

Research Article

Spatial Patterns of the Urban Agglomeration of the Yellow River Ji-Shaped Bend Based on Space of Multiple Flows

Mengyao Guo ¹, Fang Wang ¹, Ruixi Zhao ², and Xi Guo ¹

¹School of Public Administration, Inner Mongolia University, Hohhot 010020, China

²Business College, Hebei Normal University, Shijiazhuang 050024, China

Correspondence should be addressed to Fang Wang; wangf741@163.com and Xi Guo; 13327118080@163.com

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Previous studies on the space of flows have mainly focused on a single flow element and have given less consideration to the joint effect of complex correlations among multiple flows. To fill this gap, in the context of the coordinated development of the urban agglomeration of the Yellow River Ji-shaped bend (UAYB), in this study, three flows, namely population flow, logistics flow, and information flow, are selected to research the spatial patterns of the UAYB. The results show the following: (1) The information flow among cities in the UAYB is the strongest, followed by logistics flow and population flow. (2) Hohhot, Ordos, Yinchuan, and Taiyuan are the core cities and have attracted more flows to converge there; different flows have formed different central features. (3) Regarding the correlation of the three flows, information flow has a strong correlation with the other two flows. (4) From the perspective of the joint effects of the three flows considered, the hierarchy of UAYB is dominated by Hohhot and Taiyuan and subdominated by Yinchuan and Ordos; four prominent city groups have been formed with these four cities as the center. On the basis of our results, we put forward some recommendations on the integrated development of cities at various levels within the UAYB to provide a reference for its spatial optimization strategy.

1. Introduction

The urban agglomeration of the Yellow River Ji-shaped bend (UAYB) is a concept that was proposed by the Sixth Meeting of China's Central Finance and Economics Commission on 3 January 2020. "Ji" is a Chinese character that has a shape that is basically the same as the letter "n" in the English alphabet, and its shape is very similar to the shape of the middle reaches of the Yellow River. The UAYB is located in the middle "Ji"-shaped part of the Yellow River [1]. As an urban agglomeration, the UAYB is characterized by proximity and similar culture. These characteristics make the UAYB closely connected, with close geopolitical relations, a large population, goods, and information. The flow of these elements and the economic development are interactive processes [2]. In recent years, with the rapid development of the economy, much more closer connections have gradually been formed within cities of the UAYB, and the space of multiple flows are becoming increasingly complicated and

prominent. At the same time, the UAYB is a typical resource-rich area, an important energy and chemical production base, and a basic industrial base in China, as well as an important ecological barrier in the Yellow River basin. Thus, with the development of the economy and the increasing pressure on resources and the environment, the cities of UAYB are also facing the urgent problem of transformation to promote high-quality synergistic development.

Multiple flows are the primary driving forces for regional development, and in the process of these flows, complex networks of different densities are formed within an urban agglomeration [3–5]. In the past, mainstream studies on the spatial structure of urban agglomerations have been based on place space, which ignored factors such as the dynamic nature of flows and the multiple spatial interactions [6–8]. After 2000, a group of researchers conducted a large number of studies on city networks by combining the theory of "space of flows" with the theory of "world cities" [9–11].

Since then, the space of flows perspective has gained more and more attention, and “flow thinking” has been invoked to understand the position of cities in an urban agglomeration. There are three ways to examine the traditional space of flows [12]: The first way is to reflect the connection between cities through transportation or communication infrastructure [13, 14]. The second way is to analyze the urban network through the corporate spatial organization and location strategy of producer service companies or multinational companies [15]. The third way is to measure the urban network through social organizations or social groups (such as skilled immigrants and elites) [16]. Although a combination of multiple approaches can consider urban agglomeration from a static to a dynamic perspective, the lack of relational data is still a key issue that restricts empirical research on the spatial patterns of urban agglomerations.

In recent years, increased dynamic data availability has enabled researchers to identify more segmented patterns of space of flows [17, 18], and therefore more and more analyses of space of various flows have emerged. They have mainly included population flow [19–23], traffic flow [24–28], and information flow [29, 30]. Most of these previous studies have constructed origin-destination matrices based on the flow of a single element to construct urban networks for analysis. Meanwhile, some new methodologies on the space of flows have been developed. For example, Teixeira and Derudder created a flexible R package called SKYNET for the processing and transformation of airflow data [31]. Shu et al. proposed L-functions to detect the scale of flow aggregation at multiple scales [32]. In addition, new research fields have emerged regarding the space of flows. An example is the application of space of flows in the field of border enforcement [33] and industrial collaboration directions [34].

In summary, studies on space of flows have mainly focused on the flow of a single element and on reconstructing the regional spatial patterns through traffic flow and population flow. Furthermore, studies have mainly focused on the current situation of each metropolitan area, and the analysis of the integration and development of cities at various levels within urban agglomerations remains at an introductory level. At the same time, less consideration has been given to the joint effect of complex correlations among multiple flows on an urban spatial structure. In addition, with the deepening influence of both globalization and decentralization forces on urban agglomerations and the rapid economic growth in midwestern China, the network patterns of cities and urban agglomerations in the midwestern China need to be studied [35]; however, there have been few studies conducted on this region.

In this study, we take the UAYB as the research area and use a combination of the theory of space of flows and open big data. In order to avoid the limitations of the flow of a single element, in this study, we select multiple flows which contain three elements, i.e., human flow, logistics flow, and information flow, which are the most representative among cities. In addition, the linkage flow strength and spatial correlation of each flow are analyzed. By dividing the spatial

hierarchy in the region, we explore the status and role of each city in the UAYB as well as the regional development organization model. This is expected to provide a basis for the spatial optimization strategy and development policy formulation of the UAYB integration.

2. Study Area and Methodology

2.1. Study Area. The UAYB is located in the “Ji-shaped” bend at the top of the Yellow River basin. The length of the Yellow River in this section is 921 kilometers, which accounts for about one-sixth of the total length of the Yellow River. The UAYB starts from Baiyin city in Gansu province in the west and flows through Ningxia province, Inner Mongolia, and Shaanxi province to Linfen city in Shanxi province. It includes the 3 provincial capital cities of Taiyuan, Hohhot, and Yinchuan; Wuzhong and Zhongwei of Ningxia province; Wuhai, Bayannur, Baotou, and Ordos of Inner Mongolia; Yulin of Shanxi province; and Shuozhou, Xinzhou, and Luliang of Shanxi province. In total, there are 21 cities, which covered an area of nearly 557,000 square kilometers [1] (Figure 1).

2.2. Data Source. In this study, 21 cities of the UAYB were treated as nodes and a 21×21 multivalued network matrix was constructed, which mainly included three sets of values, namely, population flow, logistics flow, and information flow. The data of population flow were obtained from the “Baidu Migration Map” (<https://qianxi.baidu.com>) from 22 September 2020 to 28 January 2021. The data mapped the population flow trajectory through the information of cell phone users and showed the real-time, dynamic, and intuitive daily population flow between cities. The logistics data were obtained from 10 main logistics companies in 21 cities in the study area, namely, Yuantong, Zhongtong, Best, Shentong, Yunda, SF, ZJS, Deppon, Anneng, and Tiantian. A total of 5687 logistics sites of these 10 companies were obtained from the Kuaidi 100 website on 10 July 2021 (<https://www.kuaidi100.com>). The information flow data was obtained from the Baidu Index (<https://index.baidu.com>), which is a data analysis platform based on Baidu’s massive Internet user behavior data. Through the Baidu Index, we can get how big the search scale of the cities of UAYB in Baidu platform. This part of the data was collected in July 2021. In addition, the space of traffic flow was used to test the correlation of the above three flows in the paper, since it has partial overlapping with both population flow and logistics flow. The traffic flow was represented by railway traffic data, which were derived from the official website of the China National Railway Group Co., Ltd. (Beijing, China; <https://www.12306.cn/index/>, accessed on 10 July 2021), including all passenger train routes and times in the UAYB.

Regarding the construction of space of multiple flows, the numerical calculations and processing of space of different flows are different. The population space of flow takes the Baidu Migration big data, which mainly includes two parts: the total in-migration index and the total out-migration index. The total migration index refers to the sum of the ratio

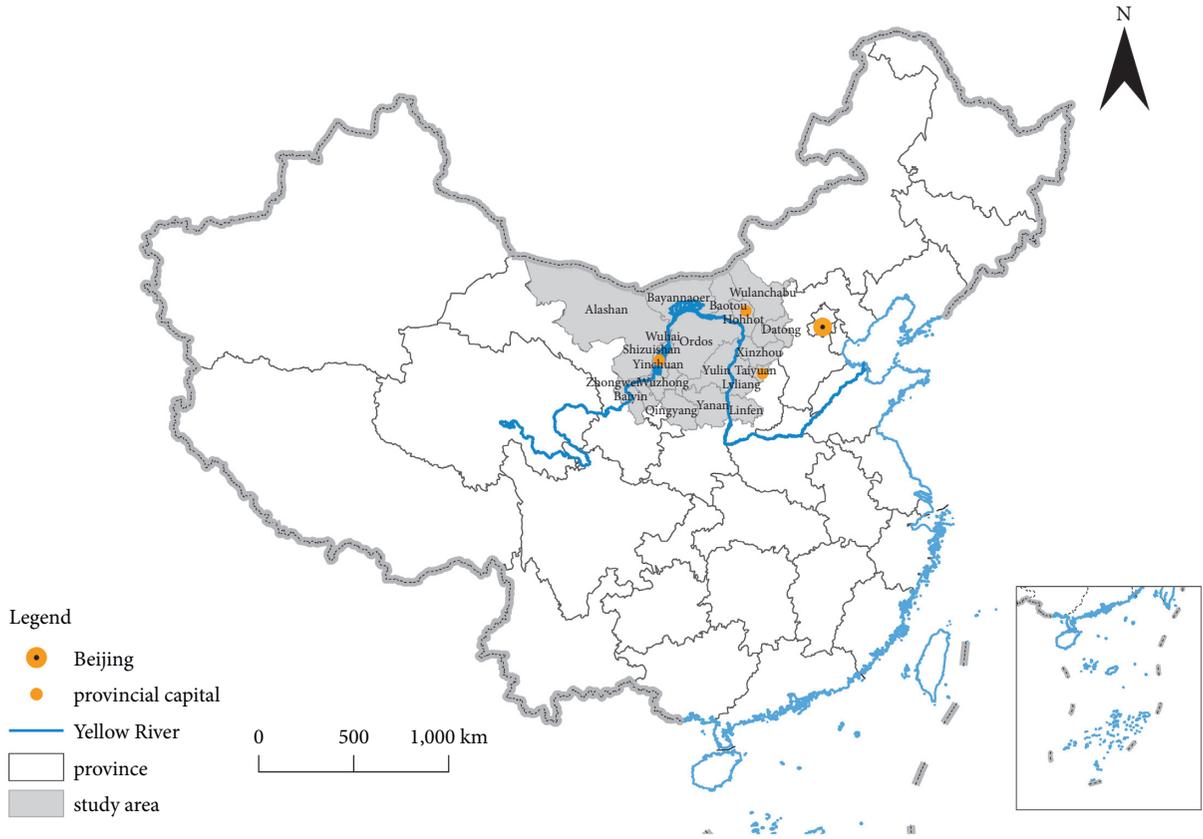


FIGURE 1: The study area.

of the population migrating from each source to the current region to the total population migrating to the current region. The total out-migration index is the sum of the ratio of the population moving out from the current region to the different in-migration locations to the total population moving out from the current region. The numerical representation of the information space of flow is the average value of the Baidu search index between two cities. The logistics space of flow is the average value of the number of logistics sites between the two cities.

2.3. Methodology

2.3.1. Social Network Analysis Methods. Social network analysis methods are widely used in the study of complex network structures. In this study, we used the overall network density, the degree centrality, and the quadratic assignment procedure (QAP) to analyze multidimensional networks in terms of nodes, hierarchies, and networks.

(1) Overall Network Density. The overall network density is an indicator that reflects the overall density of intercity connections in an urban agglomeration. The larger the network density value is, the more closely connected the cities are in the urban network. The overall network density value theoretically lies within the interval 0–1, but in the

actual urban agglomeration, the network with a density of 1 basically does not exist, and there are very few urban agglomerations that have a density value greater than 0.5. The calculation of (1) is as follows:

$$D = \frac{2L}{n \times (n - 1)}, \quad (1)$$

where D is the overall network density, L is the actual number of connections in the network, and n is the number of nodes in the network.

(2) Degree Centrality. The degree centrality is the most direct metric to portray node centrality in network analysis. The higher the degree of a node, the higher the degree centrality of the node is, which indicates the node importance in the network. Formula (2) is as follows:

$$C_D(n_i) = \sum_{j=1}^n X_{ji}, \quad (2)$$

where $C_D(n_i)$ represents the degree centrality and X_{ji} means the connection strength between nodes.

(3) Quadratic Assignment Procedure. The quadratic assignment procedure (QAP) is a common method to research the relationship between different types of networks. It compares the values of each element of the network matrix

based on data permutation to obtain the correlation and regression coefficients between matrices. It also performs a nonparametric test on the coefficients, which helps to avoid problems of the collinearity arising from relational data regression. In this study, the QAP was mainly used to compare the structure similarity of different space of flows.

2.3.2. Spatial Structure Index. The spatial structure index is an improved algorithm based on the study of regional central structure, which was proposed by Hanssens in 2013 [36]. The index is in the range from 0 to 1, where 0 indicates that the regional spatial structure shows a significant unipolar development, and 1 indicates that the regional spatial structure is significantly multipolar in character. The index can be used to evaluate the degree of dispersion of regional spatial structure of the following formula:

$$SSI = \begin{cases} \left(2 - \frac{SD}{SD_r}\right) \times 2^{-1}, & SD < SD_r \\ \frac{SD_r}{2SD}, & SD > SD_r \end{cases} \quad (3)$$

where SD is the standard deviation value of the flow between the nodes, SD_r is the standard deviation of the serial number of all nodes after ranking, and SSI is the spatial structure index.

2.3.3. Integrated Data Processing. The three flows of the matrix data are formed into a comprehensive network for normalizing the original data with the following formula:

$$S = \frac{x - \text{Min}}{\text{Max} - \text{Min}}, \quad (4)$$

where x is the original data, Min is the minimum value of the matrix data, Max is the maximum value of the matrix data, and S is the normalized data.

After the normalization, S lies in the range of 0~1; 1 indicates that the two cities are most closely connected, and 0 indicates that the two cities are most distant. The normalized data are summed to characterize the linkage flow strength of cities by the following formula:

$$R_i = \sum_j R_{ij}, \quad (5)$$

where R_i denotes the intensity of flow of city I , and R_{ij} is the intensity of the network connectivity of city i with city j . In the study of the spatial structure of integrated flow of urban agglomerations, by Wang et al., the flow of each element is regarded as equally important, with a weight of 0.33 [37].

2.3.4. Dominant Flow Analysis. Nodal regions were proposed by Nystuen and Dacey in 1961 based on graph theory [38, 39]. The central idea is to distill the hierarchical structure and organizational relationships of the major core cities and hinterland regions from the complex urban network through the dominant flow filtering method. This

TABLE 1: Overall network density of the three flows.

| Category | Density |
|------------------|---------|
| Information flow | 0.193 |
| Logistics flow | 0.186 |
| Population flow | 0.113 |

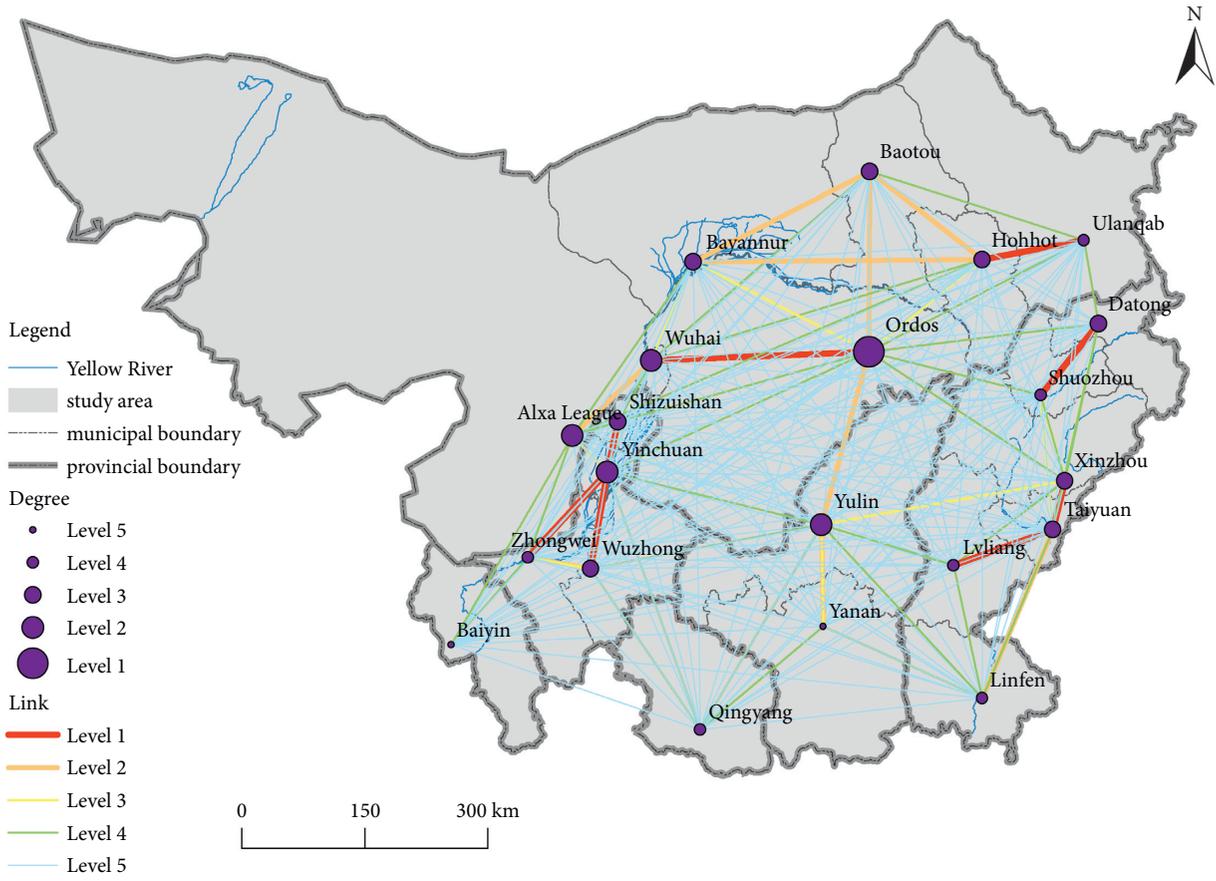
method follows the following principles: ① The largest flow of the dominant city flows to a relatively smaller city, ② the largest flow of the secondary dominant city flows to the dominant city, ③ the largest flow of the subordinate city flows to a relatively larger city, and ④ the subordination is transitive. If city A is subordinate to city B, and city B is subordinate to city C, then city A is also subordinate to city C; that is, A is also the hinterland of C.

3. Results

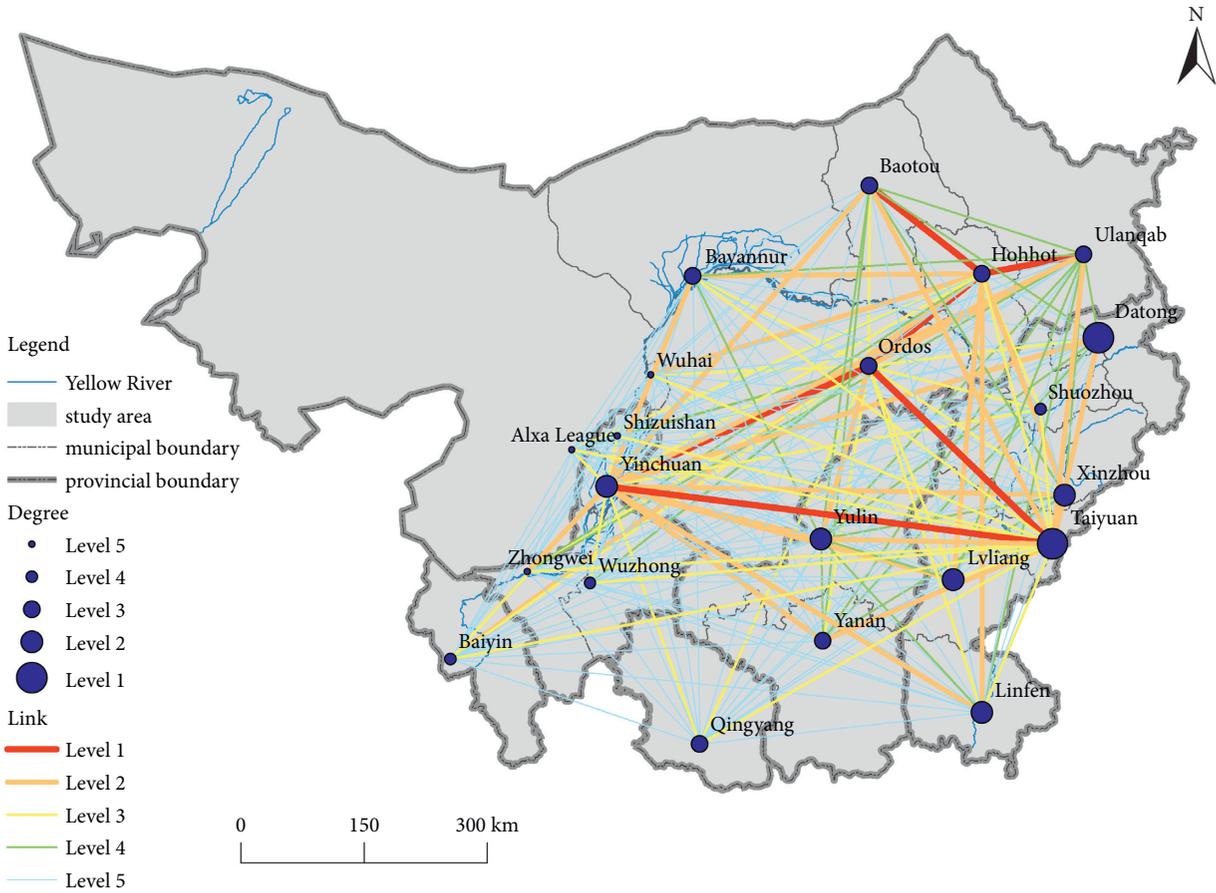
3.1. Multiple Linkages between Cities in the UAYB

3.1.1. Intensity Analysis of Multiple Linkages between Cities. The overall network density describes how closely the nodes in an urban agglomeration network are connected to each other. According to (1), we calculate the overall network density of the linkages among cities. As illustrated in Table 1, there are three different flows that differentiate the sparseness and strength of intercity connections. The information flows are a full-coverage urban network, and there are either large or small information flows between every two cities. Therefore, the network density of information flow (0.193) is also the largest. The second largest is the logistics network with a density value of 0.186. This is because the national logistics network has become more and more sophisticated with the personalization trend of increasing consumers and the significant potential development in the logistics industry in China. The overall network density has reached a high level, and logistics services basically cover all prefecture-level cities in the UAYB. Furthermore, the population flow data show that 91.43% of the cities in the UAYB have direct population linkages, but the network density value is not as high as the density values of information linkage and logistics linkage. This may be due to the low flow of population between small cities.

Then, we analyzed and compared the pattern of the three different flows. The degree centrality of cities was assigned to nodes, the strength of intercity linkages was assigned to lines, and they were all divided into five levels according to the natural break classification. There are both similarities and differences between the three flows (Figure 2). In terms of similarities, all cities in the UAYB are closely connected with each other, forming a complex network of multiple flows in the region. In addition, the cities with higher values of degree centrality in the three flows are Taiyuan, Ordos, and Yinchuan, which are provincial capitals or cities with higher levels of economic development and which play a crucial role in this region. In terms of differences, the distribution of the population flow is significantly different as compared with the logistics and information flows. We found that the larger the value of population flow, the more

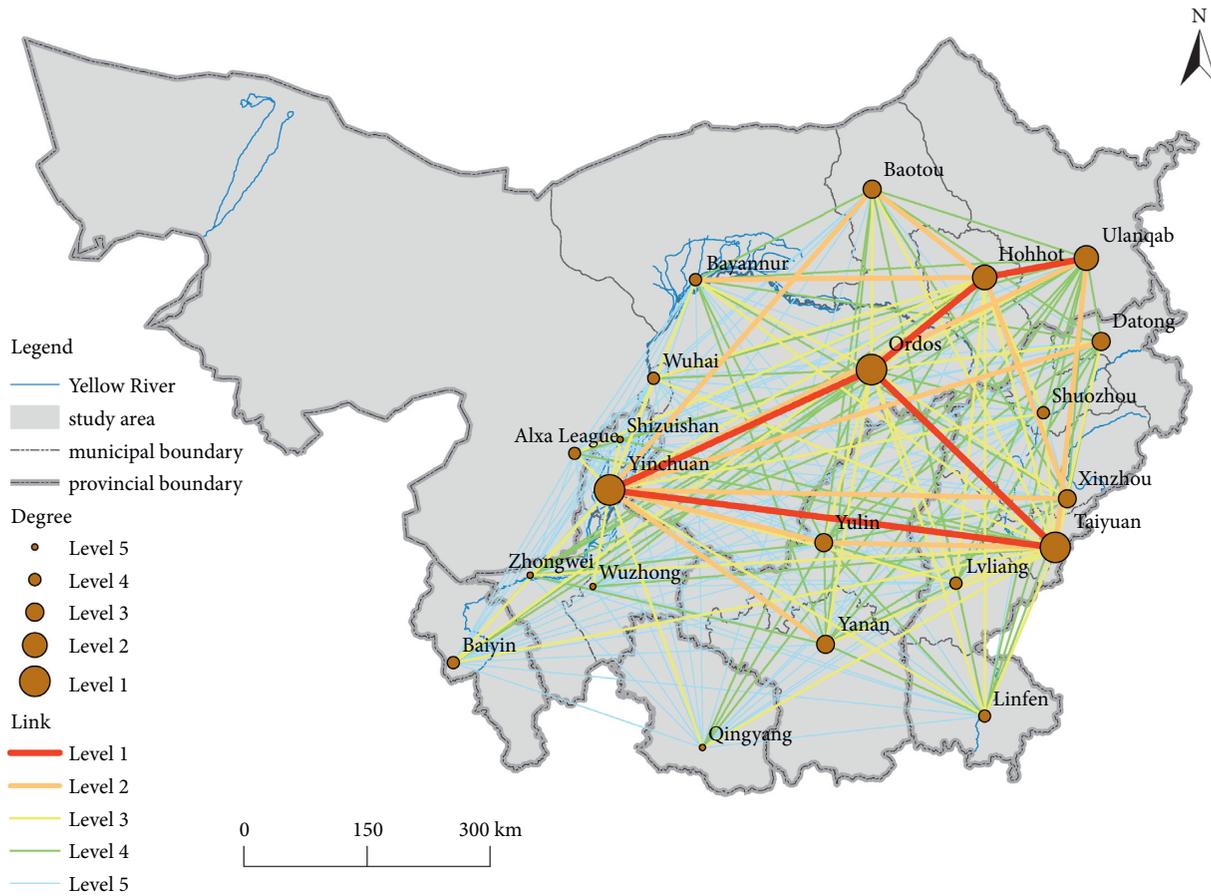


(a)



(b)

FIGURE 2: Continued.



(c)

FIGURE 2: Functional linkage intensities of the three different flows: (a) population flow; (b) logistics flow; (c) information flow.

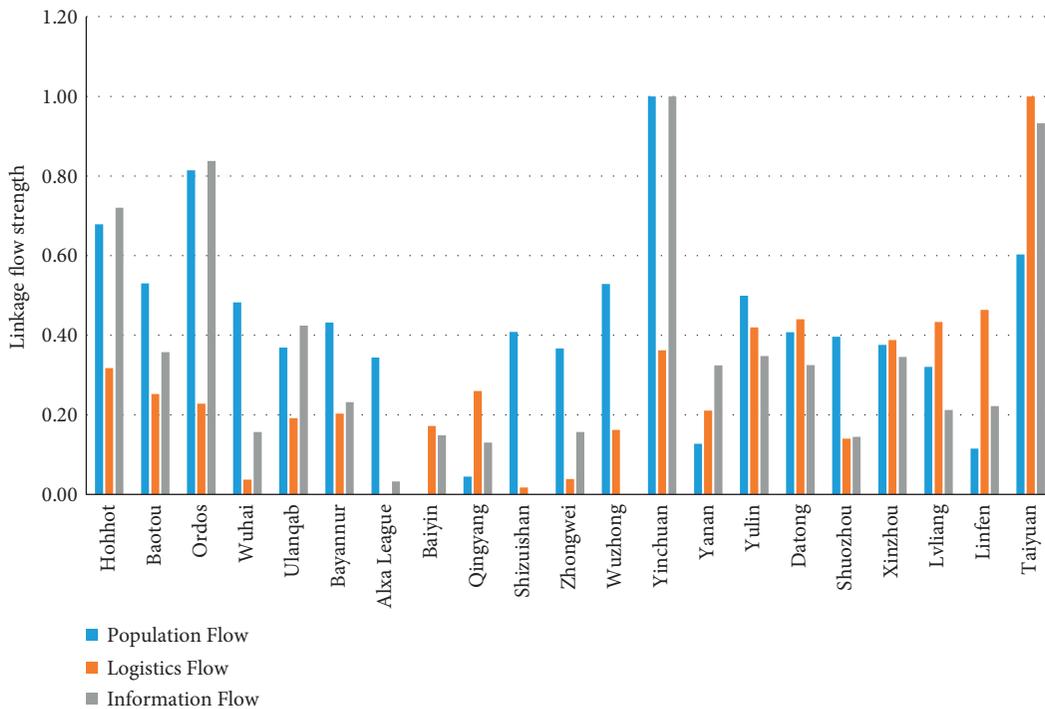


FIGURE 3: The linkage flow strengths of the three flows for each city in the UAYB.

dispersed it is, and no spatial polar core interaction occurs. This also confirms that population flows are obviously influenced by geographical distance.

Specifically, in terms of population flow (Figure 2(a)), Ordos, as a core node, generates the most population flow with surrounding cities. Among them, the population flow with Wuhai is particularly frequent. With strong economic advantages and convenient transportation, Ordos becomes the leading city in the population space of flow. It has the strongest population attraction in the region. It is followed by Yinchuan, Taiyuan, and Hohhot. The cities have all formed large population flows with their neighboring cities due to their attractiveness generated by their advantages in administration, economy, transportation, infrastructure, and employment. In addition, the population flows among fringe regions in the UAYB are also very obvious. For example, the intensity of population flows between Hohhot and Ulanqab, and Datong and Shuozhou, as well as Taiyuan and Xinzhou, is relatively high. This is due to the fact that the cities have similar cultural background and living customs and there are numerous transportation options among these cities, which has led to a large number of short distance population flows among them.

The logistics flow network of UAYB is maturely developed (Figure 2(b)). This is in line with the current background of rapid development of the logistics industry in China. It is found that the cities with high degree centrality are concentrated in the eastern part of the whole UAYB, especially in Shanxi province. There are three reasons for this. Firstly, Shanxi province was once a major coal resource province in China and has an extremely developed transportation system. The original transportation system has become the basis for the rapid development of its logistics space of flow. Secondly, Shanxi province is located in the east of the UAYB, where it is radiated by nearby developed regions, such as Beijing, Tianjin, and Shijiazhuang. Finally, Taiyuan belongs to the national logistics distribution point and is an important logistics hub in North China. In terms of the intensity of logistics flow, it basically conforms to the core interaction type; i.e., the high-intensity logistics flow is concentrated between the core cities, such as Yinchuan, Ordos, Taiyuan, Hohhot, and Baotou.

The information flow network is very similar to the logistics flow network (Figure 2(c)), in that the flows with higher spatial linkage intensity both occur in the central triangle of the region. In addition, except for Taiyuan, there are obvious differences; i.e., the core node cities within these two networks are different. The information space of flow has formed a complete regional network consisting of three core cities and two sub-core cities. The three leading cities are Ordos, Yinchuan, and Taiyuan, forming a spatial “triangle” to lead the information flows of cities in the UAYB. Furthermore, Hohhot and Ulanqab are two sub-core secondary cities, and the intensity of the information flow between them is relatively high. In addition, the information flow between these two cities and Ordos is also relatively frequent. In this way, the sub-core cities also realize real-

TABLE 2: Spatial structure index (SSI) of the three types of flows.

| Category | SSI |
|------------------|-------|
| Population flow | 0.883 |
| Logistics flow | 0.135 |
| Information flow | 0.535 |

time information linkage with the core “triangle.” The information flow connects the entire region, embodies the strong cross-territory and cross-level linkages of the information network, and enables more synergistic development among the central cities.

Finally, comparative analyses of the linkage flow strengths of the three different flows were performed for each city (Figure 3), and the spatial structure index (SSI) of the three linkages was calculated separately (Table 2). The linkage flow strength is obtained by summing and normalizing the matrices of each flow separately ((4) and (5)). Its horizontal coordinates are the cities of the UAYB, and its vertical coordinates are the normalized linkage flow intensities (Figure 3). It can be seen that the overall spatial patterns of population flow, logistics flow, and information flow are similar in the UAYB. The overall spatial pattern of the population space of flow is multipolar with an SSI value of 0.883. In addition, it is found that Yinchuan, Taiyuan, Ordos, and Hohhot have larger population movements. The overall spatial pattern of the information space of flow also tends to be multipolar with an SSI value of 0.535. In contrast, the spatial pattern of the logistics space of flow tends to be relatively unipolar with an SSI value of 0.135; in particular, Taiyuan has an absolute advantage in the UAYB region in terms of the strength of logistics flow.

3.1.2. Correlation Analysis of Multiple Linkages between Cities. In order to verify the correlation between different flows, we calculate the QAP values. The details are illustrated in Table 3. It can be seen that the information space of flow has a strong correlation with both population and logistics space of flows, with QAP correlation coefficients of 0.351 and 0.544, respectively. This is because the information space of flow is a full-coverage network, with more or less connectivity between every two cities. The spatial correlation between logistics space and population space of flow is low with a value of 0.231. Thus, traffic space of flow is introduced to further verify the correlation between these three flows. After validation with the traffic flow separately, it can be seen that the correlation between the population flow and the traffic flow is high. This is because the traffic data used in this study is that of the passenger trains between cities, and trains are the most frequent way for residents to travel. At the same time, population and goods usually take very different modes of transportation. Therefore, the correlation between traffic space of flow and logistics space of flow is low. In addition, it is obvious that information flow is also less dependent on transportation. This illustrates that information flow relies more on the Internet than on face-to-face communications.

TABLE 3: Quadratic Assignment Procedure (QAP) of the space of flows.

| Category | Traffic flow | Population flow | Information flow | Logistics flow |
|------------------|---------------|-----------------|------------------|----------------|
| Traffic flow | — | 0.436 (0.000) | 0.404 (0.000) | 0.211 (0.010) |
| Population flow | 0.436 (0.000) | — | 0.351 (0.000) | 0.231 (0.000) |
| Information flow | 0.404 (0.000) | 0.351 (0.000) | — | 0.544 (0.000) |
| Logistics flow | 0.211 (0.010) | 0.231 (0.000) | 0.544 (0.000) | — |

Note: “—” means no data, and the values in parentheses are the significance levels of the tests.

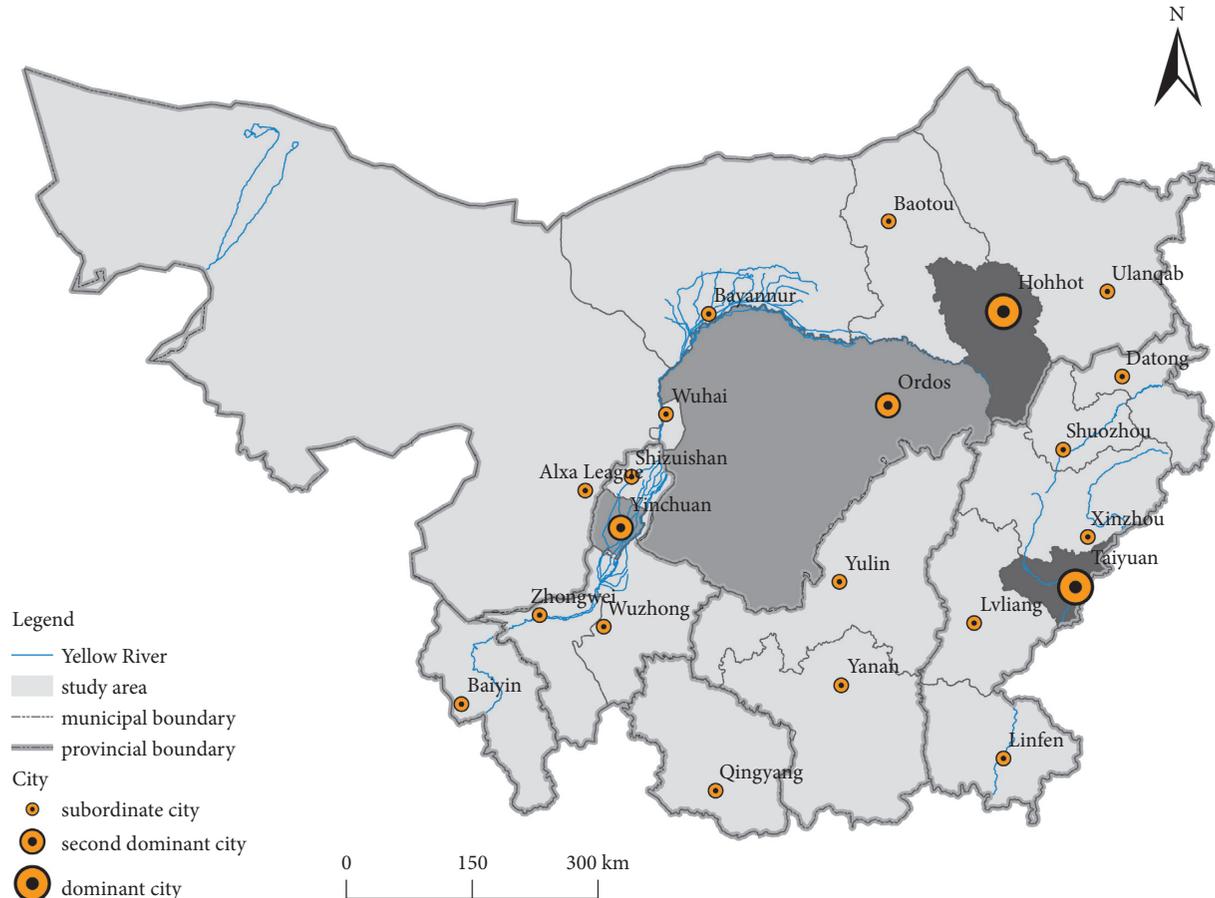


FIGURE 4: Spatial hierarchy of the UAYB by dominant flow analysis.

3.2. The Spatial Patterns of the UAYB

3.2.1. The Spatial Hierarchy of the UAYB. The analysis of different types of flows can only represent the spatial structure under a certain level of the UAYB, but it cannot fully reflect the spatial characteristics of each city in the study area. According to the results of the analysis in the previous section, the flows of population, logistics, and information are integrated to obtain the integrated flow ((4) and (5)). The network density of the integrated flow is 0.252, and the network connectivity is the strongest.

The spatial hierarchy of cities in the UAYB is analyzed using the dominant flow method (Figure 4). The flow direction of the dominant flow indicates that the dominant cities in the region are Hohhot and Taiyuan, which are the capital cities of Inner Mongolia Autonomous Region and Shanxi province, respectively, and also the hubs of economy,

politics, and culture. Therefore, they have strong comprehensive attractiveness and have the largest radiation range in the UAYB. The second dominant cities are Ordos and Yinchuan, which are directly attracted by the dominant cities. Spatially, the dominant and second dominant cities are basically located in the middle of the entire UAYB. The remaining subordinate cities are distributed among these four dominant cities, making a complex network of urban agglomeration throughout the region.

3.2.2. The Identification of Urban Groups in the UAYB. The visualization of the first dominant flows of the integrated flow reveals that the UAYB has formed two dominant urban groups and two subdominant urban groups. The two dominant urban groups are centered in Hohhot and Taiyuan, respectively, bring together the largest dominant flows of many cities, and form a large radiation area (Figure 5).

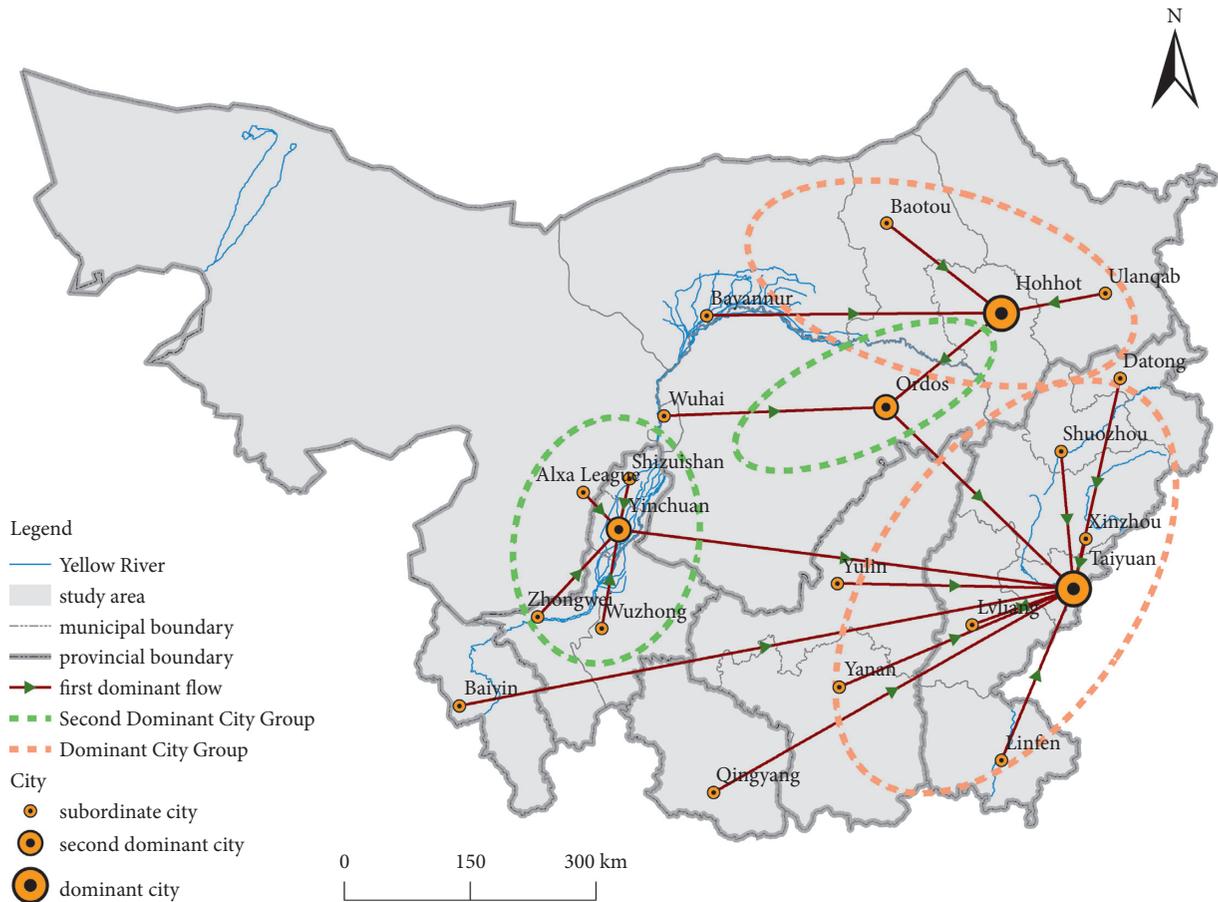


FIGURE 5: Spatial distribution of the first dominant flows in the UAYB.

The dominant urban group, with Hohhot as its core, is centered in the northeast corner of the UAYB. It has strong linkages with several other cities in the Inner Mongolia Autonomous Region. The three flows in the Inner Mongolia are not strongly linked within provinces, especially the population flow. The dominant urban group, with Taiyuan as the core, receives the largest number of dominant flows and has the widest radiation range, which basically covers the eastern and southern parts of the UAYB. Taiyuan is an extremely important node among the three flows, especially occupying the position of the dominant city in the logistics space of flow and information space of flow. At the same time, the subdominant city groups are centered in Ordos and Yinchuan, which receive relatively fewer dominant flows and form a radiation limited to the neighborhood areas with less radiation capacity. The number of cities of the Ordos urban group is relatively small. The main reason for the formation of this urban group is that the economic development level of Ordos is good, and its geographical location is in the center of the UAYB.

Furthermore, the flows of population and information are relatively more pronounced within the group centered in Ordos. The development of the group centered in Yinchuan has benefited from the proximity of the nearby cities, as well as the similar cultural background and folk customs, which has led to the strong flow of elements. Hence, a small

interactive space of flow centered in Yinchuan has been formed. It is noteworthy that although Yinchuan received a high number of first dominant flows, it formed only a second dominant city group. The more immature development of the Yinchuan city group is due to the fact that this urban group is far away from the other three urban groups and the interaction among them is not strong.

In this study, we also mapped the second and third dominant flows to research the interaction between cities in the UAYB. The details are shown in Figure 6. In this part, the details of the three flows in the previous section are represented. For instance, a large population flow is generated between Datong and Shuozhou. Except for some changes in the more connected neighborhoods, the dominant cities are Hohhot, Taiyuan, Ordos, and Yinchuan, which continue to receive most of the second dominant flows and the third dominant flows. Such a phenomenon indicates that the dominant cities in the UAYB have stronger control and attraction than the nondominant cities, while the linkages among the subordinate cities are weak and the development of the subordinate cities faces difficulties. Regional development integration is urgently needed.

Finally, the spatial structure index of the integrated flows was calculated to determine the degree of spatial dispersion of the UAYB, and the result was 0.606. This result indicates that the development dynamics of the UAYB is slightly

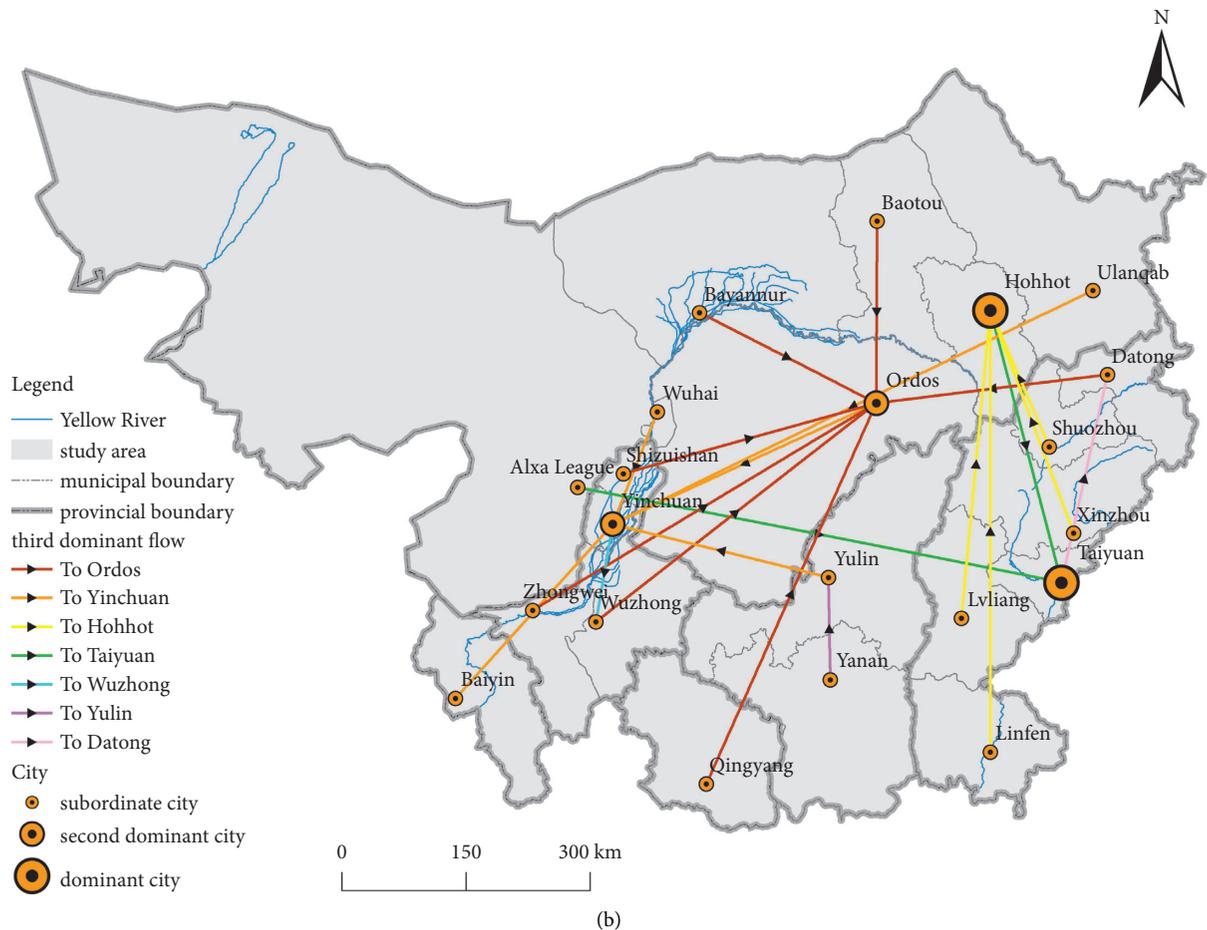
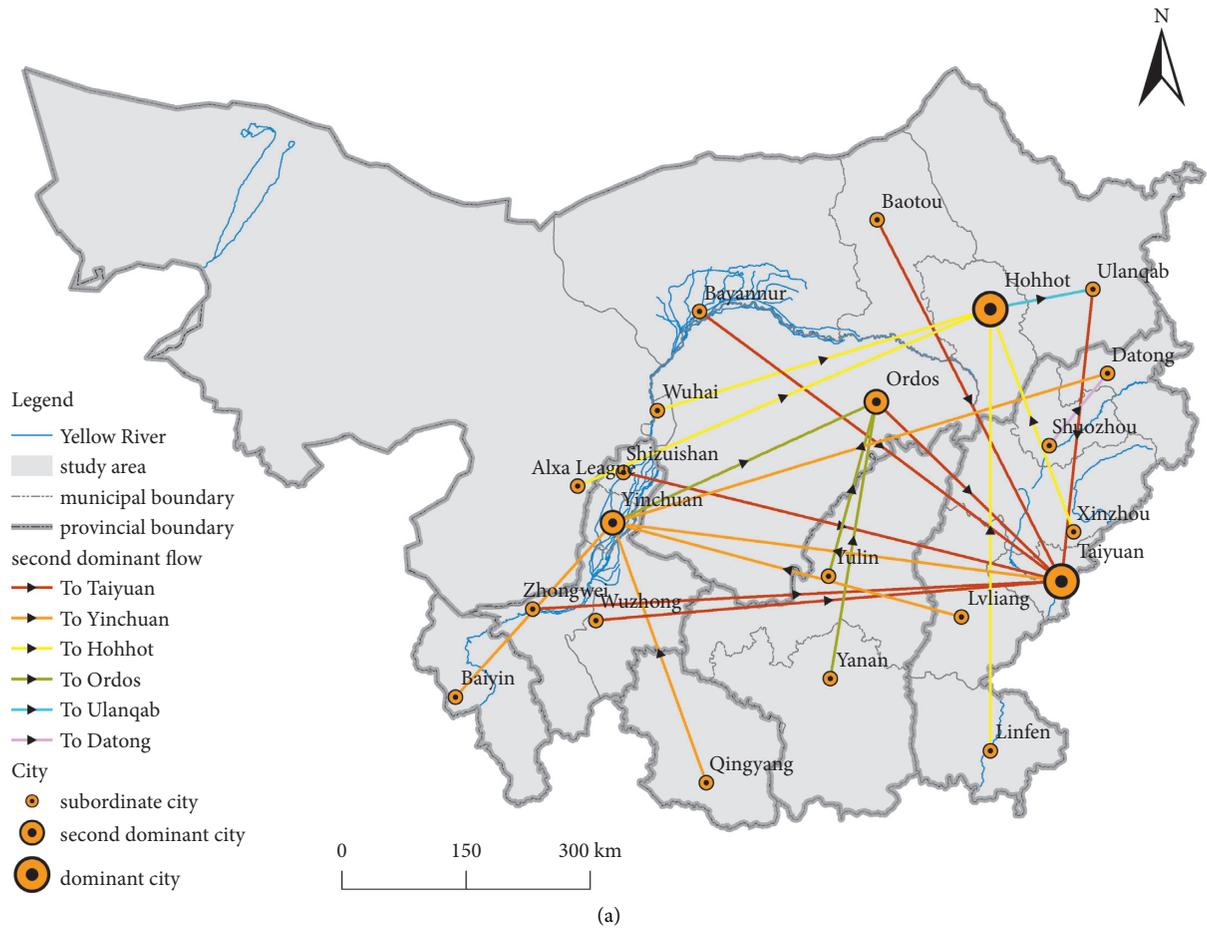


FIGURE 6: Distribution of the second and third dominant flows in the UAYB: (a) the second dominant flow; (b) the third dominant flow.

multipolar in a balanced manner. There is a need to promote the development of the dominant cities and play a more driving role in the region. Deepening the intraregional cycle will enable the development of the subordinate cities (e.g., less developed cities) and will continue to reduce the gap between the rich and the poor; therefore, it can also promote the process of regional integration in the UAYB.

4. Conclusions and Discussion

This study provides an in-depth analysis of the UAYB city agglomeration in terms of multiple linkages and regional spatial patterns, respectively. The main conclusions are as follows: (1) In terms of overall network density, the three flows all have strong development potential. Information flow received the highest score of overall network density, followed by logistics space of flow and population flow. (2) In terms of node centrality and linkage intensity, Hohhot, Ordos, Yinchuan, and Taiyuan have become the core cities and attract more types of flows in the UAYB to converge there. In contrast, the cities in the south and northwest of the UAYB are less centralized, and most of their population, materials, and technology flow to the leading cities. Regarding the population flow, Ordos, in the central part of the UAYB, has a prominent position. Taiyuan and Datong, two cities in Shanxi province, play a pivotal role in the logistics space of flow. A spatial triangle is formed in the information space of flow. The apexes are Ordos, Yinchuan, and Taiyuan, and information flows frequently among the three. (3) Regarding the correlation of the three flows, the information space of flow has a strong correlation with the other two flows. (4) The hierarchy of the UAYB is dominated by Hohhot and Taiyuan and subdominated by Yinchuan and Ordos. Four prominent city groups are formed with these four cities as the center. However, the regional comprehensive structure of the UAYB presents a multicentered, flat, and balanced situation; only the logistics space of flow shows a unipolar trend.

In order to strengthen the UAYB's overall radiation capacity and spatial linkages, as well as promote the rapid, coordinated, and comprehensive development of urban agglomerations, the following policy implications are recommended based on the results of this study: (1) Internal growth poles should be cultivated, and urban growth poles should be created. The special industries in the growth pole area, such as grassland agriculture and animal husbandry, tourism, and rare earth industry, should be taken advantage of. The transferred industries from the developed eastern regions should be actively undertaken and combined with the UAYB's own situation to achieve complementary advantages. The formation of the growth pole model should be accelerated to promote rapid development of the whole region. (2) While vigorously promoting the development of the two dominant cities of Hohhot and Taiyuan, we should also pay attention to the development and cultivation of the two second dominant cities with obvious advantages, so as to play a radiating and leading role in surrounding cities and enhance the overall concentration and radiation capacity of

the UAYB. (3) On the basis of traditional resource-based industries and basic manufacturing industries, cities in the UAYB should improve their independent innovation capabilities through introducing talents and technology and providing policy encouragement, as well as vigorously developing modern service industries and high-tech industries. In particular, cities such as Hohhot and Taiyuan should give full attention to the scientific and educational advantages of their universities, accelerate the construction of high-tech industrial parks and innovation demonstration zones, transform scientific and technological advantages into industrial advantages, promote the optimization and upgrading of urban industrial structure, and reduce the environmental pressure. (4) Hohhot and Taiyuan should make full use of their advantages in resources, technology, and information to enhance their comprehensive economic strength and realize their radiating and leading role in regional development. (5) An effort should be made to break through the limitation of the scattered regional structure in the UAYB, by speeding up the construction of intercity transportation, communication, logistics, and other networks centered in Hohhot, Taiyuan, Yinchuan, and Ordos and promoting the integrated construction of infrastructure in the UAYB. The five provinces, namely, Shanxi, Gansu, Shaanxi, Inner Mongolia Autonomous Region, and Ningxia Hui Autonomous Region, should break down administrative barriers, promote the free flow of elements, and optimize the allocation of resources. In addition, we should actively promote the sharing of public resources such as tourism, culture, and health, thus strengthening economic links among cities and promoting the integration of urban agglomerations. (6) New models to align the UAYB's development with China's major national strategies should be actively explored, and the synergistic development of the UAYB and various urban clusters in China should be developed. In addition, we should actively dovetail with the "one belt and one road" strategy to gradually enhance the UAYB's opening capacity to the outside world. The UAYB will become the frontline of opening up in northern China.

The limitations and future works of this study are as follows: Firstly, the research is limited to the UAYB and does not consider the linkage between the UAYB and external areas. Future research should consider the flows of various elements from the perspective of a larger region and even the whole country to promote the interconnectedness of the UAYB across the country. Secondly, the three flows (people, logistics, and information) selected in this study cannot cover all the flows of elements between cities. Elements such as capital flow and innovation flow should also be included in the overall research scope of multiple element flows. Thirdly, the next step can be based on a multidimensional perspective to analyze space of flows. If the time scale can be integrated into existing research, it can be combined with historical data for longitudinal comparison, thus obtaining the development history of the regional network and making existing research better, such as effectively combining policies and proposing more suitable optimization strategies.

Data Availability

This paper uses the “Baidu Migration” platform to obtain population migration data on Baidu Maps (<https://qianxi.baidu.com/>). Train routes data are from <https://www.12306.cn/index/>. Logistics sites data are from <https://www.kuaidi100.com>.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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