Research Article

Research on the Hierarchical Spatial Structure of the Urban Agglomeration of the Yellow River Ji-Shaped Bend

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Despite the rising interest in understanding the various uses of space of flows, few studies have combined the traditional static urban development level with dynamic space of flows concepts. In the context of the coordinated development of the urban agglomeration of the Yellow River Ji-shaped bend (UAYB), this study identifies the hierarchical spatial structure of the UAYB through a combination of Baidu migration big data and traditional data. The following conclusions can be drawn. (1) The cities with the strongest regional comprehensive power are Ordos, Taiyuan, Hohhot, Yinchuan, and Yulin, which cause the UAYB to present a significant “center-periphery” spatial pattern. (2) The biggest population flows mostly occur between cities in the same province, while interprovincial population flows mainly exist between cities with the strongest comprehensive power. (3) The hierarchical spatial structure of the UAYB forms a multiregion structure, with Ordos as the core. (4) The attractiveness of the UAYB is very weak, being only slightly attractive to individual surrounding provinces, while the population outflow index to economically developed areas is high. Several policy implications are proposed, which can provide important insights for planning intercity connections among the UAYB, in order to achieve more coordinated regional development.

1. Introduction

With the strengthening of economic globalization, the comprehensive competitiveness of a country often depends on its urban agglomeration development [1, 2]. As early as the beginning of the twentieth century, the spatial structure of urban agglomeration has attracted the attention of scholars. Some classic theories have gradually formed, such as the central place theory, the law of order and scale of cities, and Zipf’s law. Since the 1990s, globalization and informatization have profoundly affected the development and evolution of cities and regions around the world. Through various infrastructure and information networks, the connections between regions exceed the boundaries of central place theory, and the development of regions or cities is no longer carried out in a closed system [3, 4]. The flow of people, goods, technology, and information between cities within and outside urban agglomerations forms a dynamic and cooperative urban system, so urban agglomerations are no longer isolated systems [5]; however, the traditional theories have relatively static and isolated defects, and exploring the spatial structure of urban agglomeration no longer meets the needs of current development. Therefore, the perspective of “flow space,” based on dynamic correlation, has gradually become a hotspot in research on the spatial structure of urban agglomeration. Castells first proposed that a “space of flows” can be used as a new perspective of the urban and regional structure and pointed out that the dynamic flow of elements can replace the static regional special structure [6]. In the context of space of flows, research on the network structure, function, and relationships between cities and regions at various scales (especially at the global scale) has attracted more attention from scholars.

To date, research on the spatial structure of urban agglomerations can basically be divided into two categories. On the one hand, only traditional static data are used; on the other hand, data of space of flows are used to focus purely on
the flow pattern of elements, especially traffic flows. However, the urban spatial structure includes not only the flows of various elements but also the development level of each city in the region. To date, few studies have combined data of traditional static urban development level with data of dynamic element flows. Studying the spatial structure of urban agglomeration through the combination of traditional static data and population flow data can lead to results that are more accurate and closer to reality, which is of academic significance.

The Yellow River is the fifth largest river in the world, and as such, the Yellow River basin has a very important position in China’s economic and social development and ecological security. In 2019, “ecological conservation and high-quality development of the Yellow River basin” was proposed as a major national strategy in China (YRCC, 2013; MOEE, 2020 [7, 8]). On January 3, 2020, the Chinese government officially proposed the concept of the urban agglomeration of Yellow River Ji-shaped bend (UAYB) and emphasized the promotion of the coordinated development of this urban agglomeration. “Ji” is a Chinese character, which is the pictographic character of the shape of the middle part of the Yellow River. Therefore, UAYB is an urban agglomeration in the middle reaches of the Yellow River, where it is Ji-shaped.

The UAYB straddles the central and western parts of China, and the new Eurasian Continental Bridge passes through the border. At the same time, it is also a rare resource-rich area in China and, even, in the world. Energy resources such as coal, natural gas, and rare Earth metals are extremely rich in this region, making it unique in China’s development pattern. Therefore, with the in-depth economic development of the UAYB, its internal economic ties are also expected to become closer. As such, carrying out research on the socioeconomic connection of the UAYB has important reference value for exploring how to expand the radiation power of core cities in this urban agglomeration, accelerate the formation of a driving axis for regional development, and construct a coordinated development pattern.

In this paper, we take the UAYB as the research area, carry out regional multilevel spatial structure research through a new computational algorithm, and identify the hierarchical spatial structure of the UAYB. Our key contributions are: (i) we fill the gap in the literature related to comprehending the hierarchical spatial structure of urban agglomeration from the combination of traditional static data and population flow data and (ii) we provide a reference for the coordinated development of the UAYB. The rest of the paper is structured as follows: Section 2 summarizes the literature concerning the space of flows. Section 3 presents the study area, the data, and the methods used. In Section 4, we discuss the hierarchical spatial structure of the UAYB. Section 5 concludes this study and provides some further research possibilities.

2. Literature Review

In 1986, Friedmann proposed the importance of urban hierarchical network structure research from the perspective of urban agglomerations in the theory of world cities. He believed that cities are arranged “into a hierarchy of spatial articulations, roughly in accord with the economic power they command” [9]. Marshall pointed out, in 1989, that the spatial agglomeration and close contact of cities are necessary factors for the formation of urban agglomerations [10]. In China, Gu initially divided economic zones based on an analysis of the Chinese urban system [2]. Since then, great deal of research methods for the spatial structure of urban agglomerations have emerged, mainly including system dynamics (SD), cellular automata (CA), pressure state response model (PSR), expansion index model (AGI), and other methods. These try to sum up the characteristics, connotations, and evolution of the spatial structure of urban agglomerations, by calculating the data for each city [11, 12].

With the development of globalization and informatization, scholars have paid more attention to the impact of the space of flows on urban agglomerations. Castells has been committed to the research of information networks and modern cities since the 1980s. He first proposed that space of flows can be used as a new perspective of the urban and regional structure and pointed out that the dynamic flow of elements will replace the traditional static regional special structure [6]. In the context of space of flows, research on the network structure, function, and relationships between cities and regions at various scales (especially at the global scale) has become a hot spot. In terms of research on the measurement methods of various flows between cities, POLYNET (European Multicenter Megacity Regional Sustainable Development Management Project) has demonstrated the superiority of the theory and method of space of flows by studying eight megacities in Europe [13]. Mitchelson and Wheeler used the US Postal Service as the basic data to assess information flow, functional connection, and hinterland range between cities, as identified from the perspective of space of flows [14]. However, the abovementioned research mostly relies on the background of the individual cities in the United States, which is unique. For this, Matsumoto used aviation flow data to reveal the characteristics of urban cyberspace, focusing on the spatial structure of international airport urban agglomerations [15].

In recent years, the research of space of flows based on big data has shown an increasing trend. Early studies mostly used the characteristics of intercity traffic flow data to identify the urban hierarchical system and network spatial structure, such as bus traffic flows [16, 17], highway traffic flows [18], flight flows [19], and freight volume flows [15]. For example, Ma et al. used passenger traffic flow data to study the multicenter structure of the Shandong coastal urban belt in China and found that it has obvious characteristics of scale benefits and internalization in the spatial structure [2, 20]. Cai et al. also used traffic flow data to study the spatial structure and multicenter characteristics of urban agglomerations in the Pearl River Delta in China and found that this urban agglomeration shows a balanced development trend [21]. However, with the development of information technology and the rise of urban network research, Internet resources (e.g., represented by the Baidu Index and Tencent big data) have gradually become new directions for urban globalization and integration research from the
perspective of space of flows. For example, Qiu et al. used information flow and traffic flow data to identify and analyze the network structure characteristics of the Guangdong–Hong Kong–Macau Greater Bay Area from the two dimensions of internal and external connections, through measurement correction, spatial measurement, and social network analysis [22]. Zhou and Wang revised the relevant parameters of the gravity model, in order to measure the flows of Chinese interprovincial tourists [23].

Current research on China’s regional spatial evolution is mostly concentrated in economically developed regions, such as the Yangtze River Delta, the Pearl River Delta, and the Beijing–Tianjin–Hebei region [24–28]. There has been very little research on the UAYB. In the context of the coordinated development of the UAYB, it is urgent to carry out relevant research to explore the scientific path of coordinated development.

3. Study Area and Research Methods

3.1. Study Area. The UAYB refers to the area located at the bend of the Yellow River, of nearly 557,000 square kilometers. A 3,000 kilometer section of the Yellow River flows through this area, west from the Baiyin city of Gansu province, through Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region, Shaanxi province, to Lanzhou city of Shanxi province. It includes the three capital cities of Taiyuan, Hohhot, and Yinchuan, as well as Wuzhong, Zhongwei, Wuhai, Bayannaoer, Baotou, Ordos, Shaanxi Yulin, Shanxi Shouzhou, Xinzhou, Lvliang, and so on, for a total of 21 cities (Figure 1).

3.2. Data Source. Static population data, such as official statistical yearbooks and traditional decennial census data referenced in the past, cannot reflect the complex interactions between cities in the context of rapid urbanization in China. Baidu Maps is one of the largest map and navigation service providers in China. The Baidu migration data provided by Baidu Maps is calculated by comparing the changes in user position and the number of intelligent terminal users whose positions have changed through all kinds of vehicles, such as railways, highways, and aviation. Therefore, Baidu migration data are able to aggregate anonymized location information and provide data on population outflow and inflow for different time periods and in different regions. The migration scale index, which indicates the daily population mobility intensity between different cities, has a uniform standard and is comparable in size. We used the “Baidu Migration” platform to obtain population migration data on Baidu Maps from January 1 to March 31, 2020 (http://qianxi.baidu.com/). With outflow cities as the ordinate and inflow cities as the abscissa, a 21 × 21 directed multivalued network matrix was obtained. In addition, from the China Statistical Yearbook 2020 [29], China City Statistical Yearbook [30], and so on, basic data such as per capita GDP and the proportion of tertiary industries in 2019 were obtained.

3.3. Research Methods

3.3.1. Social Network Analysis Methods. Social network theory holds that society is a huge network composed of various relationships, where each actor is a node in the network. This work applied a node to represent each city in the network construction, with directed edges depicting population flows and edge weights measuring population flow. We analyzed the network characteristics of the UAYB by using social network analysis, from the two aspects of network density and centrality [31, 32].

- **Network density**

  - Network density refers to the degree of connection among cities in a social network. The calculation formula is as follows:

  \[
  D = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} d(n_i, n_j)}{N(N-1)},
  \]

  where \( D \) is the network density, \( N \) is the number of nodes, and \( d \) is the actual degree of connection between the two nodes.

- **Degree centrality**

  - Degree centrality indicates the number of other nodes directly connected to a node, where a node with a high degree of centrality maintains numerous contacts with other network nodes, which characterizes the importance of the node in the network [33, 34]. There are two types of measurements: in-degree centrality and out-degree centrality. In-degree centrality concerns the number of nodes connected internally to a primary node, whereas out-degree centrality refers to the number of nodes linked externally to this node. The expressions are as follows:

  \[
  \text{Ind}_{i} = \sum_{j=1}^{n} a_{ij},
  \]

  \[
  \text{Out}_{i} = \sum_{j=1}^{n} a_{ji},
  \]

  where \( \text{Ind}_{i} \) represents the in-degree centrality and \( \text{Out}_{i} \) represents the out-degree centrality. If nodes \( i \) and \( j \) are connected, \( a_{ij} \) is assigned a value of 1; otherwise, \( a_{ij} \) takes on a value of 0.

3.3.2. Evaluation Method of City Comprehensive Power. The comprehensive power of a city is an important basis to evaluate its rank and core status. Referring to previous studies [2, 22], we selected nine first-level indicators and 12 second-level indicators, considering the three dimensions of attractiveness, economic level, and social, technological, and cultural development level, to construct a comprehensive power evaluation index system for cities (Table 1). In this paper, the three dimensions of attractiveness, economic
level, and social, technological, and cultural development were treated as equally important at first; then the entropy method was used to assign weights objectively to the indicators of each dimension. Finally, the comprehensive power score of each city was obtained, according to the weights of the indicators. The specific formula is as follows:

$X = \left( X_{ij} \right)_{m \times n}, \quad 1 \leq i \leq 21, \quad 1 \leq j \leq 14. \quad (4)$

The indicators of cities are made comparable through standardization treatment. The cities and 14 secondary indices are arranged, in order to form a matrix as follows:

$X = \left( X_{ij} \right)_{m \times n}, \quad 1 \leq i \leq 21, \quad 1 \leq j \leq 14. \quad (4)$
4.1. Comprehensive Power of Cities in the UAYB. According to formulas (2)–(7), the comprehensive power of the cities in UAYB was evaluated. The results are shown in Table 2 and Figure 3.

3.3.3. Hierarchical Spatial Structure Computational Algorithm. According to central place theory, regional spatial interactions have a hierarchical structure. Therefore, we believed that there is a city with the highest scale in the region, leading the regional development (i.e., the core city), and the surrounding cities have close social and economic ties with the core city. Each city has its own radiation area, thus forming a hierarchical regional spatial structure. This paper focuses on mining this structure, based on the above data. Therefore, a regional spatial structure analysis algorithm is constructed in this paper, and the regional spatial structure was determined by computationally implementing the algorithm. This algorithm identifies the radiation area of each city, based on its comprehensive power and the strength of intercity connections (i.e., population flows), and determines the hierarchical spatial structure of the region (Figure 2).

Network relationships are formed through interactions between cities located in the same region. We determined the hierarchical spatial structure by evaluating the urban comprehensive power and the size of population flows among cities. If the city most closely contacting with city B is city A and the comprehensive power of city A is stronger than that of city B, then it is said that city B is in the radiation area. Therefore, the radiation area of a stronger city will be composed of several weaker cities. Thus, a hierarchical spatial structure analysis algorithm was constructed. The specific steps are: select any city A, compare and screen the city B with the closest connection and higher comprehensive power one by one, and designate city B as the upper-level central city of city A (if city A has the highest comprehensive power, it is said that city A has no superior central city). Then, select the next city and repeat the above process, until all cities are compared.

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4. Results

4.1. Comprehensive Power of Cities in the UAYB. According to formulas (2)–(7), the comprehensive power of the cities in UAYB was evaluated. The results are shown in Table 2 and Figure 3.

Ordost had the highest level of attractiveness in the UAYB, as well as the highest degree of association with the cities in the urban agglomeration. At the same time, Yinchuan and Yulin also had relatively high attractiveness, becoming the two subcenters with the second-highest attractiveness in the region. It is also worth mentioning that Alxa League also has a higher attractiveness. Unlike the aforementioned cities, the level of urban development in Alxa is not in line with the intensity of the city’s attractiveness. This may be due to the better development of local tourism, and the study period happened to be the reason for the local tourist peak season.

Taiyuan is the capital of Shanxi Province and is the only type I city (The State Council’s “Notice on Adjusting the Criteria for the Classification of Urban Scales.” Type I city: the population size of built-up areas is above 3 million and below 5 million and type II city: the population size of built-up areas is above 1 million and below 3 million) in the UAYB. It also has the highest economic score. In addition, Yinchuan, Baotou, Ordos, and Hohhot also have the highest economic scores, where their economic development momentum is very strong. The two provincial capital cities, Hohhot and Taiyuan, achieved high scores in social science and technological culture. This was due to the relatively good foundations of the provincial capitals, in terms of society, culture, and public services.

In general, it can be seen that the comprehensive power level of cities in the UAYB presented a significant “center-periphery” spatial pattern, with Ordos, Yulin, Hohhot, Yinchuan, and so on, as the center, while the comprehensive power scores of the cities gradually decrease to the west and north. The comprehensive power scores of these center cities were all significantly higher than those of other cities, such that they were all absolute power cities in the region. The cities in the second echelon of comprehensive power included Baotou, Alxa League, Datong, and Yan’an, which were close to the first echelon of cities spatially and were obviously affected by their radiation and driving effect. These cities have gradually risen in recent years, especially Baotou and Datong, which have experienced rapid industrial development. Other cities, such as Baiyin in Ningxia province, Shouzhou in Shanxi province, and Ulanqab and other cities in Inner Mongolia, are located in the west and north of the UAYB, being geographically far away from the first echelon of cities. In addition to inconvenient transportation, they lack the necessary development conditions. In the short term, compared with the above cities, their comprehensive power is still weak, and the gap remains large.

4.2. Regional Spatial Structure of the UAYB

4.2.1. The Network Structure Characteristics of Population Flows. First, the overall network density describes the closeness of connections between nodes in a network. The greater the value, the more connection paths and interactions between nodes. When this value exceeds its threshold, the entire network will assume a completely continuous region, forming a huge spatial group. The thresholds of
different network structures are different. The network structure of the UAYB can be abstracted into a triangular lattice; as such, the overall network density threshold is 0.5. According to formula (1), the overall network density of the UAVB was 0.409, which is close to, but has not yet reached, this threshold. This means that the intercity connection strength in the UAYB is moderate, and the channels for information circulation and population flow are relatively few. The reciprocity of information, capital, and technology needs to be further improved. Moreover, due to the relatively short development time of the transportation network that runs through the entire region in the UAYB, the integrated network of connections in the UAYB has not yet been formed.

Secondly, from the perspective of population flows between cities (Figures 4 and 5), we found that: (1) the population flows with the highest intensity level mostly occurred between cities in the same province. The total population flow (inflow and outflow) indices between Hohhot and Wulanchabu, Datong and Shuozhou, Taiyuan and Lvliang, Yinchuan and Wuzhong, and Yinchuan and Shizuishan all exceeded 3,500. These cities are close to each other spatially, have close economic ties, and have convenient transportation. (2) The interprovincial population flows are mainly between the cities with the strongest regional comprehensive power. Taiyuan, the only type I city in the region, has a high level of economic development and strong population attractiveness. Its total population flow (including inflow and outflow) index reached 23,754.48. Baotou, Hohhot, and Yinchuan are the three type II cities in the UAYB. Baotou is an important basic industrial base in China, with aluminum, copper, and rare Earth metal industries. As the capital of the Inner Mongolia Autonomous Region, Hohhot has political and economic advantages, in terms of urban development. Yinchuan takes new materials and high-end equipment manufacturing as its leading industries and has superior economic conditions. These cities occupy important economic and social positions in the UAYB and have become the main destinations of population flow. Significantly, the population flow in Taiyuan (the only

Figure 2: The computational algorithm for identifying the hierarchical spatial structure.
type I city in the region and with the second strongest regional comprehensive power) is lower than that in Yinchuan, Ordos, Hohhot, and Yulin. This is mainly due to the fact that Taiyuan is located on the southeastern edge of the UAYB. Its social and economic ties with the cities in the UAYB are relatively weak, and most of them have relatively strong connections with other regions outside the UAYB. Therefore, Taiyuan’s overall leading role in the UAYB is also relatively poor.

Finally, from the perspective of population inflows and outflows (Table 3), the top five cities, in terms of total inflow index, were Yinchuan, Ordos, Taiyuan, Hohhot, and Yulin, which also had relatively large net population inflow indices, as these cities have a higher level of economic and social development and a larger population attractiveness. Among them, Ordos also had a large total inflow index and positive net population inflow index, which means that Ordos had a high degree of social and economic activity. Except for the special case of Ordos, Wuhai, Shizuishan, Wuzhong, and Bayannaoer were the other major population outflow cities, with negative net flow population indices, and therefore, the associated population loss is serious. These cities are geographically far away from the regional center of the UAYB and are located in remote areas. They are less affected by the central city’s economic radiation, and the economic development is weak in these cities.

4.2.2. Hierarchical Spatial Structure of the UAYB. Through the regional spatial structure computational algorithm, the multitreer structure of the hierarchical structure of the UAYB was obtained (Figure 6). To further visualize the structure, the color of the patches represents the comprehensive power of cities (Figure 7). The color is divided into five levels, from light to dark. The heavier colors indicate stronger comprehensive power. The arrows point from child nodes to their father nodes. Each node represents a city, and all child nodes are attracted by their father node. The radiation area of a city depends on its own comprehensive power and intercity interaction strength (population flow).

As shown in Figures 6 and 7, Ordos became the root node by virtue of its strong comprehensive power, playing the leading role in the UAYB. The spatial interaction strength takes Ordos as the center in space and spreads radially outward in the UAYB. Hohhot, Yinchuan, Yulin, and Taiyuan were directly attracted by Ordos as the second-tier city. These four cities formed their own relatively small radiation areas. Among them, Hohhot, Yinchuan, and Taiyuan are the capitals of the Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, and Shanxi Province, respectively, which were able to gather the resources of the entire province, maintaining a strong momentum of development. They can radiate and drive the neighboring cities in terms of the economic scale, industrial structure, infrastructure, culture, and other aspects. Yulin is rich in oil, coal, natural gas, and other resources, and it is also a well-known tourist city. Therefore, its economic development is better, and its status in the UAYB is also higher.

The main radiation areas of Hohhot and Taiyuan are in their own provinces and do not extend to other provinces. This may be due to the fact that the Yellow River, as a natural provincial boundary, has a hindering effect on its radiation capacity, in terms of the natural topography, as well as administrative, historical, transportation, and other factors. Yinchuan has a relatively large radiation range. In addition
to prefecture-level cities in Ningxia Autonomous Region, it also attracts Alxa League and Wuhai City in western Inner Mongolia. As a prefecture-level city in Shaanxi Province, Yulin belongs to the UAYB, and its economic development level is higher than that of its surrounding cities.

It is remarkable that the siphoning effect of higher-tier cities on the surrounding lower-tier cities was also very obvious. The development of higher-tier cities depends on the constant delivery of production factors from the surrounding lower-tier cities, which also limits the development of the lower-tier cities. It causes lower-tier cities to face the problems of talent loss and weak economic development. Such cities include Baiyin, Qingyang, Lvliang, Linfen, and Shuozhou, which are subject to far less radiation drive than the siphoning effect of Taiyuan city, leading such lower-tier cities to face development-related difficulties.

4.3. The Connection Pattern between the UAYB and the External Regions in China. As a national-level strategic urban agglomeration, the high-quality development not only...
requires the formation of a harmonious regional spatial structure internally but also close social and economic exchanges with external regions.

The top regions of the population outflow index from the UAYB are Ningxia Autonomous Region, Inner Mongolia Autonomous Region, Shaanxi, Shanxi, Gansu, Hebei, and Beijing (Figure 8(a)). The Beijing–Tianjin–Hebei metropolitan area is the largest urban agglomeration in northern China, with strong economic power and an obvious siphoning effect. The UAYB has a strong socioeconomic connection with this urban agglomeration, and a large number of people flow out to this area. During the study period, the population outflow indices to Beijing and Hebei were 4356.05 and 6309.41, respectively. At the same time, other areas in Ningxia, Inner Mongolia, Shaanxi, and Gansu that are not in the UAYB have close ties with the UAYB, as
these areas have similar natural conditions, cultural customs, and convenient transportation with the UAYB. In addition, the developed provinces along the coast and the Yangtze River also have close ties with the UAYB. Since the reform and opening up, these areas have experienced a high level of economic development. They have become China’s main
population-carrying areas, attracting a large number of immigrants, including those from the UAYB. From the perspective of the population inflow index from external regions to the UAYB (Figure 8(b)), the areas with a higher population inflow index to the UAYB are basically the neighboring provinces, and most of these provinces have some regions (cities) included in the UAYB. Because these areas have similar natural conditions, cultural customs, and convenient transportation with the UAYB, the population inflow indices from these areas account for more than 85% of the total population inflows of the UAYB from all provinces across the country. It can be seen that the attractiveness of the UAYB to the external provinces and cities is far from sufficient, and therefore, the overall attractiveness of the entire UAYB needs to be improved.

Considering the comparison of population outflow and inflow indices, the outflow and inflow situation between most areas in China and the UAYB was basically the same. However, Shanxi, Inner Mongolia, and Hebei had much larger inflow indices into the UAYB than outflow indices from the UAYB. As the core cities of the UAYB are more attractive to other areas in the three neighboring provinces, they attract more people to move in. The indices of population outflow to Beijing, Guangdong, and Shanghai were much higher than the relative inflow indices, indicating that China’s developed provinces and cities have a relatively high level of radiation and attractiveness to the whole country, where the UAYB is no exception.

5. Conclusions and Discussion

In this paper, we evaluated the comprehensive power of cities in the UAYB and analyzed the population flows in the UAYB. Based on these analyses, we explored the hierarchical spatial structure of the UAYB. Our contribution to the literature is twofold. First, we developed a new computational algorithm to assess the hierarchical spatial structure of urban agglomeration from the combination of traditional static data and population flow data, which makes the result closer to reality. This is not very common in urban agglomerations studies, most of which focus only on static data of each city or spatial flow data between cities, thereby making it one of the strong points of the paper in our view. Second, we provide scientific reference for the development of the UAYB, which is located in the fifth largest river basin in the world, and the national-level strategic urban agglomeration. The main conclusions of this paper are as follows. (1) The cities with the strongest regional comprehensive power were Ordos, Taiyuan, Yinchuan, Hohhot, and Yulin. They are spatially concentrated in the central area of the UAYB, and as such, the UAYB presented a significant “center-periphery” spatial pattern. (2) An integrated network of connections in the UAYB has not yet been formed. The highest population flows mostly occur between cities in the same province. The interprovincial population flows are mainly between the cities with the strongest regional comprehensive power. (3) The hierarchical spatial structure of the UAYB forms a multitree structure, with Ordos City as the core, which forms the largest urban radiation area. Hohhot, Yinchuan, Yulin, and Taiyuan also have secondary radiation areas in this structure. (4) The UAYB is the most attractive to the populations of the three provinces Shanxi, Inner Mongolia, and Hebei, which are adjacent to the UAYB. Economically developed areas in China, such as Beijing, Guangdong, and Shanghai, are the most attractive areas to the UAYB, and the population outflow indices to these areas were the highest.

Some policy implications based on our findings regarding population flows of the UAYB can be noted. First, we found that cities with strong comprehensive power have a strong
control effect on the UAYB, while cities with backward development levels, such as Baiyin and Shuozhou, are in a subordinate position and have not yet entered a good coordinated development stage. However, weak cities in the periphery are key to the coordinated development of the region. Therefore, the government should promote the socioeconomic development of these relatively backward cities and improve their comprehensive power through the construction of infrastructure, technology, and culture. At the same time, the government also should strengthen social and economic ties, promote population mobility, and achieve the goal of regional coordinated development. Second, according to the results of this paper, the radiation areas of the second-tier cities are mainly inside their respective provinces, and the largest population flows mostly occur between cities in the same province. Under China’s current administrative management system, the interprovincial administrative boundary has a certain obstructive effect on the economic integration of the administrative area of the UAYB, which is manifested as a significant shielding effect. The government should take the coordinated development of the UAYB as an opportunity to break through the barriers of the boundary shielding effect, strengthen the integrated construction of market systems, public services, industrial development, infrastructure, management systems, and so on, in order to achieve the actual needs of complementarity and speed up the urban network process from “point” to “axis” to “surface” of the UAYB. Finally, from a national perspective, the attractiveness of the UAYB is very weak (only slightly attractive to individual surrounding provinces), and a large number of people have migrated to the developed areas in China. Therefore, in the long run, the government needs to formulate sound regional development strategies to improve the overall power of the UAYB, in order to promote long-term development.

This paper also has some limitations and deficiencies: it did not involve a comparative study over multiple periods. Subsequent studies can conduct longitudinal temporal comparisons based on spatial analyses, thus potentially grasping the future development trend of the UAYB and making reasonable predictions. In addition, the data collection period of this paper had some special characteristics. The population flow data were collected during the peak season of Spring Festival tourism and the peak period of the COVID-19 outbreak in China, which led to some fluctuations and anomalies. These effects require more in-depth analysis in the follow-up research.

Data Availability

This paper uses the “Baidu Migration” platform to obtain population migration data on Baidu Maps from January 1 to March 31, 2020 (http://qianxi.baidu.com/). The other data used in this study come from publicly published statistical yearbooks. A request for access to these data can be made to the corresponding authors.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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References

[1] C. Fang, "Progress and the future direction of research into urban agglomeration in China," Acta Geographica Sinica, vol. 69, no. 8, pp. 1130–1144, 2014, in Chinese.
[2] C. Gu, "A preliminary study on the division of urban economic regions in China," Acta Geographica Sinica, vol. 46, no. 2, pp. 129–141, 1991, in Chinese.
[3] S. Wang, C. Lian, and Z. Zhao, "From central place to city network: a theoretical change in China’s urban system study," Geographical Research, vol. 38, no. 1, pp. 64–74, 2019, in Chinese.
[4] P. J. Taylor and B. Derudder, World-City Network: A Global Urban Analysis, Routledge, London, UK, 2016.
[5] Y. Wang, X. Niu, and X. Song, "Research progress of regional spatial structure under the perspective of space of flow," Urban Planning International, vol. 32, no. 6, pp. 27–33, 2017, in Chinese.
[6] M. Castells, The Rise of the Network Society, Blackwell Publishers, London, UK, 1996.
[7] Yellow River Conservancy Commission, Review of Yellow River Basin, Henan People’s Press, Zhengzhou, China, 1998.
[8] Ministry of Ecology and Environment of the People’s Republic of China, "The government work report," 2020, http://www.mee.gov.cn.
[9] J. Friedman, "The world city hypothesis," Development and Change, vol. 17, no. 1, pp. 69–83, 1986.
[10] J. U. Marshall, The Structure of Urban Systems, University of Toronto Press, Toronto, Canada, 1989.
[11] N. Gaitani, M. Santamouris, C. Cartalis et al., “Microclimatic analysis as a prerequisite for sustainable urbanisation: application for an urban regeneration project for a medium size city in the greater urban agglomeration of Athens, Greece,” Sustainable Cities and Society, vol. 13, pp. 230–236, 2014.
[12] S. Y. Lee, R. J. K. Dunn, R. A. Young et al., “Impact of urbanization on coastal wetland structure and function,” Austral Ecology, vol. 31, no. 2, pp. 149–163, 2006.
[13] P. Hall, K. Pain, and Z. Luo, "The polycentric metropolis, learning from megacity regions in Europe," Shang-hai Urban Planning Review, vol. 1, p. 80, 2011.
[14] R. L. Mitchelson and J. O. Wheeler, "The flow of information in a global economy: the role of the American urban system in 1990,” Annals of The Association of American Geographers, vol. 84, no. 1, pp. 87–107, 1994.
[15] H. Matsumoto, “International urban systems and air passenger and cargo flows: some calculations,” Journal of Air Transport Management, vol. 10, no. 4, pp. 239–247, 2004.
[16] L. Dai, B. Derudder, and X. Liu, "Transport network backbone extraction: a comparison of techniques," Journal of Transport Geography, vol. 69, pp. 271–281, 2018.
[17] Y. Long and J.-C. Thill, "Combining smart card data and household travel survey to analyze jobs-housing relationships in Beijing," Computers, Environment and Urban Systems, vol. 53, pp. 19–35, 2015.
[18] D. César and L. Beauguitte, "Spatial science and network science: review and outcomes of a complex relationship,"
[19] B. Derudder, F. Witlox, J. Faulconbridge, and J. Beaverstock, “Airline data for global city network research: reviewing and refining existing approaches,” *Geojournal*, vol. 71, no. 1, pp. 5–18, 2008.

[20] X. Ma and P. Dou, “Characteristics of polycentricity spatial structure of shandong coastal city-region based on passenger traffic flow,” *Modern Urban Research*, vol. 10, pp. 101–109, 2017.

[21] L. Cai, X. Ma, W. Chen et al., “Characteristics of functional polycentricity of PRD urban region based on passenger traffic flow,” *Economic Geography*, vol. 33, no. 11, pp. 52–57, 2013, in Chinese.

[22] J. Qiu, Y. Liu, H. Chen et al., “Urban network structure of Guangdong-Hong Kong-Macao greater bay area with the view of space of flows: a comparison between information flow and transportation flow,” *Economic Geography*, vol. 39, no. 6, pp. 7–15, 2019, in Chinese.

[23] H. Zhou and F. Wang, “Research on structure characteristics of the inter-provincial tourist flow spatial network in China based on the modified gravity model,” *Geographical Research*, vol. 39, no. 3, pp. 669–681, 2020, in Chinese.

[24] Z. Wang, S. Yang, F. Gong et al., “Identification of urban agglomerations deformation structure based on urban-flow space: a case study of the Yangtze river delta urban agglomeration,” * Scientia Geographica Sinica*, vol. 37, no. 9, pp. 1337–1344, 2017.

[25] F. Niu, X. Yang, and F. Wang, “Urban agglomeration formation and its spatiotemporal expansion process in China: from the perspective of industrial evolution,” *Chinese Geographical Science*, vol. 30, no. 3, pp. 532–543, 2020.

[26] S. Wang, S. Gao, and Y. Wang, “Spatial structure of the urban agglomeration based on space of flows: the study of the Pearl river delta,” *Geographical Research*, vol. 38, no. 8, pp. 1849–1861, 2019, in Chinese.

[27] F. Niu and W. Liu, “Identifying the hierarchical regional spatial structure using internet big data,” *Journal of Geo-Information Science*, vol. 18, no. 6, pp. 719–726, 2016, in Chinese.

[28] W. Zhang and B. Derudder, “How sensitive are measures of polycentricity to the choice of ‘centres’? A methodological and empirical exploration,” *Urban Studies*, vol. 56, no. 10, 2019.

[29] National Bureau of Statistics of the People’s Republic of China, *China Statistical Yearbook*, China Statistics Press, Beijing, China, 2020.

[30] Editorial Board and Editorial Department of China City Statistical Yearbook, *China City Statistical Yearbook*, China Statistics Press, Beijing, China, 2020.

[31] E. Strano, S. Shai, S. Dobson, and M. Barthelemy, “Multiplex networks in metropolitan areas: generic features and local effects,” *Journal of the Royal Society, Interface*, vol. 12, no. 111, Article ID 20150651, 2015.

[32] F. Wei, A. Pengli, and L. Siyao, “Evolution characteristics and regional roles’ influencing factors of interprovincial population mobility network in China,” *Complexity*, vol. 2021, Article ID 6679580, 11 pages, 2021.

[33] S. Xu and F. Zhen, “Measurement and comparison research of provincial urban network centrality: taking comparative analysis of Jiangsu and Guangdong as example,” *Human Geography*, vol. 1, pp. 135–144, 2021, in Chinese.

[34] L. C. Freeman, “Centrality in social networks: I. Conceptual clarification,” *Social Networks*, vol. 1, no. 3, pp. 215–239, 1979.