Resilient Planning of Chinese Delta Cities Under Climate Change

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Abstract: Contemporary cities and territories are facing significant challenges of natural disasters due to climate change impacts. Urbanized deltas represent some of the most vibrant and diverse ecosystems. However, its unique conditions of low altitude, land subsidence, and rapid urbanization make it more vulnerable when being subject to risks such as tide, storm surge, rainstorm, etc. caused by climate change. Firstly, this article reviews recent studies on theories and practice of city and regional resilience, and analyzes the spatial implications of it. Secondly, it analyzes the geographical characteristics, regional urban system, economic and social correlation, multi-scaled life cycle, and so on of China Yangtze River Delta cities. On the basis of this, it puts forward several problems in resilience planning practices faced by the Delta area. Thirdly, it proposes that general resilience development objective of delta cities is to promote their ability to deal with climate change. Some strategies including basic principles and steps of resilience planning such as plurality and diversified infrastructure, redundancy and multi-scaled networking, self-organized and self-renewal region / neighborhood / architecture / landscape layout are put forwarded. Lastly, the key thoughts in the China Yangtze River Delta Cities resilience planning are systematically exploring uncertainties related to future trends and disruptive events, thinking through the impacts of each sector on other sectors and the area as a whole, and making joint visions and identifying strategic projects not only among public actors but also with private and civic actors.

Keywords: regional resilience; delta cities; network structure; planning and design

1. Introduction

Urban resilience is of great significance to the sustainable development of cities. As a complex social ecosystem, they have always suffered from various disasters. In order to improve their ability to cope with uncertain risks and enhance the recovery capability after major impacts, it is necessary to conduct research on the resilience of cities and regions. Because of the large population and the developed socio-economic environment, the delta cities have become an important part of the world's urban system. However, due to its special geographical location and complex artificial ecosystem, the delta cities are frequently affected by extreme weather. Therefore, they need to deal with uncertain climate disasters and the changing external environment with more resilient development strategies. As an important area of China, the urban agglomeration in Yangtze River Delta is a node connecting the “Belt and Road” and the Yangtze River Economic Belt, and plays an important role in the national social and economy development. However, the unique geographical location makes the region face the severe challenges caused by uncertain disasters. So building a resilient regional network and making relevant urban planning is very important for the sustainable development of them. This article reviews the theories of city and regional resilience, and proposes corresponding planning and development strategies based on network structure analysis of the Yangtze River Delta.

2. Research on urban and regional resilience

2.1 The resilience theories

The concept of the resilience was first proposed by Canadian ecologist Holling in his article "Resilience and stability of Ecological systems", which means that the object returns to its original state after being damaged. Then the concept has experienced several evolutions. Its meaning gradually shifts from traditional engineering and ecological resilience to evolutionary resilience. The focus of relevant research has also shifted from a linear system that seeks to achieve stability to a nonlinear system that seeks continuous adaptation, and further emphasizes learning and adjustment to the next disturbance.

2.2 Urban resilience

Since the 21st century, resilience has gradually been applied to urban research and planning, forming the concept of resilient cities. Alberti first defined urban resilience as the ability of the city's structure and function to maintain its original state after the internal and external driving forces of urban development changed. The Resilience Alliance proposes that urban resilience is the ability of a city or urban system to digest and absorb external disturbances while maintaining the original main features, structures, and key functions, and they also summarize and construct a framework for resilient urban research. Wilbanks argues that the urban resilience refers to the ability of urban systems to prepare, respond to, and recover from specific multiple threats, minimizing their impact on public safety, health, and the economy. It can be seen that the urban resilience not only refers to the ability of the city to recover after being disturbed, but also pays attention to the city's ability to predict disturbances and disasters.

Scholars from different fields have analyzed the characteristics of resilient cities from multiple perspectives. Verdowski believes that resilient cities should be characterized by dynamic balance, multiple compatibility, efficient flow and moderate redundancy. Bruno believes that resilient cities should have the ability to cope with changes in terms of technology, organization, society and economy. Allan argues that resilient cities should have adaptability, innovation, responsiveness, capital reserve capacity, and ecosystem service capabilities. Overall, urban diversification, cross-scale network connectivity, high adaptability and moderate redundancy are the main characteristics of resilient cities.

2.3 Regional resilience

As the resilience theory is gradually applied to regional scales, research on regional resilience development has received increasing attention. Regional resilience is a comprehensive measure of multi-scale social ecosystems, including prevention of potential threats, defense against disasters, and the ability to recover from disturbances. Compared with urban resilience, it emphasizes the connection between cities and the construction of regional network, which means that by building a resilience framework through urban nodes and their connections can not only enrich and stabilize the regional development process but also promote the inner cities of the region as a whole to resist uncertain disasters and risk. Regional resilience is mainly reflected in four aspects of engineering, economic, social and ecological resilience.

Engineering resilience refers to the ability to promote the coordination of different cities and effectively resist disasters by constructing regional infrastructure networks. Economic resilience refers to improving the adaptability of cities in dealing with external disturbances through the rational distribution of industries, technologies and labor in the region. Social resilience refers to the ability to maintain the stability of social systems in different cities through the cooperation of multi-level organizations. Ecological resilience refers to the ability of diverse and extensive ecosystems to absorb disturbances and maintain original ecological functions.

3. Delta regional resilience

3.1 Delta city and regional characteristics

In recent years, due to frequent climate disasters, the resilience of the delta urban area has become the focus of related research. As a special artificial ecosystem, due to the topographical conditions formed by the impact of water flow, the foundation settlement caused by a large number of constructions and the ecological damage caused by urban sprawl, the delta urban area is more vulnerable to natural disasters such as tides, storm surges and heavy rains. These factors lead to uncertainty in the future development of the Delta urban area. With the increasing climate change, the current economic development-oriented spatial planning is difficult to promote the resilience of the delta region. How to build a network between cities and enhance regional resilience is a question that must be considered in the future sustainable development of the delta urban area.

The Yangtze River Delta region is one of the most important urban agglomerations in China. It is located in the alluvial plain of the Yangtze River estuary and has typical delta natural geographical features. Moreover, the social and economic development of this region is rapid, the population is gathering, and the density of the cities is continuously increasing, forming a complex social ecosystem. This paper evaluates the resilience of this region from the perspective of urban network structure and spatial distribution pattern, and identifies the problems existing in the development process. Based on the above analysis, planning strategies for optimizing the regional network structure are proposed, which provide suggestions for the delta regional resilience development.

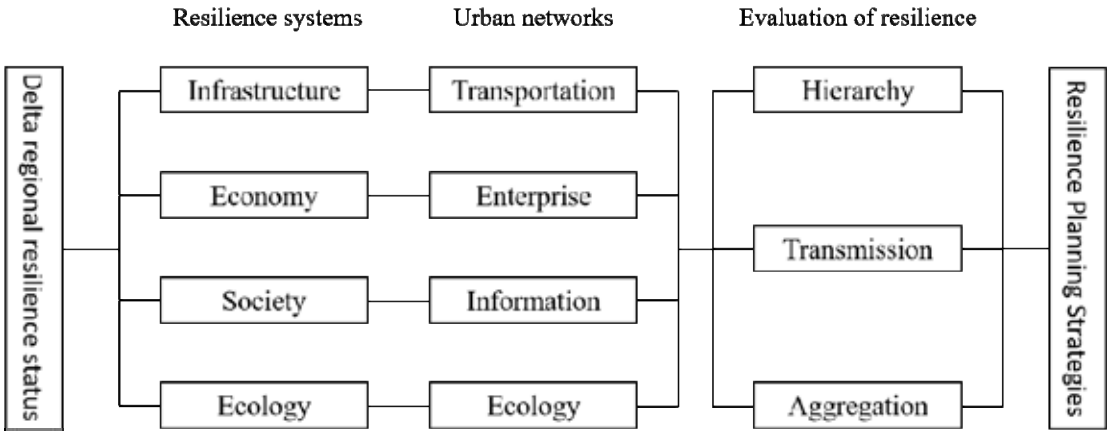

Fig. 1 Research framework for Delta region resilience

3.2 Factors influence the regional network structure resilience

The network consists of nodes and the connections between them. Nodes and connections are the two basic elements of the network. The regional network refers to the urban groups formed by the close integration of the cities as nodes through the flow of elements. And the network structure refers to the state it presents in space, including the size, number, and location of the cities participating in the construction of the network and the strength and concentration of connections between them. The ability of the network structure to cope with external disturbances and gradually restore, maintain and improve the characteristics of the original system is the resilience of the network structure. The attributes of the network structure and the characteristics of its internal systems directly affect its function and resilience. Researches consider that the location and hierarchy distribution of nodes; the heterogeneity, hierarchy, connectivity and aggregation degree of connections are important factors affecting network function and structure.

This paper takes 26 cities in the Yangtze River Delta region as the research object, and uses the complex network theory and UCINET social network analysis tools to evaluate the structure resilience of the region from engineering, economic, social and ecological aspects and proposes planning strategies. Combined with relevant research, this paper takes hierarchy, transmission and aggregation as important indicators to measure the structural resilience of the regional network. Hierarchy is represented by the number of cities of different levels in the network. A strong hierarchy means that the high-level cities in the network are dominant, which will lead to a more vulnerable structure. Transmission is used to evaluate the length of the connection path between nodes.

If it is short, various elements can be transmitted at a lower cost and faster speed, thereby improving the structure resilience of the network. Aggregation reflects the compactness of the network. A network with a low degree of aggregation contributes to the inflow of external information, thus improving the resistance to external disturbances.

3.3 Construction and evaluation of urban networks

On the basis of determining the evaluation indicators of network structure resilience, this paper constructs the transportation, enterprise, information and ecology networks in the Yangtze River Delta region from four aspects of engineering, economy, society and ecology, and analyzes their structure characteristics.

3.3.1 Construction of urban system networks

(1) Transportation network: Passenger and cargo transportation in the Yangtze River Delta region mainly relies on roads and railways. This paper calculates the traffic connection between cities by long-distance bus shifts, regular and high-speed train shifts. According to the formula:

$$T_{ij} = \frac{(Q_i + Q_j)/Q + (C_i + C_j)/C}{2D_{ij}^2}$$

the strength of the connection between cities can be determined, and then the regional transportation network model can be constructed. In the formula, T_{ij} represents the traffic intensity of i city and j city, Q_i and Q_j represent the total passenger traffic of roads and railways between two cities; C_i and C_j represent the total freight volume of roads and railways between two cities; Q and C respectively represent the average passenger traffic and average freight volume of roads and railways between the cities in the Yangtze River Delta; D_{ij} represents the sum of highways and railways between the two cities.

(2) Enterprises network: As typical multi-location organizations, enterprises have branches in many cities among the region for the purpose of expanding their scale and preempting their share, thus forming a complex enterprise network. By analyzing the financial links between the cities where the headquarters and their branches are located, urban nodes and connection matrices can be constructed to study the structure and flow relationship of the economy network. According to the formula:

$$\mathrm{V} = \sum_{j=0}^{m} v_j(a,b)$$

the strength of the connection between cities can be determined, and then the regional enterprise network model can be constructed. In the formula, V is the sum of the capital connections between all the companies in the two cities, that is, the contact value formed by the city a and the city b through m enterprises; a and b are the cities where the headquarters and branches of the company j are located, and $V_j(a,b)$ is the total investment of the company j in these two cities.

(3) Information network: The regional information network is constructed through the information links between cities reflected by the web search index. The web search index is a data statistics platform based on user behavior data. It is an indicator that reflects the attention of website users and mainstream media to some keywords. This paper obtains the web search index between cities in the Yangtze River Delta. And according to the formula:

$$\mathrm{M} = A_b \times B_a$$

the strength of the connection between cities can be determined. Then the regional information network model can be constructed. In the formula, M refers to the information flow intensity between City A and City B; A_b refers to the average value of the web search index from A to B; Ba refers to the average value of the web search index from B to A.

(4) Ecology network: Based on remote sensing images in the Yangtze River Delta, the land in the region is divided into forest land, grassland, cultivated land and other types. The areas with better integrated ecological service functions are selected as ecological sources, and the ecology network is constructed by using the least cost path model. Due to the different costs of ecological corridors passing through various types of land use, this paper first gives values for multiple land use within the region. Then according to the formula:

$$\mathrm{MCR} = f_{min} \sum_{j=n}^{i=m} (D_{ij} \times R_i)$$

In the formula, MCR is the minimum cumulative cost value, f_{min} is the minimum cost value between ecological sources, D_{ij} represents the spatial distance from source j to landscape unit I, and R_i represents the cost value of landscape unit i. The value of (D_{ij} ×R_i) can be used to measure the accessibility of a species from unit j to unit i.

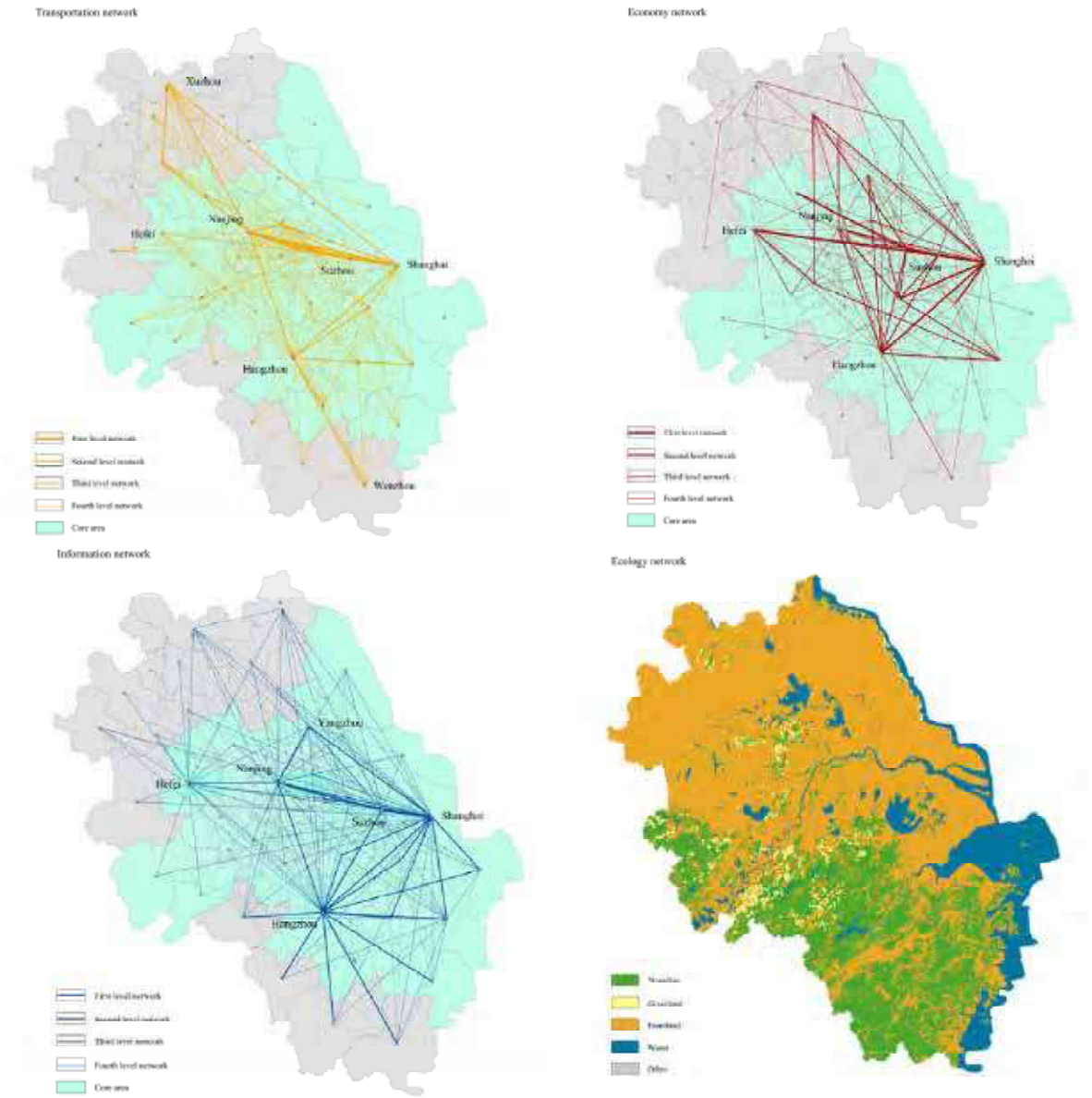

Fig. 2 Transportation, Enterprises, Information and Ecology networks

3.3.2 Evaluation of network structure resilience

(1) Hierarchy evaluation: This paper evaluates the hierarchy of regional network by degree distribution. Degree refers to the number of connections between a node and others in the network. And the distribution of degree reflects the overall structural characteristics of the network. According to the formula:

$$\ln(K_h) = In(C) + aln(K_h^*)$$

In the formula: K_h represents the degree of the node h; K_h^* represents the rank of its degree in the network; C is a constant; a represents the slope of the degree distribution curve.

The results show that the slopes of the four networks' degree distribution fitting curves are large, and |a| is between 0.6 and 0.9. This means that the Yangtze River Delta regional network has a high level of hierarchy, indicating that there is a core city group with strong dominance in the region. Among them, the hierarchy of enterprise and information networks is higher and the core cities are more prominent which means that these networks have the characteristics of heterogeneity, while the transportation and ecology networks have flat features.

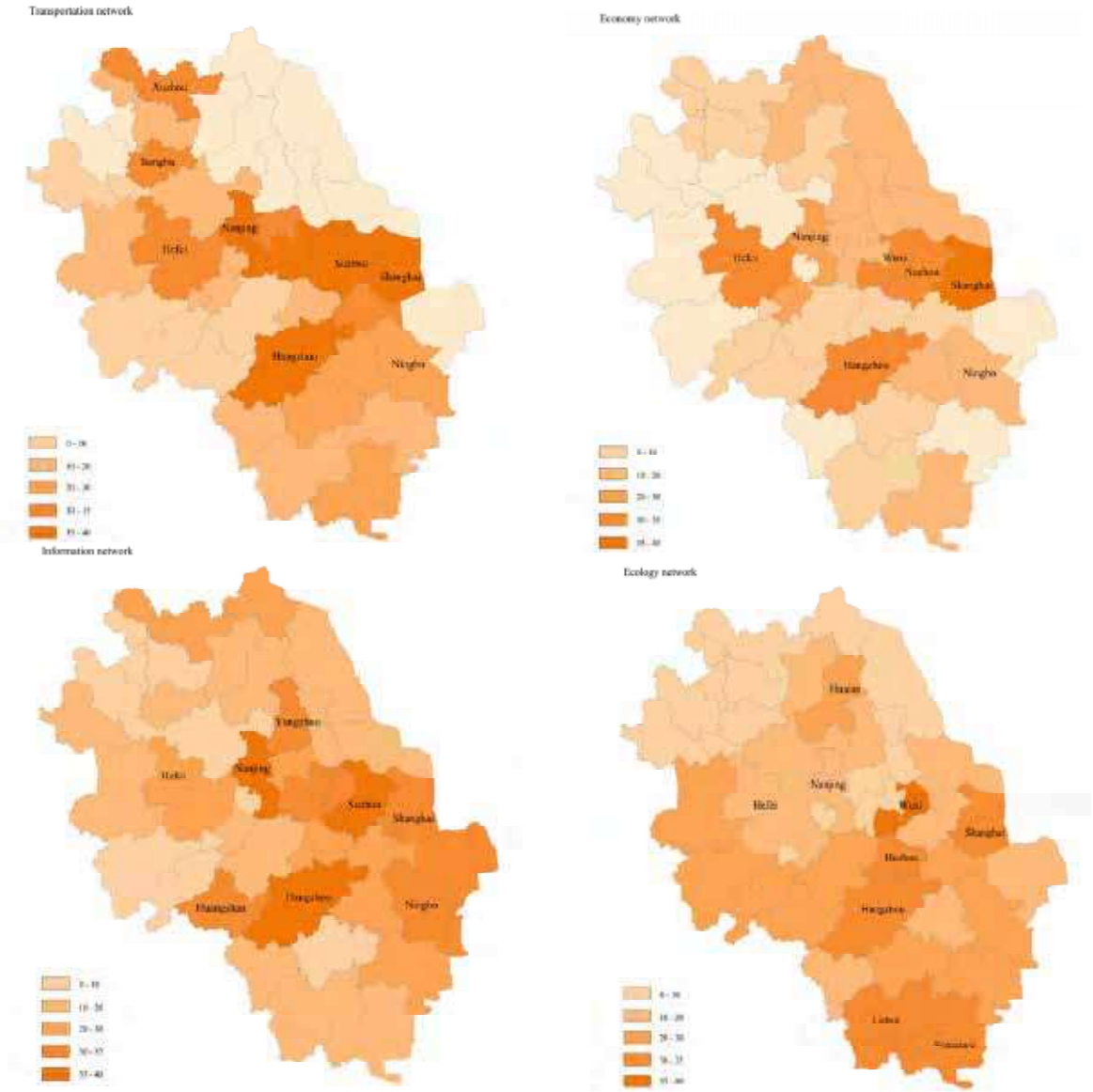

Fig. 3 Degree distribution of transportation, Enterprises, Information and Ecology networks

(2) Transmission evaluation: This paper evaluates the transmission of regional networks by the average path length. The longer the average path length of the network, the more time it takes for elements to spread from one node to another, indicating that the transmission efficiency of the network is lower, and vice versa, the diffusion effect of the network is stronger. Its formula is:

$$L = \frac{1}{1/2n(n+1)} \sum_{i \geq j} d_{ij}$$

In the formula, L is the average path length; n is the number of nodes; and dij is the distance from node i to j.

The results show that the average path lengths of the four networks are between 1.3 and 1.7, which means that the transfer of elements between cities requires only 2 nodes. It indicates that the network transmission efficiency in the Yangtze River Delta region is generally high. The average path length of the transportation network is 1.526, which is the shortest path among the four networks, and its regional accessibility and diffusivity are stronger. The average path lengths of enterprise and information networks are 1.585 and 1.573. The efficiency of factor transmission between cities is lower than that of transportation network, resulting in relatively high additional costs for activities such as personnel mobility, technology diffusion and information transmission. The average path length of the ecology network is 1.625, indicating that the number of ecological corridors in the Yangtze River Delta region is small and the connection between ecological sources is loose. It can be said that the ecological resilience of the region is not ideal.

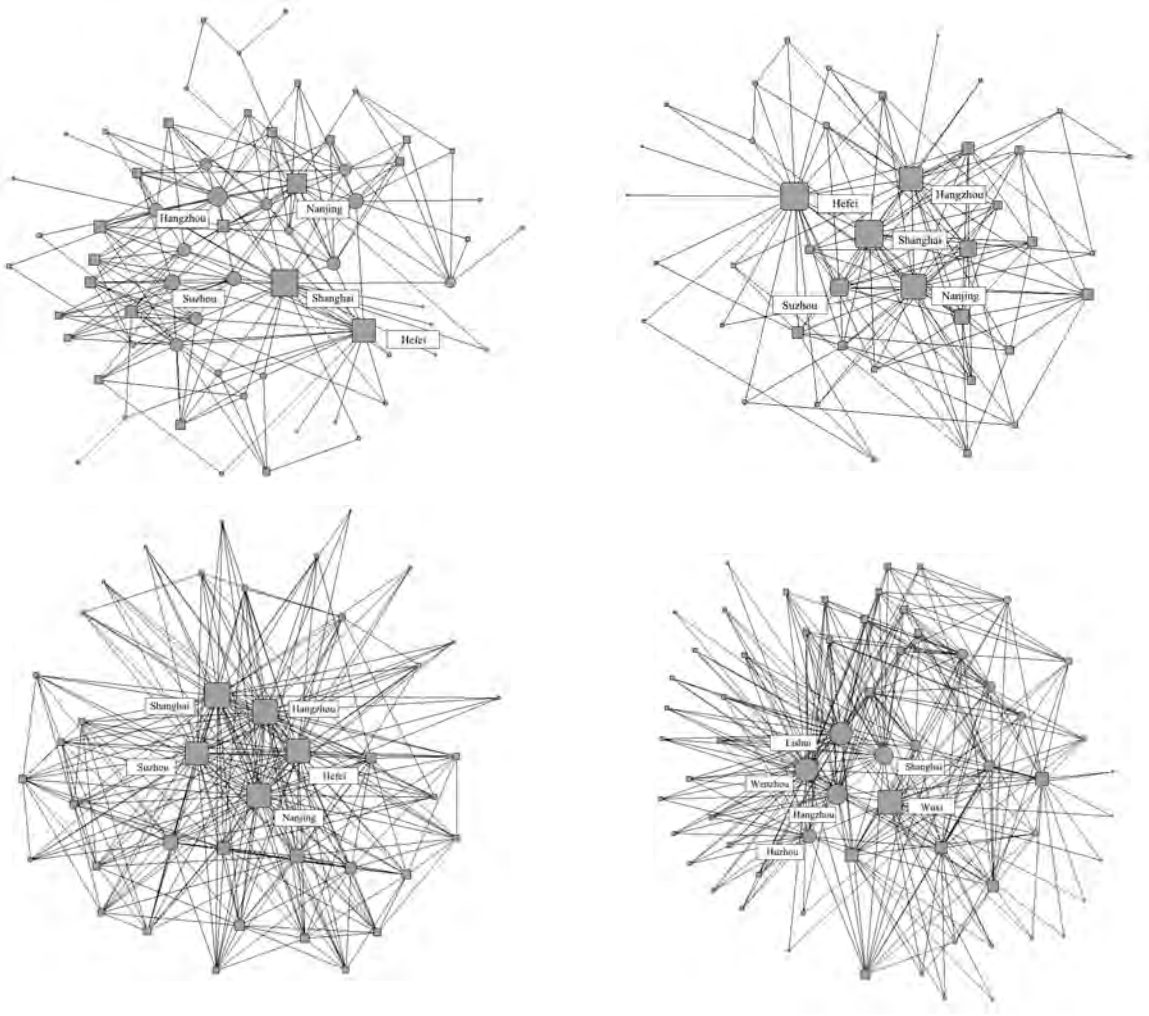

Fig. 4 Topological diagram of transportation, Enterprises, Information and Ecology networks

(3) Aggregation evaluation: Network aggregation can be evaluated by local and average clustering coefficients. The local clustering coefficient is a parameter that describes the degree of aggregation of network nodes. Since it calculates only the aggregation of a single node to neighboring ones, the overall aggregation of the network can be evaluated by calculating the average clustering coefficients of all nodes. Its formula is:

$$C_i = \frac{2E_i}{k_i(k_i - 1)}$$

In the formula: k_i is the degree of node i, which is the number of nodes adjacent to it; E_i is the number of connections between node i and the neighboring ones.

The results show that the average clustering coefficients of the four networks are all around 0.8, which indicates that most cities in the network have connections with their neighboring cities and form groups, and there are only a few isolated nodes. The regional network is well aggregated. If the local clustering coefficient of a single node city is calculated, it can be found that the values of core cities such as Shanghai, Hangzhou, and Nanjing with higher degrees are all around 0.37~0.53. It means that there are fewer connections between low-level cities which are connected to those core cities. The ordinary cities in the regional networks have more one-way connections with core cities, while the interaction between them is less.

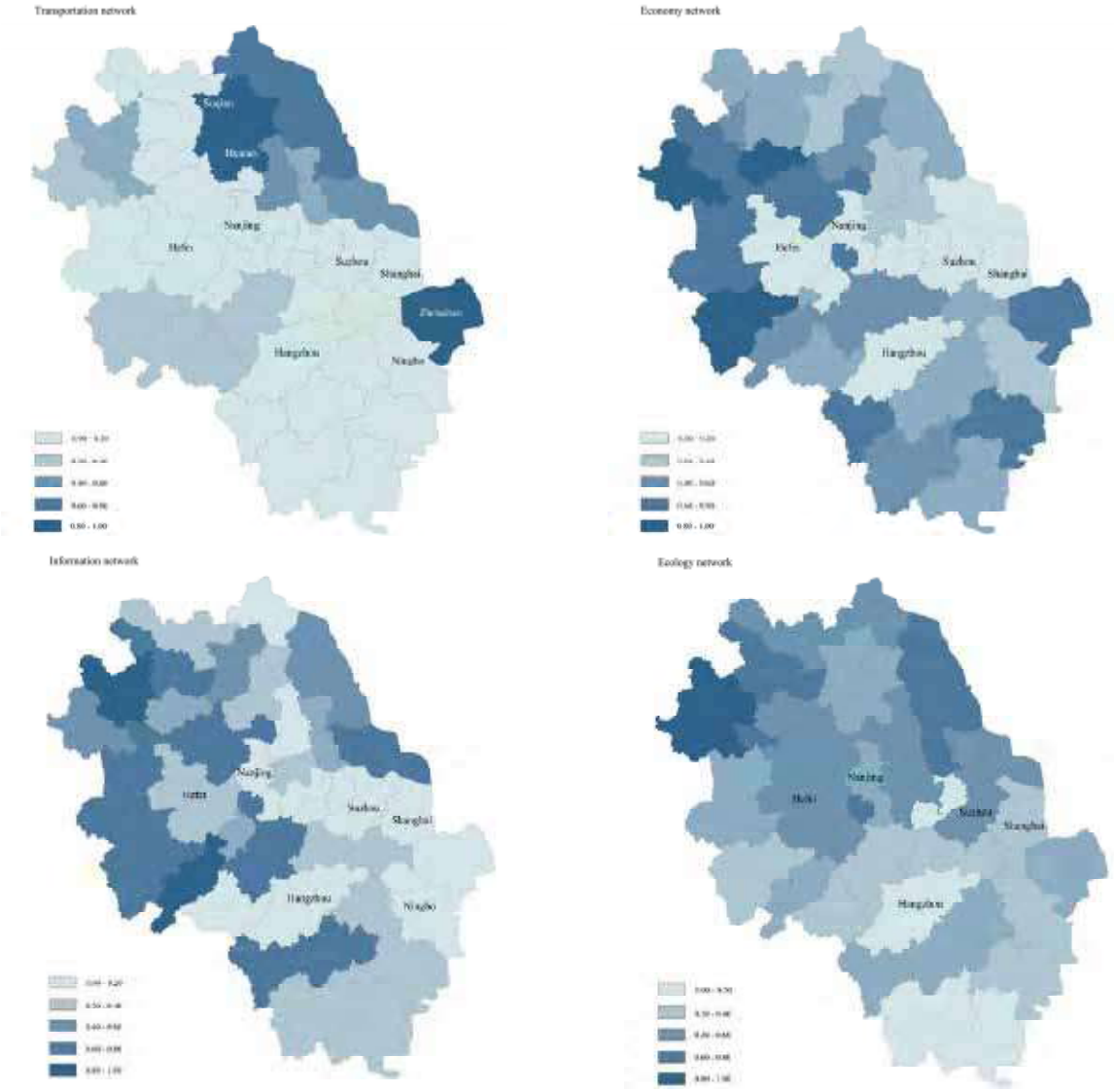

Fig. 5 Clustering coefficient of transportation, Enterprises, Information and Ecology networks

3.3.3 Network structure resilience characteristics

Overall characteristics of the network structure. Through the evaluation of the network structure, it can be seen that the central node groups of the above four networks are composed of provincial capitals such as Shanghai, Hangzhou and Nanjing, which makes the Yangtze River Delta region network forms a core-edge structure with these important cities as the core nodes. Analyze the structural characteristics of the four networks separately. In terms of transportation network, the highway and the railway system form the skeleton of the contact network in the Yangtze River Delta region, and the node cities located on the axis have a high degree of correlation, showing the core-edge structure characteristics. In addition, with the construction of high-speed railway network, the traditional structure is gradually shifting to a flat, uniform structure. The economy network in the Yangtze River Delta region has significant hierarchical characteristics. Shanghai is the absolute core of the region; Nanjing, Hangzhou, and Suzhou are at the second level as sub centers and ordinary cities in the region are in the third level. As the cores of the region, Shanghai, Hangzhou and Nanjing have high network connectivity and form a cohesive city group with the cities around them. The structure of the regional information network is relatively balanced and is gradually forming a compact information exchange circle. Shanghai, Hangzhou, Nanjing are the hubs of the network, and the intensity of information flows between them are huge. As economy and transportation connections rising, the information links within and between provinces are gradually increasing. The regional ecology network has formed a structure in which the Tai Lake is the core and several ecological corridors are connected to each other. A number of ecological sources in the area are connected along the Yangtze River Ecological Corridor, the Hangzhou Bay Ecological Corridor and the Central Ecological Axis. It can be said that the regional ecological structure framework is basically formed, but the resilience ability still needs to be strengthened.

Tab. 1 Summary of measurement results of four kinds of network structural resilience

	Hierarchy	Transmission	Aggregation
	Degree distribution	Average path length	Clustering coefficient
Transportation Network	-0.827	1.526	0.826
Enterprises Network	-0.852	1.585	0.785
Information Network	-0.815	1.573	0.819
Ecology Network	-0.844	1.625	0.751

Diversified characteristics of network connections. According to the evaluation results, the gap between the four networks in terms of transmission and aggregation is not obvious, but there are some differences in their hierarchy. Specifically, the radiation capacity of economy network is weak. The economic connections within the region have strong near-regional jurisdiction, which occur mainly between provincial capitals and cities close to them. There is not much interaction between the central urban agglomerations and the cities farther away from them, even the cities across the province. However, the radiation capacity of information and transportation networks is relatively strong, and there are more interactions between central cities and peripheral cities, which leads to cross-administrative areas connections. In addition, the hierarchy of the information network is weak, which means that it has rich and diverse contact paths while having some strong central city groups with radiation capability, make it respond quickly in the face of external disturbances. Therefore, it has good resilience. The regional ecology network has weak radiation capabilities and its hierarchy is high, which leads to its core-edge structure. The concentrated distribution of ecological sources and the insufficient number of ecological corridors will have an impact on its structure resilience. In summary, the resilience of the information network is the best, the transportation network is second, the economy and ecology networks' resilience needs to be strengthened.

It can be seen that the urban network with the core-edge structure has basically formed in the Yangtze River Delta, and the multi-system networks such as economy, society, space and ecology all have certain development resilience. This single structure reduces the radiation and connection capacity of the system. When the external conditions change drastically, the network may be broken, unable to reconnect, and reduce the resilience of the region. However, with the improvement of regional coordination capabilities and the development of transportation-communication technology, the urban network of the Yangtze River Delta will gradually transform into a center-periphery structure, forming a diverse and stable process of resilience development.

4 Strategies for optimizing network structure in the Yangtze River Delta

4.1 Promote the network structure transformation

The development of the Yangtze River Delta region spans multiple scales, involving social, economic, and environmental factors. There are extensive and complex internal connections between them. In order to enhance the resilience of the regional network structure, it is necessary to take advantage of the core urban groups' promotional capacity to drive the development, and comprehensively consider the hierarchical relationship of cities within the region to guide the coordinated development of large, medium and small cities. The improvement of regional resilience should not only clarify development goals, but also strengthen the radiation capacity of core cities which are the concentration of resource elements, and enhance regional influence and competitiveness. At the same time, it is necessary to increase the connections between cities of various hierarchy, enhance the ability to cooperate, and carry out functional division, coordinate industrial space, and share infrastructure according to the cities' advantages. In the end, it is necessary to achieve a reasonable distribution of the cities' scale and function in the network by structural adjustment, so as to improve the regional resistance to cope with external disturbances.

4.2 Enhance the flow of elements between cities

The current transmission efficiency and diffusion capacity of the Yangtze River Delta regional network is good, and the flow of factors between cities can be further improved in the following aspects. Strengthen the concentration and cooperation of enterprises. The division of functions between cities and the organization of industrial spaces are the important strategies for regional resilience development. By building advantageous industrial clusters across cities and relying on the development axis along the Yangtze River, it is possible to promote the concentration and cooperation of regional industries. Construct information exchange spaces. By implanting knowledge information carriers and focusing on cultivating high-tech innovation parks, research centers and university towns, we can promote the prosperity of regional science and technology. Accelerate infrastructure construction. It is necessary to focus on strengthening the main axis of transportation, making it a comprehensive channel with complete functions and strong transportation capacity. At the same time, we should also integrate the internal transportation networks of each province and cities, improve the carrying capacity of rail transit, and accelerate the construction of expressway and intercity railway networks. Adjust the structure of the ecosystem. In the context of national land planning, we can integrate the current ecological resources and organize existing ecological sources and corridors. And cities of different types and grades should adopt corresponding ecological protection measures, focusing on strengthening the governance and control of fragile urban areas.

4.3 Take into account multiple subjects in the regional resilience development

There are a large number of cities in the Yangtze River Delta, so the resilience development needs to take into account the diversified requirements of multiple subjects. Affected by administrative boundaries and participating entities, the current development goals and speeds of cities are different. As a whole, the Yangtze River Delta needs to eliminate the adverse effects caused by it as much as possible, so it is necessary to consider the demands of different regions. At the regional scale, a city collaborative management platform should be established to actively promote the inclusiveness of resilience development from the aspects of urban planning, industrial development, spatial convergence and infrastructure construction. At the city level, we need to ensure

the exchange of information between governments, developers and community residents, so that communication and inclusion can be used as an entry point for the development of urban resilience. Whether it is the construction of multi-functional sites or the mixed use of land, all the subjects in the city must be as compatible as possible.

5 Conclusion

Resilience is an important trend in the development of the world's cities. It is also the path that China's delta urban agglomerations must choose when they face a changing external environment. The theory of resilience planning has positive significance for both urban and regional planning. Based on the theory of urban and regional resilience development, this paper analyzes the network structure resilience of the Yangtze River Delta from the aspects of hierarchy, transmission and aggregation by constructing four networks of transportation, economy, information and ecology in the region. Overall, the region has basically formed a core-edge network structure, and multiple systems have a certain level of resilience development. The network structure of different systems has diverse characteristics, and there are differences in hierarchy, transmission, and aggregation. Among them, the resilience of information and transportation networks is strong, but the economy and ecology network has weaker resilience due to their poor radiation capability; Based on the above analysis, this paper proposes some planning strategies for optimizing the regional network structure, such as promote the structure transformation, Enhance the flow of elements and take into account multiple subjects. By studying relevant theories and conducting empirical analysis on the Yangtze River Delta, this paper hopes to explore the rational path for the resilience development of the delta urban agglomeration and improve their social ecosystem's ability to resist external disturbances.

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