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A Balance between Ideals and Reality

—Establishing and Evaluating a Resilient City Indicator System for Central Chinese Cities

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Foreword

In the 21st century, crisis may be the new normal.

—Rodin, 2014

Recent years have seen a gradual shift in focus of international policies from a national and regional perspective to that of cities, a shift which is closely related to the rapid urbanization of developing countries. As revealed in the 2011 Revision of the World Urbanization Prospects published by the United Nations, 51% of the global population (approximately 3.6 billion people) lives in cities. The report predicts that by 2050, the world's urban population will increase by 2.3 billion, making up 68% of the population. The growth of urbanization in the next few decades is expected to primarily come from developing countries, one third of which will be in China and India.

With rapid urbanization and the ongoing growth of mega cities, cities must become increasingly resilient and intelligent to cope with numerous challenges and crises like droughts and floods arising from extreme climate, destruction brought by severe natural disasters, and aggregated social contradictions resulting from economic crises. All cities face the urban development dynamics and uncertainties arising from these problems. Under such circumstances, cities are considered the critical path from crisis to prosperity, so scholars and organizations have proposed the construction of "resilient cities." On the one hand, this theory emphasizes cities' defenses and buffering capacity against disasters, crises and uncertainties, as well as recovery after destruction; on the other hand, it highlights the learning capacity of urban systems, identification of opportunities amid challenges, and maintenance of development vitality. Some scholars even believe that urban resilience is a powerful supplement to sustainable development. Hence, resilience assessment has become the latest and most important perspective for evaluating the development and crisis defense capacity of cities.

Rather than a general abstract concept, urban resilience is a comprehensive measurement of a city's level of development. The dynamic development of problems is reflected through quantitative indicators and appraisal systems not only from the perspective of academic research, but also governmental policy, so as to scientifically guide development, and measure and compare cities' development levels. Although international scholars have proposed quantitative methods for urban resilience assessment, they are however insufficiently systematic and regionally adaptive for China's current urban development needs. On the basis of comparative study on European and North American resilient city theories, therefore, this paper puts forwards a theoretical framework for resilient city systems consistent with China's national conditions in light of economic development pressure, natural resource depletion, pollution, and other salient development crises in China. The key factors influencing urban resilience are taken into full consideration; expert appraisal is conducted based on the Delphi Method and the analytic hierarchy process (AHP) to design an extensible and updatable resilient city evaluation system which is sufficiently systematic, geographically adaptable, and sustainable for China's current urban development needs. Finally, Changsha is taken as the main case for empirical study on comprehensive evaluation of similar cities in Central China to improve the indicator system.

Chapter I Introduction

Three "colliding trends" —urbanisation, globalisation and climate change—will increase stresses on cities and risk leaving many people feeling excluded.

—The Guardian, 2014

1.1 Research Background

1.1.1 Sustainable development against the background of global urbanization and uncertainty

The acceleration of economic globalization and internationalization since the 1980s has expedited the global free flow and allocation of production factors, resulting in spatial urban and regional restructuring. The spatial distribution pattern of human economic and social activities has undergone major changes, and entered an urban era. According to statistical data and predictions by the United Nations, the global population reached 6.974 billion as of 2011, including an urban population of 3.632 billion, indicating an urbanization rate of 52.1%. By 2050, the population will have increased to 9.306 billion, with 6.252 billion urban residents, an urbanization rate of 67.2%. From 2011 to 2050, the world's population will grow by 2.332 billion, and urban population will increase by 2.62 billion. Global rural population and its ratio to total population will both drop around 2020. It can be said that we are embarking upon a new era of urban spatial distribution of economic and social human activities. The urbanization rates of developed countries are also generally approaching saturation level, and no major variation is expected in the future, notwithstanding a certain amount of fluctuation. From a long-term perspective, the absolute size of urban population in developed countries is likely to experience negative growth, unless there is a large amount of immigration. With significant acceleration of urbanization, the absolute size of urban population in developing countries will continue to grow steadily. Developing countries are now becoming the main global source of urbanization, and the urbanization path of China has been taken as a research focus for urban development theories worldwide for its unique features.

The increasingly frequent global movement of population, resources, capital and information has made the world more complex and unpredictable than ever. Depletion of energy resources, soaring oil prices, global warming, frequent extreme weather and disasters, and other problems have arisen as huge challenges for urban development in the 21st century. On the one hand, there are disasters brought by emergencies like 9/11, Hurricane Katrina and the Wenchuan Earthquake; on the other, there is the cumulative pressure from financial crises, growing energy costs and changes in regional climate models. All these problems may exert an initial impact on their respective regions, but are likely to evolve into global crises. It can be said that crises, uncertainties and complexities are the universal problems of modern urban development. In an era full of crises and uncertainties, the international community is gradually discarding traditional models of development paid for primarily by resource consumption and environmental degradation. The sustainable development concept has been widely accepted and used to guide urban development practices, but has failed to bring about profound changes to current urban development models. As revealed in the Global Environmental Outlook 5 (UNEP, 2012), major progress has been made only for four out of the 90 most important environmental goals. Pressures from population growth, economic activities, global consumption and production on the environment are constantly growing, and once the Earth’s capacity is exceeded, unexpected and essentially irreversible changes will be brought to the mechanisms that all creatures depend upon for survival. Faced with such severe global environmental and urban crises, people have started questioning current urban development models, and reflecting upon its future direction.

1.1.2 Resilient cities, a supplement and extension of sustainable urbanization

Coping with the changes amid such challenges and crises, while also maintaining vitality and sustainability, has become an urgent problem. The resilient city concept was born in this context. Some scholars hold that resilience is the first choice approach (Levin et al., 1998) and a requirement (Lebel et al., 2006) for the sustainable development of natural and social systems. Rolling out the sustainable development concept in a specific space, i.e. a city, essentially means coordinating the development of social, economic and natural sub-systems, as well as systems both within the city and in surrounding areas, realizing the optimal development of complex mega-city systems as urbanization advances, and ultimately enhancing people's living standards (Cui et al., 2010).

Sustainable urbanization can serve as a multidimensional development framework emphasizing a relatively long development process, during which the prerequisites for safe urban development should be guaranteed, and crises, disasters and other impacts prevented to the extent possible. When they cannot be prevented, resilience should be developed to fend off their negative effects to maintain daily functions. In comparison to sustainable cities, resilient cities are more targeted towards specific risks. Starting from the identification of disturbances and threats faced by cities, the theory is concerned with the ability to respond to and absorb diverse pressures, and measures giving cities the ability to self-organize, and adapt and recover from pressures and changes. Hence, the resilient city concept is highly compatible with important goals yet to be realized in modern cities, offering sustainable development a powerful supplement, and giving cities a new way to cope with the crises, uncertainties and complexities of future urbanization.

1.1.3 The necessity and urgency of resilient city research in China

As Western countries struggle to resolve the global economic problems resulting from the financial crisis in 2008, China is presented with its own particular development crises. As shown in data released by the National Bureau of Statistics, its urbanization rate reached 54.8% in 2014, up 35.8% from the 19.9% in 1979 (growing by about 1% annually); about 16 million rural people have moved to cities every year for the past 35 years, leading to an urban population growth of 560 million, 1.7 times the U.S. population, and 6.8 times the German population in 2014 (Table 1-1). According to studies on urbanization in Britain, Germany, the U.S., France, Japan, South Korea, Brazil and other countries (Figure 1-1), the period when countries achieve an urbanization rate of 50% typically indicates unprecedented prosperity. "Urban diseases" start to break out, and conflicts intensify (Wu, 2013).

As predicted by China's Investment Blue Book: China's Investment Development Report

(2013) [1], the next 20 years will be the most volatile period for China's urban and rural areas. By 2030, China's urbanization will have approached 70%, and another 300 million rural people will have migrated to cities and towns. As scholars have pointed out, beneath this rapid urbanization, industrialization and economic growth, China's government and society are faced with a highly complex "condensed" urbanization process. On the one hand, China is faced with almost all the problems confronted by the Western society over the past two or three hundred years of urbanization; on the other, it must evolve from a pre-industrial society to an industrial and highly urbanized society, and deal with external environmental challenges brought about by globalization and informatization within the next few decades (Zhang, 2010). That's to say, its urban development must simultaneously transform diverse processes within a much shorter period than Western countries have through "naturally evolution," while will not only aggregate the conflicts and problems arising from urbanization, but also greatly shrink the development space available for China's urbanization (in terms of markets, energy, materials and the environment).

Year	Urban Population (10,000 People)	Total Population (10,000 People)
1979	19499	97542
1990	29651	113048
2000	45594	126333
2014	74916	136782
2017	81347	139008

Table 1-1: China's Urbanization in the Past 35 Years (Note: excluding Hong Kong, Macau and Taiwan.)

Data Source: China Statistical Yearbook

[1] China's Investment Blue Book is prepared by China Jianyin Investment Limited with researches. China's Investment Development Report (2013) gives a comprehensive and systematic review of China's investment developments in 2012, and analyzes and predicts the development trends in 2013.

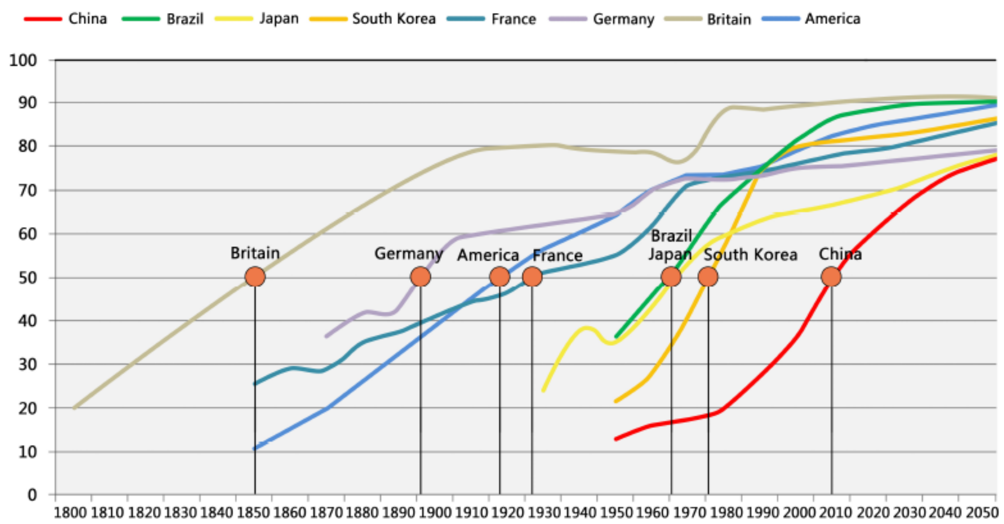


Figure 1-1: Urbanization of Typical Countries

Data Source: Wu, 2013

Unsustainable economic models, soaring resource and environment costs, and social risks resulting from growing regional and social gaps are the distinctive features of China's increasingly problematic urbanization development. As a vital means to regulate urbanization, urban planning innovations must meet tremendous tests. Resilient cities, an urban development ideal proposed by Western scholars in light of present complex and dynamic environmental changes, is a new concept in China. Due to great differences in time and space, however, it's impossible and unrealistic for China to simply follow the path taken by Western countries, or to find answers from Western countries. Therefore, it's imperative for China to explore a "flexible resilient city theory" based on its own realities, with reference to the Western research findings on resilient cities.

1.2 Verifying the Concept using a Central Chinese City (Changsha)

In light of the huge differences in urbanization between different Chinese regions, regional research has great realistic significance. China's urbanization policies can be divided into four regions: the Eastern, Central, Western and Northeast region. Eastern China was a pioneer in urbanization, while the Central region (Hubei, Hunan, Anhui, Jiangxi, Henan and Shanxi Provinces) connects the East to the West, serving as a link between the past and future (Figure 1-2).

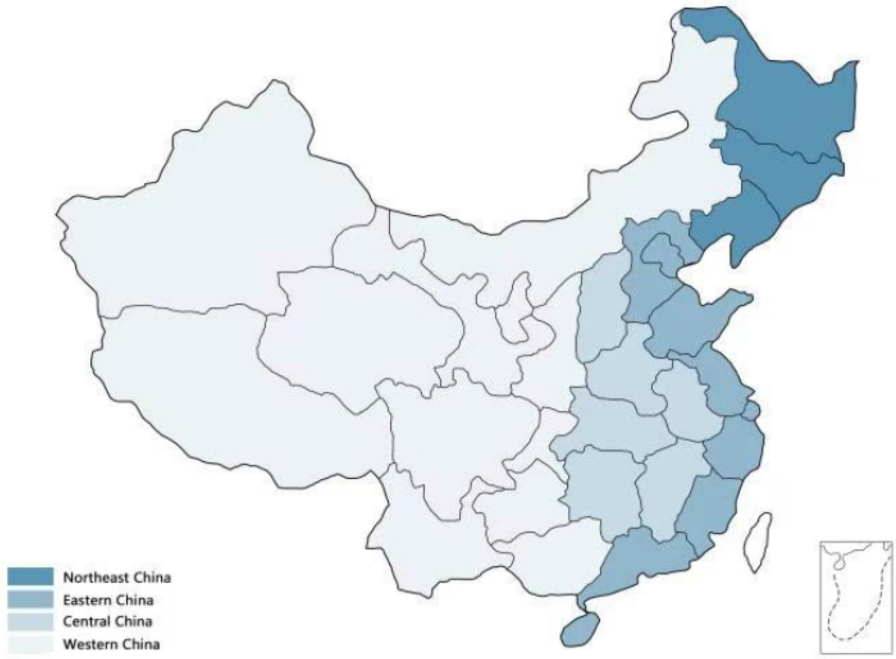


Figure 1-2: China's Urbanization Policy Zones

Data Source: Drawn by the author

Since the beginning of the 21st century, Central China has ranked first among the four regions in terms of urbanization growth, and it has embraced its latecomer advantages. In December 2017, the State Council approved the Changsha-Zhuzhou-Xiangtan megacity as a pilot zone for a resource-saving, environmentally friendly society in which the whole social economy is built upon resource conservation and harmonious co-existence between man and nature. The project is a government-initiated comprehensive reform experiment based on coordinated and sustainable development of production and consumption activities, and natural and ecological systems. As a core city within the urban agglomeration, Changsha plays a vital role in this reform. Changsha demonstrates certain commonalities with other provincial capitals in Central China in terms of economic development, social environment, and urban development crises. Therefore, it is taken as the subject for empirical study to verify the impact of the reform on urban development, providing reference for the sustainable development of similar cities in Central China.

1.3 Research Objectives and Methods

1.3.1 Research Objectives

First, this paper elaborates upon the connotations and future development objectives of resilient cities, and identifies the key fields of development related to resilient cities in Central China, in an attempt to explore the development models of resilient cities from the overall perspective of integrating humans and nature. Second, the need to refine urban planning and management by reflecting on problems through indicators and quantitative evaluation is increasing. The quantitative urban resilience methods put forth internationally by academia, however, are insufficiently systematic and regionally adaptive for China's current urban development needs. Therefore, the second objective of this paper is to establish a collection of resilient city indicators, propose a hierarchical model of urban resilience systems, and then to design an extensible and updatable resilient city evaluation indicator system. Finally, the resilience of one case city is empirically evaluated, and policy suggestions for resilient city construction are proposed.

1.3.2 Research Methods

The approach and process for this study includes three stages: identifying the key resilient city development domains, establishing an indicator system, and empirical evaluation (Figure 1-3).

1）Classifying and organizing research literature and data on resilient cities, starting from comparative analysis on urbanization in China, and Europe and North America, to summarize the resilient city development objectives and strategies proposed by relevant organizations, and identifying the connotations, future development objectives and key domains of resilient city development in central China with reference to international resilient city construction practices.

2）Putting forward a collection of resilient city indicators and an indicator classification framework consistent with China's realities, guided by the resilient city concept framework, making extensive reference to indicators released by leading international organizations like the

United Nations and the European Union, and by the Ministry of Housing and Urban-Rural Development and National Development and Reform Commission of China, as well as urban resilient indicator systems developed by the United States and Germany. Selecting about 20 experts through a questionnaire based on the Delphi Method for expert appraisal on two stages of indicators, and obtaining the preliminary outcomes of these indicators in Central China (using the example city of Changsha). Building an indicator hierarchy model based on the AHP to quantify the decision-making thinking process, verifying the consistency of the indicators, calibrating the inconsistent matrix, and determining indicator weighting.

3) Taking Changsha as a primary subject to collect data and empirically evaluate its comprehensive urban resilience, verify the operability of selected indicators, and further improve upon the indicator system based on the results. This indicator system should be extensible, selecting indicators from the collection based on city type.

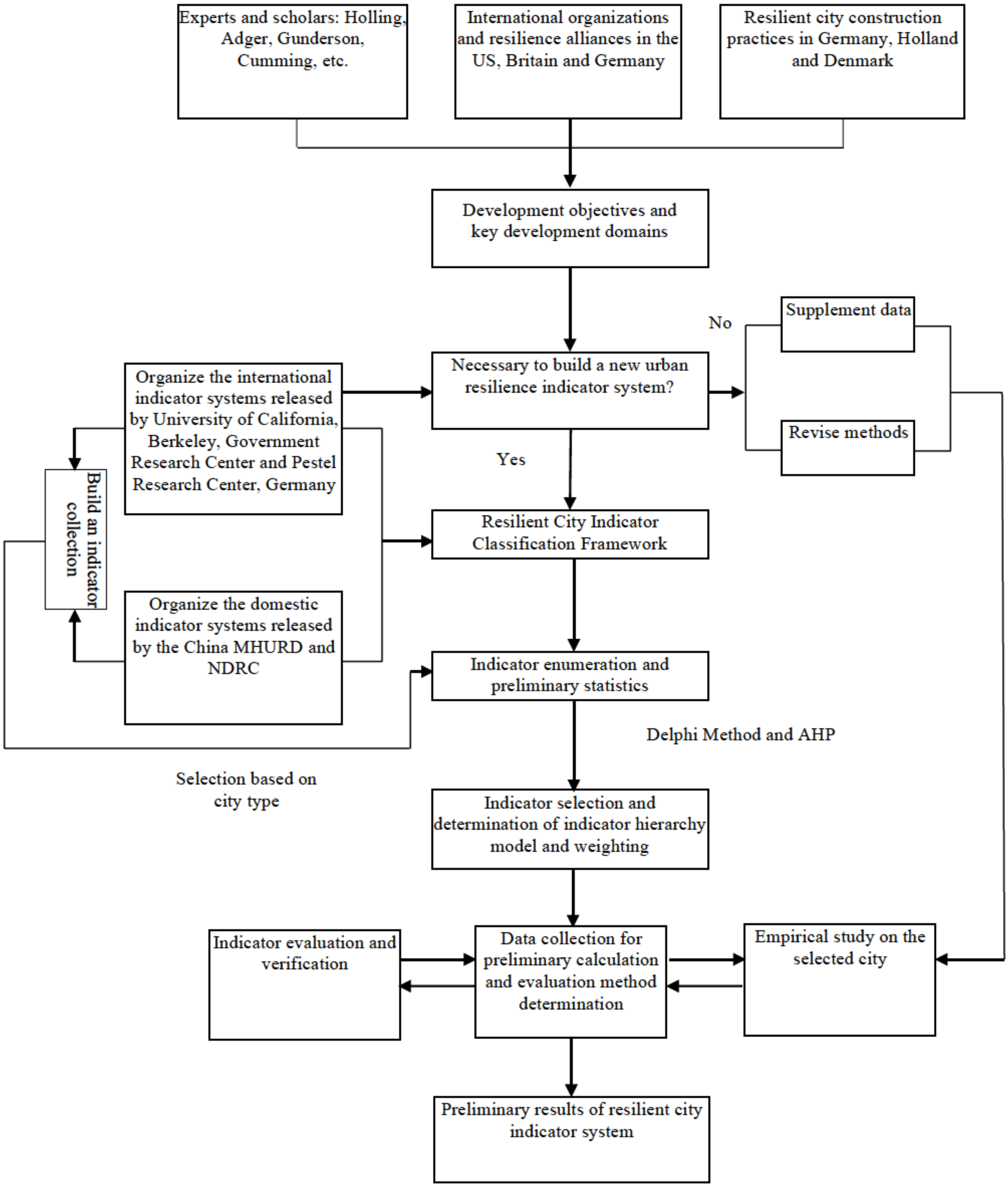


Figure 1-3: Research Approach and Process

Data Source: Drawn by the author

Chapter II Concepts and Connotations of Resilient Cities

Urban and regional resilience – a new catchword or a consistent concept for research and practice?

—Müller，2011

2.1 Differentiating the Concepts of Resilience and Resilient Cities

2.1.1 Resilience

The word "resilience" derives from the Latin word "resilio," which means to rebound. Physically speaking, elasticity is a physical property of an object. A material which deforms under stress and returns to its original shape after removal of the stress is considered to have elasticity (L.D. et al., 1986). Originating from ecology in the 1970s, the concept of resilience has been extensively used in various fields ever since. The object of study is often the interaction between a system and its environment, instead of an individual unit. The concept of resilience started thriving in different disciplines soon afterwards. Table 2-1 illustrates how resilience evolved from an engineering and biological concept to a socio-ecological concept, as summarized by Floke (2006).

Resilience concepts	Characteristics	Focus on	Context
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological/ecosystem resilience social resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibria, stability landscapes
Social–ecological resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity transformability, learning, innovation	Integrated system feedback, cross-scale dynamic interactions

Table 2-1: A Sequence of Resilience Concepts

Data Source: Floke, 2006

2.2.1.1 "Engineering Resilience" in a Single-equilibria System (Before 1973)

In 1973, Holling analyzed and criticized the "stability" theory popular in the ecological community in his paper "Resilience and Stability of Ecological Systems." As the features of the "stability" are quite similar to the single system attributes of engineering design, Holling defined such "stability" as "engineering resilience" to differentiate it from his new concept of "ecological resilience". In terms of single-equilibria systems, "engineering resilience" is characterized by constancy. The key attribute is the system's capacity to restore the original equilibrium and maintain stability after experiencing external shocks. Therefore, the ideal functioning state of the system is to reduce the number of variables, and to keep the system near the equilibrium range. The key indicator for evaluating system resilience is the time of recovery to the original equilibrium. Before the concept of "ecological resilience" was proposed, the concept and theory of "engineering resilience" had been extensively applied to ecological research. Studies on quantity shifts and interactions between predator and prey, between grazer and food, and between two rival communities are typical examples based on this concept. These studies are based on the premise of stable interaction between the two. As only a handful of elements are included, and lags, spatial heterogeneity, nonlinear changes, and quantity thresholds are not taken into consideration, these studies are a far cry from the real world (Holling, 1973).

2.1.1.2 "Ecological Resilience" in a Multiple-equilibria System (1973-1998)

When ecologists built quantitative models based on predation and other related processes in the 1960s and 1970s, they accidentally found that the multiple-equilibria models generated from non-linear functions and regeneration are completely different from previous such models built on the concept of "engineering resilience," a finding which directly led to the birth of "ecological resilience." Holling(1973) argues that resilience determines the sustainability of relationships within an ecological system, and indicates the ability of a system to return to an equilibrium state and maintain its structure and functions after a temporary disturbance. According to this concept, an open multiple-equilibria system is constant, and complex systems have the capacity to absorb external disturbances and maintain basic functions through diverse and multi-level adaptive system adjustments. The concept is thus characteristic of multiple-equilibria systems, featuring the core attribute of adaptation, and the key indicator variable of absorption. The connotative changes of the "ecological resilience" concept have given ecological scholars a new research perspective, generated research orientations like robustness, diversity and self-organization, and improved the development of the "ecological resilience" theoretical system. These theoretical results have been subsequently introduced into social-ecological resilience studies for further development.

(1) Studies on Robustness

According to the ecological resilience concept, a multiple-equilibria system can ensure functional and structural integrity after absorbing external shocks. The concept has inspired reflections and research on how a system might absorb greater external shocks and become more robust. These studies, which involve characteristic analysis on robustness, are known as robustness studies. Steele et al.(1979) pointed out that experimental ecosystems are of great value to understanding and evaluating a system's robustness; Ikeda(1980) explored the effects of stability and structure equilibrium on an ecosystem's robustness; Blackwell et al.(1996) probed the process of building robustness of a biological life support system; De'ath et al. (2000) put forward the "classification and regression trees" technique for ecological data analysis, and pointed out five of its strengths, including usability and robustness construction; Amin(2000) proposed a joint industry-government initiative of improving the security, performance, reliability, and robustness of energy, financial, telecommunications, and transport networks; and Bruneau et al.(2003) held that redundancy and resourcefulness are two important determinants of infrastructure robustness.

（2）Studies on Diversity

In contrast with "engineering resilience," which emphasizes variable control to keep the system stable, "ecological resilience" emphasizes that variable diversification is a crucial factor for maintaining multiple equilibria. Early studies on diversity involved roles and patterns of diversity in the ecosphere. For instance, Goh (1974) built a model to explore the relationships between stability and diversity in an ecosystem; Conrad (1975) found that four factors, including gene pool diversity, affect the adaptability of individuals and groups of organisms; Chapin et al. (1997) noted that a diversity of functional groups has a direct impact on the operating state of an ecosystem; and Naeem et al. (2003) pointed out that bio-diversity of reactions is a key determinant of ecological resilience. All these findings show the gradual expansion of diversity theories in ecology. Since the 1990s, diversity theory has been used more and more in socio-ecological studies, with a research focus on the interplay between urbanization and urban ecological diversity, and the utilization of diversity theory. Crawford (1994) found that nearly one hundred years of urbanization and industrialization has reduced the diversity of aquatic species in the Newark Bay estuary, New Jersey, and destroyed important natural habitats; Myers et al. (2000) explored how to utilize the biodiversity hotspots to formulate the most cost-effective plans to conserve species; while Liu et al. (2009) introduced the diversity principle into analysis on China’s industrial structure, and Kaiser(2004) applied diversity theory into research on multi-level governance innovation.

（3）Studies on Self-organization

A systematic theory developed for complex systems in the 1960s, self-organization theory is primarily used to study the formation and development mechanisms of multiple-equilibria self-organized systems: how a system can autonomously go from disorderly to orderly, and move from low-level order to advanced order under certain conditions. After the scope of research was extended from single-equilibrium to multiple-equilibria systems through the “ecological resilience” concept, self-organization theory was closely integrated into ecological research. Early self-organization studies reveal an attempt to introduce self-organization theory into ecosystems. Ivakhnenko et al. (1980, 1983) explored predicting ecosystem development through self-organization theory based the GMDH algorithm, and Onopchuk (1983) asserted that the self-organization in nonlinear dynamical systems is of great theoretical and practical significance. Ostrom(2009) established a research framework promoting the sustainable development of social-ecological systems by inspiring self-organization, marking the migration of self-organization research from ecology into social-ecological systems.

2.1.1.3 “Social-Ecological Resilience” (1998-)

The 1990s saw a revival in research on resilience, which was directly related to the context of massive exploitation of natural resources via advanced technology, emissions of enormous amounts of gases and solid wastes, seriously affecting nature and resulting in energy crises, environmental deterioration, and climate change. It was under such circumstances that the socio-ecological resilience concept was developed. Westley et al. (2002) pointed out that humans' abstracting, reflective, forward-looking and technology utilization abilities created close interactions with nature, thus systems should be established to integrated social and ecological research, instead of having the respective disciplines be independent, as previously. In 1998, Berkes et al. started using the concept of socio-ecological systems, highlighting the integration of mankind and nature, and indicating that the separation of social and ecological systems was artificial and arbitrary. Socio-ecological resilience takes overall socio-ecological systems as its scope of research. The subjective initiative of people in this system has a strong influence. Their key attribute is transformability, and the main indicator is innovation.

（1）Studies on Adaptive Circles within Socio-Ecological Systems

The theoretical proposition of nonlinear dynamic processes in socio-ecological systems is important to the understanding of social-ecological resilience. This proposition is represented by the Panarchy model and theory proposed by Holling (2002). Panarchy describes the evolution of multiple-equilibria systems. Its core concepts include time-space-(consciousness) hierarchical orders and adaptive cycles. In the two-dimensional model, using the indicators of system change potential and connectedness of control elements, the adaptive cycle is composed of 4 stages: exploitation (γ), in which both change potential and connectedness increase; conservation (κ), in which the systems reject rivals and show decreased resilience; release (Ω), in which the energy in the systems are released under external stimulation; and reorganization (α), in which the systems re-organize and the original cycle is restored, or they enter into a new cycle (Figure 2-1).

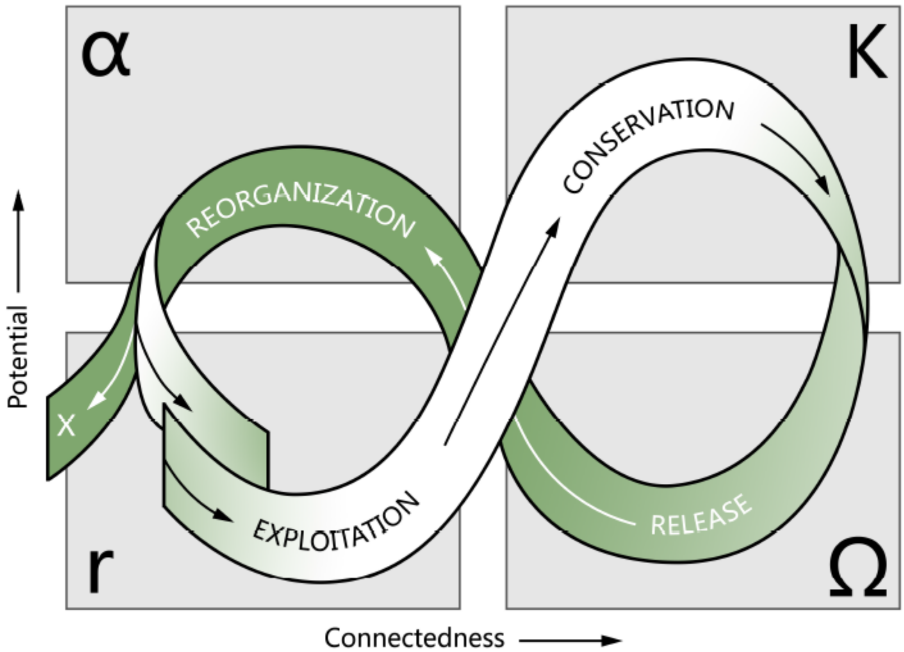


Figure 2-1: The adaptive cycle and panarchy

Data Source: adapted from Gunderson, Holling, 2002.

In hierarchical multiple-equilibria systems, revolt and remembrance results in interaction between systems at different levels, and forming a dynamic equilibrium process. The major conclusion of this research is that "the era of ecosystem management via gradually increased efficiency has ended, and has been replaced by an era of change in which ecosystem management should be ecologically resilient, and social systems should be responsive, innovative and adaptively flexible." (Holling, 2001). This theory was later put into to practice. Henrik et al. (2010) applied the Panarchy concept from ecology to social resilience research, and suggested that governments can enhancing urban resilience by harnessing social networks of urban innovation. Ruhl et al. (2012) studied how to introduce Panarchy theory into the legal system.

(2) Studies on Knowledge and Learning

Knowledge and learning studies primarily involve the establishment and development of related knowledge systems. Berkes et al. (2000) explored the respective features of professional and traditional ecological knowledge systems and their relationship; Hughes et al. (2005) pointed out that traditional barriers to communication between marine ecologists, fisheries biologists, social scientists and economists are being broken down, and multiple-equilibria systems are being used to enhanced the resilience of marine ecosystems; with respect to the relationship between education and learning, Linn et al. (2003) proposed the provision of adaptive educational programs jointly designed by teachers, subject area experts, education researchers, and program designers in the form of online programs; in terms of learning methods, Liao et al. (2012) suggested learning to cope with catastrophic floods through co-existence with periodic floods, thus enhancing urban resilience to disasters; and Dieleman et al. (2013) argued that “organizational learning” is an effective way to improve urban resilience, and proposed learning by doing, experimental learning cycles, and other concepts.

(3) Research on Institutions and Governance

Studies on institutions and governance are primarily concerned with institutional reforms. Adger (2000) explored the impact of property ownership systems on urban resilience based on the case study of Vietnam; in terms of political rights structure, Faguet (2004) showed that local governments could better allocate and utilize public resources after decentralization, and Romero-Lankao et al. (2013) pointed out that the top-down power structure practiced in Latin America played a positive role in urban transformation; based on a case study of Asian cities, Bahadur (2014) suggested enhancing cities’ capacity to cope with climate change through political restructuring; regarding the relationships between local governments and national and international organizations, Olwig (2012) explored the establishment of cooperation mechanisms for disaster prevention and relief between local governments and international organizations.

(4) Research on Adaptive Management

Studies on adaptive management are mainly about innovations in organizational patterns. Rogers et al. (2006) proposed the establishment of cooperation organizations integrating scientists, stakeholders and service agencies for river risk management; Allen et al. (2005) advised verifying management models through discontinuities and functional groups, based on self-organization of socio-ecological systems; Anderson et al. (2014) compared the results of the involvement of citizens and experts in urban greenbelt management and put forth related findings; Reddy et al. (2000) found that involvement of community leaders and stakeholders in the long process of post-disaster recovery, and locally adaptive strategies and policies, were extremely important determinants with respect to leadership and involvement patterns; Saul et al. (2011) theoretically explored the relationships between leadership and cooperation, and introduced four leadership models; and Coaffee (2013) summarized Britain's experience in urban resilience development with regards to management policies.

(5) Research on Social Resilience

Research on social resilience regards integrated socio-ecological systems a key aspect of study. Its core issues are the transformation of ecological resilience into sociology, establishment of relationships between social and ecological resilience, and determinants and assessment of social resilience. Related studies primarily involve the concept and determinants of social resilience. Adger (2000) explored the relationships between social and ecological resilience, and put forward the concept and determinants of social resilience for the first time; Dorogovtsev et al. (2002) discussed the relationships between social network evolution and resilience; Murphy et al. (2007) showed the important role of social capital in community-level emergencies; in terms of resource-economy relationships, Muller et al. (2007) studied the relationship between water resource management and urban resilience in sub-Saharan Africa; Fred (2009) probed the relationships between climate change, oil depletion and global trade; regarding the impact of technological innovation on urban resilience, Liu et al. (2005) pointed out that multi-hazard mitigation would become a new hotspot in research on earthquake engineering; Noor et al. (2012) proposed managing urban land use sprawl using GIS and remote sensing to enhance urban resilience; in vulnerability research, Adger (2006) analyzed the relationships between sociological vulnerability and resilience; Turner et al. (2003) explored the vulnerability analysis framework; and Justus (2011) studied how to enhance the resilience of vulnerable groups to disasters based on the case study of the poverty-stricken East African population.

This literature shows that that the resilience concept from ecology has found applications in human-nature interaction systems, both single-equilibrium and multiple-equilibria, and has penetrated into interdisciplinary studies involving ecology, sociology, economics and technology. Researchers in various fields have come to realize the close links between mankind and ecological systems, and the interactive relationship between their resilience and system operations. Despite distinct differences in research scope, connotations, and key indicators, they all agree that the fundamental meaning of resilience is a system's capacity to absorb external shocks and maintain its major functions in the face of crises (Ouyang et al., 2016).

2.1.2 Resilient Cities

A title search on "urban resilience OR cities resilience OR resilient cities OR resilient OR resilience" in the Web of Science reveals that the first paper in urban studies and planning was published in 2001. As of 2017, 494 papers were published (Figure 2-1).

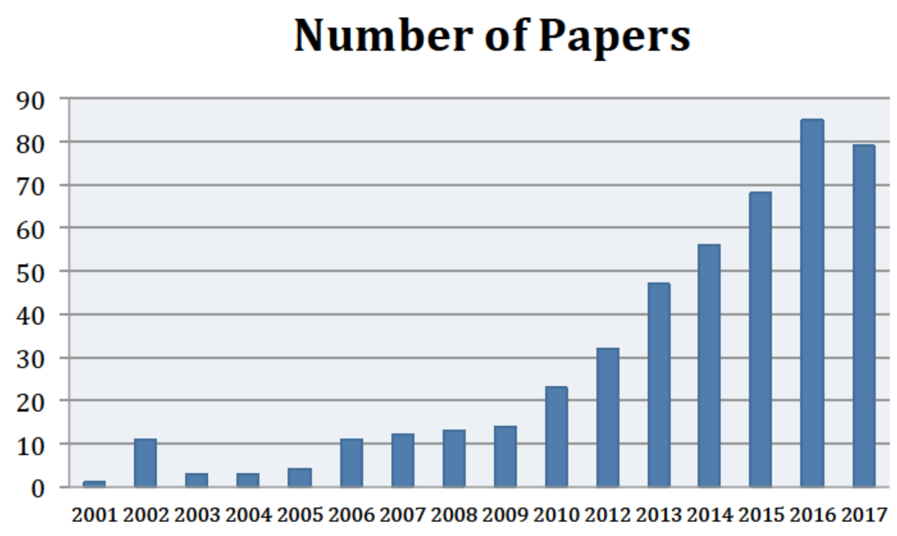


Figure 2-2: Increasing Attention to Resilient Cities

Date Source: Drawn from Search Results from the Web of Science

Gradually applied to research on urban systems since the 1990s, resilience theory has brought new prospects to urban planning research. It is closely related to problems such as climate change, energy crises, and environmental deterioration. As the physical areas impacted and damaged by these crises, cities have great vulnerabilities. It's under such circumstances that resilient cities were put forward as an ideal urban development model (Peter et al., 2009). In 1999, the University of Florida and Bell Labs jointly founded the Resilience Research Network, which later developed into a global research organization: the Resilience Alliance. Resilient cities have become an important object of inter-disciplinary collaboration. The Resilience Alliance (2007) defines resilient cities as "cities or urban systems which can absorb external disturbances while maintaining their original features, structures, and key functions, and have the capacities of self-organization and learning." It believes that urban resilience research will promote sustainable urbanization. Cumming (2011) summarized the definition of modern resilient cities in three levels: (1) the amount of disturbance that a system can absorb while still remaining within the same state or domain of attraction; (2) the degree to which the system is capable of self-organization (versus lack of organization or organization forced by external factors); and (3) the degree to which the system can build and increase its capacity for learning and adaptation. Put simply, these three levels reflect urban systems' integrity, interoperability, and self-development based on local conditions. Cities are not only socio-ecological systems, but also spatial systems and the result of interaction of urban elements, culture and history. Wilkinson (2011), arguing that resilient city research, under the current context of extreme complexity, can restructure social ecology, urban planning, and urban design, focused on the relationships between humans and nature, and dynamic development and management of cities, and put forward the operational model of "resilience strategy" which accepts the changes and uncertainties of cities and related ecological systems, maintains socio-ecological diversity following disturbances, and accordingly develops capacities for learning and self-organization. Other scholars (McEntire, 2001; Turner et al., 2003) have held that urban resilience is urban systems capacity for emergency response and recovery from disasters.

In the beginning of the 21st century, resilient city research shifted from solely qualitative to qualitative/quantitative together, and started to move from theoretical to practical with attempts at economic recovery (Simmie & Martin, 2010), post-disaster reconstruction (Colten et al., 2008; the United Nations International Strategy for Disaster Risk Reduction, 2010), urban security and post-terrorism recovery (Coaffee, 2009) and urban governance (Tanner et al., 2009). As pointed out by Gunderson and Holling (2001), resilience can be quantified based on the degree of disturbance which allows the system to keep running, absorb the changes, and remain the same. However, literature related to resilience assessment is concentrated on quantitative indicators. Only a handful of studies attempt to quantify, assess, and empirically study resilient cities. This aspect will become a research focus and difficulty in the future.

As resilient cities are a new concept in China, only a small number of research findings can be identified in the country. Sheng et al. (2006) pointed out that traditional rigid urban planning is no longer adapted to the needs of urban construction, and flexible working methods will become a new development direction for of urban planning. He elaborated upon basic thinking for flexible urban planning approaches based on the example of urban population forecasting. In 2012, Cai Jianming et al. systematically reviewed and organized resilience theories and resilient city studies in international academia, summarized the basic concepts, connotations and representative studies from the perspectives of ecological, engineering, economic, and social resilience, and predicted future research trends and orientations for resilient cities. Their study is the first relatively comprehensive summary of international research progress for resilient cities. Zhai Guofang (2016) pointed out that construction of resilient city should be put on the agenda in China and the problems of resilience city construction are insufficient theoretical research and lack of relevant regulations.

A survey of existing literature shows that resilient city studies have expanded into multiple theoretical disciplines including ecology, sociology, economics and technology, providing a broad horizon and methodological foundation for China. Methodologically, there are a great deal of qualitative studies, but a smaller number of quantitative ones, most of which are based on other countries and lack regional features. As a newcomer in the research on resilient cities, China is still absorbing the concept and focusing its research on the utilization of international resilience theories, and has yet to build a sound theoretical system.

2.2 Connotations and Functions of Resilient Cities

As pointed out by Mumford (1968) in his book *The City in History: its origins, its transformation and its prospects*, the five most fundamental functions of a city are living, creation of human civilization, education, social interaction, and economy. Resilient cities not only deliver these fundamental functions, but also accept uncertainty and changes, and manifest diversity, self-adaptation and tolerance. After repeated research on “resilience factors” in about 300 cities, the Rockefeller Foundation (2014) summarized the eight following functions of resilient cities.

2.2.1 Delivers basic needs

As large population settlements, cities should be able to continuously meet residents’ basic living needs and allow individuals and families to enjoy relatively high living standards, whether or not they are under stress. To do so, they must rely on multiple water, food and energy sources to maintain operations when a single source is under impact or stress. Storing living supplies like food, medicines and clothes, and guaranteeing the accessibility of emergency shelters are essential. Promoting the development of sustainable energy sources, rainwater collection, waste water treatment, and food self-sufficiency can alleviate pressure on energy sources, water, and food.

2.2.2 Safeguards human life

It is difficult to deal with threats like fires, floods, pollution, or terrorist attacks individually. Therefore, resilient cities must enhance prevention awareness, provide comprehensive health facilities and services, and work out emergency evacuation and response measures to ensure adequate resources to offset such impacts and safeguard human life. Such a system should include well-prepared medical staff and procedures to ensure that all residents have access to medical services during emergencies, providing overload capacity for peak demands. Furthermore, preventive measures should be formulated, and high risk areas planned or marked out, to reduce threat exposure to the extent possible.

2.2.3 Protects, maintains and enhances assets

City assets include man-made assets like infrastructure and roads, as well as natural assets like rivers, woods, soil and underground water. These assets are the lifeline of a city, providing water, energy, and food, and also form a defensive line, protecting the city from floods, landslides, and pollution. Resilient cities must protect these assets to maintain their functions, reduce the possibility of impact or stress, and provide key services in the case of such events.

2.2.4 Facilitates human relationships and identity

People of different genders, classes, races and cultural identities living in the tight space of a city are known as its residents. A good social network can strengthen connections and social interactions and allow residents to feel equal and just in life and at work, for greater tolerance, common values, social responsibilities, and social ties and trust. Social cohesion has become an important factor for coping with impact or stress events. Resilient cities are expected to guarantee social peace and stability, prevent social collapse in impact or stress events, and provide psychological support for those experiencing impact or stress. Active and interrelated communities can help build powerful cities of collective cultural identity from the bottom up; incorporating the community into the decision-making process to achieve mutual trust and support among individuals, community and government helps people to stay united in the face of unpredictable circumstances, preventing social unrest and violence.

2.2.5 Promotes knowledge, education and innovation

Cities have always been the center of knowledge and innovation, drawing creative and educated talent. Playing a crucial role in the process of impact and stress absorption, knowledge is conducive to rapid recovery, promoting prediction of potential natural disasters and research on climate change and forecasts. Cities also allow different cultures, races, languages and technologies to gather, exchange, fuse and aggregate. Cities are like an enormous closed container facilitating such aggregation, gathering all emerging forces and strengthening their interaction, bringing overall achievement to a new level. Hence, resilient cities must understand and give play to the power of knowledge, and draw lessons from the past to prevent and reduce the impact brought by crises.

2.2.6 Defends the rule of law, justice and equity

The reason why urban living has played such a major role in modern living is that it provides more complete public facilities and services, more job opportunities, better opportunities for spiritual enjoyment, and higher quality of life. The foundation holding it all together is the law. Cities implement policies and enforce laws to keep illegal acts of individuals and groups at bay, and maintain rule of law, justice, and fairness. Urban civilization depends on laws being followed and revered by all community members, government powers being effectively restrained to ensure clean and efficient government, and rights and protections being fully guaranteed. Therefore, resilient cities must defend the rule of law and justice, and facilitate the establishment of effective and fair systems. An adequately-staffed and well-trained police force and a transparent political mechanisms can curb the escalation of stress or conflict events, maintain peace, and keep residents safe.

2.2.7 Supports livelihoods

As the cornerstone of economic activities, cities concentrate resources, capital, and manpower, the preconditions for production, consumption, and profit. Through employment, urban residents provide cities with necessary services and commodities, obtaining income to support themselves and their families. Failure to provide urban residents with lifestyle-supporting jobs is a stress source, and the stress escalates with the rise of unemployment. Resilient cities may promote diverse livelihoods and jobs through financing, natural surplus increases, skills training, support for business, and social welfare. Moreover, a good key infrastructure network can improve working conditions and alleviate the impact brought by crises or stress events.

2.2.8 Stimulates economic prosperity

Cities have become the main reflection of global competitiveness. Cities may attract capital and enhance their workforces by increasing economic vitality – their capacity and potential for economic development – and ensure a sound business environment to create economic prosperity. Economic crises, massive unemployment and other phenomena are undesirable results of an unsound business environment. Furthermore, economic diversification based on industrial structure diversity and innovation-driven industrial improvement is an important means to reduce sensitivity to changes in external economic conditions. Industrial development limited to certain fields may generate robust growth, but leaves cities vulnerable to recessions, affecting the sustainable economic development. Hence, resilient cities require sound financial management, diversified economic structures, sufficient investment, and emergency stabilize funds to maintain their overall competitive edge.

2.3 Genesis and Evolution of Resilient Cities

From the ideal capital construction model, as recorded in *Kaogong Ji*[2] in ancient China, and the ideal city plan of Vitruvius in ancient Rome, mankind has never let up in its pursuit of ideal cities. Historically, numerous ideal city visions have affected urban development to a large extent.

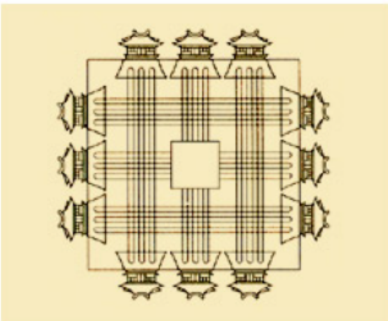


Figure 2-3: Restored Map of Imperial Capital Structure based on Kaogong Ji

Date Source: China digital science and technology museum

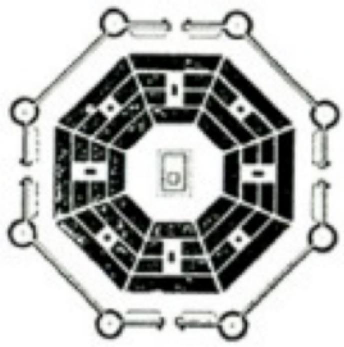


Figure 2-4: The Ideal City of Vitruvius

Date Source: The ten books on Architecture

Ancient Chinese philosophy system has always attached great importance to a harmonious

[2] The Kaogong ji, translated as the Record of Trades, Records of Examination of Craftsman, or Book of Diverse Crafts, is a classic work on science and technology in Ancient China, compiled towards the end of the Spring and Autumn period.

relationship between man and nature. Construction methods such as "unification of nature and man," "man-made goods as good as formed by heaven," and "adjustment to local conditions" in classical Chinese thoughts reflect a pursuit of harmonious coexistence of man and nature. The Western ideal city model, influenced by idealism, rationalism, humanism, post-modernism and other philosophical beliefs, has undergone a process from intuitive form to diversified development. Classical urban planners primarily constructed the forms of ideal cities in response to specific urban problems – i.e. the linear city of Mata (1882), the garden city of Howard (1898), and the satellite city of Unwin (1992). Continuous economic growth and technological revolutions since the 1950s have brought profound changes to the Western world, and generated social and environmental urban problems. Under the influence of modern scientific rationalism, idealist, rationalist, and social elitist planners and architects put forward modern ideal city models: the broadacre city of Wright (1932), Saarinen's theory of organic decentralization (1942), and the radiant city of Corbusier (1956). In the meantime, certain scholars have attempted to measure and assess urban development models using statistical data and indicators. The 1970s was a period of transformation from modernity to post-modernity in the West, which experienced a major outbreak of modern urban problems and highly complex and pressing social contradictions. During this social transition, humanism started to rise, forming a conflict with technological rationality. In urban planning, this conflict was manifested in a shift in focus from the impact of industrial technology to development of ecological, humanistic, social and philosophical thinking. The viewpoints of Eco Cities and Sustainable Cities were successively proposed.

With the transformation of the global development environment since the 1990s, in response to contemporary urban developments like rapid urbanization pressure, globalization and urban system restructuring, informatization, changes in urban lifestyles, and unprecedented attention attached to ecology and culture, academia has extensively reflected on the urban development problems of developed countries, arguing that many traditional development models like low density suburbanization development, highly dependent upon automobiles and expressways, are unsustainable. Quite a number of alternative urban planning ideas and development models have been put forth, like compact cities, low-carbon cities, and new urbanism. As an urban development model designed to reduce city vulnerability and enhance adaptability and recovery, the newly emerged resilient city concept has become an international urban planning research hotspot. According to the 2015 World Conference on Disaster Reduction (WCDR), the resilience concept has been extensively applied theoretically and practically to disaster reduction discussions and intervention measures. Phrases like “sustainable and resilient communities,” “resilient survival modes,” and “enhancing community resilience” have been seen frequently in periodicals and planning documents. On January 12, 2005, the United Nations International Strategy for Disaster Risk Reduction (UNISDR) signed the Hyogo Framework for Action 2005-2015, also known as the Hyogo Declaration. Accepted by 168 governments across the world, this framework aims to “strengthen disaster adaptability in nations and communities.” In 2010, the UNISDR launched a campaign called “Make Cities More Resilient” (UNISDR, 2010). This campaign was designed to “increase awareness of and devotion to sustainable development, reduce disaster risk, and enhance the public’s sense of happiness and security to ultimately ‘build a better tomorrow’” (UNISDR, 2010). In the latest 2014 World Development Report and 2014 Human Development Report released by the United Nations Development Programme, “resilience” was taken as the core theory. In May 2010, ICLEI, WMCCC and the Bonn’s Municipal Government jointly convened “Resilient Cities”; this Annual Global Forum, held in Bonn nine times so far, is intended to boost the adaptation and development of urban resilience against the background of global climate change and frequent disasters. In December 2011, the Durban Local Government Convention, a participant in the Mayors Adaptation Forum, passed the Durban Adaptation Charter. The 10 principles set forth in the Charter constitute the framework of current resilient city construction. Thus far, this Charter has been signed by 114 local governments from 20 countries (still growing), and submitted to the 17th conference of the parties of the UNCCC with the solemn statement that local governments would shoulder the responsibility to address climate change. “Resilient Cities” further created important documents such as the Bonn Declaration of Mayors. The 2010 Bonn Declaration of Mayors called on governments to launch a “Make Cities More Resilient” Campaign; the 2011

Bonn Declaration of Mayors reached a consensus on dealing with risks and development conditions using more integrated methods, incorporating improvements to urban resilience into the future urban development assessment, attaching importance to disadvantaged urban groups in vulnerable positions, utilizing adaptive strategies based on ecosystem balance, and realizing transformation from globally-supported to locally supported-economic models. The 2013 Bonn Declaration of Mayors affirmed the 10 principles proposed by the Durban Adaptation Charter, and further noted prominent urban problems like food safety, urban poverty and local biodiversity. Working out new connotations of the "resilient city" development strategy and providing related assessment indicators are the precondition and key to formulating a "resilient city" plan.[3] The 2013 ACSP/AESOP Joint International Congress was themed "Planning for Resilient Cities and Regions." Gradually becoming universal, resilient cities is a seminal characteristic of future development. The UN-Habitat introduced its vision for cities in the New Urban Agenda released in 2016, "We are able to inhabit and produce just, safe, healthy, accessible, affordable, resilient, and sustainable cities and human settlements, to foster prosperity and quality of life for all." How cities should introduce the resilient city theory and boost the reform of planning methods of resilient cities under this vision has become a hotspot issue and focus of attention for the planning circles.

2.4 Theoretical Foundations of Resilient Cities

As shown by the definition and connotations, resilient cities are a complex interdisciplinary phenomenon. Such systematic, complex, and diverse theories must be based on multiple foundations, including physics, sustainable development, and complexity theories.

2.4.1 Physics Foundations

The most intuitive way to conceive elasticity comes from materials like springs. Physics reveals that springs can return to their original shape and position after bending, pulling and compression. However, deformation beyond the yield point under external forces leads to plastic deformation. The yield point indicates the transformation from an elastic to a plastic behavior.

[3] http://resilient-cities.iclei.org/index.php?id=833

After the removal of external forces, materials deformed beyond the yield point do not return to their original state, demonstrating an irreversible process. Therefore, elasticity is used by physicists to describe a property of materials, structures and systems returning to their original shape or position before deformation beyond the yield point under external impact. This concept was later developed into engineering resilience by Holling (1996) with a research focus on "recovery speed" – the time the system takes to recover the equilibrium after disturbance. The concept attaches importance to efficiency, stability and predictability.

2.4.2 Sustainable Development and Sustainable Urbanization Theories

The deteriorating environmental problems since the 1960s have evolved into global problems spanning regional and national boundaries, resulting in worldwide attention paid to the environment, and reflections and explorations on development paths. The United Nations Conference on the Human Environment held in Stockholm in June 1972 woke governments up to environmental problems. In 1987, the World Commission on Environment and Development (WCED) introduced the concept of sustainable development for the first time, in a report titled Our Common Future. This comprehensive dynamic concept involving economy, society, technology, and natural environment is about "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." With assistance and support from the U.K. Department for International Development, the United Nations Human Settlements Programme (UN-Habitat) issued a research report entitled "Sustainable Urbanization – Achieving Agenda 21" in 2012, and introduced the topic of "sustainable urbanization" aiming to establish a general conceptual framework and lay a solid theoretical foundation for future international cooperation efforts (UN-Habitat, DFID, 2002). As a dynamic, multidimensional and multi-scale process, sustainable urbanization is an important aspect of sustainable development.

Relatively speaking, Sustainable Cities are an old but evolving concept, while Resilient Cities are new, but inconsistently defined. Table 2-2 compares Resilient Cities and Sustainable Cities within different scales and scopes. It shows that: 1) At a global scale, research about both

Resilient Cities and Sustainable Cities is concerned with ecosystem management and protection; the difference lies in the fact that Resilient Cities concentrate more on ecosystem self-protection and self-recovery to cope with crises, while Sustainable Cities concentrate more on the utilization and protection of ecological resources; 2) At the regional scale, Resilient Cities involve close attention to the stability and diversity of economic structure to address unknown risks and pressures, while Sustainable Cities emphasize the self-sufficiency of the local economy and environmental benefits of economic activities; 3) At the city scale, Resilient Cities are more concerned with policy management and the impact of terrorism on urban development, while Sustainable Cities tend to focus on administrative issues in sustainable development like urban planning and land use planning; 4) At the community scale, Resilient Cities focus more on economic diversity and employment security, while both concepts equally emphasize the basic needs of residents like adequate water supply, medical care and housing; 5) At the facilities scale, Resilient Cities underline the security of transportation and telecommunication facilities to ensure immediate availability in emergencies, and further stress green and earthquake-resistant building design at the micro level; sustainable Cities, by contrast, are more focused on infrastructure, building planning and layout (Zhang et al., 2018).

Although concerned with the economy, environment, society, population health, policy management and infrastructure, the priorities of Resilient Cities and Sustainable Cities vary. However, the focus on each point is different. Relative to sustainable cities, resilient cities are oriented more towards specific risks, more concerned with the capacity of urban systems to respond to diverse pressures and redundancy, and further emphasize resilient policy and management system implementation, urban infrastructure construction, and maintenance.

Scale	Items	Resilient Cities	Sustainable Cities
Global scale	Ecological environment protection	Ecological environment crises (Woolhouse, Rambaut, & Kellam, 2015) Landscapes and ecosystems for human	Ecological environment monitoring (Rees & Wackernagel, 1996) Ecological infrastructure construction

		welfare (Kareiva, Watts, McDonald, & Boucher, 2007)	(Passarini, Pereira, Farias, Calarge, & Santana, 2014)
	Resource protection and utilization	Climate change (Leichenko, 2011) Resource inventory (Campanella, 2006)	Non-renewable resource protection (Wang, 2011) Renewable resource utilization (Banai, 2005)
	Population and health	Emergency equipment and personnel (Sui, 2010) Space allocation of medical resources (Asprone & Manfredi, 2015)	Aging (Buffel & Phillipson, 2016) Health service facilities (Chelimsky, 1993)
Regional scale	Regional economic structure	Emergency funds for individuals and the public (Stone, 2008) Regional economic structure update (Barata-Salgueiro & Erkip, 2014)	Regional economic vitality improvements (Chan & Lee, 2008) Local economic circulation system (Fung & Kennedy, 2005)
	Regional resource flow	Water management (Balsells et al., 2013) Resource allocation across regions （Toubin, Laganier, Diab, & Serre, 2015）	Cyclic utilization of natural resources (Tidball & Stedman, 2013) Optimal allocation of social resources (Wang, 2011)

	Regional resource carrying capacity	Factors influencing regional carrying capacity (Davoudi, 2009) Carrying capacity calculations (Wei et al., 2016)	Carrying capacity management (Wei, Huang, Li, & Xie, 2016) Intensive use of resources (Shi & Yu, 2014)
Urban/city scale	Urban governance	Diversified employment opportunities (Beilin & Wilkinson, 2015) Social insurance and welfare (Wagenaar & Wilkinson, 2015)	Land use/urban planning (Foley et al., 2005) Urban management system (Moussiopoulos, Achillas, Vlachokostas, Spyridi, & Nikolaou, 2010)
	Urban system	Urban spatial structure (Barthel, Parker, & Ernstson, 2015) Urban flood control and drainage systems P A (Aerts et al., 2014)	Urban metabolism (Khan & Uddin, 2015) Social and economic system (Moussiopoulos et al., 2010)
	Urban Security	Corruption (Server, 1996) Terrorism (Githens-Mazer, 2012)	Safety risk monitoring and warning (Zhang & Guindon, 2006) Public awareness of risk (Bagaeen, 2006)
Community scale	Residents demand	Emergency needs of residents (Vallance, 2015) Basic security needs of residents	Residents' healthy living needs (Marsden & Sonnino, 2012 Residents' quality of life demands

		(Mehmood, 2016)	(Smith & Levermore, 2008)
	Neighborhood	New neighborhood relationships (Chelleri, Schuetze, & Salvati, 2015) Community exchange platform (Brand & Nicholson, 2016)	Neighborhood effect (Chelleri et al., 2015) Community cohesion (Eames & Egmose, 2011)
	Community management	Community emergency response (Braun-Lewensohn & Sagy, 2014) Community network development (Pauwelussen, 2016)	Diversity of community income groups (Molnar, Ritz, Heller, & Solecki, 2011) Diversity of age groups (Saadatian, Bin Sopian, & Salleh, 2013)
Facilities scale	Infrastructure management	Critical infrastructure planning (Chang, McDaniels, Fox, Dhariwal, & Longstaff, 2014) Continuity of key services Toubin et al., 2015)	Infrastructure capital investment (Chester, Pincetl, Elizabeth, Eisenstein, & Matute, 2013) Infrastructure selection (Muller, Biswas, Martin-Hurtado, & Tortajada, 2015)
	Transportation	Traffic emergency management (Testa, Furtado, & Alipour, 2015) Transportation security (Cox, Prager, & Rose, 2011)	Integrated transport networks (Sinha, 2003) Reliable and compatible communication networks (Pandolfini, Bemposta, Sbardella, Simonetta, & Toschi, 2016)

	Building	Green buildings (Zaidi & Pelling, 2015) Earthquake resistant buildings (Takewaki, Fujita, Yamamoto, & Takabatake, 2011)	Buildings plot ratios (Smith & Levermore, 2008) Architectural composition (Specht et al., 2014)

Table 2-2: A Comparison on Studies on Resilient Cities and Sustainable Cities at Different Scales and within Different Scopes

Date Source: Zhang et al.， 2018

2.4.3 Complexity Science Theories

Emerging in the 1980s, the complexity sciences are the result of further development of modern system theory and nonlinear theory. This attempt to see the complex phenomena of nature and human society from a new perspective has brought about an interdisciplinary revolution in scientific thinking. Concerned with what traditional disciplines have overlooked, it stresses the prominent features of complex systems under the interaction of phenomena including diversity, evolution, generation and emergence, uncertainty, self-organization, disorder, and chaos. The rise of complexity sciences marks the transformation of our understanding of the world from objectivity, total predictability, determinism, and reductionism to emergence, non-determinism and autonomy. Humanity’s response to the world should also break free of the limits of several layers of top-down controls into inter-level bottom-up decentralized or multicentered self-organization (Morin et al., 1999).

As a “giant open system with complexity”(Zhou, 2002), urban systems include micro and macro, static and dynamic, internal and external, temporal and spatial, and material and spiritual elements. These interconnected and interactive elements constitute an integral system (Xie et al., 1996). The elements comprising the urban mega-system can be classified in various ways, and most classifications consider cities to include a series of human and physical systems. Da Silva et al. (2012) divided urban systems into three categories, reflecting their physical elements, people, and regulations, manifested in their infrastructure, knowledge, and institutional networks respectively. Da Silva et al. further broke down those three categories in an unpublished work, as shown in Table 2-3.

Network Type	System Type	Examples
Networked infrastructure	Basic Infrastructure	Food
		Water
		Shelter
		Sanitation
		Waste management
	Community wellbeing infrastructure	Education
		Health
		Power supply
	Advanced Infrastructure	Acute health care
		Further education
		Manufacturing and Processing (Factories and Industrial Units)
		Service industries (banking, offices, others)
	Enabling infrastructure	Public transport - local level
		Transport - regional and global levels
		Transport of goods (freight, ports)
		Communications
Knowledge networks	Information Flows	Systems for the dissemination of information (e.g. radio stations, the internet, others)

	Technology	Networks to develop and access technology (e.g. research and development centres)
	Education	Institutions for education and knowledge generation (e.g. schools, universities)
Institutional networks	Governance	Systems for governing and decision making (e.g. government structures, community associations, business associations) and rules and practices supporting interaction (e.g. justice, tenure & rights, markets)
	Social Systems	Systems of social relationships, hierarchy, status, power, exchange, social reproduction
	Culture	Systems for interpretation, including issues of faith, myth and user behavior (e.g. religious beliefs and ethical positions)
	Economic Systems	Systems regulating production, exchange, and finance (e.g. markets, labour conditions, funding tools)

Table 2-3: Urban System Classification

Data Source: Rockefeller Foundation, 2014

It can be seen that cities are a complex system involving resources, energy, ecology, politics, economy, culture, management, planning, engineering and many other disciplines. Therefore, the development of resilient cities is an extensive and comprehensive systematic project. The connotation of resilient cities should be explored from multi-disciplinary perspectives to re-discover urban systems with a resilient mindset.

Chapter III Development Objectives of Resilient Cities in Central China

Given the Complexity of Large Cities, Can Urban Resilience be Attained at All?

—*Deppisch, Schaerffer，2010*

3.1 China's Urbanization Policy Zones and Development Guidelines

Considering the vast differences in urbanization between different regions in China, a regional study has great practical significance. China can be divided into four regions by urbanization policies: Eastern, central, Western, and Northeast China. With six provinces— Shanxi, Henan, Anhui, Jiangxi, Hubei and Hunan (Figure 3-1) – Central China has a land area of 1.028 million km^2, making up 10.7% of the national total. In 2016, its population was 367 million, accounting for 26.6% of the national total. Occupying the heartland, central China connects China's East with its West, and boasts abundant land and water resources, conducive to capital attraction. In addition to good transportation and other infrastructure, and a good economic and technological foundation, central China ranks in the middle nationally in terms of industrialization. However, its large population and low amount and quality of urbanization have caused tremendous employment pressures, and inadequate human capital. Moreover, systems lag, and innovation lacks.

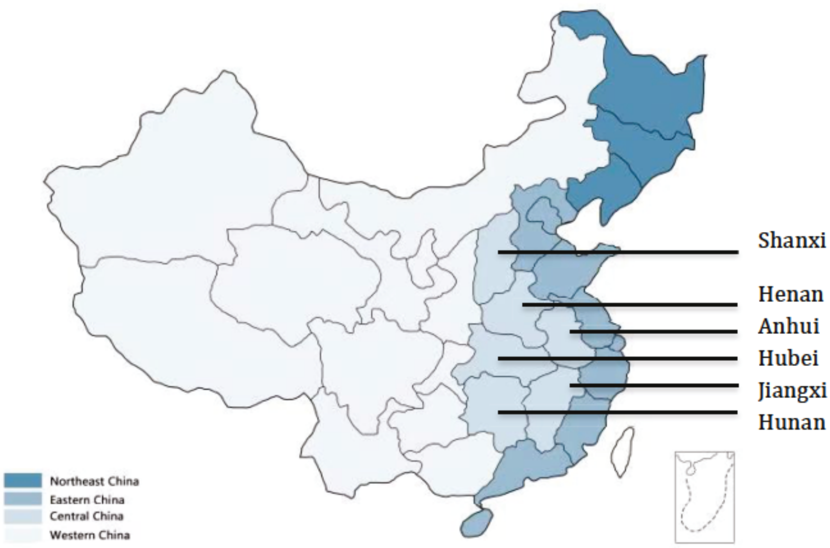


Figure 3-1: China's Urbanization Policy Zones

Data Source: Drawn by the author

As a densely populated region with great development potential, central China was once outpaced by Eastern China in development level and by the West in growth rate. There is an old saying about the central region as China's "nothing region." With the advancement of the Rise of Central China plan in 2004, and the acceleration of industrial transfer in Eastern coastal areas, central China ranks first among the four regions in terms of urbanization growth, embracing the advantages of a latecomer. The *National New Urbanization Plan* (2014-2020), calls for expediting urbanization, attracting rural workers back to their hometowns and nearby towns in Eastern China, accelerating industrial cluster development and population aggregation, and developing new pillars of growth in areas with strong resource and environmental carrying capacity. These efforts will help boost economic growth and expansion of market space from the East to the West, and South to North, propel the formation of a more rational economic layout, and help coordinate regional development. As a crucial grain producing region, central China must reverse its crude and unhealthy development model, strictly protect arable land (in particular basic farmland) and water resources, control urban sprawl and pollution, and strengthen environmental protection and governance.

	GDP (RMB 100 Million)	**Population (10,000)**	***Per Capita* GDP (RMB 10,000/Person)**	**Regional GDP (RMB 10,000/Km2)**	**Land Area (10,000 Km2)**	**Fiscal Revenue (RMB 100 Million)**	**Foreign Direct Investment (USD 10,000)**	**Per Capita Disposable Income (RMB)**
Eastern China	410186.4	52951.0	7.75	2328.0	176.2	50026.8	40046	30654.7
Central China	160645.6	36709.0	4.33	1562.7	102.8	15334.7	4267	20006.2
Western China	156828.2	37414.0	4.19	228.6	686.0	17265.2	4155	18406.8
Northeastern	52409.8	10910.0	4.80	665.9	78.7	4612.7	2772	22351.5

China								

Table 3-1: Indicators for the Four Regions of China in 2016

Data Source: China Statistical Yearbook 2017

3.2 Spatial Distribution Features of China's Urban System

3.2.1 A Gradient from High Density in the East to Low Density in the West

Due to geographic and economic conditions and administrative factors, China's cities are generally distributed densely in the East, and sparsely in the West. The Eastern coastal areas boast relatively developed cities of different sizes and grades, with city distribution density and urban population density much higher than in the central and Western regions – as well as more advanced urban systems. Central China features a large number of medium-sized cities, and a large number of metropolises and megacities. Medium-sized cities develop towards metropolises competitively based on the principle of survival of the fittest, and the transport and communication facilities of central China will be greatly updated in the future, resulting in expansion of certain urban functions along their axes, and a combination of axial and point-to-plane expansion in urban spatial distribution (Cui et al., 1999). Western China is primarily composed of small towns, lacking medium-sized cities and metropolises, with low density and a slow speed of development (Figure 3-2).

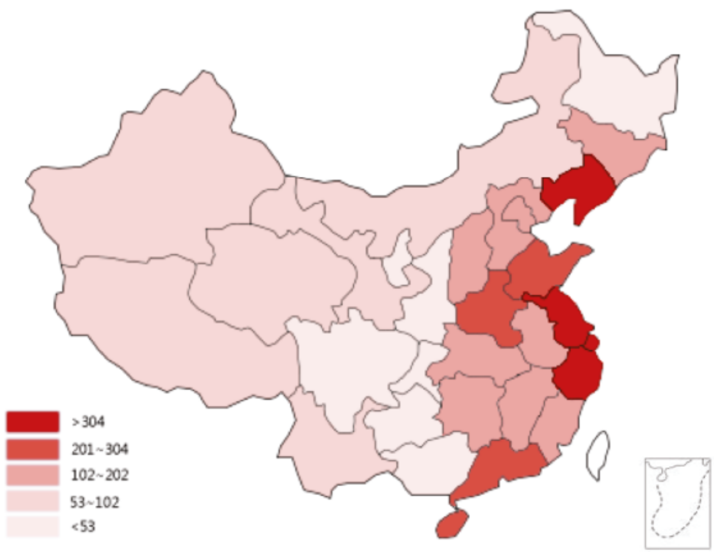


Figure 3-2: China's City Density in 2000 (Cities·km^2)

Date Source: A Study on the Spatio-temporal Evolution of China's Cities over the Past 100 Years

The Rise of central China and "Development of Western China" plan proposed by the state may reduce regional differences to some extent, but it's difficult to fundamentally reverse the spatial pattern of high density in the East, low density in the West. The gradient in China's city spatial distribution will remain; regional differences in city size and grade structure will be difficult to gap, and may possibly grow under the action of both free market selection and unrestricted human resource flow.

3.2.2 Constantly Emerging New Urban Spatial Organizations

As cities grow in number and expand in size, China's development has reached a new stage. With the construction of rapid intercity rail lines, new features of spatial combination have emerged between cities and other cities, interconnecting expressways, and regions. Closer ties have resulted in new and modified urban spatial organization forms. Metropolitan areas, megacities and city belts will gradually replace individual cities as the object of urban spatial layout. As pointed out in the *National Main Functional Area Plan* released by the State Council in December 2010, China has formed a strategic urbanization structure based on "two horizontal axes and three vertical axes," which are formed by important railways and expressways, coastal areas, and the Yangtze and Pearl rivers. These axes are densely populated with cities large and small, forming metropolitan areas, megacities and city belts (Figure 3-3). The Changsha-Zhuzhou-Xiangtan megacity, where Changsha is located, is at the junction of Yangtze River horizontal axis and Beijing-Harbin Railway and Beijing-Guangzhou Railway vertical axis.

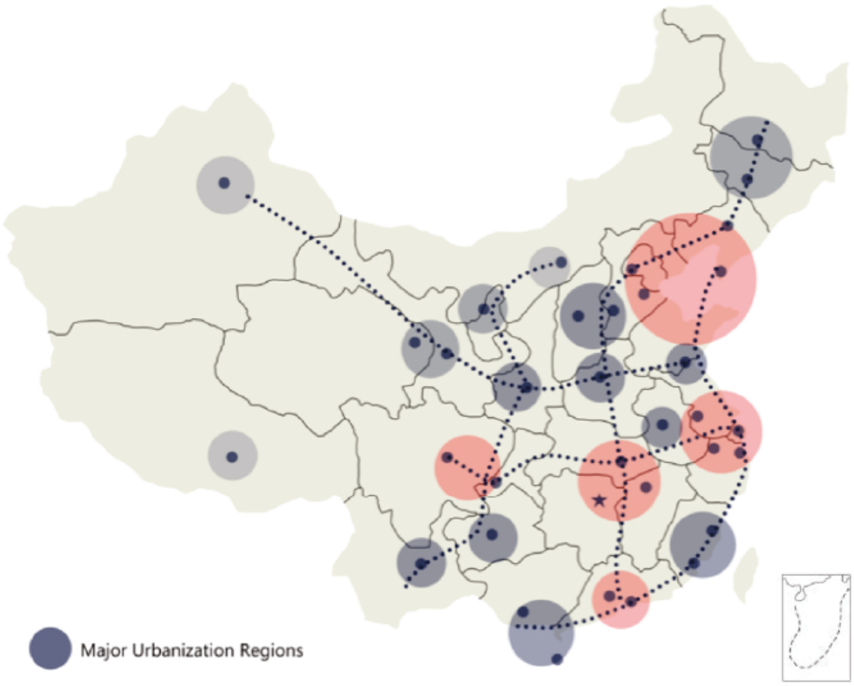


Figure 3-3: Strategic Layout of Urbanization

Data source: National Main Functional Area Plan

3.3 Commonalities and Features of Urban Development in Central China

3.3.1 Economic Development

The secondary sector has dominated the six provinces of Central China for a long time, with the tertiary sector growing at a low speed. Although it makes up about 58.2% of economic activity in the country as a whole, Central China still demonstrates a typical development model centered on industry, complemented by relatively weak services (Table 3-2). The foundation of its industrial development depends largely on major state-invested projects under a planned economic system. In terms of industrial layout, Hubei Province is dominated by automobile manufacturing and nonmetal minerals mining and dressing; Shanxi and Henan are led by coal and other resource-based industries, forming special industrial and mining cities and areas; while Anhui, Hunan and Jiangxi have been centered around resource-based industries from the 1990s, and gradually moving towards steel and mechanical machining. Therefore, Central China has developed into an industrial region primarily driven by heavy manufacturing and chemicals. The metropolises in Central China feature industry prominently, but are weak in both traditional and modern services, forming a gap with developed provinces in Eastern China (Pei, 2013). According to official statistics, the ratio of tertiary sector to total economic activity in Central China continued to grow from 2010 and 2016, and the state has issued policies to support its development, in line with the “Rise of Central China” strategy. Loans from financial institutions and local fiscal expenditures have vigorously boosted tertiary sector development. Labor input has had a positive but insignificant impact, indicating that the tertiary sector is transforming from a labor-intensive to a capital- and technology-intensive industry.

Province	1990	2000	2010	2016
Hubei	36.6:39.6:23.8	15.5:49.7:34.9	13.5:48.6:37.9	11.2:44.9:43.9
Hunan	39.7:35.6:24.7	21.3:39.6:39.1	14.5:45.8:39.7	11.3:42.3:46.4
Henan	36.4:37.0:26.6	22.6:47.0:30.4	14.1:57.3：28.6	10.6:47.6:41.8
Anhui	40.5:40.5:19.0	24.1:42.7:33.2	14.0:52.1:33.9	10.5:48.4:41.0
Jiangxi	41.9:31.8:26.3	24.2:35.0:40.8	12.8:54.2:33.0	10.3:47.7:42.0
Shanxi	20.3:52.8:27.4	10.9:50.3:38.7	6.0:56.9:37.1	6.0:38.5:55.5
Central China Average	36.6:38.9:24.5	20.2:44.6:35.2	13.0:52.4:34.6	10.0:44.9:45.1
National Average	27.1:41.6:31.3	15.9:50.9:33.2	10.1:46.8:43.1	4.4:37.4:58.2

Table 3-2: A Comparison of Industrial Structure between Central China and National Average

Data source: A Preliminary Study on the Features and Causes of Urbanization in Central China

The six provincial capitals in Central China are the most urbanized and economically developed cities in their respective provinces, but show large differences in development level. Taking the year of 2016 as an example, Wuhan had the greatest economic aggregate in Central China, ranking 3rd among China’s 27 provincial capitals; Changsha and Zhengzhou fell into the second tier in 6th and 7th places; and Hefei, Nanchang and Taiyuan were in the third tier, with economic an aggregate less than one third of Wuhan’s. From the perspective of *per capita* disposable income, however, the six provincial capitals were more uniform. While Changsha had the highest disposable income, ranking 4th among China's 27 provincial capitals, Taiyuan had the lowest, ranking 24th. (Table 3-3)

Item	Wuhan	Changsha	Zhengzhou	Hefei	Nanchang	Taiyuan
Total Area (km^2)	8494	11816	7446	11445	7402	6988
Urban Area (km^2)	1172	2151	1010	1312	617	1460
Total Population (10,000 Persons)	1077	765	972	787	523	434
Urban Population (10,000 Persons)	859	328	690	566	388	367
GDP (RMB 100 Million)	11912	9455	8025	6274	4355	2955
Ranking among China's 27 Provincial Capitals	3	6	7	9	16	21
Per capita disposable income of urban residents (RMB)	39135	43294	33214	34852	34619	29632
Ranking among China's 27	8	4	16	13	14	24
Engel's coefficient (%)	30.9	25.0	28.5	33.0	32.4	32.2

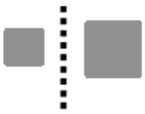
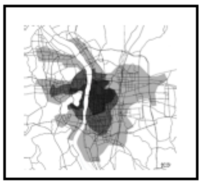
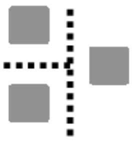
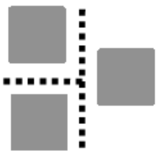
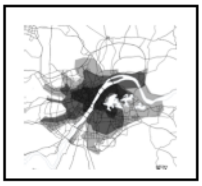
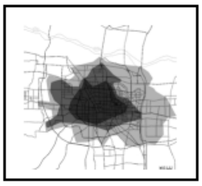
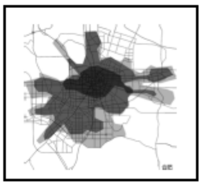
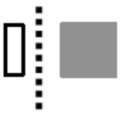
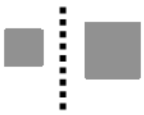
Table 3-3: A Comparison on Composite Indicators between Changsha and Major Provincial Capitals in Central China

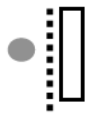
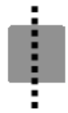
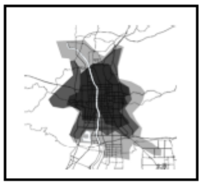
Data source: Collected by the author from Changsha Statistical Yearbook 2017, statistical information networks of respective regions and statistical bulletins of respective cities

Among the six provincial capitals of Central China, Changsha has the largest administrative area and a moderate population, and is above average with respect to economic development. Table 3-3 shows that its Engel's coefficient, revealing living quality and spending power of urban residents, and *per capita* disposable income are better than in other provincial capitals in Central China, despite a lower GDP than in Wuhan. Thus, Changsha is an important provincial capital and a key regional city in Central China, providing a good urban environment and economic foundation for resilient city construction.

3.3.2 Urban Spatial Structure

Modern Chinese urban spatial structure can be divided on the basis of combination and form into five types: single-centered block, belt, multi-centered cluster, radial, and city-satellite structures (Zhou, 2007). Graphical analysis spatial structure shows that the six provincial capitals in Central China have three spatial structure types (Table 3-4). Changsha, Wuhan and Nanchang have a multi-centered cluster structure, Zhengzhou and Hefei are radially organized, and Taiyuan manifests a single-centered block structure.

City	1999		2008		Built-up Urban Area (1999-2016)
Changsha		Single-centered blocks		Multi-centered clusters	
Wuhan		Multi-centered clusters		Multi-centered clusters	
Zhengzhou		Single-centered blocks		Radial structure	
Hefei		Single-centered blocks		Radial structure	
Nanchang		Multi-centered clusters		Multi-centered clusters	

Taiyuan		City-satellite structure		Single-centered blocks	

Built-up Urban Area 1999　Built-up Urban Area 2008　Built-up Urban Area 2016

Table 3-4: Expansion Diagram of Spatial Structure and Urban Built-up Area of Provincial Capitals in Central China from 1999 to 2016

Data source: Drawn by author

Rapid economic development and urbanization has given China's megacities general features such as fast growth, diversity and multi-centered spatial expansion (Zhou et al., 2013). Since records have become available, Changsha has taken a single-centered block structure, centered on the old town, expanding in all directions. As economic growth progressed, it took a multi-centered cluster structure, making Changsha highly representative of Chinese cities in terms of development process and urban spatial features. Structurally characterized by hills, rills, islets and towns set along the river, Changsha is also representative of cities along rivers with concentrated block development.

3.4 Key Development Areas of Resilient Cities in Central China

3.4.1 Development Crises

3.4.1.1 Resource Restriction

Amid China's accelerated urbanization, resources have provided the driving force for economic development, and naturally defined the boundaries of sustainable urban economic development. As pointed out in the No.1 Research Report on National Conditions released by the Chinese Academy of Sciences in 1989, "China will undoubtedly be restrained by three basic trends in the future. First, population size, growth and quality have defined China's modernization, future consumer base, pressure on resources and environment, and the awareness of resource balance and environmental protection. Second, its land resource development has been approaching its limits, and without self-restraint, the 'resource-production-consumption-environment' cycle will inevitably plunge it into a vicious spiral of decreasing of *per capita* resources. Finally, China's environment is delicate to begin with...agricultural resources, particularly water and soil, will approach or reach their critical carrying capacity." (National Condition Analysis Team of the Chinese Academy of Sciences, 1989)

Taking Taiyuan, in Central China, as an example, Shanxi Province, where it is located, boasts various rich resources, but its large population has resulted in a relatively low *per capita* resource share. Distinct geographic differences have further restrained the quality of Taiyuan's land, ecological and water resources. In terms of water resources, its *per capita* share is only 173 m^3, one twelfth of the national figure, half of the provincial one, and much lower than the critical water shortage limit of 1,000 m^3 *per capita*. Water shortages have become an important factor restricting its sustainable socioeconomic development. Demand for municipal water will continue to grow with increasing urban population. As Taiyuan has yet to fundamentally move away from heavy industry, given the realities of high water consumption and heavy pollution, pollution prevention and control and increased water use efficiency will become increasingly urgent tasks (Li, 2013).

Resource Constraint	Current Situation
Arable Land	China's arable land has generally approached the red line of 120 million ha, but demand for land is growing with accelerating urbanization. The growth rate of urban land use is much higher than that of urban population, and the gap has been expanding. From 1986 to 1996, urban population grew by 59%, and urban land use by 106%. From 1997 to 2003, non-agricultural population increased by 40%, and urban land use by 160%.
Water	In the normal years, China's water deficit has reached 40 billion m^3. 400 out of about 660 cities nationwide suffer from water shortages to varying degrees, and 136 severely lack water. Fifty percent of these cities have underground water pollution to varying degrees, and some face water resource crises.
Energy	In 2009, China's petroleum import volume exceeded domestic crude output for the first time, resulting in an external dependence of 52.1%, growing to 54.8% in 2010. China's external dependence in iron, copper, aluminum and other mineral products all exceed

	70%. China's overall economic development has faced an energy deficit since 1991, which has expanded since the acceleration of heavy industry growth starting since 2001. In 2010, its primary energy consumption reached 3.25 billion TCE, making it the world's largest energy consumer.

Table 3-5: Resource Constraints on China's Urban Development

Data source: Liu, 2015

3.4.1.2 Population Changes and Urbanization Pressure

As predicted by the Chinese Academy of Sciences in its Report on Chinese Urban Development released in 2013, the national total agricultural population to be urbanized before 2020 will reach 300 million, and 390 million by 2030 (Chinese Academy of Sciences, 2013). According to the 2013 China Investment Development Report, the next 20 years will be the most volatile period of urbanization. By 2030, China's urbanization level will reach 70%, and 300 million rural residents will have moved to cities and towns (Yang, 2013). Whether and how this anticipated goal will come true, however, amid increasingly grim development, is still unknown.

From 2011 to 2016, three cities among the provincial capitals in Central China saw net population growth over 500,000. Zhengzhou ranked first with a net growth of 867,000 people, Wuhan came second with 746,000 people, and Changsha ranked third with 554,000. Taking Zhengzhou, with the largest growth, as an example – although not striking in Central China economically, it has become a magnet for the huge agricultural population in surrounding areas thanks to its strengths as a provincial capital and railway hub. This population growth has provided it with rich labor resources, but its expanding population size, relatively low population quality and unstable population structure fail to meet the requirements of economic development. Furthermore, it's difficult for its urban education resources and other public resources to satisfy their demands in a short period of time, to some extent influencing and restricting the coordinated and sustainable development of Zhengzhou's economy, resources and environment.

3.4.1.3 Ecological Security

With regards to air pollution, as indicated by the China Environmental Quality Status report for the first half of 2014, released by the Ministry of Environmental Protection, over 90% of the 161 cities adopting the new air quality standard failed to meet it, calculated as an annual average. On average, only 60.3% of days were up to standard throughout the year. On the days not up to standard, the major pollutants were PM2.5, PM10, and O_3 (Ministry of Environmental Protection of China, 2014). First-tier and affluent coastal cities have increased their efforts to control air pollution over past three years, imposing caps on coal use and closing nearby coal-fueled power plants. These efforts have resulted in gradually decreased haze in Beijing, Shanghai and other Eastern Chinese cities, but worsening conditions in inland cities. In recent years, Henan (Central China) has become one of the two worst provinces for air pollution, reflecting a trend whereby polluting enterprises move towards Western China and inland cities in response to more rigorous environmental protection. Furthermore, the growth of coal power investment, and lax regulation, are the main causes of the deteriorating air quality. Taking Changsha as an example, its city proper had 267 days of good air quality in 2016, for a good air quality rate of 73.0%. Among those days, 75 had superior air quality, and 192 days were good. 79 days had slight pollution, 17 days medium pollution, and 3 days heavy pollution; there were no days of severe pollution. Hence, Changsha still has a long way to go in air quality.

With respect to soil pollution, the Investigation Report on Soil Pollution in China jointly released by the ministries of Environmental Protection and the Land and Resources in April 2014 revealed that 19.4% of arable land nationwide was polluted beyond the limits, as well as 16.1% of soil nationwide. 1.1% of soil was severely polluted, particularly in Southern and Southwest China (Ministry of Environmental Protection of China and Ministry of Land and Resources of China, 2014).

In terms of water pollution, 31% of the freshwater in top ten water systems across China, and 39% of the 62 major lakes, failed to meet drinking water quality requirements in 2012, seriously affecting health, productivity and living standards. 280 million Chinese residents currently consume unsafe drinking water. According to the 2012 Report on Environmental Conditions in China, about sixty percent of 198 prefecture-level administrative districts in China had relatively poor or very poor underground water quality (The Ministry of Environmental Protection of China, 2013).

3.4.1.4 Financial Risks

It is well known that land-derived fiscal revenue, primarily used for debt repayment or construction of municipal infrastructure, has become a key criterion by which to measure the financial resources of a local government. It is however associated with enormous financial risks, binding together residents, government and banks. With a decline in housing prices, financial risks will be transferred to the real economy via assets, resulting in economic instability. Currently, China's land-derived fiscal revenue risks are concentrated in land transfer revenue and mortgages. As China's *Budget Law* provides that local governments cannot run deficits, and debt is repaid by local financing platforms based on continuously rising housing prices, declining price will cause government debt risks, affecting fixed expenditures in medical services, education, environmental protection and other aspects of livelihood.

According to the Report on Land-derived Fiscal Revenue Dependence of 45 Cities with Housing Purchase Restrictions recently released by the Research Department of Tospur, the 45 cities with housing purchase restrictions are highly dependent on land-derived fiscal revenue. 13 are over 80% dependent: Hangzhou, Foshan, Nanjing, Changsha, Sanya, Hefei, Fuzhou, Kunming, Jinan, Xuzhou, Ningbo, Wenzhou and Chengdu. Among them, four (Hangzhou, Foshan, Nanjing and Changsha) are over 100% dependent. Hangzhou, at 156.4%, is the most dependent of the 45 cities (Zhang, 2014).

3.4.2 Key Elements of Urban Resilience

Certain cities and regions throughout history have failed to promptly adjust their development model to the changing environment and eventually fallen into decay. Examples include Ephesus in Roman times, and many declining cities and suburban towns during the U.S. subprime crisis. Those cities which have managed to revitalize themselves over history are interpretations of resilient cities, and boast the essential capacity to cope with crises and changes. We are intrigued by the features that have supported the cities that have passed all these tests. Here is a preliminary study on this topic based on the development experience of selected cities.

Case I Pittsburgh: Diversifying away from a single-product economy

Located in the State of Pennsylvania, on the eastern coast of the United States, downtown Pittsburgh boasts a developed water system. The waterfront region is a key area for urban transformation. As of the first half of the 20th century, its abundant mineral resources, convenient inland waterways, and ports gave Pittsburgh prominent development advantages for steel. A traditional American industrial city, Pittsburgh was known as the Capital of Steel and City of Smog. However, urban development was evidently dependent on resources and heavy pollution. In the 1960s, the U.S. steel industry was outcompeted by Asian companies due to its outdated business strategies and relatively high labor costs. Accordingly, the downtown area suffered from rising unemployment and severe population loss.

Having undergone three transformation stages from post-war revival, secondary revival and subsequent development over the 70 years since 1945, Pittsburgh has gradually been transformed from a resource-based city dominated by steel to a post-industrial city led by high-tech industries like software, AI and biopharmaceuticals. In 2009, *The Economist* magazine rated it the most livable city in the U.S. Public-private partnerships have been the driving force for its long transformation process. For spatial planning, its infrastructure built the basic foundation for transformation, improvement transportation infrastructure improved the accessibility of its various districts, and mixed functionality and creation of small-scale spaces enhanced the vitality of the city.

Case II The Ruhr Region: Improving the environment and expanding urban functions

Previously, as one of the world's most important industrial hubs, the Ruhr Region in Western Germany led in mineral exploration and steel manufacturing technology. Contributing 12% of the GDP of former West Germany, it was its most economically developed region. The tremendous changes in industrial structure and market structure of the 1970s led to the gradual replacement of coal with cheaper petroleum, natural gas and imported coal. With increasingly uncompetitive industrial production, the region was faced with severe unemployment. With an unemployment rate of 15%, Emscher had the worst unemployment in Germany in the late 1980s. In addition to acute social problems, the Ruhr Region also experienced gradual economic recession and severe environmental pollution brought by long-term industrial production.

In 1989, the Nordrhein-Westfalen government established an Internationale Bauausstellung (IBA) to address the prominent social problems in the region, which decided to collect excellent plans via international competitions (Klaus, 2004). Five projects were completed before 2000. The final one – Emscher Park – demonstrated the highest degree of regional thinking, markedly recovering and improving the environment, integrating and developing public spaces, creating job opportunities, and delivering cultural innovation and residential optimization. The 10-year construction of the park made outstanding contributions to the eventually successful transformation of the region from an industrial to a cultural region. In 2010, the IBA launched "cultural programs", allowing Emscher Park to continuously improve the Ruhr Region and remake historical sites into new regional hotspots.

Case III London: Constructing ecological infrastructure and comprehensive communities focusing on living environment

Once heavily polluted, London has pioneered air pollution control and ecological urban construction over the past 100 years. After improvement, the once deadly River Thames has grown into London's largest wildlife habitat. Through construction of Metropolitan open land, Green Belts and Green Corridors, Greater London has formed a basic open space network system structure. Currently, it has about 130 municipal natural reserves, 1,500 varieties of trees and 300 bird species. Its urban diversity reflects the environmental status of London and quality of residents' living.[4]

In this post-industrial period, a global economic recession and excessive suburbanization

[4] http:www.London.gov.uk

have brought such socioeconomic problems like the decline of the old town and employment. Therefore, urban renewal and rejuvenation have started to become social reform and economic revival, featuring diversification of objectives, conservation of historical environments and focus on public involvement. Successful urban renewal lacks an effective governance model, including open and transparent decision-making and cooperative implementation mechanisms. Public-private-community partnerships have been widely accepted as the sustainable development outlook and humanism become more widespread. Taking public involvement and interaction into full consideration, London's urban rejuvenation has introduced new bottom-up political thinking and expanded the ideas and perspectives on urban development (Du et al., 2015).

Despite various changes and risks, these Western cities have been active in addressing problems and embracing prosperous development. They are characterized by the following elements:

(1) A focus on ecological recovery, promoting and maintaining the diversity of society, land use and ecosystems, and adapting to the complex ever-changing external environment.

(2) Diversifying the economy to withstand structural changes and periodic crises, facilitating rapid economic recovery.

(3) Transforming industry according to local conditions, achieving a balance between employment and growth, and steadily developing society, encouraging innovation, accumulating social capital and driving innovation industries as the source of urban prosperity.

(4) Developing the capacity and vitality to cope with urban grassroots social changes by promoting social trust and developing social networks and community leadership.

3.4.3 Key Areas of Resilience

As a management tool, the resilient city indicator system should be consistent with urban development strategies and goals. As mentioned in the Master Plan of Changsha City (2003-2020) (Revised in 2013), Changsha's development goals are to put people first, create spaces for harmonious development of man and nature, change the growth model, and follow a "resource-saving, eco-friendly, economically prosperous and socially harmonious" path. Table 3-6 illustrates the major strategies, objectives and monitoring criteria for urban development in Changsha.

Objective	Strategy	Criteria
Resource Conservation	Improve comprehensive service facilities and optimize energy structure	-Reduce energy demand -Improve energy utilization efficiency -Actively develop new and renewable energy sources
Eco-friendliness	Greatly improve the urban environment	-Prioritize public transportation -Improve surface water quality -Improve air quality -Improve urban environment
Economic Development	Enhance economic competitiveness	-Municipal GDP growth -Growth of the tertiary sector and diversification -Economic development driven by technology and fine culture
Social Harmony	Expand urban space, enhance urban functions, optimize land use, and improve Changsha's strengths in education and cultural production	-Improve public service facilities -Ratio of residential districts with basic service functions -College and university R&D -Enhance urban safety standards and public service level

		-Affordable housing for low-income families

Table 3-6: Major Objectives and Monitoring Criteria for Urban Development in Changsha

Data source: Collected from Master Plan of Changsha City (2003-2020) (Revised in 2013)

Table 3-7 summarizes the major policy objectives, strategies and suggested monitoring benchmarks for urban development strategies in Central China.

<table>
<tr><th></th><th>Objective</th><th colspan="2">Strategy</th><th>Criteria</th></tr>
<tr><td>Economy</td><td>Enhance cities' economic competitiveness</td><td rowspan="2">Create conditions for concentrated development in the following fields:</td><td>-Transportation facilities and services

-Food processing and pharmaceuticals</td><td>1. GDP growth

2. Per capita GDP growth

3. Development of non-traditional businesses and emerging industries

4. Growth of the tertiary sector and diversification</td></tr>
<tr><td>Society and Culture</td><td>Help poverty-stricken residents, laid-off workers of state-owned enterprises and migrant workers integrate into society and benefit from economic growth</td><td>— Education and culture

— IT facilities and services</td><td>1. Re-employment ratio of laid-off workers

2. Sufficient funding for income support projects

3. Employment ratio of rural population in cities</td></tr>
</table>

	Develop a unique Hunan culture and improve the strengths of the Changsha-Zhuzhou-Xiangtan megacity in education and cultural production			1. Output value and export level of cultural products 2. Ratio of college students from other provinces 3. R&D level based on colleges and universities
Environment and Infrastructure	Greatly improve the urban environment	Environmental improvement		1. Improved surface water quality 2. Improved air quality 3. Improved urban environment
Finance	Sustainable management of revenue and expenditures	Develop and practice the concept of integration		1. Reduced on-budget deficit 2. Better loan access from commercial channels 3. Adequate funds for operation and maintenance

Table 3-7: Major Objectives and Monitoring Criteria for Urban Development in Central China

Data source: Performance Indicator Handbook for China's Urban Development Strategies

As shown above, resources, the environment, economy and society are the major concerns for urban development in Central China. Based on the above analysis, China's urban development faces ecological, social and economic risks. Therefore, the key areas of urban resilience should be associated with ecology and infrastructure, society and economy.

3.4.3.1 Key Fields for Social Resilience Improvement: Community and Identity

Social resilience is the capacity for communities or people to address external stresses caused by social, political, or environmental changes. In the face of stress resulting from changes in population, cities, and climate, the assurance systems, disaster warning mechanisms, and emergency response strategies of various urban networks and organizations must be improved to enhance social resilience. Urban disaster resilience can be reflected in rationalization and diversification of gender, age, race, social strata, and economic ability. A sense of local identity can prevent social groups or individuals from stress arising from environmental changes reducing investment in the community. Education directly affects residents' quality of life, communication ability, access to information, and problem solving ability.

The key areas of social resilience improvement include urban communities, social organizations, urban public health systems, urban public facilities and infrastructure, urban planning, and urban governance systems.

With respect to urban governance, against a background of economic globalization, the original government-led urban management model has shifting to cooperation. Urban interest groups like government, commercial organizations and social groups have formed diverse partnerships for urban governance, characterized by multi-centered cities, transparency, flexibility and tolerance. Research indicates that these resilience strategies can help cities cope with external shocks and uncertainties (Cai et al., 2012). In Asia, especially in the Asian-Pacific region deeply edified by Confucian traditions, government management functions are often interwoven with social service functions, maintaining public supplies and residents' living standards at a certain level. Due to the increasingly weak capacities of municipal governments, quite a number of non-governmental organizations have provided supplementary functions, and greatly enhanced local economic development and residents' lives. According to research, many NGOs in South Korea, Indonesia and Malaysia have helped improve inadequate official municipal infrastructure via private cooperation and sponsorships (Yang, 2004). Thanks to economic prosperity and democracy, Southeast Asian people are highly involved in politics, generating impressive development in urban governance. For instance, over 60,000 NGOs were established in the Philippines from the overthrow of the dictatorship in 1986 to the early 1990s, including

10,000 groups centered on poverty alleviation. Furthermore, the Philippines amended the constitution in 1987 and passed a Local Government Code in 1991. These measures have reflected the determination of the government to decentralize power to cities, vigorously advancing urban governance. In Africa, South Africa probably boasts the most developed NGO network. According to preliminary estimates, it has no less than 54,000 NGOs, which are quite active (Swilling, 1994). Their purposes range from technical consulting to pro bono services for low-income communities, environmental protection, and inter-class, interracial and cross-regional mutual trust building and conflict resolution. They have played a dominating role in South Africa's municipal government functions, a practice which has influenced South Africa and all Anglophone African countries.

Although developing countries started research on urban governance later than developed ones, and they face more prominent and pressing problems in the process of urbanization, their urban development after WWII shows that they are just as committed to self-improvement as Western countries. Notably, the continuous fast population growth and tremendous urban development crises faced by developing countries have further inspired exploration of new urban governance methods and identification of rational and effective governance models suited to local realities, through trial and error.

3.4.3.2 Key Fields for Economic Resilience: Industrial and Economic Diversification

A city's economic resilience involves the diversification of economic models and industrial types, and the prevention of dependence on a single industry. The dependence of the Chinese urban economy on land-derived fiscal revenue has driven up financial risk. Another important aspect of economic resilience involves the impact of excessively-priced housing on future economic activities and urban life. Furthermore, efforts to enhance the innovation ability of enterprises and to transform industry in line with local conditions can help improve the potential economic level of a region.

Key areas for economic resilience improvement of a city include industries, energy structure, and transport.

3.4.3.3 Key Fields for Environmental and Infrastructure Resilience Improvement: Urban Ecology and Key Infrastructure

The ecology and resilience of a city are interdependent. On the one hand, improvement in the ecology of a city helps enhance its resilience, boost its defenses against external man-made and natural disasters, and propel its overall development process. On the other, urban resilience can act the other way around upon the environment. High resilience can effectively alleviate such "urban diseases" in urban development as traffic congestion and environmental deterioration, maintaining self-buffering and self-repair abilities against disasters in operation, and reducing loss to the extent possible.

In addition to ecosystems, the vulnerability of buildings and the transit system should also be reduced to ensure the continuous supply of key services in emergencies, and the fast recovery of service functions. For instance, New York City has invested over USD 20 billion in a series of infrastructure recovery and resilience incentive programs. These programs aim for the sustainable provision of services through the regional infrastructure system, shortening client waiting time and transport outage time resulting from weather, and doubling the number of medical facilities and hospital beds in areas subject to 100-year floods.

Key areas for a city's infrastructure resilience improvement include its ecology, transport system, and green infrastructure.

Chapter IV Establishment of Resilient City Indicator System

Resilience is not a generic concept that can be applied in the abstract. To be resilient, or to measure the resilience of a system, we need to identify the 'stressor' or signal disruptor that we want to be resilient against.

—Desouza, Flanery, 2013

4.1 Role and Objectives of Resilient City Indicator System

As complex megasystems composed of environment, society and economy, cities involve resources, energy, ecology, politics, economy, culture, management, planning, engineering and many other disciplines. The construction conditions, development orientations and technical measures in the construction of resilient cities vary by their geography and culture, therefore resilient city development is an extensive, comprehensive and systematic project. Considering that exploration on resilient cities is moving from theoretical to practical, an indicator system can make their abstract and complex systems understandable and measurable, with well-defined development objectives and normative assessment criteria to guide planning, construction and management.

As pointed out by Gunderson and Holling (2001), resilience can be quantified based on the degree of disturbance while the system still keeps running, absorbs the changes and remains in a static state. Research on resilient systems – particularly on the quantification, assessment and demonstration of resilient cities – however did not start until 2010, and is now in a process of exploration from theoretical to practical, which will become a domestic and international research topic in the future. Globally speaking, resilient cities have started drawing attention from all sectors of society, and became a new buzzword for planning in Western countries since the conference held in Bonn in 2010. Quite a number of countries, including the US, Britain, Australia and Switzerland, have formulated urban development strategies and policies based on "resilience" theory. Since then, indicator practices launched by international NGOs and indicator studies attempted by state-led government organizations have thrived. Among Chinese theoretical research on urban development, studies about sustainable cities, eco-cities and low-carbon cities are on the rise, but those on urban resilience are rarely found. The major theoretical basis of resilient cities still derives from research findings of international scholars. Recent years have seen China convening many academic seminars along the theme of resilient cities. In 2012, the College of Architecture and Landscape Architecture of Peking University hosted a seminar on resilient cities, including discussions on how cities should maintain resilience in the face of natural and man-made disasters, against the background of climate change and resource depletion. It was China's first collective discussion and exchange about resilient cities. In June 2013, "Creating Resilient Cities in China: Planning and Science" was the theme for the 7th Annual Conference of the International Association for China Planning (IACP). China has started to gain a comprehensive and systematic understanding of the development status of overseas resilient cities, but studies on resilience indicators have yet to be conducted. Hence, establishing a Chinese resilient city assessment indicator system directed towards the characteristic problems of China's urbanization is a current focus of resilient city research in China.

The overall goal is to develop a reasonable and highly operable indicator system to make the abstract and complex resilient cities systems understandable and measurable, and allow urban planners to understand the current status and future development of resilient cities on a regular basis, and provide data support for urban planning, construction, management and decision-making. China's cities greatly vary by government policies, climate, economic foundation, infrastructure, laws and regulations. The specific goals of the system are therefore to create: (1) A universal indicator bank, allowing different regions to select indicators or extend their indicator system based on the features of their cities, offering a research basis for development of various indicator systems; (2) An assessable and measurable indicator framework for comparisons between cities in Central China and a single city over time; (3) A set of implementable and manageable standards and requirements to effectively guide resilient city planning, monitoring and assessment and specific construction practices.

4.2 Chinese and International Research on Related Systems

4.2.1 Systems Developed by International Organizations

4.2.1.1 City Resilience Index in Germany

In 2010, the Pestel Research Center in Germany made the first nation-wide assessment of regional resilience in the hope of discussing future regional development models from the 18 indicators in 6 areas (Table 4-1) and how to preserve the functions of a region or a city in crises via resource allocation and indirect social capital (Pestel Institut, 2010). German cities and regions were divided into seven categories based on their resilience capacity: very high, high, somewhat high, medium, somewhat low, low and extremely low. The results indicated that Eastern and Western Germany were relatively resilient, while other regions had complex strengths and weaknesses. The study showed that internationally competitive regions and cities like Frankfurt are not necessarily resilient; lesser-known regions like Landkreis and Regensburg demonstrate relatively high urban resilience resulting from social stability, decentralized energy supply, adequate arable land and high forest coverage, which are effectively buffers against crises and disasters.

Dimensions	Indexes
Society	Educational Level Workforce Ratio Medical Services
Living	Resident Relocation Renter Ratio Residential Area
Transportation	Transportation Area Public Transport Private Car Ownership

Land Use	Farmland Area Green Buildings Forest Coverage Rate
Energy	Wind Energy Utilization Rate Biogas Utilization Rate Solar Energy Utilization Rate
Economy	Commuting Second Industry Professionals Financial Deficit

Table 4-1: Indicators Influencing Cities' Resistance to Crises

Data source: Pestel Institut， 2010

4.2.1.2 Resilience Capacity Index of the University of California, Berkeley

In 2013, the Government Research Center of the University of California, Berkeley released the Resilience Capacity Index (RCI), composed of three areas with four indicators each (Table 4-2). The RCI can be used to assess a metropolitan area's self-adjustment and adaptation to future external changes and measure the strengths and weaknesses of a region, enabling regional leaders to identify differences with other regions[5]. Using the RCI, they assessed 361 American metropolitan areas and divided resilience capacity into five grades: very high, high, medium, low and extremely low (Figure 4-1). The results indicate that regions with relative high resilience often have higher scores in economic diversification, medical insurance coverage and metropolitan area stability, while those with high population mobility and low stability tend to demonstrate lower resilience.

[5] http://brr.berkeley.edu/rci/

Dimensions	Indexes	Sub-indexes
Regional Economic Capacity	Income Equality	Gini coefficient-measured by household income
	Economic Diversification	Economic distribution measured by work or GDP
	Regional Affordability	Housing expenditure ratio
	Business Environment	Business environment, ratio of well-run businesses
Socio-Demographic Capacity	Educational Attainment	Ratio of bachelor's degrees holders or higher to total population aged 25 or above
	Without Disability	Ratio of physically challenged to total population
	Out of Poverty	Poverty level calculated by the income-expenditure ratio of households over the past year
	Health-Insured	Ratio of population covered by public medical insurance to total population in the metropolitan area
Community Connectivity Capacity	Civic Infrastructure	Proportions of civic health organizations, social advocacy organizations, commercial associations and other professional organizations, trade unions and political groups
	Metropolitan Stability	Ratio of residents living in the area over five years to those living under five years
	Home ownership	Home ownership ratio
	Voter participation	Voting rate

Table 4-2: Resilience Capacity Index

Data source: http: //brr.berkeley.edu/

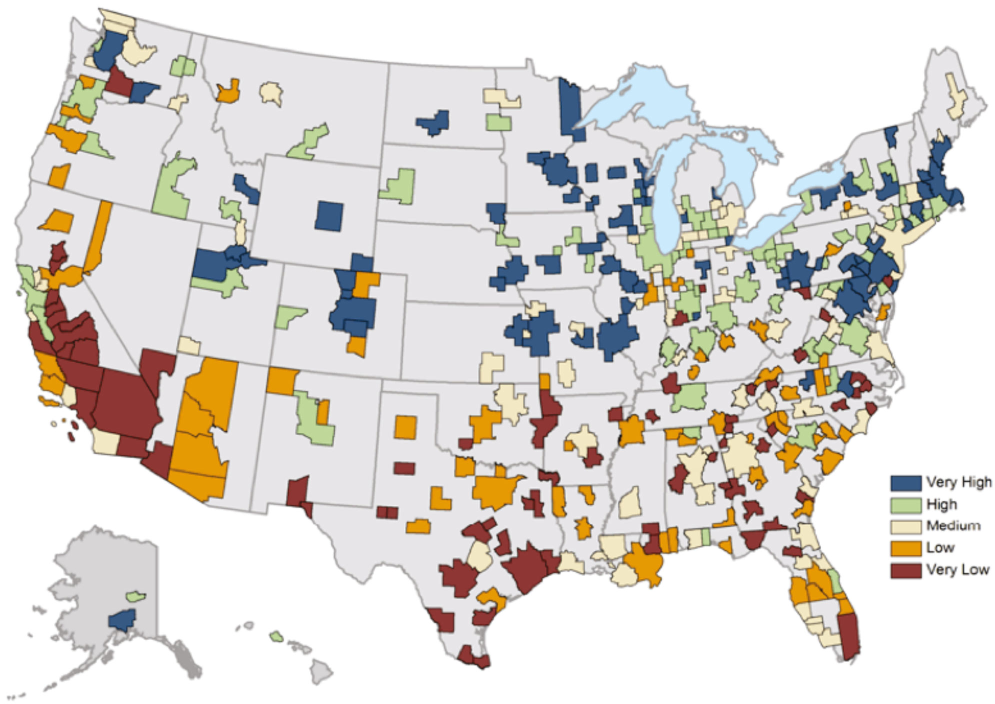


Figure 4-1: Resilience Capacity of Metropolitan Areas in the United States

Data source: http: //brr.berkeley.edu/rci/

4.2.1.3 City Resilience Index of the Rockefeller Foundation

In 2014, the Rockefeller Foundation used four indicator systems to research, build and evaluate urban resilience: health and well-being, economy and society, urban systems and services, and leadership and strategies. Each category of indicators is composed of three parts, each of which consists of several sub-indices (Table 4-3). Weak indicators in any part may threaten cities' overall resilience. These indicators are also performance indicators which can be used to describe the results of resilient city construction, but not recovery actions. "The purpose of the City Resilience Index is to provide cities with a robust, holistic and accessible basis for assessment so that they are better placed to make investment decisions and engage in urban planning practices that ensure people living in cities – particularly the poor and vulnerable – survive and thrive no matter what shocks and stresses they encounter." (Rockefeller Foundation, 2014).

In December 2013, the Rockefeller Foundation launched the 100 Resilient Cities Network.

Cities applied to be included into the Network might be faced with challenges like fires, floods, earthquakes, high unemployment, traffic, violence or food or water shortage. The purpose of this event was to help cities be prepared for disasters and stresses and better provide all people with basic services at any time. In 2014 and 2015, 67 cities were added to the Network, including international metropolises like New York and London, and domestic cities like Deyang, Sichuan Province and Huangshi, Hubei Province.

Dimensions	Indexes	Sub-indexes
Health and Well-being	Minimal human vulnerability	Housing; Energy supply; Drinking; water; Sanitation; Food supply
	Diverse livelihoods and employment	Labour policies; Skills and training; Business development and innovation; Financing mechanisms; Protection of livelihoods
	Effective safeguards to human health and life	Public health systems; Quality healthcare; Medical care; Emergency response
Economy and Society	Collective identity and community support	Community support; Community cohesion; Identity and culture; Engaged Citizens
	Comprehensive security and rule of law	Systems to deter crime; Corruption prevention; Policing; Criminal and civil justice
	Sustainable economy	Public finances; Business continuity planning; Economic base; Business environment; Integration with regional and global economies
Urban Systems and Services	Reduced exposure and fragility	Hazard exposure and mapping; Codes, standards and enforcement; Protective ecosystems; Protective infrastructure
	Effective provision of critical services	Stewardship of ecosystems; Infrastructure services; Spare capacity; Maintenance; Continuity for critical assets and services Stewardship of ecosystems; Infrastructure services; Spare

		capacity; Maintenance; Continuity for critical assets and services
	Reliable Mobility and Communications	Transport networks; Transport operations and maintenance; Communications technology; Technology networks
Leadership and Strategies	Effective Leadership and Management	Government decision-making; Co-ordination with other government bodies; multi-stakeholder collaboration; hazard monitoring and risk assessment; Government emergency management
	Empowered stakeholders	Education for all; Community awareness and preparedness; Mechanisms for communities to engage with government
	Integrated Development Planning	City monitoring and data management; Planning process; Land use and zoning; Planning approval process

Table 4-3: City Resilience Index of the Rockefeller Foundation

Data source: Rockefeller Foundation, 2014

4.2.1.4 The Climate and Disaster Resilience Initiative

The Climate Disaster Resilience Index (CDRI) jointly developed by the University of Madras and Kyoto University was used to assess the resistance capacity of Chennai to disasters. According to this study, “the ability to avoid a shock or to respond to it depends, therefore, not only on various actors (communities and institutions), but also on whether the physical infrastructure, the social cohesion and economic situation of the communities, and the environmental and institutional capacities are able to withstand climate-related disasters.” (Joerin et al., 2010).

Based on that, the CDRI is comprised of 25 sub-indexes covering materials, society, economy, institutions and nature; each sub-index includes 5 variables, creating 125 data points. It’s a comprehensive resilience index designed to comprehensively assess each region of Chennai (Table 4-4). Its assessment results are divided into 5 grades – the higher the grade, the better the resilience. Qualitative interpretation is used to supplement the quantitative results. According to the assessment, the northern region of Chennai shows relatively low economic and natural resilience, due to high poverty and unemployment rates. The southern region demonstrates higher resilience, due to its developed economy, low population density and good natural environment. The Research also shows that areas that experience fast population growth rates or urbanization trends have a better infrastructure and are more likely to respond adequately in the event of a disaster, in comparison to areas with lower population growth rates.

Dimensions	Indexes
Physical	Electricity, Water, Sanitation and solid waste disposal, Accessibility of roads, Housing and land use
Social	Population, Health, Education and awareness, Social capital, Community preparedness during a disaster
Economic	Income, Employment, Household assets, Finance and savings, Budget and subsidy
Institution	Mainstreaming of disaster risk reduction and climate-change adaptation, Effectiveness of zone's crisis management framework, Knowledge dissemination and management, Institutional collaboration with other organizations and stakeholders, Good governance
Natural	Intensity/severity of natural hazards, Frequency of natural hazards, Ecosystem services, Land use in natural terms, Environmental policies

Table 4-4: Climate Disaster Resilience Index

Data source: Joerin et al., 2010

4.2.1.5 Disaster Resilience Indicators

After a comparison on conflicts and focuses of sustainable development strategies and resilience strategies, researchers at the University of South Carolina selected 36 parameters relating to society, economy, institutions, infrastructure and community as major disaster resilience indicators (Table 4-5) (Cutter, 2010). These disaster resilience indicators were developed in the hopes of arousing the research interest of various communities, increasing discussions, building public interest and providing a method for policy makers and other scholars to measure cities' resistance to disasters. This study covered 736 counties in the southeast United States, and the research findings rank resilience capacity in descending order. The spatial distribution diagram reflecting resilience grades intuitively shows which regions demonstrate high and low resilience.

Dimensions	Indexes
Social Resilience	Educational equity； Age； Transportation access； Communication capacity； Language competency； Special needs； Health coverage
Economic Resilience	Housing capital； Employment (percent employed)； Income and equality； Single sector employment dependence；Employment (percent female labor force participation)；Business size; Health Access
Institutional Resilience	Mitigation; Flood coverage; Municipal services; Political fragmentation; Previous disaster experience; Mitigation and social connectivity
Infrastructure Resilience	Housing type; Shelter capacity; Medical capacity; Access / evacuation potential; Housing age; Sheltering needs; Recovery
Community	Place attachment; Political engagement; Social capital-religion; Social capital–civic

Table 4-5: Disaster Resilience Index

Data source: Cutter, 2010

4.2.1.6 10 Essentials of City Resilience

Launched by the United Nations International Strategy for Disaster Reduction (UNISDR) in 2010, the Making Cities Resilient Campaign put forward three principles: more exchanges, wise investment and safe construction. Fully reflecting these three principles, the 10 Essentials of City

Resilience were developed based on the five key points of disaster resilience capacity of countries and communities as set forth in the Hyogo Framework for Action 2005-2015 (UNISDR, 2010). In May of that year, the UNISDR released the Handbook of Local Government Leadership and the Local Government Self-Assessment Tool to help assess the risks of cities who signed onto the Campaign and implemented sustainable disaster mitigation plans. The following aspects were emphasized: 1) Research including data collection and threats response; 2) Organization including policies, planning, coordination and fundraising; 3) Infrastructure including social infrastructure and crisis action systems; 4) Response capacity including information provision and capacity building; 5) Environment including eco-service function maintenance and improvement; 6) Recovery including joint review, service support and scheme planning. The Handbook elaborates upon 85 disaster recovery indicators for 10 sub-systems (Table 4-6). The 10 Essentials of City Resilience are the foundation of a city's commitment to enhance disaster resilience capacity and make up the rules to be followed by the member states. In 2015, UNISDR, along with a group of over 100 distinguished city and expert partners, has updated the "Ten Essentials." The New "Ten Essentials," building upon the previous set, focuses on initiating advocacy activities towards urban resilience. The New Ten Essentials are listed as follows: 1) Organise for disaster resilience 2) Identify, understand and use current and future risk scenarios 3) Strengthen financial capacity for resilience 4) Pursue resilient urban development and design 5) Safeguard natural buffers to enhance the protection functions offered by natural ecosystems 6) Strengthen institutional capacity for resilience 7) Understand and strengthen societal capacity for resilience 8) Increase infrastructure resilience 9) Ensure effective preparedness and disaster response 10) Expedite recovery and build back better.

Dimensions	Indexes	Sub-indexes
Institutional and administrative frameworks	Organization and cooperation	7 indicators
	Skills and experience	1 indicator
	Integrated disaster resilience and initiative	1 indicator

Financing and Resources	Financial plan and budget	3 indicators
	Incidental expenses	1 indicator
	Rewards and subsidies	5 indicators
Multi-Hazard Risk Assessment – Know Your Risk	Risk assessment	3 indicators
	Renewal process	1 indicator
Infrastructure Protection, Upgrading and Resilience	Infrastructure protection	2 indicators
	Communication	3 indicators
	Power	3 indicators
	Water	3 indicators
	Gas	4 indicators
	Transportation	6 indicators
	Law and order	2 indicators
	Administration	1 indicator
	Computer systems	2 indicators
Protect Vital Facilities: Education and Health, (Food and Water) supplies	Educational institutions	3 indicators
	Health care	3 indicators
Building Regulations and Land Use Planning	Land utilization	3 indicators
	Construction specifications	2 indicators
Training, Education and Public Awareness	Education and awareness	2 indicators
	Training	1 indicator

	Language	1 indicator
Environmental Protection and Strengthening of Ecosystems	Biosystem services	3 indicators
Effective Preparedness, Early Warning and Response	Early warnings	1 indicator
	Event management planning	1 indicator
	Employee feedback requirements	2 indicators
	Requirements for equipment and relief supplies	1 indicator
	Things, shelters, staple goods, fuel supplies	4 indicators
	Interoperability and inter-agency compatibility	2 indicators
	Military drills	2 indicators
Recovery and Rebuilding Communities	Announcement of event recovery plans in advance	2 indicators

Table 4-6: The Ten Essentials of Making Cities Resilient

Data source: Compiled from the UNISDR Report Summary, 2010

4.2.1.7 City Resilience Profiling Programme

The City Resilience Profiling Programme puts emphasis on providing countries and local governments with various tools and develops standard and simplified indicator systems to measure and enhance resilience to disasters (including those related to climate change), and guide future planning and development based on hazard and risk assessments. Through partnerships with international organizations like UNISDR, academic and research institutions, the private sector, NGOs and other stakeholders, the City Resilience Profiling Programme, now in the research stage, will formulate a set of comprehensive urban planning and management methods to study and monitor any city's resilience in the face of all potential hazards[6]. The tools

[6] http://unhabitat.org/urban-initiatives/initiatives-programmes/city-resilience-profiling-programme/

and policies developed by this Programme will be verified and revised by the 10 cities selected on the basis of the bidding documents received by the UN-HABITAT since an invitation for bids was issued in November 2012. The selected cities are balanced in terms of geographic location, economic level, population size, disaster situation and implementation of resilience.

4.2.2 Systems Developed by China

4.2.2.1 China's Sustainable Development Assessment Indicator System

For China, it's imperative and essential to prioritize the reduction of energy consumption and pollution due to its unsustainable development situation. A set of simplified indicators is needed to achieve effective balance between economic development, social equality and environment. Therefore, a research group comprised of the China Center for International Economic Exchanges and Columbia University's Earth Institute has developed a new indicator system to evaluate China's sustainable development with reference to international experience. This system includes 41 preliminary indicators from the five themes of economic development, social livelihood, resources and environment, consumption and emissions, and governance and protection. According to the research group, the development of the indicator system fully reflects the basic facts of increasing ecological pressure on consumers with the domestic demand transition and continuous moderate-to-high economic growth. Sustainable production and consumption have been taken into account as much as possible, and the two drivers of growth and governance have been given equal weight, reflecting the two key complementary themes of steady economic growth and sustainable governance. Furthermore, on the basis of data accessibility and preliminary data screening, the group also constructed provincial-level sustainable development indicators and created 28 indicators in 5 categories (Wang et al., 2017).

Dimensions	Indexes	Sub-indexes
Economic Development	Innovation	3 indicators
	Structural optimization	3 indicators

	Steady growth	3 indicators
Social Livelihood	Education and culture	3 indicators
	Social security	2 indicators
	Sanitation and health	3 indicators
	Equality	2 indicators
Resources and Environment	Land and resources	3 indicators
	Water	2 indicators
	Atmosphere	2 indicators
	Biodiversity	1 indicator
Consumption and Emissions	Land consumption	1 indicator
	Water consumption	1 indicator
	Energy consumption	1 indicator
	Emissions of major pollutants	1 indicator
	Generation of hazardous waste	1 indicator
	Emissions of greenhouse gases	2 indicators
Governance and Protection	Governance input	3 indicators
	Waste water utilization	2 indicators
	Solid waste disposal	1 indicator
	Hazardous waste disposal	1 indicator
	Garbage disposal	1 indicator
	Waste gas treatment	1 indicator

	Reduction of greenhouse gas emissions	2 indicators

Table 4-7: China's Sustainable Development Assessment Indicator System

Data source: Wang et al., 2017

4.2.2.2 Performance Indicator Handbook for China's Urban Development Strategy

The Performance Indicator Handbook for China's Urban Development Strategy, sponsored by the China City Online Organization (CCOO), is a city performance assessment project managed by the United Nations. This project is intended to help Changsha, Zhuzhou, Xiangtan, Guiyang, Shenyang and other cities develop a complete set of performance indicators, promote a need-based methodology, and develop and utilize indicators corresponding to the priority strategies and operational issues identified through their urban development strategies. The focus of the program is to help them examine their current practices in identifying and measuring the improvement in citizens' living standards and performance in key areas of urban management. Furthermore, it takes these indicators as tool to demonstrate the value of helping city administrators adjust their policies, plans, project investments and management practices to achieve the objectives set by their urban development strategy. The indicators corresponding to various objectives and strategies in urban development are set up from the very beginning of the process of developing an urban development strategy objective system. Hence, the indicators selected for different cities, and their grouping, may vary. These indicators fall into six categories: economic life, social development, living quality, urban infrastructure, environmental management and international cooperation. Under each category are several items (Table 4-8). The main purpose of the Performance Indicator Program for China's Urban Development Strategies is not to make inter-city comparisons, but rather to give full play to the goals to be achieved through comparison.

Dimensions	Indexes	Sub-indexes
Economic Life	GDP (City)	4 indicators

	Industrial structure	6 indicators
	Fixed asset investment	3 indicators
	Employment	5 indicators
	High-tech industries	1 indicator
	Tourism	2 indicators
	Local government's financial standing	5 indicators
Social Development	Population	6 indicators
	Families	2 indicators
	Vitality and public health	8 indicators
	Education and human resources	9 indicators
	Income distribution and social security	6 indicators
	Security	5 indicators
Living Quality	Family income, expenditures and prices	10 indicators
	Housing	2 indicators
	Culture and communication	6 indicators
	Security	5 indicators
Urban Infrastructure	Land utilization and development	6 indicators
	Water, power and gas	8 indicators
	Transportation	7 indicators
	Infrastructure	2 indicators
Environmental Management	Air quality	3 indicators

	Water quality	3 indicators
	Garbage disposal and recycling	3 indicators
	Noise pollution	4 indicators
	Nature	2 indicators
	Environmental protection and planning	3 indicators
International Cooperation	Trade	4 indicators
	Foreign direct investment	2 indicators

Table 4-8: Performance Indicators for China's Urban Development Strategies

Data source: Performance Indicator Handbook for China's Urban Development Strategies, 2002

4.2.2.3 Settlements and Environment Award Assessment Indicator System

In response to the Habitat Scroll of Honour Award set up by the United Nations Commission on Human Settlements, the China Ministry of Housing and Construction has established a "China Settlements and Environment Award" to recognize cities and towns whose urban-rural construction and management maintains sustainable development strategies, improves urban-rural environmental quality and creates good human settlements. In 2016, the Ministry of Housing and Construction released a new edition of the assessment indicator system. The basic system is composed of 65 indicators in six categories: living environment, environment, social harmony, public security, economic development and resource conservation.

Dimensions	Indexes	Sub-indexes
Living Environment	Housing and community	4 indicators
	Municipal infrastructure	7 indicators
	Transportation	3 indicators
	Public services	7 indicators

Environment	Urban ecology	2 indicators
	Urban greening	5 indicators
	Environmental quality	3 indicators
Social Harmony	Social security	2 indicators
	Old-age programs	2 indicators
	Programs for the physically challenged	2 indicators
	Security for migrant workers	1 indicator
	Public participation	1 indicator
	History, culture and city features	2 indicators
Public Security	Urban management and municipal infrastructure security	2 indicators
	Social security	2 indicators
	Disaster prevention	3 indicators
	City emergency response	1 indicator
Economic Development	Income and consumption	2 indicators
	Employment level	1 indicator
	Capital investment	1 indicator
	Economic structure	1 indicator
Resource Conservation	Energy conservation	4 indicators
	Water resource conservation	4 indicators
	Land conservation	1 indicator

Table 4-9: China Settlements and Environment Award Assessment Indicator System

Data source: Complied on the basis of the China Settlements and Environment Award Assessment Indicator System, 2016

4.2.2.4 Low-carbon City Standards

In 2010, the Chinese Academy of Social Sciences released new standards for low-carbon city assessment, which has become a relatively well-established low-carbon city standard system. The system is divided into 12 indicators in four categories: carbon productivity, low-carbon consumption, carbon alternative resources and low-carbon policies. According to these standards, a city whose carbon productivity indicators are at least 20% higher than the national average can be considered low-carbon.

Dimensions	Indexes
Carbon Productivity	Carbon productivity, energy consumption per unit product of key industries
Low-carbon Consumption	Carbon emissions per capita, consumption-related carbon emissions *per capita*
Carbon Alternative Resources	Proportion of non-fossil energy in primary energy consumption, forest coverage rate, carbon dioxide emissions per unit of energy consumption
Low-carbon Policies	Low-carbon economic development plans, carbon emissions monitoring, statistics and supervision systems, public awareness of low-carbon economy, implementation rate of building energy conservation standards, non-commodity energy incentives and efforts

Table 4-10: China's Low-carbon City Standards

Data source: http://www.cusdn.org.cn

4.3 Finalization of Resilient City Indicator Framework

A good classification framework is the premise for a scientific, evidence-based indicator system. As the above analysis shows, widely adopted indicator system frameworks, known as topical indicator frameworks, are based on specific development goals, areas and topics. The key point of the framework is to be used as a management tool. In developing the system, therefore, organizational management should reflect the goals, key areas and major issues of resilient city development strategy from the very beginning, and proper indicators must be selected for each respective topic.

4.3.1 Analysis of Chinese and International Indicator Frameworks

4.3.1.1 International Frameworks

Table 4-7 summarizes of international research relating to resilient city indicators. They can be categorized into two types: based on urban systems, and on climate change and disaster risk management. The classification of indicator systems and selection of indicators varies due to differences in understanding of resilient cities and the objectives of different countries and organizations.

	Project Name	Organization	Scope of Application	Year	Number of Indicators	Purpose
Based on urban systems	City Resilience Index	Pestel Research Center Germany	Cities	2010	18 indicators in 6 dimensions	Maintaining the functions of a region or a city through crises via resource allocation and indirect social capital
	Resilience Capacity Index	Buffalo Regional Institute of the University of California, Berkeley	Metropolitan areas	2011	3 dimensions, each with 4 indicators	Assessing the adaptation and self-adjustment of a metropolitan area to future external changes and measuring the strengths and weaknesses of a region, enabling regional leaders to identify differences with other regions.

	City Resilience Index	Rockefeller Foundation	Cities	2014	4 dimensions, 12 key indicators and 130-150 secondary indicators	Providing cities with a comprehensive and operable approach to better guide investment decision-making and urban planning practices, ensuring the survival and continuous prosperity of citizens (particularly disadvantaged groups) in the face of any shock or pressure.
Based on climate change and disaster risk management	Climate and Disaster Resilience Initiative	The University of Madras and Kyoto University	Cities	2010	5 dimensions, 25 key indicators and 125 secondary indicators	Helping governments better understand the potential risks faced by cities.
	Disaster Resilience Indicators	The University of South Carolina	Countries	2010	5 key indicators and 36 secondary indicators	Assess the status of disaster resilience within communities.
	10 Essentials of City Resilience	UNISDR	Cities	2012	10 dimensions, 41 indicators	Allowing for unforeseen circumstances in urban infrastructure construction, helping local governments and policy makers formulate public policies and make decisions, reducing the risks

						from disasters and enhancing disaster resilience.
	City Resilience Profiling Programme	UN-HABITAT	Cities	2012	In the research stage	Providing national and local governments with tools to measure and enhance resilience to disasters and climate change.

Table 4-11: Summary of Resilient City Indicator Related Research

Data source: Drawn from related materials

Structurally speaking, indicator systems generally adopt two- or three-level structures, and are classified by the topics or areas involved. The City Resilience Index and Climate and Disaster Resilience Initiative both have two levels, while the other systems use three. The first level of each system, which can be referred to as the objective level, identifies the resilient city development vision and major urban elements. The lowest level is the Sub-indexes level, where the indicators are specified. The Resilience Capacity Index developed by the University of California, Berkeley and the Rockefeller Foundation as well as 10 Essentials of City Resilience also have a index level which decomposes the objective level.

From the perspective of objectives and content, the resilient city assessment indicators are primarily used to measure the cities' capacity to respond to social changes, economic turmoil and natural disasters. Internationally recognized indicators measuring the performance of states, regions and cities are used to the extent possible to make the indicators representative and universally acceptable. Therefore, frequently-seen items related to society, economy and infrastructure are incorporated into the systems, and contents relating to community development, energy, natural conditions and public involvement are added based on individual cases. Most indicator systems are concerned with 3-5 dimensions, and include 4-5 indicators under each topic and 5-6 variables under each indicator. In order words, there are less than 150 indicators in total. To be specific, the six indicator systems include indicators involving residents' basic needs such as educational level, medical insurance, income level and living conditions. Other frequently mentioned indicators include traffic accessibility, land utilization rate, social involvement, business operations, infrastructure protection capability and emergency management. Certain indicators are also included for disasters specific to local conditions. For instance, flood control coverage is included in the Disaster Resilience Indicators in light of the frequent flooding seen in some Southeastern US cities. No institutional assessment indicators are included in the City Resilience Index, cooperation with related institutions and enterprises is not mentioned in the Disaster Resilience Indicators, and no indicators of land utilization and infrastructure are found in the Resilience Capacity Index. The 10 Essentials of City Resilience are the most comprehensive indicator system so far.

4.3.1.2 Chinese Frameworks

Chinese indicator system classification frameworks for assessment of overall city development have drawn inspiration from internationally-recognized methods. Taking China's three-level sustainable development indicator system as an example, the first level consists of five themes, including the three most frequently seen themes of sustainable development: society (social livelihood), economy (economic development) and nature (resources and environment). Two themes associated with nature are added: consumption and emissions and governance and protection. The second and third levels divide the five categories into 24 items and 41 preliminary indicators. UN-HABITAT has adopted a three-level indicator system for the designated performance indicators of the Changsha, Zhuzhou, and Xiangtan (CZT) region, as well as Guiyang and Shenyang. The system is composed of 6 dimensions: economic life, social development, quality of life, urban infrastructure, environmental management and international cooperation. Under each category are specific topics, and under each indicator are topics. The China Settlements and Environment Award Assessment Indicators is also a three-level system. The first level features 6 dimensions: living environment, environment, social harmony, public security, economic development and resource conservation. 24 indexes are covered between these dimensions, including housing and community, municipal infrastructure and transportation. Several sub-indexes are selected to reflect each topic. The Low-carbon City Assessment System released by the Chinese Academy of Social Sciences has fewer indicators. The 12 indicators centered on the four categories of carbon productivity, low-carbon consumption, carbon alternative resources and low-carbon policies however play only a limited role in guiding cities' comprehensive and coordinated development.

4.3.2 Finalization of Framework for Central China

In light of the above analysis on international and Chinese indicator systems, considering the development trends and features of Central Chinese cities, the resilient city indicator system classification framework of this study: 1) Complies with international standards; 2) Fully reflects all fields of resilient city development. Based on studies and expert discussions, the framework is determined to consist of four dimensions: society, economy, urban infrastructure and urban governance. Under each dimension are topics according to the collected indicator database. Indicators are assigned under each topic to reflect respective conditions (Figure 4-2).

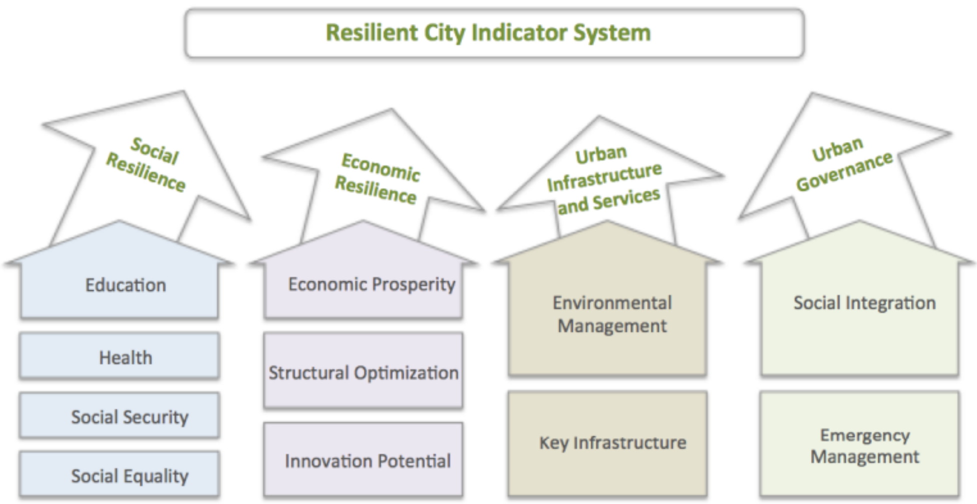


Figure 4-2: Resilient City Indicator System in Central China

Data source: Drawn by the author

4.4 Indicator System Principles

As can be seen from the definition and connotations as well as various international studies on resilient city indicators, resilient cities are a complex interdisciplinary phenomenon. Resilience capacity is a comprehensive measurement of urban development. Through processing of superficial data and phenomena, essential internal connections and change patterns can be abstracted and expressed using simplified indicators. The indicators reveal the causes and mechanisms of resilient cities. Each indicator system is intended to identify the root sources of resilience, and explore the internal connections among its driving factors from various perspectives. In comparison to other urban assessment indicator systems, these ones should be problem-oriented and risk-specific, centered around the ability of urban systems to respond to and absorb diverse pressures (Liu et al., 2014). The major elements of the resilient city system, like society, economy, environment, population health, policy management and infrastructure, should be reflected in and integrated into the indicator system. As complete urban systems, resilient cities reflect the interaction of ecology, society, economy, culture and urban spatial systems. The normal operation of these systems depends on coordination between sub-systems and elements. The indicator system must reflect the connotations of resilient cities and consider the overall social and economic characteristics, while also aiding decision making and public understanding. Therefore, the following principles must be followed in developing the system:

4.4.1 Integrity and Hierarchy

Resilient cities are complex systems consisting of different levels and elements, including human society and related basic elements, relations and behaviors. Hence, an indicator system should comprehensively reflect their development features, with indicators representing the main features and conditions of urban development as well as the dynamic changes and development trends of sub-system coordination. Moreover, the normal operation of urban systems depends on functional groups at different levels. Therefore, the high level indicators should summarize the low level ones, which decompose and lay a foundation for the former.

4.4.2 Problem Orientation

In comparison to other urban assessment indicator systems, resilient city systems should be problem-oriented and risk-specific, concerned with the ability to respond to and absorb diverse pressures.[97] Therefore, the indicators should be selected by city, and should reflect major elements of the resilient city system like society, economy, environment, population health, policy management and infrastructure.

4.4.3 Evidence-based Approach

The indicators should come from related domestically and internationally influential urban systems. Their consolidation and screening should be based on scientific definitions and computing methods, combining qualitative and quantitative indicators, and reflecting and measuring the development goals of resilient cities.

4.4.4 Operability

The operability principle emphasizes availability (based on realistic statistics), comparability (cities with different features should have a basic indicators for uniform measurement, comparison and assessment), predictability (the variables selected must be practically measurable or scientifically aggregable) and controllability (indicators must be rationally adjustable as needed for urban development, as the ultimate purpose of the system is to adjust cities' development directions and models). Indicators should be easily accessible or calculated from easily accessible indicators, and selected from those under government monitoring or accessible at low costs. In accordance with the principles of parsimony, simplicity and ease of operation, the indicators should apply to horizontal comparisons of cities with similar nature, type and size, and to vertical comparisons of a city over time.

4.4.5 Dynamics and Statics

Everything develops over time, and the target values or criteria measuring cities' development level must be dynamic. Resilient cities are a both target and a process. The indicator system should therefore take the features of dynamic change into full consideration, and comprehensively reflect the development status and future trends of resilient cities to facilitate prediction and decision-making. Similarly, the system should maintain relative stability in terms of content over a certain period, and thus reflect a combination of static and dynamic indicators.

4.5 Methods for Indicator System Establishment

In 2008, Cutter et al. proposed the Baseline Resilience Indicators for Communities (BRIC) on the basis of existing research on resilience theories, dividing resilience into six categories, including social, economic, and community resilience. Through factor analysis, they also identified 49 single indicators. These indicators, collected from statistical data published by the government or research institutions, are used to quantify regional resilience through value assignment, and thus obtain the resilience capacity of different regions. The BRIC score is a relative value which can be used to compare different regions at different times. This highly practical and replicable model has been widely accepted and been adopted by a number of scholars and research institutions, further attesting to the quantifiability of resilience. Considering the inherent differences between China and Western countries, urban resilience evaluation indicators can't be directly drawn from foreign frameworks. Due to the inapplicability of certain indicators in the BRIC and other similar foreign evaluation systems to Chinese cities, the indicators must be re-selected and localized. In reference to the findings from domestic and foreign literature review. Therefore, this dissertation selected indicators and established a composite indicator system integrating quantitative and qualitative research on the basis of the meanings of city resilience, the principles of indicator systems, the development conditions of domestic cities, and data availability.

4.5.1 Indicator Collection

The selected indicators should comply with internationally accepted standards, and be consistent with China's national conditions and statistical systems. In accordance with these classification frameworks, therefore, upon extensive data collection, this study has selected 13 international indicator databases including the Rockefeller Foundation's City Resilience Index, and four Chinese indicator systems, including the Technology Outline of Chinese Sustainable Development, as references (Table 4-12).

Category	Indicator System	Organization
International Systems	City Resilience Index	Pestel Research Center, Germany
	Resilience Capacity Index	The University of California, Berkeley
	City Resilience Index	Rockefeller Foundation
	Climate Disaster Resilience Index (CDRI)	The University of Madras and Kyoto University
	Disaster Resilience Indicators	The University of South Carolina
	10 Essentials of City Resilience	UNISDR
	City Resilience Profiling Programme	UN-HABITAT
	City Prosperity Index	UN-HABITAT
	City Prosperity—State of the World's Cities	UN-HABITAT
	Sustainable Development Indicators	United Nations Commission on Sustainable Development
	Global City Indicator System	GCIF
	City Database	Asian Development Bank
	City Audit	Eurostat
Domestic Systems	Performance Indicator Manual for China's Urban Development Strategies	China City Online Organization (CCOO)
	Technology Outline for Chinese Sustainable Development	Ministry of Science and Technology

	Low-carbon City Assessment System	Chinese Academy of Social Sciences
	Settlements and Environment Award Assessment Indicator System	Ministry of Housing and Construction

Table 4-12: Index systems from China and abroad for indicator selection

Data source: Drawn by the author

4.5.2 Indicator Screening

After preliminary selection, the indicators were screened through interviews with experts and scholars and an online questionnaire-based survey. Resilient city evaluation is concerned with a multitude of complex phenomena and interaction of multiple factors. The Delphi method, a scientific expert opinion evaluation method, can objectively select relatively important evaluation indicators from the indicator databases using the opinions of experts, and it serves as a scientific basis for qualitative analysis. Through multiple rounds of opinion collection from selected experts, and summary of expert opinions for each round, the data are first organized, then sent to each expert for analysis and appraisal. The experts then put forward new arguments and opinions based on the organized data, so as to finally draw a largely consistent and highly reliable conclusion or plan.

1. Preliminary Selection

The 17 international and Chinese indicator databases relating to city resilience indicators were incorporated into the selection process. All indicators from the databases were classified and consolidated into topics. After removal of indicators evidently inconsistent with China's national conditions and statistical systems, a certain number of candidate indicators were selected. Indicators released by the state or assessed annually were used to the extent possible.

2. Interviews with Experts

Interviews were conducted with six representative experts and scholars in the Changsha urban planning field: Mr. Huang Li, Chief of the Village and Town Office of the Hunan Province Department of Housing and Construction, Mr. Tan Chunhua, Vice President of the Changsha Planning and Design Institute, Dr. Zhao Xuebin, Deputy Chief Planner of the Hunan Architectural Design Institute, Professor Ye Qiang of the School of Architecture of Hunan University, and Professor Xie Mingjing of the School of Architecture and Art of Central South University. The preliminary indicators were selected based on the experts' views on their inclusion, as well as their nomination of new indicators. See Appendix I for the expert questionnaire.

Figure 4-3: Interview with Experts

Data Source: Photograph by the author

3. Online Questionnaire

An online expert opinion collection survey was conducted from March 10 to April 10, 2018. This survey invited 15 experts from planning design units, government departments, enterprises and colleges in Hunan Province to advise via E-mail on the inclusion of the selected preliminary indicators into the system, grade the preliminary system and determine the indicator selection and indicator weights. See Appendix II for this questionnaire.

4.6 Indicator Selection Statistics

See Tables 4-13 and 4-14 for the results of first-round expert interviews and second-round online questionnaire.

Dimensions	Indicators	Sub-indexes	Rate of Selection	New Indicator Feedback
Social Resilience	Education	Ratio of population with college education or above to population aged 15 or above	60%	
		Ratio of Technical Professionals to Jobs	20%	
		Average educational level of the population aged 15 or above	40%	
		Teacher-student ratio	60%	
		Ratio of educational expenditure to local government expenditure	100%	
		Number of high education graduates per 10,000 population	80%	
		Per Capita Land Area of Public Cultural Facilities	80%	
	Health	Average life expectancy	100%	Medical expenditure per capita
		Percent of population aged 65 or above	80%	
		Number of physicians per 10,000 population	60%	
		Number of hospital beds per 10,000 population	60%	
		Percent population with basic endowment insurance coverage	60%	
		Beds in social welfare institutions per 100 senior population	20%	
	Social Security	Percent population with basic social insurance	100%	Ratio of fiscal

		coverage		expenditure on social security to total fiscal expenditure
		Per capita fiscal expenditure on social security	60%	
		Occupation rate of government-subsidized housing projects	40%	
		Number of minimum living allowance recipients	60%	
	Social Equality	Gini Coefficient	80%	Coverage rate of government-subsidized housing
		Housing price-to-income ratio	80%	
		Percent of residents with *per capita* housing area less than 15 m^2	20%	
Economic Resilience	Economic Prosperity	*Per Capita* GDP	80%	Percent of land revenue to local fiscal revenue
		Engel's coefficient	60%	
		Per capita disposable income of urban residents	100%	
		Registered urban unemployment rate	60%	
		Local fiscal revenue to GDP ratio	80%	
		Total retail sales of consumer goods	60%	
	Structural Optimization	Proportion of value added by the tertiary sector to GDP	100%	
		Ratio of value added by the secondary sector to GDP	0	
		Ratio of value added by the high-tech industry to industrial value added	100%	

	Innovation Potential	Ratio of expenditure on R&D to fiscal expenditure	100%	
		Number of valid invention patents per 10,000 population	60%	
Urban Infrastructure and Services	Environmental Management	Urban air quality compliance rate	80%	
		Average days of compliance with PM2.5 annual concentration	60%	
		Water quality compliance rate in functional areas of urban water environment	80%	
		Centralized treatment rate of urban sewage	100%	
		Daily household waste output *per capita*	40%	
		Decontamination rate of household garbage	100%	
		Multipurpose utilization rate of industrial solid wastes	100%	
		Urban greening coverage rate	40%	
		Per capita parks and green space	100%	
		Coverage rate of park and green space service radius	40%	
	Resource Conservation	Annual domestic water consumption *per capita*	60%	
		Water consumption per RMB 10,000 GDP	100%	
		Renewable water utilization rate	80%	
		Industrial water reuse rate	40%	

		Energy consumption per RMB 10,000 GDP	100%	
		Proportion of renewable energy usage	100%	
		Proportion of new energy vehicle usage	60%	
	Key Infrastructure	Density of public transport network	100%	
		Walking and cycling traffic share	20%	
		Urban public water supply coverage	60%	
		Urban gas penetration	80%	
		Internet penetration	80%	
		Average commuting time	80%	
		Urban shelter area *per capita*	60%	
Urban Governance	Social Integration	Public participation	100%	
		Membership of private social groups	80%	
		Voter participation rate	20%	
		Ratio of residents living in the area over five years to those living under five years	60%	
	Emergency Management	Emergency command information platforms	80%	
		Natural disaster warning systems	80%	
		Coverage rate of digital urban management systems	80%	
		Emergency communications services	60%	
	Comprehensive	Expert consulting organizations	40%	One-stop planning

	Development Planning	Speed of administrative approval	40%	platforms
		Risk-based land utilization planning	60%	3D approval system
		Integrated management and construction of underground urban utility tunnels	60%	Integrity of planning systems

Table 4-13: Indicator selection after expert interviews

Data source: Drawn by the author

Dimensions	**Indicators**	**Sub-indexes**	**Rate of Selection**
Social Resilience	Education	Ratio of population with college education or above to the population aged 15 or above	60%
		Proportion of Technical Professionals among Jobholders	20%
		Average educational level of the population aged 15 or above	40%
		Teacher-student ratio	80%
		Proportion of educational expenditure to local government expenditure	100%
		Number of higher education graduates per 10,000 population	80%
		Per capita land area of public cultural facilities	60%
	Health	Average life expectancy	100%
		Percent of population aged 65 or above	80%
		Number of physicians per 10,000 population	60%
		Number of hospital beds per 10,000 population	60%

		Percent population with basic endowment insurance coverage	60%
		Beds in social welfare institutions per 100 senior population	20%
		Medical expenditure *per capita*	20%
	Social Security	Percent of population with basic social insurance coverage	100%
		Per capita fiscal expenditure on social security	60%
		Occupation rate of government-subsidized housing projects	40%
		Number of minimum living allowance recipients	60%
		Ratio of fiscal expenditure on social security to total fiscal expenditure	60%
	Social Equality	Gini Coefficient	80%
		Housing price-to-income ratio	80%
		Percent of residents with *per capita* housing floor space less than 15 m^2	20%
		Coverage rate of government-subsidized housing	80%
Economic Resilience	Economic Prosperity	*Per capita* GDP	80%
		Engel's coefficient	60%
		Per capita disposable income of urban residents	100%
		Registered urban unemployment rate	60%
		Local fiscal revenue to GDP ratio	80%

		Total retail sales of consumer goods	40%
		Percent of land revenue to local fiscal revenue	40%
	Structural Optimization	Ratio of value added by tertiary sector to GDP	100%
		Ratio of value added by secondary sector to GDP	0
		Proportion of value added by high-tech industry to industrial value added	100%
	Innovation Potential	Ratio of expenditure on R&D to fiscal expenditure	100%
		Number of valid invention patents per 10,000 population	60%
Urban Infrastructure and Services	Environmental Management	Urban air quality compliance rate	80%
		Annual average days in compliance with PM2.5 concentration	60%
		Water quality compliance rate in functional areas of urban water environment	80%
		Centralized treatment rate of urban sewage	100%
		Daily household waste output *per capita*	40%
		Decontamination rate of household garbage	100%
		Multipurpose utilization rate of industrial solid wastes	100%
		Urban greening coverage	40%
		Per capita parks and green space	100%
		Coverage rate of park and green space service radius	40%
	Resource	Annual domestic water consumption *per capita*	60%

	Conservation	Water consumption per RMB 10,000 GDP	100%
		Renewable water utilization	80%
		Industrial water reuse	40%
		Energy consumption per RMB 10,000 GDP	100%
		Proportion of renewable energy usage	100%
		Proportion of new energy vehicle usage	60%
	Key Infrastructure	Density of public transport network	100%
		Walking and cycling traffic share ratio	20%
		Urban public water supply coverage rate	60%
		Urban gas penetration rate	80%
		Internet penetration rate	80%
		Average commuting time	80%
		Urban shelter area *per capita*	60%
Urban Governance	Social Integration	Public participation	100%
		Membership of private social groups	80%
		Voter participation rate	20%
		Ratio of residents living in this area over five years to those living under five years	60%
	Emergency Management	Emergency command information platforms	80%
		Natural disaster warning systems	80%
		Coverage rate of digital urban management systems	80%

		Emergency communications services	60%
	Comprehensive Development Planning	Expert consulting organizations	40%
		Speed of administrative approval	40%
		Risk-based land utilization planning	60%
		Integrated management and construction of underground urban utility tunnels	60%
		One-stop planning platforms	20%
		3D approval systems	20%
		Integrity of planning system	20%

Table 4-14: Indicator selection after online questionnaire

Data source: Drawn by the author

4.7 Resilient City Indicator System Results

Considering the results of the first-round expert interviews and second-round of online questionnaire, duplicate indicators reflecting the same problems, as well as indicators not under regular state monitoring or lacking data were removed; inclusion of forward-looking and innovative indicators not under regular state monitoring was also considered. Finally, 32 indicators covering four targets – society, economy, urban infrastructure and services, and urban governance – were selected in the "dimension, indicator, and sub-index" levels (Table 4-15).

Target	Dimensions	Indicators	Sub-indexes
Resilient City Assessment Indicator System	Social Resilience (A1)	Education (B1)	Teacher-student ratio (C1); Proportion of educational expenditure to local government expenditure (C2); Number of higher education graduates per 10,000

			population (C3)
		Health (B2)	Average life expectancy (C4); Number of physicians per 10,000 population (C5); Number of hospital beds per 10,000 population (C6)
		Social Security (B3)	Percent population with basic endowment insurance coverage (C7); Ratio of fiscal expenditure on social security to total fiscal expenditure (C8); Number of minimum living allowance recipients (C9)
		Social Equality (B4)	Coverage rate of government-subsidized housing (C10); Housing price-to-income ratio (C11)
	Economic Resilience (A2)	Economic Prosperity (B5)	Per Capita GDP (C12); Engel's coefficient (C13); *Per capita* disposable income of urban residents (C14); Registered urban unemployment rate (C15); Local fiscal revenue to GDP ratio (C16)
		Structural Optimization (B6)	Ratio of value added by the tertiary sector to GDP (C17); Ratio of value added by the high-tech industry to industrial value added (C18)
		Innovation Potential (B7)	Ratio of expenditure on R&D to fiscal expenditure (C19); Number of valid invention patents per 10,000 population (C20)

	Urban Infrastructure and Services (A3)	Environmental Management (B8)	Urban air quality compliance rate (C21); Water quality compliance rate in functional areas of urban water environment (C22); Multipurpose utilization rate of industrial solid wastes (C23); *Per capita* parks and green space (C24); Water consumption per RMB 10,000 GDP (C25); Energy consumption per RMB 10,000 GDP (C26)
		Key Infrastructure (B9)	Density of public transport network (C27); Urban gas penetration rate (C28); Internet penetration rate (C29)
	Urban Governance (A4)	Social Integration (B10)	Public participation (C30); Members of private social groups (C31)
		Emergency Management (B11)	Presence of emergency command information systems (C32)

Table 4-15: Resilient City Indicator System Results

Data source: Drawn by the author

4.8 Detailed Explanation of Changsha Resilient City Indicator System

4.8.1 Social Resilience

(1) Teacher-student ratio (%)

This indicator reflects the relative numbers of teachers and students in schools, an important measure of educational resources and educational and teaching management, and a significant indicator for international and regional educational comparisons. Due to differences in economic and educational development conditions and systems, teacher-student ratio requirements vary by country and region, as well as with training goals, teaching content, and teaching methods of different types of schools at different levels. Generally, for similar schools at the same level, with the same conditions, at the same time, the more students the teachers are responsible for, the higher their workload and the utilization rate of human and financial resources; the fewer students they are responsible for, the lower their workload and the utilization rate of human and financial resources. Given the same number of students, a higher teacher-student ratio indicates better teaching quality for individual students. The formula to compute teacher-student ratio is as follows:

Teacher-student ratio = (Total teachers of schools at different levels/registered students) x 100% (Data source: Changsha Municipal Bureau of Statistics)

(2) Ratio of educational expenditure to local government expenditure (%)

The ratio of educational expenditure to local government expenditure compares a local government's expenditures on education to its total expenditures, measuring urban development potential, and the extent to which a country or a region values educational investment. The absolute level and growth of educational expenditure by a local government is limited by its total fiscal revenues, and affected by people's awareness of educational development; the relative amount and growth of a government's educational expenditure primarily depends on the latter. The formula to compute the ratio of educational expenditure to total local government expenditure is as follows:

Ratio of educational expenditure to local government expenditure = (operating costs of educational departments/local government expenditure) x 100% (Data source: Changsha Statistical Report)

(3) Number of higher education graduates per 10,000 population (1/10,000)

Higher education means specialized expert training following general education. China's higher education consists of vocational, undergraduate and postgraduate education, in the forms of full-time, half-time and part-time higher education. There are comprehensive, dedicated and junior colleges as well as state-, locally- and privately-run universities. This indicator measures the availability of highly educated labor, which reflects education and training policies, as well as cities' competitive development potential amid their economic restructuring and industrial upgrading. For cities, promoting higher education effectively expands demand by promoting beneficial economic circulation; promotes economic restructuring by acceleration industrial upgrade, improving comprehensive national strength; and alleviates employment pressure by expanding investment in human capital and enhancing the quality of the population. Growth in this indicator plays an important role in social development. (Data source: Changsha Statistical Yearbook.)

(4) Average life expectancy (years)

The average life expectancy is the average number of years those born at the same time can expect to live, under the assumption that current age-specific mortality rates remain unchanged. However, mortality rates change constantly, therefore it is an assumed indicator. The calculation method is as follows: population born at the same time is tracked, and the number of deaths in various age groups is recorded until the last person is deceased; the average life expectancy of this group is thus calculated and assumed to be that of the current generation.

Life expectancy is limited by socioeconomic conditions and medicine, generating large differences between societies and periods. Physical conditions, genetic factors and living conditions result in idiosyncratic differences. The level of a society's economic development and medical services is important indicator of population health, reflecting quality of life. (Data source: Changsha Statistical Yearbook)

(5) Number of physicians per 10,000 population (1/10,000)

This indicator measures standards of health and medical facilities. Physicians are medical professionals certified by medical management authorities. This is one of the important indicators evaluating population health and human rights conditions of respective countries. It is calculated as follows:

Number of physicians per 10,000 population = Number of Physicians/Urban Population (Data source: Changsha Statistical Report)

(6) Number of hospital beds per 10,000 population (1/10,000)

The Number of hospital beds per 10,000 population refers to the number of beds available for every 10,000 urban residents. Beds are a core element of the medical service system and a major indicator to measure a country's general health resources and service capacity. This indicator is primarily intended to measure the supply of local medical resources for residents' basic medical care. It is calculated as follows:

Number of hospital beds per 10,000 population = number of hospital beds/urban population (Data source: Changsha Statistical Report)

(7) Percent population with basic endowment insurance coverage (%)

Percent population with basic endowment insurance coverage is the ratio of personnel entitled to basic endowment insurance to the total number of employees in state-owned enterprises and organizations. Basic endowment insurance is the nucleus of China's pension system and retirees' main income source. It is automatically activated when legally defined seniors "completely" (characterized by laborers separating from the means of production) or "essentially" (characterized by involvement in productive activities no longer as the main social life activity) withdraw from social working life. It's important to note that the legal retirement age (which varies by country) is a practical measurement criterion. Basic endowment insurance is intended to guarantee the basic living needs of seniors and provide them with a stable and reliable source of income.

The significance of basic endowment insurance is reflected in three respects. First is the re-production of the labor force: endowment insurance system helps with the normal generational shift of labor force, whereby seniors retire at an old age and the youth become employed, guaranteeing a rational employment structure. Second is social security and stability:

it provides seniors with basic livelihood protection and proper care. As the population ages, seniors will make up a greater proportion of the total population. Therefore, basic endowment insurance, guaranteeing seniors' basic income is a basic living guarantee for a considerable portion of society. Finally, for economic development: the endowment insurance systems of various countries, especially with partial and complete accumulation pension fundraising models, are linked with their equality and efficiency. The amount of pensions available to retirees is directly associated with their wages and contribution during their working period, which spurs laborers to work harder and improve their working efficiency. Therefore, this indicator is significant to the formulation and supervision of social welfare policies. It is computed as follows:

Percent population with basic endowment insurance coverage = Number of personnel entitled to basic endowment insurance in state-owned enterprises and organizations/total number of employees in state-owned enterprises and organizations (Data source: Changsha Statistical Yearbook)

(8) Ratio of fiscal expenditure on social security to total fiscal expenditure (%)

The ratio of fiscal expenditure on social security to total fiscal expenditure is the proportion of its expenditures on social security to total fiscal expenditure. Fiscal expenditures on social security refers to government fiscal expenditure on basic livelihood protection for temporarily or permanently incapacitated members of society, who are deprived of job opportunities or faced with life challenges due to various reasons. It generally consists of expenditures on social insurance, social welfare, preferential treatment and compensation for soldiers, natural disaster relief, housing security and rural social security. Social security expenditures are used for system operations and residents' minimum living standard guaranteeing, a means of adjusting distribution, narrowing income and property gaps, ensuring social equality, and maintaining social peace. This indicator reflects the efforts of a government to protect its local disadvantaged groups, narrowing the wealth gap through re-distribution. It is calculated as follows:

Ratio of fiscal expenditure on social security to total fiscal expenditure = (fiscal expenditure on social security/total fiscal expenditure) x 100% (Data source: Changsha Statistical Report)

(9) Number of minimum living allowance recipients (10,000's)

This indicator refers to the non-rural population receiving minimum living allowance in cities. The minimum living allowance system, as a type of social security, refers to the government giving a certain cash subsidy to households with *per capita* income less than the minimum living standard determined by the government – below the poverty line – so they can meet their basic living needs. This indicator measures the poverty-stricken population and the demand for income subsidies. Decreasing this value is crucial for social stability. Access to a minimum living allowance or social relief is a basic right of citizens. In modern society, especially during socioeconomic transformation, the causes of poverty are generally more attributable to social than personal factors. Therefore, social relief is a compelling social obligation for countries and societies. Today, social relief is often considered a pure government act, and the most fundamental re-distribution or payment transfer system completely operated by the government. This responsibility is usually confirmed by legislation on minimum living security. Social relief for every citizen is a basic right protected by law, but it only provides capital or materials to meet minimum living needs, and intends to strike a balance between equality and efficiency. Reflecting the humanitarian spirit, it does not address the causes of poverty or help the truly poverty-stricken population, but rather is only intended to provide the recipients with a living standard equal to or slightly higher than the minimum to prevent dependence or unearned profit. (Data source: Changsha Statistical Yearbook)

(10) Coverage rate of government-subsidized housing (%)

Coverage of government-subsidized housing is the ratio of households enjoying government-subsidized housing to permanently registered urban households. Government-subsidized housing refers to social security housing provided for low and medium-income families by the government, specifying the applicants, construction standards and sale price or rent standards. Low-rent housing, affordable housing, policy-based rentals, targeted resettlements, and government-subsidized housing has improved the living conditions of low-income urban residents, promoting social stability. It is calculated as follows:

Coverage rate of government-subsidized housing = (households enjoying government-subsidized housing to permanently registered urban households) x100% (Data source: Changsha Housing Security Service Bureau)

(11) Housing price-to-income ratio

Housing price-to-income ratio is the ratio of housing prices to annual household income of urban residents, roughly depicting the relationship between household income and housings price in a city. It is the most comprehensive indicator relating to housing markets and affordability. The indicator can be used to measure consumers' actual purchasing power towards property.

It also measures the degree to with commodity housing prices stray from their real value, and predicts their future trends. According to the World Bank, the ratio generally ranges from 1.8 to 5.5 in developed countries, and 3 to 6 is healthy in developing countries. The greater the value, the lower households' ability to pay for housing. The ratio is calculated as follows:

Housing price-to-income ratio = (unit area price of housing available for sale × urban housing floor area *per capita*) / average annual household income (Data source: Changsha Statistical Yearbook, China Index Academy)

4.8.2 Economic Resilience

(1) *Per capita* GDP

Per capita GDP is the ratio of GDP to the permanently registered population of an area. Often used in development economics to measure development, it is an important macroeconomic indicator. It reflects economic development and productivity in cities, and is an effective tool to understand the macroeconomic conditions of a country or region. It is calculated as follows:

Per capita GDP = GDP/Average Population. (Data source: Changsha Statistical Yearbook)

(2) Engel coefficient (%)

Engel's coefficient refers to households' ratio of food expenditure to total expenditure. Looking at changes in consumption structure based on statistical data, the German statistician Engel proposed that the lower a household's income is, the more of its income or expenditure is spent on food; food expenditures decrease in related to household income or expenditure with the growth of the latter. Engel's coefficient measure household affluence levels, and is often used internationally to evaluate living standards in a country or a region. The poorer the population, the greater the coefficient, and vice versa. Engel's coefficient is calculated as follows:

Engel's coefficient = (food expenditure *per capita*/total expenditures *per capita*) x 100% (Data source: Changsha Statistical Yearbook)

(3) *Per capita* disposable income of urban residents (RMB)

The *per capita* disposable income of urban residents is the ratio of total household income after deducting individual income taxes, social security fees paid by individuals and bookkeeping subsidies for survey costs. Total household income refers to the sum of income from wages and salaries, net business income, income from property, and income from transfer from all family members living in the household during the investigation period, excluding income from sale of property and debt. *Per capita* disposable income of urban residents has long been taken as an important indicator, reflecting the income level of residents – a foundation of understanding lifestyle changes, an important basis for all levels of government to formulate labor employment and social security policies, and a crucial basis for calculations of national income distribution and national economic accounting. As income can be used for consumption, investment, purchase of stocks and funds for savings it reflects residents' and households' spending power; the faster it grows, the higher the spending power of residents. Meanwhile, it reflects changes in living standards: if it grows faster than commodity prices, it indicates that living standards have increased, and vice versa. The indicator is calculated as follows:

Per capita disposable income of urban residents = (total household income - individual income taxes - social security fees paid by individuals - bookkeeping subsidies) / total family members (Data source: Changsha Statistical Yearbook)

(4) Registered urban unemployment (%)

The rate of registered urban unemployment is the ratio of registered urban unemployed to the sum of that plus urban jobholders. The rate reflects overall economic conditions, and is the most sensitive monthly economic indicator in the market. Generally, a decrease in unemployment indicates sound overall economic development, and helps with currency appreciation. Increasing unemployment reveals economic slowdown and currency depreciation. Its formula is as follows:

Registered urban unemployment = registered urban unemployed / (urban jobholders + registered urban unemployed) x100% (Data source: Changsha Statistical Yearbook)

(5) Local fiscal revenue to GDP (%)

The ratio of local fiscal revenue to GDP reflects the monetary revenue of government departments. Fiscal revenue is an important indicator to measure the government's financial strength. The scope and quantity of public supplies and services provided by the government in social and economic activities depends to a large extent on the adequacy of fiscal revenue. The ratio is a comprehensive indicator reflecting the financial concentration of a state or a region. Given a uniform national taxation system, it is also a crucial parameter revealing the performance and structural quality of a regional economy. Regions may have a varying degree of economic structural optimization and vary in economic quality due to differences in tax payment capacities between industries, which can manifest in the fiscal revenue to GDP ratio. The formula to calculate local fiscal revenue to GDP is as follows:

Local fiscal revenue to GDP = local government revenue / GDP x 100% (Data source: Changsha Statistical Yearbook)

(6) Ratio of value added by the tertiary sector to GDP (%)

The value added by the tertiary sector is the growth in value of the service industry within a period (generally a year), in comparison to the previous settlement cycle. Generally speaking, the ratio grows with economic development. If a region's ratio consistently grows faster than its industrial growth, it means that the local economy is transforming from a previously industrial economy to a service-driven economy, which will affect economic growth, employment and every aspect of the region, improving employment resilience and income distribution. The development of tertiary sector is a result of scientific and technological progress and productivity improvement. Today, the development of the tertiary sector has become one of the important signs of regional productivity. The ratio is a key indicator measuring cities' economic development, and the national economy and comprehensive strength. It is calculated as follows:

Ratio of value added by the tertiary sector to GDP = (value added by the tertiary sector/GDP) x 100% (Data source: Changsha Statistical Report)

(7) Ratio of value added by the high-tech sector to industrial value added (%)

The ratio of value added by the high-tech industry to industrial value added refers to value added by industrial enterprises above the designated size. The high-tech industry is a collective term for businesses engaged in research, development, production or technical services for one or multiple technologies or products, a knowledge- and technology-intensive sector. Value added by the high-tech industry refers to the final output in monetary terms from industrial production of all units designated as high-tech companies above designated size within the reporting period. It is the balance of total final output from all productive activities minus the material costs and labor services consumed or transferred during production. Transformation of traditional and basic industries through the high-tech industry can improve industrial structure, labor productivity and resource consumption. The formula of this indicator is illustrated below:

Ratio of value added by the high-tech industry to industrial value added = (value added by the high-tech industry/industrial value added) x 100% (Data source: Changsha Statistical Report)

(8) Ratio of expenditure on R&D to fiscal expenditure (%)

The ratio of expenditure on R&D to fiscal expenditure compares government expenditure on R&D and public education to total fiscal expenditures. Scientific research and experimental development are systematic and creative activities to increase knowledge (including cultural and social) and create new applications based on these findings. These activities can be divided into fundamental and applied research and experimental development. Expenditure on science and technology activities is the sum of spending of manpower, property, materials, time and information resources during R&D, excluding investment in commercialization. As science and technology are the primary productive forces, most countries attach great importance to R&D investment. The ratio of R&D expenditure to GDP reflect a country or region's scientific and technological level and independent innovation capacity. The formula for this indicator is as follows:

Ratio of expenditure on R&D to fiscal expenditure = (expenditure on R&D + expenditure on public education)/government fiscal expenditures x 100% (Data source: Changsha Statistical Yearbook)

(9) Number of valid invention patents per 10,000 population (1/10,000)

The number of valid invention patents per 10,000 population is the number of invention patents within the validity period granted by domestic and international IP administrations held per 10,000 urban residents. This is an internationally accepted indicator mainly reflecting the independent innovation capacity, quality of scientific research output and level of market application of a country or a region. As a kind of intangible IP, patents can be transformed into real wealth through industrial production and manufacturing. (Data source: Changsha Statistical Report)

4.8.3 Urban Infrastructure and Services

(1) Urban air quality compliance rate (%)

The urban air quality compliance rate is the ratio of days with an air pollution index less than 100 to the number days in the year. The air pollution index (API) is the daily environmental air pollution index at specified points in the urban built-up area, a method used to reflect and evaluate air quality. The concentrations of several air pollutants under regular monitoring are simplified into a simplex conceptual numerical form, and air quality conditions and pollution level are manifested in grades. This simple and intuitive result is easy to use and apply to cities' air quality conditions and variation within a short period of time. Superior air quality means an API less than 50, equivalent to the national level one air quality standard, and compliant with the air quality requirements of natural reserves, tourist attractions and other areas under special protection. Fine air quality means an API between 50 and 100, equivalent to the national level two air quality standard, and compliant with the air quality requirements of residential zones, commercial districts, cultural districts, general industrial zones and rural areas. Air quality relates directly to energy consumption, environmental policies, urban density, traffic volume and industrial density. The formula for urban air quality compliance rate is shown below:

Urban air quality compliance rate = (days with air pollution index less than 100/365) x 100% (Data source: Changsha Environment Protection Agency)

(2) Water quality compliance rate in functional areas of urban water environment (%)

The water quality compliance rate in functional areas of urban water environment measures the rate of conformance of surface water within the city jurisdiction to the corresponding requirements of functional water bodies, and of cross-boundary water bodies within the city to national or provincial assessment targets. Enterprises directly emitting pollutants to the ocean refers to enterprises directly emitting pollutants to the ocean through pipelines, ditches and facilities. The assessment methods their for emission compliance are the same as those for key industrial enterprises. (Data source: Changsha Environment Protection Agency)

(3) Multipurpose utilization rate of industrial solid wastes (%)

The multipurpose utilization rate of industrial solid wastes is the proportion of industrial solid wastes comprehensively utilized to the wastes generated. Industrial solid wastes refer to solid wastes generated from industrial production activities. The re-utilization of industrial solid wastes refers to their recycling, treatment and re-use, recycling materials and energy from solid wastes through management and technological measures (physical, chemical and biological), accelerating the material and energy cycle and creating economic value. Multipurpose utilization of industrial solid wastes reduces production costs and energy consumption, and increases production efficiency and environmental benefits. This indicator reflects urban production efficiency and environmental protection level, and is calculated as follows:

Multipurpose utilization rate of industrial solid wastes = (quantity of industrial solid wastes comprehensively utilized/quantity of industrial solid wastes generated) x 100% (Data source: Changsha Statistical Yearbook)

(4) *Per capita* parks and green space (m^2/population)

Per capita parks and green space is the ratio of parks and green space to population in a city. Parks and green space are urban green spaces opened to the public, primarily designed for recreation, equipped with certain recreational and service facilities, and capable of ecological improvement, landscape beautification, and disaster prevention and reduction. They make up an integral part of urban construction land, the urban green space system and municipal infrastructure. *Per capita* urban parks and green space measures the open green space accessible to the urban population, reflecting the overall environment and quality of life for residents. It is calculated as follows:

Per capita parks and green space = urban green space/urban population (Data source: Changsha Statistical Yearbook)

(5) Water consumption per RMB 10,000 GDP (m^3/RMB 10,000)

Water consumption is the sum of water withdrawal and reuse. If the latter is not included, it equals the former. This indicator reflects the consumption of water resources, efforts in water conservation and consumption reduction, and utilization efficiency, revealing the utilization of water resources in economic activity, and reflecting changes in economic structure and utilization efficiency. It is calculated as follows:

Water consumption per RMB 10,000 GDP = total water consumption/regional GDP (Data source: Changsha Water Resource Report)

(6) Energy consumption per RMB 10,000 GDP (TCE/RMB 10,000)

Energy consumption per RMB 10,000 GDP refers to the energy consumed to produce one unit of GDP of a country or Gross Regional Product (GRP) of a region. Total energy consumption is the sum of all energy resources consumed by sectors involved in material and non-material production and consumption within a certain period of time. It is an aggregate indicator reflecting energy consumption, composition and growth. The indicator reflects the consumption of energy resources and efforts in energy conservation and consumption reduction, showing the utilization of energy resources among economic activities within a country or a region, as well as changes in the economic structure and utilization efficiency of energy resources. It is calculated as follows:

Energy consumption per RMB 10,000 GDP = total energy consumption/GDP (Data source: Changsha Bureau of Energy)

(7) Density of public transport network (km/km^2)

The density of public transport networks is the ratio of total length of public road centerlines to the urban built-up area, reflecting how near residents are to bus routes. It is an important indicator to assess the service level of public transportation. In line with the transportation development strategy of "public transportation first," increasing the density makes public transportation more appealing to citizens. It plays a significant role in easing urban traffic congestion, facilitating energy conservation and emission reduction and boosting sustainable development. The formula for calculating the density of the public transport network is shown below:

Density of public transport network = total length of public road centerlines/built-up area (Data source: Changsha Statistical Yearbook)

(8) Urban gas penetration rate (%)

The urban gas penetration rate is the ratio of urban residents using natural gas to the urban population. Natural gas is a quality fuel and ideal urban gas source. Economical and easy to extract, store and use, it is widely used around the world. Gas is an integral part of urban infrastructure, and its development plays an extremely important role in urbanization. Thanks to its economic efficiency and environmental advantage as clean energy, with the diversification of China's natural gas sources and improvement of urban gas pipeline facilities, natural gas has increasingly dominated urban gas. The penetration rate measures the share of urban population using natural gas, which relates to urban energy structure and formulation of environmental policies. Its computational formula is as follows:

Urban gas penetration rate = (number of urban residents using natural gas/urban population) x 100% (Data source: Changsha Statistical Yearbook)

(9) Internet penetration rate (%)

The internet penetration rate is the ratio of households with internet access to population. It reflects the proportion of frequent internet users within a country or a region. Internationally, it is often used to measure how connected a country or a region is to the external world, and its degree of informatization. It is calculated as follows:

Internet penetration rate = (urban households with internet access/urban population) (Data source: Changsha Statistical Yearbook)

4.8.4 Urban Governance

(1) Public participation

In a narrow sense, public participation means participation in elections in representative politics to elect representative institutions and personnel, an important indicator of modern democratic politics and a significant responsibility of modern citizens. In a broader sense, it refers to the participation of all those concerned with public interests and management of public affairs in decision-making, as well as citizens' political participation. In terms of specific activities, it refers to general public participation to promote social decision-making and activity implementation.

Public participation is a continuous two-way exchange of views to enhance public understanding of practices and processes by government institutions to investigate and solve problems. The government should promptly and completely disclose information and meaning about projects, plans, planning or policy formulation, and evaluation events to the public and actively solicit public opinions on these events. Public participation is a planned action which allows citizens to participate in the decision-making process, preventing conflicts between citizens and the government, or among citizens, via two-way exchange between the government and activity developers, and citizens. (Data source: political participation of democracy index, *The Economist*)

(2) Membership in private social groups (persons)

Social groups are organizations established for certain purposes, common activity collectives established in accordance with certain tenets, institutions and systems to effectively realize specific goals. With the sophistication of social development and urban governance, the government increasingly needs to assign more social affairs to public groups and social organizations, especially social management and public service affairs. This is also a way to guarantee people's freedom and rights. (Data source: Changsha Statistical Yearbook)

(3) Presence of emergency command information platforms

Emergency command information platforms are the primary means to enhance capabilities of disaster warning, post-disaster emergency rescue and public emergency response. On January 1, 2012, the Changsha Emergency Command Center was completed and put into operation. Building on the foundation of the basic 110 Command Center, the Center is composed of intensive report receipt and handling, intelligent command and dispatch, emergency integration, and field visual video application systems, greatly enhancing emergency response capacity. (Data source: http://news.cnr.cn/gnxw/201201/t20120107_509027855.shtml)

Chapter V Empirical Study and Analysis—A Comprehensive Assessment of Changsha as a Resilient City

From metaphor to measurement: Resilience of what to what?

—Carpenter, 2001

5.1 Urban Development Overview

5.1.1 Urbanization

Changsha, capital of Hunan Province, has a total area of 11,800 square kilometers and population of 7,645,200. It is the political, economic, cultural and transport center of Hunan, and the core city of the Changsha-Zhuzhou-Xiangtan economic agglomeration. Just as in China as a whole, Changsha's urbanization has gone through four stages. The first stage was the period between founding of the PRC and reform and opening (1949-1977). Industrialization or urbanization charted a complex course in light of political factors. In 1949, Changsha had an urbanization rate of 12.4%. Three decades later, in 1977, the rate only rose to 19%, generating an annual urbanization rate of 0.24%. The second stage from the reform and opening in 1978 until the end of 2001. During that period, Changsha's urbanization rate jumped from 20.7% to 44.7%, an annual rate of 1.04%. The third stage was the decade of rapid development from 2002-2012. Urbanization grew from 46.2% to 69.4%, an annual rate of 2.32%. The fourth stage began in 2013. Urbanization increased from 70.6% to 75.9% in 2016, an annual rate of 1.8%. Urbanization has entered a stage of steady growth (Table 5-1). In 2016, Changsha had an urban population of 5,809,600, a net increase of 1,877,000 from 2007, with annual average growth of 187,000. The city's urbanization rose by 15.7% from 2007, making it 18.5% higher than the national average and 23.1% higher than the provincial average.

Year	1949	1977	1978	2001	2002	2003	2004
Urbanization (%)	12.4	19.0	20.7	44.7	46.2	49.2	51.2

YoY Growth (%)	—	6.6	1.7	24.0	1.5	3.0	2.0
Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Urbanization (%)	53.9	56.5	60.2	61.3	62.6	67.7	68.5
YoY Growth (%)	2.7	2.6	3.7	1.1	1.3	5.1	0.8
Year	**2012**	**2013**	**2014**	**2015**	**2016**		
Urbanization (%)	69.4	70.6	72.3	74.4	75.9		
YoY Growth (%)	0.9	1.2	1.7	2.1	1.5		

Table 5-1: Changsha's Urbanization Development

***Data source:** Organized by the author on the basis of Changsha Statistical Reports on National Economy and Social Development; "--" indicates no data available*

5.1.2 Economic Performance

Changsha ranked 12th in terms of GDP of Chinese provincial capitals in 2007, with a gap of RMB 10.1 billion with Changchun, in 11th place. In 2016, it crossed the RMB 500 billion mark, ranking 6th among the 27 provincial capitals, surpassing Zhengzhou, Changchun, Shijiazhuang and Harbin. Rapid industrial development played a crucial role in this ranking jump.

In 2016, Changsha realized a GDP of RMB 932.37 billion (Figure 5-1), resulting in a year-on-year growth of 9.4%, and giving it a 6th place ranking among provincial capitals. The top three places were Guangzhou, at RMB 1,961.094 billion, Chengdu, at RMB 1,217.023 billion, and Wuhan at RMB 1,191.261 billion. Nanjing, in fifth place, exceeded Changsha by RMB 117.932 billion. The gap between Changsha and cities like Wuhan and Chengdu is primarily attributable to the sluggish tertiary sector.

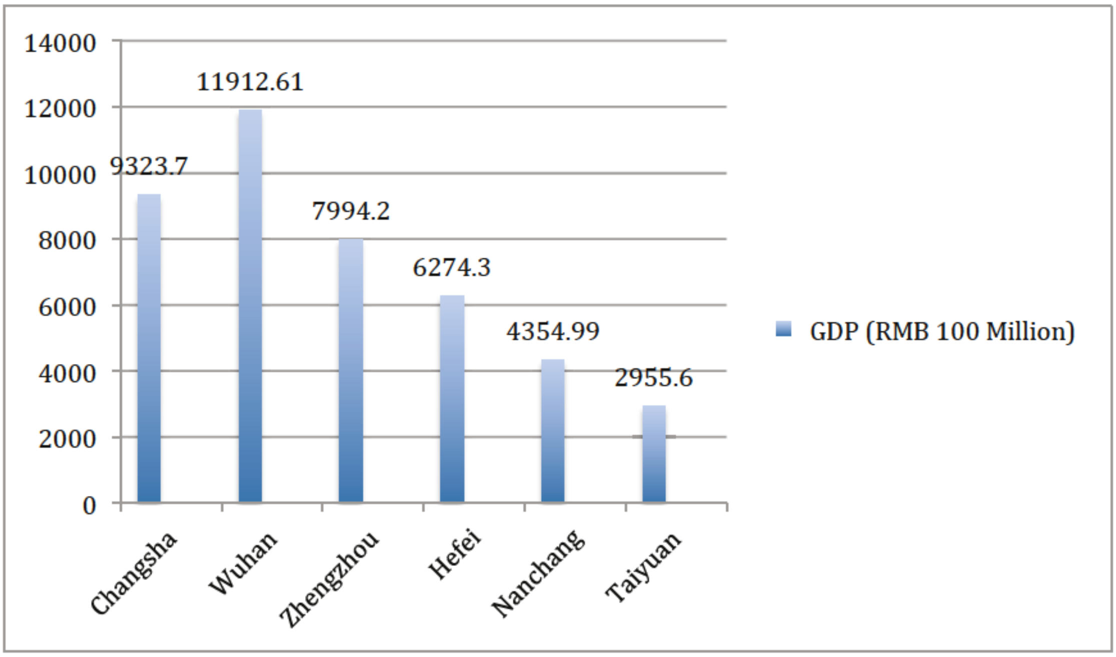


Figure 5-1: A Comparison of GDP of Provincial Capitals in Central China in 2017

Data source: Compiled by the author on the basis of 2017 Statistical Report on National Economy and Social Development of Cities

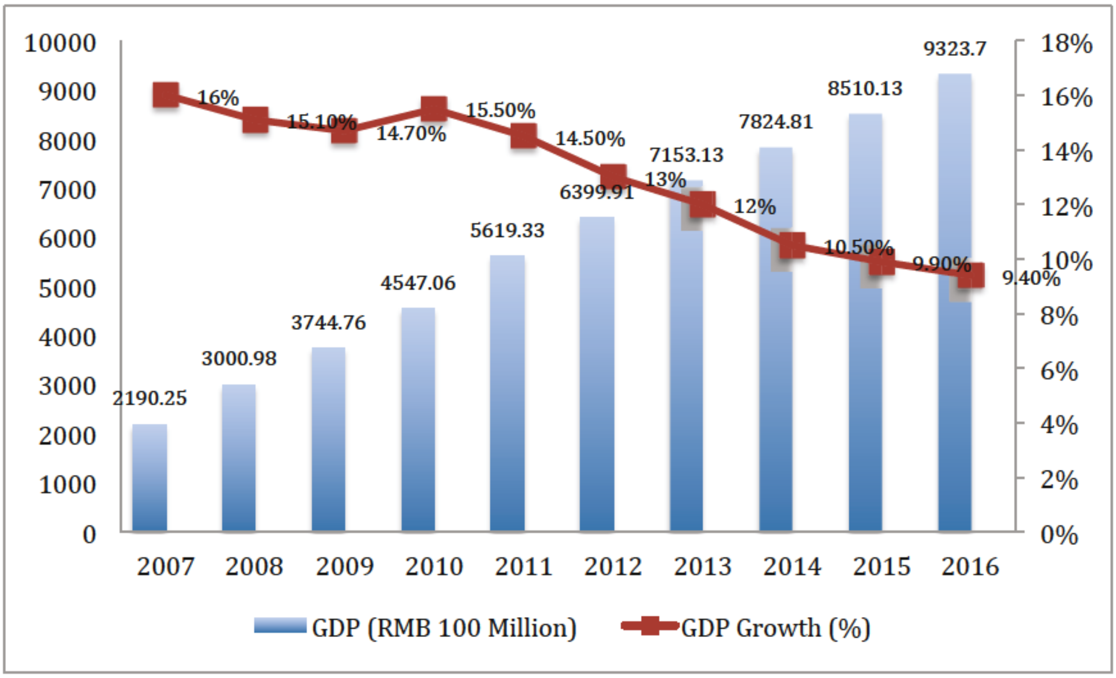


Figure 5-2: Changsha GDP and its Growth Rate from 2007 to 2016

Data source: Compiled by the author on the basis of Statistical Reports on National Economy and Social

Development of Cities

Since the implementation of the reform and opening, Changsha's industrial structure has changed greatly. In 1978, it only had a GDP of only RMB 1.68 billion, featuring a structure of secondary sector first, followed by the primary and tertiary sectors. In 2016, its GDP jumped to RMB 932.37 billion, and the sector structure was changed to secondary, tertiary, then primary sectors, with the ratios of 4.0:48.2:47.8 respectively, with qualitative changes in the economic aggregate and its composition (Figure 5-3). Among the three sectors, primary sector only accounted for 4% of GDP, contributing little to GDP and its growth. The secondary sector grew slower than the tertiary sector, contributing less to GDP and its growth. The tertiary sector dominated and become the major force driving economic growth. In recent years, the ratio of Changsha's tertiary sector to GDP has increased, but it remains lower than the national and provincial capital average, and shows a huge gap from developed cities. In 2016, the ratio of Changsha's tertiary sector to GDP was 47.8%, ranking 21st among the 27 capitals, 8.3% lower than the provincial capital average and 3.8% lower than the national average. In comparison with the provincial capitals, the economic aggregate gap between Changsha and cities like Guangzhou, Wuhan, Chengdu, Nanjing and Hangzhou primarily reflects differences in the tertiary sector (Table 5-2). In 2016, Changsha achieved RMB 447.268 billion of value added in the tertiary sector, RMB 166.063 billion less than in Nanjing, RMB 182.226 billion less than in Wuhan, RMB 229.558 billion less than in Hangzhou, RMB 199.059 billion less than in Chengdu, and a full RMB 897.235 billion less than Guangzhou. The development of Changsha's tertiary sector mainly depends on the growth of traditional service industries. It lacks high-end service industries like finance, insurance and IT, or support of pillar industries.

City	**Tertiary Industry**			
	GDP (RMB 100 Millions)	**Economic Aggregate (RMB 100 Millions)**	**Ratio (%)**	**Ratio Ranking**

Guangzhou	19610.9	13445.0	68.6	3
Chengdu	12170.2	6463.3	53.1	15
Wuhan	11912.6	6294.9	52.8	16
Hangzhou	11050.5	6768.3	61.2	7
Nanjing	10503.0	6133.3	58.4	10
Changsha	9323.7	4472.7	47.8	21

Table 5-2: Tertiary Industry and Its Ratio to Economic Aggregate in Selected Provincial Capitals in 2017

Data source: Compiled by the author on the basis of 2016 Statistical Report on National Economy and Social Development of Cities

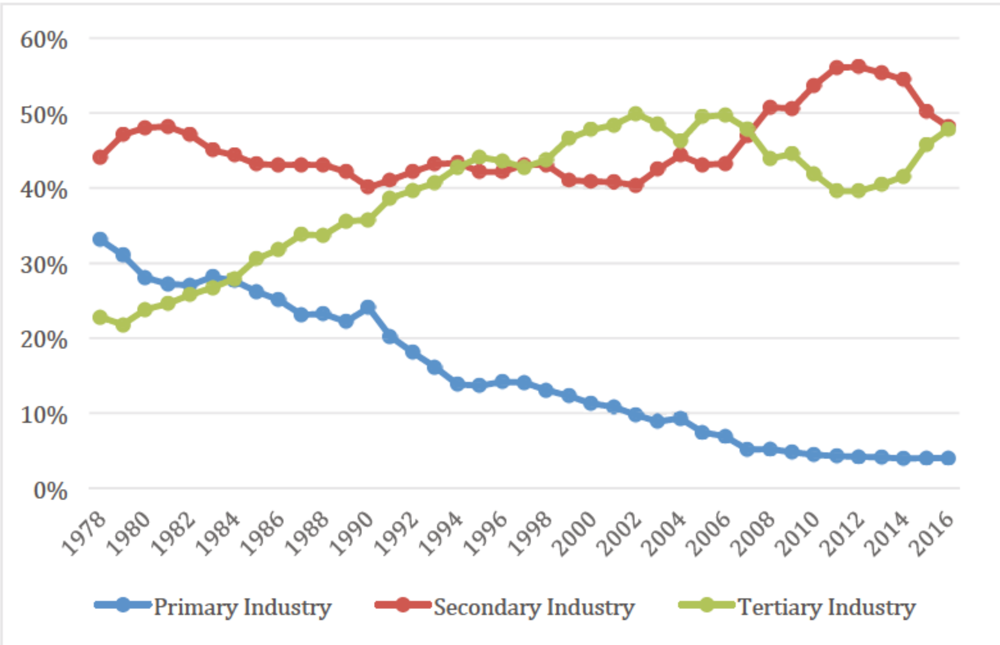


Figure 5-3: Changsha's Economic Structure from 1978 to 2016

Data source: Compiled by the author on the basis of Statistical Reports on National Economy and Social Development of Cities

5.1.3 Resources and Environment

The densely distributed waterways of Changsha give the city abundant water resources, a strength unmatched by many areas. The rainfall is abundant but unevenly distributed spatially and temporally. April to July makes up 50% of the annual rainfall, resulting in frequent droughts and floods. In 2016, with the strong El Nino, Changsha was hit by the biggest flood since 1999, with local rainfall hitting a 200-year record high. The waterline of Xiangjiang River in Changsha Station reached only 0.08 meters under the warning level. Furthermore, Changsha boasts massive underground water reserves, but a small portion are accessible and exploitable. In 2016, Changsha's *per capita* water resources stood at 1,822 m^3 and *per capita* water consumption of 479 m^3; 39 m^3 of water was consumed per RMB 10,000 GDP, and 33 m^3 per RMB 10,000 industrial value added. Development and utilization of water resources was quite low, at only 38.1%. With Changsha's rapid economic and social development, problems like water shortages, severe water pollution and deteriorating water environment have become increasingly prominent bottlenecks limiting the sustainable socioeconomic development of the city.

With respect to energy consumption, Changsha is a typical energy importer, as local energy output is far from meeting demand for production and living. All refined oil products are imported from other places; natural gas is supplied by the "West-East" Natural Gas Transmission Project; coal and power shortages are indisputable; and with the utilization of solar, wind, biomass and geothermal energy still at a preliminary stage, 81% of the city's energy is imported. The acceleration of urbanization and industrialization, especially with an industrial structure centered on heavy industry, has resulted in relatively fast energy consumption growth. Industry takes up the largest share in total energy used by society. Now at an important crossroads of industrialization and urbanization, Changsha development still demands large amounts of energy and is expected to maintain growth momentum in the future.

5.2 The Necessity of Building Changsha into a Resilient City

In the past decade, Changsha's urbanization rate rose from 60.2% in 2007 to 75.9%, with an annual average economic growth rate leading China's provincial capitals. However, such development comes at the opportunity cost of "overdrawing" from people's quality of life and future development drive, which gradually manifests in the form of "urban disease" (Hao, 2014) in society, economy, environment and politics in the background of a complex, ever-changing global environment.

5.2.1 Unreasonable Land Use and Intensifying Social Polarization

From the perspective of land use, urbanization manifests as urban land occupation and its growth. Changsha's built-up area increased from 157 square kilometers in 2007 to 364 square kilometers in 2016, a net increase of 207 square kilometers in just 10 years. Arable land in the urban outskirts and rural areas has given way to rural enterprises, residential buildings, expressways, development zones, and other key infrastructure projects. Meanwhile, land utilization in the city center has been continuously intensifying with spatial and functional adjustment, upgrading of regional industries, construction of infrastructure, and development of commercial residences. Unreasonable or incoherent utilization of urban land during the process of urbanization will bring about a range of social problems – for instance urban residence inequality. A number of urban poor must live in low-rent houses and shanty towns; the low coverage rate of government-subsidized housing and incomplete construction, allocation, assessment, pricing and supervision systems have provided no total solution to this problem. There is also the phenomenon of disparities in residential space, in which disadvantaged groups live in marginalized areas, residential space in the city problem becomes polarized, and "urban villages" and "rich communities" coexist. Low-income social groups thus quickly develop a sense of "deprivation."

In 2016, Changsha's registered urban unemployment rate was 2.74%, lower than the national average of 4.02%. Although its employment problem is currently less prominent than in other cities, it does exist. For instance, the employment structure of primary, secondary and tertiary sectors is misallocated. Changsha's employment structure of 21.5: 34.2: 44.3 in the primary, secondary and tertiary sectors respectively in 2016 is far from those of developed countries, where the tertiary sector makes up two thirds of total employment. The unemployment insurance and social relief systems are not well designed. Misallocated employment is a root cause for urban poverty.[100] According to data from the Changsha Municipal Bureau of Statistics, 143,100 urban residents in Changsha received a basic living allowance of RMB 550/month in 2016, forming a new urban social class – the urban poor. As pointed out by the economist Lewis, the change in income distribution is the most politically significant aspect of the development process, and the aspect most susceptible to jealousy, social instability and turmoil (Arthur, 1989). Due to a widening gap between the rich and the poor, and poorly-designed living, medical service and employment systems and other basic social security systems, deprivation of the urban poor and unmet employment demand is a risk factor for various crimes.

5.2.2 Misallocated Economic Structure and Low Energy Utilization

Changsha is primarily characterized by unhealthy economic development at the cost of high resource consumption. The city has higher energy consumption and lower utilization efficiency than other developed cities in China. In 2016, the comprehensive energy consumption of its six high-consumption industries –petroleum refining, chemical engineering, non-metallic mineral product manufacturing, ferrous metal smelting, non-ferrous metal smelting, and power generation – accounted for 61.5% of total energy consumption of industrial enterprises above the designated size. However, these six industries only contributed to about 30% of the value added by all industries, which speaks volumes about the low production efficiency of these high energy consumption enterprises, adding industrial value only through extensive energy consumption. As shown in Table 5-3, coal, gasoline and power are the major types of energy consumed by Changsha. In terms of energy end use, coal has dropped from 51.18% in 2005 to 37.97% in 2010; use of higher-quality energy sources such as power, natural gas and gasoline has continued to increase accordingly. Thus, coal remains the primary energy source of Changsha, while certain coal resources have been replaced by power and petroleum resources. The use of natural gas and other clean fuels is still low.

Year	Coal	Power	Gasoline	Natural Gas
2005	51.18%	28.17%	17.38%	3.27%
2010	37.97%	35.31%	24.67%	2.05%

Table 5-3: The Makeup of Changsha's Energy End Use in Coal, Power, Gasoline and Natural Gas in 2005 and 2010

Data source: Organized by the author on the basis of Changsha Statistical Yearbooks

Figure 5-3 shows that the primary sector has been shrinking in the economy, while secondary sector has been steadily growing and the tertiary sector has been growing since 2012. In 2016, the tertiary sector of Changsha contributed more to GDP than the secondary sector, but showed a huge gap from developed countries and the final goal of economic and industrial structure development. The primary driving force should be services. The combined action of misallocated economic and industrial structure and low energy utilization has restricted economic development and progress. A structural economic slowdown has become an important issue faced by the government and society, and a crucial factor limiting urban development.

5.2.3 A Deteriorating Pollution Situation Inhibiting Urbanization

Urban economic growth has fallen under the so-called "resource curse," and overuse of local resources has resulted in severe environmental degradation of the city and its surroundings. General water pollution and waste and annually increasing waste water discharge have put increasing pressure on the environment. In 2016, Changsha set up 30 water quality monitoring sections in four rivers with a total length of 688.8 km. The middle and lower reaches were found to have severe water pollution based on indicators of major pollutants including ammonia nitrogen and total phosphorus. With respect to discharge of main pollutants of industrial wastewater, industrial wastewater discharge and COD discharge stood at 5,102 and 16,257 tons respectively in 2015, with growth of 26% and 9.2% respectively from 2011. The year-on-year growth of discharge has exerted a substantial impact on the ecology of Xiangjiang basin. Despite the abundant water resources, man-made pollution and waste during the urbanization process has presented Changsha with challenges such as severe water shortages and quality problems, seasonal shortages, and engineering water shortages.

Accumulating pollution of solid wastes by year has further jeopardized the environment. Since the acceleration of its urbanization, Changsha's industrial solid wastes have grown rapidly. In 2016, it generated 1.226 million tons of industrial solid waste, increasing by 19.8% from the last year; the waste was primarily composed of other wastes (about 546,000 tons), coal ash (301,000 tons) and slag (147,000 tons), mainly from thermal power generation, which made up 44% of industrial waste. The continuous growth of urban population has rapidly increased household wastes. In 2016, Changsha's urban areas disposed 2.189 million tons of household wastes in sanitary landfills, an increase of 159,000 tons from 2015 with year-on-year growth of 7.82%. Industrial and urban household wastes not only take up extensive urban land resources and pollute the water, atmosphere, soil and corps, but have also affected urban-rural environmental sanitation and the appearance of the city. They have grown into a bottleneck hindering urban-rural socioeconomic development, affecting quality of life and limiting Changsha's ecological and sustainable development.

As the core of the Changsha-Zhuzhou-Xiangtan megacity, Changsha has made enormous economic progress, and at the same time polluted its atmosphere and suffered from severe waste gas pollution. In 2016, it had 267 days of fine air quality, a fine air quality rate of 73.0%, including 75 days of superior air quality and 192 days of fine quality. The major pollutant indexes were PM2.5 and PM 10. In comparison to last year, there were 9 more days of fine air quality, a growth rate of 2.3%; there were 11 fewer days of heavy pollution, and no days above heavy pollution. From 2013 to 2016, the rate of fine urban air quality gradually rose, there were more days of fine air quality, days of above heavy pollution were effectively controlled, and the concentrations of PM10 and PM2.5 gradually decreased. The PM2.5 sources show that motor vehicle exhaust and pollution from industrial production and construction are the major causes of haze. As of the end of 2016, 2.2 million motor vehicles were registered in Changsha, 92.7% more than at the end of 2011. As the number of vehicles has almost doubled, pollution from exhaust will have a more prominent impact on air quality. The atmospheric is important for human survival. As industry develops and urbanization accelerates, atmospheric pollution will develop into a more prominent problem. Air pollution will not only result in major loss of resources, but also limit further economic and social development.

5.2.4 Worsening Government Credit and Increasingly Direct Urban Governance

During the current process of urbanization, featuring unbalanced economic structure and land utilization, the central government's public investment has shown a phenomenon of high growth and low efficiency. The local government's long-term dependence on land-derived fiscal revenue and unfair wealth distribution among social groups caused by the housing market has aggravated the internal conflict between social equality and growth. Ultimately, the public credit of the government organs accumulated during rapid economic growth will start to face the potential threat of a slowdown (Yang, 2012).

The main current decision-making systems of Chinese cities can be divided into two categories: official and unofficial. Under each category there are two forms: top-down and bottom-up. The first tier of government, the second tier of urban planning authorities and the third tier of citizen participation are involved in official decision making. Thus far, China has implemented a three-level management system of city, district and sub-district, involve the government, planning authorities and citizens in urban management activities. In reality, however, the current system is still led by the government under the habitual influence of old management model. Although public hearings and expert inquiries have been put in place, their right to speech can't be guaranteed. The directness of urban governance remains a problem, which will result in less efficient urban management and serious resource waste.

To summarize, Changsha is now at a challenging stage of urban development and is exposed to emerging uncertainties and unpredictable events. Therefore, urban planners and administrators face a need for a new perspective to think afresh about urban development changes and deepen their understanding of planning and administration.

5.3 A Comprehensive Assessment of Changsha's Urban Resilience from 2007-2016

5.3.1 Assessment Process

5.3.1.1 Urban Scope

The scope of assessment is the city proper of Changsha, composed of six districts: Furong, Tianxin, Yuelu, Kaifu, Yuhua and Wangcheng. An indicator database has been built using materials such as Changsha Statistical Reports[7] and Changsha Statistical Yearbooks[8] from 2007-2018. See Appendix III for the initial data.

5.3.1.2 Indicator Weights

The rationality of indicator weights will directly impact the overall accuracy of the assessment. As the resilient city system assessment is a multi-goal decision-making problem, the weight of respective indicators should reflect their importance to city resilience. The Analytic Hierarchy Process (AHP) is hereby used to scientifically determine the weight of the indicators, and subsequently rationally assess urban resilience and its trends. As a scientific system engineering decision making method, the AHP can assess and compare qualitative and quantitative factors on the same scale. The main idea is to decompose a complex problem into component factors and establish a hierarchical model based on their hierarchical relationships. The relative importance of factors on each level is determined after comparison in pairs, then a judgment matrix is built to calculate the weight of each indicator. The specific steps are as follows:

[7] The *Changsha Statistical Report* is a report on economic and social development conditions released by the Changsha Municipal Bureau of Statistics.

[8] The *Changsha Statistical Yearbook* is a comprehensive yearbook fully reflecting the economic and social development conditions of Changsha, including a large amount of statistical data about the economic and social development of the whole city, respective districts, and counties, as well as over time. The *Yearbook* is a crucial reference for multiple disciplines to gain a comprehensive and in-depth understanding of Changsha.

(1) Building a hierarchical structure and allocating the indicators

Based on the questionnaire results (Appendix I), a three-level hierarchical structure composed of "dimension, indicator, and sub-index" is built using the relationships and categorization of the indicators selected using AHP. The first level is the dimension level A, including society, economy, urban infrastructure and services, and urban governance; the second level is the 11 second grade indicators for the indicator level B, including education, health and social security; the third level is the 32 indicators for the sub-index level C. See Table 4-15 for the resilient city assessment indicator system established by this paper.

(2) Indicator Standardization

While certain indicators are positive indicators, where higher values are better, others are negative, where the opposite is true. Others have different dimensions and units. To eliminate the consequent incompatibility of the indicators, therefore, negative and dimensional indicators must be standardized before comprehensive assessment. Standardization ensures that all indicators point in the same direction and removes indicators with excessive magnitude differences so that indicators on the same level can be compared. Data on the indicators in the factor level from 2007 and 2016 were collected. A few missing values were filled in using the average of the previous and following years. The six negative indicators -number of minimum living allowance recipients, housing price-income ratio, Engel's coefficient, registered urban unemployment rate, water consumption per RMB 10,000 GDP, and energy consumption per RMB 10,000 GDP – were standardized using the following formula:

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}$$

Then all indicators were normalized to the value range from 0 to 1 using the following formula to prevent impact on final assessment results due to excessive dimensional differences:

$$y_{ij} = \frac{x_{ij} - \min_{l \le i \le n}\{x_{ij}\}}{\max_{l \le i \le n}\{x_{ij}\} - \min_{l \le i \le n}\{x_{ij}\}}$$

Wherein, X_{ij} is the initial data of evaluation indicator and Y_{ij} is the standardized data. By filling in missing value, standardizing negative indicators and normalizing the data, the initial indicator data is transformed into complete, directionally consistent and comparable standard data for the sake of further assessment and analysis.

(3) Establishing the Indicator Comparison and Judgment Matrix

The 15-expert panel compared the indicators in the same levels in pairs (Appendix II), and quantitatively differentiated their importance on a scale from 1-9 and the reciprocals of those numbers to establish the AHP judgment matrix (Table 5-4). Take the Dimensions level as an example (Table 5-5).

Scale	1	3	5	7	9	2, 4, 6, 8
Meaning	Two factors of the same importance	One factor slightly more important than the other	One factor significantly more important than the other	One factor much more important than the other	One factor extremely more important than the other	Between the above adjoining judgments
Reciprocal	If the judgment of factor i in relation to j is a_{ij}; the judgment of factor j in relation to i is $a_{ji}=1/a_{ij}$					

Table 5-4: Judgment Scale of Factors' Relative Importance from 1-9

Data source: Drawn by the author on the basis of AHP Principles

D	**A1**	**A2**	**A3**	**A4**	**A1**	**B1**	**B2**	**B3**	**B4**	**A2…A4**	**B1**	**C1**	**C2**	**C3**	**B2…B11**
A1	1	1/5	1/7	1/9	**B1**	1	3	1	1		**C1**	1	1	1/3	

A2	5	1	1/3	1/3	**B2**	1/3	1	3	3		**C2**	1	1	1/3	
A3	7	3	1	1/3	**B3**	1	1/3	1	1		**C3**	3	3	1	
A4	9	3	3	1	**B4**	1	1/3	1	1						

Table 5-5: The AHP judgment matrix of Dimensions level

Data source: Drawn by the author

(4) Indicator Weighting

MATLAB software was used to calculate the maximum eigenvalue and eigenvector of respective judgment matrices based on the scores graded by the experts, generating total sorted weight of the indicators on each level after normalization (Table 5-6).

Target	Dimensions	Weight	Indicators	Weight	Sub-indexes	Weight
Resilient City Indicators	Social Resilience (A1)	0.4259	Education (B1)	0.1219	Teacher-student ratio (C1)	0.0416
					Ratio of educational expenditure to local government expenditure (C2)	0.0646
					Number of higher education graduates per 10,000 population (C3)	0.0157
			Health (B2)	0.1438	Average life expectancy (C4)	0.0797
					Number of physicians per 10,000 population (C5)	0.0346
					Number of hospital beds per 10,000 population (C6)	0.0294
			Social Security	0.0714	Percent population with basic	0.0354

			(B3)		endowment insurance coverage (C7)	
					Ratio of fiscal expenditure on social security to total fiscal expenditure (C8)	0.0185
					Number of minimum living allowance recipients (C9)	0.0175
			Social Equality (B4)	0.0887	Coverage rate of government-subsidized housing (C10)	0.0529
					Housing price-to-income ratio (C11)	0.0358
	Economic Resilience (A2)	0.3618	Economic Prosperity (B5)	0.1507	*Per capita* GDP (C12)	0.0202
					Engel's coefficient (C13)	0.0257
					Per capita disposable income of urban residents (C14)	0.0376
					Registered urban unemployment rate (C15)	0.0408
					Ratio of local fiscal revenue to GDP (C16)	0.0266
			Structural Optimization (B6)	0.1130	Ratio of value added by the tertiary sector to GDP (C17)	0.0402
					Ratio of value added by the high-tech industry to industrial value added (C18)	0.0728
			Innovation Potential (B7)	0.0980	Ratio of R&D expenditure to total fiscal expenditures (C19)	0.0719

					Number of valid invention patents per 10,000 population (C20)	0.0261
	Urban Infrastructure and Services (A3)	0.1276	Environmental Management (B8)	0.0822	Urban air quality compliance rate (C21)	0.0214
					Water quality compliance rate for functional areas of urban water environment (C22)	0.0182
					Multipurpose utilization rate of industrial solid wastes (C23)	0.0083
					Per capita parks and green space (C24)	0.0120
					Water consumption per RMB 10,000 GDP (C25)	0.0110
					Energy consumption per RMB 10,000 GDP (C26)	0.0112
			Key Infrastructure (B9)	0.0454	Density of public transport network (C27)	0.0241
					Urban gas penetration rate (C28)	0.0123
					Internet penetration rate (C29)	0.0090
	Urban Governance (A4)	0.0935	Social Integration (B10)	0.0608	Civic Participation (C30)	0.0455
					Membership of civic health organizations, social advocacy organizations, commercial associations, trade unions and political groups (C31)	0.0153
			Emergency	0.0327	Presence of emergency command	0.0327

			Management (B11)		information platforms (C32)	

Table 5-6: Indicator Weight Table

Data source: Drawn by the author

(5) Consistency Check

Judgments may vary due to objective complexity and diverse human understanding, necessitating consistency checks on the judgment matrices. Based on the AHP, the consistency ratio is defined as CR = $\frac{CI}{RI}$. CI is the consistency index, which is related to the specific judgment matrix. Suppose that the maximum eigenvalue of the judgment matrix is λmax and the order is n, then CI= $\frac{\lambda max-n}{n-1}$. RI is the random consistency index, which is only related to the order of the judgment matrix, and has a value range as shown in Table 5-7. When the CR is less than 0.1, the consistency of the judgment matrix is considered acceptable. As the computed results show, the CR of each matrix is less than 0.1, revealing satisfactory consistency.

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 5-7: RI Average Value Range

Data source: Alexander, Saaty, 1997

5.3.1.3 Composite Score Calculation

The final composite score can be calculated using the indicator weights and values using the following formula:

$$S=\sum_{i=1}^{n} w_i x_i \quad (i=1、2……n, j=1、2…..m)$$

Wherein, W_i refers to the comprehensive weight of level three indicators to level one indicators; X_i represents the standard value of three indicators and S composite score of resilient cities. The indicators in the factor level as shown in Table 5-5 can be weighted in combination with the standardized initial indicator value to calculate the composite score and criterion level scores, as shown in Table 5-8.

Year	Composite Urban Resilience Score	Social Resilience	Economic Resilience	Urban Infrastructure and Services	Urban Governance
2007	0.364586507	0.165962356	0.136242226	0.038021851	0
2008	0.422488744	0.213554412	0.123748123	0.046082483	0.001158226
2009	0.466905079	0.204256845	0.132373567	0.062555057	0.026963332
2010	0.376544008	0.117191295	0.138768421	0.054413562	0.052585304
2011	0.47889039	0.215287549	0.109507737	0.095269995	0.046645073
2012	0.590597191	0.288833913	0.115473888	0.093642991	0.079529437
2013	0.552831609	0.225719346	0.156500489	0.074638081	0.082388267
2014	0.582516356	0.1919946	0.214795383	0.082637278	0.081377521
2015	0.629846383	0.216814819	0.278183155	0.088392703	0.046455707
2016	0.693908131	0.23560481	0.272269245	0.108937814	0.070537781

Table 5-8: Changsha Composite City Resilience Scores

Data source: Drawn by the author

5.3.2 Analysis of Results

The relative development level of urban resilience of Changsha in the 10 years starting from of 2007 is assessed. To more intuitively present the results, the composite score is mapped onto the chart in Figure 5-4:

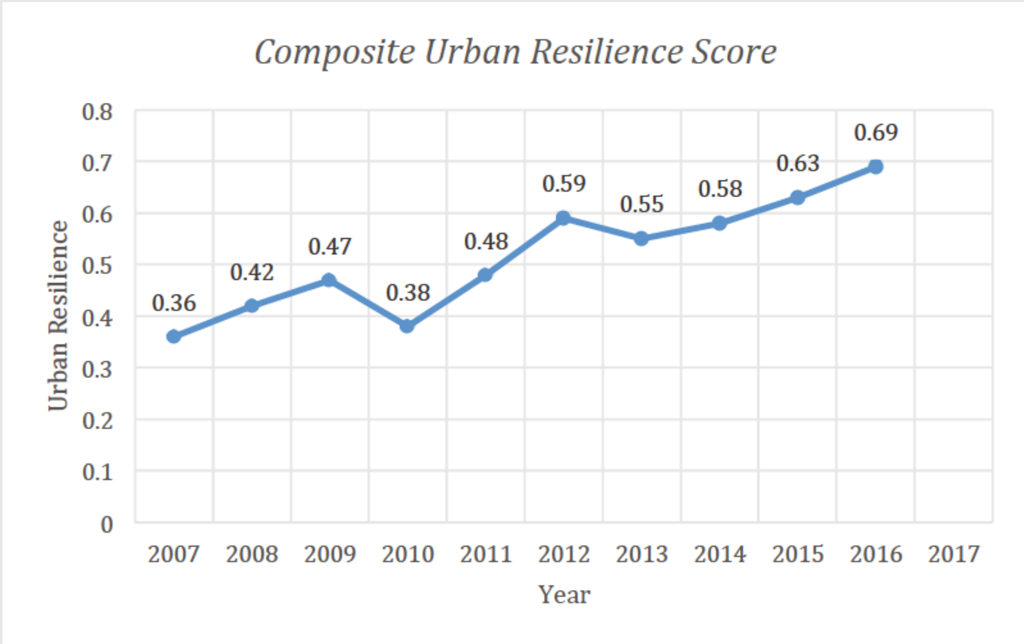


Figure 5-4: Changsha City Resilience Index from 2007-2016

Data source: Drawn by the author

The following conclusions can be drawn from the computed results:

(1) The computed indicator weight results show that, experts generally believe that city resilience should be first reflected in social change response capacity (0.4259). Differences in educational and health level, social equality and security directly affect the degree of vulnerability of different social groups. Second, the self-efficiency of the urban economic system after the occurrence of disasters (0.3618), reflected in economic prosperity and structural diversity, as well as self-learning and innovation capability, is also quite important. With respect of urban infrastructure and services (0.1276), resilient cities emphasize the capacity to responding to external shocks on resource recycling, ecosystem, energy sources and other social-environmental systems, as well as on transport, communication facilities and other key facilities. Finally, the governance capacity of the government (0.0935) has become an important

means for emergency response, leading urban society, economy and ecology into a more sustainable and resilient direction. As the organizational and management body for local society, the municipal government can work with civil society groups to improve disaster warning capacity and organization, management, planning and action capacity during and after the disaster. Economic prosperity (0.1507), health (0.1438), education (0.1219) and structural optimization (0.1130) are the top four indicators in the domain level. As shown from the questionnaire-based survey results, experts showed high consistency in the grading of these four areas. In the factor level, Average life expectancy (0.0797), ratio of value added by the high-tech industry to industrial value added (0.0728), density of the public transport network (0.0241) and civic participation (0.0455) scored highly.

(2) Changsha's resilience is generally good, and the index grew slowly, with fluctuations, during the research period. Resilience is a relative value, and Changsha's resilience increased from 0.39 in 2007 to 0.69 in 2016. However, there were two declines, in 2010 and in 2013, and the index hit a minimum in 2010 (Figure 5-4). As the city resilience radar chart in Figure 5-5 shows, urban infrastructure and services, urban governance demonstrated a normal development momentum, and economic resilience was flat from 2007 to 2010, but social resilience suffered a major decline. Among the 32 sub-indexes, 14 revealed negative changes, seven of which were in relation to social resilience. The social resilience radar chart (Figure 5-6) reveals a great change in housing price-to-income ratio in 2010. According to an analysis report (2010) by Changsha Real Estate Development Research Center[9], the price of semi-finished houses in Changsha rose by over 30% in 2010, reaching RMB 1,500/m^2, and pushing up trading volume. After a purchase limitation policy of "one new commodity house for each household"

[9] Analysis report on the real estate development of Changsha and its causes prepared in 2010 by Changsha Real Estate Development Research Center, under the Changsha Municipal Commission of Housing and Urban-rural Development.

was imposed in the first-tier cities of Beijing, Shanghai, Shenzhen and Guangzhou in 2010, the house trading volumes in tier-one cities decreased. In response, investors and home buyers started to shift their attention to tier-two cities. Together with the market expectation that Changsha would introduce the same purchase policy and a property deed tax policy, housing purchases increased, accelerating growth of prices. As further indicated by the Changsha Statistical Yearbook 2010, the population of Changsha grew 13.45% from 2009 to 2010. The large population influx to the city resulted in negative changes in data closely related to population base, such as teacher-student ratio, number of hospital beds per 10,000 population, and percent population with basic social insurance coverage. Coupled with rising house prices, Changsha's urban resilience index saw a substantial drop in 2010.

Figure 5-5: City Resilience Radar Chart

Data source: Drawn by the author

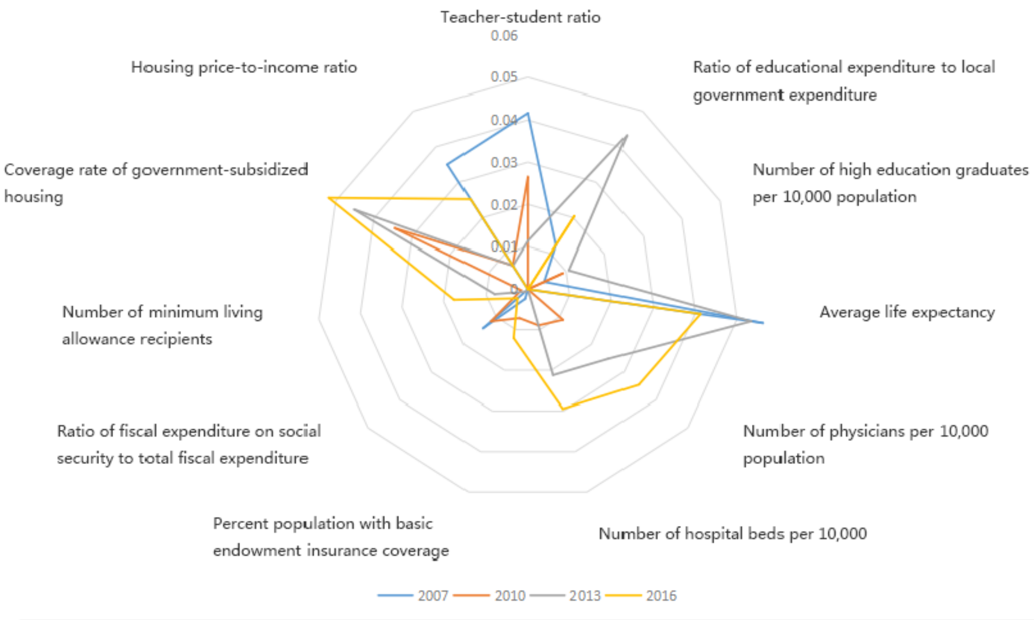


Figure 5-6: Social Resilience Radar Chart

Data source: Drawn by the author

The index fell slightly in 2013 from 2012 (Figure 5-5). 13 of the 32 sub-indexes – mainly relating social resilience, urban infrastructure and services – declined; there was progress in economic resilience and urban governance. In response to the 2008 economic crisis, in 2009, China started to implement infrastructure investment incentive policies to boost economic growth, and results began to show in terms of economic development. However, the extensive construction of infrastructure and real estate had a major impact on the environment. The urban air quality compliance rate, water quality compliance rate, and multipurpose utilization rate of industrial solid waste all saw major declines in 2013 (Figure 5-7), affecting composite urban resilience indexes. 2013 was also known as "the year of awakened citizen environmental awareness": for the first time in history, the National Meteorological Center of the CMA issued special warnings against haze; the People's Daily and other media released public-interest ads to enhance public environmental awareness; the most rigorous standards in history for vehicle petroleum products were implemented; coal-fueled power plants were gradually moved from urban centers; natural gas and new energy were promoted to replace petroleum as a fuel for urban public transport on a pilot basis; the establishment of the China Low-carbon Alliance, joined by a number of enterprises and non-governmental organizations, was announced; environmental authorities took the initiative to release emission data and other information for companies under monitoring starting September 2013; and policies like electricity price reform, resource tax reform, and carbon taxes were put on the agenda.[10]

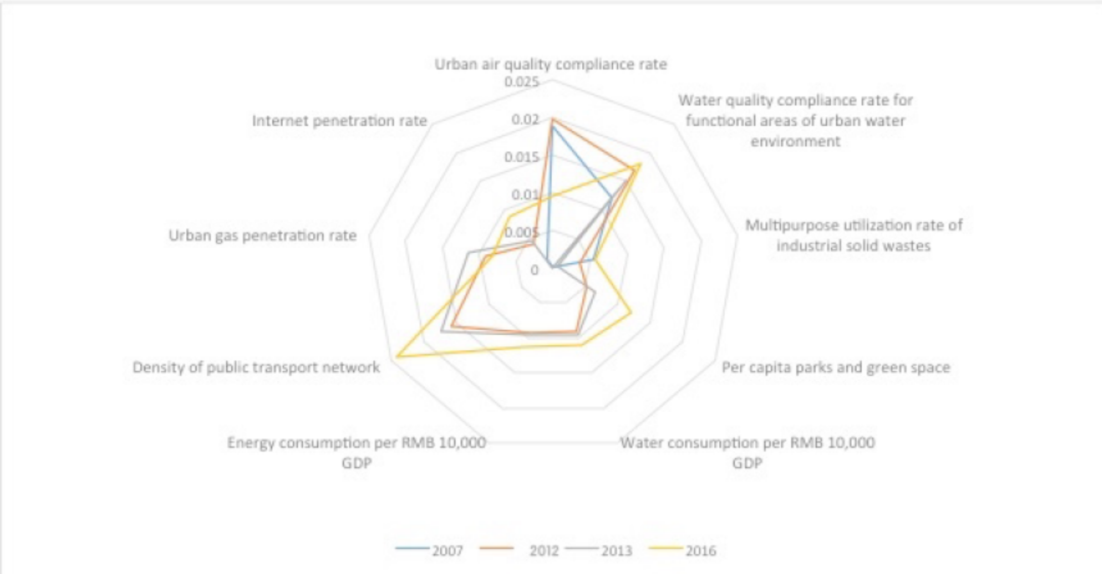


Figure 5-7: Urban Infrastructure and Services Radar Chart

Data source: Drawn by the author

From the general evaluation results, society, economy, urban infrastructure and services, and urban governance showed a steady upward trends, with no general decline. As Changsha is in a stage of rapid urbanization, zoning adjustment, urban population, social welfare and infrastructure construction all face major changes, leading to substantial changes in individual indicators in certain years – especially social resilience, which has maximum weight, and consequently exerts a major impact on Changsha’s comprehensive resilience.

[10] http://www.wenming.cn/wmpl_pd/zlzs/201307/t20130722_1359731.shtml

Chapter VI Strategies and Approaches to Build Resilient Cities in Central China

Urban resilience: What does it mean in planning practice?

—Wilkinson, 2012

The development goal of resilient cities is sustainable development of urban social collaboration, economic diversity and ecological co-existence. Their planning and construction is an extensive, comprehensive and complex system project. Considering that exploration of resilient cities is moving from theoretical to practical, a reasonable and feasible indicator system is needed to simplify the complex systems of resilient city planning and construction, and allow urban administration and decision-making authorities to define their development orientation and objectives, accurately measure the current level of development, and guide their planning, construction and management of resilient cities. Despite the common development objectives of resilient city construction, China's complex and vast terrain and varying levels of development make the process diverse. Various guidance policies and technical assurance systems should therefore be formulated rationally In light of different regions' resource, climate, economic and other conditions. Measures should be further introduced In line with the specialties involved in resilient city development to scientifically and rationally guide resilient city construction on the ground, and to facilitate collaborative progress in different regions using tailored approaches towards the common goal of developing resilient cities. On the basis of previous research, and considering the current problems and risks of urban development in Central China and key areas of resilience, four approaches to constructing resilient cities are hereby proposed.

6.1 Diversify Economic Development and Enhance Self-reliance

The key to the sustainable economic development of Chinese cities is to transform their economic development model. As pointed out by many scholars, China's urban development model of growth at all costs is based on unrestricted consumption of land, energy, and other resources. The academic debate on growth vs. development has never ended. The New Urbanization concepts proposed by the central government in recent years reflect a transformation in governance philosophy from unrestricted growth based on energy and resource consumption to sustainable development prioritizing improvement in social life and establishment of ecological civilization. From the perspective of resilient city development, China must reorient its urban economic development drivers and enhance adaptation to external risks.

6.1.1 Establishing Diverse Growth Drivers

As covered in Chapter III, Central Chinese cities boast a good foundation for industrialization, but bottom-up economic development is weak. To achieve sustainable economic development, new innovation-centered growth drivers must be developed to continuously boost the quality and efficiency of economic growth. Macroscopically, innovation-driven development is the key to successful economic transformation and upgrade; microscopically, incentive mechanisms and proper competition are the keys to shift business from imitation to proprietary innovation and enhancement of core competitiveness. In terms of industrial structure, therefore, vigorous efforts should be made to develop high value added and taxable high-tech industries. Technological and socioeconomic development should be further integrated, particularly trans

The 2016 Global Innovation Index released by the WIPO revealed that for the first time, China made its way into the world's top 25 most innovative economies. However, it only had 22 patents filed under the Patent Cooperation Treaties (PCT) per 1 million people, lower than the world average of 29, and only one eighth of the U.S. total, and one sixteenth of Japan. A narrowing gap with the state of the art means that core technologies and superior products cannot be acquired through imitation. Therefore, development of superior products with technological content and high value added has become the key to improving current business performance and gaining a foothold in increasingly competitive markets, as well as an effective way to enhance economic quality and efficiency.

6.1.2 Enhancing Self-reliance and Defending against External Risks

To eliminate the negative impact of external risks on urban development, it's essential for cities to establish self-reliance systems to reduce dependence on external food, energy, and resources. Certain international practices can provide inspiration for China. Munich is Germany's first large city to meet the challenge of 100% power supply via renewable energy sources. The city encourages the use of sustainable energy via planning and design, to realize energy localization; It promotes carpooling, walking, and biking, and car parks near metro stations have been converted into bicycle parking lots. The United States has established an online alliance to support local economy, food and energy sources. For instance, the Oberlin Project (Ohio) has revitalized the local economy, reduced carbon emissions, and restored local agriculture, forestry and food supply through better cooperation with the city council, local colleges and universities, and businesses. The details are implemented at the community level. Experience has proved that such integrated measures are successful in terms of economy, society and ecology.

6.2 Improving Mechanisms for Coordination between Social and Ecological Urban Systems

As resources are constantly being used up and the impact of climate change grows, resilient cities are expected to continuously provide ecological services, requiring improvement in mechanisms to coordinate social and ecological urban systems. The traditional way to reduce the vulnerability of transportation system and energy supply facilities is to enhance infrastructure technology, which will remain an important approach in the future. Facing new challenges like climate change, however, socially and ecologically integrated methods will hold greater potential. Ecological urban systems like parks, gardens, green rooftops and urban farms provide urban life with indispensable ecological services such as climate regulation, disaster prevention, soil loss prevention, and entertainment and cultural enrichment.

Central Chinese cities have always been threatened by frequent heat waves and floods. Urban greening has become an extremely important countermeasure. They can mitigate the urban heat island effect; green rooftops and walls can lower the temperature of the city; the cooling effect of trees greatly decreases energy consumption and carbon dioxide emissions; interception of rainwater by vegetation reduces the risk of flooding; ecological systems – forests and wetlands in particular – are important buffer systems to reduce flooding and purify water. The central ministries of Finance, Housing and Urban-rural Construction, and Water Resources have finance two batches of pilot sponge cities since April 2015 with a focus on resolving urban construction problems in water environment, water ecology and waterlogging. The results have however not been satisfying. According to incomplete statistics from *China Economic Weekly*, 10 of the first batch of 16 pilot cities, as well as 9 of the second batch of 14, were subject to waterlogging, hence 19 cities of the 30 pilot cities (63%) were affected. Among these cities were provincial capitals in Central China including Wuhan and Nanning. Thus, sponge cities are not built overnight; it may take 5-10 years or longer. Taking Singapore as an example, it has been a decade since the launch of its sponge city campaign. As a tropical island with ample rainfall, Singapore has shown a continuous uptrend in maximum annual rainfall over the past 3 decades, but has seldom suffered from waterlogging. All this is attributable to the scientifically designed and rationally distributed rainfall collection and urban drainage systems. In 2006, the Public Utilities Board (PUB) of Singapore launched the ABC Water Programme (Figure 6-1). "The aim of the ABC Waters Programme is to seamlessly integrate the Environment (Green), Waterbodies (Blue), as well as the Community (Orange) to create new community spaces and to encourage lifestyle activities to flourish in and around the waters. As the community gets closer to water, people will better appreciate and cherish our valuable water resource and hence develop a sense of stewardship towards water."

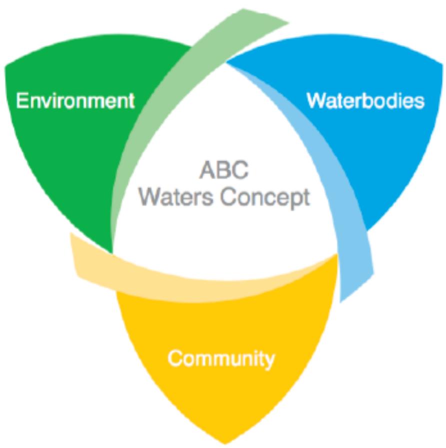


Figure 6-1: ABC Waters Concept

Data Source: https://www.pub.gov.sg/abcwaters/designguidelines

6.3 Comprehensively Improving Urban Functions

A City can be viewed as an intricate metabolic system in continuous motion and circulation. All cities depend on the energy, water, commodity and other ecological system services to support urban operations. As highly-dependent, connected and open systems, cities' resilience is affected by the capacity of other regions to provide them with supplies and services. Therefore, cities need to set highly important functions and facilities as redundant backup modules, and adopt a decentralized temporal-spatial layout to prevent single points of failure. In the case of functional loss of a certain part following a disaster, diverse and redundant backup modules can immediately repair the most serious defects, and quickly resolve the system paralysis resulting from the failure. The Wenchuan Earthquake in 2008 led to the blockage of the only highway from Beichuan County to the downtown area, bringing much inconvenience to rescue efforts and teaching us a profound lesson. Important infrastructure and service facilities involving power supply, telecommunications, road evacuation, food supply, and medical systems should be allocated redundantly.

The following three aspects of urban metabolic flows should be prioritized: optimizing transportation, disposing of waste, and diversifying energy sources.

6.3.1 Transportation System Optimization

Traffic congestion has become a persistent problem in many Chinese metropolises. According to the *Amap 2017 Traffic Analysis Report on Major Chinese Cities*, over 26% of Chinese cities were congested during rush hour in 2017, particularly in Central China (Figure 6-3). Transportation is the second largest global greenhouse gas emissions source, second only to the energy sector.

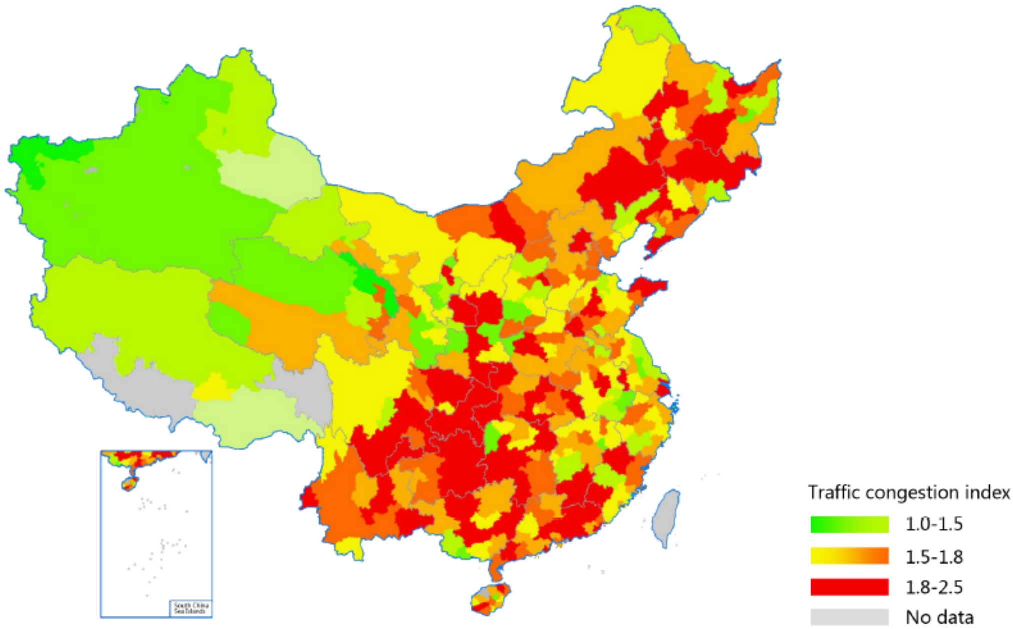


Figure 6-2: Traffic Congestion Map of Chinese Cities during Peak Commuting Hours in 2017

Data source: 2017 Traffic Analysis Report on Major China Cities

Transit system resilience should focus on the following areas: (1) Connectivity: all types of transport facilities should be integrated into an interconnected network offering convenient and fast transfers among metro, rapid bus transit, general buses, and taxis; (2) Development of rational urban forms and structures to reduce trips and traveling distance. Compact development should be promoted, pedestrian streets constructed, and basic life services like stores, schools and entertainment facilities provided within walking distance. In Kanton Basel-Stadt, Switzerland, for example, 95% of the residents live within an area 350m away from the station; people can use any transport facility without limited for CHF 700 every year. Therefore, forty percent of Basel residents hold annual transport passes. The Chinese Urban Residential Planning and Design Standards, released in 2018, proposed the concept of "5-min, 10-min and 15-min community life circles." This concept allows citizens to enjoy basic public service facilities involving elderly care, medical care, education, commerce, transport, recreation, and sports within a 5-min, 10-min and 15-min walking distance, reducing urban operating costs and enhancing community exchange and inclusion.

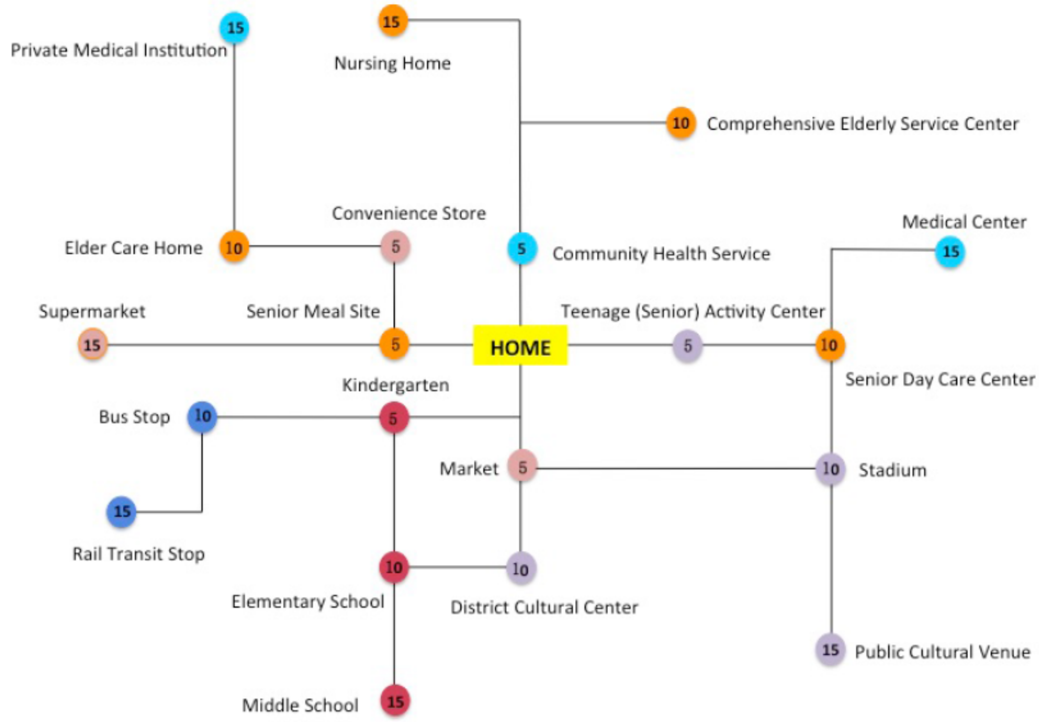


Figure 6-3: 5-min, 10-min and 15-min community life circles

Data source: Drawn by the author

6.3.2 Urban Waste Disposal

(1) Reducing the overall quantity of waste. The most important area is currently better implementation of waste classification. Urban ordinances on waste classification and disposal have now been formulated in Japan, Europe and North America. Germany, with one of the earliest and most developed classification systems, has a well-designed waste classification and disposal system. Household waste is placed into receptacles of different colors based on category: brown bins are for organic garbage (including leftovers, fruit peels, bones and other kitchen and garden waste); yellow bins (or bags) are for light packaging (like plastic bags, boxes and milk cartons); blue bins are for waste paper and boxes; waste glass is put into the brown, white and green bins based on categorization; and the black or gray bins are for other non-classified waste. Furthermore, residents are expected to deposit bulk, toxic, hazardous, and electronic waste at specialized recycling points. Used clothes can be put into the specialized

neighborhood boxes set up by the Red Cross. Used furniture and home appliances can be placed at the curb for those who need them or given to specialized personnel for disposal. Waste classification is the obligation of every German citizen. Improper classification is subject to heavy fines, and affects individuals' social reputation. Many cities publish their own waste classification handbooks to familiarize residents with classification principles. At the beginning of each year, updated handbooks and waste collection schedules specifying the sub-district of the household and fixed weekly waste collection times are dropped into each household mailbox by the government. The garbage bins or bags must be placed on the street one day before the specified collection date. Figure 6-2 shows the waste collection schedule for Freising from June to December 2018.

(2) Enhancing waste collection, re-utilization and recycling capacity. Waste treated in an untimely or improperly manner pollutes the environment and severely impacts sanitation. With a change in mentality, waste can be taken as an inexhaustible "urban treasure" with great development potential. Norway, for example, has introduced laws and regulations on waste disposal. The *Regulations Relating to the Recycling of Waste* provides rigorous requirements and restrictions on the landfilling, incineration and transport of waste, and corresponding recycling and disposal policies regarding different waste types. The basic principle of waste disposal is to achieve maximal recycling and utilization, supported by waste reduction. In Oslo, recycling and utilization is jointly handled by the municipal health and energy authorities. The waste is further sorted after shipment to treatment plants. The Oslo-based Haraldrud treatment plant is equipped with the world's largest optical sorting equipment, which can separate green bags containing food and blue bags containing plastic products from other household wastes via color identification. The plant sorts, recycles and disposes of 100,000 tons of waste per year. Food waste is used to produce methane and biofertilizers; plastic and paper products, general metals and glass is reused to manufacture products; home appliances, batteries and hazardous industrial wastes like heavy metals is reused or landfilled after decontamination; the remaining waste is incinerated after extracting metals.

(3) Improving waste disposal capacity, such as waste-to-power and organic waste

composting technology. Energy transformation and biotreatment are extensions of waste disposal. Current energy transformation technology is primarily reflected in the following points: first, the energy generated from incineration is used to heat hot-water pipelines for regional heating; second, steam generated from incineration and methane from landfills is used for power generation; third, methane from anaerobic fermentation of food waste and sludge from sewage plants is used to produce biofuels for public transport; finally, food waste can be used to produce solid or liquid biofertilizers. The waste incineration plant at the center of Basel factory district, Switzerland handles household waste from 700,000 locals. The hot steam generated by incinerating the waste plus woody debris is used for power generation and heat supply for 5,000 households, resulting in an energy utilization rate of 80%.

6.3.3 Energy Source Diversification

Reducing cities' dependence on fossil fuels, lowering carbon dioxide emissions, diversifying energy sources, and improving utilization efficiency will become essential measures to mitigate climate change.

(1) Diversification of energy sources, including renewable sources like solar and wind, and non-renewable sources like nuclear. It is most important to identify the unique resources and opportunities of each city. The U.S. Department of Energy announced that by 2030, 20% of US power would come from wind power. Freiburg, Germany has installed solar panels in many buildings, and implemented the Energy-Plus Plan in certain areas so that each green building can meet its own energy needs, while generating excess energy for other buildings.

(2) Better energy security through a combination of centralized and distributed models. In addition to the development and utilization of solar and wind energy, grains and trees can be used to expand small-scale and distributed bio-energy. Crops and trees can serve as bio-energy raw materials, and at the same time make up an integral part of the cityscape. The ideal state of bio-energy use is that all biofuel raw materials come from food supply by-products. A thermal power station in Vauban, Freiburg takes wood dust, branches and barks – byproducts of local forestry and logging industries – as fuels to provide heat and power for 5,000 residents and

1,000 local businesses. Thus, each city can devise energy strategies based on their own features to make good use of local renewable resources.

(3) Promotion of energy-saving technologies like green building. Some researchers believe that each rooftop can make use of photosynthesis. Besides green rooftops designed for city beautification and rainwater collection with solar PV panels installed, rooftops for collection of algae-based biofuels also exist. The most promising biofuel resource for the future will perhaps be blue-green algae, which can be extensively planted on rooftops. With sunshine, air and a small amount of nutrients, it can grow 10 times faster than other biofuel resources. Blue-green algae grown on urban rooftops can continuously provide raw materials for the local biofuel industry and small-scale generators. (Peter Newman, et al., 2012)

6.4 Establishing Adaptive Planning and Promoting Joint Social Governance

With cities' increasing complexity and expansion, we see the inadequacy and powerlessness of urban planning and management, as well as the consequences brought by power change. As the dynamics of cities is non-linear, it is impossible to resolve urban problems using traditional linear planning. Therefore, innovative planning methods must be explored in response to urban complexity. Urban resilience provides a new perspective to plan and analyze complex urban dynamics. Participation of stakeholders like the government, commercial organizations and social groups in the planning process should be promoted, form diverse partnerships. Learning platforms should be provided to improve adaptation and transformation capacity. The reconstruction of New York after Hurricane Sandy delivers three key messages. First, the continuous progress of science and technology has provided adequate information for us to take action against climate change, and cities can update their own climate forecasting and urban climate change action plans. Second, we should plan the metropolitan area as a whole and cover the whole city with infrastructure. For instance, the New York City Climate Action Task Force consists of a range of regional transport providers who are responsible for the operation of metro, buses and railway inside and outside the city and metropolitan area. Disasters and extreme events don't follow administrative boundaries, and measures to enhance urban resilience should not be limited by jurisdiction. On the contrary, these measures should include interconnected energy, water, transport, telecommunications, sanitation, health, food and public safety systems. Last, urban decision-makers, infrastructure managers, the public, and other key participants and researchers should be involved, and scientists and stakeholders should work together to identify risks. (Rosenzweig, 2014)

Chapter VII Summary and Outlook

Cities face an uncertain future, and we're helping them prepare. Cities face an uncertain future, and we're helping them prepare.

—100 Resilient Cities

7.1 Summary

The significance of a resilient city indicator system is to more scientifically, accurately, and comprehensively measure a city's strengths and weaknesses, evaluating its capacity to adapt and self-regulate in response to future external changes, for more scientific planning and decision-making. There are certain limitations to this study. First is dependence on the availability and accuracy of basic statistical such data as population, socioeconomic conditions, environment and infrastructure. Amid rapid urbanization, Chinese cities all face the problems of data shortage or difficulty in data collection, so indicators under government monitoring have been included to the extent as possible. Second, the fundamental connotations of resilient cities directly determines the regionalism of assessment indicators. Due to China's marked regional differences in urbanization, it is impossible to assess greatly varying cities using uniform criteria. Many indicators incorporated into this system are frequently seen in current systems developed by international organizations. Although seemingly ordinary, this indicator list reflects the focus points of Central China cities, taking their development priorities and limiting factors into consideration. Although a set of basic indicators is recognized for each city, the indicators should be screened or extended based on the features and policy preferences of each city to finalize the system.

In future research, the system may be further improved by adding new indicators and re-defining the current ones, so as to better serve the development goals and efforts of resilient cities. Due to data shortages, certain indicators not included in this system may be re-considered in subsequent research. For instance, detailed data regarding employment and value added by certain industries is required to measure economic diversification; maintenance, which manifests in infrastructure construction and maintenance fund size, is essential to measure infrastructure quality; considering the small number of governance indicators, reliability indicators may be used. Furthermore, more cities may be chosen for empirical research on urban resilient assessment to facilitate horizontal comparison, and provide more basic data for resilient city construction.

7.2 Outlook

In 2013, the Rockefeller Foundation kicked off its 100 Resilient Cities Program, and proposed studying, developing and assessing the resilience of cities through the City Resilience Index. The program provides USD 164 million in grants for the 100 cities selected, helping them build resilience and improve their resistance to external shocks and disasters through formulation and implementation of resilience plans and provision of technical support and resources. As pointed out by Michael Berkowitz, Global President of the 100 Resilient Cities Program, "change in a city will not show in a half or one year, and may require generational efforts."[11] Improvement in urban resilience, therefore, also requires a common planning vision to inspire involvement of the whole society. Certain cities in China have mapped out vision plans in recent years, like Shanghai 2040 and Shenzhen 2040. The Shanghai 2040 Conceptual Plan put forward a vision to build an ecological, socially harmonious, intelligent, low-carbon, safe, convenient, and livable city. The plan emphasizes implementation of green development strategies, construction of a compact, efficient and low-carbon city, active industrialization of housing and development of green buildings, control of transportation energy consumption, prioritization of public transport, and advocacy of low-carbon transport. The Shenzhen 2040 Urban Development Strategy launched the website www.sz2040.com to advance "holistic vision and common planning." The public is encouraged to share its opinions and suggestions about the development ideas and tentative plans of Shenzhen 2040 and reach a consensus through preliminary surveys on 1,000 enterprises and 10,000 people and topical consulting.

Comprehensive resilience sustainable development indicators are needed to guide cities to realize the common vision of long-term sustainable development, replacing the previous simplistic GDP criterion with a new indicator system incorporating society, economy and ecology.

[11] http://www.zaihuangshi.com/thread-13306-1.html

Therefore, one of the greatest challenges on this research is information collection, sharing and analysis. Notably, data collection, organization and application has always been a huge bottleneck for quantitative research in China. Government data is consistent, but not systematic, publicly accessible or targeted; data from commercial researchers and consultants is more publicly accessible (for a fee) and targeted, but not consistent or systematic. Certain international cities have opened data up to the public. In response to the Open Data Movement in Canada, for instance, over 20 municipal governments have given open access to official data relating to urban space, transportation and infrastructure. In addition to increasing the transparency of government, this practice has brought about innovative online applications, and allowed citizens to give prompt feedback to decision-makers to improve urban services. Through better exchanges between citizens and local government, these livelihood improvement policies can gain influence and improve their effect, boosting social integration. Chinese metropolises have started to advance open data sharing as well. In June 2012, Shanghai launched the datashanghai.gov.cn website. As of the end of July 2018, the website had cumulatively opened up over 1,600 data sources from 43 departments in 11 key areas, including economic development, resources, environment, education, technology, and road transit.

Finally, the outlook of resilient city and planning research is expressed with the theme of the 54^{th} ISOCARP Congress 2018: “Cool Planning: Changing Climate and Our Urban Future.” “We believe the future of civilisation now more than ever depends on the way we plan and manage our cities and towns. Their role in the evolving planetary climate drama is three-fold – cities and towns are the villains; the victims, and the potential saviours. Villains – because urban areas are the principal consumers and polluters of the tiny habitable layer on our planet we call the “biosphere”. Victims – because more than half of humanity lives in urban areas, and almost all of them are exposed to some form of climate impact. Saviours – because the possible remedies and solutions can be applied efficiently, effectively and in time, only when populations are concentrated. So the root cause of, and the solution to, the global climate crisis are fundamentally urban.”

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Abbreviation

UNEP	United Nations Environment Programme
AHP	The Analytic Hierarchy Process
GMDH	Group Method of Data Handling
WCDR	World Conference on Disaster Reduction
UNISDR	The United Nations International Strategy for Disaster Risk Reduction
ICLEI	Local Governments for Sustainability
WMCCC	World Mayors Council on Climate Change
UNCCC	United Nations Climate Change Conference
ACSP/AESOP	Association of Collegiate Schools of Planning / Association of European Schools of Planning
UN-Habitat	United Nations Human Settlements Programme
WCED	World Commission on Environment and Development
DFID	Department for International Development
TCE	Ton of Standard Coal Equivalent
GDP	Gross Domestic Product
IBA	Internationale Bauausstellung
R&D	Research and Development
NGOs	Non-Governmental Organizations

WWII	World War II
PRC	People's Republic of China
COD	Chemical Oxygen Demand
MATLAB	Matrix & Laboratory
CMA	China Meteorological Administration
WIPO	World Intellectual Property Organization
PCT	Patent Cooperation Treat
ISOCARP	The International Society of City and Regional Planners

Appendix I Expert Interview Questionnaire on Central China Resilient City Indicator System

Dear Mr./Ms.____,

Thank you for your support on this interview! Please share your suggestions on whether the following candidate indicators should be incorporated into the resilient city assessment indicator system, and nominate new indicators to be included.

Thanks again for your great support!

Social Resilience Indicators:

Topic	Indicator Name	Your Suggestion	Computation Method (Units)
Education	Ratio of the population with college education or above to the population aged 15 or above	○Include ○Exclude	Ratio of the population with college education or above to the population aged 15 or above. Unit: %
	Ratio of Technical Jobholders	○Include ○Exclude	Number of professionals/total number of jobholders x 100％ Technical professionals means employees in any professional position, possessing professional knowledge and skills, employed by any organizations or company.
	Average educational level of the population aged 15 or above	○Include ○Exclude	(Undergraduates x 16 + college graduates x 14.5 + technical school graduates x 12.5 + senior high school graduates x 12 + junior high school graduates x 9 + elementary school graduates x 5.5) ÷ population aged 15 or above.

			Unit: Year
	Teacher-student ratio	○Include ○Exclude	(Total teachers of schools at different levels/registered students) x 100%
	Ratio of educational expenditure to local government expenditure	○Include ○Exclude	(operating costs of educational departments/local government expenditure) x 100%
	Per Capita Land Area of Public Cultural Facilities	○Include ○Exclude	Land area of public cultural facilities (m^2) / urban population (persons)
	What other indicators do you think should be included for this topic?		
Health	Average life expectancy	○Include ○Exclude	The average number of years those born at the same time can expect to live
	Percent elderly population	○Include ○Exclude	Ratio of population aged 65 or above to total population
	Number of physicians per 10,000 population	○Include ○Exclude	Number of Physicians/Urban Population (10,000 people)
	Number of hospital beds per 10,000 population	○Include ○Exclude	number of hospital beds/urban population(10,000 people)
	Medical insurance coverage rate	○Include ○Exclude	Number of employees with medical coverage (10,000 people)/Number of employees who

			should be covered (10,000 people) ×100%
	Beds in social welfare institutions per 100 elderly population	○Include ○Exclude	Beds in social welfare institutions per 100 elderly population = Number of beds in social welfare institutions in the city proper / population aged 60 or above (100 people)
	What other indicators do you think should be included for this topic?		
Social Security	Percent population with basic social insurance coverage	○Include ○Exclude	Number of employees with three-part insurance coverage (10,000 people)/Number of employees who should be covered by three-part insurance ×100%
	Per capita fiscal expenditure on social security	○Include ○Exclude	Fiscal expenditure on social security/ total population
	Target completion rate of government-subsidized housing projects	○Include ○Exclude	(households enjoying government-subsidized housing to permanently registered urban households) x100%
	Number of minimum living allowance recipients	○Include ○Exclude	This indicator measures the population below the poverty line and demand for income subsidies. Decreasing this value is crucial to guaranteeing social stability. The number of non-agricultural households receiving minimum living allowance.
	What other indicators do you		

	think should be included for this topic?		
Social Equality	Gini Coefficient	○Include ○Exclude	The percent of income used for uneven distribution to total income
	Housing price-to-income ratio	○Include ○Exclude	(unit area price of housing available for sale × urban housing floor area per capita) / average annual household income
	Percent of residents with *per capita* housing floor space less than 15 m^2	○Include ○Exclude	Percent of households with *per capita* housing floor space less than 15 m^2 to total urban households (%)
	What other indicators do you think should be included for this topic?		

Economic Resilience Indicators:

Topic	Indicator Name	Your Suggestion	Computational Method (Units)
Economic Prosperity	*Per Capita* GDP	○Include ○Exclude	GDP/Average Population
	Engel's coefficient	○Include ○Exclude	(food expenditure per capita/total expenditures per capita) x 100%
	Per capita disposable income of urban residents	○Include ○Exclude	(total household income - individual income taxes - social security fees paid by individuals - bookkeeping subsidies) / total family

			members
	Registered urban unemployment rate	○Include ○Exclude	Registered urban unemployment / (urban jobholders + registered urban unemployment) x100%
	Ratio of local fiscal revenue to GDP	○Include ○Exclude	This indicator reflects the revenue resilience of local government. A growing ratio of local fiscal revenue to GDP indicates local fiscal revenue growing faster than urban output. Local government revenue/ GDP x 100%
	Total retail sales of consumer goods	○Include ○Exclude	Information regarding wholesale and retail enterprises, food and beverage companies can be accessed via Comprehensive Reports (CR) released by government statistical bureaus.
	Ratio of land revenue to local fiscal revenue	○Include ○Exclude	
	What other indicators do you think should be included for this topic?		
Structural Optimization	Ratio of value added by the tertiary sector to GDP	○Include ○Exclude	value added by the tertiary sector (RMB 10,000)/GDP (RMB 10,000) x 100%
	Proportion of value added by the secondary sector to GDP	○Include ○Exclude	Value added by the secondary sector (RMB 10,000) / GDP (RMB 10,000) x 100%

	Ratio of value added by the high-tech industry to industrial value added	○Include ○Exclude	(value added by the high-tech industry/industrial value added) x 100%
	What other indicators do you think should be included for this topic?		
Innovation Potential	Ratio of expenditure on R&D to GDP	○Include ○Exclude	(expenditure on R&D + expenditure on public education)/government fiscal expenditures x 100%
	Number of valid invention patents per 10,000 population	○Include ○Exclude	The number of valid, non-expired invention patents granted by domestic and international IP administrations owned per 10,000 people. A comprehensive indicator to measure the quality of scientific research output and level of market application in a country or a region.
	Higher education graduates per 10,000 population	○Include ○Exclude	Higher education graduates per 10,000 population
	What other indicators do you think should be included for this topic?		

Indicators of Urban Infrastructure and Services:

Topic	Indicator Name	Your Suggestion	Computational Method (Units)
Environmental Management	City air quality compliance rate	○Include ○Exclude	Days with air pollution index less than 100 /365 x 100%
	Annual average of days in compliance with PM2.5 concentration	○Include ○Exclude	Days of PM2.5 per unit volume measured in the ambient air of urban built-up areas conforming to national standards
	Water quality compliance rate for collective drinking water sources	○Include ○Exclude	The water quality compliance rate for collective drinking water sources is the percent of water from collective water sources for drinking supply to the city proper complying with quality standards to total water withdrawal
	Centralized treatment rate of urban sewage	○Include ○Exclude	Urban sewage treated by sewage plants (10,000 tons)/total urban sewage discharge (10,000 tons) x 100%
	Daily household waste output *per capita*	○Include ○Exclude	Household waste generated in 24 h/regional population (t/person)
	Decontamination rate of household waste	○Include ○Exclude	Decontaminated household waste (10,000 tons)/total household waste (10,000 tons)
	Multipurpose utilization rate of industrial solid wastes	○Include ○Exclude	(quantity of industrial solid wastes comprehensively utilized/quantity of industrial solid wastes generated) x 100%
	Urban greening coverage rate	○Include ○Exclude	Green area in built-up area (10,000 m^2)/total built-up area (10,000 m^2) x 100%

	Per capita parks and green space	○Include ○Exclude	urban green space (10,000 m^2)/urban population (10,000 m^2) Parks and green space in built-up area (10,000 m^2)/total built-up area (10,000 m^2) x 100%
	Coverage rate of park and green space service radius	○Include ○Exclude	Residential land area within park and green space service radius/total residential land area x 100%
	What other indicators do you think should be included for this topic?		
Resource Conservation	Annual domestic water consumption *per capita*	○Include ○Exclude	Daily domestic water consumption/urban population. Unit: Liter
	Water consumption per RMB 10,000 GDP	○Include ○Exclude	Total water consumption in the city proper/ GDP in the city proper (RMB 10,000)
	Renewable water utilization rate	○Include ○Exclude	Re-utilized urban sewage/urban sewage discharge x 100%
	Industrial water reuse rate	○Include ○Exclude	Ratio of industrial reused water to total industrial water consumption (%)
	Annual *per capita* energy consumption	○Include ○Exclude	The ratio of total urban energy consumption to urban population
	Ratio of renewable energy usage	○Include ○Exclude	Renewable energy usage (TCE)/total urban energy consumption (TCE) x 100%

	Ratio of new energy vehicle usage	○Include ○Exclude	The ratio of new energy vehicles put into use in the city to motor vehicles in the city (%)
	What other indicators do you think should be included for this topic?		
Key Infrastructure	Ratio of public transport to total traffic	○Include ○Exclude	Ratio of public transport to total traffic = Total number of people using public transportation (10,000 people)/Total number of travelers in the city (10,000 people) x 100%
	Walking and cycling traffic share	○Include ○Exclude	Total number of people walking and cycling (10,000 people)/Total number of travelers in the city (10,000 people) x 100%
	Urban public water supply coverage rate	○Include ○Exclude	Population in the built-up area using public water (10,000 people)/ Population in the built-up area (10,000 people) x 100%
	Urban gas penetration rate	○Include ○Exclude	number of urban residents using natural gas (10,000 people) / Population in the built-up area (10,000 people) x 100%
	Internet penetration rate	○Include ○Exclude	Internet penetration rate = Urban households with internet access (households)/urban population (1 million people)
	Average commuting time	○Include ○Exclude	Average time needed to go travel work via bus, cycling or walking
	Urban shelter area *per*	○Include	Shelter area in the built-up area (m^2) /

	capita	○Exclude	Population in the built-up area (persons)
	What other indicators do you think should be included for this topic?		

Urban Governance Indicators:

Topic	Indicator Name	Your Suggestion	Computational Method (Units)
Social Integration	Public participation	○Include ○Exclude	The city has established and effectively implemented well-designed public participatory planning, design, construction and management systems, and built information-based platforms for public participation. (Qualitative index)
	Number of civic health organizations, socially advocacy organizations, commercial associations and other specialized organizations, trade unions and political groups	○Include ○Exclude	
	Voter participation rate	○Include ○Exclude	
	Ratio of residents living in the area over five years to those living under five years	○Include ○Exclude	

	What other indicators do you think should be included for this topic?		
Emergency Management	Presence of emergency command information platforms	○Include ○Exclude	Presence of well-designed emergency command systems, local plans for emergencies, and drills. Emergency command information platforms are the primary means to enhance capabilities of disaster warning, post-disaster emergency rescue and public emergency response
	Presence of natural disaster warning systems	○Include ○Exclude	
	Coverage rate of digital urban management systems	○Include ○Exclude	The digital urban management platform has been put into operation for over 1 year after completion, with a settlement rate ≥90%; the problems of urban energy utilization, environmental management, urban construction, public safety, government service, social services and transportation have been generally alleviated and archives are clearly and effectively managed to keep important municipal infrastructure under control.
	Emergency communications services	○Include ○Exclude	

	What other indicators do you think should be included for this topic?		
Comprehensive Development Plan	Presence of expert consulting organizations	○Include ○Exclude	
	Administrative approval speed	○Include ○Exclude	The time needed to set up a company
	Risk-based land utilization planning	○Include ○Exclude	Presence of land suitability evaluations (location, economy, infrastructure, and engineering)
	Integrated management and construction of underground urban utility tunnels	○Include ○Exclude	Presence of general surveys on underground utilities in the urban built-up area, a uniform urban comprehensive management information system for underground utilities, and interconnection and information sharing between and dynamic update of specialized utility information systems, specialized plans for underground urban utility tunnel construction, underground utility tunnels in new urban districts, industrial parks, development zones and newly-built roads, underground utility tunnel construction in old towns; and well-designed investment, operation and management regulations for

			underground utility tunnels.
	What other indicators do you think should be included for this topic?		

Appendix II Questionnaire on Central China Resilient City Indicators

Dear Mr./Ms.______,

Thank you for supporting this questionnaire on resilient city indicators!

Resilient cities are an ideal and model for urban development in response to complex and dynamic environmental changes. The assessment methods and systems of urban resilience capacity are the most important aspect of resilient cities. The indicators regarding urban resilience assessment proposed in international academia, however, are insufficiently systematical and regionally adaptive for China's current urban development needs. This study, therefore, establishes a resilient city assessment indicator system for Central China. Its purposes are (1) To set up an assessable and measurable indicator framework for inter-city comparisons in Central China and comparisons of a single city over time; (2) To formulate a set of feasible and manageable standards and requirements to effectively guide the implementation of resilient city planning, monitoring and assessment plans and direct construction practices. Hence, we hereby solicit your valuable opinions for the second time. Please share your suggestions on whether the preliminarily selected indicators should be incorporated into the system and grade them to determine their weighting.

Nature of Your Organization: (College/university, government, private sector, social group, other)

Name of Organization:

Your Professional Title: (Junior, Intermediate, Senior, Other)

Your Age: (Below 30, 30-45, 45-60, Over 60)

Thanks again for your great support!

Target	Dimensions	Indicators	Sub-indexes
Resilient City Assessment Indicators	Social Resilience (A1)	Education (B1)	Teacher-student ratio (C1); ratio of educational expenditure to local government expenditure (C2); number of high education graduates per 10,000 population (C3)
		Health (B2)	Average life expectancy (C4); number of physicians per 10,000 population (C5); number of hospital beds per 10,000 population (C6)
		Social Security (B3)	Percent population with basic endowment insurance coverage (C7); ratio of fiscal expenditure on social security to total fiscal expenditure (C8); number of minimum living allowance recipients (C9)
		Social Equality (B4)	Coverage rate of government-subsidized housing (C10); housing price-to-income ratio (C11)
	Economic Resilience (A2)	Economic Prosperity (B5)	*Per capita* GDP (C12); Engel's coefficient (C13); *per capita* disposable income of urban residents (C14); registered urban unemployment rate (C15); ratio of local fiscal revenue to GDP (C16)
		Structural Optimization (B6)	Ratio of value added by the tertiary sector to GDP (C17); ratio of value added by the high-tech industry to industrial value added (C18)
		Innovation Potential (B7)	Ratio of expenditure on R&D to fiscal expenditure (C19); number of valid invention patents per 10,000 population (C20)

	Urban Infrastructure and Services (A3)	Environment Management (B8)	City air quality compliance rate (C21); water quality compliance rate for functional areas of urban water environment (C22); multipurpose utilization rate of industrial solid wastes (C23); *per capita* parks and green space (C24); water consumption per RMB 10,000 GDP (C25); energy consumption per RMB 10,000 GDP (C26)
		Key Infrastructure (B9)	Density of public transport network (C27); urban gas penetration rate (C28); internet penetration rate (C29)
	Urban Governance (A4)	Social Integration (B10)	Civic engagement (C30); Members of civic health organizations, social advocacy organizations, commercial associations, trade unions and political groups (C31)
		Emergency Management (B11)	Presence of emergency command information platforms (C32)

I. Notes

This questionnaire determines the relative factors weighting of the Resilient City Assessment Indicator System for Central China. The questionnaire is designed on the basis of AHP, which compares factors in the same level in pairs. The scale is divided into 9 levels: extremely unimportant 1/9, quite unimportant 1/7, relatively unimportant 1/5, slightly less important 1/3, equally important 1/1, slightly more important 3/1, relatively important 5/1, quite important 7/1, and extremely important 9/1. The factors within the same group should be logically consistent. For instance, if A > B and A < C, C > B must be true, otherwise the questionnaire will be invalid.

2. Questionnaire

■ Second Level (Dimension Level)

● What is the relative importance of the following groups of factors to "resilient cities?"

1. Society vs. economy? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

2. Society vs. urban infrastructure and services? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

3. Society vs. urban governance? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

4. Economy vs. urban infrastructure and services? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

5. Economy vs. urban governance? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

6. Urban infrastructure and services vs. Urban governance? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

■ Factors in the Third Level (Indicator Level)

● What is the relative importance of the following groups of factors to "society"?

1. Education vs. health? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. Education vs. social security? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

3. Education vs. social equality? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

4. Health vs. social security? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

5. Health vs. social equality? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

6. Social security vs. social equality? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

- What is the relative importance of the following groups of comparison factors to "economy"?

1. Economic prosperity vs. structural optimization? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

2. Economic prosperity vs. innovation potential? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

3. Structural optimization vs. innovation potential? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

- What is the relative importance of the following group of factors to "urban infrastructure and services"?

1. Environmental management vs. key infrastructure? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following group of comparison factors to "urban governance?"

1. Social integration vs. emergency management? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

■ Factors in the Fourth Level (Sub-index Level)

- What is the relative importance of the following groups of factors to "education?"

1. Teacher-student ratio vs. ratio of educational expenditure to total local government expenditure? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. Teacher-student ratio vs. number of higher education graduates per 10,000 population? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

3. Ratio of educational expenditure to total local government expenditure vs. number of higher education graduates per 10,000 population? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5
D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1
G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following groups of factors to "health"?

1. Average life expectancy vs. number of physicians per 10,000 population? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5
D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1
G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. Average life expectancy vs. number of hospital beds per 10,000 population? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5
D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1
G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

3. Number of physicians per 10,000 population vs. number of hospital beds per 10,000 population? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5
D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1
G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following groups of factors to "social security?"

1. Percent population with basic endowment insurance coverage vs. ratio of fiscal expenditure on social security to total fiscal expenditure? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5
D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. Percent population with basic endowment insurance coverage vs. number of minimum living allowance recipients? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

3. Ratio of fiscal expenditure on social security to total fiscal expenditure vs. number of minimum living allowance recipients? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following group of factors to "social equality?"

1. Coverage rate of government-subsidized housing vs. housing price-to-income ratio? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following groups of factors to "economic prosperity"?

1. Per capita GDP vs. Engel coefficient? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. *Per capita* GDP vs. *per capita* disposable income of urban residents? (   )

A. Extremely unimportant 1/9   B. Quite unimportant 1/7   C. Relatively unimportant 1/5

D. Slightly less important 1/3   E. Equally important 1/1   F. Slightly more important 3/1

G. Relatively important 5/1   H. Quite important 7/1   I. Extremely important 9/1.

3. *Per capita* GDP vs. registered urban unemployment rate? (   )

A. Extremely unimportant 1/9   B. Quite unimportant 1/7   C. Relatively unimportant 1/5

D. Slightly less important 1/3   E. Equally important 1/1   F. Slightly more important 3/1

G. Relatively important 5/1   H. Quite important 7/1   I. Extremely important 9/1.

4. *Per capita* GDP vs. ratio of local fiscal revenue to GDP? (   )

A. Extremely unimportant 1/9   B. Quite unimportant 1/7   C. Relatively unimportant 1/5

D. Slightly less important 1/3   E. Equally important 1/1   F. Slightly more important 3/1

G. Relatively important 5/1   H. Quite important 7/1   I. Extremely important 9/1.

5. Engel's coefficient vs. *per capita* disposable income of urban residents? (   )

A. Extremely unimportant 1/9   B. Quite unimportant 1/7   C. Relatively unimportant 1/5

D. Slightly less important 1/3   E. Equally important 1/1   F. Slightly more important 3/1

G. Relatively important 5/1   H. Quite important 7/1   I. Extremely important 9/1.

6. Engel's coefficient vs. registered urban unemployment rate? (   )

A. Extremely unimportant 1/9   B. Quite unimportant 1/7   C. Relatively unimportant 1/5

D. Slightly less important 1/3   E. Equally important 1/1   F. Slightly more important 3/1

G. Relatively important 5/1   H. Quite important 7/1   I. Extremely important 9/1.

7. Engel's coefficient vs. ratio of local fiscal revenue to GDP? (   )

A. Extremely unimportant 1/9   B. Quite unimportant 1/7   C. Relatively unimportant 1/5

D. Slightly less important 1/3   E. Equally important 1/1   F. Slightly more important 3/1

G. Relatively important 5/1　　H. Quite important 7/1　　I. Extremely important 9/1.

8. *Per capita* disposable income of urban residents vs. registered urban unemployment rate? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　　H. Quite important 7/1　　I. Extremely important 9/1.

9. *Per capita* disposable income of urban residents vs. ratio of local fiscal revenue to GDP? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　　H. Quite important 7/1　　I. Extremely important 9/1.

10. Registered urban unemployment rate vs. *ratio* of local fiscal revenue to GDP? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　　H. Quite important 7/1　　I. Extremely important 9/1.

- What is the relative importance of the following group of factors to "structural optimization?"

1. Ratio of value added by the tertiary sector to GDP vs. ratio of value added by the high-tech industry to industrial value added? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　　H. Quite important 7/1　　I. Extremely important 9/1.

- What is the relative importance of the following group of comparison factors to "innovation potential?"

1. Ratio of expenditure on R&D to fiscal expenditure vs. number of valid invention patents per 10,000 population? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following groups of comparison factors to "environment management?"

1. City air quality compliance rate vs. rate of good quality surface water? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. City air quality compliance rate vs. multipurpose utilization rate of industrial solid wastes? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

3. City air quality compliance rate vs. *per capita* parks and green space? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

4. City air quality compliance rate vs. water consumption per RMB 10,000 GDP? (   )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

5. City air quality compliance rate vs. annual energy consumption per capita? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

6. rate of good quality surface water vs. multipurpose utilization rate of industrial solid wastes? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

7. rate of good quality surface water vs. *per capita* parks and green space? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

8. Rate of good quality surface water vs. water consumption per RMB 10,000 GDP? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

9. Rate of good quality surface water vs. annual energy consumption *per capita*? (　　)

A. Extremely unimportant 1/9　B. Quite unimportant 1/7　C. Relatively unimportant 1/5

D. Slightly less important 1/3　E. Equally important 1/1　F. Slightly more important 3/1

G. Relatively important 5/1　H. Quite important 7/1　I. Extremely important 9/1.

10. Multipurpose utilization rate of industrial solid wastes vs. *per capita* parks and green space? (　　)

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

11. Multipurpose utilization rate of industrial solid wastes vs. water consumption per RMB 10,000 GDP? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

12. Multipurpose utilization rate of industrial solid wastes vs. annual energy consumption *per capita*? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

13. *Per capita* parks and green space vs. water consumption per RMB 10,000 GDP? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

14. Per capita park green space vs. annual energy consumption *per capita*? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

15. Water consumption per RMB 10,000 GDP vs. annual energy consumption *per capita*? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following groups of factors to "key infrastructure?"

1. Density of public transport network vs. urban gas penetration rate? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

2. Density of public transport network vs. internet penetration rate? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

3. Urban gas penetration rate vs. internet penetration rate? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1.

- What is the relative importance of the following group of factors to "social integration?"

1. Civic engagement vs. number of resident organizations and stakeholder alliances of government, business and social groups? ( )

A. Extremely unimportant 1/9 B. Quite unimportant 1/7 C. Relatively unimportant 1/5

D. Slightly less important 1/3 E. Equally important 1/1 F. Slightly more important 3/1

G. Relatively important 5/1 H. Quite important 7/1 I. Extremely important 9/1

Appendix III Initial Database of Resilient City Assessment Indicators for Changsha (2007-2016)

Topic	Indicator Name	Units	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Education	Teacher-student ratio		0.081	0.081	0.078	0.077	0.075	0.074	0.073	0.074	0.07	0.07
	Ratio of educational expenditure to total local government expenditure	%	14.38	14.92	15.01	13.37	13.89	18.68	16.92	15.71	15.62	15.05
	Number of higher education graduates per 10,000 population	1/10,000	276.5	320.8	314	295.5	295.1	305.4	301.5	270.1	260	260.1
Health	Average life expectancy	Years	77.88	78.06	77.04	76.01	78.66			76.91	77.14	77.38
	Number of physicians per 10,000 population	1/10,000	21.3	24.0	25.8	25.9	26.9	28.2	31.8	33.3	34.4	35.7
	Number of hospital beds per 10,000 population	Beds/10,000 people	46.3	54.0	62.6	60.5	66.3	71.8	80.2	87.0	88.9	93.3
Social Security	Percent population with basic endowment insurance coverage	%	55.1%	55.7%	58.1%	56.5%	60.1%	64.8%	54.4%	55.3%	57.0%	57.9%

Topic	Indicator Name	Units	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	Ratio of fiscal expenditure on social security to total fiscal expenditure	%	11.3	12.65	12.57	10.52	9.97	8.58	7.22	6.95	7.35	7.96
	Number of minimum living allowance recipients	10,000 people	29.85	24.49	29.31	28.7	26.43	25.27	24.23	21.56	19.87	17.55
Social Equality	Coverage rate of government-subsidized housing	%	12.49%	13.12%	15.73%	17.94%	16.85%	18.52%	19.62%	20.27%	20.84%	20.67%
	Housing price-to-income ratio		5.9	6.37	5.83	8.36	7.76	6.68	8.37	8.94	7.21	6.75
Economic Prosperity	*Per capita* GDP	RMB	33711	50846	57271	67212	80441	91025	100906	109195	117076	124122
	Engel's coefficient	%	34.88	36.88	32.29	34.14	35.96	36.3	29.49	26.45	26.01	24.95
	Per capita disposable income of urban residents	RMB	16153	18282	20238	22814	26451	30288	33662	36826	39961	43294
	Registered urban unemployment rate	%	3.12	3.41	3.47	2.89	2.86	2.88	2.89	2.85	2.6	2.74
	Ratio of local fiscal revenue to GDP	%	10.08	10.26	10.72	11.01	10.32	10.52	10.36	10.95	11.53	11.00
Structural	Ratio of value added by the tertiary sector to	%	47.9	44.0	44.6	41.9	39.6	39.6	40.5	41.6	45.8	47.8

Topic	Indicator Name	Units	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Optimization	GDP											
	Ratio of value added by the high-tech industry to industrial value added	%	43.8	44	41.8	34.34	38.33	39.9	44.72	62.43	72.9	76.95
Innovation Potential	Ratio of expenditure on R&D to fiscal expenditure	%	3.43	3.66	3.43	3.3	2.96	2.68	2.88	2.8	2.61	2.36
	Number of valid invention patents per 10,000 population	Patents/10,000 people	6.1	7.0	9.0	13.0	13.8	20.9	20.3	21.6	26.5	25.8
Environmental Management	City air quality compliance rate	%		89.89	91.23	92.58	93.4	90.7	56.7	62.2	70.7	73
	Water quality compliance rate for functional areas of urban water environment	%	62.5	70.5	82.5	87.50%	88.3	86.2	77.6	75.9	80.6	92.9
	Multipurpose utilization rate of industrial solid wastes	%	95.02	89.65	90.62	99.73	98.42	91.5	86.47	85.51	86.15	95.2

Topic	Indicator Name	Units	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	Per capita parks and green space	m^2	4.81	5.31	5.64	5.29	5.75	5.66	5.71	6.16	6.40	6.50
	Water consumption per RMB 10,000 GDP	M^3/RMB 10,000	160	126	101	84	67	59	54	49	44	39
	Energy consumption per RMB 10,000 GDP	TCE/RMB 10,000	0.223	0.167	0.150	0.132	0.114	0.089	0.085	0.076	0.066	0.061
Key Infrastructure	Density of public transport network	Km/Km^2	0.42	0.42	0.47	0.49	1.49	1.52	1.62	1.63	1.65	2.10
	Urban gas penetration rate	%	22.92	22.54	39.59	40.29	50.68	53.38	61.17	63.76	47.03	49.92
	Internet penetration rate	Households/1 Million People	32.9	26.3	31.6	36.9	38.4	45.1	47.8	50.4	56.6	69.1
Social Integration	Civic engagement		2.78	2.78		3.89	3.89	3.89	3.89	3.89	2.78	3.33
	Membership of civic health organizations, socially advocacy organizations, commercial associations and other specialized organizations, trade unions	10,000 people	6.81	7.03	7.59	8.12	7.02	7.05	7.58	7.39	9.35	9.64

Topic	Indicator Name	Units	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	and political groups											
Emergency Management	Presence of emergency command information platforms		0	0	0	0	0	1	1	1	1	1

Acknowledgements

As I typed in the last word of my doctoral thesis, marking the imminent completion of another important milestone in my life, I couldn't help but recall the joy of returning to Bauhaus University six years ago. At that time, I had no idea of what an "excruciating" future I had ahead of me — the all-inclusive resilience research was so overwhelming that selecting a proper research direction was like looking for a needle in a haystack. I went back and forth between China and Germany a dozen times in an attempt to close the gaps with my supervisor in space and time…

Over the past six years, we have organized multiple academic exchanges between the School of Architecture, Hunan University and Bauhaus University. In August 2013, the international seminar "the Mechanism of Spatial Structure Evolution in Chinese and German Cities and Regions and its Evaluation" was held in Hunan University; in June 2014, the workshop "Ideal Spatial Planning against the Background of Crises, Urbanization and Governance Innovation" was held in Bauhaus University. These exchanges were aimed at introducing emerging issues, the latest theories, and successful practices in Chinese and German urbanization development and planning to scholars, doctoral students and undergraduates in both countries. Thanks to these exchanges, I finally figured out my research direction.

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May one remain a young boy after a journey of half one's life! I would like to use this sentence to remind me to remember my childhood dream and inspire myself to forge ahead in the future!

Announcement

Ich erkläre hiermit ehrenwörtlich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen order Hilfsmittle benutzt habe.

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Changsha, 12.12. 2018