Postprint: Spatial Correlation Network of Resilience and Its Influencing Factors in the Guanzhong Plain Urban Agglomeration

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Abstract

Based on the entropy method, this study measures the comprehensive evaluation index of urban resilience for 11 cities in the Guanzhong Plain urban agglomeration from 2011 to 2020, analyzes the spatiotemporal evolution characteristics of their resilience, and employs social network analysis and quadratic assignment procedure to examine the spatial correlation network structure and its influencing factors. The results indicate that: (1) The overall resilience of cities within the Guanzhong Plain urban agglomeration shows an upward trend, with resilience levels exhibiting a pattern of decreasing from the provincial capital outward to the periphery. (2) The resilience network structure of the urban agglomeration has become more complex and robust; however, inter-regional resilience connections display strong hierarchical characteristics and have not yet achieved a fully interconnected state. (3) Xi' an, Xianyang, and Tongchuan exhibit strong centrality, capable of generating substantial resource spillovers to surrounding or peripheral cities, with a pronounced "core-periphery" structure in the urban agglomeration. (4) Differences in geographical proximity, economic development level, degree of opening-up, government fiscal support, level of scientific and technological development, and transportation infrastructure all significantly influence the evolution of the urban agglomeration' s resilience spatial network structure. The Guanzhong Plain urban agglomeration can enhance urban resilience and intercity connectivity through approaches such as constructing intercity digital management and exchange platforms, strengthening transportation network construction, and increasing investment in scientific and technological innovation.

Full Text

Preamble

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Research on the Spatial Correlation Network of Resilience and Its Influencing Factors in the Guanzhong Plain Urban Agglomeration

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Abstract: This study constructed an urban resilience evaluation index system that included four dimensions: economy, society, ecological environment, and infrastructure. Based on the entropy method, the resilience comprehensive evaluation index of 11 cities in the Guanzhong Plain urban agglomeration, northwest China from 2011 to 2020 was measured, and the spatiotemporal evolution characteristics of their resilience were analyzed, and moreover, the social network analysis method was used to analyze the structural and functional connections between cities in the resilience network of the Guanzhong Plain urban agglomeration. Furthermore, the quadratic assignment procedure was used to explore the comprehensive factors that affected the resilience network structure of the Guanzhong Plain urban agglomeration. The results indicated the following. (1) The overall resilience of each city in the Guanzhong Plain urban agglomeration was on the rise, and the resilience level showed a decreasing trend from provincial capital to the periphery. (2) The resilience network structure of urban agglomerations had become more complex and robust; however, the resilience connections between regions exhibited strong hierarchical characteristics and cities had not yet fully achieved interconnectivity. (3) Xi' an, Xianyang, and Tongchuan had strong centrality and could generate significant resource spillovers to surrounding or peripheral cities. The "core-edge" structure of urban agglomerations was obvious. (4) The level of economic development, openness, government financial support, scientific and technological development, differences in transport infrastructure, and geographical proximity all significantly affected changes in the resilient spatial network structure of the urban agglomeration. Therefore, to enhance the resilience of the Guanzhong Plain urban agglomeration and the connection between cities, one must first build an intercity digital management and exchange platform and promote the diffusion of resource elements from high- to low-agglomeration areas. Second, the construction of transportation networks must be strengthened, investment in scientific and technological innovation must be increased, and foreign trade and economic cooperation must be strengthened in the construction of "the Belt and Road". This study reveals the position and role of each city in the resilience development process in the spatial association network of the Guanzhong Plain urban agglomeration, analyzes the spatial spillover effect of resilience development in the Guanzhong Plain urban agglomeration, and provides a new perspective on the study of urban resilience development from a geographically spatial perspective.

Keywords: urban resilience; spatial correlation network; social network analysis; Guanzhong Plain urban agglomeration

Introduction

Cities currently face complex and changing external environments and internal pressures, while also being impacted by natural disasters and public crises. Building resilient cities represents a pathway to mitigate disaster impacts and achieve high-quality development. The report from the 20th National Congress of the Communist Party of China proposed constructing a coordinated development pattern of large, medium, and small cities based on urban agglomerations and metropolitan areas, improving urban planning, construction, and governance levels, and creating livable, resilient, and smart cities. Under the urban cluster development model, identifying focal points for constructing internal resilience development plans and strengthening urban internal construction will constitute a new direction for urban governance. Urban resilience refers to the continuous prevention and control capability of a particular system or multiple coupled systems within a city, representing a comprehensive measure of urban complex system safety. Enhancing the resilience level of urban agglomerations can be achieved through regional interactions and connections, while the flow and complementarity of factor resources such as economy and infrastructure between cities can improve each city' s internal capabilities for prevention, resistance, response, adaptation, and recovery.

The Guanzhong Plain Urban Agglomeration is located in the inland center of China and serves as an entry point for driving the central and western regions toward high resilience development levels. In April 2022, the National Development and Reform Commission issued the "Implementation Plan for the Construction of the Guanzhong Plain Urban Agglomeration during the 14th Five-Year Plan Period," which pointed out that relying on Xi' an as a national central city, modern metropolitan areas should be cultivated, the carrying capacity of node cities along development axes should be enhanced, and the spatial development cohesion of urban agglomerations should be improved. Evidently, the Guanzhong Plain Urban Agglomeration will enter a new stage of development. Meanwhile, rapid urbanization has led to increasingly severe resource and environmental constraints and uncertain risks for urban agglomerations. Therefore, analyzing the network characteristics of resilience development in the Guanzhong Plain Urban Agglomeration holds significant importance for promoting integrated and symbiotic resilience connections and a high-quality regional development pattern within the urban agglomeration.

Literature Review

Reviewing existing literature, research on urban agglomeration resilience mainly includes three aspects. First, studies on the spatio-temporal evolution of comprehensive resilience or specific dimensions of urban agglomerations. For example, He Shanfeng et al. [1] employed the forced determination method, entropy method, and spatial autocorrelation analysis to examine the spatio-temporal evolution characteristics and correlations of urban flood disaster resilience in the Yangtze River Delta region. Chen Xiaohong et al. [2] constructed an urban resilience measurement model using neural networks and genetic algorithms to measure the resilience of the Chengdu-Chongqing urban agglomeration and predicted the spatio-temporal evolution patterns within the next five years. Second, further analysis of factors influencing regional resilience development based on spatio-temporal evolution. Zhang Peng et al. [3] used spatial econometric methods to study the impact of various factors on the overall resilience and subsystem resilience of cities in Shandong Province. Ning Jing et al. [4] utilized geographically weighted regression models to analyze the impact of human activity intensity on urban resilience changes in districts and counties of Inner Mongolia. Some scholars have also conducted research solely from the perspective of influencing factors. Third, studies on the network characteristics of urban agglomeration resilience. Wei Ye et al. [5] employed social network analysis to examine the spatial characteristics of network resilience in the Guangdong-Hong Kong-Macao Greater Bay Area. Jiang Hui et al. [6-8] analyzed the spatio-temporal evolution characteristics and spatial network effects of economic resilience from the perspectives of Chinese agriculture, Chinese cities, and the Yangtze River Delta urban agglomeration.

After reviewing existing literature, it becomes clear that research on the spatial network of urban agglomeration resilience has mostly focused on examining the comprehensive resilience situation of urban agglomerations from a subsystem perspective using traditional statistical analysis methods, neglecting potential connections between different regions and lacking comprehensive network analysis from a geographical spatial perspective. Moreover, from a regional perspective, research on the resilience of the Guanzhong Plain Urban Agglomeration remains scarce. In view of this, this study combines social network theory with urban resilience research, employing a modified gravity model and social network analysis to analyze the spatial network structure characteristics and influencing factors of resilience in the Guanzhong Plain Urban Agglomeration, aiming to provide references for enhancing the connectivity and collaborative resilience governance level of urban agglomerations.

Study Area

The planned scope of the Guanzhong Plain Urban Agglomeration spans 7 cities in central Shaanxi Province, 3 cities in eastern Gansu Province, and 2 cities in southern Shanxi Province, specifically: Xi' an, Baoji, Xianyang, Tongchuan, Weinan, and Shangluo in Shaanxi; Tianshui, Pingliang, and Qingyang in Gansu; and Yuncheng and Linfen in Shanxi. The area covers approximately 107,000 km^2, with a permanent population of about 42 million and a regional GDP of approximately 6.4 trillion yuan. Currently, the node cities of the Guanzhong

Plain Urban Agglomeration are accelerating development, with continuous improvement of the comprehensive three-dimensional transportation network and steady progress in ecological governance, making it an important region leading the development of Northwest China. However, compared with urban agglomerations such as the Yangtze River Delta, the development gap of the Guanzhong Plain Urban Agglomeration remains significant, with few core cities and insufficient radiation-driven capacity for surrounding areas, resulting in low coordination levels. Exploring a development model suitable for the Guanzhong Plain Urban Agglomeration remains highly important.

Methodology

2.1 Indicators and Data

Based on existing literature [9-12] and the aforementioned research on urban agglomeration resilience, the selection of indicators focused on the connotation of urban resilience and its matching characteristics with the Guanzhong Plain Urban Agglomeration. The first-level indicators were divided into four dimensions: economic resilience, social resilience, ecological environment resilience, and infrastructure resilience. Economic resilience reflects balanced urban-rural development, market potential, and openness; social resilience manifests stable population structure, talent reserves, and management and education guarantees; ecological environment resilience considers ecological security, urban livability, and urban capacity for handling waste, sewage, and garbage; infrastructure resilience focuses on transportation and communication accessibility and urban crisis response capabilities. A total of 24 indicators were selected to construct the urban resilience comprehensive evaluation index system (Table 1). Research data were sourced from the *China City Statistical Yearbook* (2012-2021), statistical yearbooks of Shaanxi, Shanxi, and Gansu provinces and various prefecture-level cities, the *China Urban Construction Statistical Yearbook* (2012-2021), development statistical bulletins of various prefecture-level cities, and the China Economic Network statistical database. Missing data were supplemented using Bayesian interpolation.

2.2 Research Methods

Entropy Method. The entropy method primarily utilizes the characteristic that entropy can measure uncertainty to determine the validity and value of existing indicators, which can avoid subjective bias in subjective weighting methods and provide highly credible indicator weights [13]. Using this method requires specific values of multiple evaluation indicators. Therefore, this study employed the entropy method to calculate the weights of resilience evaluation indicators for the 11 cities in the Guanzhong Plain Urban Agglomeration. The steps are as follows:

First, standardize the evaluation indicators, primarily using the extreme value standardization method:

Forward indicators:

$$X_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} + 0.0001$$

Reverse indicators:

$$X_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} + 0.0001$$

where X_{ij} represents the original value of the ith city ($i = 1, 2, ..., m$) in the jth indicator ($j = 1, 2, ..., n$); $\max(X_{ij})$ and $\min(X_{ij})$ represent the maximum and minimum values of the jth indicator, respectively.

Second, calculate the entropy value (E_j) of the jth indicator:

$$E_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \ln(P_{ij})$$

Third, measure the urban resilience comprehensive evaluation index (S_i):

$$S_i = \sum_{j=1}^{n} W_{jX_{ij}}$$

where m is the number of selected samples; n is the number of urban resilience comprehensive evaluation indicators; P_{ij} is the proportion of the jth indicator in the ith year; and W_j is the weight of the urban resilience evaluation indicator.

Modified Gravity Model. Existing research indicates that spatial correlation relationships are constrained by geographical distance and exhibit distance decay [14]. For the spatial correlation relationships of urban agglomeration resilience, if the distance between two cities is relatively close and both cities have relatively high resilience levels, the correlation between the two cities is closer, and the overall resistance to risks is stronger. Therefore, drawing on the research of Li Nan et al. [15], this study modified the gravity model as follows:

$$F_{ij} = K_{ij} \frac{L_{iL} j}{D_{ij}^r}$$

where F_{ij} represents the connection strength between cities i and j; L_i and L_j represent the urban resilience development levels of cities i and j, respectively, calculated using the entropy method; D_{ij} represents the shortest highway distance between cities, queried using Amap considering the time span of this study and the wider applicability of highway transportation in the study area; r is the friction coefficient, typically set to 2; and K_{ij} is the gravitational coefficient, set as $K_{ij} = \frac{L_i}{L_i + L_j}$ to represent the directionality of intercity connections.

Based on the modified gravity model, the total connection volume of city i to other cities (F_i) was calculated:

$$F_i = \sum_{j=1}^{n} F_{ij}$$

After processing, the spatial connection matrix of intercity resilience level development was obtained. The average value of each row was used as the threshold for that row; values above the threshold were recorded as 1, indicating an association in resilience level development between the two cities, while values below the threshold were recorded as 0, indicating no association.

Social Network Analysis Method. This method is an interdisciplinary analytical approach that uses mathematical methods and graph theory tools to explore how relational structures affect structural components or the whole from a "relationship" perspective [16], and is currently widely used in network structure analysis across different fields. This study primarily employs four indicators—network density, number of network relationships, network hierarchy, and network efficiency—to characterize the overall network characteristics of the resilience development spatial association in the Guanzhong Plain Urban Agglomeration. Three centrality indicators—degree centrality, closeness centrality, and betweenness centrality—are used to measure the position and role of each city in the resilience development process within the spatial network.

Quadratic Assignment Procedure (QAP) Regression Analysis. QAP is a non-parametric test method for studying relational data that does not require consideration of variable independence [17]. Since factors affecting regional urban resilience development levels have interactive relationships, this study selected the QAP method to explore the factors influencing the spatial network structure of resilience in the Guanzhong Plain Urban Agglomeration. Drawing on relevant research [18-21], geographical proximity, economic development level differences, population growth rate differences, openness differences, government financial support differences, environmental regulation differences, transportation infrastructure differences, and scientific and technological level differences were selected as explanatory variables. Geographical proximity was coded as 1 for adjacent cities and 0 otherwise. The remaining variables were represented by intercity differences in per capita GDP growth rate, permanent population growth rate, export trade volume as a proportion of GDP, the ratio of fiscal expenditure to fiscal revenue, comprehensive utilization rate of general industrial solid waste, highway freight volume, and the proportion of science and education expenditure in public fiscal expenditure. The association strength between city i and city j within the urban agglomeration was used as the dependent variable. The model was designed as follows:

$$N = f(D, G, P, O, F, R, I, T)$$

where N is the spatial relationship matrix of resilience level development in the Guanzhong Plain Urban Agglomeration; D, G, P, O, F, R, I, T are the intercity difference matrices of the above variables. To eliminate dimensional effects, each variable matrix was standardized using the extreme value method.

Results

3.1 Resilience Measurement and Temporal Evolution Trends

Based on calculations using the entropy method, the resilience development levels of the Guanzhong Plain Urban Agglomeration from 2011 to 2020 were obtained (Table 2). From an overall perspective, significant differences exist in the resilience levels of the Guanzhong Plain Urban Agglomeration, with mean resilience development levels ranging from 0.1915 to 0.6365, similar to the research results of Gao Zhigang et al. [22], and Xi' an has consistently maintained the highest comprehensive resilience level. From a temporal perspective, except for a few cities that experienced slight declines followed by increases in their resilience indices, the overall urban resilience comprehensive levels in the Guanzhong Plain have shown an upward trend, indicating favorable development momentum. Calculating the growth rate from the base period to the final period, the cities with the largest growth were Weinan and Baoji, with increases of 139.65% and 121.90%, respectively. These cities occupy a secondary central position in the urban agglomeration and are more susceptible to trickle-down effects during resilience development. The city with the smallest growth was Xi' an at 30.98%, primarily because its resilience index was already far higher than other cities in the base period, and also because its economic, social, ecological environment, and infrastructure resilience indices showed fluctuating and slow growth trends.

Taking four time nodes (2011, 2014, 2017, and 2020) as examples, ArcGIS software' s natural breaks method was used to classify the urban resilience comprehensive indices of prefecture-level cities in the Guanzhong Plain Urban Agglomeration into high, relatively high, medium, and low resilience levels. The results show that in 2011, the overall resilience level of the Guanzhong Plain Urban Agglomeration was not high, with low-resilience cities distributed widely across large areas, only Xi' an reaching a relatively high level, and the spatial non-equilibrium of urban agglomeration resilience being significant. In 2014, Xi' an maintained its relatively high resilience level, the number of medium-resilience cities increased to 3 (Baoji, Xianyang, and Tongchuan), and the number of low-resilience cities decreased to 7. In 2017, the spatial distribution pattern of resilience levels in the Guanzhong Plain Urban Agglomeration changed significantly, with most cities experiencing varying degrees of growth in their sub-system resilience levels, making Xi' an the only high-resilience city in the urban agglomeration and Baoji, Xianyang, and Tongchuan becoming relatively high-resilience cities. Notably, Tianshui and Qingyang experienced negative growth in both social and ecological environment resilience levels. In 2020, Xi' an remained at a relatively high resilience level, the number of relatively high-resilience cities increased to 5 (Baoji, Xianyang, Tongchuan, and Yuncheng), and the number of medium-resilience cities increased to 4 (Weinan, Shangluo, Pingliang, and Linfen). The social resilience level of Qingyang had been declining since 2017 with a decrease of 24.78%, preventing its already low resilience level from improving significantly, remaining at a low level. Different from the previous situation where only Xi'an was at a relatively high level, the Guanzhong Plain Urban Agglomeration has relatively formed a multi-center pattern, but medium-resilience cities still account for more than half of all cities, indicating considerable room for improvement in the overall resilience level of the urban agglomeration.

[Figure 1: see original paper]

Overall, the resilience levels of the Guanzhong Plain Urban Agglomeration show a spatial pattern decreasing from the provincial capital outward, with medium-resilience cities distributed widely across the urban agglomeration. From a temporal perspective, the resilience levels of all cities show a steady upward trend, possibly because the planning compilation was initiated in 2018 and the "Guanzhong Plain Urban Agglomeration Development Plan" was issued in 2018, with policy dividends promoting the urban agglomeration' s collaborative development model and improving regional accessibility to some extent. However, changes in the overall characteristics of the urban agglomeration' s resilience network had not yet become apparent.

3.2 Network Structure Characteristics

3.2.1 Overall Network Structure Analysis Based on the modified gravity model, a spatial connection matrix of urban resilience level development was constructed, and Ucinet 6.0 software was used to analyze the overall network structure characteristics of the Guanzhong Plain Urban Agglomeration (Figure 2). The results show that the number of network relationships and network density of the Guanzhong Plain Urban Agglomeration' s resilience connections changed consistently, showing a trend of rising, falling, and then rising again, indicating that overall, intercity resilience connections are trending positively. The number of network relationships increased by 4.76%, and network density increased from 0.42 to 0.44, demonstrating that cooperation and resource circulation among cities within the urban agglomeration gradually increased during the study period. However, network density remained below the 0.5 average level, and the number of relationships was far less than the maximum possible number of relationships among cities in the urban agglomeration (110), indicating that the spatial connection degree of resilience level development in the Guanzhong Plain Urban Agglomeration needs further improvement. The reason lies in the fact that medium-resilience cities still constitute the majority within the urban agglomeration, with large gaps existing between them and central cities.

[Figure 2: see original paper]

Network hierarchy showed a slight increase in the first two years of the study period, followed by a small increase again in 2018, indicating a relatively high hierarchy in urban resilience level development, with strong hierarchical characteristics in intercity resilience connections. This is because the flow of resources such as economy, education, and medical care within the urban agglomeration is heavily influenced by the Xi' an-Xianyang growth pole, and differences in resilience development levels among cities also exist to some extent. Network efficiency showed a slight increase in 2014, followed by a declining trend, indicating that while cities improved their resilience development levels, spillover paths increased, connections and multiple superposition phenomena within the urban agglomeration increased, and the stability of the network structure gradually strengthened. Overall network characteristic indicators showed fluctuations in 2014 and 2018, possibly due to the promulgation of the "Guanzhong Plain Urban Agglomeration Development Plan" in 2018, which strengthened connections among neighboring cities, though full interconnectivity had not yet been achieved during this period.

The "Xi' an-Xianyang integration" plays a significant role in the spatial network structure of resilience level development. Leveraging inherent location advantages, resources can be conveniently exchanged among cities while synergizing with surrounding cities to drive the development of the Guanzhong Plain Urban Agglomeration. Overall, the resilience spatial correlation network structure of the Guanzhong Plain Urban Agglomeration has become more complex and robust, with Xi' an, Xianyang, and Tongchuan serving as important nodes that influence surrounding or peripheral cities through spatial agglomeration or diffusion effects.

3.2.2 Individual Network Structure Analysis Taking four time nodes as examples, the individual network structure characteristics of the 11 cities in the Guanzhong Plain Urban Agglomeration were measured, with results shown in Table 3.

Degree centrality measures whether and how many direct resilience connections a city has with other cities. Xi' an' s degree centrality has consistently been 10, indicating its core position in the resilience correlation network of the Guanzhong Plain Urban Agglomeration, with high economic market vitality, abundant scientific and technological resources, and strong radiation capacity to other node cities. Xianyang and Tongchuan' s degree centrality has consistently ranked in the top three, with the former stably at 9, indicating their similarly central positions in the urban agglomeration, close connections with other cities during resilience development, and strong agglomeration and diffusion effects on surrounding cities. Baoji and Pingliang' s degree centrality remained at 6-7, reaching the urban agglomeration average in 2020, indicating their relatively strong influence on surrounding cities but without further expansion. Weinan, Shangluo, Tianshui, Qingyang, Yuncheng, and Linfen have consistently remained below the average during the study period, indicating weak associations with central cities in the urban agglomeration and weak roles in the network. Overall, the changing trend of degree centrality in the Guanzhong Plain Urban Agglomeration' s resilience spatial network reflects the Matthew effect of "the strong getting stronger," with a significant core-periphery structure.

Closeness centrality emphasizes optimal spatial distance and measures the smoothness of resilience connections between cities. Xi' an' s closeness centrality has remained stable at 100, indicating its position as an absolute central actor in the urban agglomeration, able to form resilience connections with every city without transit through other cities. In addition to Xi' an, Tongchuan and Xianyang have consistently remained above the mean during the study period, placing these three cities in the primary central position of the urban agglomeration with the most convenient factor communication and highest external connection efficiency. Baoji, Yuncheng, Weinan, and Pingliang have consistent values close to the mean, placing these four cities in the secondary central position of the urban agglomeration with relatively smooth connections to other cities. Shangluo, Qingyang, Tianshui, and Linfen occupy peripheral positions in the network structure with relatively scarce resources, being more controlled by other cities during resilience development, but their closeness centrality values all exceed 70, indicating they are not absolute peripheral actors.

Betweenness centrality emphasizes the strategic location importance of intermediary cities and is directly related to city type, level, and scale. Xi' an, Xianyang, and Tongchuan have consistently remained above the mean, with Xi' an and Tongchuan showing high values, indicating their roles as "mediators" in the urban agglomeration, regulating and controlling network connections. Baoji, Weinan, Pingliang, and Yuncheng have values between 0-1.5 during the study period. These cities, due to good industrial foundations or energy advantages, have certain intermediary roles in the network but with weak effects. Shangluo, Tianshui, Qingyang, and Linfen have consistently had betweenness centrality values of 0, indicating that these cities with small economic volumes and insufficient characteristic industries have difficulty influencing the resilience level development of other cities and play no intermediary or bridging role in the network structure. From a temporal evolution perspective, except for Weinan, whose betweenness centrality showed an upward trend compared to the initial period, other cities showed declining or stable trends, with Xi'an and Tongchuan showing clear declining trends, indicating their decreasing absolute central control roles and deepening resilience connections among cities in the urban agglomeration, with the network structure developing toward a more balanced direction.

3.3 Influencing Factors of the Resilience Spatial Correlation Network

QAP regression analysis was conducted on the 2020 data using Ucinet 6.0. After 2,000 random permutations, the adjusted R^2 was 0.242, passing the significance test at the 1% level, indicating that the selected influencing factors could explain 24.2% of the changes in the resilience spatial network structure of the Guanzhong

Plain Urban Agglomeration. The regression results are shown in Table 4.

Specifically: (1) **Geographical proximity difference** is significantly positive at the 1% level, indicating that the closer the cities are, the lower the time cost, and the easier it is to generate resource agglomeration and spillover. (2) **Economic development level difference** and **openness difference** have negative and positive regression coefficients, respectively, both significant at the 1% level. This shows that economic development level differences have a significant negative effect on the urban agglomeration' s resilience network, and balanced economic development among cities can drive coordinated resilience development in the Guanzhong Plain Urban Agglomeration. Openness is an important way to achieve interconnectivity. Relying on cities with high openness to drive those with low openness, and building east-west two-way trade channels through comprehensive transportation networks, has a significant positive impact on improving the resilience development level and forming the resilience network of the urban agglomeration. (3) **Government financial support** has a positive regression coefficient significant at the 5% level, indicating that larger differences in government financial support lead to more intercity connections, and effective government financial support and correct guidance have significant impacts on the development of the urban agglomeration' s resilience network. (4) **Transportation infrastructure difference** is significantly negative at the 5% level, indicating that large differences in transportation infrastructure inhibit the development of the urban agglomeration' s resilience network structure. Reducing freight flow between cities is not conducive to stimulating consumption and production, and improving transportation infrastructure will promote socioeconomic activities within the urban agglomeration. (5) **Scientific and technological level difference** has a negative regression coefficient significant at the 1% level, indicating that to some extent, resilience resources flow more easily between cities with similar scientific and technological levels. Areas with high scientific and technological levels often have more scientific and educational innovation talents and higher information acquisition capabilities, making it an urgent problem to solve regarding how to reduce regional differences in scientific and technological levels. (6) **Population growth rate difference** and **environmental regulation difference** have negative but non-significant regression coefficients, indicating that their reduction has not yet shown obvious effects on the formation and development of the urban agglomeration's resilience network.

Discussion and Conclusions

4.1 Conclusions

This study comprehensively reveals the structural characteristics and functional features of each city in the resilience spatial correlation network of the Guanzhong Plain Urban Agglomeration, providing a new perspective for studying urban resilience development from a geographical spatial perspective. Additionally, previous research has rarely analyzed comprehensive influencing factors, while this study explores the factors influencing the resilience correlation structure of urban agglomerations, aiming to identify the driving forces for enhancing the safety and sensitivity of the Guanzhong Plain Urban Agglomeration and enriching the research content on its resilience. However, some limitations remain. First, network-based research has paid little attention to the dynamic impact of disasters themselves on cities, and due to difficulties in obtaining indicators, disaster-related indicators were not quantified in detail. Second, no horizontal comparison was made with other urban agglomerations regarding the development of resilience correlation network structures, which could be improved in future research.

Based on the findings, the following conclusions are drawn: (1) Temporally, the resilience of each city in the Guanzhong Plain Urban Agglomeration shows an overall upward trend, with the spatial pattern of resilience levels decreasing from the provincial capital outward. Medium-resilience cities are widely distributed across the urban agglomeration, and the spatial non-equilibrium of resilience levels was significant in 2011. (2) From the perspective of overall network characteristics, both the number of network relationships and network density show rising, falling, and then rising trends; network hierarchy is relatively high, with strong hierarchical characteristics in intercity resilience connections; network efficiency shows a declining, rising, and then declining trend, with the stability of the urban agglomeration' s network structure gradually strengthening. "Xi' an-Xianyang integration" and Tongchuan serve as important nodes in the urban agglomeration, but cities have not yet fully achieved interconnectivity. (3) From the perspective of individual network characteristics, the resilience network of the Guanzhong Plain Urban Agglomeration exhibits a relatively obvious core-periphery structure. Xi' an, Xianyang, and Tongchuan maintain high centrality levels, playing dominant roles in the network structure and generating significant resource spillovers to surrounding or peripheral cities. Shangluo, Tianshui, Qingyang, and Linfen occupy peripheral positions in the urban agglomeration, with weak roles in resilience resource diffusion. (4) Based on regression results, geographical proximity, economic development level, openness, government financial support, and transportation infrastructure differences all significantly influence the changes in the resilience spatial network structure of the Guanzhong Plain Urban Agglomeration.

4.2 Recommendations

This study proposes the following recommendations: (1) Xi' an, Xianyang, and Baoji are areas with high resource and technology agglomeration in the urban agglomeration. Intercity digital management and exchange platforms should be built to promote the diffusion of resource elements from high- to low-agglomeration areas. The radiating role of Xi' an, Xianyang, and Tongchuan should be leveraged to promote resource flow through industrial chain construction and coordination mechanisms, providing more development opportunities and space for small and medium-sized cities in planning, reducing Xi' an' s siphon effect, and weakening internal non-equilibrium and hierarchy within the urban agglomeration. (2) The concept of resilience construction should be integrated into relevant regional plans, with adaptive strategies for subsystems such as communication and logistics established according to local conditions based on different resilience development histories. The social security system should be improved in terms of medical care, education, and employment, characteristic industries should be developed economically, and distributed functional zones should be reasonably planned in urban management to narrow regional differences. (3) Within the urban agglomeration, safe and effective comprehensive transportation networks should be further promoted through the Internet of Things and big data to improve transportation efficiency. Fiscal expenditure on science and technology should be increased, and investment in scientific and technological innovation should be boosted. Cities with weak technological levels should actively introduce innovative talents, commercial exchanges within the urban agglomeration should be promoted, and foreign economic and trade cooperation should be strengthened in the construction of the "Belt and Road." The government should formulate guiding policies for cities with weak industrial foundations and insufficient market vitality to promote the overall resilience level development of the Guanzhong Plain Urban Agglomeration.

References

[1] He Shanfeng, Liang Shuang, Wu Shaohong, et al. Analysis on spatio-temporal evolution and relevance of urban flood disaster resilience in Yangtze River Delta[J]. Resources and Environment in the Yangtze Basin, 2022, 31(9): 1988-1999.

[2] Chen Xiaohong, Lou Jinnan, Wang Ying. Evolution and dynamic simulation of the temporal-spatial pattern of urban resilience in Harbin-Changchuan urban group[J]. Scientia Geographica Sinica, 2020, 40(12): 2000-2009.

[3] Zhang Peng, Yu Wei, Zhang Yanwei. Spatial-temporal differentiation and its influencing factors of Shandong Province' s urban resilience[J]. Urban Problems, 2018(9): 27-34.

[4] Ning Jing, Zhu Ran, Zhang Xinyuan, et al. Evaluation and analysis of urban resilience of districts and counties in Inner Mongolia[J]. Arid Land Geography, 2023, 46(7): 1217-1226.

[5] Wei Ye, Xiu Chunliang. Study on the concept and analytical framework of city network resilience[J]. Progress in Geography, 2020, 39(3): 488-502.

[6] Jiang Hui. Analysis of the spatial network effect of China' s agricultural economic resilience[J]. Guizhou Social Sciences, 2022(8): 151-159.

[7] Xie Huiqiang, Yang Dan, Zhang Kuan. Spatio-temporal evolution and network structure of urban economic resilience in China[J]. East China Economic Management, 2022, 36(11): 64-74.

[8] Zhang Mingdou, Zhang Zhen. Spatial correlation network of urban economic resilience in the Yangtze River Delta urban agglomeration[J]. Geography and Geo-Information Science, 2023, 39(1): 69-79.

[9] Li Yanjun, Ma Gang, Song Shuya. Spatio-temporal differentiation of urban resilience in the Mid-Yangtze River urban agglomerations[J]. Regional Economic Review, 2022, 56(2): 88-96.

[10] Shi J, Wang X, Wang C, et al. Evaluation and influencing factors of network resilience in Guangdong-Hong Kong-Macao Greater Bay Area: A structural perspective[J]. Sustainability, 2022, 14: 8005.

[11] Wang Xuan, Shi Jialu, Ci Fuyi. The spatio-temporal evolution characteristics of resilience of urban agglomerations in the Yellow River Basin[J]. Statistics and Decision, 2022, 38(5): 70-74.

[12] Zhang Xiaojuan, Tang Qifeng, Zhang Zhen. Spatial differentiation characteristics and its influencing factors of urban resilience in the Yellow River Basin[J]. Areal Research and Development, 2022, 41(6): 48-54.

[13] Hao Ji, Zhang Shaojie. Evaluation of inter-provincial ecological data in China based on entropy method[J]. Information Science, 2021, 39(1): 157-162.

[14] Li Nan, Li Xiaodong, Liu Xiang, et al. Evolution of spatial and temporal pattern of regional economic connection network in Xinjiang[J]. Arid Land Geography, 2022, 45(6): 1978-1987.

[15] Li Nan, Zhang C, Jiao L D, et al. Analysis on the spatial-temporal evolution of urban agglomeration resilience: A case study in Chengdu-Chongqing urban agglomeration, China[J]. International Journal of Disaster Risk Reduction, 2022, 79: 103167.

[16] Gao Zhigang, Ding Yuying. Measurement of urban resilience and its influencing factors of cities in northwest China[J]. Science & Technology Review, 2021, 39(24): 118-129.

[17] Shi Tao. The analysis of the spatiotemporal evolution and driving factors of urban resilience in Yellow River Basin[J]. Regional Economic Review, 2022(1): 139-149.

[18] Sun Zhongrui, Fan Jie, Sun Yong, et al. Structural characteristics and influencing factors of spatial correlation network of green science and technology innovation efficiency in China[J]. Economic Geography, 2022, 42(3): 33-43.

[19] Jia Jianqi, Zhao Lin, Gao Xiaotong, et al. Spatial correlation network structure and its influencing factors[J]. Geography and Geo-Information Science, 2021, 37(5): 46-54.

[20] Yue Li, Lei Yanyan. Construction of spatially linked network of green water resources efficiency in the Yellow River Basin and its evolutionary factors[J]. Journal of Northwest Normal University (Social Sciences Edition), 2022, 59(2): 62-74.

[21] Wang Shiliang. Research on urban resilience and improvement methods of Inner Mongolia[D]. Hohhot: Inner Mongolia Normal University, 2022.

[22] Lu H, Zhang C, Jiao L D, et al. Analysis on the spatial-temporal evolution of urban agglomeration resilience: A case study in Chengdu-Chongqing urban agglomeration, China[J]. International Journal of Disaster Risk Reduction, 2022, 79: 103167.

[23] Khan M, Wu Q, Yan S Q, et al. Factors affecting urban resilience and sustainability: Case of slum dwellers in Islamabad, Pakistan[J]. Journal of Urban Planning and Development, 2021, 147(4): 04021053.

[24] Li L, Zhang P, Wang C. What affects the economic resilience of China's Yellow River Basin amid economic crisis: From the perspective of spatial heterogeneity[J]. International Journal of Environmental Research and Public Health, 2022, 19: 9024.

Note: Figure translations are in progress. See original paper for figures.