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Analysis of Urban Resilience in Water Network Cities Based on Scale-Density-Morphology-Function (SDMF) Framework: A Case Study of Nanchang City, China

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Abstract: In the face of increasing disturbance factors, resilience has become an important criterion for measuring the sustainable development of cities. Quantitatively describing the development process of urban resilience and identifying key areas and important dimensions of urban resilience are of scientific significance for understanding the evolutionary law of urban resilience, guiding regional risk prevention, and building an environment for urban resilience development. For this study, taking Nanchang City as a case study and dividing the natural water network groups, the resilience index system was constructed from scale, density, morphology, and function by drawing on the theory of landscape ecology on the basis of considering the internal relationship between urban development attributes and disturbance factors. On this basis, the study focuses on the evolution process and development differences of resilience in various dimensions from the water network groups and quantitatively describes the coordinated development status and adaptive phase characteristics of urban resilience. This study not only enriches the research scale and perspective of urban resilience but also provides specific spatial guidance for formulating resilient urban planning and promoting sustainable urban development.

Keywords: scale-density-morphology-function (SDMF); coupling coordination model; adaptive cycle theory; urban resilience; Nanchang City

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1. Introduction

With the acceleration of urbanization, large-scale populations flow from rural areas to urban areas, and urban construction space continues to expand [1]. Cities also are gradually becoming major forces, influencing and changing global and regional social and environmental conditions [2]. Rapid urbanization plays a vital role in pooling high-quality human capital and promoting social prosperity. At the same time, the uncertainty and unknown risks faced by urban systems have increased significantly with the acceleration of urbanization [3,4]. These uncertainties and unknown risks include not only the cumulative pressure brought about by the city's own development but also the acute shock from natural disasters [5,6]. A vast majority of the population in the 21st century lives in a dangerous networked reality. Sensitive and fragile urban systems, growing risk disturbances, and increasingly acute conflicts between people and land pose great threats to the safety and quality of life of urban residents [7,8]. This phenomenon seriously restricts the survival and sustainable development of cities. As a new paradigm of safety science research, resilience has increasingly become one of the hot topics in regional sustainable development science [9,10]. Different international cities or regional organizations have generally noticed the importance of building a resilient environment and have begun to carry out relevant policy plans and incorporate them into practice [11–14]. The Habitat III New Urban Agenda focuses considerable attention on the need to improve urban resilience [15]. Cities such as

Rotterdam, Chicago, and Melbourne have proposed urban resilience development plans to combat climate change [16]. As the largest developing country in the world, China also will build resilient cities, improve urban governance, and strengthen risk prevention and control in the governance of megacities in its future development plans. While the uncertainties facing these regions may seem incomparable, they all see resilience as an effective way to advance urban safety and sustainability [17,18].

Resilience is an ambiguous concept that is widely used in various disciplines and different research fields. Their common feature describes the ability of the research object to withstand external pressure and absorb shocks, focusing on the compressive state of the object and recovery state after the shock, which is a typical concept of engineering resilience. Scholars generally believe that the concept of modern resilience mostly originated from ecology and research on complex adaptive systems [19]. In 1973, the ecologist Holling used the concept of resilience for the first time to describe the persistence of a system and its ability to absorb changes and disturbances and to measure the ability of an ecosystem to spontaneously reorganize after a disturbance [20,21]. During this period, the concept of resilience was further expanded, and its connotation not only focused on the ability to withstand pressure but also emphasized the adaptability and stability of the system [3]. Beginning in the 2000s, there was a "social shift" in the field of ecological resilience that incorporated theoretical constructs from the social sciences, including transitions and transformations, to explain multiple desirable pathways and evolved into what is now known as socioecological resilience [22,23]. Socioecological resilience argues that resilience should be seen not only as the recovery of the initial state of the system but also as the ability of complex socioecological systems to self-organize and adapt to stress and constraints [24]. Overall, the concept of resilience has gone through a process of deepening from the narrow sense of engineering resilience and ecological resilience to the broad sense of social and ecological resilience [20]. The research perspective has expanded from a single ecological perspective to multiple perspectives, including ecology, economy, society, and technology [25,26]. The focus of the research has changed from emphasizing the monomorphic equilibrium and polymorphic equilibrium of the system to a dynamic nonequilibrium state [27,28], and the exploration of the relationships among the internal elements of the system has changed from a simple linear to a complex nonlinear relationship [29,30].

In the 1990s, scholars began to integrate resilience theory with urban systems and used them to address the sustainable development of urban systems after disasters and environmental changes with the increasing uncertainty faced by cities [19]. Urban resilience also has become a popular academic topic in the field of urban planning [14,28,31,32]. At present, urban resilience research mainly focuses on three aspects. (1) Conceptual analysis of urban resilience. There is no complete consensus on the concept of urban resilience, which has been defined by different scholars from different perspectives. From the perspective of disaster management, some scholars regard resilience as a method to reduce losses and believe that urban resilience is the ability of urban systems to operate and effectively recover after disasters [33]. Although this concept emphasizes the organizational power of resilience to disasters and the systemic nature of cities, it still retains the connotation of engineering resilience. To this end, scholars and international organizations have integrated adaptability into the concept of urban resilience. It is generally believed that urban resilience refers to the ability of urban systems to absorb damage and reduce changes and impacts caused by disturbances, shocks, or natural disasters, and finally, adapt to these changes [9,22,32,34]. With the deepening of urban resilience research, the academic community has comprehensively defined the concept of urban resilience from the aspects of multielement systems [18,23], multi-dimensional resilience [35,36], and multiscale object systems [37–39]. In 2016, Meerow made a relatively complete and rigorous definition of urban resilience after systematically reviewing the relevant literature. He argues that urban resilience is the socioecological and sociotechnical network of urban systems and all their components across time and space scales to maintain or rapidly restore required functions, adapt to change, and rapidly transform system aspects that limit current or future resilience to interference [23]. This definition not only emphasizes the importance of temporal and spatial scales but also regards resilient cities as an ideal state, which has been widely used in many resilience studies [26,35,40,41]. (2) Quantitative measures of urban resilience. To better establish the connection between theory and practice and guide the scientific construction of resilient cities, scholars have developed a variety of tools and models to measure urban resilience from different perspectives. Among these measurement methods, the index system method for specific urban dimensions or specific disaster management is widely used, such as the economic resilience assessment model, community resilience assessment model, infrastructure resilience assessment model, and urban resilience for specific types of disturbances such as earthquakes, floods, and climate change [26,42]. Scholars also have proposed a comprehensive resilience assessment system for the entire urban system based on various dimensions. At the same time, under the background of disciplinary integration, multidisciplinary methods such as economic models [19], ecological methods [43,44], and system simulation [45,46] have been applied to urban resilience research, and the research perspective has been rapidly expanded. (3) Development strategies for resilient cities. Although academic circles have different definitions of the concept of urban resilience, there is a general consensus on the development strategy of resilient cities. They believe that versatility, redundancy and modularity, biological and social diversity, multiscale networks and connectivity, and adaptive planning and design should be the basic principles generally followed in the construction of urban resilience from the concept of resilience [32,47–49]. In the process of building a specific resilient urban environment, scholars have proposed specific paths, such as advocating green living and production methods [8,50], rationally configuring blue–green landscapes [35,51], strengthening public participation [52], adjusting urban institutional structure and development policies [53], optimizing urban forms [17] and improving infrastructure construction [38]. Overall, the research literature on urban resilience has mostly focused on the concept of urban resilience and on specific cases of urban resilience construction. In terms of the quantitative measurement of urban resilience, urban disaster risk is the research object, and the ability of cities to respond to or adapt to natural disaster events is mostly discussed from the perspective of short-term engineering resilience. Additionally, cities are often used as the basic unit in the process of quantitative measurement, and less attention is given to the heterogeneity of the internal space of the city or the evolutionary characteristics on the temporal scale.

Scientifically quantified urban resilience can help effectively guide the actual construction of resilient cities. In this process, the identification of uncertainty factors is a key element in assessing urban resilience, and the limitations of data and tools also limit the development of resilience assessments [54]. At the same time, as a complex and open system, the nonlinearity, self-organization, and uncertainty of urban development, and the complexity and interaction of internal elements of the city, also increase the difficulty of the comprehensive assessment of urban resilience [55]. Urban resilience assessment urgently needs to introduce perspectives and methods from other subjects to enrich research perspectives and cases of urban resilience. Among these perspectives, landscape patterns are considered one of the most promising mediators for observing and intervening in urban resilience [44]. Landscape ecology theories and methods also are used in urban resilience assessments [7,43,44]. In view of this, this paper, based on the theory of evolutionary resilience, combined with the theory of landscape ecology and spatial analysis methods, constructs an analysis framework of urban resilience that integrates scale, density, morphology, and function. Starting from the internal heterogeneity of urban resilience and the coupling and coordination characteristics of resilience dimensions, this paper innovatively divides the basic units of urban water network groups, quantitatively measures the multi-dimensional resilience status and development characteristics of urban water network groups, and proposes differentiated resilience development strategies. The specific research objectives of this paper mainly include: (1) Clarifying the relationship between urban disturbance factors and urban development attributes, constructing urban scale, density, morphology, and function resilience analysis methods combined with landscape ecology theories and models. These constitute the framework for urban resilience assessment; (2) Combining the analysis framework with remote sensing image data, socioeconomic statistical data, and planning data quantitatively measures the dynamic evolution characteristics and identifies the key dimensions of Nanchang's urban resilience from the scale of water network group; (3) Based on the coupling coordination model, we quantitatively measure the coupling and coordination status of the resilience of each dimension in each water network group in Nanchang City. At the same time, we combine the adaptive cycle theory with the coupling coordination status to reveal the characteristics of the adaptive phase of the water network cluster and propose differentiated governance strategies for the resilience development of the water network groups at each adaptation phase. These specific goals provide relevant knowledge for city managers to understand the evolutionary laws of urban resilience, transform urban governance thinking and also enrich the scale and perspective of urban resilience research.

This article is structured as follows. This section provides an overview of the relevant research background and related research progress, followed by the theoretical framework. The materials and methods section details the data, sources, and methods required for this paper. The results show the evolution of urban scale, density, morphology, and function resilience at the water network cluster scale, probe the key dimensions of Nanchang's urban resilience, and analyze the adaptive phase and main development strategies of each water network unit. The discussion part explains the background and reasons for choosing the scale of water network clusters, analyses the advantages and functions of urban resilience from the perspective of landscape patterns, and considers the relevant deficiencies and future prospects of this research. Finally, the conclusion section summarizes our findings and their implications for urban resilience governance.

2. Theoretical Framework

A city is a dynamic, open system that not only includes the complex evolution of man–land relationships but also the spatiotemporal coupling process of internal elements [56,57]. From the perspective of man–land coupling relationships, humans have an impact on the urban environment by changing the landscape structure and function, and the urban environment offers feedback on human activities through the effect of landscape pattern evolution [58]. Therefore, the landscape pattern can be regarded as the spatial medium of human activities acting on the urban area. Its process can not only reflect the growth and development of urban regional structure but also reflect the intensity of human activities in the urban area [14,44]. As an important material basis of urban systems, landscape patterns can be regarded as a bridge between human activities and sustainable urban development [59]. Human activities have promoted the transformation of urban and rural landscapes. The disorderly expansion of construction land and high-intensity development continue to compress the space suitable for construction land and further increase the sensitivity and vulnerability of the ecosystem [50,60]. These phenomena directly lead to the loss of scale resilience of cities, which is a major challenge for sustainable land use [61]. The high agglomeration of socioeconomic factors in urban areas results in a significant increase in urban density, which can easily disrupt the natural flow of energy and resources between man-made and natural environments [62,63]. At the same time, the contradiction between supply and demand between ecological carrying capacity and ecological footprint also will affect the sustainability of ecosystem services provided by the environment [62], which not only increases the frequency and intensity of disturbance factors but also magnifies their adverse effects, which reduces the mitigation effect of urban density on disasters. Urban morphology is an important way to achieve sustainable and resilient cities [40,63], and the unreasonable allocation of built-up land and ecological space will weaken the permeability of ecological elements in the built environment, reducing the mitigation power of interference and the robustness of the system; this is not conducive to the improvement of the resilience level of urban morphology [4]. The simplification of urban functions easily breeds potential risks, and diversified functions easily meet the diverse needs of the urban system. The richer the types of urban ecological functions are, the stronger the interactions between various functions, and the less likely the urban system will collapse under the risk effect. Scale and density resilience constrain urban scale and density through ecological sensitivity and ecological carrying capacity. Morphology and function resilience reshape and guide urban morphology and function through disaster events.

As a complex of multi-dimensional elements, the resilient development of a city is not determined by a single dimension but by the overall coupling of urban element dimensions [26]. Urban disturbance factors (including the cumulative pressure of its own development and the acute impact of natural disasters) exert pressure on the urban man–land system. The urban man–land system also responds to disturbance factors. There are significant differences in the reflections and results of this interaction between different regions in the process of dynamic urban development. Urban areas with a high-level coupling of dimensions can gradually alleviate and overcome the adverse impact of disasters and even take this opportunity to achieve longer-term development. This type of area has a strong ability to adapt and adjust. In the face of this situation, urban areas that are in an uncoordinated (including transitional, developmental status) or low-level coupling state will show a lagging response-ability and insufficient adaptability. After encountering an adverse impact, it will further amplify or accelerate the consequences of the disaster impact and make the city prone to a slump in development. To this end, this paper divides the dynamic process of urban resilience into four phases: release, conservation, exploitation, and reorganization combined with the adaptive cycle model. It corresponds to the adaptive cycle phase one by one according to the coupling and coordination state of the urban system and its influence. We believe that in the low-level coupling state, the level of each dimension of resilience is very low, leaving the entire urban system in a highly sensitive state, and the system's ability to adjust and adapt to disturbance factors is seriously insufficient. The development of urban resilience is in the release phase. In the transitional state, the coupling level of each dimension of resilience is low, and the urban system shows insufficient flexibility and low potential in the face of disturbance. The urban resilience system is in the conservation phase. In the developmental state, the degree of coupling and coordination of system resilience is good, the overall resilience level is high, and the city is in the exploitation phase. However, after long-term development, cities are prone to gradually appear incompatible, the potential of the system declines, the cumulative risk increases, and it is easy to enter the release phase. In a high-level coupling state, resilience elements are in a highly coupled state, urban functions and structures are complete, and high potential and adaptation are important foundations for alleviating external disturbances during this period. The urban resilience system is in the reorganization phase of the adaptive cycle.

Based on the above theoretical analysis (Figure 1), this paper constructs an analysis method for urban scale, density, morphology, and function resilience from the perspective and model of landscape ecology and uses the coupling coordination degree to reveal the development status and adaptive phase characteristics of urban resilience. In contrast, this method further expands the perspective of urban resilience research, simplifies the complex steps of previous urban resilience research, and breaks through the content of single-dimensional urban resilience research. This provides differentiated strategies for achieving resilient development within cities based on the identification of the resilient development status and adaptive phase characteristics within the city.

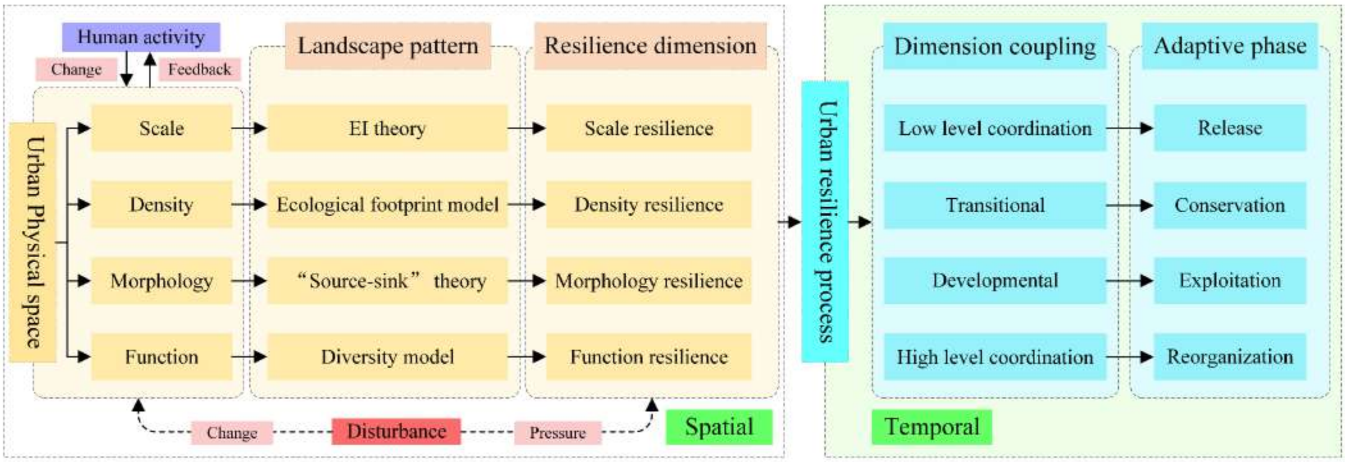


Figure 1. Theoretical framework for urban resilience based on the perspective of landscape pattern.

3. Materials and Methods

3.1. Study Area and Data

Nanchang is located in East China. It is the capital city of Jiangxi Province and the core city of the urban agglomeration in the middle reaches of the Yangtze River (Figure 2a). In 2020, the permanent population in the urban area was 6.255 million, the built-up area was 465 km^2, and the total urban production was CNY 574.551 billion. Nanchang City has many water network areas that constitute a natural river system, such as the Ganjiang River, Fuhe River, Yudai River, and Jinjiang River crisscrossing the territory. There are many lakes, including Qingshan Lake, Aixi Lake, Junshan Lake, and nearly 100 other large and small lakes. Nanchang City is adjacent to Poyang Lake and is the apex city of the Ganjiang Delta (Figure 2). Overall, the pattern of "riverside, adjacent lake, and multiple waters" created the background characteristics of Nanchang's landscape of "city in the lake, lake in the city". It belongs to a typical water network city in southern China. At the same time, after experiencing "cross-river development", administrative division adjustments, and metropolitan development strategies, the scale and density of urban social and economic factors have been significantly increased. Due to the resulting uncertainty, perturbation factors have increased significantly, such as heat waves, floods, traffic jams, crimes, etc. The ever-increasing scale of cities has gradually destroyed the background of natural landscapes and threatened regional ecological security, resulting in a further increase in ecological sensitivity. As Nanchang is a fast-growing water network city, the comprehensive urban governance and resilient environment construction of Nanchang City has become more urgent under the synergistic influence of its landscape background and diversity of disturbance factors, particularity of geographic location, high concentration of social and economic factors, and need for rapid urban development.

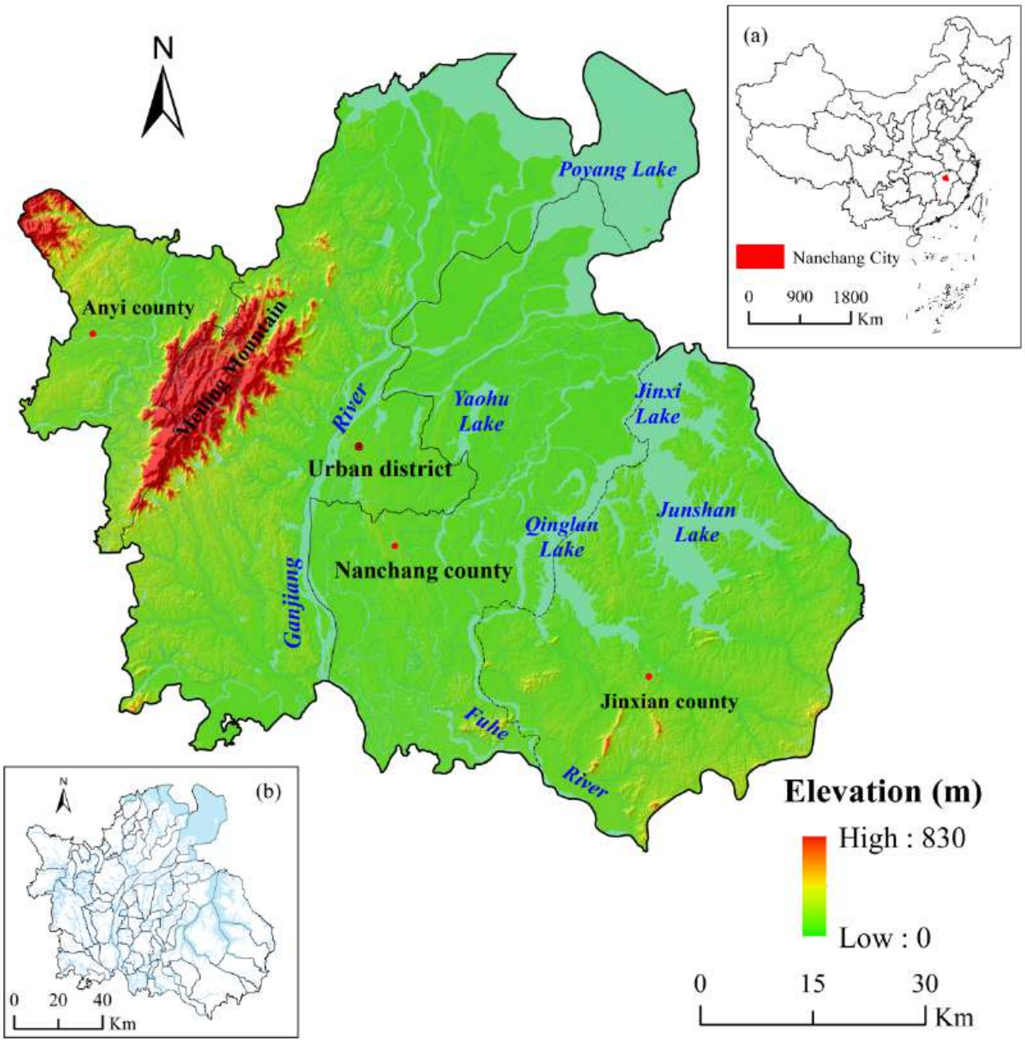


Figure 2. Location (**a**) and site evaluation units (**b**) of the study area.

To accurately present the characteristics of resilience evolution in various dimensions within the city and to identify the phases of resilience development of different organizational units, this paper uses the SWAT model to divide the region into 75 basic water network group units (Figure 2b) based on the DEM and water system of Nanchang City. In this study, the data required to calculate urban resilience indicators included remote sensing images, DEM data, water network data, population density data, land-use data, and socioeconomic statistics. The data sources are shown in Table 1.

Table 1. Sources of study area data.

Data	Source	Accuracy
Landsat Remote Sensing Image Data	Geospatial Data Cloud (China) (http://www.gscloud.cn/, accessed on 15 May 2021)	30 m
DEM Data	Chinese Academy of Sciences Resource and Environmental Data Center (http://www.resdc.cn/, accessed on 21 July 2021)	30 m
Population Density Data	WorldPop (https://www.worldpop.org/, accessed on 7 December 2020)	100 m
Urban Resources and Energy Utilization	China Economic and Social Development Statistics Database (http://tongji.cnki.net/kns55/navi/navidefault.aspx, accessed on 16 September 2021)	-
Nanchang water network Data	Gaode Map (https://www.amap.com/, accessed on 9 November 2021))	Vector
Suitable construction area	Nanchang Municipal Bureau of Natural Resources and Planning (http://bnr.nc.gov.cn/ncszrzyj/index.shtml, accessed on 24 October 2021)	Vector

3.2. Methods

In the context of rapid urbanization, urban sprawl has led to the densification of construction land landscapes. The contiguous expansion of built-up areas has accelerated the transformation of cultivated land into non-agricultural land, accelerated the compression of green space, decreased ecosystem connectivity, and weakened service capabilities. Faced with the continuous pressure of urban disaster-causing factors, the city's adaptability and resilience have declined, and the level of urban resilience development is insufficient. In the process of urban development, urban scale, density, morphology, and function are considered to be important dimensions of resilient development. These four dimensions are unified in the city system. Moderate urban scale, reasonable urban density, excellent urban morphology, and functional pattern are considered to be effective paths to resolve acute shocks and chronic pressures in the process of urban development. From the perspective of landscape ecology and urban material space, this paper attempts to introduce concepts and theories such as ecological infrastructure, ecological footprint, "source-sink" model, and diversity. An index model of urban scale, density, morphology, and function resilience was built and formed a "four-dimensional integration" evaluation system for comprehensive urban resilience. On the whole, the assessment framework constructed measures the comprehensive resilience development trend of cities from the perspectives of supply and demand, redundancy, and adaptation, and simplified the traditional complex steps of disaster identification and post-disaster recovery. At the same time, in order to further determine the coupling status and stage characteristics of the resilience of various dimensions within the city, a comprehensive measurement is carried out by referring to the coupling coordination model.

3.2.1. Scale Resilience Model

Based on the theory of ecological infrastructure and landscape security patterns in landscape ecology, many scholars generally believe that when the city scale exceeds or encroaches on the service scope of ecological infrastructure (EI), the city's ability to cope with disasters and its ability to recover will be impaired. Urban resilience development encounters a bottleneck [43]. This paper defines urban scale resilience based on the proportional relationship between the scope of urban construction areas and suitable construction areas under the constraints of ecological infrastructure. The scale resilience model can be written as:

$$SR_i = L_i / C_i \tag{1}$$

where SR_i is the scale resilience index of Group i. L_i and C_i are the suitable construction land area and actual construction land area in Group i, respectively. The larger the scale resilience index is, the lower the degree of urban construction land encroachment on EI and the stronger the urban resilience and adaptability.

3.2.2. Density Resilience Model

The density of urban human activities directly affects the sustainable development level of the ecosystem. The greater the density of human activities is, the greater the pressure on the natural environment, the higher the possibility of an unbalanced human–land relationship, and the weaker the sustainable development ability. The ecological footprint theory compares the relationship between the demand for the ecological footprint of human activities and the carrying capacity of the ecosystem from the perspective of supply and demand to characterize the state of regional sustainable development [3,64]. This paper uses ecological footprint theory to construct the urban density resilience index. The density resilience model can be written as:

$$DR_i = \frac{EC_i * (1 - 12\%)}{EF_i} = \frac{(1 - 12\%) * \sum R_k \times Y_k \times A_{ik}}{P_i * \sum R_k \times C_j / W_j} \tag{2}$$

where DR_i is the density resilience index of Group i. EC_i is the ecological carrying capacity of Group i. EF_i is the ecological footprint of Group i. R_k and Y_k are the equilibrium factor and yield factor of the productive land of type k, respectively. A_{ik} is the area of productive land of type k in Group i, P_i is the population in Group i, C_j is the per capita consumption of commodity j in Group i, and W_j is the global average output of type j consumer goods. Referring to existing research [43], six types of production land use, including cultivated land, forest land, grassland, water area, construction land, and fossil energy land, are used in the calculation of ecological footprint. According to the Nanchang Statistical Yearbook, 14 types of material consumption and fossil energy consumption, such as grain, edible vegetable oil, fresh vegetables, liquor, melons and fruits, tea, pork, beef and mutton, fresh eggs, poultry, fresh milk, aquatic products, energy consumption, and electricity are converted into 6 types of production land use. Due to the differences in the ecological productivity of the six types of production land use, this paper selects the equilibrium factor and the yield factor with reference to the existing studies on the ecological footprint of Nanchang City [65]. At the same time, according to the World Commission on Environment and Development (WCED) report, 12% of the ecological carrying capacity is used to protect biodiversity. Through the above analysis and comprehensive calculation, the per capita ecological footprint in 2000, 2010, and 2020 was 0.481, 0.548, and 0.752, respectively (Table 2). The smaller the density resilience index is, the greater the ecological deficit and overload phenomenon in the group, the less resilient the urban development, and the lower the potential for sustainable urban development.

Table 2. Per capita ecological footprint calculation of Nanchang City.

Land Use	**Equilibrium Factor**	**Yield Factor**	**Demand Area (ha/per Capita)**			**Equilibrium Area (ha/per Capita)**		
			2000	**2010**	**2020**	**2000**	**2010**	**2020**
Cultivated land	2.800	2.030	0.093	0.071	0.062	0.259	0.199	0.175
Forest land	1.100	1.900	0.009	0.009	0.014	0.010	0.010	0.015
Grass land	0.500	0.370	0.261	0.369	0.582	0.131	0.184	0.291
Water	0.200	2.300	0.258	0.391	0.681	0.052	0.078	0.136
Construction land	1.100	1.800	0.023	0.063	0.117	0.025	0.069	0.129
Fossil energy land	2.800	0.000	0.001	0.003	0.002	0.004	0.008	0.007
Per capita integrated Ecological footprint			Deduction of 12% of biodiversity area			0.481	0.548	0.752

3.2.3. Morphology Resilience Model

Excellent urban morphology plays an important role in alleviating the acute shock and chronic pressure of the city. Scholars generally believe that the "source–sink" theory provides a new perspective for measuring the layout of urban morphology. From the perspective of the "source–sink" theory and the generation process of urban disasters, the grey landscape (construction land) is the main area where urban disasters occur, and it belongs to the "source" landscape. Blue–green landscapes (waters, woodlands, grasslands) have a mitigating effect on urban disasters (flooding, heat islands, etc.), and they belong to "sink" landscapes [35,43]. This paper measures urban morphological resilience from the perspective of the balance of "source" and "sink" landscape spatial characteristics. The morphology resilience model can be written as:

$$MR_i = \frac{L}{L_i} = \frac{L}{\sum\limits_{j=1}^{n} \min\left(D_{ijk}\right)/m} \tag{3}$$

where MR_i is the morphology resilience index of Group i. L_i is the average distance index from the "source" patch to the "sink" patch in Group i. D_{ijk} represents the distance from the grid of "source" patch j in Group i to the grid of "sink" patch k in the region. m, n are the grid number of "source" patches and the grid number of "sink" patches in Group i, respectively. L is a constant, indicating the average distance index between the "source" landscape and the "sink" landscape in the region. The larger the value of MR_i is, the better the spatial balance of the "source" and "sink" landscapes and the stronger the urban morphology resilience. Among them, the calculation of L_i is mainly realized through the ArcGIS 10.2 software (ERSI, Redlands, CA, USA) platform. The specific process is as follows. Firstly, the surface landscape of the study area is divided into two basic types: "source" and "sink" landscape by the Clip Tool. Secondly, the surface landscape of the study area is rasterized by the Polygon to Raster Tool, and the grid precision is 30 m. We believe that the study area is composed of grids of the same scale; the grid can measure the length and area. The interior of the "source" patch and the "sink" patch contains several such grids. Finally, the distance from each grid inside a "source" patch to the nearest "sink" patch grid uses the Near Tool. To calculate, add up first and then divide by the grid number of the "source" patch. The average distance index of the "source" patch can be obtained.

3.2.4. Functional Resilience Model

Cities are complex systems with organic combinations of various functions. Versatility also is recognized as one of the important strategies for building resilient cities. From the perspective of ecosystem services, the system's functions and its diversity levels, such as climate regulation, water conservation, soil conservation, and environmental purification, played an important role in alleviating disasters and strengthening the system's self-organization level [32]. The concept of diversity in landscape ecology provides a methodological reference for measuring urban functional resilience. Referring to related research on the ecosystem function of Nanchang [66], this paper constructs the urban functional resilience index from the perspective of diversity. The functional resilience model can be written as follows:

$$FR_i = -\sum_{j=1}^{m} \left(F_{ij} * \ln F_{ij}\right) \tag{4}$$

where FR_i is the functional resilience index of Group i. F_{ij} is the ratio of the value of j-type ecosystem services to the value of the overall ecosystem services in group i. From the perspective of ecosystem service value, this paper selects 9 types of ecosystem service functions, including gas regulation, climate regulation, water conservation, soil formation and protection, waste disposal, biodiversity conservation, food production, raw materials, and entertainment culture. Based on the land use data of Nanchang City, referring to the setting of the service value coefficients of various ecosystems in relevant studies (Table 3), the value of various functions and their proportions in each group area were measured. The larger the value of FR_i is, the richer the types of ecological functions, the stronger the interactions between various functions, the less likely the urban system will collapse under the risk effect, and the stronger the urban functional resilience.

Table 3. Ecosystem service value coefficient of land use types in Nanchang City (Yuan/hm^2·a).

Ecosystem Service Function	Cultivated Land	Forest Land	Grass Land	Water	Construction Land	Unutilized Land
Gas regulation	1691.590	11,841.100	2706.540	0.000	0.000	0.000
Climate regulation	3011.020	9134.560	3044.850	1556.260	0.000	0.000
Water conservation	2029.900	10,826.140	2706.540	68,949.000	0.000	101.500
Soil formation and protection	4939.430	13,194.360	6597.180	33.830	0.000	67.660
Waste disposal	5548.400	4431.950	4431.950	61,506.030	0.000	33.830
Biodiversity conservation	2402.050	11,029.130	3687.660	8424.090	0.000	1150.280
Food production	3383.170	338.320	1014.950	338.320	0.000	33.830
Raw materials	338.320	8796.240	169.160	33.830	0.000	0.000
Entertainment culture	33.830	4330.460	135.330	14,682.960	0.000	33.830

3.2.5. Coupling Coordination Degree Model

Scale, density, morphology, and function are the basic attributes of a city's dynamic development. The organic combination of the four can be used to reflect the development status of the city from the perspective of urban physical space. Therefore, coupling and coordination among the four subsystems of scale, density, morphology, and function are required in the process of realizing urban resilience development. In this paper, the score values of each subsystem are subjected to range standardization, and the coupling principle in physics is used to quantitatively measure the coupling coordination degrees among scale resilience, density resilience, morphology resilience, and functional resilience in the process of dynamic urban development. In this way, the state and phase of urban resilience development can be accurately judged. The coupling coordination degree model can be written as [67,68]:

$$CCD_i = \sqrt{C_i \cdot U_i} \tag{5}$$

$$C_i = 4 \times \left[\frac{SR_i \cdot DR_i \cdot MR_i \cdot FR_i}{(SR_i + DR_i + MR_i + FR_i)^4} \right]^{\frac{1}{4}} \tag{6}$$

$$U_i = a \cdot SR_i + b \cdot DR_i + c \cdot MR_i + d \cdot FR_i \tag{7}$$

where CCD_i is the coupling coordination degree of Group i, which belongs to [0, 1]. C_i and U_i are the coupling index and coordination degree of Group i, respectively. SR_i, DR_i, $MR_{i,}$ and FR_i are the scale, density, morphology, and functional resilience index of Group i, respectively. a, b, c and d are undetermined coefficients. According to related research, scale and density resilience dominate the development of comprehensive urban resilience, while morphology and function resilience can accelerate or hinder the mitigation or adaptation of urban risks [43,68]. Therefore, this paper assigns a, b, c and d as 0.3, 0.3, 0.2, and 0.2, respectively.

4. Results

4.1. Evolution Characteristics of Scale Resilience in Nanchang City

The scale resilience indices of each groups area in Nanchang City under the 3 time periods of 2000, 2010, and 2020 were calculated by using Formula (1), and 50%, 100%, and 150% of the average scale resilience of Nanchang City in 2000 were used as the critical values. The resilience index of each group in Nanchang is divided into four categories, low, medium-low, medium-high, and high resilience levels (Figure 3), and the characteristics of the resilience evolution of each group in Nanchang are discussed.

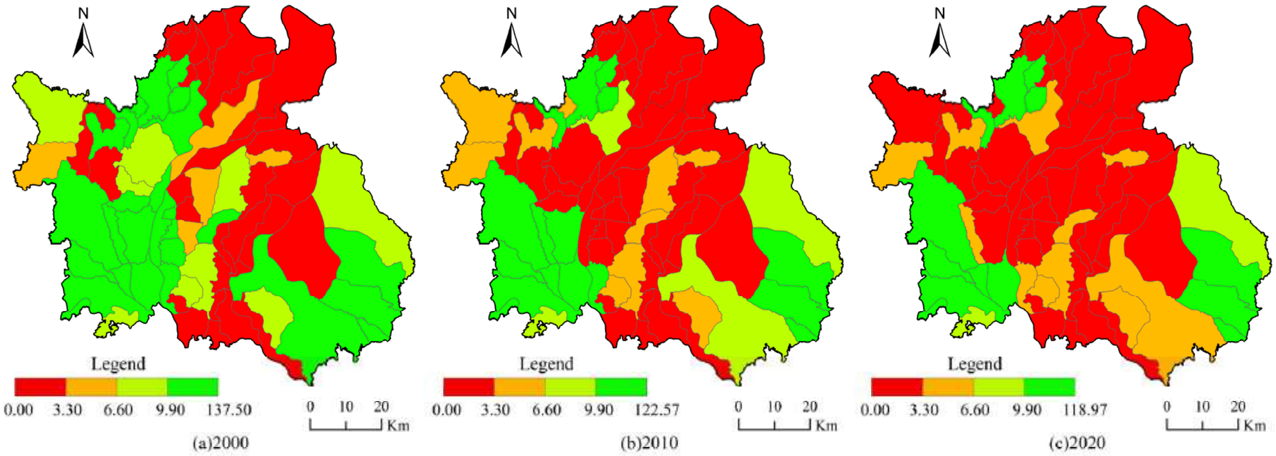


Figure 3. Spatial evolution of scale resilience of Nanchang City based on water network group.

The average scale resilience index of Nanchang City dropped from 6.6 to 2.7, and the maximum value of scale resilience dropped from 137.50 to 118.97. The changes in these two indicators indicate that the scale resilience level of Nanchang City showed a decline. The scale safety constraints faced by urban development have gradually become prominent. In the context of accelerating urbanization, the number of high-level resilience clusters in Nanchang has rapidly decreased from 27 to 13, and correspondingly, the number of low-level resilience clusters has risen from 34 to 49. The spatial distribution of scale resilience shows that the resilience of various clusters in Nanchang has the characteristics of spatial agglomeration. Its spatial pattern has gradually expanded from the Poyang Lake area in northern Nanchang City and the coastal area along the Ganjiang River in the central area to the Meiling Mountain area in the west and the Yaohu Lake–Qinglan Lake–Jinxi Lake–Junshan Lake area in the east. The scope of low-level resilience in the central urban area continues to expand. The high-level resilience zone changed from a two-cluster pattern to a multicluster pattern, and its spatial scope continued to shrink during the study period. Under the strategy of retreating counties and merging districts and the city's cross-river development strategy, Nanchang City's urban construction land continued to expand, the construction land in the central city area gradually became saturated, and land resource conditions became more restrictive. The southward development strategy of the city not only provides construction space for the subsequent development of the city but also effectively shares the city scale risk of Nanchang. Within the scope of ecologically sensitive areas and urban construction prohibited areas, tourism development and rural settlement expansion have further compressed the blue–green (lake, woodland, and grassland) ecological space. The severe fragmentation of the ecosystem and the continuous loss of ecological service functions will become important factors restricting the development of urban resilience.

4.2. Evolution Characteristics of Density Resilience in Nanchang

The ecological footprint demand and ecological footprint supply of each group are calculated based on the ecological footprint model. The density resilience model (Formula (2)) was used to measure the density resilience index of each group in Nanchang. Taking 50%, 100%, and 150% of the average density resilience of Nanchang in 2000 as critical values, the density resilience index of each cluster in Nanchang is divided into four categories: low, medium-low, medium-high, and high resilience levels (Figure 4). We use it to summarize the temporal-spatial characteristics of the density resilience of the urban group divided by the water network.

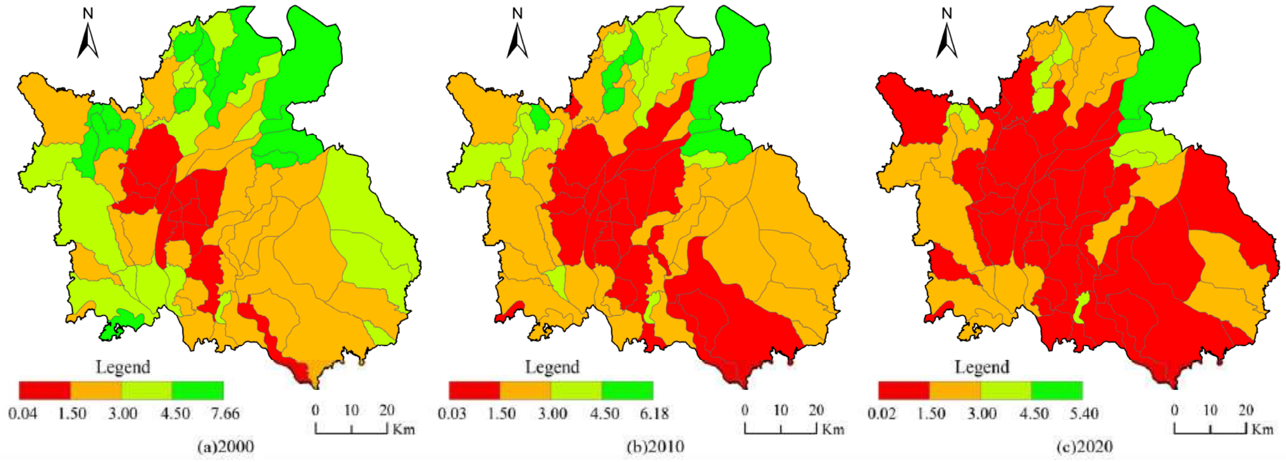
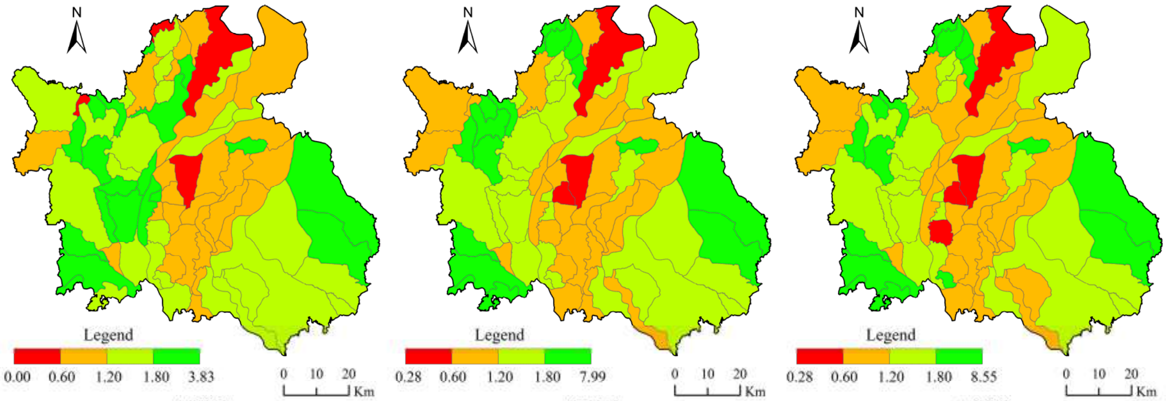


Figure 4. Spatial evolution of density resilience of Nanchang City based on water network group.

During the study period, due to the increasing factors of population size, energy consumption, and construction land demand, the overall ecological footprint of Nanchang City continued to increase, while the regional ecological carrying capacity showed a downward trend. Changes in the ecological footprint and ecological carrying capacity have led to the gradual emergence of ecological deficits and the continuous decline of the overall density resilience in Nanchang. During the study period, the maximum value of density resilience showed a significant decrease, and the minimum value changed little. From the perspective of the spatial distribution of density resilience, the low-level clusters of density resilience expand from the central city to the eastern and southern regions of Nanchang. This expansion pattern is closely related to the cross-river development of Nanchang City, the construction of the Changdong Industrial Zone, and the southward development strategy. The groups where Jinxian County and Anyi County are located were transformed into low-level resilient areas in 2010 and 2020, respectively. These groups have assumed the role of population interception in the central urban area, which is conducive to alleviating urban risks caused by density agglomeration. The groups of high-level density resilience shrink from the lower Fuhe River area in the south, the Meiling area in the west, and the lakeside area to only the lakeside area.

4.3. Evolution Characteristics of Morphology Resilience in Nanchang

According to the “source–sink” landscape theory, the urban construction land is set as the “source” landscape, and the forestland, grassland, and water area are classified as the “sink” landscape. Formula (3) is used to calculate the morphological resilience index of each group in Nanchang, where the average distance of the “source” and “sink” landscape is set as the average distance index between construction land and ecological landscape land in 2000, which is 479.39. Using the critical values of 50%, 100%, and 150% of the average morphological resilience of Nanchang in 2000, we divided the morphological resilience of each group into four types, low, medium-low, medium-high, and high toughness levels (Figure 5), to explore the temporal-spatial differentiation law of morphological resilience in Nanchang.



(a)2000 (b)2010 (c)2020

Figure 5. Spatial evolution of morphology resilience of Nanchang City based on water network group.

The average value of the urban morphology resilience index of Nanchang experienced a process of change that first declined and then rose, and the maximum value expanded from 2000 to 2020. The change in morphological resilience was closely related to the urban expansion pattern through the analysis of remote sensing images of Nanchang. The urban expansion model of Nanchang City was internal filling and marginal expansion from 2000 to 2010. The expansion area was concentrated on the banks of the Ganjiang River and the county seats of Anyi and Jinxian. Nanchang City had multiple modes of urban expansion from 2010 to 2020. Group development increased the accessibility of construction land to ecological space, and the urban development morphology was optimized. From the perspective of the spatial distribution of the morphological resilience index of each group, the low-level morphological resilience area extended from the northern lakeside and the old downtown in the middle to the new city cluster in the south. The low-medium resilience level area gradually expanded from the lakeside area to the south. The morphological resilience level of the group in the lakeside area dropped significantly, affected by the construction of the Binhu New Area. Meiling Mountain is an important ecological barrier area in Nanchang. During the study period, the resilience of its surrounding clusters also showed a downward trend affected by tourism development and rural settlement expansion. The suitable construction land in the central urban area was gradually depleted with the continuous development of urban construction on both sides of the Ganjiang River. The incremental construction space of the city was mainly concentrated in the area south of Nanchang. In the future, urban development should focus on the relationship between construction land and ecological space, strengthen the construction of ecological infrastructure, and take the initiative to create an urban morphology with a highly coupled "source" and "sink" landscape.

4.4. Evolution Characteristics of Function Resilience in Nanchang

We believe that the richer the regional ecosystem functions are, the stronger the interactions among the functions and the less likely the urban system will collapse under the risk effect. Formula (4) is used to calculate the functional resilience index of each group in Nanchang in 2000, 2010, and 2020. According to the distribution of the functional resilience index, the average value and the average ± one standard deviation value of Nanchang City in 2000 were selected as the critical value, and the functional resilience index of each group in Nanchang City was divided into four categories: low, medium-low, medium-high, and high resilience levels (Figure 6). We use this to discuss the evolution of functional resilience in Nanchang.

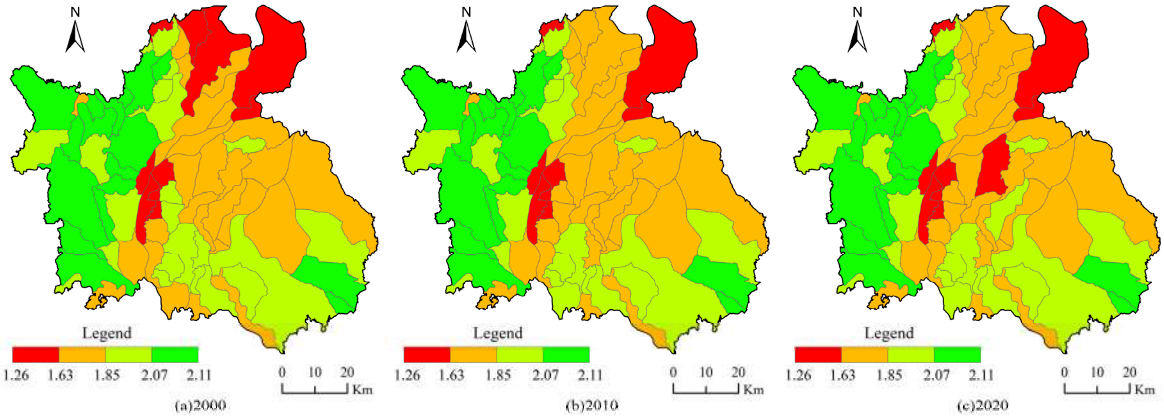


Figure 6. Spatial evolution of function resilience of Nanchang City based on water network group.

The functional resilience index of Nanchang has a downward trend, which is closely related to the loss of ecosystem services and the decline in diversity caused by changes in the urban landscape pattern. It is prominently manifested in the continuous expansion of urban construction land, which is continuously compressing the space of cultivated land, forest, and grassland. The functional resilience of groups in Nanchang City shows a pattern of east–west differentiation with the Ganjiang River as the boundary. The functional resilience level of the clusters east of the Ganjiang River is mainly low-medium. The groups in this area are mostly based on a single landscape type (water area, construction land). However, the single type of landscape and the concentration of distribution reduce the stability and safety of ecosystem functions. The low-level areas of functional resilience have gradually expanded from the lakeside area and central urban area in the north of the city to the group area around Yaohu Lake. The area to the west of the Gan River has relatively rich landscape types (woodland, grassland, waters, arable land), the ecosystem functions are stable, and the level of functional resilience is at a medium-high level. In the process of urban development and renewal in the future, we should pay attention to constructing a mosaic pattern of grey (construction land), blue–green (water, woodland, grassland), and yellow (arable land) landscapes to enhance the landscape diversity and functional stability in the group and improve the ecosystem's ability to mitigate urban risks.

4.5. The Comprehensive Evolution Pattern of the Resilience Subsystem in the Water Network Group

This paper uses the range standardization method to normalize the scale, density, morphology, and functional resilience of the 4 subsystems of each group area so that the value range of each subsystem is from 0 to 1. At the same time, it is divided into high and low, named the priority type and hysteresis type, respectively, according to the average value of each resilience subsystem. The subsystems are spatially superimposed to form the urban resilience system development type area of each group area in Nanchang (Figure 7), which is mainly used to observe the shortcomings in the process of urban resilience development.

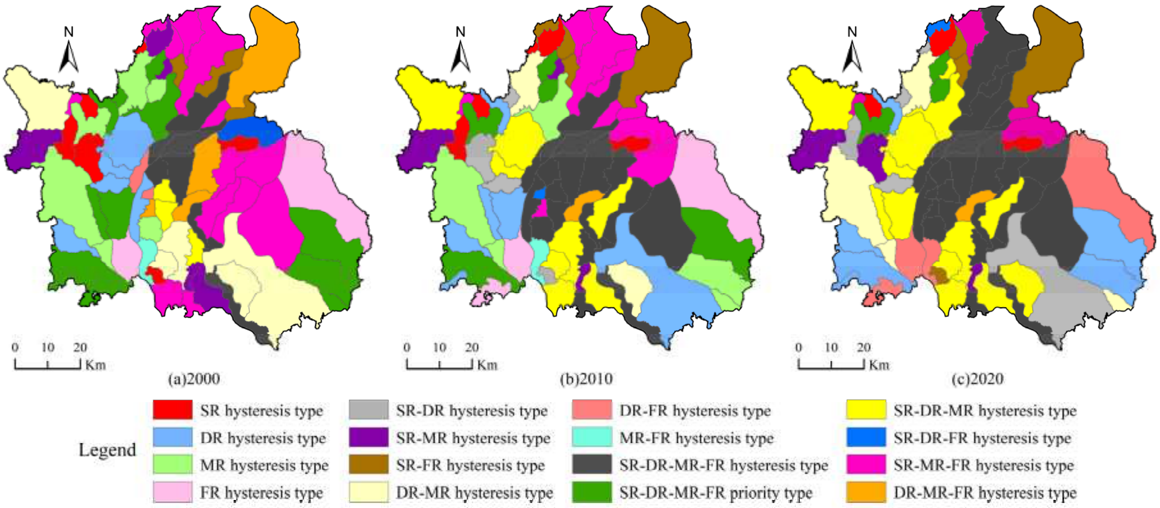


Figure 7. Combination of resilience subsystem in Nanchang City based on water network group. Note: SR, DR, MR, FR represent scale resilience, density resilience, morphology resilience, and functional resilience, respectively.

Figure 7 shows the evolution of the resilience of various subsystems in Nanchang from 2000 to 2020. Only a small number of groups are affected by the lag of a single subsystem, and more clusters are affected by the interactions of the lagging development of multiple types of subsystems in Nanchang. Among them, scale and density resilience are the dominant factors in the development of urban resilience, and their influence on the coordinated development of resilience systems of various groups is becoming increasingly significant. During the study period, each group was affected by morphological resilience and functional resilience, which were affected by factors such as water network segmentation and urban green infrastructure construction. The number of urban scale-density-morphology-function resilience priority groups, dropped from 12 in 2000 to 3 in 2020. The spatial scope of this type of cluster continues to shrink. The reason is that the sprawling expansion of urban construction land has led to the gradual emergence of the contradiction between the high concentration of socioeconomic factors and the local sensitivity of the urban landscape. The spatial pattern of the development type shows that the single-system resilience lagging groups are concentrated from the west of the Ganjiang River to the city’s marginal areas. The dual-system resilience lagging groups are distributed in scattered points in the neighboring Poyang Lake area, Anyi County, Nanchang County, and Jinxian County, turning to a ring-shaped agglomeration pattern at the edge of the city. The three-system resilience lagging groups shifted from the neighboring Poyang Lake area and Yaohu Lake–Jinxi Lake–Qinglan Lake–Junshan Lake groups to the Ganjiang west bank and southern Nanchang groups. The four-system resilience lagging groups extend from the middle of the Ganjiang River to the area along the Ganjiang River and the area east and south of Nanchang.

On the whole, the combination of scale, density, morphology, and functional resilience of each group during the study period not only has a certain inheritance but also has some significant changes. The number of lagging resilience types and low resilience group units has been increasing, and the overall resilience level has shown a downward trend in Nanchang. There is a phenomenon in which the priority type shifts to a single system or a multisystem lag, and the single system lag to a multisystem lag.

4.6. Phase Characteristics of Urban Resilience Based on Coupling Coordination Degree and Adaptive Cycle Model

In this paper, the coupling coordination degree model is used to calculate the coupling coordination index of the scale, density, morphology, and functional resilience of each group in Nanchang City. Based on relevant research results [67,68], using 0.3, 0.5, and 0.7 as critical values, it can be divided into four types: low-level coupling, transitional, developmental, and high-level coupling. At the same time, we can comprehensively determine the adaptive cycle phase and characteristics of each group in Nanchang by combining adaptive cycle theory, the type of coupling coordination, and the city development trend. Figure 8 shows the coupling and coordination types and the adaptive cycle phase of various groups in Nanchang.

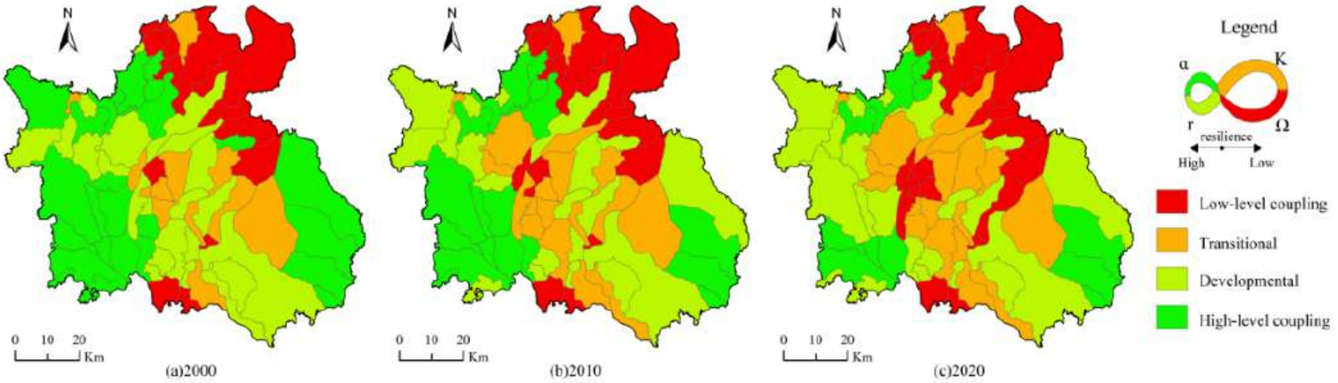


Figure 8. Adaptive cycle phase of urban resilience of each group based on coupling coordination degree.

The low-level coupling zone has the characteristics of stability and expansion in the spatial pattern. Regional groups, such as the nearby Poyang Lake area in northern Nanchang and the downtown and Phoenix ditch areas in southern Nanchang, were in a low-level coupling state during the study period, and their spatial transitions were relatively small. The low-level coupling groups showed a certain expansion trend in the area, such as near Poyang Lake and downtown. The low-level coupling groups in eastern Nanchang City and the western bank of the Ganjiang River showed zonal and flaky expansion. Combining Nanchang's land use planning and remote sensing images, it is clear that the near Poyang Lake area and the Phoenix ditch area are mainly prohibited areas for urban construction, and the scale of construction land far exceeds the area of suitable construction areas. However, the construction land has become saturated, and the ecological deficit has been severe in the downtown area and on the west bank of the Ganjiang River. The low-level coupling areas are all in a highly sensitive state. The system will face collapse when faced with the interference of uncertain external factors. Each group of this type of area is in the release phase (Ω) of the adaptive cycle. This type of group should reasonably adjust functional zoning, advocate a low-carbon production and living mode, allocate regional population, and optimize the group structure so that the area can be effectively updated and conserved, and the regional resilience will gradually recover.

The transitional group is located in the outer area of the low-level coupling group. It and the low-level coupling group together form a "center–periphery" structure in spatial distribution. This type of group showed a significant expansion trend during the study period, mainly expanding from the main urban area and eastern Nanchang to southern Nanchang and along the Ganjiang River. Under the influence of the spread of urban construction land and the unreasonable layout of elements, the risk level within the transitional group has increased significantly. However, the scale, density, morphology, and functional potential of each group were low, and the system flexibility of the group declined. This type of group is more susceptible to interference from chronic stress and acute shock factors inside the city. Each group is in the conservation (K) phase of the adaptive cycle. At this phase, the group should strengthen ecological infrastructure construction and ecosystem conservation during the construction process. At the same time, it also is necessary to optimize the spatial layout of urban material elements to enhance the stability of urban functions and structures.

The developmental groups have continued to expand. They are mainly distributed in Anyi County, Jinxian County, Meiling Mountain, and south of Nanchang City. The urban construction land of this type of group is in the early stage of development. The scale of its construction land is small, but its concentration of social factors has increased, and its ecological connectivity has gradually weakened. The incoordination among scale, density, morphology, and function brought about by urban development and construction will lead to a downward trend in the potential of groups. This type of group is mainly in the exploitation (r) phase of the adaptive cycle. At this phase, urban construction should pay attention to the coupling and coordination among various subsystems, such as scale, density, morphology, and function, to promote the smart growth of the urban system.

The range of high-level coupling groups continues to shrink, particularly in the area on the west bank of the Ganjiang River. In 2020, high-level coupling groups will be distributed only in the northern and southern Meiling Mountains and the Junshan Lake area. This type of group has the characteristics of generally weak human activity intensity, complete ecological infrastructure, stable functional structure, and a high degree of coupling between subsystems. They are in the reorganization (α) phase of the adaptive cycle. Groups at this phase should control or reduce the risk of interference caused by human activities, maintain the support and recovery capabilities of natural ecosystems to risk disasters, and pay attention to the coordinated development relationship between ecological sensitivity and urban construction.

5. Discussion

5.1. Determination of City Group Unit Divided by Natural Water Network

The city's water network has been affected by the natural water system from the emergence to the development of the city. This type of city is densely populated and economically active due to the vertical and horizontal waters and convenient transportation, forming a water transportation hub and a commercial center. At the same time, the native landforms and island corridor blocks, interweaving of waters, and construction space are distributed according to the water, and they constitute a unique landscape ecological background under the natural water network. As a common basic geographical form, water network cities are widely distributed in the middle reaches of the Yangtze River, the Yangtze River Delta, the Pearl River Delta, and other regions in China, accounting for 10.74% of Chinese cities [69]. Under the background of rapid urbanization, high-intensity human activities and extremely fragile landscape backgrounds are the main characteristics of water network cities. The increasingly sharp contradiction between human activities and landscape backgrounds also directly restricts the sustainable development of this type of city.

The development of river systems and the SWAT model are combined to divide the city into numerous water network group units based on this common basic geographic form, thus forming the basic scale unit of this study. This scale division method not only follows the natural background of the city's water network well but also better describes the impact of the natural water network on urban expansion. Compared with the administrative unit and grid unit in traditional research [3,43,44], the method of water network groups not only refines the spatial heterogeneity of urban resilience to a certain extent but also considers the relative openness of the water network system. In general, this paper uses the hydrological model to divide the natural boundary of the basic unit, which enriches the basic scale of urban research and provides a planning basis for the construction of a resilient development model of "water and land symbiosis" for water network cities.

5.2. Advantages of Urban Resilience Framework from the Perspectives of Landscape Patterns and Coupling Models

The four attributes of scale, density, morphology, and function are not only the basic characteristics of dynamic urban development but also the macro and dominant indicators used to measure the state of urban development. This paper constructs a four-dimensional evaluation index system of urban resilience from the perspective of element movements and landscape pattern processes. The evaluation indicators established in this paper emphasize how cities can minimize disaster losses and maximize follow-up sustainable development based on their development status under the acute impact of natural disasters and their own chronic pressures rather than describe the urban response process under the influence of one disaster or multiple disasters. The four-dimensional integrated resilience evaluation method based on the perspective of landscape patterns simplifies the complex steps of disaster identification and post-disaster recovery in previous urban resilience assessments [43,44]. It provides a new perspective and new method for comprehensively understanding the evolution characteristics of urban resilience and quickly identifying key areas for urban resilience development.

As a giant system of dynamic evolution, the organic coordination of internal elements is the key driving force in promoting the sustainable development of the city [26]. This paper's authors believe that the construction of an urban resilient development environment also requires the coupling and coordination of factors such as scale, density, morphology, and function. Using the coupling coordination degree model to analyze the coupling coordination status of each group is conducive to identifying the key dimensions or shortcomings of urban resilience development. Distinguishing the adaptive phases of urban resilience according to the size of the coupling coordination index, summarizing the characteristics of the development phases of different regions, and understanding the transformation speed and frequency of regional resilience development are helpful in formulating differentiated resilience environmental strategies in a timely manner.

5.3. Limitations and Prospects for Further Study

The resilience assessment method constructed in this paper from the four dimensions of scale, density, morphology, and function focuses on the impact of human activity intensity (urban space expansion, population agglomeration, resource consumption, etc.) on the development of urban resilience, which is an in-depth discussion from the side of urban material space structure. The parametric alternative of the landscape ecology method based on resilience thinking will further enhance the perspective of resilient city research and enrich the urban resilience measurement method system. As a city is a multifactor complex system, urban resilience includes not only the four dimensions discussed in this paper but also social and economic structure and level, social organization and function, and other aspects. Therefore, it is necessary to establish a relatively comprehensive and systematic indicator system method [68]. Scholars generally believe that landscape patterns can be used as an important regulatory approach for the optimization of urban resilience patterns, and there must be differences in landscape optimization strategies between different dimensions and different regions [43,44,70]. Using the scale nesting method to clarify the spatial and temporal response relationship of the landscape pattern process to urban resilience under different scale backgrounds will help guide the healthy and sustainable development of the city based on the landscape pattern optimization strategy for key regions and dimensions. These issues also will be the focus of future research.

6. Conclusions

As a complex social-ecological system, cities face dual disturbances, such as chronic pressure brought about by their rapid development and acute shocks caused by natural and man-made disasters. The community has begun to pay extensive attention to the construction of a resilient development environment in cities to improve the ability of urban systems to adapt and adjust to uncertain disturbances. Although the theory and case studies of urban resilience have developed considerably, few scholars have explored the spatiotemporal evolution process of urban resilience under special geographical forms. Based on the special geographical form of the water network city, this paper enriches the basic scale of urban research starting from the grouping unit divided by the water network. This study introduces the perspective of landscape ecology into the research on urban resilience and establishes a resilience assessment method consisting of the four indicators of scale, density, morphology, and function from the basic dimensions of urban development.

These expand the research perspectives and quantitative measurement methods of urban resilience. At the same time, this study strengthens the detection of key water network groups and key dimensions of urban resilience development and depicts the coordination status and stage characteristics of urban resilience systems, which also provides scientific decision-making for resilience-oriented refined governance and adaptive planning.

In specific practice, we propose differentiated governance strategies, which include: (1) Group areas in a low-level coupling state should reasonably adjust functional zoning, advocate low-carbon production and living patterns, optimize group structure and morphology, and promote the gradual recovery of regional resilience through renewal and conservation measures. (2) In transitional group areas, ecological infrastructure construction and ecological land conservation should be strengthened, and the spatial layout of urban material elements should be optimized. (3) In developmental groups, smart growth should be implemented in the process of construction. At the same time, the region should also pay attention to the coupling and coordination relationship between various subsystems, such as scale, density, morphology, and function. (4) Group areas with high levels of coupling and coordination should reasonably control the risk of uncertain interference caused by human activities and pay attention to the fragility and sensitivity characteristics of the ecological background in future development.

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