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Evolution of Integrated Development in Urban Agglomerations in China: Perspectives on Economic Linkages and Urban-Rural Equilibrium

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Abstract

Understanding the evolution of urban agglomerations is crucial for formulating resilient and inclusive spatial development policies. This study takes the Chengdu-Chongqing urban agglomeration in China as a case study, utilizing a modified gravity model to describe economic interactions among spatial units, measuring urban-rural equilibrium through income disparity, and applying Exploratory Spatial Data Analysis (ESDA) to examine the spatial associations between economic agglomeration and urban-rural balance. The main findings are as follows: (1) The intensity of economic linkages and the level of urban-rural equilibrium in the Chengdu-Chongqing urban agglomeration have significantly improved across the study area. (2) The spatial organization of the region shows a significant flattening trend, forming a significant "point-axis system" around the two core cities of Chengdu and Chongqing. (3) Regional imbalance continued to expand, exhibiting a distinct spatiotemporal co-evolution characterized by a "core-periphery" structure. The study concludes that the excessive dominance of core cities and the limited driving ability of sub-core cities are the main obstacles to the integrated development of the Chengdu-Chongqing urban agglomeration, and this study proposes development strategies from the aspects of improving infrastructure, promoting industrial transfer, and emphasizing institutional guidance.

Keywords

Urban agglomeration; Integration; Space evolution; Planning Strategy; China

1. Introduction

In the context of globalization and informatization, urban agglomerations have emerged as key spatial configurations shaping future urban competition and urbanization, while also functioning as platforms for promoting rural revitalization and achieving the integrated development of urban and rural areas (Fang & Yu, 2017; Melo et al., 2009). Understanding their integrated evolutionary dynamics is fundamental to formulating more flexible and inclusive regional spatial development policies.

The term "integration" was originally prevalent in economics and geography, stemming from scholars' focus on "regional economic integration"(Yang et al, 2021). The "integration" of urban agglomerations can be seen as a process where regional units within the urban agglomeration, based on their unique and common characteristics, are

integrated into a single economic space through transportation and communication infrastructure networks(He et al., 2019). This enables the effective aggregation and diffusion of factors among regional units, forming a development community that maximizes overall benefits(Fu et al., 2023). The study of the geographical spatial form of regional economic integration in urban agglomerations is an important means for formulating spatial planning strategies and conducting regional spatial optimization(Liu et al., 2022; Zhu et al., 2019). Consequently, a series of regional spatial structure theories have emerged to explain the phenomena of spatial agglomeration and diffusion in regional integration. In terms of research content, early regional spatial structure thought based on industrial location theory mainly focused on the impact of regional resource endowment conditions on development. However, with the development of the modern information society, the time-space compression effect brought about by the information and transportation revolutions has rendered traditional location theory ineffective(Tong et al, 2020). The research paradigm of "space of flows" based on the "connection" perspective has gradually arisen(Castells & Hall, 1994; Zhao et al., 2021). Urban networks are established through material flow elements such as population(Baudino, 2021; Li et al., 2022) and transportation(Tian et al., 2023), and information flow elements such as enterprise branches(Rupasingha & Marré, 2020) and mobile phone signaling. Complex network analysis and other methods are used to analyze various aspects such as the spatial organization of urban agglomeration integration(Fang et al., 2020), infrastructure network construction(Yang et al., 2024), land resource transformation and utilization(Zhu et al., 2020), and high-quality development evaluation(Xu et al., 2022). Urban-rural equilibrium is a more advanced demand in the integrated development of urban agglomerations(Li, 2012), which entails removing development obstacles to facilitate the free movement and equitable exchange of factors across urban and rural spaces, thereby realizing convergence in factor returns(Bosworth & Venhorst, 2018). In fact, the balanced development of urban and rural areas has remained a key topic in academic circles. Due to divergent interpretations of its meaning, researchers have proposed different sets of indicators, such as those based on urban-rural spatial connections and covering economic, spatial, and ecological dimensions(Zhou & Yang, 2023; Zhou et al., 2020). A growing trend in research focuses on analyzing urban-rural interactions from angles such as input-output relationships, human capital(Li et al, 2022), and income gaps between urban and rural regions(Ma et al., 2020a). The methods of evaluation have become more diverse, with tools like spatial econometric models, spatial autocorrelation techniques, and coupling coordination degree models being continuously adopted in relevant research.

Currently, relevant research has conducted extensive investigations on the integration of urban agglomerations, with the spatial perspective being gradually enhanced. However, relevant quantitative research rarely takes into account the deeper requirement of balanced urban-rural development for the integration of urban agglomerations(Liu et al., 2013). Simultaneously, the majority of research objects were concentrated in more developed urban agglomeration areas, while less attention has been given to developing urban agglomerations. Consequently, taking the Chengdu-Chongqing urban agglomeration (hereinafter abbreviated as the "CCUA") in China as an example, this paper analyzed the spatio-temporal evolution characteristics of the urban agglomeration area from the dimensions of spatial organization and rural-urban equilibrium, as well as their spatial correlation systems. The conclusions of this paper can offer a theoretical basis for understanding the characteristics of the integration evolution of urban agglomerations and formulating regional development policies.

2. Materials and Methods

2.1. Study Area

In April 2016, the Chinese national department issued the "CCUA Development Plan" (hereinafter abbreviated as the "Plan"), elevating the construction of the CCUA to a national strategy in China. In terms of spatial construction, the "Plan" proposed to construct a spatial layout scheme of "one axis, two belts, dual cores, and three zones" for the urban agglomeration, along with an integrated development mechanism for industrial division of labor and cooperation and infrastructure interconnection. The "Chengdu part" and "Chongqing part" of this urban agglomeration shared a common history and culture, thereby possessing a favorable foundation for integrated development. Regarding research units, considering the special administrative structure of Chongqing municipality, the Yuzhong, Jiangbei, Nanan, Jiulongpo, Shapingbat, Dadukou, Beibei, Yubei, and Banan of Chongqing were combined into a main urban area spatial unit. The CCUA in this study encompassed 36 spatial units (Figure 1).

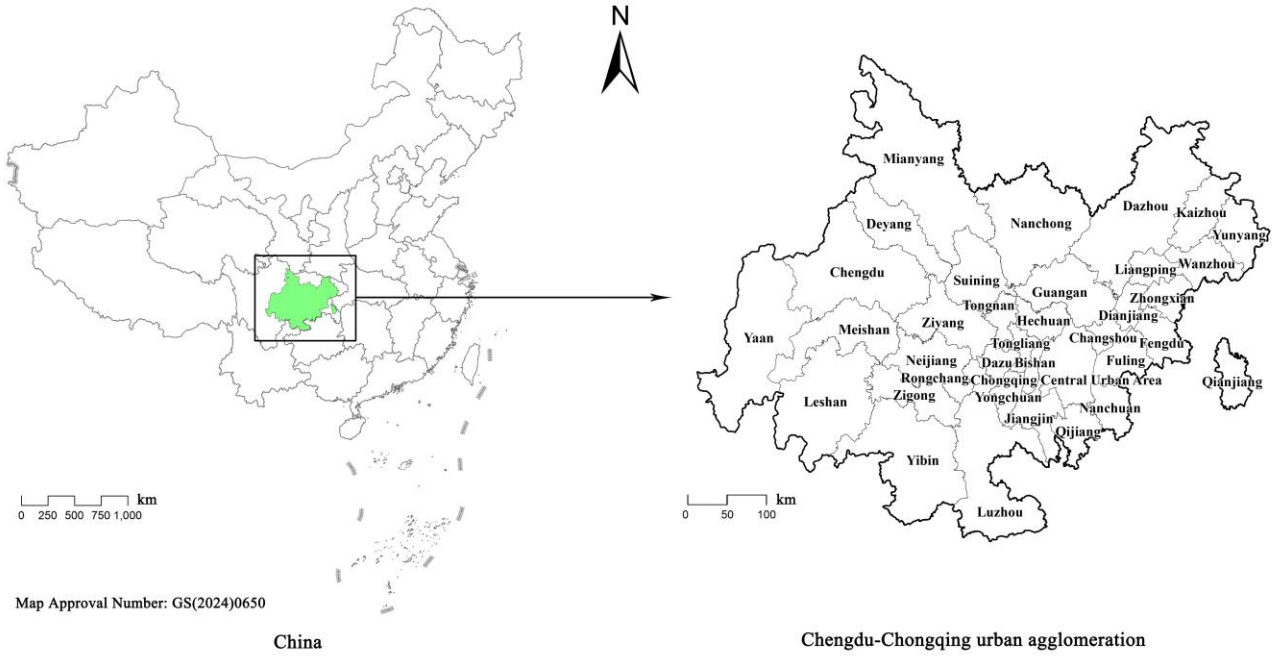

Figure 1: Study Area. (image by the authors)

Note: These maps were drawn according to the standard map with drawing No. GS (2024) 0650, which was downloaded from the standard map service website of the Ministry of Natural Resources of the People's Republic of China. No modifications were made to the base map.

2.2. Methods

Based on the aforementioned theoretical foundation, this paper investigates the "integration" level of urban agglomerations through two key dimensions: spatial organization and rural-urban equilibrium. This study constructs an economic linkage network for the CCUA using an enhanced gravity model (Zhao et al., 2021). The urban-rural per capita income gap serves as a proxy indicator to assess the level of rural-urban equilibrium(Liu et al., 2013). Finally, the spatial correlation characteristics between the economic agglomeration intensity of each spatial unit and its urban-rural development balance are further examined via spatial autocorrelation analysis.

2.2.1. Evaluation Indicators

(1) Economic connection intensity

This paper establishes an economic connection network of the CCUA based on a gravitational model improved by time distance, and uses the "degree centrality" in complex networks to measure the level and status of each regional unit in the economic connection of the urban agglomeration area. The calculation formula is as follows:

$$R_{ij} = K_{ij}\frac{\sqrt{P_iG_i}\sqrt{P_jG_j}}{T_{ij}^2},\ \ K_{ij} = \frac{G_i}{G_i+G_j} \tag{1}$$

In the formula, R_{ij} is the economic connection intensity between regional unit i and regional unit j. K_{ij} is a constant. G_i is the GDP scale of regional unit i. P_i is the scale of the permanent resident population of regional unit i. T_{ij} is the shortest travel time between regional unit i and regional unit j. Unit: 100 million yuan × 10,000 people/h².

In complex network analysis, centrality is mainly used to measure the status of network nodes in the network. This paper uses the degree centrality to measure the status of each spatial unit of the CCUA in the spatial organization of the urban agglomeration. The formula is as follows:

$$C_i = \sum_{j=1}^{n} R_{ij}/(n-1) \tag{2}$$

In the formula, C_i represents the degree of centrality of the regional unit i, that is, the total economic connection scale of this regional unit. Unit: 100 million yuan × 10,000 people/h^2.

(2) Urban-Rural Equilibrium Index

Urban-rural equalization can be understood as the narrowing of differences in labor productivity and labor income between urban and rural areas; thus, the urban-rural per capita income gap serves as a substitute indicator for assessing the degree of urban-rural development balance.

2.2.2. Exploratory Spatial Data Analysis (ESDA)

Aggregation and diffusion are the basic driving forces for the spatial evolution of urban agglomeration integration. The ESDA can be used to quantitatively analyze and visualize the aggregation and diffusion patterns of factors among various regional units. The bivariate local autocorrelation analysis can reflect the spatial correlation and spatial distribution characteristics of the spatial organization of the CCUA and the level of rural-urban equilibrium. The calculation formula of the local Moran index is as follows:

$$Local\ Moran'\ I = \frac{y_i - \bar{y}}{\frac{\sum_{j=1, j\neq i}^{N} w_{ij}}{N-1} - \bar{y}^2} \sum_{j=1, j\neq i}^{N} (y_i - \bar{y}) \quad (3)$$

In the formula, N represents the number of spatial units, y_i and y_j represent the observed values of the variables of interest; $\bar{y}$ is the mean value of the observed values of the variable y; w_{ij} represents the elements in the spatial weight matrix. The horizontal axis represents the rural-urban equilibrium index, and the vertical axis represents the factor aggregation and dispersion ability index. Firstly, the bivariate local autocorrelation will produce four types of spatial units: high-high (HH), low-low (LL), high-low (HL), and low-high (LH). HH and LL represent local positive correlations, while LH and HL represent local negative correlations. In this empirical study, HH means that a spatial unit with a relatively high level of rural-urban equilibrium is surrounded by spatial units with a relatively high total economic connection; HL means that a spatial unit with a relatively high level of rural-urban equilibrium is surrounded by spatial units with a relatively low total economic connection; LL means that a spatial unit with a relatively low level of rural-urban equilibrium is surrounded by spatial units with a relatively low total economic connection; LH means that a spatial unit with a relatively low level of rural-urban equilibrium is surrounded by spatial units with a relatively high total economic connection.

2.3. Data Sources

The economic data, such as population and GDP, used in this paper are sourced from the annual statistical yearbooks of Chongqing and Sichuan; the transportation data are from the national and provincial trunk lines, expressways, and railway data sets of OSM. The high-speed railway data set is from the data as of December 2021. By sorting out the opening and operation times of different railways and expressways, slice data for 2011, 2015 and 2019 are obtained. The highway speed refers to the average design speed, and the railway running speed refers to the regulations in the high-speed railway network documents issued by the National Railway Administration and the National Development and Reform Commission and other departments.

3. Results

3.1. Evolution Characteristics of Spatial Organization

3.1.1. Overall Characteristics of Spatial Organization

From 2011 to 2019, the economic connection intensity of the CCUA showed exponential growth. In 2011, the total economic connection of the urban agglomeration was only 423.06, but this value increased to 984.82 in 2015 and directly jumped to 2680.28 in 2019. From the perspective of the economic connection network structure of the CCUA, it shows obvious hierarchical characteristics (Figure 2). In 2011, only the economic connections between Chengdu and Deyang, and between Chengdu and Mianyang were at the first level, and only the economic connections between Chengdu and Ziyang, between Neijiang and Zigong, between the main urban area of Chongqing and Bishan, and between the main urban area of Chongqing and Jiangjin District were at the second level. The back-to-back development problem of Chengdu and the main urban area of Chongqing, as the core cities of the CCUA, was serious, and problems such as a low degree of interconnection were prominent. This problem still had not been improved by

2015. In 2015, the first and second levels of the economic connection network structure of the CCUA still revolved around the main urban areas of Chongqing and Chengdu. Among them, the connections between Suining and Nanchong, between Guang'an and Nanchong, and between Neijiang, Zigong, and Yibin began to form relatively strong connection areas outside the main urban area of Chongqing and Chengdu, which laid the foundation for the subsequent construction of the urban dense area of the CCUA. From 2016 to 2019, the regional coordinated development institutional mechanism was gradually improved, a number of key transportation infrastructure projects were gradually implemented, the core status of the main urban area of Chongqing and Chengdu was further strengthened, and their connection intensity also rose to the first level. As can be clearly seen from Figure 3c, the main urban area of Chongqing began to widely radiate regional units such as Dazhou, Guang'an, Suining, Neijiang, Zigong, Yibin, and Luzhou. The "one axis, two belts" spatial pattern was basically formed.

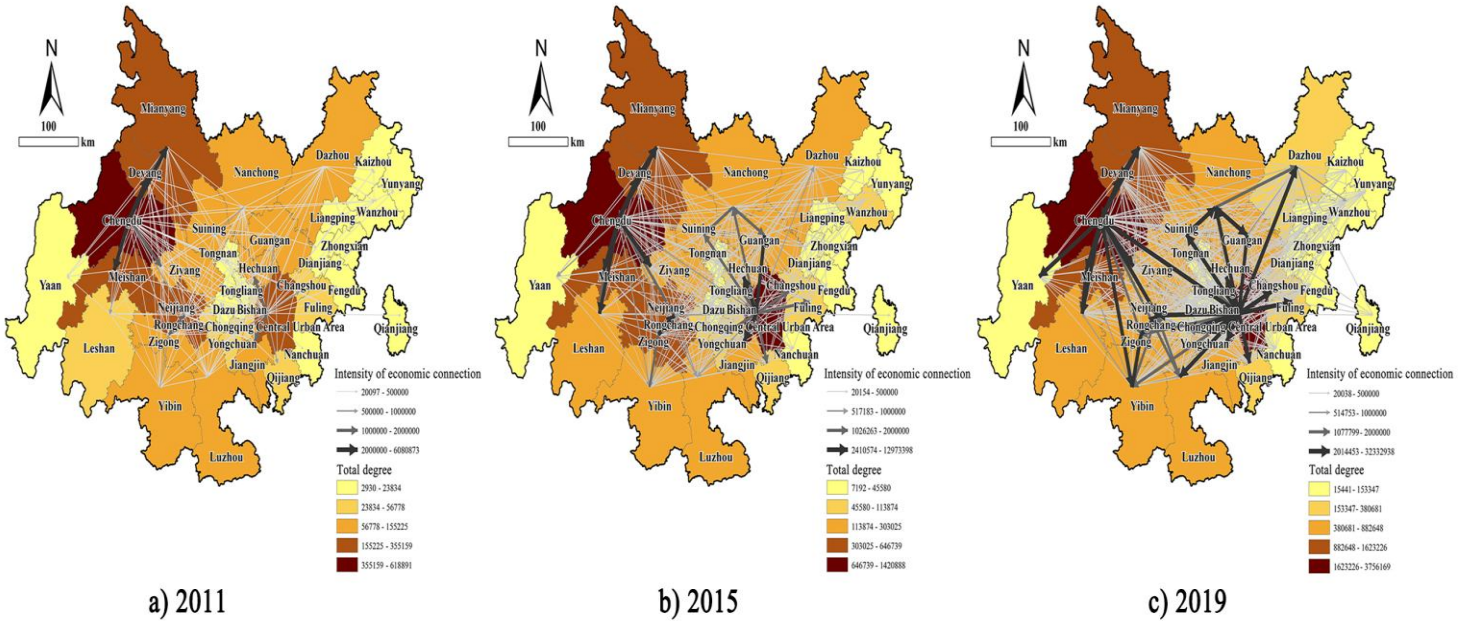

Figure 2: The Integrated Spatial Organization Characteristics of the CCUA. (image by the authors)

Note: For a better graphical effect, only the economic connections with an economic connection intensity value higher than 200 million yuan × 10,000 people/h² are selected in the figure.

3.1.2. Characteristics of Spatial Organization of Core Areas and Urban Dense Areas

By further standardizing the total economic connection scale of each regional unit to obtain the relative economic connection intensity (Figure 3), it can be found that from 2011 to 2019, the relative economic connection intensity of the main urban area of Chongqing increased from 11.19% to 14.15%, while the relative economic connection intensity of Chengdu decreased from 19.50% to 18.16%. This may imply that as an urban agglomeration with a "twin-city" core, the spatial state of the CCUA is gradually developing towards a more balanced state. At the same time, by analyzing the economic connection scale and relative change amount between the "dual-core" areas of the CCUA and other regional units from 2011 to 2019 (Figure 3), it could be found that the radiation ability of the main urban area of Chongqing to other regional units has increased more significantly compared to Chengdu, and the regional units with a more significant increase are mostly regional units in Sichuan (including Suining, Nanchong, Neijiang, Zigong, Luzhou, etc.), which is consistent with the previous analysis, indicating that the Chengdu-Chongqing urban area has entered the stage of "dual-core driven" development from "dual-core back-to-back development".

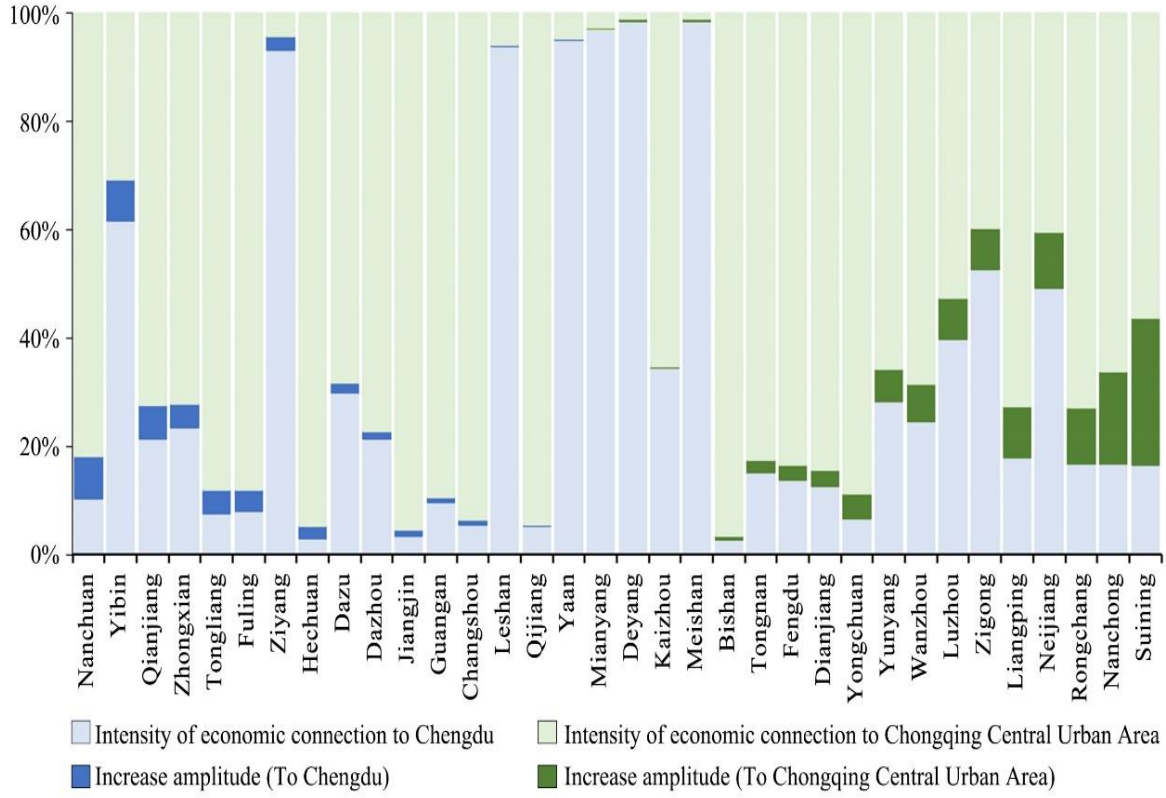

Figure 3: Statistics on the Scale of Economic Connections between the CCUA "Dual Core" and Other Regional Units from 2011 to 2019. (image by the authors)

At the same time, although the total economic connection scale of the three urban dense groups in southern Sichuan, Nansuiguang, and Dawan for internal and external economic connections has shown a relatively obvious increase, from the perspective of proportion, the total internal economic connection scale and the proportion of the economic connection scale of other regional units have generally decreased (Table 1). The reason for this phenomenon may be that the discrete degree of the economic connection scale of each regional unit in the urban agglomeration decreases year by year, and the scale advantage degree of the three urban dense areas is weakened; the economic connection scale between the southern Sichuan and Nansuiguang urban dense areas and the main urban area of Chongqing and Chengdu has shown a small increase, but the relative economic connection intensity between the Dawan urban dense group and the main urban area of Chongqing has shown a small decrease. The reason for this phenomenon may be that the spatial distance is too far, resulting in being at the edge of the spatial organization of the urban agglomeration, and it is difficult for the infrastructure construction of the urban group to effectively radiate to this area. From a horizontal comparison, the total economic connection scale of the three urban dense groups has a relatively large gap. Compared with the southern Sichuan urban dense group, in the Nansuiguang urban dense group, when the economic connection scale with core cities such as Chongqing and Chengdu and other regional units was not much different in magnitude, the internal economic connection gap is very obvious, indicating that the Nansuiguang urban dense group is still in the early stage of cultivation and development, and the organizational cooperation level of each regional unit within it still needs to be improved; while the economic connection scales of all items in the Dawan urban dense group are very low, indicating that in the absence of external driving force, the organizational cooperation relationship among each regional unit within it has not been well formed, and the institutional heterogeneity caused by belonging to different administrative jurisdictions may also be one of the hindering factors.

Table 1 Analysis of the Economic Connection Scale of the Dense Clusters of Cities and Towns in the CCUA

Name	Year	Internal economic connections	External economic connections		
			To the Chongqing Central Urban Area	To Chengdu	To other spatial units
Chuangnan	2011	1086.41 (9.78%)	125.45 (1.13%)	136.37 (1.23%)	417.86 (3.76%)
	2015	1988.73 (7.32%)	257.88 (0.95%)	288.21 (1.06%)	1007.76 (3.71%)
	2019	4403.37 (6.08%)	1026.04 (1.42%)	961.29 (1.33%)	2566.51 (3.54%)
Nansuiguang	2011	343.95 (3.10%)	164.98 (1.49%)	52.85 (0.48%)	321.45 (2.89%)
	2015	1013.14 (3.73%)	646.94 (2.38%)	116.73 (0.43%)	926.25 (3.41%)
	2019	2141.11 (2.96%)	1496.53 (2.07%)	238.09 (0.33%)	2223.39 (3.07%)
Dawan	2011	85.73 (0.77%)	61.80 (0.56%)	18.25 (0.16%)	202.73 (1.83%)
	2015	155.08 0.57%	168.95 (0.62%)	39.33 (0.14%)	499.94 (1.84%)
	2019	339.62 (0.47%)	376.93 (0.52%)	112.56 (0.16%)	1201.59 (1.66%)

Note:

1. The percentage in the table represents the proportion of the economic connection intensity of the research unit in the total scale of the CCUA in that year.

2. The Chuannan urban dense group includes spatial units such as Zigong, Neijiang, Luzhou, and Yibin. The Nansuiguang urban dense group includes spatial units such as Nanchong, Suining, and Guangan. The Dawan urban dense group includes spatial units such as Dazhou, Wanzhou.

3.1.3. Evolution Characteristics of Rural-Urban Equilibrium

Research data shows (Figure 4) that from 2011 to 2019, the level of rural-urban equilibrium in the CCUA has been continuously improving. Compared with the rural-urban equilibrium index of the CCUA in 2011, most of the regional units with a relatively high improvement range are important node positions in the "Plan" (including Chengdu City, Meishan City, the main urban area of Chongqing, Suining City, Mianyang City, Yibin City, Ziyang City, etc.). At the same time, the standard deviation of each regional unit has been continuously expanding (from 0.028 in 2011 to 0.033

in 2019), indicating that the overall dispersion degree has increased, and the polarization of the regional rural-urban equilibrium level has become more serious.

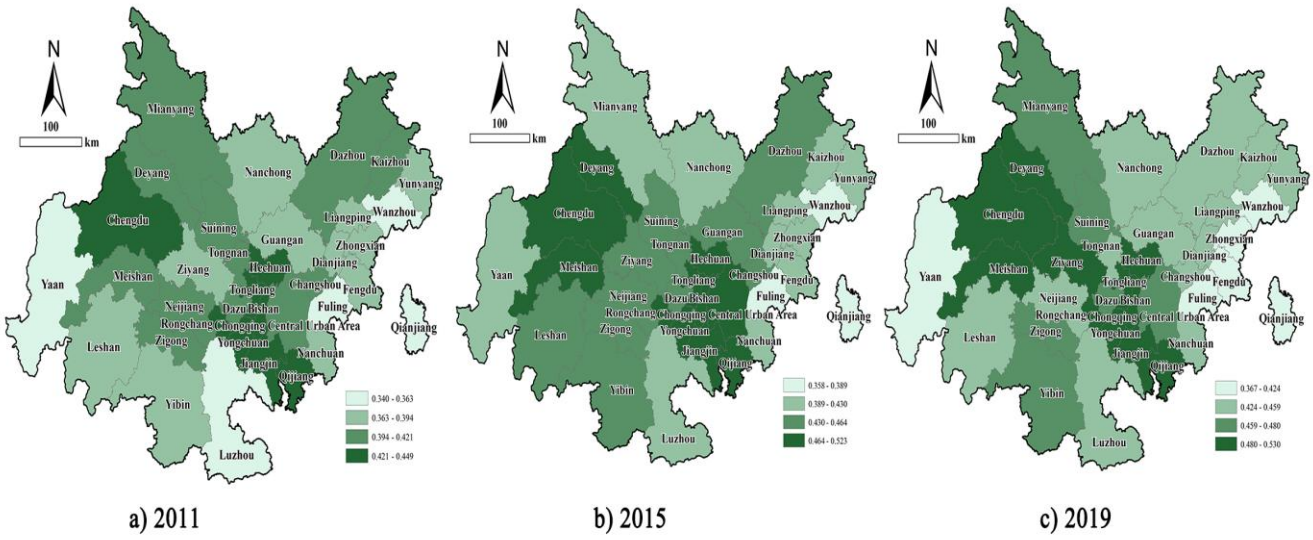

Figure 4: Statistics on the balanced development level of urban and rural areas in the CCUA. (image by the authors)

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.2. Bivariate Local Spatial Autocorrelation Analysis

Through the bivariate local autocorrelation analysis of the economic connection scale of each regional unit in the urban agglomeration and the level of rural-urban equilibrium, it can be found that there is a significant positive spatial autocorrelation between the two as a whole. The Moran index is 0.315, 0.283 and 0.378 in 2011, 2015 and 2019, respectively, indicating that as a whole, the ability of each regional unit in the CCUA to participate in spatial organization has been significantly improved, which has promoted its rural-urban equilibrium level. However, from the perspective of clustering analysis results (Figure 5), the regional units showing positive correlation (HH and LL) were mainly concentrated in the main urban area of Chongqing and the northeast region of Chongqing, and the range of this positive correlation area has an expanding trend; while the regions showing negative correlation (HL and LH) were mainly concentrated in the marginal areas of Sichuan, with only Ya'an City and Luzhou City. There is a significant "core-edge" spatial differentiation characteristic in the spatial autocorrelation of the two. Firstly, the HH regional units were mainly concentrated around the "polar core" of the urban agglomeration development, that is, the main urban area of Chongqing. In this area, the economic connection scale of each regional unit was relatively high, and the rural-urban equilibrium level was also relatively high, and the range has gradually expanded to the entire southwest region of Chongqing. In fact, this area has been working on establishing an urban-rural integration system and narrowing the urban-rural gap in recent years, and was selected as a national urban-rural integration development area in early 2020; the LL regional units were mainly concentrated in the northeast region of Chongqing, and the range of this area has been continuously expanding. The most significant manifestation was that Dazhou City changed from HL to LL in 2019. In this area, the economic connection scale of each regional unit was relatively low, and the rural-urban equilibrium level was also at a low level. The LH regional units had a slight shift. In 2011, they were Ya'an City and Luzhou City, in 2015, only Ya'an City, and in 2019 Ya'an City was corrected to Luzhou City, this type of regional unit has a relatively low rural-urban equilibrium level, but was affected by the radiation of regional units with a relatively high economic connection scale around it.

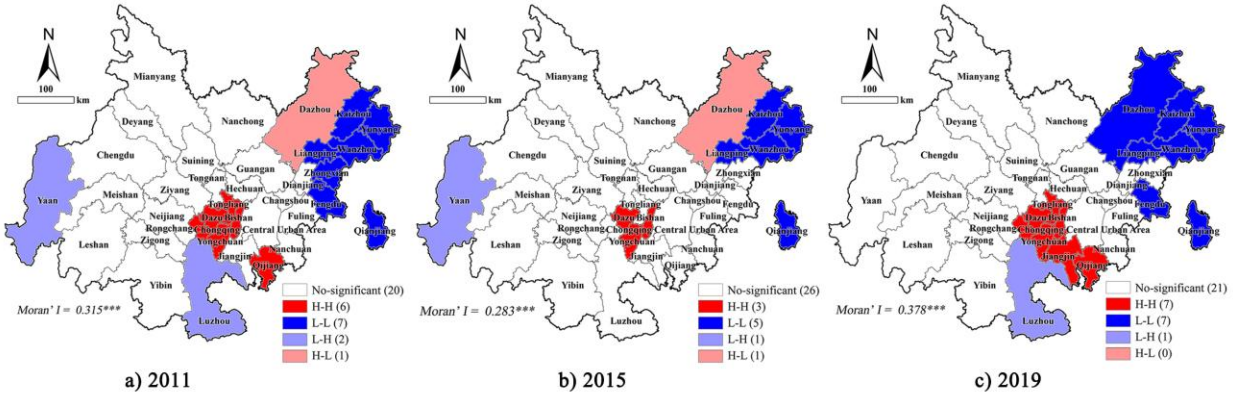

Figure 5: Bivariate local spatial autocorrelation LISA map. (image by the authors)

4. Discussion

4.1. The Evolutionary Characteristics of Integrated Development in the CCUA

The research results showed that both the economic connection intensity and the level of urban-rural equilibrium in the CCUA have significantly improved within the study period. However, the issue of regional imbalance was continuing to expand, exhibiting a significant spatiotemporal conjugate evolution with a "core-periphery" pattern. This is somewhat similar to the conclusions drawn by Ma(Ma et al., 2020b) and Zhang(Zhang et al., 2021), who found that the spatial aggregation of county-level urban-rural integration units has intensified in Chinese urban agglomerations. Wang(Wang et al., 2024) also identified a similar spatial process in his study on rural areal functions in the Xi'an metropolitan area of China.

The spatial organization of urban agglomerations was still primarily driven by the dual cores of Chongqing and Chengdu. Spatial units with higher levels of economic linkages and urban-rural equilibrium were concentrated along the "Chengdu-Chongqing main urban area" axis, and decreased towards the edge of the urban agglomerations. In terms of spatial organization, the integrated spatial organization of CCUA is still in the stage of development of the “point-axis system”. Although the economic connection intensity between the two core cities and other spatial units has been strengthened thanks to the increasing radiation scope of Chengdu and Chongqing, the economic connection intensity between the sub-core cities(e.g. Wanzhou, Qianjiang, Mianyang, Leshan, Nanchong, Luzhou, Yibin, etc.) and the surrounding spatial units has not been effectively improved. This is reflected in the increasing share of the core areas of Chengdu and Chongqing in the relative economic connection intensity with each other's spatial units, and the decreasing share of the relative economic connection intensity between the sub-core cities and other spatial units. This makes CCUA's spatial organization structure tend to be flat, and it is difficult to form a “networked” organizational form. As for the urban-rural equilibrium, as the "core" areas of Chengdu, Chongqing, and their corridors rise in spatial organization, the level of urban-rural equilibrium in these areas has simultaneously improved. In contrast, "peripheral" areas have seen a rise in spatial organization capacity accompanied by a relative decrease in urban-rural equilibrium. This phenomenon may be attributed to the fact that the "potential" gained by these peripheral regions in participating in the spatial organization of the urban agglomeration is mainly concentrated in urban areas, with limited penetration into rural systems, or the strong centripetal forces of urban areas creating a significant siphoning effect on rural development factors.

A networked, nested structure is often considered an advanced stage of urban agglomeration integration. Various types of factors are allocated freely and efficiently within the region, avoiding the over-sizing of central cities and sharing development opportunities, thereby enhancing the overall competitiveness of the region. In this process, different levels of cities, such as small towns, large and medium-sized cities, and megacities within the urban agglomeration, constitute a relatively independent but closely linked vertically nested integrated spatial structure, forming a multilevel spatial structure that is linked to each other. The results of this paper confirm that the core cities, such as Chengdu and Chongqing, of CCUA are too dominant, while the sub-core cities have limited radiation-driven ability despite their own development level having been improved to some extent. This makes the spatial organization of the whole city cluster still in the stage of “point-axis” development. It is difficult for various factors to achieve free

and efficient allocation between regions and between urban and rural areas, and it is difficult to maximize the sharing of development opportunities and development results.

4.2. Fit measures for the integrated development of CCUA

Regional economic development is often uneven. Myrdal proposed that there exist "diffusion effects" and "backwash effects" between the core and peripheral areas of a region(Yao et al., 2021). From the experience of the more successful city agglomerations in the world, such as the Tokyo Urban Agglomeration (TUA) in Japan and the Northeast Atlantic Coast Urban Agglomeration (NACUA) in the U.S., the improvement of infrastructure, the promotion of industrial transfers, and the focus on institutional guidance may be effective measures to promote the development of CCUA integration.

First, infrastructure such as transportation, communications and municipal services is the basic support vehicle for the movement of various factors, and the level of modern transportation, especially railroads and highways, often determines the speed and scale of the integration of urban agglomerations. During the development of the TUA, a multi-level rail transit network covering core cities, core cities and sub-cities, urban employment areas and residential areas, and localized areas within the cities was gradually formed through many rail transit constructions, effectively supporting and promoting the integrated development of the TUA through the development strategy of “giving priority to public transportation”. Therefore, it's necessary to continue to promote transportation and other infrastructure construction to expand the “Chengdu-Chongqing Development Axis” in the Plan and to strengthen the core area's “synergistic radiation” to the two wings of CCUA. And it's also necessary to focus on establishing a corridor for connecting urban-rural regional elements in the edge area of the urban agglomeration, strengthening the flow channels of elements from the urban regional system to the rural regional system, and establishing a more extensive integrated development power and base. Secondly, according to the resource conditions and industrial base of each geographical unit within the urban agglomeration, giving full play to its comparative advantages and realizing complementarity of advantages and industrial clustering are the endogenous driving forces for the integrated development of urban agglomerations. In the NACUA, New York, Philadelphia, Boston, and Washington are the cities that have formed different industrial positioning and urban functions, and all have dominant industrial sectors. In CCUA, Chengdu and Chongqing, as the core cities, are the headquarters of various industries, forming various types of knowledge-intensive industrial clusters; while the fringe areas of CCUA often have a good ecological and landscape environment, labor resources and other comparative advantages. In the industrial layout, attention should be paid to promoting industrial diffusion and regional linkage. Finally, how to solve the restrictions of cross-administrative division interests and institutional heterogeneity on the integration of urban agglomerations is also a key point in the construction of the CCUA. The flow and allocation of resource elements in the urban agglomeration area do not have a spatial "ownership", and the resource allocation rights owned by local governments often form obstacles to the cooperation between different regional units. This paper's empirical evidence confirms this view (Table 1). The connections of the regional units of several large urban dense areas with Chengdu and the main urban area of Chongqing have been continuously strengthened, but the internal relative economic connection intensity has a tendency to decrease, and at the same time, the diffusion will of other edge regional units was insufficient. Therefore, it is necessary to establish a top-down regional coordination and integrated award mechanism and a bottom-up active cooperation mechanism.

4.3. Limitations and further research

It is worth noting that there are still many deficiencies in this study regarding the development of the indicator system and the analysis of influencing mechanisms. Firstly, the spatial organization of urban agglomerations in this study does not take into account the differences in the spatial organization characteristics of different elements, such as population, industry and transportation, which limits the examination of the differences in the functions of cities under different functional scenarios. Second, "urban-rural equilibrium" is a very rich concept, involving economic, spatial, ecological and other aspects, and the evaluation of "urban-rural equilibrium" in this paper only adopts a proxy variable. Although there are many existing studies that can be drawn on, this paper simplifies the work due to the availability and completeness of multivariate data, which also leads to the unitary nature of the study. Additionally,

this study lacks a discussion on the formation of the spatial patterns of "spatial organization" and " urban-rural equilibrium " in urban agglomeration integration, as well as the inter-construction mechanisms between these two subsystems.

As for future research directions, we suggest further refining the depiction of "spatial organization" and " urban-rural equilibrium" in order to understand the integration characteristics of urban agglomerations in different dimensions. Furthermore, additional analytical methods (such as spatial econometric models, geographic detectors, etc.) could be incorporated to explore the influencing mechanisms of spatial evolution in urban agglomeration integration by analyzing the interconstructive process between different subsystems of "spatial organization" and "urban-rural equilibrium".

5. Conclusions

This study aims to understand the spatial evolution characteristics of urban agglomeration integration. This study first constructs the spatial relationship network of the CCUA from a connectivity perspective, focusing on analyzing the spatial pattern of the network and the hierarchical position of each spatial unit within the network system. Using the urban-rural per capita income gap as a substitute variable to measure the level of urban-rural equilibrium, the study further investigates the spatial correlation characteristics of economic connection intensity and urban-rural equilibrium for each spatial unit. During the study period, the integration level of the CCUA generally improved significantly. However, the integrated spatial organization characteristics of the CCUA are still in the "point-axis system" development stage, and the issue of regional imbalance is continuously expanding. This study suggests establishing the driving force and foundation for the integration development of the CCUA by strengthening the radiation capacity of core cities and establishing connectivity corridors for urban-rural regional elements in peripheral areas. This study provides valuable insights for the integrated spatial planning of other developing urban agglomerations.

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Ethics Approval

Not applicable.

Conflict of Interest

The authors declare there is no conflict.

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