

Study on the Evolution of Economic Linkage Network Structure and Its Impact on Economic Growth in the Guanzhong Plain Urban Agglomeration (Postprint)

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Abstract

This study employs urban flow intensity to modify the traditional gravity model for constructing an economic linkage matrix, and utilizes social network analysis methods to examine the evolutionary characteristics of the economic linkage network structure and its impact on economic growth in the Guanzhong Plain urban agglomeration from 2008 to 2018. The findings indicate that: (1) The centrality level of the urban agglomeration is relatively weak, the economic network is in a stage of polarized development, and regional development imbalance is pronounced. (2) The influence of Xi'an continues to expand, while the influence of non-core cities diminishes, creating a "lamp shadow effect" within the region. (3) The degree of agglomeration within cohesive subgroups evolves from loose to tight, and the coupling between the three-tier cohesive subgroups of cities and their provincial administrative divisions transitions from non-coupled to fully coupled. (4) The average coreness value of the urban agglomeration is relatively low but gradually increasing, with the core area evolving from a Xi'an-centered single-core structure to a dual-core development structure comprising Xi'an and Xianyang. (5) The effects of city centrality, influence, and agglomeration on urban economic growth exhibit variations.

Full Text

Evolution of Economic Connection Network Structure in the Guanzhong Plain City Cluster and Its Impact on Economic Growth

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Abstract: This study employs a modified gravity model incorporating urban flow intensity to construct an economic connection matrix, and utilizes social network analysis to examine the evolution of economic connection network structure and its impact on economic growth in the Guanzhong Plain City Cluster from 2008 to 2018. The results indicate: (1) The network centralization level of the city cluster is weak and declining annually, with the economic network still in a polarized development phase, highlighting severe regional development imbalances. (2) The agglomeration degree within cohesive subgroups has evolved from loose to tight clustering, with non-core cities' influence decreasing and a "shadow effect" emerging within the region. (3) The hierarchical structure of urban cohesive subgroups has transitioned from being decoupled from provincial administrative boundaries to becoming fully coupled with them. (4) The average coreness value of the city cluster is low but gradually increasing, with the core area evolving from a single-core structure centered on Xi' an to a dual-core structure comprising Xi' an and Xianyang. (5) The effects of urban centrality, influence, and agglomeration on economic growth vary significantly.

Keywords: economic connection; network structure; economic growth; social network analysis; Guanzhong Plain City Cluster

Introduction

In the context of economic globalization, city clusters have gained increasing prominence as interurban connections intensify. Regional spatial structures have evolved from monocentric to polycentric configurations, shifting the focus of regional spatial interaction research toward network-based perspectives. Contemporary theories such as "network society," "space of flows," "central flow theory," and the "interlocking network model" have been validated by economic geographers in the development of world cities. Networks consist of nodes and connections between them—the most fundamental elements of any network system. Urban networks can be conceptualized as clusters of cities interacting through economic flows, information flows, technical flows, and other media.

Building upon the foundational work of foreign scholars, Chinese researchers have adapted these theories to China' s specific context, conducting numerous studies on economic connections and urban network spatial patterns. For instance, Gu Chaolin et al. [?] employed the gravity model to measure spatial connection intensity among Chinese cities, delineating the Chinese urban system into a hierarchical structure of national, regional, and local levels. Hu Ying et al. [?] utilized the gravity model and urban flow intensity model to quantify economic connections within the middle reaches of the Yangtze River city cluster. Yu Jinkai et al. [?] modified the traditional gravity model by incorporating industrial complementarity, comprehensive economic quality, and economic dis-

tance to analyze the Shandong Peninsula city cluster. Zhong Yexi et al. [?] examined the evolution and driving mechanisms of the Yangtze River Economic Belt's network structure from a network structural perspective.

Following the introduction of the gravity model from physics into economics by Reilly [?], subsequent scholars applied it to urban system interaction analysis and extended its use to transportation, trade, investment, and tourism across various spatial scales. In 2018, the Guanzhong Plain City Cluster Development Plan was officially approved by the State Council, establishing it as China's seventh national-level city cluster and elevating its development to a national strategic priority. This presents unprecedented opportunities for the Guanzhong region. The national government has proposed objectives for the area, including "building an internationally influential city cluster," "comprehensively enhancing openness and cooperation," and "becoming an important growth pole leading Northwest China's development." These goals demand not only population and economic agglomeration but also enhanced collaborative development and cultivation of new regional growth poles. Consequently, research on the evolution of economic connection network structure and its impact on economic growth in the Guanzhong Plain City Cluster is particularly crucial.

Complex network theory has been increasingly applied in economic geography, with social network analysis emerging as a vital method for studying urban economic network structures. However, existing research on economic connections often relies on single time points, lacking long-term spatiotemporal evolution analysis that could explain the changing network patterns and their effects on urban economic growth. Moreover, most studies focus on city clusters in the Yangtze River basin and eastern coastal regions, with minimal attention to western Chinese city clusters. Addressing these gaps, this study examines the Guanzhong Plain City Cluster, constructing an evaluation framework for urban economic connection networks and employing complex network theory and social network analysis tools to investigate network structural characteristics and their influence on economic growth from 2008 to 2018. The findings aim to provide policy recommendations for optimizing the economic network and promoting regional collaborative development.

1 Study Area

According to the Guanzhong Plain City Cluster Development Plan, the study area encompasses 11 prefecture-level cities: Xi'an, Baoji, Xianyang, Weinan, Tongchuan, Shangluo (partial counties), Yuncheng and Linfen (major counties) in Shanxi Province, and Tianshui, Pingliang (partial counties), and Qingyang in Gansu Province, covering a total area of $10.71 \times 10^4 \text{ km}^2$ with a permanent population approaching 4×10^7 . Due to the lack of county-level industrial statistics, this research adopts the 11 prefecture-level cities as study units for analyzing network structure evolution and its impact on economic growth (Figure

1).

Figure 1. Cities and administrative boundaries in the Guanzhong Plain City Cluster

2 Methodology

2.1 Data Sources

Given space limitations, this study selected three representative years (2008, 2013, and 2018) as temporal nodes. Basic data for urban economic quality and regression model control variables were obtained from the *China City Statistical Yearbook* and provincial statistical bulletins of Shaanxi, Shanxi, and Gansu. Intercity driving distances were derived from Baidu Maps.

2.2 Model Construction

2.2.1 Economic Connection Network Model: A Modified Gravity Model The gravity model is widely applied in spatial interaction analysis. This study employs it to measure economic connection networks by constructing an urban economic connection intensity matrix to derive “relational data” between cities. The general gravity model is:

$$T_{ij} = K \frac{M_i M_j}{D_{ij}^b}$$

where T_{ij} represents the economic connection intensity between city i and city j ; K is a general coefficient; b is the distance friction coefficient, following Gu Chaolin’s research findings on China’s urban system [?], we set $b = 2$ and $K = 1$; n is the number of cities; D_{ij} is the distance between cities (measured by shortest driving distance); and M_i and M_j represent urban quality, typically measured by GDP and population.

However, GDP and population alone cannot fully capture urban economic connection levels. As Chinese cities integrate into global production networks, production factors flow with unprecedented speed and scale, strengthening regional economic connections. Urban cluster networks evolve from “point space” to “flow space,” where functional complementarity and factor circulation become crucial determinants of economic connections. The urban flow intensity model effectively captures the impact of external functions on urban connections. Therefore, this study incorporates urban flow intensity to modify urban quality in the gravity model.

Urban flow intensity is calculated as [?]:

$$F_i = E_i \times N_i$$

where F_i is the urban flow intensity of city i ; E_i is the external function volume; and N_i is the efficiency of external functions.

Using urban employment by sector as the indicator for urban functions, we calculate external function volume (E_i) through location quotients. The location quotient for sector j in city i is:

$$Lq_{ij} = \frac{G_{ij}/G_i}{G_j/G}$$

where G_{ij} is employment in sector j of city i ; G_i is total employment in city i ; G_j is national employment in sector j ; and G is total national employment.

If $Lq_{ij} \leq 1$, city i 's employment share in sector j is less than or equal to the national average, indicating no external function, thus $E_{ij} = 0$. If $Lq_{ij} > 1$, the city provides external services, and E_{ij} is:

$$E_{ij} = G_{ij} - G_i \times \frac{G_j}{G}$$

Total external function volume (E_i) aggregates across m sectors:

$$E_i = \sum_{j=1}^m E_{ij}$$

Functional efficiency (N_i) is measured as GDP per employee:

$$N_i = \frac{GDP_i}{G_i}$$

Since agriculture is a non-basic sector in the Guanzhong Plain City Cluster, this study calculates urban flow intensity based on 14 secondary and tertiary industry sectors: mining, manufacturing, electricity/gas/water production and supply, construction, wholesale/retail, transportation/warehousing/postal services, hospitality, information technology, finance, real estate, leasing/business services, scientific research/technical services, water conservancy/environment/public facilities management, resident services/repair, education/health/social security, culture/sports/entertainment, and public administration.

Finally, we modify the gravity model using urban flow intensity (F) and GDP to represent urban quality. The revised formula for economic connection intensity is:

$$T_{ij} = \frac{F_i \times GDP_i \times F_j \times GDP_j}{D_{ij}^2}$$

where F_i and F_j are urban flow intensities; GDP_i and GDP_j are gross domestic products (in 10^8 yuan); and D_{ij} is the shortest driving distance between cities (in km).

2.2.2 Network Structure Analysis: Social Network Analysis Social network analysis examines the attributes and structural characteristics of connections between nodes. Using UCINET 6.2, this study analyzes the evolution of centrality, influence, cohesive subgroups, and core-periphery structure.

Centrality. Centrality quantifies the central importance of nodes. We examine both degree centrality (individual node centrality) and graph centralization (overall network centrality) [?].

Influence. Node influence is analyzed using structural hole theory through network efficiency and constraint metrics. Higher efficiency indicates greater non-redundancy in connections and stronger influence, while higher constraint reflects network closure and weaker influence [?, ?].

Cohesive Subgroups. Cohesive subgroup analysis employs clustering methods to examine internal relationships and hierarchical differentiation within city clusters [?, ?]. We analyze the number, composition, and hierarchical characteristics of subgroups in the Guanzhong Plain City Cluster.

Core-Periphery Structure. This analysis categorizes nodes into core and peripheral regions based on connection density and agglomeration [?]. By measuring each city's coreness value, we examine the distribution and evolution of core-periphery structures.

2.2.3 Impact of Network Structure on Economic Growth: Regression Model Using GDP change between consecutive study periods as the economic growth index, we select four network structure indicators: degree centrality, network efficiency, constraint, and coreness. Drawing on existing research, we include four control variables: tertiary industry share of GDP (industrial structure), retail sales share of GDP (consumption level), population density (labor force), and construction land ratio (urban development). Using SPSS 23, we conduct multiple linear regression analysis to examine the effects of network structure and control variables on economic growth.

3 Results

3.1 Evolution of Economic Connection Network Structure

Calculating intercity economic connection intensities via the modified gravity model and visualizing them in ArcGIS 10.5 reveals that from 2008 to 2018, overall connection intensity gradually strengthened and diversified, though the network remains in an early development stage (Figure 2).

Figure 2. Economic connection networks of Guanzhong Plain City Cluster in 2008, 2013, and 2018

3.2 Network Structure Characteristics

3.2.1 Centrality Analysis To eliminate the effects of price indices and economic scale variations, we standardized centrality values. Results show:

1. **Different trajectories across cities:** Xi' an and Xianyang, the two most central cities, exhibit continuously increasing degree centrality, reflecting enhanced resource concentration by core cities. In contrast, Baoji, Tongchuan, Linfen, and Pingliang show declining centrality, indicating diminishing economic status of secondary centers.
2. **Massive disparities:** Xi' an' s centrality is over 10 times that of the lowest-ranked city, revealing severe polarization. Xi' an dominates the region while secondary centers remain underdeveloped. In 2018, Xi' an accounted for 44% of the cluster' s total GDP, while the second-largest economy (Baoji) represented only about 20% of Xi' an' s size.
3. **Weak overall centralization:** Graph centralization values were 20.88% (2008), 19.81% (2013), and 18.96% (2018), indicating weak and declining network centralization. The decline in non-core cities' centrality outweighs the rise in core cities' centrality, confirming the network remains in a polarized development phase. As the core of the Belt and Road Initiative and the cluster' s central city, Xi' an' s "centrality" has been continuously strengthened, weakening surrounding cities' resource aggregation capacity. The substantive progress of "Xi' an-Xianyang integration" during the 13th Five-Year Plan accelerated Xi' an metropolitan area construction, enhancing core city centrality while reducing non-core cities' centrality.

3.2.2 Influence Analysis Network efficiency and constraint values reveal:

1. **Xi' an' s dominance:** Xi' an exhibits the highest efficiency and lowest constraint, with constraint decreasing and efficiency increasing continuously since 2008, indicating its growing influence.
2. **Declining influence of other cities:** All other cities show a U-shaped trend in constraint (first decreasing, then increasing) and an inverted U-shaped trend in efficiency (first stable, then decreasing), reflecting shrinking influence.
3. **Provincial disparities:** Shaanxi cities (Baoji, Xianyang, Tongchuan, Weinan, Shangluo) show lower influence than Shanxi and Gansu cities. This "shadow effect" likely results from the "Greater Xi' an" construction concentrating resources and limiting development opportunities for neighboring cities.

4. **Negative correlation:** Efficiency and constraint show negative correlation, consistent with structural hole theory.

3.2.3 Cohesive Subgroup Analysis The evolution of cohesive subgroups shows:

1. **2008:** Subgroups were loosely organized, primarily as 2-city clusters (e.g., Yuncheng-Linfen, Weinan-Shangluo). Some cities like Tianshui and Tongchuan failed to form strong clusters, indicating low agglomeration.
2. **2013:** The number and structure changed modestly, but 2-city clusters remained dominant. However, subgroup hierarchy became more pronounced, showing a “pyramid” distribution.
3. **2018:** Significant structural changes occurred. Three-level subgroups emerged, with all cities appearing in tertiary subgroups. Secondary subgroups increased, forming tighter small groups. The core city Xi’an appeared only in primary subgroups, while other cities formed tertiary subgroups, indicating loose internal clustering.
4. **Administrative coupling:** In 2008 and 2013, subgroup divisions were decoupled from provincial boundaries (e.g., Pingliang-Baoji cluster; Qingyang-Xianyang cluster). By 2018, tertiary subgroup divisions fully aligned with provincial administrative divisions, demonstrating that geographical proximity and administrative boundaries have become endogenous drivers of network development.

Figure 3. Centrality characteristics of economic connection networks in the Guanzhong Plain City Cluster

Figure 4. Influence characteristics of economic connection networks in the Guanzhong Plain City Cluster

Figure 5. Cohesive subgroup analysis of economic connection networks in the Guanzhong Plain City Cluster in 2008, 2013, and 2018

3.2.4 Core-Periphery Structure Analysis Core-periphery analysis reveals:

1. **Low but rising average coreness:** The cluster’s mean coreness value is low (0.01-0.20 for most peripheral cities) but gradually increasing, indicating strengthening internal agglomeration.
2. **Severe polarization:** Xi’an’s coreness ranges 0.74-0.96, while peripheral cities like Tongchuan and Qingyang range 0.01-0.20, showing extreme divergence.
3. **Structural evolution:** In 2008, the core area consisted solely of Xi’an. After 2013, Xi’an and Xianyang formed a dual-core structure, reflecting the spatial manifestation of “Xi’an-Xianyang integration.” Using coreness

>0.5 as core area and 0.25-0.5 as semi-periphery, Figure 6 illustrates this evolution.

Figure 6. Core, semi-core, and peripheral structures of Guanzhong Plain City Cluster in 2008, 2013, and 2018

3.3 Impact of Network Structure on Economic Growth

After multicollinearity testing identified correlation between degree centrality and constraint, we employed stepwise multiple linear regression. The adjusted R^2 reached 0.712 with significant F-values, indicating high model fitness (Table 1).

Table 1. Results of regression analysis between economic network structure and economic growth

Variable	Coefficient	Significance
Degree Centrality	0.847***	$p < 0.001$
Efficiency	0.623***	$p < 0.001$
Constraint	0.215*	$p < 0.05$
Coreness	0.089	n.s.
Adjusted R^2	0.712	

Note: , , * indicate significance at $p < 0.05$, $p < 0.01$, $p < 0.001$ respectively.*

3.3.1 Network Structure Effects Degree Centrality: The highly significant positive coefficient (0.847) indicates that enhanced centrality directly promotes local economic growth. As the Guanzhong network remains in early development, strengthening intercity economic linkages facilitates factor mobility and utilization, fostering secondary centers and improving economic efficiency.

Efficiency: The significant positive coefficient (0.623) shows that higher efficiency enables cities to access more non-redundant key resources, enhancing control and allocation capacity, thereby increasing regional influence and promoting growth.

Constraint: The positive coefficient (0.215) suggests that moderate constraint on core cities' influence benefits overall regional growth. In this polarized network, excessive dependence on Xi' an' s absolute influence restricts intercity interaction, limiting other cities' development.

Coreness: The non-significant effect indicates that while network "cohesion" may concentrate factors and stimulate growth, excessive cohesion can create path dependence and resource rigidification, hindering sustainable development.

3.3.2 Control Variables Industrial structure, consumption level, and labor force positively affect economic growth, suggesting that optimizing industry mix, boosting consumption, and attracting population benefit the cluster. Urban construction investment shows slight negative effects, indicating potential “crowding out” effects.

3.3.3 Policy Recommendations Based on these findings, we propose:

1. **Strengthen Xi'an's leading role:** Enhance Xi'an's comprehensive service functions, industrial clustering, logistics hub, openness, and cultural cohesion. Advance “Xi'an-Xianyang integration” to elevate the greater Xi'an area's centrality and influence.
2. **Promote radiation effects:** Leverage Xi'an's network influence through differentiated, complementary, and collaborative development models to rationalize resource allocation, enhance connectivity, and cultivate secondary centers to drive peripheral city development.
3. **Guide planning and industrial layout:** Clarify distinctive industrial positioning for core, semi-peripheral, and peripheral cities to promote more rational agglomeration patterns and network structures, ultimately serving the Belt and Road Initiative.

4 Discussion

As China's seventh national-level city cluster, the Guanzhong Plain City Cluster's economic network development remains in its early stages, lagging significantly behind coastal city clusters. Traditional gravity models using GDP and population only reflect economic scale, not factor-level interactions. Given Xi'an's dominance and weak internal connectivity, this study's urban flow intensity modification provides a valuable extension by capturing factor complementarity and mobility, more accurately revealing network structural characteristics.

The regression model further analyzes how network structure affects economic growth, offering theoretical foundations for future development strategies. However, urban economic connections also depend on governance systems and innovation capacity, suggesting future research should incorporate more variables and examine additional network properties for comprehensive understanding.

5 Conclusions

This study constructs an economic connection network for the Guanzhong Plain City Cluster using a modified gravity model, analyzing network structure evolution (2008-2018) through social network analysis and examining growth impacts. Key conclusions:

1. **Centrality:** Network centralization is weak and declining. City centrality varies dramatically with different trajectories. Severe polarization exists, with underdeveloped secondary centers and development dominated by polarization effects.
2. **Influence:** Xi'an exhibits the highest efficiency and lowest constraint, with growing influence. Non-core cities' influence is relatively declining, creating a "shadow effect." Shaanxi cities show lower influence than Shanxi and Gansu cities.
3. **Cohesive Subgroups:** Internal agglomeration evolved from loose to tight. In 2018, subgroups show hierarchical "pyramid" distribution. Subgroup divisions transitioned from decoupled to fully coupled with provincial administrative boundaries, indicating geographical proximity and administrative divisions as endogenous drivers.
4. **Core-Periphery Structure:** Average coreness is low but rising. Core-periphery divergence is severe. The core area evolved from Xi'an single-core to Xi'an-Xianyang dual-core structure.
5. **Growth Impacts:** Centrality and efficiency significantly and positively correlate with economic growth. Constraint has positive effects, while coreness is non-significant, suggesting excessive cohesion may hinder sustainable development.

The urban flow-modified gravity model effectively measures the Guanzhong Plain City Cluster's network structure, accurately reflecting its evolution and existing problems.

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Figures

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Figure 1: Figure 1

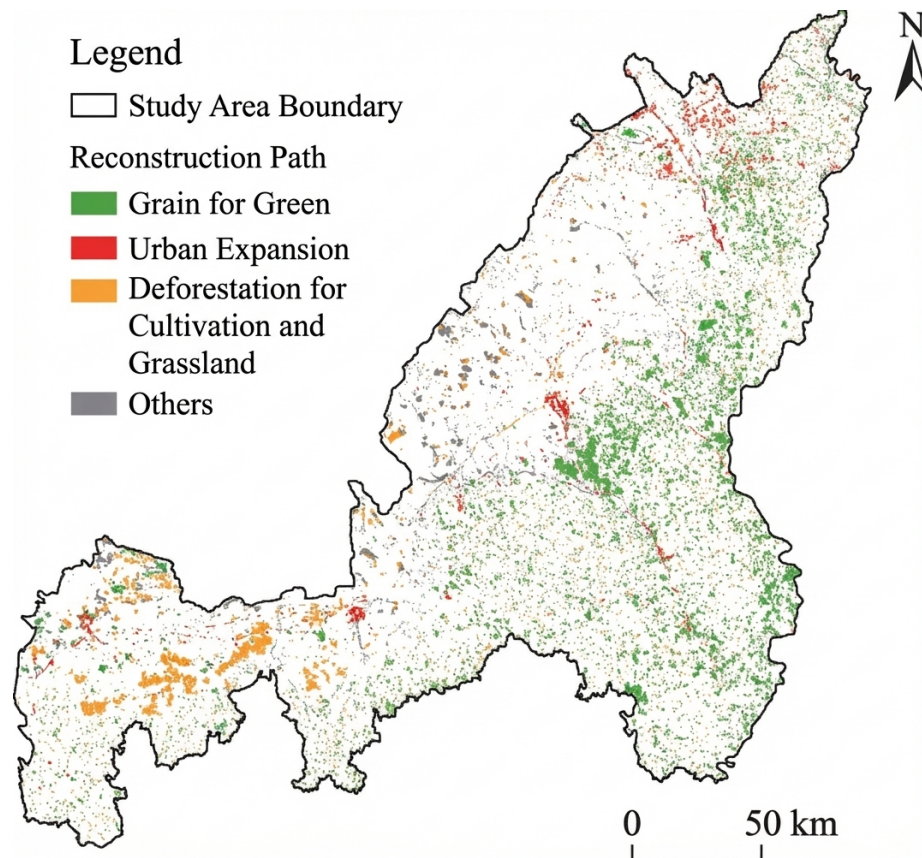


Figure 2: Figure 2

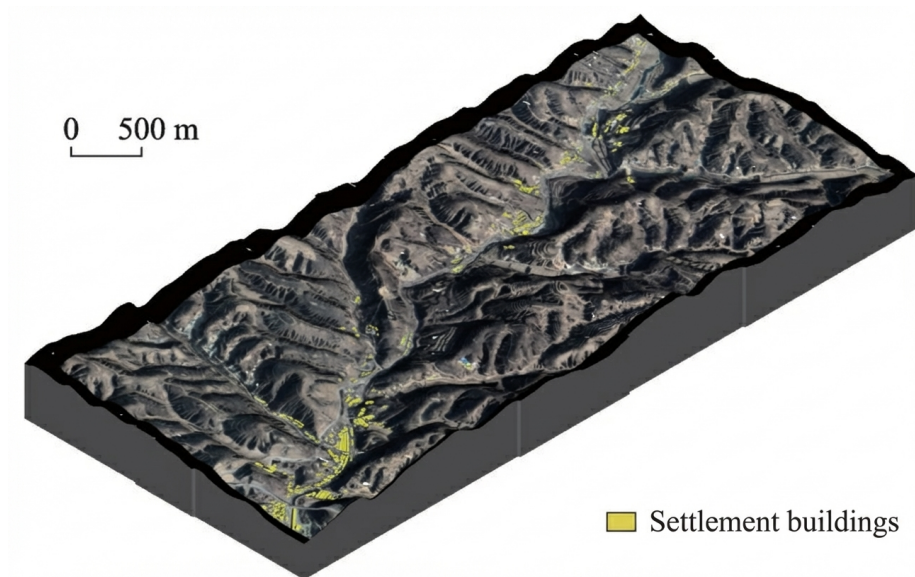


Figure 3: Figure 3

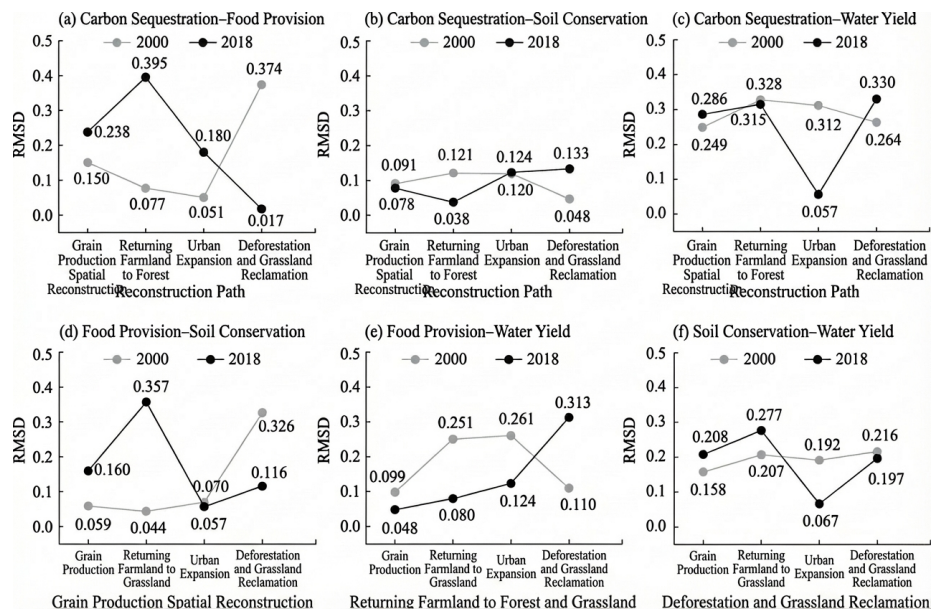


Figure 4: Figure 4

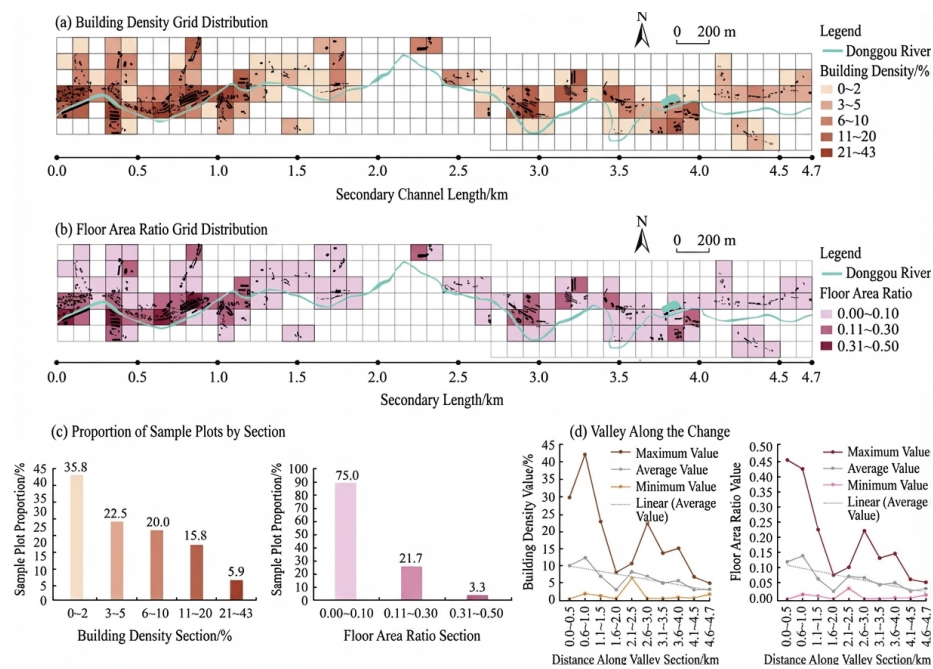


Figure 5: Figure 6