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Identifying Restructuring Types of Rural Settlement Using Social Network Analysis: A Case Study of Ezhou City in Hubei Province of China

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Abstract: Social interaction has become one of the key factors affecting the spatial reconstruction of rural settlements (SRRS). However, most studies ignored the multi-scale impact of social networks on the identification of restructuring types of rural settlements. This paper, taking Ezhou City of Hubei Province, China as the case study area, developed a potential inter-settlement network through considering settlements as nodes, and inter-settlement interactions induced by the spatial disparity of public facilities as edges, divided towns in Ezhou City into three zones based on community structure at the town level, and then identified four types of rural settlements in light of the characteristics of cluster patterns and centrality at the patch level. The results show that the inter-settlement network in Ezhou City presents apparent disparities in terms of community structure, cluster patterns and centrality. In community analysis, high inter-community and intra-community interactions are concentrated in well-developed areas in the north and east, while weak interactions between communities occur in the southern areas dominated by traditional agricultural production. Accordingly, three zones are divided such as the urban-leading zone, urban-rural integration zone and rural-leading zone. For the network centrality and cluster patterns, high-level rural settlements are mainly distributed in the urban-leading zone, followed by the urban-rural integration zone and the rural-leading zone. Moreover, the lump cluster pattern is observed in each zone, but the chain pattern and dispersed pattern largely occur in the rural-leading zone. At same time, four types of rural settlements are identified, namely urbanized settlements, central settlements, grassroots settlements and relocated settlements. The corresponding plans are discussed in different zones regarding urbanization, integration and characteristics to provide meaningful insights for policymakers to guide SRRS. This study would contribute to our understanding of the impact of social network involved in daily life on rural settlement reconstruction, and expect to provide theoretical and methodological support for rural sustainable development in practice.

Keywords: rural settlement reconstruction; public service facility; inter-settlement network; spatial differences; zonal division

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1 Introduction

Since the policy of reform and opening up, China has made great progress in urbanization and industrialization, with an increase of urban population from 17.9% in 1978 to 60.6% in 2019 (National Bureau of Statistics of China, 2020). However, the rapid urbanization has attracted massive rural labor flooding into cities, leading to population decline and the emergence of hollowed villages (Liu et al., 2013; Chen et al., 2014). It has fully illustrated the inefficient use of rural construction lands and inharmonious human-land relations in rural areas (Long et al., 2012; 2016; Liu et al., 2018). To revitalize rural development, an important strategy of 'building a

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new countryside' was put forward by the Chinese central government back in 2005 (Long et al., 2010). Then, in 2017, the Rural Vitalization Strategy (RVS) was proposed in the report of the 19th National Congress of the Community Party of China, aiming to construct a beautiful countryside with prosperous industry, livable ecology, civilized rural style, effective governance and affluent living (Li et al., 2020). Under this circumstance, rural spatial restructuring has been used as a significant instrument to solve increasingly serious human-land conflicts and realize rural sustainable development (Long, 2014; Rao, 2020). In particular, rural settlements, as the carriers of farmers' living and production, can reflect the interaction between human activities and the geographical environment (Hosseini et al., 2015; Lu et al., 2020). Therefore, the spatial reconstruction of rural settlements (SRRS) is the key to practice the construction of beautiful countryside and improve human settlement environment (Tian et al., 2018).

SRRS, as a type of spatial rearrangement of land use, emphasizes reorganization of the spatial distribution of rural settlements by exploring different restructuring directions and modes (Kong et al., 2021). This calls for rational village-town systems in which different rural settlements have varied functional orientations and hierarchical roles (Liu et al., 2019). Different restructuring modes including in situ urbanization, concentrated rural settlements and hollowed village consolidation have been proposed (Tian et al., 2016; Lu et al., 2020). Thus, it is essential to identify the restructuring types of rural settlements, as it can provide targeted guidance for SRRS, improve land use efficiency and alleviate rural human-land contradiction (Long, 2014; Kong et al., 2021). Recently, SRRS has received considerable attention from scholars, and numerous empirical studies have discussed the appropriateness of spatial reconstruction modes. The criterion for identifying the restructuring modes of rural settlements has been changed from only stressing the superiority of production and rank size, such as rural settlement size (He et al., 2019), population size (Porta et al., 2013) and farming radius (Lu et al., 2020), to considering the convenience of travel and livability of the living environment (Li et al., 2014; Ma et al., 2018; Zhao et al., 2019). However, the rapid development of globalization and urbanization has contributed to the emergence of transportation networks, information networks and production networks. In this context, rural settlements are no longer isolated, but tightly interconnected by population, information and material flows (Tacoli, 1998; Milbourne and Kitchen, 2014). Influenced by various spatial interactions, rural residents' cognitions and demands for living space and the roles of rural settlements have changed qualitatively (Cui et al., 2019). Therefore, traditional reconstruction methods stressing a single attribute of rural settlements, to some extent, can not provide reasonable interpretations for the current spatial layout of rural settlements due to a lack of capturing the spatial interaction among rural settlements.

Spatial interaction theory is widely applied to describe various element flows and reflect interconnections between them. It focuses on the mode and structure of the social network formed by spatial interaction and the identification of individual roles and functions from the overall perspective (He et al., 2017). Social network is an important component of rural life, which has direct influence on residential mobility, the evolution and distribution of rural settlements and even future rural development (Wong et al., 2016; Hang and Payne, 2017). Given that social networks have exhibited remarkable advantages in population migration, employment and housing (Hou et al., 2015; Zhang et al., 2020), a growing number of scholars have extended social network analysis to discriminate the roles of rural settlements in social networks (Wang et al., 2016). Specifically, Su and Wang (2018) constructed a village spatial network using an improved potential model and identified three kinds of restructuring modes: central village diffusion type, grassroots village growth type and scattered rural settlement promising type. Tian (2016) proposed a restructuring method of rural settlement by observing spatial and non-spatial connections among settlements, analyzed the characteristics of social networks and revealed the hierarchy of village-town systems, that is, central villages, marginal villages and general villages. The above research undoubtedly provided a supportive reference for rural planning and reorganization. However, most studies have discussed the construction of social networks, and identified the restructuring modes and types of rural settlements from the overall perspective based on a single centrality indicator, such as degree centrality, in which connections can be modeled based on actual observations and simulation approaches like gravity model and radiation model (Tian et al., 2016; Esch et al., 2014; Cui et al., 2019; Kong et al., 2021). Few works have focused on the

multi-scale impact of social networks on the identification of rural settlement restructuring types. In fact, due to regional discrepancies in resource endowment and economic development, the spatial heterogeneity of social networks is obvious at the town level and patch level. Therefore, it is necessary to explore different criteria to identify the roles and types of rural settlement in social networks in local conditions.

Moreover, social networks are multiplex relationship networks in rural areas that consist of diverse interactions (Faust et al., 2000). Daily interaction for the purpose of working, education, recreation and so on, has proven promising to provide guidance for rural settlement relocation (Milbourne and Kitchen, 2014; Kong et al., 2021). Since public service facilities serve as important incubators of daily interactions, residents need to travel between various settlements to satisfy their needs for public facilities such as schools, hospitals and markets (Tian et al., 2018; Gieling et al., 2019). Obviously, the spatial differences of public facilities have the potential to illustrate interactions among settlements and regional discrepancies of social networks. However, how the spatial allocation of public facilities shapes social networks in rural areas has not received sufficient attention.

This paper attempts to construct an analytical framework to identify the restructuring types of rural settlements based on the multi-scale characteristics of social networks. To be specific, this paper would like to address the following key issues: 1) constructing an inter-settlement network based on the daily interaction between rural settlements and public service facilities; 2) carrying out zonal division at the town level based on the community structure of the inter-settlement network; 3) comprehensively evaluating the roles and significance of rural settlement in the inter-settlement network at the patch level; 4) identifying the restructuring types of rural settlement in the SRRS? We expect the findings would provide guidance for SRRS.

2 Materials and Methods

2.1 Study area

Ezhou City (30°00′N–30°06′N, 114°32′E–115°05′E) is a medium but rapidly growing city located in the eastern part of Hubei Province in the central China (Fig. 1). It consists of 21 towns and 4 streets, covering a total area of 1596 km^2 and a population of 1.3 million in 2019, of which rural population accounted for approximately 35% (Ezhou City Bureau of Statistics, 2020).

Ezhou is a nation-level demonstration of urban-rural integration development in China, in which the urbanization rate increased from 30.00% in 1990 to 65.91% in 2019. However, rapid urbanization leads to an increase in the demand for urban construction land. It is critical to reorganize the development potential of rural settlements to meet the demands of urban development. On the other hand, with large migration of rural surplus labor flowing into urban areas, the non-agricultural transfer of labor contributes to stable growth in farmers' income, which was 19 313 yuan (RMB) in 2019 (Ezhou City Bureau of Statistics, 2020), far higher than the average level of Hubei Province. At the same time, the phenomena of multi-homesteads for one family and hollowed out are increasingly prominent. In addition, rural settlements are relatively scattered and fragmented in the southern areas, such as Tujiaonao and Taihe which is not conductive to infrastructure construction and the allocation of public service facilities. This result indicates that rural settlements were inefficiently used in Ezhou City. Hence, SRRS has been implemented as an effective tool to solve land-related problems and optimize the spatial structure of rural construction land: some rural settlements need to be demolished to new suitable sites, while some need to be consolidated into urban areas to support urban development. It is necessary to explore the spatial structure and identify the restructuring types of rural settlements to support the decision-making of the rural settlement reconstruction.

2.2 Data source and processing

We collected data as follows: 1) Land-use data and road data in 2018 were derived from Bureau of Natural Resources and Planning of Ezhou; 2) Population data at village level were acquired from Bureau of Statistics of Ezhou (Ezhou City Bureau of Statistics, 2015), and were calculated at patch level according to the proportion of the patch area. 3) Nine types of public service facilities were derived from Baidu Map POI (point of interest, http://lbsyun.baidu.com) and the field investigation to represent four types of interactions: education, healthcare, recreation and shopping. The spatial distribution and amount of each public facility are shown in Fig. 2.

2.3 Methodology

Fig. 3 illustrates the framework of the construction and evaluation of inter-settlement networks. The framework comprises three stages: 1) constructing the spatial network of rural settlements; 2) carrying out a two-level analysis, including the community structure at the town

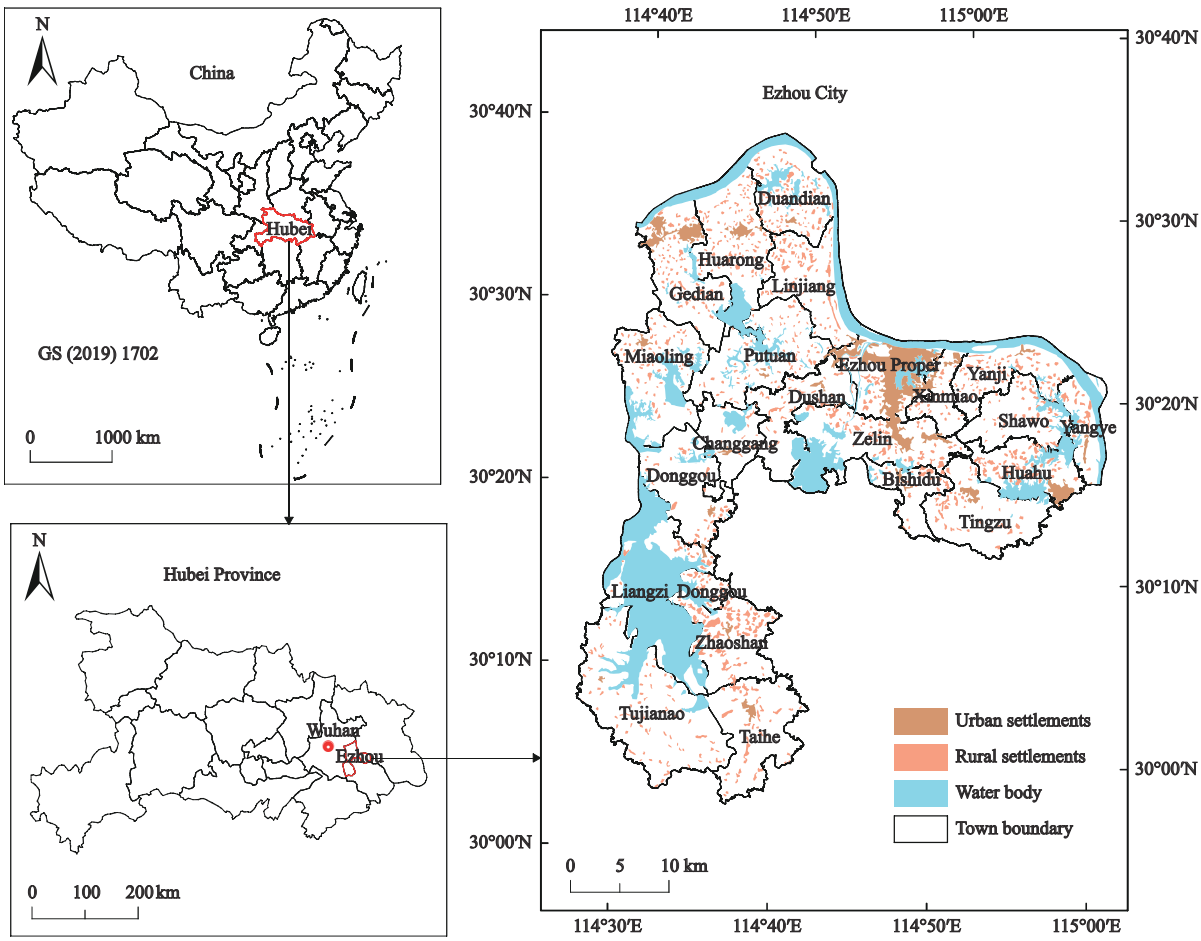

Fig. 1 Location of Ezhou City, Hubei Province, China

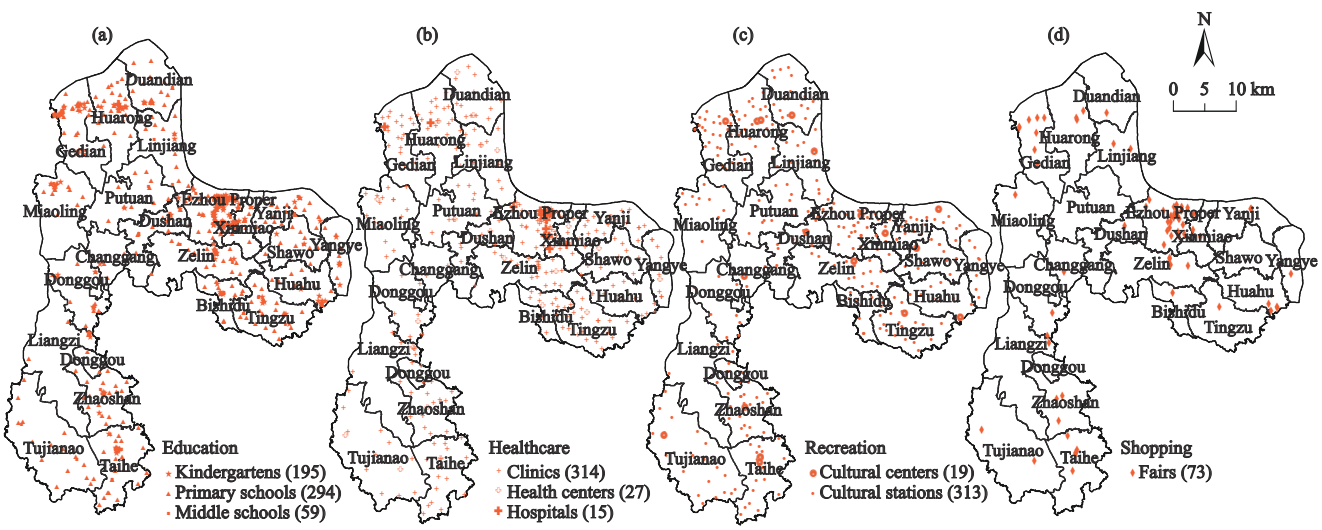

Fig. 2 Spatial distribution of education facilities (a), healthcare facilities (b), recreation facilities (c) and shopping facilities (d) in Ezhou City

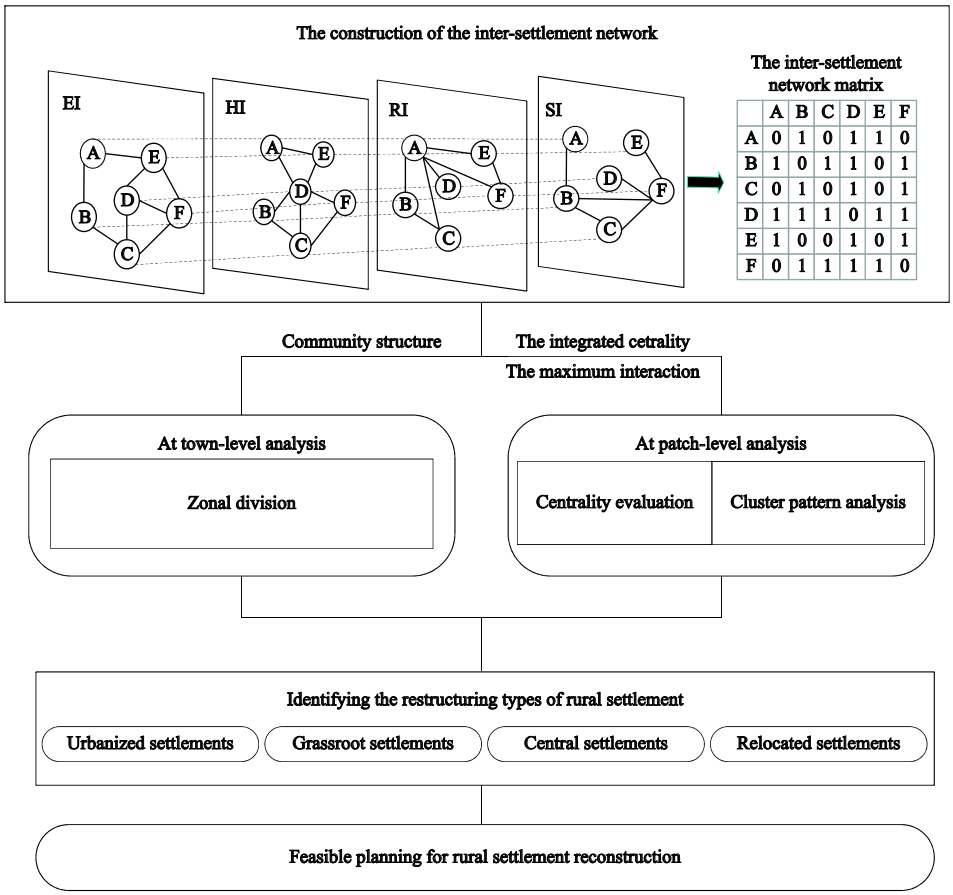

Fig. 3 Flow chart of construction and evaluation of inter-settlement networks; EI is the education-based interaction, HI is the health-care-based interaction, RI is the recreation-based interaction and SI is the shopping-based interaction. A, B, C, D, E and F are the network nodes (settlements). Solid lines and number '1' represent the existence of links between two settlements, and number '0' represents the non-existence of links

level, integrated centrality and cluster patterns at the patch level; and 3) identifying the restructuring types of rural settlements according to zonal differences of centrality and cluster patterns. At the first stage, urban and rural settlements were taken as nodes, and interactions among settlements were taken as edges based on public service facilities in the inter-settlement network, which was measured based on the improved gravity model in rural areas. The second stage includes a two-level analysis. At the town level, the towns of Ezhou were divided into three zones, and the development directions of each zone was determined in light of the inter-community strength and intra-community strength. At the patch level, the significance of each rural settlement was evaluated in the inter-settlement network by comprehensively considering three kinds of centrality indicators. At the final stage, four restructuring types of rural settlement in SRRS were identified by combining the zonal differences with the centrality and cluster patterns.

2.3.1 Construction of the inter-settlement network

Spatial interactions among rural settlements mainly originated from various flows of population and elements. Sparse data in rural areas make the representation of inter-settlement interactions a great challenge. Public service facilities serve as important incubators of daily interactions. Knowing which rural settlements exist sharing public facilities can provide useful information about the potential interactions among rural settlements (Faust et al., 2000). Therefore, the basic assumption behind the spatial network is a link exists between two settlements sharing the same facilities within interactive areas. As shown in Fig. 4, there is a sharing public facility p_2 between settlements S_1 and S_2 in the interactive areas, so it can be seen that the link exists between them in the final social network. The interaction strength is closely related to the population and distances between two settlements in the traditional simulation model (gravity model). In this study, we modified the popula-

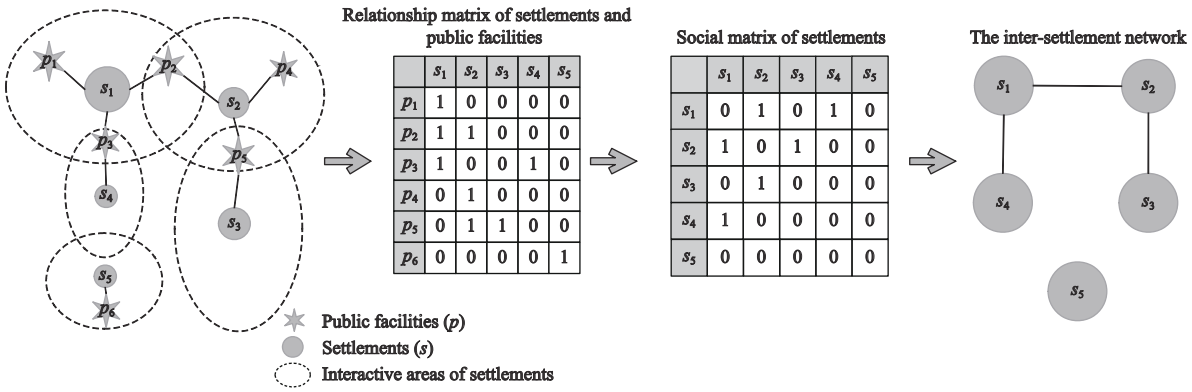

Fig. 4 Interaction diagram of rural settlements based on sharing public service facilities

tion based on the number of shared facilities, which is equal to the sum of the population visiting to sharing facilities, not the total population of each rural settlement. The interaction strength based on a certain category c of public facility is calculated as:

$$IS^{c}_{mn} = \sum_{j=1}^{J} (P_m \times SP_{mj}) \times (P_n \times SP_{nj}) \times D_{mn}^{-2} \quad (1)$$

where $IS_{mn}{}^{c}$ is the spatial interaction based on a certain category c of public facility between settlement m and n; P_m and P_n are the population of settlements m and n. SP_{mj} and SP_{nj} are the possibility of settlements m and n attending to sharing facility j, representing the comprehensive adjustment of actual population flow; J is the number of sharing facilities in the category c of facility; and $D_{mn}{}^{-2}$ is the travel time from settlement m to settlement n.

In general, people are more likely to attend to facilities with higher service capacity and closer distances among competing facilities within ideal interactive areas (Huff, 1963). Assuming that the service capacity of each facility remains constant, the possibility of settlement m attending to facility j can be formulated as:

$$SP_{mj} = \frac{S_j \times D_{mj}^{-2}}{\sum_{j=1}^{J} S_j \times D_{mj}^{-2}} \quad (2)$$

where, SP_{mj} is the possibility that settlement m attends to facility j; S_j represents the service capacity of facility j, which is set to 1; and $D_{mn}{}^{-2}$ is the travel time from settlement m to facility j.

Then, the total interaction between settlement m and n is calculated using Formula (3)

$$IS_{mn} = \sum_{r=1}^{R} \sum_{c=1}^{C} w_r \times w_c \times IS^{c}_{mn} \quad (3)$$

$$w_c = \frac{N_c}{N_r} \quad (4)$$

where IS_{mn} is the total interaction between settlement m and n with regard to all relationships. R is the relationship type, C is the category of public facilities in relationship r. w_c denotes the interaction frequency of a certain category c of public facility, determined by the amount of public facility in a certain category c, and the total number of public facilities in a certain relationship r. w_r is the weight of relationship c, determined by the Delphi method. To facilitate the analysis and visualization of the inter-settlement network, the interaction of each settlement with higher than the average value is retained, and some spurious and statistically insignificant interactions are ignored.

In this paper, the time cost that residents can accept is different with regard to various types of public facilities. Time-cost accessibility can provide references for the interactive areas of rural settlements in daily life. Thus, the interactive time of each type of public facility is determined by the vehicle choices and land-use types (Tian et al., 2018). According to our investigation, motorbikes, public buses and private cars are the preferred transportations for residents when attending middle schools, health centers, hospitals, cultural centers and fairs, while walking is the main choice for residents to go to kindergartens, primary schools, clinics and cultural stations. The time cost of different scenarios is listed in Table 1. The ideal interactive time of each type of public facility is determined by its average shortest distance, and the specific details of public service facilities and interactive areas are listed in Table 2.

Table 1 Time costs in different situations in Ezhou City

Spatial objects	Highway	Main road	Country road	Urban settlement	Rural settlement	Other land	Water
Speed (km/h)	120	60	30	6	4	3	1
Time cost (min/10m)	0.005	0.010	0.020	0.100	0.150	0.200	0.600

2.3.2 Structure of the inter-settlement network

(1) Community structure detection

Community structure depicts the existence of sub-groups with close intra-community connections but loose inter-community connections, which can provide a useful reference for zonal division at the town level. To detect the community structure in the network, the Louvain algorithm is used to identify community structure in this paper, and the modularity (Q) is used to evaluate the quality of the network partition (Newman and Girvan, 2004). The modularity is defined as follows:

$$Q = \sum_{c=1}^{n} \left[L_c/m - (k_c/2m)^2 \right] \tag{5}$$

where, Q represents the modularity, n is the number of communities, m is the sum of total interactions in the network, L_c is the sum of intra-community interactions for community c, and k_c is the total interactions of community c.

(2) Centrality analysis

Many previous studies confirmed that the significance and role of individual node in social networks affected willingness, performance, and accessibility to resources (Isaac and Matous, 2017; Xia et al., 2020). It is actually consistent with three network centrality indicators: strength centrality, betweenness centrality and closeness centrality. Strength centrality combines the notions of degree and edge weight, depicting the amount and intensity of ties a node has with other nodes (Opsahl et al., 2010; Cao et al., 2019). A settlement with higher strength centrality is expected to access more resources through direct connections with other settlements. Betweenness centrality measures the probability of a node being on the shortest path between any two nodes, which captures intermediary position of a settlement serving as a bridge to facilitate interaction between other settlements (Hang and Payne, 2017; Xia et al., 2020). A settlement with higher betweenness centrality generally has a greater capacity to provide public facilities for other settlements in the inter-settlement network. Closeness centrality refers to the sum of the shortest paths from a given node to all other nodes (Opsahl et al., 2010). A settlement with higher closeness centrality interacts with other settlements to obtain public services more quickly and efficiently. The formulas of the three centrality indicators can be found in Erath et al.(2009) and Opsahl et al.(2010). However, given that the above-mentioned centrality indicators often stress a certain aspect of settlements, an integrated centrality is developed using the entropy method to compound three indicators. This not only embodies the connections of a settlement with other settlements but also considers the role serving as a bridge in the network. It can be defined as follows:

$$IC_i = \alpha S_i + \beta B_i + \gamma C_i \tag{6}$$

where IC_i is an integrated centrality of node i. S_i, B_i and C_i represent the strength, betweenness and closeness centrality of node i, respectively. α, β and γ are the corresponding weights of each centrality metric, which were set to 0.463, 0.532, 0.005, respectively.

Table 2 Interactive time of each public facility in Ezhou City

Interaction	Public service facility	Interactive time
Education	Kindergartens	20 min by walking
	Primary schools	20 min by walking
	Middle schools	20 min by car
Healthcare	Clinics	20 min by walking
	Health centers	20 min by car
	Hospitals	38 min by car
Recreation	Cultural stations	20 min by walking
	Cultural centers	25 min by car
Shopping	Fairs	30 min by car

2.3.3 Identification of restructuring types of rural settlement

Centrality and cluster patterns, as two important factors of the network play significant roles in identifying types and directions in the SRRS. The examination of centrality reveals the significance of each settlement in the network, while the cluster pattern reflects residents' preference for destinations in daily interactions, which facilit-

ates the identification of social centers and relocated directions. Accordingly, the cluster pattern is determined by the maximum interaction strength diagram. The most interconnected settlement of each rural settlement is discovered according to the maximum interconnection strength. The settlements with the greatest number of maximum connection strength are identified as social centers.

In this paper, we combined centrality and cluster patterns to identify the restructuring types of rural settlements. Four types of rural settlements are classified, namely urbanized settlements, central settlements, grassroots settlements and relocated settlements. The judgement rules are listed in Table 3. Specifically, 1) in terms of urbanized settlements, benefiting from close distance to urban areas and convenient transportation, people in urbanized settlements tend to go to urban areas to obtain public services and goods. These settlements therefore often have strong interaction with urban settlements and high-level centrality in the inter-settlement network; 2) central settlements, owing to the abilities of providing relatively complete public services and goods, also have high centrality and serve as social centers for local residents to come together; 3) infrastructure and public facilities around grassroots settlements are often relatively poor, which can only meet the basic needs of farmers. As they lack competitiveness and attractiveness, the daily population flow is mainly outflow. Thus, grassroots settlements generally have medium-level centrality but do not serve as social centers; 4) relocated settlements with distant locations and scattered distributions often suffer from inadequate infrastructure and public facilities, such that loose interactions occur between relocated settlements and other settlements. Hence, they generally have low centrality and dispersed patterns. Certainly, to avoid the concentrated distribution of central settlements and relocated settlements in regions, we also considered development modes of zones and ranked the significance of network centrality within each zone, rather than from the overall perspective.

Table 3 Discrimination criteria of classification of rural settlements in Ezhou City

Four restructuring types	Centrality			Clustering centers	
	High	Medium	Low	Yes	No
Urbanized settlements	●	–	–	–	●
Central settlements	●	–	–	●	–
Grassroots settlements	–	●	–	–	●
Relocated settlements	–	–	●	–	●

3 Results

3.1 Construction of the inter-settlement network

Social networks based on the demands of rural residents to public service facilities consist of education-based interactions, healthcare-based interactions, recreation-based interactions and shopping-based interactions in Ezhou City. As stated earlier, all interactions are weighted and form an inter-settlement network. In the inter-settlement network (Fig. 5), 1088 settlements are connected with a total of 26 034 spatial links. To facilitate analysis, only the top 10, 000 links are extracted for visualization, and the interaction strengths are divided into three levels: high, medium and low. The result shows that the interactions of the inter-settlement network have a heterogeneous spatial distribution and that spatial hubs exist. Specifically, the network density is high and links are crisscrossed in the north and east, while the network density is relatively low and links are mainly distributed along the traffic in the south. It indicates that settlements in the north and east are more closely connected than those in the south. In terms of interaction strength, high-level interactions are largely distributed around urban areas and along the main traffic, with the greatest number in Ezhou Proper and northern towns such as Gedian and Huarong.

3.2 Zonal division based on community structure analysis

Based on the structure of the inter-settlement network, we conducted community structure analysis in Pajek 5.09 (Fig. 6a). There are 17 communities with the modularity of 0.94, implying a significant spatial coherence. Settlements in the same community have closer interactions. To better illustrate the community structure, the interaction strengths in the same and different communities were aggregated as intra-community and inter-community interaction strengths. It showed obvious differences in community size, intra-community strength and inter-community strength.

The size of communities ranges from 10 to 131, with an average size of 64. More than half the communities

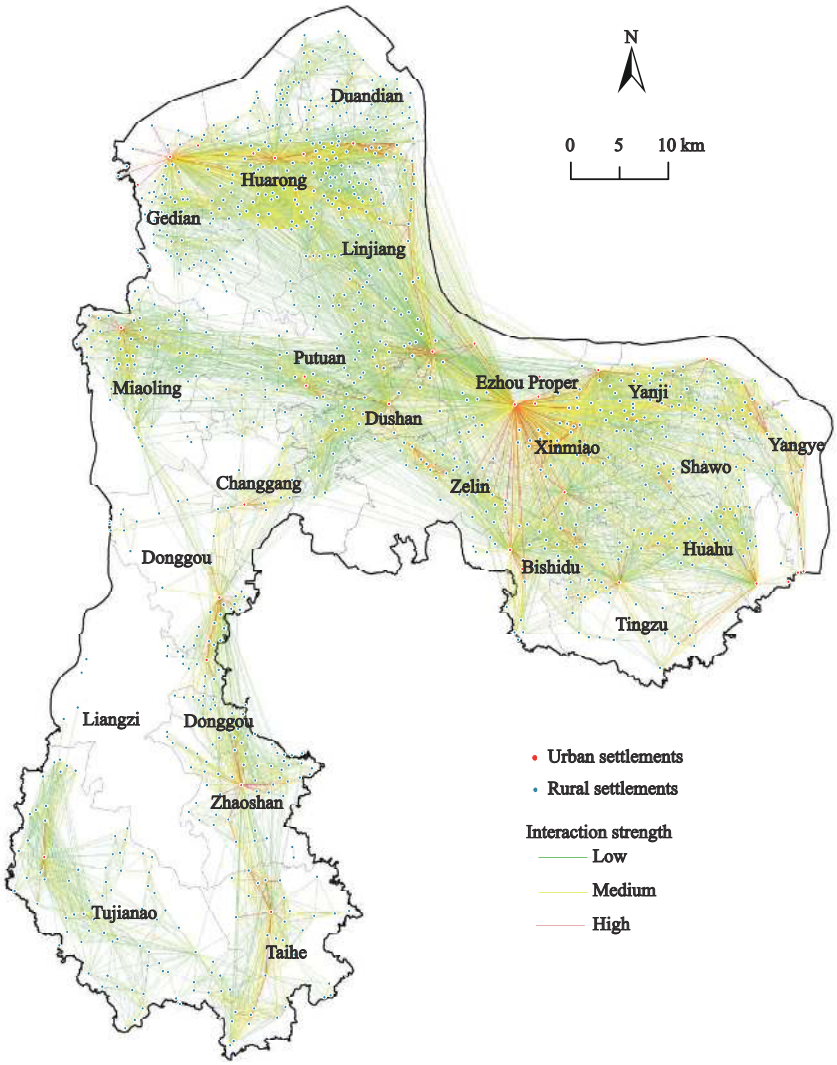

Fig. 5 Spatial distribution of the inter-settlement network in Ezhou City

are larger than the average size, with the largest number in C6 centered the Ezhou Proper. Moreover, it shows a certain degree of spatial consistency between the scope of communities and towns, indicating that most residents tend to conduct daily interactions in the same towns. In terms of interaction strength, two hubs can be observed, i.e., C3 and C6, which have strong inter-community and intra-community interactions. The neighboring communities (C2, C5, C7, C9, C12 and C13) only have high inter-community interactions with C3 and C6, that is, there is a dense interaction with other communities, but loose interaction within communities. In comparison, although communities in the south are relatively larger, they have low inter-community and intra-community strength, indicating loose interactions in the south.

The zonal division at the town level is determined by the inter-community strength and intra-community strength in the community structure. The two metrics are used to reflect the attractiveness and cohesion of towns and rural areas. A total of 25 city and towns in Ezhou City are divided into three zones using cross discrimination (Fig. 6b), in which the average value of two metrics are viewed as the threshold of the discrimination of 0.231 and 0.134, respectively. Communities with higher than the average value in the inter-community and intra-community strength are divided into the urban-leading zone, which coincides with the geographical scape of the Ezhou Proper, Gedian, Huarong, Zelin and Xinmiao. These towns, especially the Ezhou Proper and Gedian as centers of urban development, have absolute advantages in population size, infrastructure and public

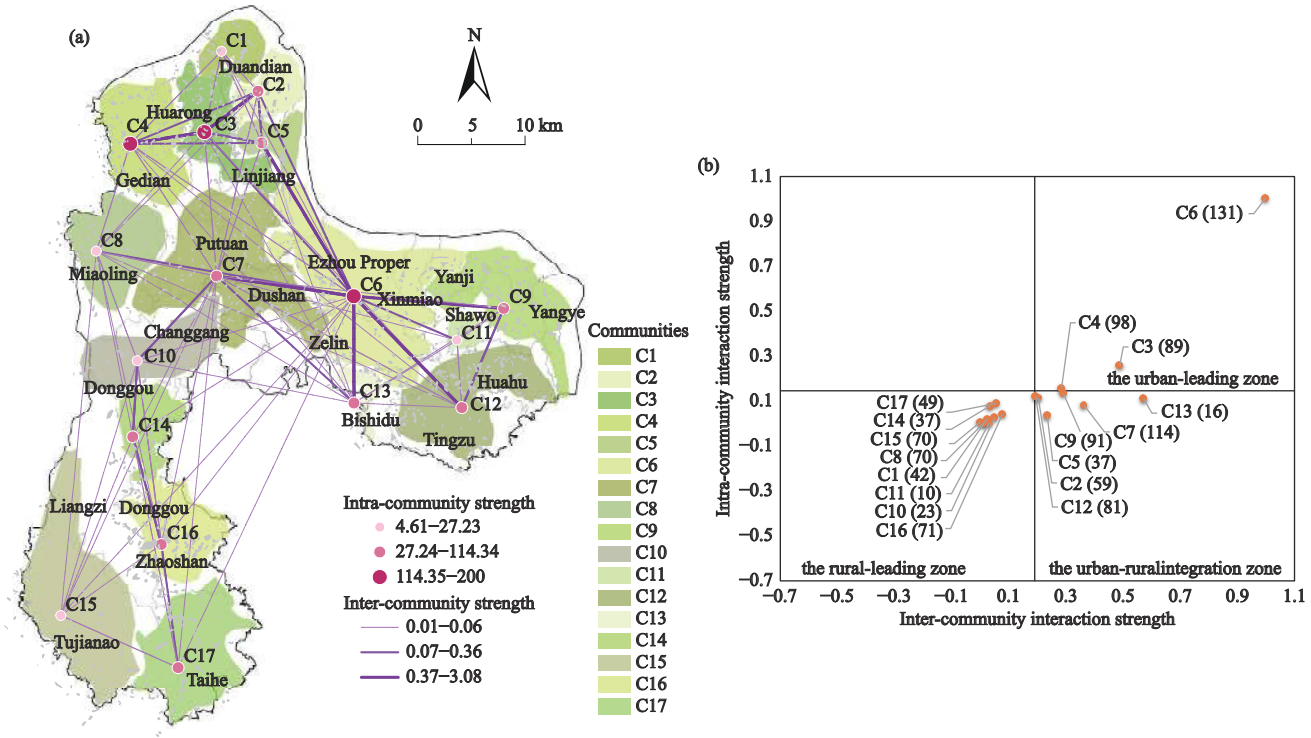

Fig. 6 Community structure in the inter-settlement network (a) and cross discrimination of towns by inter-community and intra-community strength (b) in Echou City. the numerical values in brackets represent the number of settlements in communites

facilities, such that they have strong internal cohesive forces and external attractions. Communities with higher than average value in the inter-community strength but lower values of intra-community strength are divided into the urban-rural integration zone. These towns include Duandian, Linjiang, Putuan, Dushan, Yanji, Shawo, Yangye, Huahu, Tingzu and Bishidu. Compared with towns in the urban-leading zone, the weakness in these towns is relatively low-level urbanization and a less-perfect public facility system, which limits the cohesive force of urban areas to internal rural settlements. Influenced by strong radiation, settlements in this zone prefer going to towns in the urban-leading zone to obtain services and goods. Communities with low inter-community and intra-community strength are classified into the rural-leading zone. Towns in these communities are largely distributed in southern Ezhou City, and the economics and diversity of their public facilities lag behind those of other towns, which results in loose interactions in the zone.

3.3 Distribution of settlements' centralities in different zones

Four kinds of centrality indicators are measured, and the spatial distribution are shown in Fig 7 and the basic statistics of centrality indicators in different zones are listed in Table 4. To facilitate visualization and analysis, their values are divided into three levels based on the natural breaks method: high, medium and low. It can be seen that all centrality indicators show considerable heterogeneities.

Strength centrality. The city average value of strength centrality is 3.311. The average value in the urban-leading zone scores higher than 7, far from the city average value. By contrast, the average values in the urban-rural integration zone and rural-leading zone are lower than 2, especially for the rural-leading zone, which scores the lowest at 1.673. The high-level settlements are largely situated around urban areas and along the main traffic in the central regions, including the Ezhou Proper, Zelin and Xinmiao, showing a downward trend toward the peripheral regions.

Betweenness centrality. The city average value of betweenness centrality is 0.0036, and the urban-leading zone has the highest average value of 0.004. The average values of the remaining zones are similar to the city average value. Moreover, the number of settlements (86) with high betweenness centrality is the greatest in

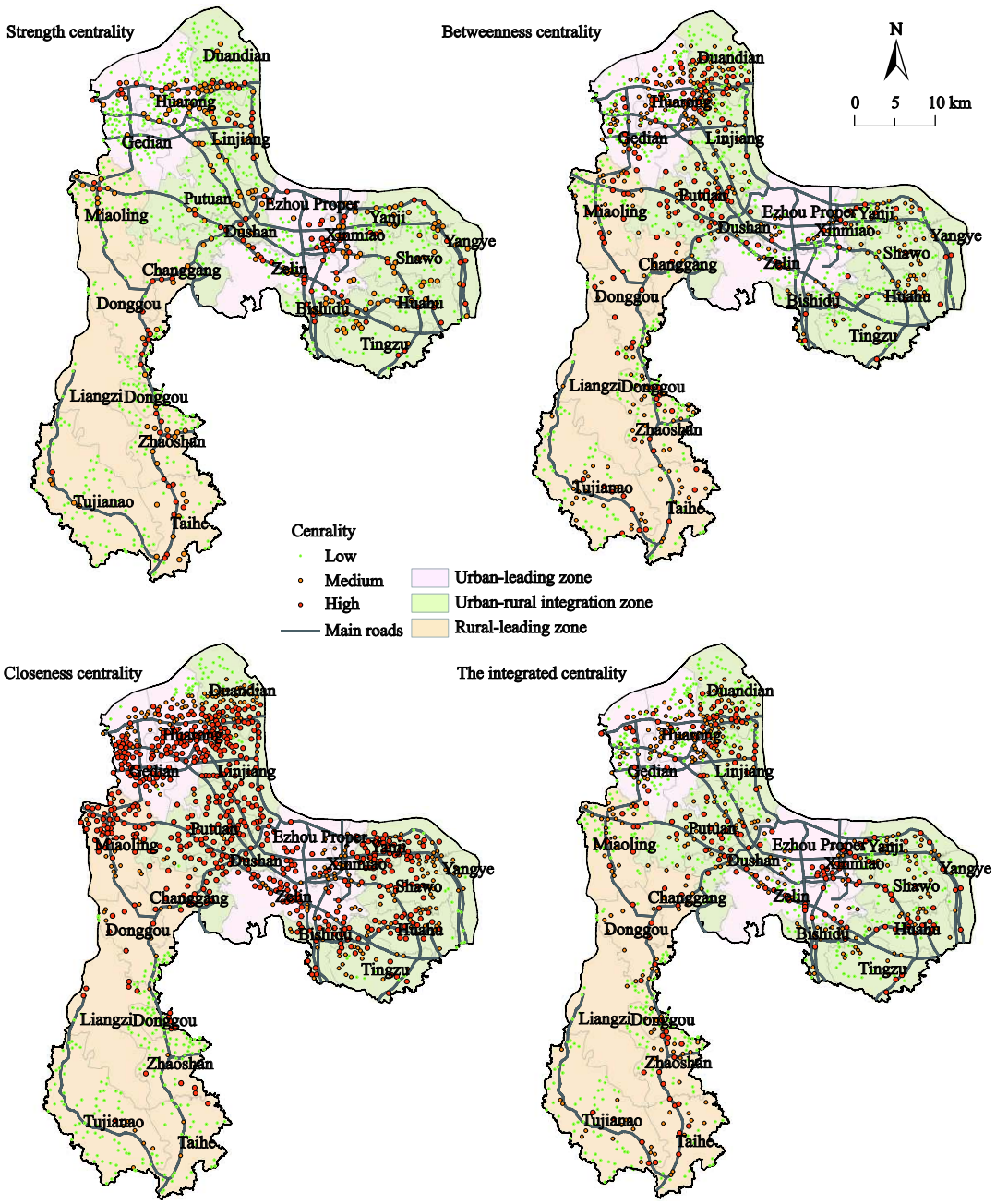

Fig. 7 Spatial distribution of four kinds of centrality indicators in Ezhou City

the urban-rural integration zone, implying that these regions have many settlements acting as bridges to facilitate interactions even if their interactions are not strong. Obviously, a large proportion of high-level settlements are concentrated in Putuan, Dushan, Duandian, Linjiang, and a few are scattered in the east and south.

Closeness centrality. The city average value of closeness centrality is 0.386. The urban-leading zone and urban-rural integration zone have higher average values of 0.407 and 0.401, respectively, while the lowest average value is 0.351 in the rural-leading zone. There are a great number of settlements (497) falling into the interval of high value in the north and east, indicating that most settlements have close interactions with each other in these regions.

Integrated centrality. According to the results of the previous three centralities, the integrated centrality of settlements comprehensively reflecting the significance of settlements was evaluated. The value ranges from 0.0001 to 0.977, with a city average value of 0.015.

Similarly, the average value in the urban-leading zone is the highest in three zones. Moreover, compared with medium-level and low-level settlements, the number of high-level settlements is relatively small, with the largest number in the urban-leading zone and urban-rural integration zone. With a decrease in the centrality value, the number of settlements with medium values increases. They are distributed far away from urban areas and traffic. Additionally, most rural settlements have comparatively low centrality and are distributed in every town, with the highest numbers in Miaoling, Shawo and Tujianao. Almost all urban settlements have high centrality, and a few rural settlements in suburbs and along traffic also have high centrality, which indicates that urban settlements and a small proportion of rural settlements occupy the key position and become cores of the overall network. Overall, the urban-leading zone has the highest average value in all centrality indicators, followed by the urban-rural integration zone and the rural-leading zone, indicating that the strongest interactions in the urban-leading zone, but the loosest interactions in the rural-leading zone.

3.4 Differential pattern of clustering in rural settlements

To identify social centers among settlements, the maximum interaction of each settlement was extracted from the inter-settlement network (Fig. 8). To alleviate regional differentiation, in addition to typical lump cluster patterns, e.g., urban settlement-centered lump clusters and rural settlement-centered lump clusters, chain patterns were also considered a kind of cluster patterns. Rural settlements that did not belong to any of three patterns were classified as dispersed patterns. Two kinds of lump cluster patterns are the most common in the urban-leading zone. Moreover, the number of rural settlements in the urban settlement-centered lump cluster is relatively large in the urban-leading zone. The results indicate that urban settlements and some rural settlements have a great impact on surrounding settlements. Similarly, settlements in the urban-rural integration zone also show obvious lump cluster patterns, with a few chain clusters and dispersed patterns in Shawo and Putuan. However, the small scale of urban settlement-centered lump clusters indicates the relatively weak attraction of these towns to rural settlements. Interestingly, we found that many rural settlements are directly connected with urban settlements such that the scale of urban settlement-centered clusters is also very large in the rural-leading zone. Additionally, the chain patterns and dispersed patterns predominate in most rural areas, while rural settlement-centered cluster patterns are

Table 4 Basic statistics of centrality indicators in different zones of Ezhou City

Zone	Centrality	Minimum value	Maximum value	Average value	High-level settlements
The whole area	Strength	0.00	263.50	3.31	110
	Betweenness	0.00	0.24	0.01	168
	Closeness	0.25	0.63	0.39	602
	Integrated centrality	0.00	0.98	0.02	161
Urban-leading zone	Strength	0.00	263.50	7.46	45
	Betweenness	0.00	0.24	0.04	40
	Closeness	0.26	0.63	0.41	199
	Integrated centrality	0.00	0.98	0.03	55
Urban-rural integration zone	Strength	0.00	82.14	1.97	36
	Betweenness	0.00	0.15	0.04	86
	Closeness	0.26	0.52	0.40	298
	Integrated centrality	0.00	0.32	0.01	61
Rural-leading zone	Strength	0.00	57.88	1.67	29
	Betweenness	0.00	0.10	0.0	42
	Closeness	0.25	0.45	0.35	105
	Integrated centrality	0.00	0.31	0.01	45

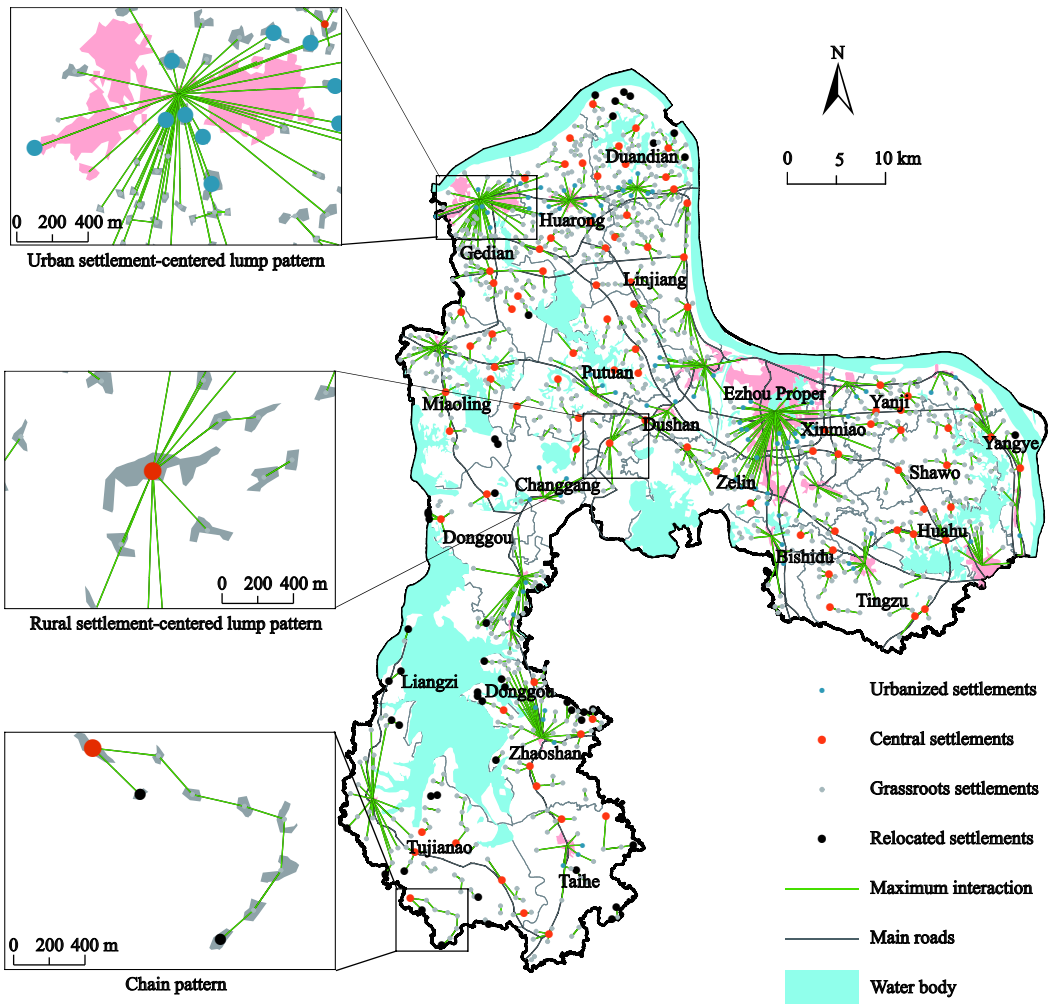

Fig. 8 Distribution of four restructuring types of rural settlements in Ezhou City

largely distributed in Miaoling.

3.5 Restructuring types of rural settlements

Considering the differences in centrality and clustering patterns in different zones, the classification of rural settlements was carried out. Four types of rural settlements were identified for rural reconstruction planning (Fig. 8), i.e., urbanized settlements, central settlements, grassroots settlements and relocated settlements. The characteristics of each type of rural settlement are listed in Table 5.

A total of 90 rural settlements serve as urbanized settlements with the highest average interaction strength (3.32), but their average link number is relatively low (18.01). Except for Linjiang, Shawo and Tujianao, urbanized settlements are spatially gathered around each town, with the most settlements in Ezhou Proper, Gedian and Duandian. Benefiting from close geographical location to urban areas and convenient transportation, urbanized settlements tend to obtain public service and

Table 5 Statistics of four types of rural settlement in Ezhou City

Classification	Average interaction strength	Average link number	Patch number
Urbanized settlements	3.32	18.01	90
Central settlements	2.60	27.48	95
Grassroots settlements	0.49	22.38	820
Relocated settlements	0.03	15.46	49

goods in urban areas. There are 95 rural settlements acting as central settlements, with a relatively strong average interaction strength of 2.48 and a high average link number of 27.48. Spatially, central settlements are homogeneously distributed along the main roads. In comparison, most settlements belong to grassroots settlements. Although they account for a large proportion of the patch number (820), they present a relatively low average interaction strength (0.49). Additionally, a small proportion of rural settlements (49) are determined to be removed. They have the lowest average interaction strength (0.03) and average interaction number (15.46), implying weak interactions among them. Spatially, they largely lie near the town boundaries and water conversation areas, with the most in Duandian, Zhaoshan, Liangzihu and Tujianao.

4 Discussion

4.1 Multi-scale differences in the inter-settlement network

In rural China, human beings are the intrinsic determinant of rural settlements (Hu and Wang, 2020). The basic purpose of SRRS is to meet people's needs and improve people's quality of life (Wang et al., 2017). Desire for public service facilities, as a major representative of basic life needs, impels people to flow from origin settlements to destination settlements and generate intimate daily interactions. Therefore, this paper developed an inter-settlement network composed of education, healthcare, recreation and shopping interactions from the perspective of public service facilities. Aiming to achieve targeted management in the SRRS, specific zones based on the characteristics of community structure were determined, and four types of rural settlements were identified on the basis of regional differences in terms of centrality and cluster pattern.

Scientific partition at the town level is the premise and basis for the identification of rural settlement restructuring types. This can not realize the even distribution of rural settlement types if classification is accomplished according to a unified standard on a larger scale. It easily brings out a large area of rural settlement relocation in relatively backward areas and an excessive concentration of central settlements in well-developed areas. Therefore, zonal division is necessary in the SRRS. According to Fei (1992), he described the Chinese rural village as an 'acquaintance society' that contains some small-scale communities. The members within each community interact intimately, but the interactions between communities are weak. The community structure can provide a reasonable basis for zonal division avoiding subjective partitioning. Based on the urban development level and population size, each town was equipped with diverse public service facilities. Therefore, the inter-settlement network has a significant spatially coherent structure, and three zones have been divided based on the inter-community interaction strength and intra-community interaction strength. Towns in the urban-leading zone usually have relatively high urbanization levels and perfect public facility systems such that they have strong cohesion to internal settlements and attractions to external settlements. Affected by the strong radiation of the core city and towns, residents in neighboring towns still prefer to conduct daily activities in the Ezhou Proper and Gedian. The cohesion of these towns has been seriously weakened, as interpreted by high inter-community strength but low intra-community strength. In comparison, due to the limitations of terrain and economic conditions, the public service facilities in the south are lacking such that their capacities to interact with other settlements are limited. Communities in this region have relatively loose interactions.

In terms of centrality and cluster patterns, it also presents obvious diversities in different zones. Ezhou City involves a heterogeneous town-village system that ranges from the central urban area, general towns, central settlements to grassroots settlements. Existing studies have illustrated that social interactions are highly correlated with population distribution, infrastructure and public services (Liu et al., 2019). That is, the greater the population and public facilities, the closer the interaction among settlements. Thus, in daily life, residents generally favor visiting higher-level towns and villages to obtain a richer series of goods and services, which causes the heterogeneous characteristics of the inter-settlement network. As previously stated, settlements in the urban-leading zone have absolute dominance in the interaction population, public facilities and transportation. Thus, many settlements in this zone have high centrality. Urban settlements and central settlements are very attractive to surrounding settlements such that the lump cluster pattern becomes a common

phenomenon in this zone. In the second zone, because the population and public facilities are smaller than those in the urban-leading zone, convenient transportation makes residents favor commuting to adjacent high-level towns to obtain public goods and services, which leads to a relatively weak attraction of urban settlements. However, a large number of central settlements still act as bridges to facilitate interactions among other rural settlements in rural areas far from urban areas. Accordingly, settlements with high betweenness centrality and rural settlement-centered cluster patterns are mostly distributed in this zone. Owing to insignificant urbanization in the rural-leading zone, massive rural population outflows. Most Public facilities are concentrated in town centers such that residents from remote settlements suffer various inconveniences in their daily lives. Specifically, some residents need to travel to local towns to meet their needs of public service and goods, while other residents only interconnect with neighboring settlements with loose interactions. Consequently, rural settlements largely have low centrality, and the urban settlement-centered lump patterns control this zone. A few settlements belong to the chain cluster patterns and dispersed patterns.

4.2 Implications for rural settlement reconstruction

Restructuring and optimizing the network structure is an effective approach for instituting improvement measures to accommodate rural development (Hang and Payne, 2017; Xia et al., 2020). More accurate structural analysis is necessary to strengthen interactions among settlements and improve the performance of the social network. Therefore, rural reconstruction and regional development plans should coexist to reduce regional differences and direct rural revitalization based on specific interactions.

We provide corresponding strategies for three zones ranging from urbanization (urban-leading zone), integration (urban-rural integration zone) to characteristics (rural-leading zone). As shown in Fig. 9, towns in the urban-leading zone experienced relatively rapid urbanization and urban expansion, which promotes the upgrading of rural transformation development and triggers tremendous land use transitions. Influenced by the strong radiation from urban areas, the suburbs gradually become transitional regions where populations increasingly gather in cities and towns under the needs of improvement of their living conditions. Urbanization is the primary goal in the progress of the SRRS in the urban-leading zone. Policymakers should give priority to the consolidation of urbanized settlements by reasonable in situ urbanization. Meanwhile, some grassroots settlements with higher centrality and close to urban areas should be prepared for future urban expansion. In the urban-rural integration zone, an efficient solution is promoting the integrated development of urban and rural areas by enhancing the cohesion and influence of urban settlements and central settlements. Urban areas and central settlements are well-known as critical regions for all urban-rural public service facilities. On the one hand, policymakers should improve the diversity of public facilities in urban areas to enhance the attractiveness to surrounding rural settlements such that some advantageous clustering areas, such as urbanized settlements, can be transformed moderately into urban areas. On the other hand, central settlements need to make full use of the advantages in information and policies to expand the scope of goods and services. This can enable other settlements convenient access to public facilities, thus strengthen daily interactions among settlements and attract the migration and agglomeration of scattered, small-scale rural settlements. In terms of grassroots settlements in this zone, they should be preserved in principle. However, with the further promotion of SRRS, grassroots settlements with low centrality will finally move toward natural decline by gradually directing the population outward. In terms of the rural-leading zone, it is difficult to achieve high-level urbanization. However, depending on abundant natural resources and ecological bases, the regions have the potential to attract inflows of population. Policymakers should select central settlements and potential grassroots settlements to build a series of characteristic villages (folk villages, ecological villages and cultural villages) and realize the construction of a new socialist countryside by improving their supporting infrastructures and rural tourism supply chain. Additionally, policymakers should attach significant importance to the demolition and resettlement of relocated settlements in this zone. The development potential and ecological vitality of relocated settlements should be continuously stimulated to reduce the regional imbalance. Given that rural residents are definitely more inclined to be removed to settlements where

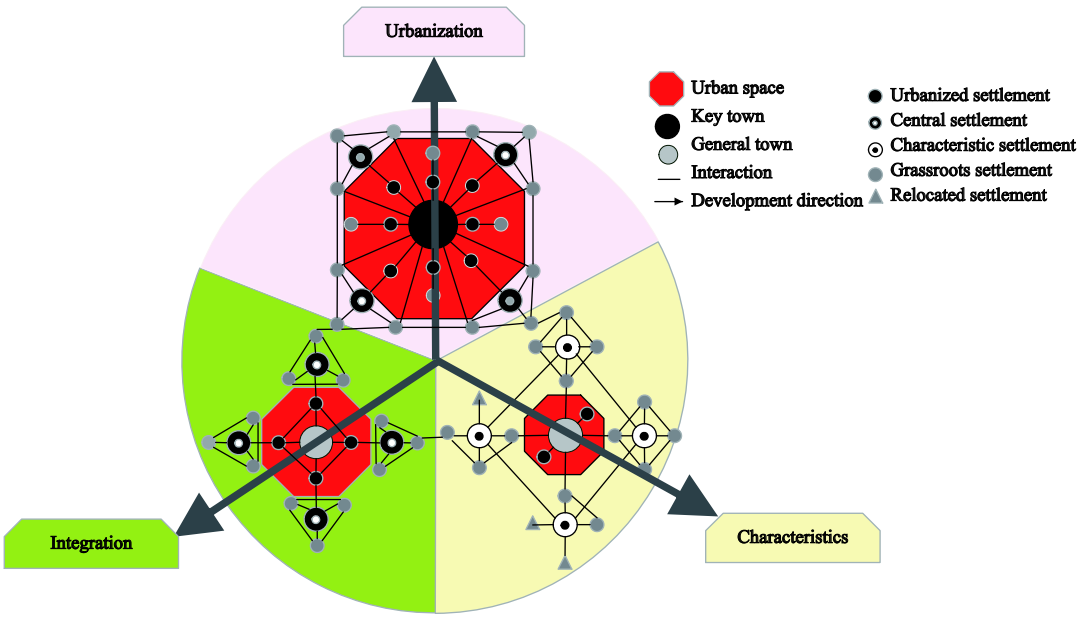

Fig. 9 The pattern of rural settlement reconstruction in different zones

they have strong interactions, the restructuring directions of relocated settlements are determined based on the maximum interaction strength.

4.3 Future works

Although this study proposed a new idea and effective method for constructing an inter-settlement network and exploring the influence of the spatial network on rural settlement reconstruction, several imitations still exist. First, spatial interactions among settlements rely on daily behaviors of farmers, but only a few of them were considered in this work due to a lack of population migration data. Merging cellular signaling data, navigation, personal location service apps and other data will be our first choice in evaluating social interactions of rural settlements in the future. Second, this study attempted to capture the roles and importance of rural settlements with a strong emphasis on the connectivity and dominance in the spatial network. Actually, this is rather complex and affected by multiple factors, such as natural environments, economy and society. Future research should pay more attention to these limitations.

5 Conclusions

In this study, we constructed an inter-settlement network composed of education, healthcare, recreation and shopping interactions based on the demands of residents for public facilities. We subsequently divided all towns into three zones based on community structure at the town level, and then identified four restructuring types of rural settlements in light of the spatial differences of centrality and clustering patterns at the patch level. Detailed suggestions for SRRS were provided based on the research findings.

Our results indicated an obvious spatial coherence in community structure analysis. Communities with high-level inter-community and intra-community interactions were observed in the Ezhou Proper, Gedian, Huarong, Xinmiao and Zelin. Influenced by the strong radiation of Ezhou Proper and Gedian, adjacent communities, including Yangye, Huahu, Tingzu, Bishidu, Dushan and Duandian, have high inter-community interactions but relatively low intra-community interactions. In the south, most communities have low inter-community and intra-community interactions, implying loose interactions among rural settlements. Additionally, four restructuring types of rural settlements were identified based on the centrality and cluster patterns: urbanized settlement, central settlements, grassroots settlements and relocated settlements. According to the spatial differences in different zones, corresponding strategies of rural settlement reconstruction were proposed ranging from urbanization, integration and characteristics, and priority types of rural settlements were determined in different regions. As a whole, social networks simulated by the needs of rural residents for public facilities could truly reflect social interactions in daily life. Mean-

time, multi-scale analysis of social networks can provide more accurate information to identify the restructuring types of rural settlements. Although this study was conducted in Ezhou city, the employed methodology would also be useful to other rural areas in China, which can help policymakers develop reasonable strategies for SRRS.

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