Construction of Regional Multi-dimensional Proximity Network from the Perspective of Collaborative Agglomeration — Analysis of Geographical Proximity Networks in Contiguous Rural Spaces

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Abstract
This study applies collaborative agglomeration theory to investigate how geographical proximity influences rural spatial networks across 678 villages in Xinghua, China. We analyze three key dimensions of geographical proximity network: morphological distribution patterns, geographical scale relationships, and cultural superposition characteristics. Based on this, it was found that the river network and historical wei-field development jointly shaped the settlement pattern of clustering in the east and dispersion in the northwest. And the region forms a "core-edge" network structure with the urban area and Dainan Town as the core, and the northwest water network area as the edge. Water-aligned cultural resources show dual-core clustering with collaborative potential. Study provides spatial optimisation basis for rural contiguous development, and further integration of industrial and social proximity will be constructed in the future.

Key Words: Geographical proximity network; Rural space; Morphology agglomeration; Gravity model; Regional multi-dimensional proximity

1. Introduction

In the context of global urbanisation and sustainable development, the concept of "Collaborative Governance" proposed in the 2016 United Nations New Urban Agenda breaks through the limitations of traditional administrative boundaries and advocates cross regional collaboration to address global challenges such as climate change. This concept has gained widespread consensus not only in the study of various factors such as environment and transportation in cities (Fan et al., 2022, Wang and Zhao, 2021, Jinsoo and Suh, 2012), but also in the analysis of urban networks(Luo et al., 2025) and industrial associations between urban clusters, revealing the promoting effect of collaborative agglomeration on regional innovation (Ma et al., 2021, Huggins and Prokop, 2017, Shearmur, 2012). Similarly, rural spaces are also showing a significant trend of collaborative development(He et al., 2019, Luo et al., 2020), gradually transitioning from dispersed layout to networked agglomeration through resource integration and functional complementarity. This new paradigm of coordinated urban-rural development provides important theoretical support and practical paths for regional spatial reconstruction.

The formation and development of contiguous rural spaces are the result of multiple factors working together. This study draws on the concept of multi-dimensional proximity (Tobler, 1970, Ma et al., 2021, Zhou et al., 2024) in economic geography, which is divided into geographic proximity, social proximity and cognitive proximity. The study applied them to rural spatial analysis to reveal how these factors synergistically shape the spatial organisation of rural spaces. From a spatial perspective, geographical proximity shapes the similarity of regional background characteristics through natural geographical conditions and historical accumulation. From the perspective of development, social proximity is manifested as the convergence of industrial technology paths and development directions. From a cognitive perspective, the values of villagers and development vision constitute the impetus for promoting collaborative development. Through complex interactions of the three dimensions, they jointly affect the agglomeration form and collaborative development path of rural spaces. This study takes the geographical proximity of rural spaces as the starting point, and provides a theoretical basis for revealing the underlying factors of regional coordinated development by analyzing their spatial distribution characteristics and network correlation mechanisms.

In terms of the geographical agglomeration of contiguous rural spaces, academic and practical study on rural areas mainly focuses on three aspects: spatial distribution patterns, historical dynamics, contiguous protection methods, and patterns. 1) Study on the spatial distribution patterns of villages. Most studies evaluate the spatial layout of rural spaces at the meso and micro scales through modeling methods such as gravity models and rank scale rules(Liu et al., 2024, Sun et al., 2025), and use this as a basis to divide rural clusters and optimise resource allocation. 2) Study on the formation and evolution mechanism of rural geographic space from the perspective of historical evolution. By proposing a hierarchical model of the "human-earth-network" relationship in cyberspace (Guo et al., 2021), the relationship between different elements combined and overlaid in space to form different spatial forms can be determined. Then, the correlation analysis and classification of the division of concentrated contiguous areas were carried out, emphasizing the layering of history. 3) Exploration of traditional village contiguous protection methods and models. This aspect emphasises the formation of a comprehensive control system covering the entire process from the perspective of operational management and control (Pan et al., 2024). The three major stages are sorting out the resource base before application, formulate protection and utilisation guidelines during planning, and regularly monitor the results after implementation, which are interrelated. Most current study examines key villages through multi-factor analysis while neglecting studies on ordinary village patterns. Additionally, these studies consistently overlook historical and cultural dimensions in their assessment of village influencing factors.

In the process of conducting study on rural spaces, the geographical background characteristics serve as the basic carrier of spatial similarity and functional connections, providing a background explanatory framework for identifying the agglomeration characteristic of rural space. After incorporating historical and cultural factors, they profoundly influence the spatial organisation mode and development path of rural space together. This study constructs a geographical proximity network analysis model from the perspective of collaborative agglomeration. Through quantitative analysis of geographical scale, history and other data, it not only intuitively displays the spatial distribution pattern of villages, but also reveals the potential multi-dimensional proximity relationship network between settlements. Thus, it can break through the static description limitations of traditional rural spatial study. By combining this with subsequent social and cognitive proximity analysis, study could deepen from spatial proximity to functional proximity. Thereby we can identify key hubs and weak links in regional collaborative development more accurately.

2. Study region and background

Xinghua is a county-level city under the jurisdiction of Jiangsu Province and managed by Taizhou in China. It is located in the central part of Jiangsu Province, between the Yangtze River and the Huai River. The total area of the city is 2393 square kilometers, with 26 townships and 3 streets under its jurisdiction, and a total of 678 incorporated villages. Xinghua is a typical Lixiahe Plain, centered around a plain depression based on beach tidal flats. The overall style is unique and has the potential for collaborative agglomeration and development. And it has currently achieved full coverage of development-oriented village planning, shouldering the important task of national-level rural revitalisation work such as the Construction of Characteristic Rural Demonstration Areas. This study combines the case of Xinghua to illustrate the practical characteristics of rural space, providing ideas and practical guidance for the delineation of regional collaborative agglomeration units.

The landform of the same origin is gradually differentiating, with distinctive features

Geomorphic bases with similar regional ranges will gradually generate regional differentiation due to the dual effects of human intervention and natural evolution. For example, Xinghua is located in the hinterland of the Lixia River. Since ancient times, the hydrographic net has been dense and the lakes and marshes have been intertwined. Although the terrain is similar, it has gradually differentiated due to the evolution of the hydrographic net and human activities during history, forming unique landscape patterns such as raised fields, wei-fields, and lakes and marshes (Yuan, 2025). In the early days, our ancestors lived by water, built embankments and fields, and piled up soil which formed raised fields to adapt to the water environment, laying the foundation for the basic agricultural form (Shi et al., 2022, Yuan and Wang, 2019). With the development of water transportation and the rise of docks along the river, commercial and handicraft industries have gathered, and the settlement pattern has evolved accordingly(Hu, 2024). Areas with dense river networks form streets and markets due to the prosperity of commerce and trade. On the edge of the lake, fishing villages have emerged due to aquaculture. Areas with less dense river networks are still dominated by traditional agriculture.

Settlements are difficult to cluster due to their scattered and disordered distribution

The traditional small-scale agricultural production methods and scattered rural industries have jointly led to the inefficient spatial structure of villages. It manifests as limited residential area size and scattered factor allocation, making it difficult to form agglomeration effects. Despite the continuous efforts of the country's rural development policies in recent years, the problems of low space utilisation efficiency and fragmented layout have not been fundamentally alleviated. For example, Xinghua rural areas also have problems of scattered scale and spatial fragmentation. Due to the scattered raised fields formed during the development of wei-fields in the Ming Dynasty, farmers settled nearby, forming a "one wei-field, one village" pattern. Some villages are distributed in a bead-like pattern along tributaries such as the Bangyan River and the Luting River. The average size of these villages is much smaller than that of incorporated villages in Jiangsu Province, China, where the average village typically has about 350 households. Due to the overall lack of central agglomeration areas, coupled with the trend of hollowing out and idle homestead land, there are serious problems of scattered scale and spatial fragmentation.

The phenomenon of insufficient resource utilisation and uneven development of villages and towns is prominent

The insufficient utilisation of characteristic resources, policy differences, and varying development drivers can lead to the formation of a multi-level differentiated development pattern in the region (Wang et al., 2024). For example, the development of rural areas in Xinghua presents obvious characteristics of differentiated driving forces, forming an unbalanced spatial pattern. The cultural and tourism driven areas, represented by Shagou Town and Qianduo Town, rely on historical and cultural resources and raised field landscape to drive the development of tourism supporting industries in surrounding villages. But due to their limited radiation range, villages 5 kilometers away have not been affected and are still dominated by traditional industries. Therefore, the development of villages is insufficient and uneven.

3. Construction of geographic proximity network and empirical study of Xinghua

The geographical proximity network is mainly divided into three components, namely morphological distribution characteristics, geographical scale characteristics, and cultural superposition characteristics. Study uses morphological distribution characteristics as the geographical background attributes of this region to determine its resource endowment and spatial agglomeration properties. During the study process, regional differences were followed. On this basis, specific network analysis is carried out through the geographical scale characteristics of the region, representing the multi-dimensional connectivity of village and town clusters, emphasizing the connectivity of network scale. Finally, an abstract network analysis is conducted based on the cultural attributes of villages and towns to determine the relationship between different geographical backgrounds and cultural elements, focusing on the collaborative development of culture.

Morphological distribution characteristics

Construction of morphological characteristics method system

In order to determine whether villages and towns have similar resources and characteristics in morphology, the study is divided into two dimensions based on terrain, land use, resource endowment, and other characteristics. Firstly, eight types are extracted from the patch and class agglomeration characteristics to study their morphological distribution agglomeration patterns. Then, from the perspective of the overall pattern, the above types will be assigned contract values to distinguish the degree of difference between each indicator. Thus, the aggregation, cohesion, and fragmentation characteristics of the geographical distribution of villages and towns were determined. The overall regional morphological features were summarised.

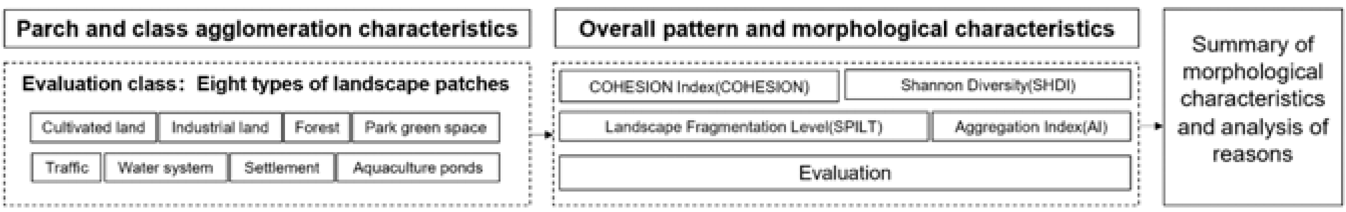

Fig.1 Technical route for evaluating morphological distribution characteristics

The study evaluated the region using the landscape pattern index tool in Fragstats, and the moving window algorithm was employed for image generation and processing. The moving window algorithm opens an analysis window centered around each pixel, calculates the selected level of indicators, and returns the calculation results to the centre of the window. By repeating this process for each pixel, the final result is the generation of a new grid surface that represents a gradient of the local landscape structure. This can reflect the detailed features of the landscape pattern and the differences in internal space.

Tab.1 Patch and class agglomeration characteristics and overall pattern and morphological characteristics indicators

Index	Formula	Formula description	Index explanation
Shannon Diversity（SHDI）	$SHDI = -\sum_{i=1}^{m}(P_i \times \ln P_i)$	Measurement index based on information theory, reflecting landscape heterogeneity.	In a landscape system, the richer the land use and the higher the degree of fragmentation, the greater the content of uncertain information, and the higher the calculated SHDI value.
Aggregation Index（AI）	$AI = \left[\frac{g_{ii}}{max - g_{ii}}\right](100)$	Used to describe the degree of aggregation of different patches or regions in a landscape, as well as the connectivity between patches of each landscape type.	A higher degree of aggregation indicates that patches of the same type are clustered together, while a lower degree of aggregation indicates that they are more dispersed and can be used to evaluate the agglomeration patterns of patches of the same type in the landscape.
Cohesion Index（COHESION）	$CO = \left[1 - \frac{\sum_{j=1}^{m} p_{ij}}{\sum_{j=1}^{m} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \times 100$ p_{ij} represents the circumference of the num. j patch in the num. i type landscape， A is the total area of the landscape	Used to describe the degree of aggregation of spatial structures within patches in a landscape, the index reflects the spatial connectivity or aggregation within patches of the same type.	A higher COHESION value indicates that different types of plaques are more concentrated or densely distributed together, forming a more compact spatial structure.
Landscape Fragmentation Level（SPILT）	$S = \frac{N_i}{A_i}$ N_i is the number of patches in landscape i， A_i is the total area of landscape i	The degree of fragmentation or fragmentation of a landscape refers to the degree of separation between different patches in the landscape.	When the landscape is divided into multiple smaller segments, the degree of fragmentation is higher; When the landscape maintains large continuous patches, the degree of fragmentation is lower.

3.1.1. Measurement of morphological characteristics

In the analysis of patch and class agglomeration characteristic, this study quantified the agglomeration patterns of eight types of landscape patches in Xinghua, including cultivated land, aquaculture pond, water system, forests, transportation, settlement, green space, and industrial land, based on aggregation index.

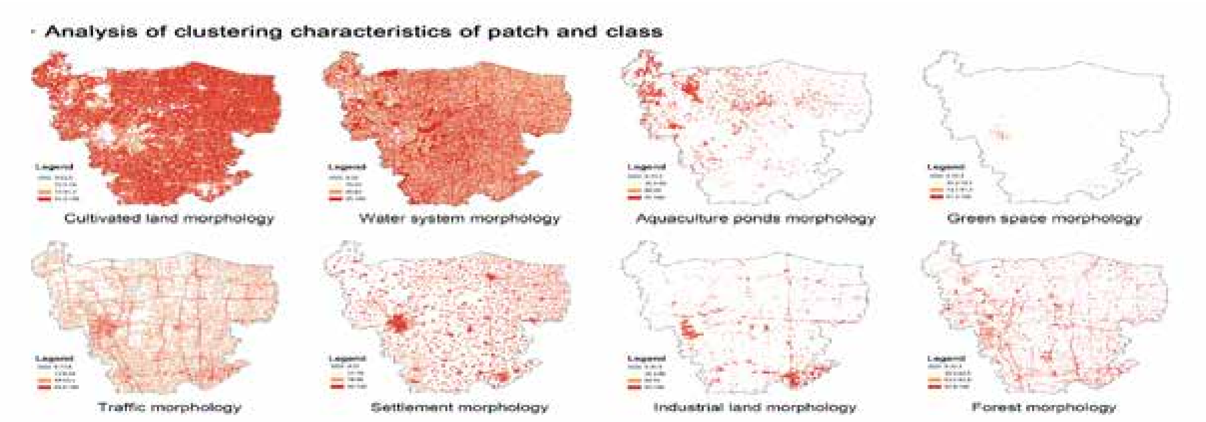

Fig.2 patch and class agglomeration characteristics

The results indicate that cultivated land shows significant agglomeration in the northeast and southwest regions, while the agglomeration degree is weaker in the central, western, and northwest regions. The complementary spatial feature is the high concentration of aquaculture ponds and water systems in the northwest. The aquaculture ponds are uniformly clustered in small areas in the north, and are less distributed in the south. The water system forms an overall uniform agglomeration pattern in the eastern and southern parts, but is more scattered in the central and northwestern parts, with scattered large blocks distributed irregularly.

In terms of settlement agglomeration characteristics, Xinghua presents three significant agglomeration cores. Firstly, there is a radiating agglomeration area centered around the central urban area of Xinghua in the central and western regions. Secondly, there is an industrial led agglomeration area centered around Dainan Town in the southeast, consisting of multiple secondary agglomeration points. Finally, there is a small-scale agglomeration area centered around Anfeng Town in the northwest. The distribution of other settlements is relatively scattered and has not formed a clear centripetal structure. The transportation network is highly consistent with the agglomeration pattern of settlements, with the main agglomeration areas distributed in the central and western regions, southwest, southeast, and northeast. The eastern transportation nodes are evenly distributed, while the northwest is significantly sparse.

This spatial differentiation is closely related to the regional geomorphological features. As can be seen from Figure 3, the overall geomorphology of Xinghua can be divided into swamp, western raised field, southern wei-field, central small wei-field and east big wei-field five parts.

Wei-fields are widely distributed throughout the region, indicating that Xinghua has a low-lying terrain and has long relied on artificial reclamation to transform swamps into farmland. The wei-field system has universality in this region. So in the analysis of the clustering characteristics of cultivated land, we found that there is not much difference in the clustering level of the entire region. On the basis of this regular distribution in the water network system, the transportation system is evenly distributed in the northeast and south, with big wei-fields concentrated in the northeast and small wei-fields distributed uniformly in the south. And artificial embankments for flood control and irrigation have been built in the northeast, combined with natural water systems, to develop into contiguous and orderly big wei-fields.

There are a large number of swamp areas in the central and northwestern parts. Corresponding to the clustering characteristics of aquaculture ponds, it was found that the current swamp areas are a composite form of wetlands, lakes, wei-fields, and aquaculture ponds. It can be seen that this area has not only been transformed into wei-fields for traditional agricultural planting, but also diversified development through raised fields and aquaculture ponds, such as aquaculture and wetland tourism development. Swamp and wetland resources are utilised at multiple levels in this way.

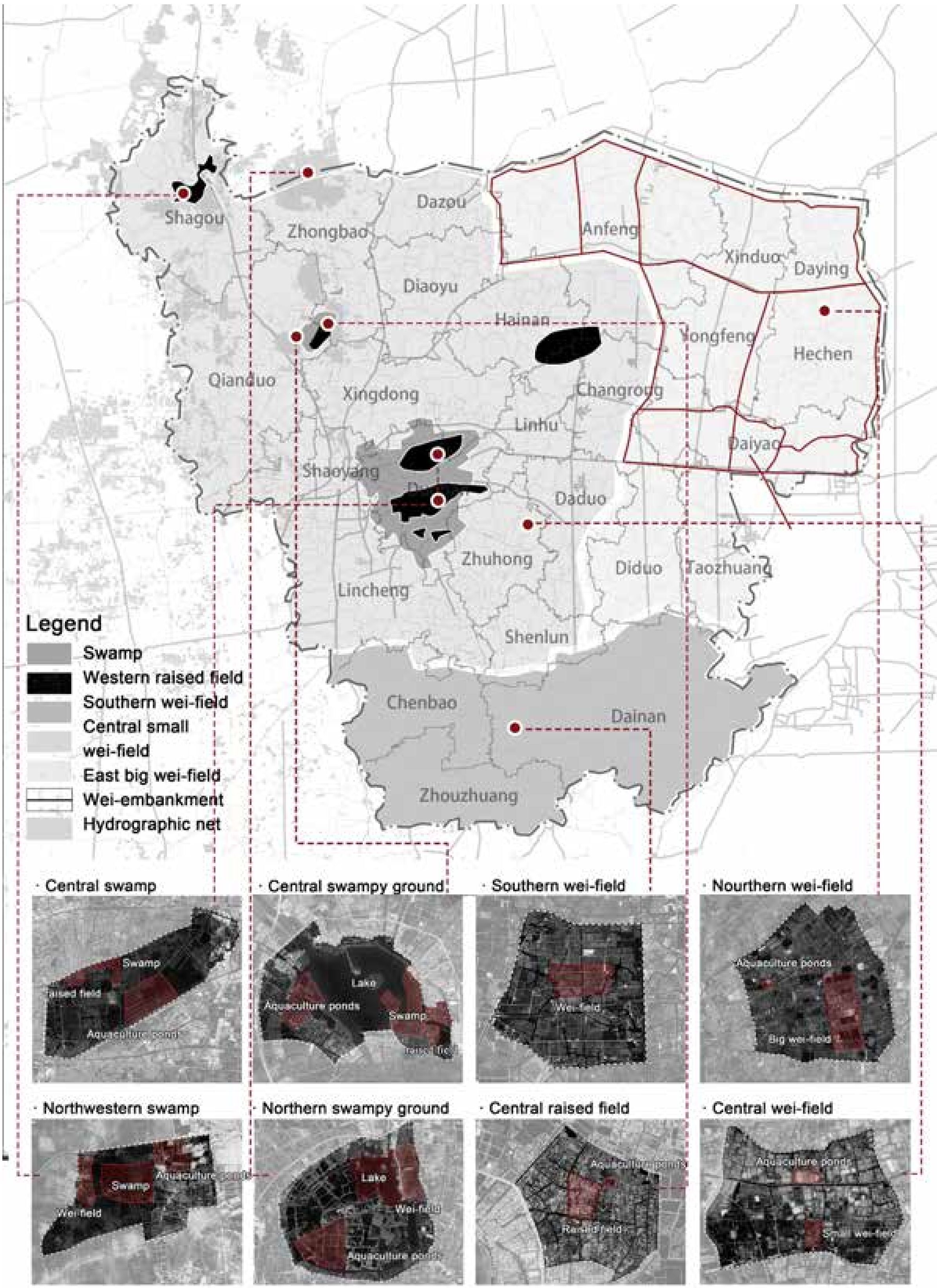

Fig.3 Regional geomorphic features: Explanation for agglomeration characteristic of patch and class

In the analysis of the overall pattern and morphological characteristics, this study selected four landscape pattern indicators, namely aggregation index (AI), cohesion index (COHESION), Shannon diversity index (SHDI), and landscape fragmentation level (SPILT), to systematically quantify the spatial structure of Xinghua. These indicators reveal the characteristics of regional landscape patterns from four dimensions: patch aggregation degree, spatial connectivity, type diversity, and landscape segmentation degree.

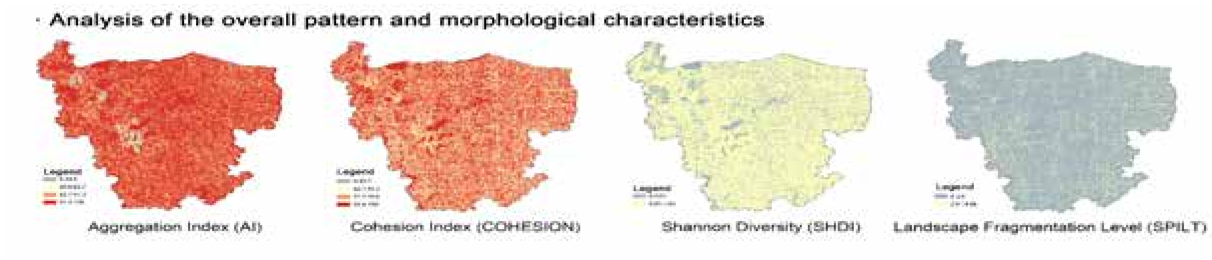

Fig.4 Overall pattern and morphological characteristics

The aggregation index shows that the overall aggregation degree of Xinghua is relatively high, indicating that the same type of land use patches in the region tend to be concentrated. Specifically, the eastern and southern regions exhibit obvious clustering characteristics of the same type of patches, which is mainly related to the local large-scale agricultural production layout. There are three significant areas of low polymerisation degree in the central and northwestern regions, indicating that the distribution of patches of the same type in these areas is relatively scattered. It should be influenced by the natural terrain such as swamps and the historical development model of raised fields and scattered wei-fields formed as a result.

The cohesion index shows that the overall spatial connectivity of the region is strong, with the index generally>82.7, but there is significant spatial differentiation. It is worth noting that the central and northwestern regions exhibit abnormally high values, reflecting that although these areas have a lower degree of aggregation. But different types of patches have formed a dense and interwoven compact spatial structure, which is related to the traditional raised field agricultural system in the area. In contrast, the cohesion index distribution in the eastern and southern regions is uniform and the values are moderate, indicating that the patch combinations in these areas are relatively loose. Their spatial connectivity needs to be improved.

The Shannon diversity analysis results show that the overall SHDI value is relatively low, indicating that the overall land use types in the region are relatively single, which is consistent with the landscape characteristics of Xinghua dominated by agriculture. However, the northwest region exhibits significantly higher diversity values, indicating the coexistence of multiple land use types and the formation of a more complex landscape mosaic fusion area. This high diversity is firstly due to the transitional geographical location of the region, and secondly due to the diverse land use patterns such as raised landscape planting, aquaculture, and wei-field agricultural planting. The landscape heterogeneity and uncertainty it brings need to be taken seriously in subsequent planning.

The results of landscape fragmentation show that the overall landscape integrity of the region is strong, and the degree of fragmentation is relatively low. Further analysis shows that this integrity is mainly due to the developed water system network in the region. These water systems not only divide the landscape, but also serve as a link between different landscape units. It is worth noting that although the overall fragmentation is low, a certain degree of landscape segmentation can still be observed in local areas, such as around towns, which should be the result of human disturbance caused by land reclamation and construction activities.

3.2 Geographical scale characteristics
3.2.1 Construction of geographic scale network based on gravity model
In response to the problems of scattered scale and spatial fragmentation, we introduce and improve "network methods" such as gravity models and social network analysis based on the various scale characteristics and transportation accessibility of villages and towns. By doing so, we can characterise the connectivity of rural communities from multiple dimensions, identify high-level nodes, and determine the "centre" and "edge" of the

region. And the study emphasises network connectivity, with the aim of identifying rural areas that are spatially dispersed and have integrated elements under low-density conditions.

The gravity model can measure the interaction between two spatial entities and is widely used in the study of regional spatial structures. Based on the spatial scale characteristics of rural areas, the following improvements are made to the traditional gravity model to measure the network correlation strength of geographical scale between villages and towns. The study replaces the "comprehensive quality parameter" with the "comprehensive geographic scale of villages and towns" as the core parameter for measuring the attractiveness and radiation effect of villages and towns. Traditional gravity models typically use single indicators such as total population and GDP to represent mass parameters. However, rural areas are different from cities in that their population size is small and the differences are not significant. In addition, Xinghua has always had a landscape with dense river networks and intertwined lakes. Therefore, the study comprehensively considers the size of villages and towns, water systems, cultivated land, and population, and incorporates them into the gravity model.

$$R_{ij} = K_{ij}\frac{M_i M_j}{D_{ij}^2}$$

$$K_{ij} = \frac{g_i}{g_i + g_j} = \frac{G_i/p_i}{G_i/p_i + G_j/p_j}$$

R_{ij} is the strength of the connection between village node i and village node j. M_i and M_j respectively represent the comprehensive calculation results of the indicator items of a certain village node, which is the gravity value of the village. D_{ij} represents the distance between node i and village node j. K_{ij} is the correction coefficient. G_i and G_j represent the area of the town or street where the village is located. p_i and p_j represent the population of the township or street where a village is located. The correction coefficient is used to adjust the size of villages and towns based on township data.

Tab.2 Index of comprehensive geographic scale

Element	Index	Unit	Data sources	Weight
Area Scale	Total area of administrative village	km^2	Survey data of land-use	0.190769
	Proportion of land area for village construction	%	Survey data of land-use	0.28968
Scale of water system	The total length of the water system flowing through the village area	km	*List of Backbone Rivers in Jiangsu Province Revised in 2018* OpenStreetMap	0.117638
	Proportion of water area within the village area	%	OpenStreetMap	0.052713
Scale of cultivated land	Proportion of cultivated land area in villages	%	Survey data of land-use	0.141012
Population scale	Population of administrative villages	/	Jiangsu Government Service Network https://www.jszwfw.gov.cn/*Layout planning of towns and villages in Xinghua Revised in 2022*	0.208188
Area Scale	The area of the town or street where the village is located	Km^2	Survey data of land-use	/
Population scale	The seventh population census of the township or street where the village is located	/	*Statistical Review of Xinghua*	

3 .2.2 Data standardisation processing and weighting
The study used Min-Max normalisation method to normalise data such as village area and river length. And the entropy weight method and analytic hierarchy process are used to calculate the weights of each indicator separately and comprehensively consider them to obtain the weight of each indicator, thereby calculating the gravity value of the village node. According to the gravity model formula mentioned above, the strength of the connections between two villages can be calculated. When processing data, the distribution of network related data will exhibit a heavy daily distribution characteristic, and the core structure will be obscured by a large amount of data with excessively small connection values. The study used heavy tail extraction method to extract network associations that are greater than the average, and ignored the association values between two villages that are less than the average as being too small. The gravity model constructed in this study is an undirected matrix between two villages, and the pairwise connections between each village are visualised on the ArcGIS platform. Study categorises the size of connection values using the natural breakpoint method and constructs a network association pattern for the geographic scale of villages and towns.

3.2.3 Measurement of the network correlation pattern of geographical scale
Preliminary assessment of the centrality based on the comprehensive scale of village and town geography to determine the level of each village and town, clarify the unit centre and the geographical network correlation pattern between each village and town. Firstly, the centrality of each village and town is determined based on their comprehensive geographic scale, and the villages and towns are divided into three levels. From the perspective of node attributes (Fig.5), strong gravity villages and towns are mainly concentrated in the central urban area of Xinghua, Dainan Town in the southeast, and Anfeng Town in the northeast, forming a multi-core structure. The villages and towns with moderate gravity are distributed in a circular pattern around the core nodes. The weak gravity village points are scattered in the northwest and the edge of the village, forming the end nodes of the network system. This “core edge” spatial differentiation pattern reflects the uneven agglomeration of regional geographic scale factors. From Fig. 6, it can be seen that the centrality of geographical scale and network correlation strength within the region are consistent with the distribution of transportation networks. The comprehensive geographical scale of villages and towns in the central and eastern regions with developed transportation routes is relatively strong. It shows an opposite trend to the distribution of water networks to some extent, with areas with denser water networks having relatively weaker overall geographic scale of villages and towns.

There is a significant “core-edge” differentiation pattern in the strength of geographical scale network associations within the region. The high-intensity correlation is concentrated in two core areas: the central and western regions centered around the Xinghua central urban area, and the southeastern Dainan Town area. The correlation strength between these two core areas is the highest, forming the main axis of the regional network. Medium intensity checkpoints are mainly distributed around the core area, connecting secondary nodes such as Anfeng Town and Zhouzhuang Town. But the regularity of their correlation is not obvious. Low intensity associations are sporadically distributed in the densely populated water network areas in the northwest and the agricultural areas in the east, exhibiting short distance and low-density connectivity characteristics. However, the hierarchical nature of the overall network correlation strength and the secondary centres of aggregation are not obvious.

The geographical factors that contribute to the formation mechanism are influenced by topography and hydrology. High intensity association areas are mainly distributed in the central and southern small wei-field areas with good water system connectivity but moderate water network density, while low-intensity association areas are concentrated in the northwest lake and depression areas. The complex water system significantly reduces regional connectivity. And it is related to the distribution characteristics of settlements. The first level associated nodes are located in areas with large settlement scales and dense distributions, which conforms to the core agglomeration law of the central place theory. The small and scattered settlement scale in the edge area leads to a decrease in network connection strength. At the same time, it is also affected by the accessibility of transportation, and the high-strength interconnected corridor is spatially consistent with major transportation channels such as provincial highway and Yanjing River. However, the northwest region is affected by water system segmentation, and the land transportation network is sparse, which directly restricts the frequency of node interaction. From the perspective of historical development path, the central urban area, Dainan Town, and Anfeng Town, as traditional regional centres, have long accumulated infrastructure and public service advantages, making them natural hotspots of network attraction. The peripheral areas are limited by natural geographical conditions and transportation location, and their development is relatively lagging behind.

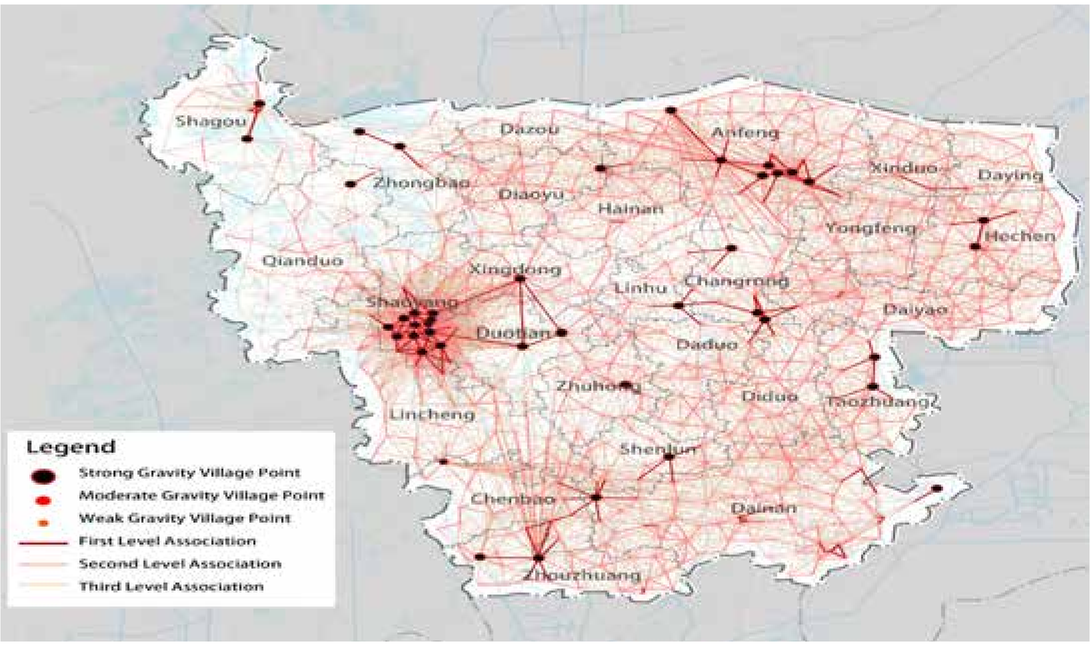

Fig.5 Geographical scale network correlation gravity model for villages and towns

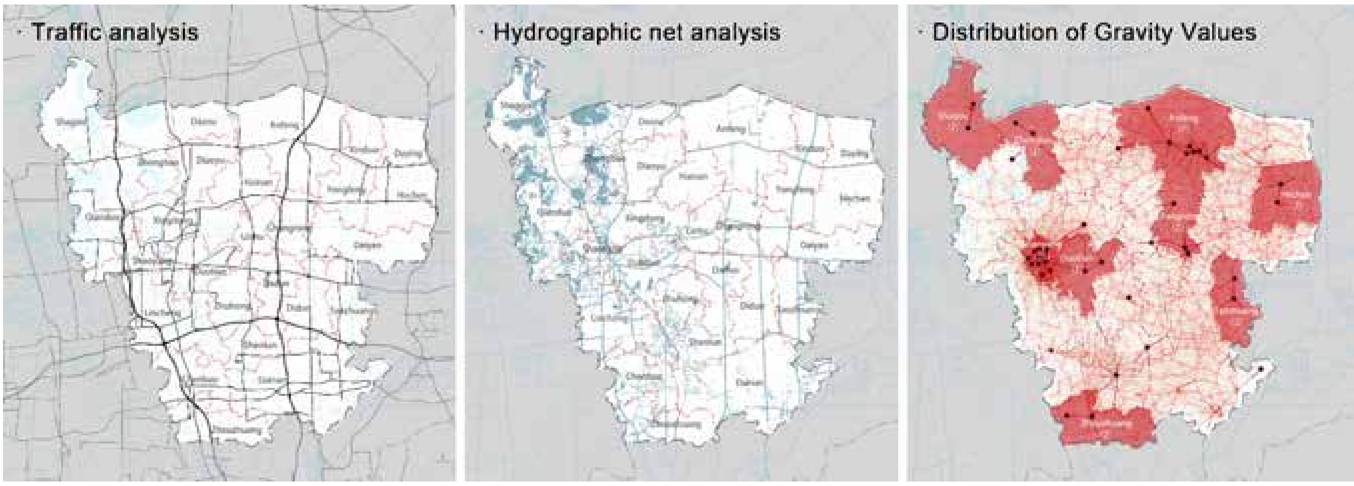

Fig.6 Geographic feature analysis of gravity model

3.3 Cultural superposition characteristics

3.3.1 Distribution characteristics of geographical name categories

The classification of place names and distribution of settlements in Xinghua area exhibit significant geomorphic adaptability and explicit features of historical elements. The settlement types can be divided into four categories: water dominated, agricultural, commercial, and military. The distribution pattern of these settlements is closely related to the unique swamp and wei-field landform and historical and cultural factors in the area.

Tab.3 Geographical name classification explanation

Type of place name		Main Words	Settlement type	Description
Natural geographical name	River system	ditch	Water dominated settlement	Flowing water channel
		sea		The waters near the connection between the mainland and the ocean
		jiang		The general term for large rivers
		river		Natural or artificial large waterways
		port		A river bay that can be anchored
		marsh		Shallow water lake, a depression with accumulated water and grass
		bay		Bend of river
		sand		Arable land by the water's side
		bridge		A bridge, a building erected on water or in the air for passage
		dam		Buildings used to reinforce embankments in hydraulic engineering
	Agriculture	duo	Agricultural settlement	A raised high field formed by excavating a network of deep trenches or accumulating soil along a lake or river network
		pasture		Fields in suburb
		wei		Rice paddies surrounded by earthen embankments
		mount		The towering part formed by the ground, the soil slope
		forest		Clusters of trees
		yard		Vegetable garden, orchard
Humanistic place name	Business	yao	Commercial settlement	Places for firing bricks, tiles, and ceramic vessels, coal kilns
		zao (stove)		Salt boiling household
		chang		Flat open space, threshing ground
	Military	fort	Military type settlement	Small fort, a market town or shop with a city wall
		ton		A few smaller households are established, with surnames added in front of them
		manor		The post station belongs to the official and garrison fields, as well as some official villages
		guan		Temporary stationed barracks
		town		The walls surrounding the city are used for defense
		barrack		Living and camping around the soil

The distribution of settlements and the types of place names in Xinghua area deeply reflect the dual influence of natural landforms and historical culture. Water dominated settlements are widely distributed in areas with dense river networks, and settlements named after words such as "port" and "bay" highlight the adaptive use of water environment by local residents. Agricultural settlements are marked by characters such as "duo" and are concentrated in artificially transformed wei-field and stack areas, reflecting the wisdom of wetland agriculture development. The distribution of military settlements such as "fort" and "ton" in the northern region is not only related to flood control needs, but also closely related to the history of Zhang Shicheng's uprising in this area at the end of the Yuan Dynasty. Some defensive settlements may be remnants of military activities at that time. Commercial settlements such as "yao" and "zao" are scattered, reflecting the layout of salt and handicraft industries relying on water transportation. This settlement distribution pattern vividly demonstrates the human land relationship jointly shaped by natural wetland environment and historical and cultural elements.

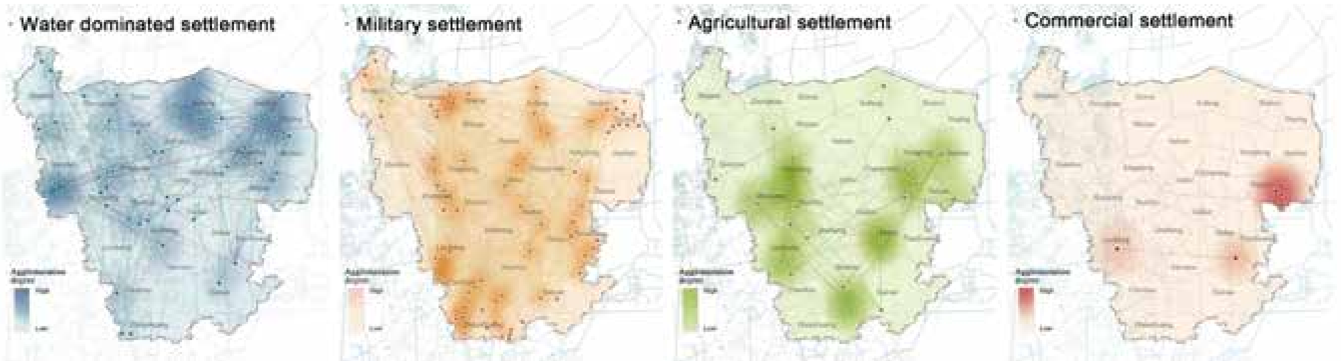

Fig.7 Geographical name analysis results

3.3.2 Analysis of the distribution of historical and cultural values

Tab.4 Historical and cultural elements

<table>
<tr><th>Heritage type</th><th>Category</th><th colspan="2">Quantity</th></tr>
<tr><td rowspan="6">Cultural relics</td><td>Archaeological Sites</td><td>5</td><td rowspan="6">337</td></tr>
<tr><td>Traditional architectural group</td><td>9</td></tr>
<tr><td>List of Historical Buildings</td><td>197</td></tr>
<tr><td>artifacts of the revolution</td><td>14</td></tr>
<tr><td>Traditional street and alley spaces</td><td>19</td></tr>
<tr><td>All levels of cultural heritage preservation units</td><td>93</td></tr>
<tr><td>Intangible cultural heritage</td><td>Traditional skills, folk customs, traditional music, traditional dance, traditional drama, folk literature, traditional medicine</td><td colspan="2">124</td></tr>
</table>

By sorting out the carriers of historical and cultural values in Xinghua, they are divided into two parts: Cultural relics and intangible cultural heritage. The distribution of historical and cultural values is analyzed using kernel density and gravity models. The results show that the historical and cultural resources in Xinghua area have formed a distribution pattern centered on the urban area and radiating along the main water systems. The high-density areas are mainly concentrated in two areas: one is the core cultural circle centered on Xinghua Ancient City, which includes a large number of Ming and Qing Dynasty ancient buildings and celebrity residences. The second is the sub-centre cultural circle around Shagou Ancient Town, characterised by modern commercial buildings and revolutionary sites. These two high-density areas are interconnected through a water transportation network, forming the main axis of regional culture. And there is a significant cultural radiation effect within the region. The national level cultural heritage sites in the central region, such as the Jiangzhuang Site and Xinghua Duotian, as well as provincial-level cultural heritage sites, constitute the main attraction source and have a significant attraction effect on the surrounding cultural resources.

From the perspective of time and space, the formation of this distribution pattern has a profound historical and geographical background. The sites from the Neolithic Age to the Spring and Autumn Period and Warring States Period are mostly distributed around lakes with higher terrain, reflecting the survival strategy of early humans who chose to live higher. During the Ming and Qing dynasties, with the development of wei-field agriculture and the prosperity of imperial examination culture, a gentry cultural circle centered on ancient cities and spread along water systems was formed. It is manifested as densely distributed literati residences and clan ancestral halls. Since modern times, commercial activities and revolutionary movements have left unique cultural imprints in ancient towns such as Shagou, making the region a typical representative of multicultural integration.

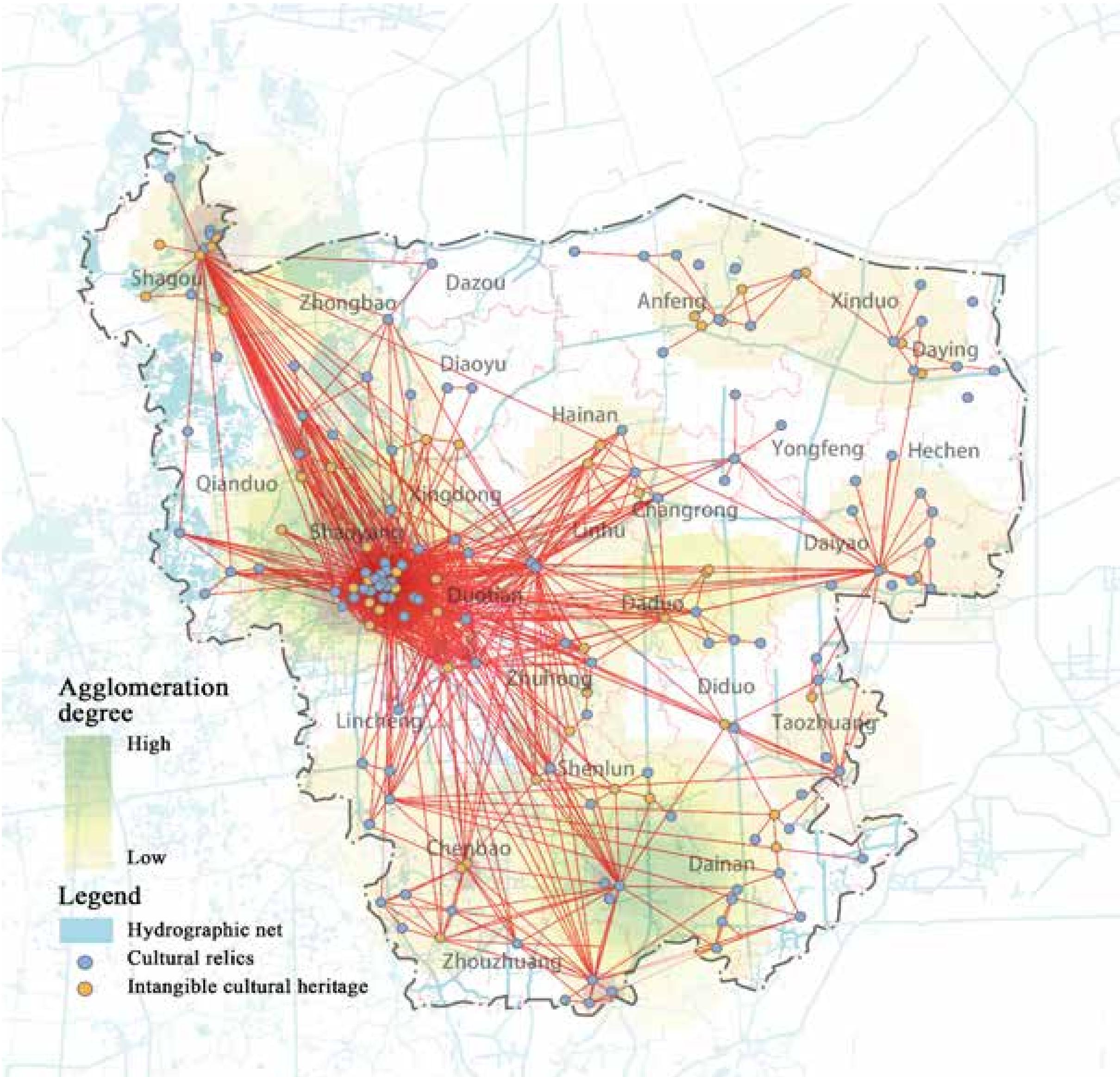

Fig.8 Analysis of gravity model and agglomeration degree based on historical and cultural values

Overall, the spatial distribution of cultural resources is highly consistent with the regional water system network and the geographical scale network of villages and towns measured in the previous section. Bridges, docks and other water transportation facilities are distributed along the river, forming a key link connecting various cultural nodes. Special cultivation methods such as raised field and wei-field are also transformation methods that people adopt based on hydrological conditions. This cultural landscape pattern, with water as its veins, vividly demonstrates the characteristics of the relationship between people and land in Xinghua as a water town area. At the same time, the cultural layering effects of different historical periods have resulted in significant spatiotemporal overlapping features of regional cultural landscapes, providing important samples for understanding the historical and cultural evolution of the Lixiahe region.

4. Conclusion and discussion

This study is based on the perspective of collaborative agglomeration and systematically investigates the multi-dimensional proximity relationships of rural contiguous spaces in Xinghua by constructing a geographical proximity network analysis model. The study reveals the profound impact of geographic background characteristics, scale network correlations, and cultural superposition effects on the spatial organisation of rural settlements, providing new theoretical basis and practical inspiration for regional coordinated development.

4.1 Geographical morphological characteristics shape the spatial differentiation of settlements

The morphological distribution characteristics of rural settlements in Xinghua reflect the synergistic effect of geographical background conditions and cultural development activities. As a typical area in the hinterland of Lixia he, the natural geographical features of dense river networks form the basic framework of settlement distribution, while the artificial wei-field system formed in historical periods further strengthens this spatial pattern. Specifically, the eastern big wei-field area has benefited from the systematic construction of embankments, forming a concentrated and orderly cluster of settlements. The northwest lake and swamp area maintains a relatively scattered distribution of settlements due to the preservation of natural wetlands. This spatial differentiation is manifested in the landscape pattern as follows: the eastern and southern agricultural dominated areas have higher patch aggregation and lower landscape diversity, reflecting the characteristics of large-scale agricultural production. The northwest region, on the other hand, exhibits high landscape heterogeneity due to the coexistence of various utilisation methods such as raised field agriculture and aquaculture. Moreover, the core agglomeration area of the settlement is highly aligned with the main transportation corridors in space, which confirms the crucial role of transportation conditions in the development of the settlement. At the same time, the traditional development of "one wei-field, one village" formed since the Ming Dynasty, and the resulting small-scale characteristics of settlements, still influence the distribution pattern of regional settlements today. These findings not only reveal the decisive influence of natural geographical conditions on the spatial organisation of settlements, but also demonstrate the lasting shaping effect of historical development paths on contemporary settlement patterns, providing important basis for understanding the spatial evolution mechanism of rural settlements.

4.2 The correlation of geographic scale networks presents the fundamental correlation characteristics of centrality

This study constructs a gravity model based on geographic scale indicators, including basic elements such as area, water system, cultivated land, and population, aiming to strip away complex factors and focus on the fundamental impact of geographic background on village associations. We found that the village and town network present a spatial agglomeration pattern centered on the central urban area of Xinghua and Dainan Town, while the water network intensive area in the northwest forms an associated vulnerable area due to natural barriers. This "core-edge" structure reflects the basic distribution law of geographical scale elements: strongly correlated nodes are mostly concentrated in areas with superior transportation conditions and complete geomorphic units, and the correlation strength decays significantly with distance. However, this single dimensional analysis also exposes limitations: Firstly, the network structure presents a flattened feature, which can only identify explicit associations in spatial proximity and lacks explanatory power for cross regional functional connections. Secondly, some villages with collaborative potential, such as those with rich cultural resources but smaller scale, have not been highlighted. This indicates that although geographic scale networks can effectively characterise the spatial basis of village associations, in order to comprehensively reveal the mechanism of collaborative development, it is still necessary to incorporate dimensions such as cultural proximity and industrial complementarity for comprehensive analysis.

4.3 Cultural superposition effect strengthens regional synergy potential

The analysis of place names and the distribution of historical and cultural resources reveal the spatiotemporal layering of natural and cultural elements. Water dominated settlements are distributed along the river network, agricultural settlements are concentrated in wei-field areas, and military settlements are related to historical defense needs. The cultural resources present a distribution pattern with Xinghua Ancient Town and Shagou Ancient Town as the dual cores, and radiate to the surrounding areas through the water system network. Moreover, cultural layers from different historical periods exhibit significant overlapping effects in space. For example, Neolithic sites are mostly distributed around lakes with higher terrain, while literati residences from the Ming and Qing dynasties are distributed in a strip along the main water system. The deep interweaving of cultural landscapes and geographical environments not only strengthens regional cultural identity, but also provides a spatial framework based on historical context for cross village functional collaboration.

The study breaks through the limitations of traditional administrative boundaries and reveals the spatial differentiation pattern and network connectivity characteristics of rural settlements in Xinghua from the perspective of geographical proximity. It lays the foundation for the subsequent integration of multidimensional proximity research such as organisational proximity and social proximity. The geographical background characteristics shape the initial distribution pattern of settlements, while the cultural overlay effect further enriches the potential for regional coordinated development. Moreover, there is a significant spatial autocorrelation between the types of landforms and the distribution of cultural heritage, revealing the layered effect of the coupling between nature and culture. To promote regional coordinated development, it is necessary to innovatively utilise the cultural aspects of villages based on similar geographical resources. Cultural coding strategies can be used to transform agricultural place names such as “duo” and “wei” into ecological agricultural brand logos, such as Qianduo Town achieving tourism revenue growth through the “duo tian (raised field)” IP. Utilise existing resources to activate historical networks. For example, by utilizing the Ming and Qing water transportation corridors to connect scattered cultural nodes, a cross-town cultural industry chain can be formed in the Dainan Shagou area, driving the participation of surrounding villages in collaborative operations. This transforms the hierarchical effect of historical and cultural heritage into an endogenous driving force for the development of rural characteristics. This can not only solve the problem of mismatch between spatial planning and administrative boundaries, but also organically integrate cultural heritage into development planning through quantitative historical and cultural analysis, achieving the coexistence and prosperity of natural ecology and humanistic values.

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