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Ecological Resilience Assessment and Optimization Suggestions to Yangtze Middle Reaches Megalopolis

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Ecological Resilience Assessment and Optimization Suggestions to Yangtze Middle Reaches Megalopolis

Xiao Zhang

Abstract

Research on the assessment and regulatory management of regional ecological resilience is of great significance for both urbanization and sustainable development. This study selects Yangtze Middle Reaches Megalopolis which includes 4 urban agglomeration sub-regions such as Wuhan Agglomeration, Xiang-Yi-Jing City Belt, Chang-Zhu-Tan Agglomeration and Surrounding Poyang Lake Agglomeration totaling 31 cities in China as objects. Using systematic analyze combined with a comprehensive index assessment method, the study establishes an index system to assess the ecological resilient capacity for regional change and renewal. Regional ecological organization, function and maintenance as three major factors are placed emphasis on the assessment. And each of them involves 2-4 specific indexes including climate, vegetation coverage, urban eco-facilities and so on. In addition, the entropy value method is adopted to identify the weight of each index. After collecting datum and calculation, the resilience capacity of each city can be obtained. Then the GIS and regression model are used to analyze the results of ecological resilience in respective cities or regions. The results reveal the spatial differentiation among cities and the distribution pattern of the ecological resilience in the Yangtze Middle Reaches Megalopolis. There appear to be a small resilience capacity in the megalopolis meanwhile fragmentation is remarkable. The spatial distribution of ecological resilience capacity in the 4 urban agglomeration sub-regions is classified as balance pattern, severe fragmentation pattern and linear gradient pattern. Furthermore, city's population size is also verified to impact ecological resilience. Three suggestions for optimization are put forward in the discussion part. They are integrated promotion strategy, sub-regional control strategy and population control strategy. It is worth noting that 'Ecological Resilience Bank' is proposed creatively.

Keywords: Ecological Resilience, Capacity Assessment, Yangtze Middle Reaches Megalopolis, Optimization of Development.

Introduction

With the accelerating process of urbanization and industrialization, environment issues have come out such as excessive expansion of urban land, climate abrupt change, resource shortage and frequently occurred disasters in cities. Under this circumstance, the sustainable development of the region has received much attention from governments and urban planners. Since the 20th century, the notion of resilience has gained increasing prominence on urban sustainable development and environment management (Leichenko, 2011). In 2010, UNISDR - United Nations Committee on Disaster Reduction, launched the first "international conference on cities and adaptation to climate change", with the proposal of "Resilient City". After that lots of research groups and institutions related to resilience were set up in the United States, Britain, Germany, Australia and many other countries. In 2013, "Planning for Resilient Cities and Regions" has become the theme of the joint annual meeting of the alliance of Planning schools in America and Europe. For recent years, Chinese Ministry of Natural Resources has been established which made ecological resilience received more attention in China. Resilience can be divided into four priority areas: economy, society, engineering and ecology. Ecological resilience, as a new insight into region system, is therefore regarded as the key for taking actions to handle urban and regional environment problems and promoting a sustainable future (Folke, 2006; Leichenko, 2011; Pickett et al., 2013).

Resilience was initially defined as a response to environmental disturbance or the way that habitats and ecosystems can reorganize spontaneously after a disturbance by a Canadian ecologist (Holling, 1973). After that, the notion has been applied in regional planning including urban ecology, urban theory, social vulnerability and especially something about climate change (Leichenko, 2011; Wardekker et al., 2010) or hazards and disasters (Burby et al., 2000). With the in-depth study on "regional resilience" and "resilient region", the practical application of ecological resilience in the region is gradually expanded. After applied to regional ecological systems, "resilience" redefines the connotation of regional development and competitiveness. There is therefore a need for a readily accessible and transparent method to measure ecological resilience capacity. In the paper, the regional ecological resilience is defined as self-adjustment capacity when the region system is disturbed by Black Swan Events so that it can adapt to the new environment, recover and innovate.

Although the definition of ecological resilience is gradually clear, relatively little research exists on how it works and how to assess its capacity in the region. In 2013, the regional research team at the state university of New York developed the Resilience Capacity Index (RCI) which involves 12 indexes. And the 12 indexes of RCI focus on regional economy, population-society and community connectivity these three aspects. After that the indicator system was developed by the institute for Social and Environmental Transition (ISET) to combat climate change which is focus more on ecology but for design. Both quantitative and non-quantitative factors are taken into accounts in the system which includes nearly 40 indexes. The indicator system is positioned to be replicable among city governments in Asia and as the main part of Asian Cities Climate Change Resilience Network (ACCCRN), but has not yet been released to public. Several indexes are introduced to assess the resilience of spatial planning by academia (Fleischhauer, 2008; Frazier et al., 2013; Zhong, 2010; Peng et al., 2015), but on the whole, studies conducted to assess ecological resilience capacity in the region are scare and this work has not gone through a complete and thorough analysis involving both ecology and urban planning. Based on the former researches, the paper attempts to explore a relatively complete assessment framework of ecological resilience in the region and sub-regions to make development in the region more environment-friendly and sustainable.

Materials and Methods

Study Site

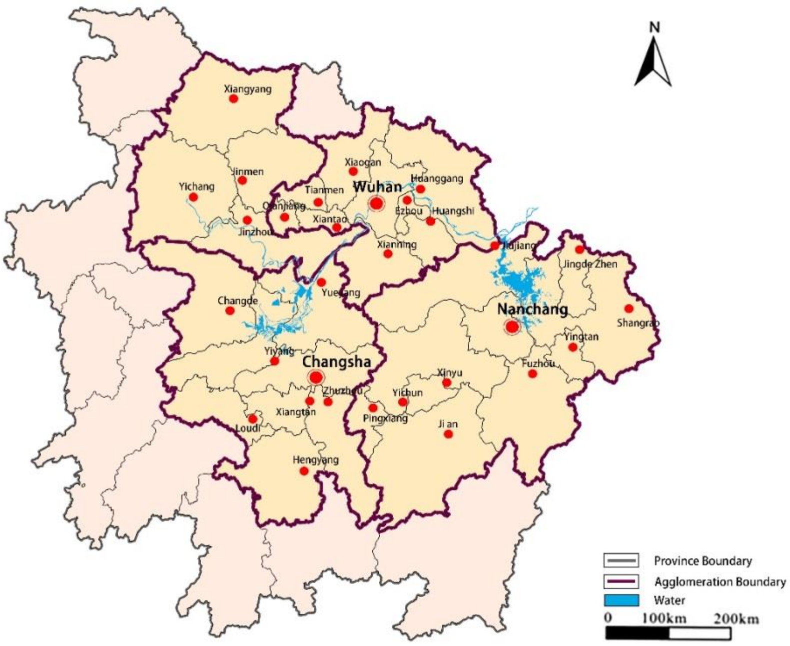
The development in the regional scale is more important today than past. In this study, the targeted area is the Yangtze Middle Reaches Megalopolis which is located at the central part of China, with rich natural resources, dense population and some types of productive disasters. And the Yangtze Middle Reaches Megalopolis is now a fast-growing urban agglomeration. After Chinese Ministry of Natural Resources established, the development and ecological protection of the Yangtze Middle Reaches Megalopolis has become a hot topic. Research on the assessment and regulatory management of the Yangtze Middle Reaches Megalopolis' ecological resilience is of great significance for both urbanization and sustainable development. The Megalopolis area includes 4 medium-sized urban agglomerations, involving 31 cities. Among these agglomerations, Wuhan Agglomeration and Xiang Yi Jing Agglomeration are in the Hubei province. Wuhan Agglomeration includes Wuhan city, Huangshi city, Huanggang city, Ezhou city, Xiaogan city, Xianning city, Xiantao city, Tianmen city and Qianjiang and Wuhan city is provincial capital of Hubei province. Xiang-Yi- Jing Agglomeration includes Xiangyang city, Yichang city, Jingmen city and Jingzhou city. Chang-Zhu-Tan Agglomeration includes Changsha city, Yueyang city, Changde city, Yiyang city, Zhuzhou city, Xiangtan city, Hengyang city and Loudi city in Hunan Province and Changsha city is the provincial capital. Surrounding Poyang Lake Agglomeration in Jiangxi province includes Nanchang city, Jiujiang city, Jingde Zhen city, Yingtan city, Shangrao city, Xinyu city, Fuzhou city, Yichun city, Pingxiang city and Ji'an city and in all of those 10 cities, Nanchang city is the provincial capital. As cities are shown in Figure 1 and Table 1. There are 13 cities in Hubei province, 8 cities in Hunan province and 10 cities in Jiangxi province as the study object to achieve the assessment.

Table 1. *Yangtze Middle Reaches Megalopolis*

Agglomeration	Province	City
Wuhan	Hubei	Wuhan, Huangshi, Huanggang, Ezhou, Xiaogan, Xianning, Xiantao, Tianmen, Qianjiang
Xiang-Yi-Jing	Hubei	Xiangyang, Yichang, Jingmen, Jingzhou
Chang-Zhu-Tan	Hunan	Changsha, Yueyang, Changde, Yiyang, Zhuzhou, Xiangtan, Hengyang, Loudi
Surrounding Poyang Lake	Jiangxi	Nanchang, Jiujiang, Jingde Zhen, Yingtan, Shangrao, Xinyu, Fuzhou, Yichun, Pingxiang, Ji'an

Source: Urban Agglomeration Development Plan for the Middle Reaches of the Yangtze River 2015.

Figure 1. *Yangtze Middle Reaches Megalopolis*



Source: Author.

Assessment Index

Plenty of international ecologists believe that ecological resilience is significantly related to climate and biodiversity (Peterson et al., 1998; Gunderson, 2000). While some ecological scholars assessed ecological vulnerability by vegetation coverage, moisture, temperature, biological potential productivity and soil organic matter (Qiao et al., 2008). And among the previous researches, the ecological resilience index system included the green area rate of built-up areas, the area of public green space, the disposal rate of "three wastes" in production and life. The system of ISET included aspects such as weather and climate, coastal areas and sea level rise, headwater, water quality, biodiversity and ecosystems as well as tropical island effect. The assessment is classified with regional ecological organization, vitality and function. Overall considering previous studies, the paper selects organization, function and maintenance as main factors. The organization factor includes Mean Annual Precipitation, Sunshine Duration, Mean Annual Temperature and Water Resources which are selected to assess the primary condition of the ecosystem in the Yangtze Middle Reaches Megalopolis. And the function factor includes 2 indexes such as Forest Cover Rate and Sulfur Dioxide Treatment Rate to assess the biodiversity while the maintenance factor includes Sulfur Dioxide Treatment Rate and Comprehensive Utilization Rate of Industrial Solid Waste to assess the green infrastructure of ecological environment. Due to life garbage treatment rates of most cities in the Yangtze Middle Reaches Megalopolis are nearly 100%, which means life garbage treatment rate has little influence on the final assessment, the Life Garbage Treatment Rate index is not selected in the assessment. Overall, each of factor includes 2-4 specific indexes and finally 8 indexes are chosen to assess the ecological resilience of the cities in the Yangtze Middle Reaches Megalopolis as is shown in Table 2.

Weight Coefficient

The study adopts entropy method to weight the indexes of ecological resilience. The method is based on the entropy value, that is, the weight of the selected index is calculated according to the variation degree of each index, which is objective and scientific. According to the characteristics of entropy, the randomness and disorder degree of an event can be judged by calculating the entropy value, or the dispersion degree of an index can be judged by the entropy value. The greater the dispersion degree of the index is, the greater the influence of the index on the comprehensive evaluation.

The data supporting the ecological resilience assessment in this paper is derived from the Statistical Yearbook of Chinese City, Water Resources Statistical Yearbook and Climatological Statistics in 2017. Following is the calculating process.

Assuming there are *m* evaluation objects and evaluation indexes, the original data matrix is constituted as:

$X_{ip,}(i=1,2,3\ldots\ldots n;\ p=1,2,3\ldots\ldots m)$

$$X_{ip}=(X_{ip})_{n\times m}=\begin{bmatrix} X_{11} & X_{12} & \ldots & X_{1m} \\ X_{21} & X_{22} & \ldots & X_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ X_{n1} & X_{n2} & \ldots & X_{nm} \end{bmatrix}$$

The main steps are as following:

① Index dimensionless (standardized) process: the results were obtained using z-score standardization.

②Calculate the index probability after standardization. Calculate the proportion or probability of the *p* index in the *i* area after standardization.

$$Y_{ip} = X_{ip}' \Big/ \sum_{i=1}^{m} X_{ip}' \quad (1)$$

③Calculate information entropy of the *P* index.

$$e_p = -(\ln m)^{-1} \sum_{i=1}^{m} (Y_{ip} \times \ln Y_{ip}) \text{ , } (0 \leqslant e_p \leqslant 1) \quad (2)$$

④Weight of the *P* index.

$$w_p = (1 - e_p) \Big/ \sum_{p=1}^{n} (1 - e_p) \quad (3)$$

For (1) - (3), X_{ip} denotes the evaluation index value of the *p* item in the *i* city; *M* is the number of cities to be evaluated; *N* is the evaluation index number. The values of ecological resilience index of 31 cities in Hubei province, Hunan province and Jiangxi province were calculated, after the weight *W* of each evaluation index obtained, as shown in Table 2. According to it, the weight coefficient of the organization index(A1) is 0.6909, the function index(A2) is 0.2048 and the maintenance index(A3) is 0.1043. The most important index is the Water Resources while the useless is the Sulfur Dioxide Treatment Rate for the ecological resilience assessment.

Table 2. *Assessment Indexes of Ecological Resilience*

Index A	Index B	Weight Coefficient
Organization (A1)	Mean Annual Precipitation (B1)	0.1420
	Sunshine Duration (B2)	0.0629
	Mean Annual Temperature(B3)	0.1017
	Water Resources(B4)	0.3843
Function(A2)	Forest Cover Rate(B5)	0.1237
	Green Rate of Built-up Area(B6)	0.0811
Maintenance(A3)	Sulfur Dioxide Treatment Rate(B7)	0.0393
	Comprehensive Utilization Rate of Industrial Solid Waste(B8)	0.0650

Source: Author.

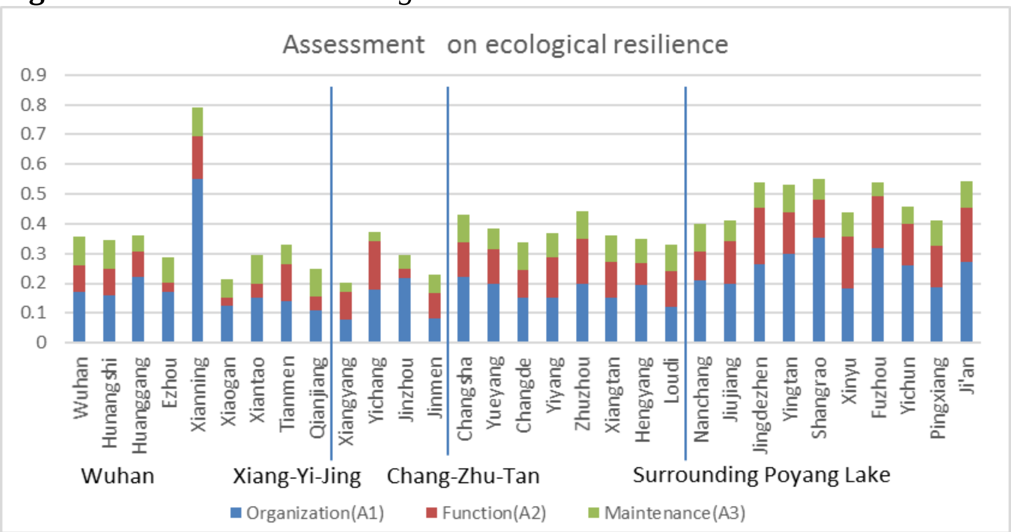
Results

In this large, prospective ecological resilience assessment of 31 cities in the Yangtze Middle Reaches Megalopolis, lots of conclusions such as the ecological resilience capacities of 31 cities and 4 agglomerations, the influence of each factor on the ecological resilience and the spatial distribution of the capacity in the Megalopolis can be drawn. The spatial distribution of ecological resilience is obviously regular. And the values of cities conformed to a Gaussian distribution, most cities are assessed to be less resilient. Also it is statistically observed that remarkable value of organization index is the most important influencing factor of the ecological resilience. And a prominent correlation can be discovered between the water resource and resilience capacity in the assessment. So it can be concluded that the protection of the ecosystem in the Yangtze Middle Reaches Megalopolis is of great significance to improve ecological resilience and especially associated with the protection of water resource.

The Overall Assessment

The product sum of each normalized index score and its weight is the comprehensive evaluation value of each city. Figure 2 below shows the results of the ecological resilience capacity assessment in the Yangtze Middle Reaches Megalopolis. According to the results, the capacities ranges from 0.1941 to 0.7865 and among them, Xianning city in Wuhan Agglomeration achieves the highest value 0.7865 while Xiangyang city also in Xiang-Yi-Jing City Belt gets the lowest and both of them are in Hubei province. The mean value is 0.3878 and the standard deviation is 0.1186 that means the mean capacity is relatively small and the differences between the values are also at the relatively low level. 58% cities' ecological resilience is below the average line. Wuhan city, the provincial capital of Hubei province gets 0.3571. Nanchang city which is the provincial capital of Jiangxi province gets 0.3958. And Changsha city, the provincial capital of Hunan province gets the highest value 0.4243 among the three provincial capitals. 8 of 9 cities in Wuhan agglomeration and all 4 cities in Xiang-Yi-Jing City Belt get the lower values of ecological resilience which are below the mean value. And all 10 cities in Surrounding Poyang Lake Agglomeration achieve higher value than the average. It can be concluded that Surrounding Poyang Lake Agglomeration are more resilient than other three sub-regions in the Yangtze Middle Reaches Megalopolis.

Figure 2. *Assessment on Ecological Resilience*



Source: Author.

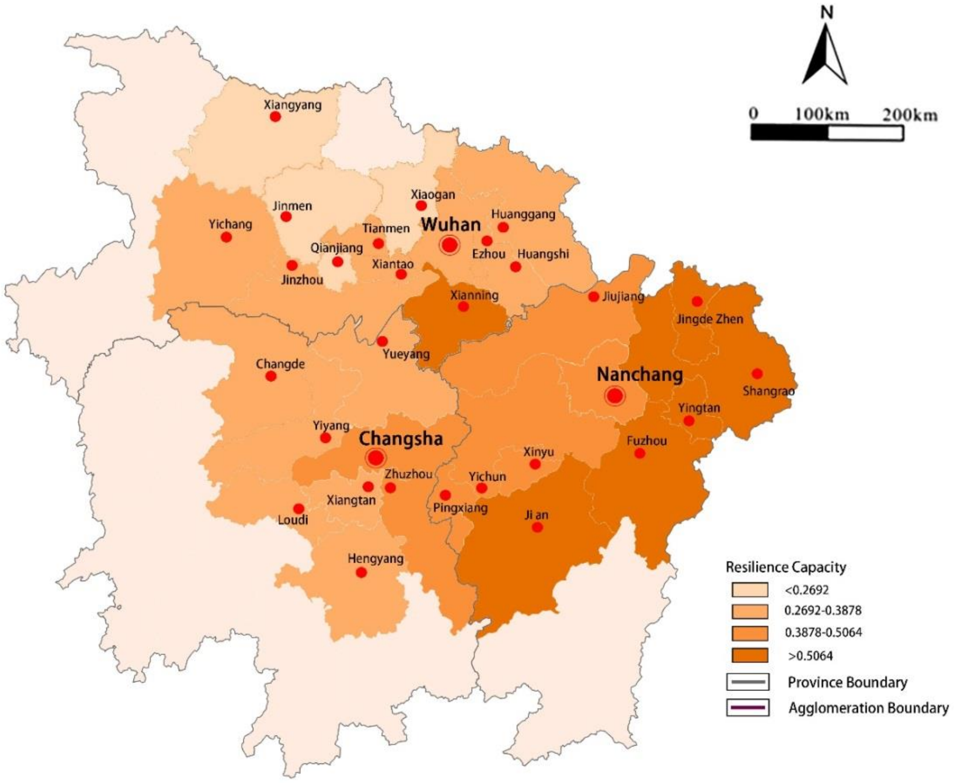
According to the values of the assessment, the capacity is divided into four grades by standard deviation classification method, which is used to show the difference between the value of element attributes and the average value as shown in the Table 3. The higher the value is, the more resilient the city is. Reclassified by the 4 grades with the ArcGIS, the capacity distribution map can be obtained as Figure 2. There are four cities including Qianjiang city, Xiaogan city, Xiangyang city and JInmen city get the Grade 1 which have the lowest ecological resilience capacity while 6 cities including Xianning city, Shangrao city, Jingde Zhen city, Yingtan city, Fuzhou city and Ji'an city are in the Grade 4. 14 cities which are Wuhan city, Yiyang city, Yichang city, Jingzhou city, Huangshi city, Ezhou city, Huanggang city, Tianmen city, Yueyang city, Xiantao city, Loudi city, Hengyang city, Changde city and Xiangtan city get the Grade 2 and 7 cities including Xinyu city, Nanchang city, Zhuzhou city, Jiujiang city, Pingxiang city and Yichun city are in the Grade 3. As shown in the table 3, 21 cities' ecological resilience capacities are going to be close to the mean which account for two-thirds of all cities. And meanwhile it seems to be a normal distribution for the number of cities in these four grades. The most cities are at grade 2 while only 4 cities are at grade 1 and 6 cities are at grade 4.

Table 3. *Capacity Classification of ecological resilience*

Capacity（V）	**0 < V≤(M-σ)**	**(M-σ) < V≤M**	**M < V≤(M+σ)**	**V > (M+σ)**
Grade	1（4）	2（14）	3（7）	4（6）
City	Qianjiang, Xiaogan, Xiangyang, JInmen	Wuhan, Yiyang, Yichang, Jinzhou, Huangshi, Ezhou, Huanggang, Tianmen, Yueyang, Xiantao, Loudi, Hengyang, Changde, Xiangtan,	Changsha, Xinyu, Nanchang, Zhuzhou, Jiujiang, Pingxiang, Yichun,	Xianning, Shangrao, Jingde Zhen, Yingtan, Fuzhou, Ji'an

Note: M is average, σ is standard deviation. From grade 1 to 4, the capacity is growing.
Source: Author.

Figure 3. *Capacity Distribution of Ecological Resilience in the Region*



Source: Author.

The spatial capacity distribution demonstrates a remarkable fragmentation as is shown in Figure 3. Overall, the capacities of the cities are arranged in a regularly gradient from southeast to northwest according to the top grade to the bottom grade. 5 of 6 resilient cities are located at the Surrounding Poyang Lake Agglomeration and are also in the Jiangxi province. However, the ecological resilience is relatively weak in the northwest region of the megalopolis, especially in Hubei province.

The Assessment for 4 Urban Agglomeration Sub-Regions

As for the 4 urban agglomeration sub-regions in the megalopolis, the result values are shown by Table 4. The capacities are different a lot from each other but they are all close to the mean value. Wuhan Agglomeration, Xiang-Yi-Jing City Belt and Chang-Zhu-Tan Agglomeration are less resilient than Surrounding Poyang Lake Agglomeration obviously. Figure 4-6 show 8 indexes value of each city which can clearly reveals the differences between various cities and urban agglomerations in terms of organization, function and maintenance.

Figure 4. *The Organization Index of Each City*

Figure 5. *The Function Index of Each City*

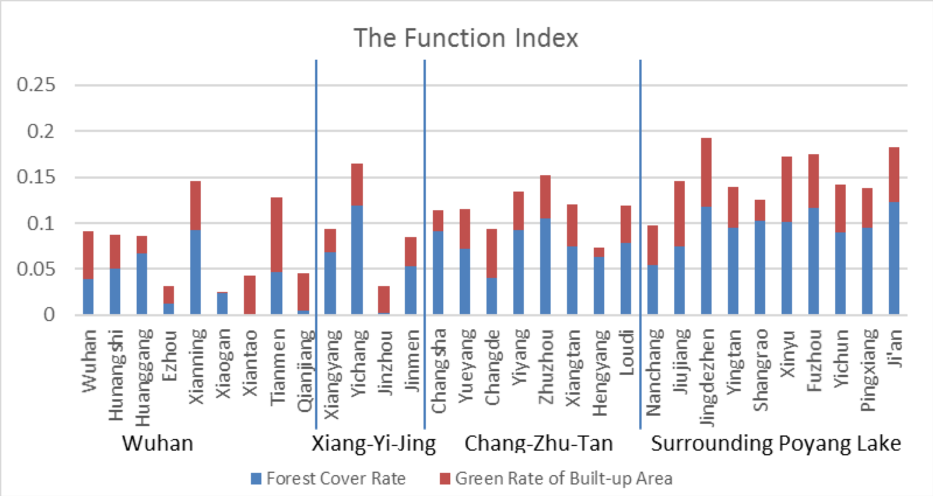
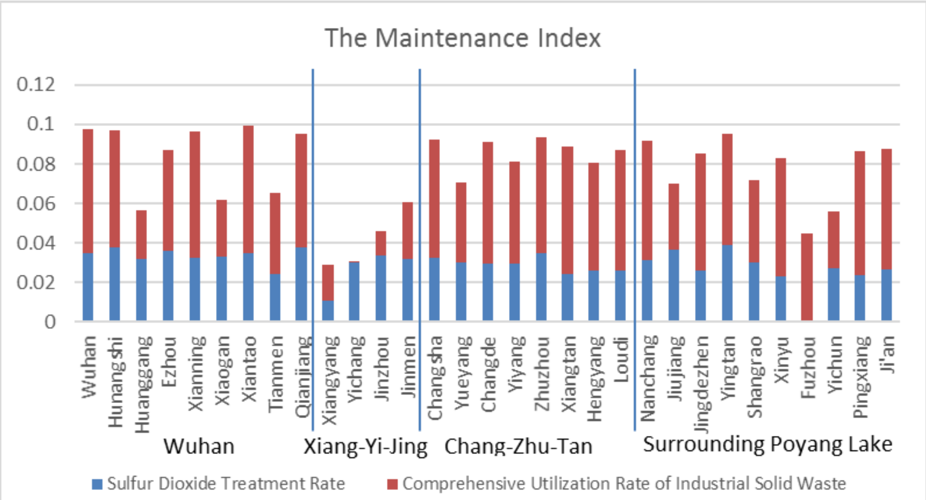


Figure 6. *The Maintenance Index of Each City*



Unexpectedly Wuhan Agglomeration gets a low capacity value which is 0.3584 and below the mean value, meanwhile its dispersion degree is 0.1585 which is above average. Compared with other agglomerations, the dispersion degree of ecological resilience capacity in the Wuhan Agglomeration, is far less than the standard. In other words, the cities' ecological resilience differentiation in Wuhan Agglomeration is larger than other agglomerations. The conclusion can be drawn that the geographical distribution of the ecological resilience isn't balanced and overall ecological resilience of the Wuhan agglomeration is weak. Compared to other agglomerations, it is apparent that the organization index value is low and nearly all cities in the agglomeration get the value below 0.2 except Xianning which gets the highest value on the organization index from Figure 4. The function index values of cities in Wuhan agglomeration are various as shown in Figure 5. From Figure 6, cities in Wuhan agglomeration have paid more attention to environmental infrastructure construction and their maintenance index values are high.

It should be noted that also in Hubei province, Xiang-Yi-Jing City Belt shows the lowest capacity of ecological resilience among the 4 urban agglomeration sub-regions. Its dispersion degree is 0.0662 which is far less than the standard. That means all the 4 cities in Xiang-Yi-Jing City Belt have a similar low ecological resilience. Consistent with previous studies, the organization and maintenance index values are relatively poor as shown in Figure 4,6 so it should be paid attention when optimize the resilience of this agglomeration. There are significant differences between cities in Xiang-Yi-Jing City Belt on all of three main indexes from Figure 4-6 and it can be concluded that resilience capacities of cities in this agglomeration is random and different a lot from one another. Compared with Hunan province and Jiangxi province, this randomness is particularly obvious in Hubei province and especially in north.

With regard to Chang-Zhu-Tan agglomeration, the ecological resilience value is 0.3696 and below the mean value. Among the 8 cities, 7 cities, accounting for about 81.2% of the urban agglomeration area, are at low resilience level. Although compared with the first two urban agglomerations, the ecologic resilience is stronger. The dispersion degree of ecological resilience is 0.038 which is far less than the standard and the spatial distribution is balanced. The organization and function index values are low but maintenance index value is high. In the process of urban agglomeration development, it pays little attention to urban microclimate, water source, forest and green space in Chang-Zhu-Tan agglomeration.

Surrounding Poyang Lake Agglomeration is assessed as the most resilient. The resilience capacity values of cities are all above the mean value. And its dispersion degree is only 0.06 which means spatial difference of ecological resilience is small. Its organization and function index values are higher a lot than the other three urban agglomerations but its maintenance index values differ widely from one city to another. Sulfur dioxide treatment of Fuzhou city is apparently weak. Jiujiang city, Shangrao city, Xinyu city and Yichun city need to improve the construction of their environmental facilities.

Table 4. *The Ecological Resilience Capacity of Agglomerations*

Agglomeration	**Wuhan**	**Xiang-Yi-Jing**	**Chang-Zhu-Tan**	**Surrounding Poyang Lake**
Capacity	0.3584	0.2694	0.3696	0.4763
Dispersion Degree (σ=0.1186)	0.1585>σ	0.0662<σ	0.038<σ	0.06<σ
Spatial Distribution				
Features	Fragmentation	Linear Gradient	Balance	Linear Gradient

Consistent with previous studies, the spatial distribution features can be observed and summarized as three types as shown in Table 4. They are fragmentation, balance and linear gradient. Within the Wuhan agglomeration, there is an apparently weak correlation on the ecological resilience between cities. There is the most resilient city, Xianning city and the least resilient city, Xiangyang city. Large spatial variation and differentiation of resilience capacity between cities make severe fragmentation in Wuhan agglomeration. Cities in Chang-Zhu-Tan Agglomeration are relatively similar. Its spatial distribution feature belongs to balance. Xiang-Yi-Jing City Belt and Surrounding Poyang Lake Agglomeration are classified as Linear Gradient. The ecological resilience increases or decreases linearly in a certain direction. The capacities of the cities are arranged in a regularly gradient from southeast to northwest according to the top grade to the bottom grade in Surrounding Poyang Lake Agglomeration while they are arranged in a regularly gradient from south to north in Xiang-Yi-Jing City Belt.

The Analysis of Population Density

Consistent with the definition of ecological resilience, Black Swan Events causing interference for ecological resilience in the spatial differentiation are explored in depth. And in terms of the external Black Swan Events, urban ecosystem is often disturbed and infracted by various social manufacture and living activities. It also can be proved that the urban ecosystem is closely related to the urban development and the pressure of the expanding number of people. Therefore, the pressure of population size which decides the gross of manufacture and activities can be regarded as a long-term Black Swan Event suffered by cities and regions in the developing process. So population density can be an important factor to analyze the interference and disturbance.

In this paper, the datum involving the number of household population and the land area in each city's administrative region are also obtained from the

Statistical Yearbook of Chinese Cities in 2017. Population density can be got when divide the two numbers. Also, population densities of 31 cities can be divided into four grades by standard deviation classification method as shown in Table 5. For the perspective of cities, Table 3 and Table 5 show that among 31 cities in the urban agglomeration, the three provincial capitals with high dense population and rapid economic development have relatively low ecological resilience, namely Wuhan city, Nanchang city and Changsha city.

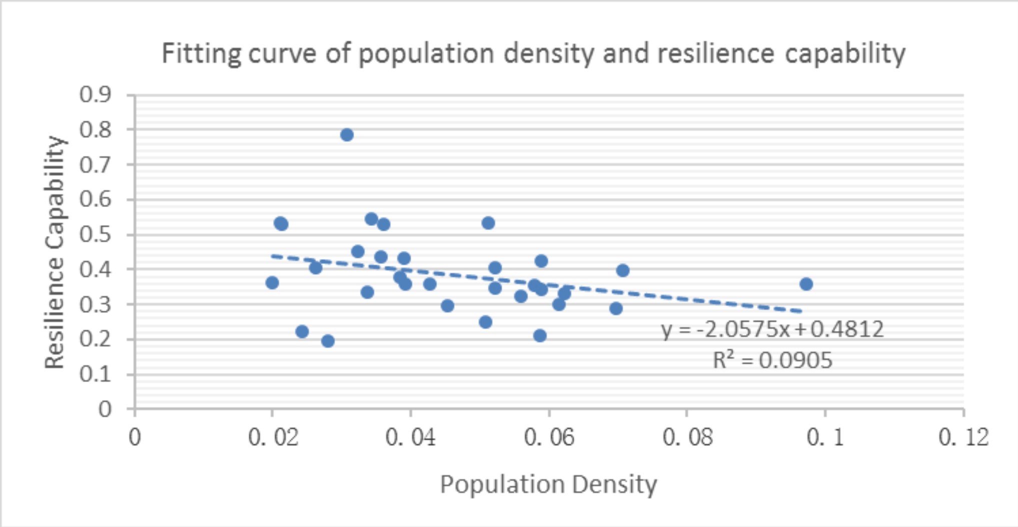
Table 5. *The Population Density of Cities*

Population density（V）	**0 < V≤(M-σ)**	**(M-σ) < V≤M**	**M < V≤(M+σ)**	**V > (M+σ)**
Grade	1（12）	2（9）	3（9）	4（1）
City	Xianning, Yingtan, Fuzhou, Shangrao, Jiujiang, Yichang, Zhuzhou, Changde, Xiangyang, Yichun, JInmen, Ji'an	Jingde Zhen, Xinyu, Pingxiang, Huanggang, Yueyang, Yiyang, Qianjiang, Jinzhou, Hengyang,	Changsha, Huangshi, Ezhou, Xiaogan, Nanchang, Tianmen, Loudi, Xiantao, Xiangtan,	Wuhan

Note: M is average, σ is standard deviation. From grade1 to 4, the density is growing.

In order to analyze the impact of population density disturbance on ecological resilience qualitatively, the population density and ecological resilience of 31 cities are plotted as scatter plots. Then the regression analysis is carried out to reveal the essence and discover the laws. Finally, the curve equation obtained by linear fitting of scatter plot is y=-2.0575x+0.4812 (R^2 =0.0905), as shown in Figure 7. The slope of the fitting curve is negative and the covariance value is small, indicating that there is a strong negative correlation between the population density and ecological resilience. It can be concluded that the pressure of population agglomeration has a negative impact on the ecological resilience of cities and regions.

Figure 7. *Fitting Curve of Population Density and Resilience Capacity*



Discussion

According to the former study, following are several suggestions and implementations for optimization to improve the capacity of ecological resilience in the Yangtze Middle Reaches Megalopolis.

Megalopolis Space Integrated Promotion Strategy

Owing to weak ecological resilience of all cities, spatial management should be strengthened to restore the ecological space in the Megalopolis integratedly. Government should focus more on improving the resilience capacity of cities with low resilience capacity to make spatial distribution balanced, so that a healthy ecological network system can be formed in the region. And meanwhile there should be a unified minimum index system for all cities. In this system, every index value will be set a minimum value number to ensure that ecological resilience capacity will not be further decreased. On the one hand, most cities with below-average resilience capacity should improve their ecological resilience by strictly controlling the utilization of natural resources to reduce disaster. Government should accelerate afforestation to increase vegetation coverage rate and cope with various unpredictable interference events. The north part of the megalopolis should be concerned a lot, especially for cities in the Xiang-Yi-Jing City Belt. Specifically, the ecological resilience within the region can be improved by controlling various indexes. On the other hand, more attention should be paid to the infrastructure establishment for disaster prevention and mitigation as well as the arrangement of disaster prevention facilities to deal with the Black Swan Event when it happens.

Relying on the golden waterway of the Yangtze river, the spatial management such as the Blue Line, Green Line and Red Line[1] can be regulated for ecological restoration. To protect and utilize the water resources of the region properly, water resource management systems should be implemented in the cities where the Yangtze river flows through, such as Yichang city, Jingzhou city, Yueyang city, Xianning city, Wuhan city, Ezhou city, Huanggang city, Huangshi city and Jiujiang city. The management should include red line of water resources development and utilization and the red line of water use efficiency. Water resources demonstration in project construction is one of the key measures in the furthering of water license management. Along the Yangtze river, the Han river, Poyang lake, Dongting lake and other water resource become a water network system. The water resources protection belt and ecological isolation belt of this network should be regularized to enhance water and soil conservation capability. In addition to that, cities with severe water resource shortage should be placed emphasis on and government should make more preparations against natural disaster.

Urban Agglomeration Sub-regional Control Strategy

According to the assessed resilience capacities and spatial distribution of 4 urban agglomerations, government of city or urban agglomeration should analyze the existing resilience situation and put forward its countermeasures in the light of local condition respectively. For the region with balanced spatial distribution, the strategy of balanced development is adopted. For region with unbalanced spatial distribution, more efforts should be made to optimize cities with small resilience capacity. To optimize the spatial distribution of ecological resilience, the capacity should be enlarged especially for the northern space of each urban agglomeration. The conception of 'Ecological Resilience Bank' can be put forward to balance development and ecological conservation uniformly within the scope of urban agglomeration. The bank aims to establish the maximum liabilities that urban agglomeration can afford for disturbance, provide green-infrastructure and disaster prevention facilities, as well as set the aim of ecological construction and protection. It can make ends meet on utilization of ecological resources and environmental consumption within urban agglomeration. Meanwhile, if a city develops more than the upper limit, it can borrow development from another city in the same urban agglomeration so that ecological resilience capacity can be protected in the region.

For Xiang-Yi-Jing City Belt, public green space in built-up area and forest cover of Xiangyang city, Jingzhou city and Jingmen city should be planned to increase, and the consumption of natural resources and the pollution of ecological environment should be strictly controlled in this City Belt. Wuhan Agglomeration is located in the middle reach of Yangtze river but with severely fragmented spatial distribution of ecological resilience which hinders

[1]Blue Line, Green Line are protection boundary lines for green land and water and Red Line is regulated to control construction by Chinese government.

the whole sustainable development. Government of Wuhan Agglomeration, especially Huanggang city, Xiaogan city and Qianjiang city, should strengthen the regulation of industrial enterprises with large energy consumption and heavy pollution, for instance they should strictly regulate to reduce the "three wastes" emissions so that the organization and function index of resilience capacity can be controlled: Meanwhile according to anti-pollution capacity of water resource, water conservation strategies can be concluded for cities in Wuhan Agglomeration. Government has to take steps to increase vegetation cover and regulate microclimate. As for Chang-Zhu-Tan Agglomeration, Loudi city, Yueyang city and Xiangtan city whose capacities are below the average should make policy according to their own conditions like above strategies. However, for Surrounding Poyang Lake Agglomeration with strong ecological resilience, regulation can be relatively relaxed, but the utilization of ecological resources and environmental consumption should be within the corresponding threshold range.

Population Control Strategy

Population size control strategies are proposed to protect ecological resilience from the pressure to overspend. Population size should be determined by ecological resilience capacity of each city. By using the curve fitting of population density versus resilience capacity, the size of urban population can be calculated, so that the disturbance of people's production and living activities to the city can be quantified. For cities whose ecological resilience capacity are below average, control the population to protect the ecological environment, restrict the high-polluting enterprises strictly, and encourage the entry of enterprises that are environment-friendly and resource-saving. Only ecological resilient cities can properly loosen population size control, and industrial structure scientific planning should also be implemented to achieve sustainable development.

Conclusions

Taking the Yangtze Middle Reaches Megalopolis as an example, the purpose of this study is to assess the ecological resilience capacities of cities. Based on the forefather's research of both ecology and urban planning on ecological resilience, three main factors including organization, function and maintenance were employed to establish a more systematic and interdisciplinary index assessment system. Then the index datum of 31 cities was obtained from Chinese City Statistical Yearbook in 2017, and the weight of each index was calculated by entropy method and final assessment was completed. After that, in terms of sub-regions level and cities level, the strength and weakness of the ecological resilience were compared and analyzed. There is a conclusion that the ecological resilience is weak and the spatial distribution law is linear decline in the Yangtze Middle Reaches Megalopolis. And then, the influence of different indexes on the sub-regions was further analyzed, which served as the basis for the optimization and improvement strategy of the ecological resilience in the following paper. What's more, in combination with the definition of ecological resilience, urban population density is considered as a long-term disturbance, and the obtained fitting curve of the relationship between population density and ecological resilience proves that urban population density has a negative effect on urban ecological resilience. Three optimization suggestions are put forward finally. And the concept 'Ecological Resilience Bank' is proposed to establish to balance the development and eco-protection in each agglomeration.

In this paper, the data source is reliable, and the research method is scientific and rigorous. In general, it is of great significance for the assessment of regional ecological resilience and the study of the influencing factors of regional ecological resilience. It is also of great empirical significance to select 31 cities in the urban agglomeration of the middle reaches of the Yangtze river in China as research objects. However, the data of this study, although collected as possible as I could, has certain limitations. Hence the datum of the study is limited by time and types. Further research is recommended to analyze more factors that influence ecological resilience and pay more attention on the resilience change in a time for resilience is a dynamic process. And as the cognition of the intrinsic motivation of ecological resilience is still inconclusive, the index system construction of urban ecological resilience assessment still needs to be further studied to verify whether the system used in this paper is scientific and reasonable.

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