urban Vulnerability in Shanghai

3.1. Evolution Characteristics of Resource Vulnerability

Shanghai's urban resource vulnerability fluctuated but remained high between 2002 and 2008. From 2008 to now, it has shown a decreasing trend, but it has a certain volatility (Fig. 2). The fluctuation of the index is greatly influenced by the sub-index resource security vulnerability index (C2), while the resource utilization vulnerability index (C1) of Shanghai has been in a steady decline, indicating that the utilization of energy and resources such as water, electricity and land has been steadily increasing.

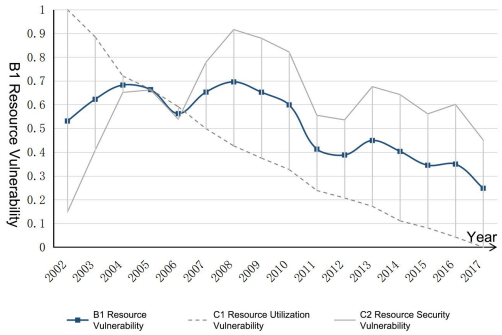


Figure 2 Trend of Urban Resource Vulnerability in Shanghai (2002-2017)

Source: Drawn by the author

From the perspective of resource security vulnerability, it is found that, except for 2006, the resource vulnerability of Shanghai increased from 2002 to 2008, and declined after 2008. The urban construction land security capacity in Shanghai has always been under great pressure, especially the per capita cultivated land area. In recent years, the rapid development of Shanghai in the context of globalization has brought tremendous demand for living space of urban population. Therefore, urban cultivated land is facing severe pressure. In 2015, the per capita cultivated land area

of Shanghai is only 0.008 hm^2/person, accounting for only 8.15% of the national average (0.982 hm2/person) (Gao, 2018). Food the city demand is largely transferred from other provinces. In 2013, Shanghai established the basic land use strategy of "total lock-in, incremental decline, stock optimization, flow efficiency enhancement and quality improvement". Then the government put forward population restriction and a series of related policies to clarify that the city has entered the "reduced development" mode in order to implement population structure optimization and move towards a new stage of innovative urban development.

3.2. Evolution Characteristics of Eco-Environment Vulnerability

Shanghai's eco-environment vulnerability index decreased from 0.755 in 2002 to 0.133 in 2017, which indicates that the carrying capacity of urban eco-environment has increased greatly, and the capacity of eco-environment as the material carrier of the city has been greatly enhanced. The sub-index urban ecological vulnerability index (C3) shows a downward trend in general, but the fluctuation is large. The whole evolution process can be divided into three stages: the fluctuation is flat during 2002 to 2004, the rapid decline during 2004 to 2009 and the slow decline after 2009 (Fig. 3). The change of the index reflects that China's urban development has moved from the dominant stage of economic construction to the period of green ecology and sustainable development. The concrete manifestation of urban construction is that the forest coverage and green coverage of built-up areas in Shanghai have increased rapidly in the past 15 years. According to the data of Shanghai Statistical Yearbook 2017, the forest coverage and green coverage of built-up areas in Shanghai are 16.2% and 39.1% respectively.

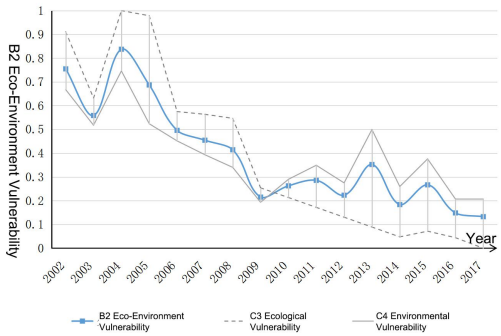


Figure 3 Trend of Urban Eco-environment Vulnerability in Shanghai (2002-2017)

Source: Drawn by the author

In contrast, the reduction rate of urban environmental vulnerability index (C4) is smaller. In recent years, good results have been achieved in the construction of ecological environment in Shanghai: the carbon emission per unit GDP has decreased, the centralized treatment rate of urban sewage has been over 90% since 2012, and the domestic waste has been treated completely harmlessly since 2014. Relevant data show that Shanghai's air quality index(AQI) has improved significantly in the pre- and mid-2010 World Expo, indicating that the implementation of the four rounds of "three-year action plan for environmental protection" since 2000 and the implementation of air pollution control measures during the Expo have achieved

remarkable results. From 2009 to 2012, the ratio of days with good air quality has been above 90%. However, after the World Expo, air pollution rebounded seriously, and air quality declined sharply since 2013 (66% in 2003). Although AQI of Shanghai has increased in recent years, it is still lower than the national average. The decrease of air quality is mainly manifested in the obvious increase of NO_2 and PM_{10} concentrations. Besides the unfavorable diffusion of pollutants in winter, the main reasons are the relaxation of temporary control measures during the World Expo, the large number of construction projects, the rise of construction dust pollution, the rebound of straw incineration and garbage incineration, and the aggravation of local air pollution (Huang et al., 2013).

3.3. Evolution Characteristics of Economic Vulnerability

Overall, the vulnerability of Shanghai's urban economy has continued to decline over the past 15 years, with a sharp decline during 2003 to 2007, an upward trend during 2007 to 2009 and a flat fluctuation in the past four years (Fig. 4).

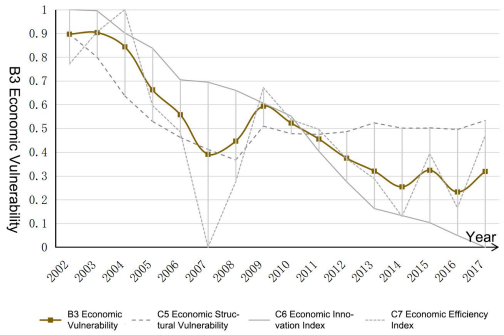


Figure 4 Trend of Urban Economic Vulnerability in Shanghai (2002-2017)

Source: Drawn by the author

Among them, economic structural vulnerability (C5) declined steadily from 2002 to 2008, and then the change became flat. During 2002 to 2008, Shanghai's industrial structure was in a period of rapid transformation. During this period, the economic development aimed at adjusting and optimizing industrial structure and improving industrial innovation ability. The proportion of tertiary industry to GDP rose rapidly. The dependence on urban foreign trade the ratio of total urban exports to GDP) increased first and then decreased, and finally stabilized at about 43%. The index of economic extroversion has both positive and negative aspects. Under the background of economic globalization, Shanghai is in the vanguard position of integrating into the international network, and its market openness ranks first in China. However, while gaining export growth to accelerate economic growth, Shanghai recognizes that there are huge risks behind the higher degree of dependence on foreign trade - the regional economy will be very sensitive to the fluctuations of the world economy.

Therefore, Shanghai focuses on the cultivation and development of the domestic market, optimizing the industrial structure, and vigorously developing technological progress and technological innovation in order to increase the resilience and adaptability of the urban economy to external influences. Shanghai's investment

intensity in R&D has increased from 1.9% in 2002 to nearly 3.9% in 2017. Focusing on technological innovation capability can improve Shanghai's position in the world economy, change the situation of high dependence on the international market, and develop the self-control of enterprises' living conditions.

3.4. Evolution Characteristics of Social Vulnerability

Social vulnerability consists of human development vulnerability (C8), social environment vulnerability (C9) and infrastructure vulnerability (C10). The analysis finds that Shanghai's social vulnerability has been declining steadily from 2002 to 2017, and the decline rate of urban social vulnerability is the fastest from 2010 to 2012 (Fig. 5).

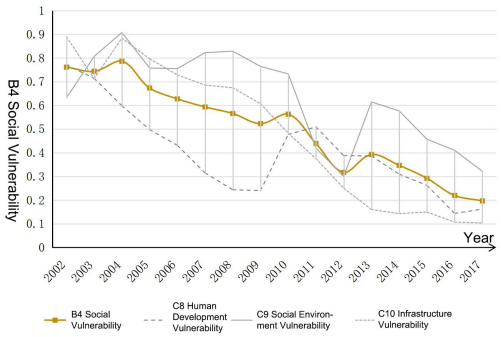


Figure 5 Trend of Urban Social Vulnerability in Shanghai (2002-2017)

Source: Drawn by the author

From 2010 to 2012, the rapid decline of urban social vulnerability is mainly affected by social environmental vulnerability (C9). This change is reflected in the rapid decline of urban registered unemployment rate and the rapid rise of social insurance coverage at indicator layer (Layer D) . It can be seen that the construction of Shanghai's urban social welfare and basic security system is advancing. Urban development is paying more and more attention to "social justice", and vulnerable groups are receiving more attention and social security.

In addition, the material living standards of residents have steadily improved, with the annual growth rate of per capita GDP in Shanghai reaching 10.7% between 2002 and 2017. Urban infrastructure construction has been improved, and the medical, educational and housing conditions have been improved. However, the difference between urban and rural areas in Shanghai is very significant. In 2004, the difference index between urban and rural areas in Shanghai reached the highest level, which was 2.36. And the average value in the past five years is 2.29, which has always been above the international standard value of 2. In the new period of "urban-rural integration" development, we need to explore the road of rural revitalization, promote the coordinated development of urban-rural economy and society, and build a new urban-rural relationship.

4. Evolution Analysis of Urban Comprehensive Vulnerability

4.1. Evolution Characteristics of Urban Comprehensive Vulnerability

From 2002 to 2017, Shanghai's urban comprehensive vulnerability declined from 0.74 to 0.2, and the overall vulnerability fluctuated continuously in the form of "N" (Fig. 6). The development process of urban comprehensive vulnerability can be roughly divided into five stages: fluctuation rising stage (2002-2004), extreme decline stage (2004-2006), slow decline stage (2006-2010), rapid decline stage (2010-2012), fluctuation declining stage (2012-2017). The peak value of urban comprehensive vulnerability is 0.79 in 2004, and the ecological vulnerability is also at its maximum. This shows that Shanghai's ability to resist external adverse effects such as climate change and natural disasters is very weak in 2004, and the possibility of damage is the greatest, and the cycle of restoring urban functions is the longest.

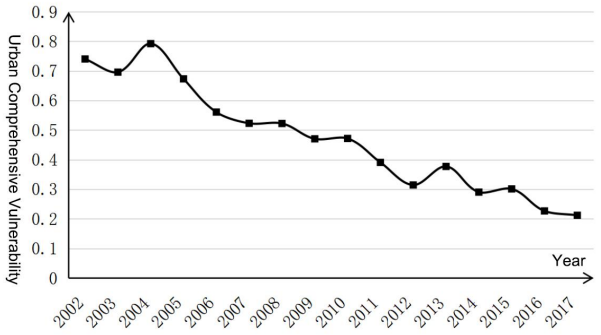


Figure 6 Trend of Urban Comprehensive Vulnerability in Shanghai (2002-2017)

Source: Drawn by the author

Since 2006, with the adjustment and effective implementation of Shanghai's targeted urban development strategy, the contradictions of various systems in the process of urbanization have been constantly mended. In addition, the hosting of the 2010 Shanghai World Expo international events has greatly promoted the construction of the ecological environment, economy and society in Shanghai.

4.2. Factor Interconnection Analysis

Overall, from 2002 to 2017, the vulnerability of urban resources, ecology, economy and society in Shanghai showed a downward trend as a whole, but there was a complex synergistic and causal relationship between the evolution of the four elements (Fig. 7).

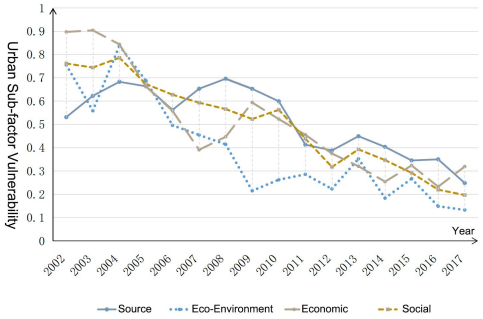
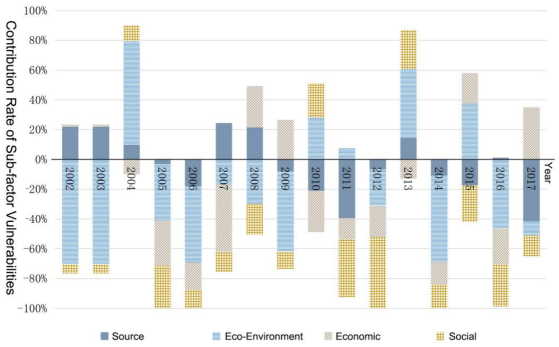


Figure 7 Trend of Sub-factor Vulnerabilities in Shanghai (2002-2017)

Source: Drawn by the author

From the point of view of the contribution rate of resources, ecology, economy and social vulnerability to urban comprehensive vulnerability, the mechanism (positive or negative) and magnitude of each sub-factor have great fluctuation (Fig. 8). The obvious evolution characteristics are as follows: (1) the contribution rate of economic vulnerability is the lowest, but it has increased significantly in the past 15 years, from 6.2% in 2002 to 35.0% in 2017; (2) the contribution rate of ecological vulnerability is the largest, but the dominant position of urban comprehensive vulnerability has weakened in recent years.



Note: The positive contribution rate of the sub-elements in the figure indicates that the sub-factors have a negative correlation with urban vulnerability in the next year, which means that the comprehensive vulnerability of the city is increased.

Figure 8 Contribution Ratio of Sub-factor Vulnerabilities (2002-2017)

Source: Drawn by the author

This shows that Shanghai has changed from the absolutely eco-environment-dominant vulnerability to a more diversified and balanced vulnerability composition pattern. It also shows that the city is more resistant, adaptable and transformable in the face of adverse disturbances from resources, ecology, economy and society. Shanghai is more capable of sustainable development.

5. Conclusion and Research Prospects

5.1. Conclusion

In the face of adverse events such as global climate change, the protection of urban basic security and sustainable development should be given priority. Urban vulnerability is a matter of "survival". This paper evaluates Shanghai's urban

vulnerability from four sub-factors: resources, eco-environment, economy and society. The results show that:

①During 2002 to 2017, the urban comprehensive vulnerability of Shanghai showed a fluctuating downward trend, among which the rate of decline during 2004 to 2006, and 2010 to 2012 was relatively high, which was the result of the urban construction driven by mega-events.

② Shanghai has changed from an absolutely eco-environment-dominant vulnerability to a more diversified and balanced vulnerability structure. Now four sub-factor vulnerabilities develop in a balanced way. It shows that the city has more resistance, adaptability and transformation ability when facing adverse disturbances of resources, ecology, economy and society.

③The contribution rate of resource vulnerability has also risen. This is mainly due to the enormous pressure on cultivated land and the increasing demand of foreign population in Shanghai.

④What can not be ignored is that the reduced ecological vulnerability is still the main cause of urban vulnerability, which is mainly due to the loosening of urban air quality control and changes in climatic conditions after the World Expo.

5.2. Research Prospects

Because of data limitation, the time interval of this study is too short to observe the coupling mechanism between Shanghai's development law and the four sub-factors more holistically and objectively. In addition, this paper evaluates the comprehensive vulnerability of Shanghai in order to explore the transformation and sustainable development path under the new development challenges. But how to measure urban vulnerability? How to explore the occurrence function of urban vulnerability? What is sustainability and transformation mechanism of urban function under adverse interference? These are the research problems that this paper can not solve but need to be discussed in depth.

6. References

An, Shiwei; Wan, Sanmin; Li, Xiaojian (2017) "Evaluation and Risk Control on Urban Vulnerability in Henan Province", Economic Geography, Vol. 37 No.5:81-86.

Cheng, Lin; Xiu, Chunliang; Zhang, Zhe (2011) "Urban vulnerability and preventive measures to it", Urban Problems, No.4:45-47.

Fang, Chuanglin; Wang, Deli (2011) "Comprehensive measures and improvement of Chinese urbanization development quality", Geographical Research, Vol. 30 No.11:1931-1946.

Fang, Chuanglin; Wang, Yan (2015) "A comprehensive assessment of urban vulnerability and its spatial differentiation in China", Acta Geographica Sinica, Vol. 70 No. 2:234-247.

Gao, Jing (2018) Spatial and Temporal Change Characteristics and Influencing Factors of Cultivated Land in Shanghai Suburbs, Master, East China Normal University.

Gu, Honghong (2016) Social Vulnerability Assessment of Natural Disasters in Shanghai Based on Community Scale, Doctor, Shanghai Normal University.

Huang, Yanmin; Wei, Hai-Ping; Duan, YuSen; Zhang, YiHua (2013) "Ambient Air Quality Status and Reason Analysis of Shanghai World Expo", Environmental Monitoring in China, Vol. 29 No.5:58-63.

Li, Bo; Han, Zenglin (2010) "Regional System Vulnerability of Man-Land Relationship in Coastal Cities -a Case Of Dalian City", Economic Geography, Vol. 30 No.10:1722-1728.

Liu, Haiyan (2008) Study on Urban Land Use Guarantee in the Process of Urbanization in China, Doctor, Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences.

Pan, Runqiu; Ma, Jun(2016) "Vulnerability and Its Pattern Changes of Shanxi's Coal-Based Cities", Resources & Industries, Vol. 318 No.3:1-6.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., ... & Polsky, C. (2003) "A framework for vulnerability analysis in sustainability science", Proceedings of the national academy of sciences, Vol. 100 No. 14, 8074-8079.

Wang; Lucang; Shi, Kaiwen; Liang, Zhen (2017) "Study on Comprehensive Evaluation and Dynamic Evolution of Urban Vulnerability: Taking Lanzhou City as an Example". Ecological Economy, Vol. 33 No.9:137-141+179.

Wang, Yan; Fang, Chuanglin (2014) "Comprehensive Evaluation and Dynamic Evolution Analysis of Daqing's Urban Vulnerability", Scientia Geographica Sinica, Vol. 34 No.5:547-555.

Xu, Jun; Li, Guifang; Wang, Yuhong (2015) "Review and prospect of resource-based city vulnerability in China and Abroad", Resources Science, Vol. 37 No.6:1266-1278.

Yu, Yingying (2011) "Research on evaluation system of city vulnerability", Journal of Beijing Institute of Machinery, Vol. 26 No.1:57-61+72.

Zhang, Xiaorui; Li, Tao; Fang, Chuanglin; Wang, Zhenbo (2016) "Comprehensive Measurement of Urban Vulnerabilit", Geography and Geo-Information Science, Vol. 32 No.02:89-93.

Zhao, Yinbing; Zhang, Tingting; Hong, Yan (2018) "On the Evolution of Urban Vulnerability in Chengdu", Scientific and Technological Management of Land and Resources, Vol. 35 No.3:98-107.

Zhu, Hongbo; Zhang, Anlu (2007) "Analyzing Temporal and Spatial Distribution Characteristics of Pressure Index of Cultivated Land in China", Resources Science, Vol. 29 No.2:104-108.