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Evaluation Indexes and Spatial-Temporal Features towards Urban Resilience of Sichuan Province in China from 2003 to 2013

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Abstract

New pattern urbanization, which is explored and developed in China for improving urban resilience and reducing urban vulnerability. Urban resilience is a comprehensive ability of a city for dealing with the uncertainty risk disasters through a combination of urban economy, urban engineering, urban society and urban ecology. When the city system and its subsystems have certain resilience in development, it will promote sustainable development. How to assess urban resilience? What is the spatial-temporal law on the development of urban resilience? These answers have an important practical significance for promoting the construction of the modern urbanization and sustainable development of cities and regions. Based on the above, this study constructed the measurement system on urban resilience, chose 21 cities of Sichuan province in China as a case, and analyzed the spatial-temporal law on the development of urban resilience empirically. The conclusions are as follows: The level of urban resilience was on the rise, and the characteristics of spatial heterogeneity on urban resilience were presented, and the spatial agglomeration degree increased gradually. The resilience of urban economic system, urban engineering system, and urban ecological system revealed a cluster characteristic in Sichuan province, but urban social system was not obvious.

Keywords

Urban Resilience, Assessment System, Spatial-Temporal Evolution, Sustainable Development

1. Introduction

In the process of social and economic development, city faces the pressure of population concentration, resource consumption and environmental pollution. Uncertainty events brought by natural hazard and human-made disasters more frequent in urban area, with growing impact on city's economic and social development. Urban diseases become apparent indefinitely, which will increase the potential social and economic losses in the city. Urban resilience is the ability of an urban system, urban community, or urban society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard promptly and efficiently (Jha, Miner, & Stanton-Geddes, 2013). Urban resilience includes four components, that are infrastructural, institutional, economical, and social. The practice of urban construction in advanced countries shows that resilient city construction is a more effective way to do with potential threats, such as flood, drought, terrorist activity and air pollution (Jha, Miner, & Stanton-Geddes, 2013). Theoretically, the resilient city is a city that has the capacity to undertake, recover and prevent various potential impacts or shocks on urban engineering, economic, social and environmental. Resilient city has been a hotspot in the development of urban areas now (Pu & Qiu, 2016).

China is facing the pressure of urbanization, and how to improve urban resilience and urban sustainable development, to improve socio-economic progress (Pu & Qiu, 2015; Suárez et al., 2016). Sichuan is an important economic center in Western China, its engineering, social, economic and environmental development level directly determines the level of urbanization construction of Sichuan, is a matter of Sichuan's dream of building a powerful agricultural province. How to measure urban resilience? What is the spatial-temporal law on the development of urban resilience? Especially the earthquake in 2008, whether did it impact of urban resilience of Sichuan province, it is just an interesting question.

Researchers from multiple disciplines are studying the feedback, dynamics, and behavior of urban vulnerability and urban resilience in the face of urban crisis, such as the axioms and mean of urban resilience (Campanella, 2006; Surjan, Sharma, & Shaw, 2011; Wilkinson, 2012), Climate change and urban resilience (Childers et al., 2012; Grimm et al., 2008; Leichenko, 2011), spatial planning and urban resilience in the flood risk (Tyler & Moench, 2012; Deppisch & Schaerffer, 2011; Cruz et al., 2013), urban resilience and human-dominated ecosystems (Lu, 2014), urban infrastructure systems (Ernstson et al., 2010; Wilbanks et al., 2012), urban resilience index (Ouyang & Wang, 2015; Attoh-Okine, Cooper, & Mensah, 2009), urban social resilience (Sellberg, Wilkinson, & Peterson, 2015) and resilient cities (Cutter, Burton, & Emrich, 2010; Desouza & Flanery, 2013; Vale, 2014). Furthermore, topics on urban resilience and its related domain have become hot-debated focus (Pu & Qiu, 2016; Beilin & Wilkinson, 2015). It is necessary to describe the status qua on urban resilience measure for exploring urban and regional development.

In this article, we will establish an evaluation system of urban resilience; identify the spatial-temporal features of urban resilience of Sichuan province.

2. Materials and Methods

About research route, firstly, form four subsystems of urban resilience; secondly, collect and deal with the data; thirdly, get urban subsystem index and a composite index; then, analyse the result on urban resilience; finally, feedback message. Detailed research route is illustrated in Figure 1.

2.1. Index Choice

Four subsystems of urban resilience which include urban engineering subsystem, urban economic subsystem, urban society subsystem, and urban ecology subsystem (see Table 1).

Two indicators of urban engineering subsystem have been selected, such as communication index and livelihood protection index. Some indicators of urban economic subsystem have been observed out, including economic potential index, economic effectiveness index, and economic innovation index. Society development index and human development index have been picked for urban society subsystem. Meanwhile, environmental efficiency index and environmental governance index have formed for urban ecology subsystem.

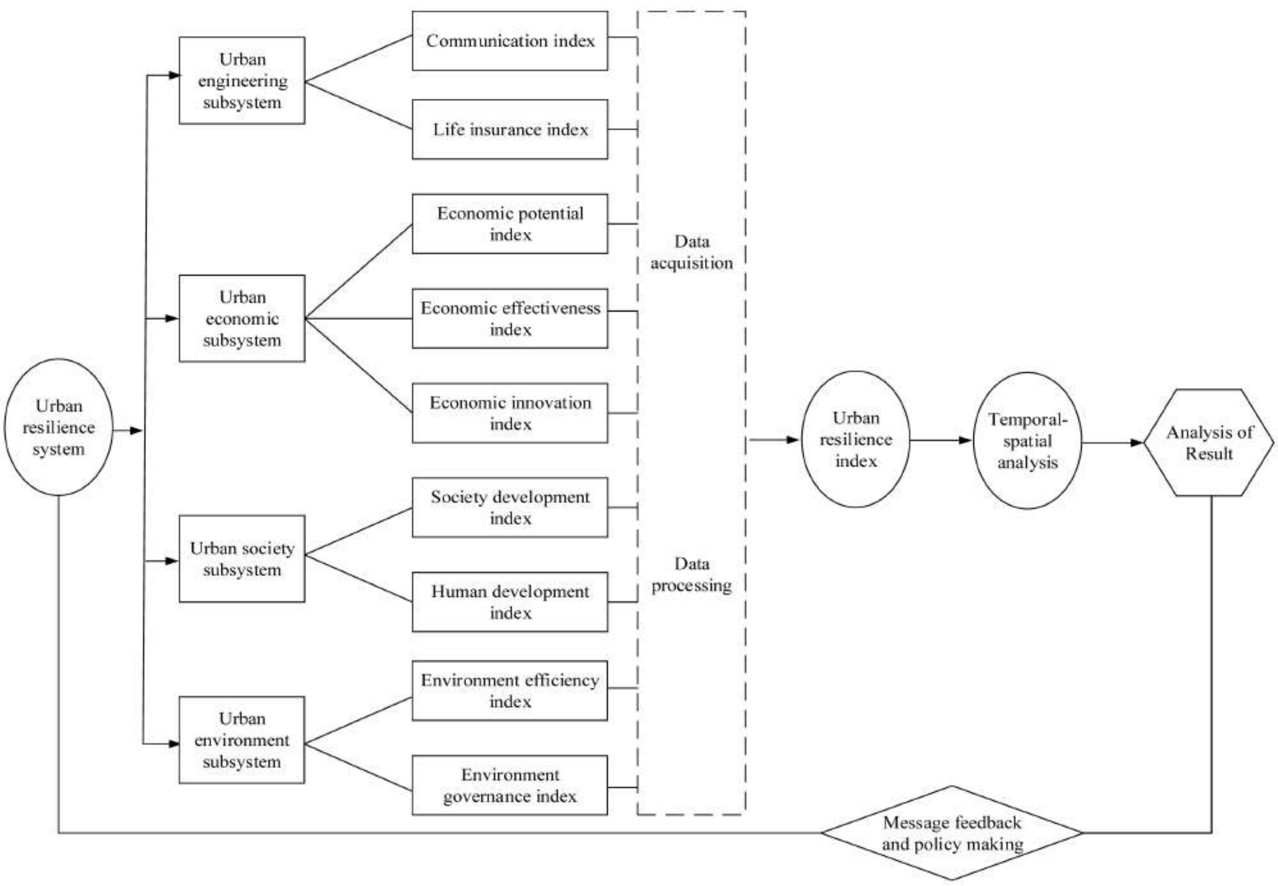

Figure 1. Research technique route.

Table 1. The evaluation index of urban resilience.

Total system	subsystem	The third system	The evaluation index	SI (unit)
Urban resilience system (s)	Urban engineering subsystem (x_1)	The level of communication (x_{11})	Bus number per ten thousand people (x_{111})	1
			Road area per capita (x_{112})	m^2
			Mobile phone number per capita (x_{113})	1
		The level of livelihood protection (x_{12})	Water resources per capita (x_{121})	Tons per person
			Power resources per capita (x_{122})	Kwh per person
	Urban economic subsystem (x_2)	The level of economic potential (x_{21})	GDP growth rate (x_{211})	%
			Tertiary industry proportion (x_{212})	%
		The level of economic effectiveness (x_{22})	GDP per square kilometers (x_{221})	Ten thousand Yuan per km^2
			GDP per ten thousand persons (x_{222})	Ten thousand Yuan per person
		The level of economic innovation (x_{23})	Technology input proportion (x_{231})	%
	Urban society subsystem (x_3)	The level of society development (x_{31})	Population density (x_{311})	Persons per km^2
			Urbanization rate (x_{312})	%
		The level of human development (x_{32})	Unemployment rate (x_{321})	%
			Medical level index (x_{322})	Doctors per ten thousand persons
			Learning resource index (x_{323})	Books per thousand persons
			Student number in university (x_{324})	1
	Urban ecology subsystem (x_4)	The level of environment efficiency (x_{41})	Green cover rate (x_{411})	%
		The level of environment governance (x_{42})	Industrial solid waste utilization (x_{421})	%
			Living sewage treatment rate (x_{422})	%
			Urban rubbish treatment rate (x_{423})	%
			Sulphur dioxide treatment rate (x_{424})	%

2.2. Data Standardized

The urban system is an organic whole of urban engineering subsystem, urban economic subsystem, urban society subsystem, and urban ecology subsystem. In urban synthetic system, those subsystems interacted each other. Therefore, the composite urban resilience system is expressed as: $S = f\left(x_1, x_2, x_3, x_4\right)$, where x_1 represents urban engineering subsystem, x_2 is on behalf of urban economic subsystem, x_3 is urban society subsystem, x_4 represents urban ecology subsystem, and f is a composite function.

The indicator of the four subsystems is $x_{ij} = \left(x_{ij1}, x_{ij2}, \cdots, x_{ijk}\right), i \in [1, l]$,

$j \in [1, m], l \geq 1, m \geq 1$. It can describe running state of four subsystems (*ij*) about urban engineering subsystem, urban economic subsystem, urban society subsystem, and urban ecology subsystem. Where α_{ijk} is upper limit and β_{ijk} is lower limit. There are $\beta_{ijk} \leq x_{ijk} \leq \alpha_{ijk}, k \in [1, n]$, and $n \geq 1$.

In addition, one indicator has two kinds: one is positive index. It is better when one index value is higher; conversely, it is the lower. The other is a negative index. It is better when one index value is lower. Data standardized about index (x_{ijk}) can be defined.

$$Y_{ij}(x_{ij}) = \begin{cases} \dfrac{x_{ijk} - \beta_{ijk}}{\alpha_{ijk} - \beta_{ijk}} \left(i \in [1,4], j \in [1,3], k \in [1,4]\right), & \text{when } x_{ijk} \text{ is positive} \\ \dfrac{\alpha_{ijk} - x_{ijk}}{\alpha_{ijk} - \beta_{ijk}} \left(i \in [1,4], j \in [1,3], k \in [1,4]\right), & \text{when } x_{ijk} \text{ is negative} \end{cases} \tag{1}$$

where $y_{ij}(x_{ij}) \in [0,1]$. Its value is greater, and the contribution is higher.

2.3. Index Weight

At present, index weight methods include subjective method, objective method, and mixed method. The former has expert scoring method and Delphi method; the middle include entropy value method, standard deviation method and CRITIC method (Suárez et al., 2016); the latter is a mixture method subjective method and objective method. This study selected CRITIC method to do with weight of the index.

Firstly, confirming the effect of indexes:

$$C_k = \delta_k \sum_{k=1}^{n} \left(1 - r_{jk}\right), k \in [1,4] \tag{2}$$

Among them, C_k represents the impact of index (*k*) in the subsystem, δ_k is half on the standard deviation of index (*k*), r_{jk} represents the correlation coefficient between index (*j*) and index (*k*). The value of C_k is greater, and it is more important to the subsystem.

Secondly, confirming the weight of index:

$$\omega_k = \frac{C_k}{\sum_{k=1}^{n} C_k}, k \in [1,4] \tag{3}$$

where ω_k is objective weight of index (*k*). Then, the matrix of weight coefficient $R_\omega = \{\omega_1, \omega_2, \cdots, \omega_k\}$ will be gained.

2.4. Index Model

Firstly, the contribution of index (y_i) can be shown by $y_{ij}(x_{ij})$. For using of different forms of data, it is necessary to use the linear weighted sum method for data processing. The model of subsystem is followed.

$$Y_i(x_i) = \sum_{q=1}^{p} \omega_k Y_{ij}(x_{ij}), w \geq 0, \sum_{q=1}^{p} \omega_k = 1 \tag{4}$$

Secondly, urban resilience index for each city can be got from following forum.

$$S = \frac{1}{4}\sum_{q=1}^{4} Y_i\left(x_i\right), i \in [1,4] \tag{5}$$

3. Empirical Study and Results

3.1. Sampling and Data

Sichuan province locate in Western China, which includes 21 cities, such as Chengdu city, Panzhihua City, Deyang City, Neijiang City, Mianyang City, Zigong City, Yibin City, Yi Autonomous Prefecture of Liangshan, Tibetan Autonomous Prefecture of Aba, and so on. Urban natural ecosystems are fragile, in recent years, natural disasters brought a serious threat to the urban security and urban development.

Relative data were collected about Sichuan province, including 21 cities. Index data came from Sichuan province statistical yearbook (2004-2014) and Chinese city statistics yearbook (2004-2014).

3.2. Data Processing

Firstly, according to Formula (1), standardized original data of the index by statistical software (SPSS21). Secondly, confirmed index weight for each city according to the former Formula (2) and Formula (3). Moreover, get urban subsystem resilience using Formula (4). Finally, using the Formula (5), urban resilience index was calculated respectively. Specific data are shown in **Table 2**.

3.3. Data Analysis

Table 3 shows urban resilience index of Sichuan province presented a rising trend from 0.188 in 2003 to 0.752 in 2013. The change of urban resilience consists of two stages. On the first phase from 2003 to 2008, urban resilience of Sichuan province was promoted from 0.188 to 0.448 gradually. On the second phase from 2008 to 2013, it was promoted from 0.448 to 0.752. **Figure 2** shows that there was a inflect point in 2008. Because the Wenchuan earthquake happened at Tibetan Autonomous Prefecture of Aba in Sichuan province. Sichuan was mistaken as "unsafe" area. With the policy and resource support of nation, urban resilience index demonstrated an increasing tendency in 2009.

Specially, there were different from change of urban subsystem resilience. Urban engineering resilience presented a little change from 2003 to 2007, but it kept a rapid growth since 2008. Urban economic resilience had a growth trend from 2003 to 2013, but there was a drop point in 2008. Urban social resilience and urban ecology resilience kept increasing since 2003. **Figure 3** shows that both urban engineering resilience and urban economic resilience were hit hard by the earthquake. After disaster, due to the attention of social public, urban four subsystem resilience had been rapidly promoted. Meanwhile, because of people's concern about ecological environment and social progress, urban ecology resilience and urban social resilience were getting better.

Table 2. Urban resilience index of 21 cities of Sichuan Province from 2003 to 2013.

City/Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Chengdu	0.175	0.330	0.391	0.366	0.538	0.576	0.607	0.756	0.786	0.825	0.767
Zigong	0.317	0.484	0.347	0.357	0.394	0.394	0.406	0.463	0.640	0.601	0.692
Panzhihua	0.366	0.327	0.393	0.292	0.412	0.431	0.471	0.487	0.590	0.640	0.758
Luzhou	0.292	0.485	0.447	0.520	0.360	0.380	0.421	0.491	0.676	0.677	0.781
Deyang	0.307	0.451	0.401	0.357	0.432	0.386	0.422	0.503	0.661	0.702	0.694
Mianyang	0.277	0.306	0.356	0.335	0.503	0.421	0.490	0.538	0.644	0.695	0.688
Guangyuan	0.182	0.293	0.369	0.334	0.421	0.359	0.491	0.500	0.558	0.598	0.739
Suining	0.264	0.434	0.300	0.480	0.468	0.510	0.589	0.521	0.584	0.571	0.645
Neijiang	0.189	0.337	0.277	0.369	0.407	0.416	0.449	0.529	0.640	0.632	0.683
Leshan	0.266	0.293	0.287	0.369	0.419	0.452	0.495	0.524	0.595	0.670	0.747
Nanchong	0.257	0.293	0.298	0.374	0.500	0.446	0.455	0.444	0.502	0.603	0.633
Meishan	0.229	0.354	0.344	0.498	0.464	0.450	0.401	0.404	0.466	0.531	0.668
Yibin	0.345	0.388	0.358	0.411	0.546	0.574	0.462	0.529	0.609	0.674	0.670
Guang'an	0.187	0.375	0.283	0.419	0.404	0.468	0.481	0.590	0.542	0.652	0.694
Dazhou	0.294	0.366	0.436	0.485	0.604	0.576	0.457	0.474	0.551	0.595	0.534
Ya'an	0.313	0.338	0.399	0.399	0.464	0.416	0.455	0.472	0.584	0.720	0.603
Bazhong	0.267	0.377	0.319	0.379	0.366	0.415	0.439	0.472	0.551	0.559	0.681
Ziyang	0.212	0.311	0.286	0.399	0.358	0.406	0.453	0.505	0.546	0.583	0.688
Aba	0.104	0.206	0.233	0.285	0.275	0.342	0.441	0.486	0.627	0.697	0.850
Garzê	0.105	0.241	0.215	0.312	0.312	0.426	0.498	0.588	0.735	0.672	0.930
Liangshan	0.206	0.331	0.211	0.307	0.285	0.375	0.475	0.575	0.701	0.754	0.793

Table 3. Urban subsystem resilience of Sichuan Province.

Year	Y1	Y2	Y3	Y4	S
2003	0.289	0.228	0.192	0.046	0.188
2004	0.310	0.304	0.481	0.251	0.337
2005	0.326	0.354	0.502	0.335	0.379
2006	0.205	0.447	0.522	0.439	0.403
2007	0.233	0.651	0.544	0.515	0.486
2008	0.206	0.356	0.639	0.590	0.448
2009	0.372	0.622	0.615	0.613	0.556
2010	0.668	0.656	0.686	0.771	0.695
2011	0.625	0.682	0.802	0.768	0.719
2012	0.807	0.546	0.862	0.850	0.766
2013	0.951	0.507	0.650	0.901	0.752

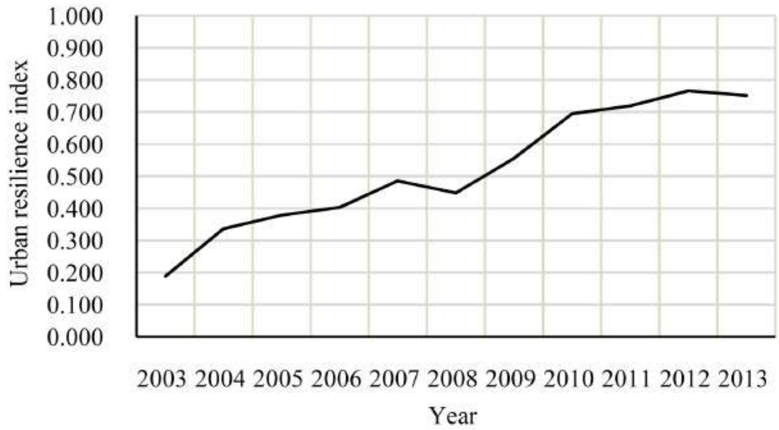

Figure 2. Urban resilience index of Sichuan Province.

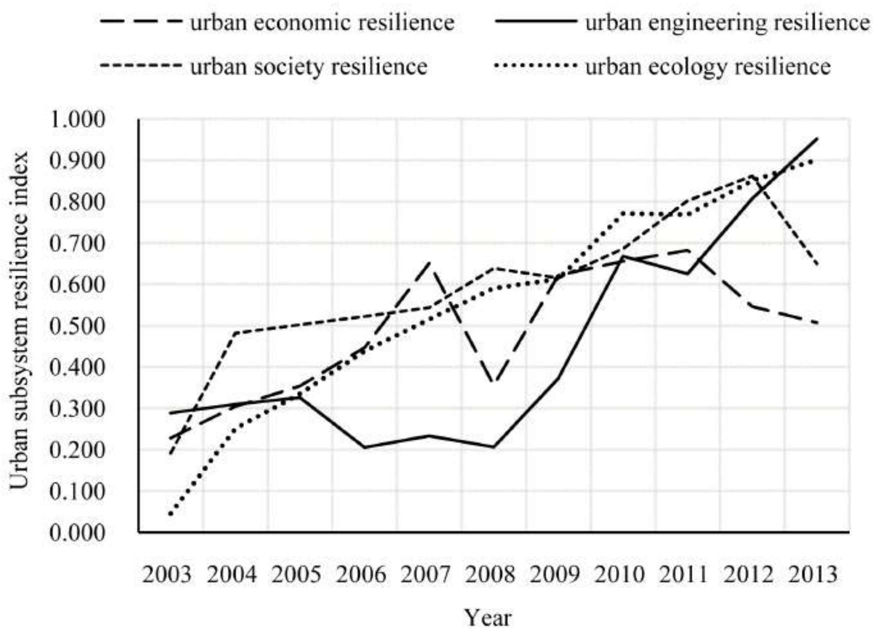

Figure 3. Urban subsystem resilience index of Sichuan Province.

LISA figure has been used for judging the temporal-spatial aggregation and differentiation of urban resilience of Sichuan province. Figure 4 shows that the urban resilience of Sichuan province had obvious spatial differentiation pattern in 2003 and 2008. High-low regional polarized city, Ya'an city, had appeared in 2003. This means that urban resilience of Ya'an city was relatively flexible, and its surrounding cities were low. High-high regional diffused city, Guang'an city, had appeared in 2008. This mean that urban resilience of Guang'an city was relatively flexible, and its surrounding cities were high too. In 2013, there were two regional diffused cities (Tibetan Autonomous Prefecture of Garzê and Tibetan Autonomous Prefecture of Aba), one low-high regional subsiding city (Ya'an city) and two low-low regional infectious cities (Guang'an city and Nanchong city), as showed in Table 4.

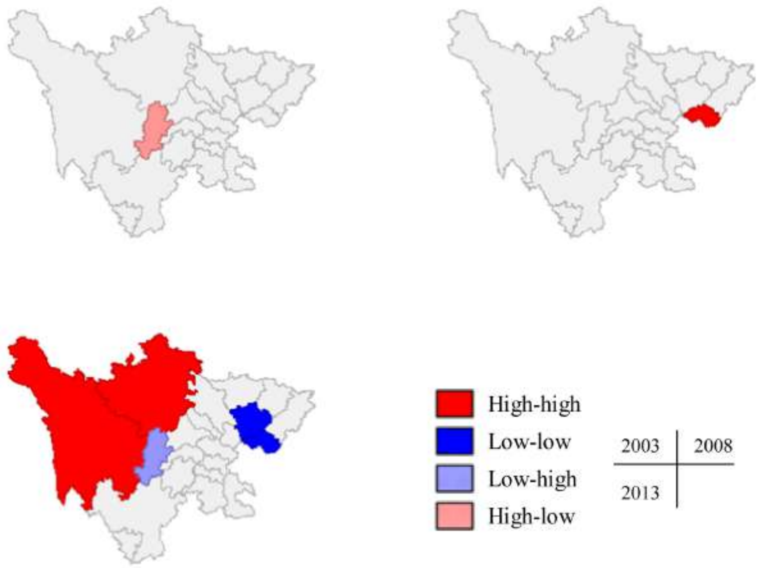

Figure 4. LISA figure of urban resilience index of Sichuan Province.

Table 4. Spatial differentiation type of Sichuan in 2013.

Type	HH	LH	LL
City Name	Aba, Garzê	Ya'an	Guang'an, Nanchong
City Number	2	1	2

4. Conclusion and Implications

Based on theories of resilient city and sustainable development, the model of urban resilience about urban engineering resilience, urban economic resilience, urban social resilience and urban ecology resilience was established, the advance state of them was evaluated. These are a basement of urban and regional integration progress with urban four subsystems.

5. Limitations and Prospects

This study has its limitations, for example, the data are only from yearbook. Meanwhile, this work is not covered with the social governance. Moreover, the index in our study has yet to be further improved. In the future, some studies towards urban resilience will be further. Firstly, urban resilience measure model will be improved by introducing weather indicators and local cultural indicators, such as air pollution, rate of blue sky, cultural exchange, cultural protection. Secondly, synergy development of urban subsystem will be strengthened, and change of urban subsystem resilience should be analyzed, and warning system about disaster should be formed. Thirdly, some case studies will be done for metropolis, such as Beijing, Shanghai, Chengdu, for their sustainable development. Finally, scope of relative research will be broadened, such as a regional research and a national research.

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Conflicts of Interest

The authors declare no conflict of interest.

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