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EDITED BY
Qingsong He,
Huazhong University of Science and Technology, China

REVIEWED BY
Ming Chen,
China Academy of Urban Planning and Design, China
Chunzhi Yang,
Chinese Society for Urban Studies, China

*CORRESPONDENCE
Huimin Wang,
huiminwang@biem.edu.cn

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A study on land compactness of urban agglomeration-example from Beijing-Tianjin-Hebei

Huiying Wang[1], Huimin Wang[2]* and Xuehan Xiong[3]

[1]School of Government, University of International Business and Economics, Beijing, China, [2]Department of Aviation Economics and Management, Beijing Institute of Economics and Management, Beijing, China, [3]Development Holdings Co., Ltd., Hainan, China

Compactness, intensity, efficiency and greenness are becoming the goals of regional governance in China. This study, based on the compact development theory, takes the urban agglomeration of Jingjinji as the research object, uses the composite index to construct a compactness index system based on production-living-ecological space and adopts entropy method to measure and analyze the degree of compactness. The results show that there is an obvious internal differentiation in Jingjinji, and the overall situation is not compact. Composed of production, living and ecological spaces, the compactness of the territorial space differs significantly. Production space is of the highest degree compactness, followed by living space and the lowest is ecological space. By comparing each index, compactness degrees of economic factors and municipal production facilities are better than those of the production land and transportation. Compactness degrees of Social factors of living space are more developed than those of residential land and public services. The overall compactness degree of the ecological space is the lowest, but the degrees of compactness are relatively balanced and there are small differences. The compactness degree of the green land is slightly lower than that of pollution treatment.

KEYWORDS

land use, compact development, production-living-ecological space, urban agglomeration, territorial space

1 Introduction

Starting from "14th Five-Year Plan", China focused on the overall and systematic governance of the entire territorial space, classified into production, living and ecological spaces (PLES). Meanwhile, the urban agglomeration has become the main geographical unit and spatial development pattern in China due to significant aggregation of population and economic functions. However, the main problem has been that regional development is unbalanced, uncoordinated and incompact in some urban agglomerations, especially in the Beijing-Tianjin-Hebei region (also known as Jingjinji).

From the perspective of PLES in the urban agglomeration of Jingjinji, the development of production space is seriously differentiated, and high efficiency has not yet been achieved in every city. The provision of living space is not diverse and

abundant, so high-quality development has not yet been achieved. In addition, the ecological space is not adequately protected by the Regulations for the Implementation of the Land Administration Law, the policy that should scientifically control territorial planning.

Above all, a series of economic, social and ecological problems still exist in the Jingjinji urban agglomeration. Therefore, how to formulate a governance plan in accordance with local conditions and promote heterogeneous regions to exploit comparative advantages and achieve highly efficient and qualified development, has become an inherent requirement for the Jingjinji urban agglomeration in order to further optimize territorial space.

2 Literature review

In the context of spatial governance and planning, academic research on land governance has also achieved new progress. Since the conservation and use of land resources is one of the important goals of spatial governance, the compact development theory related to urban development has been gradually adopted in spatial governance research. The compact development theory originates from the "compact city" proposed by European and American countries to achieve sustainable development.

Danziger and Satty 1973) were the first to present the compact city theory in the context of achieving sustainable development (Dantizing and Satty, 1973). They believed that a compact city was a complex, highly connected and dynamic system with 17 advantages. In 1990, Commission of the European Community (CEC) formally defined it as an urban spatial layout that differed from traditional urban characteristics, emphasizing high-density space, convenient transportation, multi-purpose land use, and focusing on social and cultural diversity (Burchell Robert and Sahan, 2003). Handy pointed out that an important aspect of compact development is the moderately mixed use of urban land (Handy, 1992). Rueda et al. (2000) believed that compact development was a new mode of urban construction and spatial development layout with efficient mixed land use (Rueda, 2000). Burton (2000) discussed the impact of compact cities on the livelihoods and welfare of low-income groups and believed that compact city planners should consider transportation capacity and layout, as well as encourage low-carbon public transportation. This could decrease public traffic congestion and make better use of public infrastructure, but reduced living space and affordable housing may be a negative impact on compact development (Burton, 2000). Newman and Kenworthy 1998) argued that compact cities with high population density and mixed land use functions improved the use of urban space and prosperity of central urban areas (Newman and Kenworthy, 1998).

With the rapid development of urbanization in China at the end of the 20th century, Chinese scholars began to focus on the theory of compact development. They have largely expanded and enriched the compact city theory at the provincial, prefectural, megacity or county levels, including the research related to definition, measurement, influencing factors and mechanisms, urban land use, urban spatial layout, urban ecological space management and control, etc. (Qiu, 2012). These scholars believed that compact development was not only a spatial layout but also a mode of development (Chen and Jia, 2006; Li and Zhou, 2014; Huang et al., 2015). Most scholars believe that compact development refers to a kind of urban development mode, which can improve the efficiency of urban operation and quality of life through rational land use, allocation of resources and personnel, as well as configuration of public facilities in a certain density in urban space (Jian and Xia, 2016).

In recent years, urban agglomerations have developed into the main form of regional development in China, and the concept of compactness has been introduced in the study of urban agglomerations. The study of urban compact development provides a theoretical basis for the study of urban agglomeration compactness. According to the purpose of a compact city, a compact urban agglomeration is resource-saving, high-density and efficient, but not necessarily environmentally friendly and ecological. It depends on the agglomeration of factors such as industry, transportation, economy, space and population. The index to measure the compactness of cities and urban agglomerations is called the degree of urban compactness or the degree of urban agglomeration compactness (Fang and Qi, 2007).

Scholars have conducted research on the compact development of urban agglomerations in the Yangtze River Delta, the middle reaches of the Yangtze River, the Shandong Peninsula, Guanzhong and Changsha-Zhuzhou-Xiangtan. Studies generally agree that compact development is a strategy that can optimize land use and curb urban sprawl in terms of land resources. It can also improve the economic, social, and ecological environment within urban agglomerations through reasonable planning and construction, thus contributing to sustainable development. In this regard, different scholars have studied the mechanism of compactness that affects the economy, social welfare and the environment (Huang et al., 2014; Wang et al., 2017; Zhang et al., 2018) (Huang et al., 2014; Wang et al., 2017; Zhang et al., 2018).

Regarding compact development of production space, existing studies show that compact development of urban agglomeration has a good economic effect as it increases urban operation efficiency and output, saves resources and decreases labor consumption (Yang et al., 2021). As for the living space, the greater the compactness, the more time and transportation costs can be saved. Accordingly, the efficiency of space operation can be improved and a reasonable regional pattern of labor division can be achieved (Hu, 2019). In the

context of a compact city, ecological space mainly refers to the gain or loss of the natural environment caused by production and life activities, rather than the ecological layout (Fang, 2013). All these studies provide a theoretical basis for optimizing the territorial space governance through compact development. Fang Chuanglin (2013) proposed the theory of territorial pattern optimization from the PLES perspective. This theory had a guiding role in the development and protection of territorial space (Mao et al., 2009). Regarding the measurement methods of compactness, Fang Chuanglin et al. (2013). used the spatial interaction index, population density, and urban density to construct the urban agglomeration abundance index. Mao Guangxiong et al. (2009) constructed a compactness model from the perspective of economics, urban land, transportation and population (Cheng et al., 2010). Qin Cheng et al. (2010) used the entropy method to construct a compactness model to research compactness degree of Guangxi Province (Haughton and Hunter, 1994).

Based on existing domestic and foreign studies related to compact cities, this paper considers that: 1) space governance of urban agglomeration should improve space utilization efficiency, meet the needs of urban residents, and improve the environmental quality. Reasonable land use, allocation of resources and personnel, and configuration of public facilities, can improve the efficiency of urban operations and quality of life in urban agglomerations, and thus achieve sustainable urban development (Russell et al., 1975; Lv and Meng, 2019); and 2) compact development of urban agglomeration is not one-dimensional or one-sided high-density or intensive development of land, population, and economy, but an efficient, high-quality and rational layout and arrangement under three-dimensional territorial space framework. This framework is composed of land (foundation of cities), organizational functions (structure of cities), factors (content of cities) and integrated development of the economy, society and environment in the territorial space of the urban agglomeration.

At present, China's social and economic development has entered a new normal. In order to meet optimize the layout of land and space, it is necessary to further optimize the urban spatial structure and organization. The theory of compact development meets the needs of space optimization for efficiency and quality and its research provides a theoretical basis. This study attempts to: 1) construct a PLES spatial framework from the perspectives of production, life, and ecology; 2) measure and analyze the degree of PLES compactness; and 3) provide appropriate governance countermeasures for land optimization in the Jingjinji urban agglomeration.

3 Study area

The area of the Jingjinji urban agglomeration, including Beijing, Tianjin and 11 prefecture-level cities in Hebei Province, is 218,000 km^2, or 2.3% of the country's land area (Lin and Xu, 2014). As the largest and most dynamic urban agglomeration and economic zone in northern China, the Jingjinji urban agglomeration is the third pole of China's future economic growth, after the Yangtze River Delta and the Guangdong-Hong Kong-Macao urban agglomeration. As a consequence of the unbalanced spatial development and the long-term poverty constraints in the past, it lags behind the other two core regions. Jingjinji's overall development level is still significantly lower than that in the other two regions, and there is room for improvement in its overall development.

All three major urban agglomerations rely on the development of central cities, but the Yangtze River Delta and the Guangdong-Hong Kong-Macao urban agglomerations are developing well, while the Jingjinji urban agglomeration is clearly lagging behind. In Jingjinji, internal connections between cities are not close enough; the central city cannot play a leading role effectively; the whole urban agglomeration is not compact; the industrial strength of most cities is weak, and the geographical reach is limited. At the same time, under the strategic and coordinated development of Beijing, Tianjin and Hebei and the construction of the Xiongan New Area, the spatial structure and organization of these regions need to be further optimized, i.e., a comprehensive renovation of territorial space is needed. Accordingly, the compact development theory satisfies the needs of further optimization of land governance in the Jingjinji urban agglomeration. Therefore, based on the above theory, this study analyzes the spatial development of the Jingjinji urban agglomeration. However, since However, since the Xiongan New Area in the urban agglomeration is not developed and its statistical data has not been shown in the official yearbook, this study follows the traditional research scope and takes 13 cities in the Jingjinji urban agglomeration as the object of this research.

4 Methodology and index system

4.1 Establishment of an index system for measuring the degree of compactness

The degree of compactness of urban agglomeration in this paper refers to the measurement of production, living and ecological space compactness of urban agglomerations. It reflects the efficiency and quality of urban layout and arrangement in order to solve the compactness problem of the Jingjinji urban agglomeration and achieve coordinated spatial development. From the connotation and function of compact development, the studied indices should include land use, economic factors, infrastructure, public services, and ecological environment. Based on the economic, social and environmental effects of the compact development theory, and in combination

with the strategic objectives of the territorial spatial pattern of PLES, i.e., intensive and efficient production space, moderate and livable living space, and picturesque ecological space, proposed in "14th Five-Year Plan", this paper constructs a framework for measuring the degree of compactness of PLES from three aspects of production space, living space and ecological space (Chen et al., 2022).

Taking into account the indices of urban compactness constructed by earlier scholars, and by following scientific, practical and hierarchical principles, data availability and quantification, this study constructs a comprehensive index system for the measurement of urban compactness of the Jingjinji urban agglomeration within the PLES framework as the first-level index (Table 1). Combined with the PLES definition, indicators related to production space include production land, economic factors, transportation and municipal facilities; indicators related to living space include residential land, social life and public services; and indicators related to ecological space include indicators of green land and ecological environment (Wang and Guo, 2017). The indicators of production land, transportation, residential land, public service, green land and pollution treatment are from the official statistical yearbook. Economic factors and indicators of municipal facilities, as primary indicators of production space, are decomposed into secondary indicators of GDP per capita, proportion of output value and employees in secondary and tertiary industry, area of urban roads per capita, density of drainage pipelines, and efficiency of public transport system. Commercial vitality, density of realized foreign investments, density of investments in science and technology and other indicators are also added to the system of secondary indicators. The social life indicator of living space, with reference to the urban social life data in the China City Statistical Yearbook, is decomposed into the index of population employment density, average wage of employees, density of social retail sales of consumer goods, the index of revenue density of telecommunications and postal services, the density index of mobile phone ownership, and the density index of Internet broadband access.

4.2 Measurement method of degree of compactness

Given the overlap of information between multi-index variables and the subjectivity of determining the index weight, this study uses the entropy method to measure urban compactness, which mainly determines the weight coefficient by the degree of difference between index values[27]. Specifically, the variation degree of the index is positively correlated with the entropy. The greater the degree of variation, i.e., more information is covered, the greater the weight. On the contrary, the smaller the degree of variation of the index, i.e., less information is covered, the smaller the weight.

The measurement process is divided into five steps: constructing the original index data matrix, nondimensionalization of data, calculating the entropy of the evaluation index, defining the weight of the evaluation index, and calculating the sample evaluation.

The steps of the measurement are as follows:

1) Constructing the original index data matrix. Assuming there are m sample cities and n evaluation indices, which are used to form the original index data matrix. Xij represents the index j of the city i to be evaluated.

$$X = \{Xij\}_{m\times n} \ (0 \le i \le m,\ 0 \le j \le n)$$

2) Nondimensionalization of data. Formulas 1, 2 correspond to the Nondimensionalization of the positive index and the negative index, respectively, of which $maxXi$ and $minXi$ are the maximum and minimum values of the sample city i and indicators j. Yij represents the dimensionless value of each index in the two formulas. Since all indices used in this study are positive, we use Formula 1 to make the initial data dimensionless and construct the matrix.

$$Y = \{Yij\}_{m\times n} \ (0 \le i \le m,\ 0 \le j \le n)$$

$$Yij = (Xij - minXi)/(maxXi - minXi) \quad (1)$$

$$Yij = (maxXi - Xij)/(maxXi - minXi) \quad (2)$$

3) Calculating the entropy value of the evaluation index. The information entropy of each data group is obtained by Formulas 3, 4. Pij is the proportion of the index j in the index value of city i, and Ej is the entropy value of the indicator j. If $Pij = 0$,

$$define\ limPij{*}lnPij = 0.$$

$$Ej = -ln(n)^{-1}\sum Pij * lnPij \quad (3)$$

$$Pij = Yij/\sum Yij \quad (4)$$

4) Defining the weight of the evaluation index. Wj is the weight of the evaluation index j calculated according to Formula 5 as follows:

$$Wj = (1 - Ej)/\sum(1 - Ej) \quad (5)$$

5) Calculating the evaluation value of the sample. It is possible to obtain a comprehensive evaluation value Fi by multiplying Wj and Yij in Formula 6 as follows:

$$Fi = \sum_{j=1}^{n} Wj * Yij \quad (6)$$

TABLE 1 Index system of degree of compactness in the Jingjinji urban agglomeration.

	Level 1 indicator	Level 2 indicator	Meaning
Production space	Production land	Intensity of urban development and utilization	Proportion of urban construction land
		Output intensity per unit area	GDP of the municipal district/land area of the municipal district
	Economic factors	Business vitality	Total sales of wholesale and retail commodities in the municipal district/area of the municipal district
		Density of foreign capital use	The amount of foreign capital actually used in the current year/area of the municipal district
		Investment intensity in science and technology	Total investments in science and technology in the municipal district/area of the municipal district
		GDP per capita	GDP/total population of the municipal district
		Proportion of the output value of secondary and tertiary industries	Output value of secondary and tertiary industries in urban area/GDP of urban area
		Proportion of employees in secondary and tertiary industries	Number of employees in the secondary and tertiary industries in urban areas/number of employees in urban areas
	Transportation	Road network density in the built-up area	Road area/municipal area
		Density of highway freight volume	Total highway freight volume/urban road area
		Density of highway passenger volume	Total highway passenger traffic volume/urban road area
	Municipal facilities	Density of infrastructure investment	Investment in urban infrastructure construction/area of the municipal district
		Urban road area per capita	Urban road area/total population of the municipal district
		Drainage pipe density	Length of drainage pipe/area of the municipal district
		Efficiency of public transport system	Total number of bus passengers/actual number of buses at the end of the year
		Taxi density	Actual number of taxis in operation at the end of the year/land area of the municipal district
Living space	Residential land	Proportion of residential land	Residential land/municipal area
		Population density of residential land	Average annual population/residential land in municipal district
	Social life	Population employment density index	Employed population per unit/total area of the municipal district
		Average wage of staff and workers	Total salary of employees per unit/number of employees per unit
		Retail sales density of social consumer goods	Total retail sales of social consumer goods in the municipal district/area of the municipal district
		Postal revenue density	Total revenue of postal service/area of the municipal district
		Telecom revenue density	Total revenue of telecommunication business/area of the municipal district
		Mobile phone holding density	Number of mobile phone subscribers at the end of the year/area of the municipal district
		Internet broadband access density	Number of Internet broadband access users/area of the municipal district
	Public service	Density of educational services	Education expenditure in the municipal district/land area in the municipal district
		Density of medical services	Number of hospital beds in the municipal district/total population of the municipal district
		Density of cultural services	Collection of public books per 10,000 people
		Degree of perfection of social security	Participation rate of basic old-age insurance for urban workers
Ecological space	Green land	Green coverage rate of the built-up area	Green coverage area of built-up area/urban land area
		Proportion of park green space	Area covered by park green space/urban land area
	Pollution treatment	Comprehensive utilization rate of industrial solid wastes	Utilization of industrial solid waste/production of industrial solid waste
		Harmless treatment rate of domestic garbage	Harmless treatment capacity of domestic waste/clearance capacity of domestic waste
		Treatment rate of urban domestic sewage	Sewage treatment capacity/sewage discharge

5 Data source and preliminary calculation results

Based on relevant data from the China Urban Statistical Yearbook in the period 2015–2019 and the statistical yearbooks of provinces and cities, this study calculates the index weights and the degree of compactness in each year from 2014 to 2018 for 13 cities in the Jingjinji urban agglomeration. Comprehensive evaluation results are obtained and shown in Table 2.

To compare and analyze the degree of compactness of 13 cities in the Jingjinji urban agglomeration, this study calculates the degree of compactness of production space, living space and ecological space. The average level of compactness of the production space is 0.1463 and the standard deviation is 0.1010. In addition, the degrees of compactness of the five cities are higher than the average, of which Cangzhou (0.4035) has the highest degree of compactness, followed by Beijing (0.2370), Tianjin (0.1900), Langfang (0.2327) and Xingtai (0.1646). Hengshui (0.0466) has the lowest degree of compactness, far below the average.

Regarding the living space, the average level of compactness degree is 0.1100 and the standard deviation is 0.0711. In addition, Cangzhou (0.2961), Langfang (0.1846), Beijing (0.1640) and Xingtai (0.1431) have higher degrees of compactness compared to the average level. On the contrary, Zhangjiakou (0.0516) has the lowest degree of compactness.

From the perspective of ecological space, the average degree of compactness is 0.0283 and the standard deviation is 0.0067. The degrees of compactness of six cities are higher than the average level and they include Qinhuangdao (0.0377) with the highest degree, followed by Shijiazhuang (0.0365), Handan (0.0358), Beijing (0.0346), Xingtai (0.0318) and Cangzhou (0.0313). The lowest degree of compactness is noticed in Chengde (0.0200).

6 Comparative analysis of compactness in Beijing, Tianjin and Hebei

According to results, the compactness of 13 cities in the Jingjinji urban agglomeration can be divided into five grades using the natural breaks method: not at all compact, not compact, relatively compact, compact and very compact (Table 3).

6.1 Comprehensive analysis of urban agglomeration compactness

It can be seen from Table 2 that the overall spatial compactness of 13 central cities is less than 1, which indicates that the overall level of urban compactness is not high in the Jingjinji urban agglomeration. Overall, the urban agglomeration is not compact and is very differentiated. According to the calculation results (Table 2), urban compactness decreased significantly from 2014 to 2015, and then was stable with a slight upward trend. The explanation for this trend is that since the Jingjinji Coordinated Development Strategy was presented in 2014, each city has taken certain measures to achieve the goal of integrated development, which has promoted the compact development.

There are cities in each group of degrees of compactness (Table 3, Figure 1). Among the cities, only Cangzhou is a very compact city. Compact cities include Langfang and Beijing, while relatively compact cities include Xingtai, Tianjin, Shijiazhuang and Handan. On the contrary, Baoding and Qinhuangdao are not compact cities and Tangshan, Zhangjiakou, Chengde and Hengshui are not at all compact cities. The results of the classification show that the development of the central city to some extent drives the development of the surrounding cities, but the diffusion effect is very limited. At the same time, it causes a significant “siphon effect”, which is why Beijing has a distinctive impact only on cities that are close to it, so the compactness of Beijing is just fine. Some cities in the eastern coastal areas of the urban agglomeration, although far from Beijing, with small municipal districts and a good location, belong to the group of compact cities along with most cities in the central part of the agglomeration. The southern part of the agglomeration has a poor basis for development and is far from the central cities and their impact, so the urban space is not compact. Moreover, the production and living spaces of the northern cities are not further developed due to their main ecological protection functions. Accordingly, their degree of compactness is low, although they are located near the central cities.

6.2 Unbalanced development of PLES compactness

From the perspective of the compactness of PLES in each city, the compactness of production and living space is significantly higher than that of ecological space. Furthermore, the compactness of all three types of spaces shows a gradient decline. This is the result of the government’s long-term goal of developing cities for economic growth. Even under the new normal, which attaches great importance to living and ecological spaces, the development basis of the production space still makes cities more compact. A comparison of the compactness degree of PLES in each city shows the deepening divide between cities.

According to Figure 2, the degrees of compactness of production and living spaces in Cangzhou, Beijing and Langfang, which are very compact and compact cities, are much higher than those in Tianjin and Shijiazhuang, which are relatively compact cities. Other cities have lower urban compactness but have a relatively compact production and living spaces. This shows that

TABLE 2 Comprehensive evaluation results of compactness in the Jingjinji urban agglomeration.

City	2014	2015	2016	2017	2018	Average value
Beijing	0.5128	0.4457	0.3957	0.4014	0.3998	0.4311
Tianjin	0.3346	0.3743	0.3221	0.2704	0.2210	0.3045
Shijiazhuang	0.2503	0.2376	0.2826	0.3183	0.1829	0.2543
Tangshan	0.1270	0.1166	0.1126	0.1685	0.1425	0.1335
Qinhuangdao	0.3551	0.1207	0.1421	0.1677	0.1352	0.1841
Handan	0.4225	0.3643	0.1365	0.1860	0.1214	0.2461
Xingtai	0.2238	0.2668	0.3263	0.1318	0.7290	0.3356
Baoding	0.5268	0.1019	0.1437	0.1720	0.1257	0.2140
Zhangjiakou	0.2717	0.1301	0.0939	0.0946	0.0922	0.1365
Chengteh	0.1353	0.0957	0.1225	0.1687	0.1292	0.1303
Cangzhou	0.5941	0.7076	0.8280	0.8363	0.6752	0.7283
Langfang	0.3500	0.3576	0.4678	0.5250	0.4961	0.4393
Hengshui	0.1169	0.1169	0.0949	0.1528	0.1228	0.1208

TABLE 3 Classification of the Jingjinji urban agglomeration compactness.

Degree	Compactness	City
Level Ivery compact	0.4393–0.7283	Cangzhou
Level II compact	0.3356–0.4393	Langfang Beijing
Level III relatively compact	0.2140–0.3356	Xingtai Tianjin Shijiazhuang Handan
Level IV not compact	0.1365–0.2140	Baoding Qinhuangdao
Level V not at all compact	0.1208–0.1365	Tangshan Zhangjiakou Chengde Hengshui

giving priority to reasonable layout and investment in the production space provides a good foundation for its development and thus improves the compactness of production space. However, the compact development of living and ecological spaces should be also promoted.

6.2.1 Comparative analysis of production space compactness

The degree of compactness of the production space in the Jingjinji urban agglomeration is unbalanced with standard deviation of 0.1149, which indicates a wide gap. In general, cities with a higher level of economic development have a higher degree of compactness of production space. However, the compactness of production space in Beijing and Tianjin is not the highest despite their high level of economic development due to “Big City Disease” caused by rapid development that negatively affects the efficient operation and high-quality development of the urban space (see Figure 3).

Compact development of economic factors and municipal facilities is better, while land for production and transportation is relatively poor in the Jingjinji urban agglomeration. The compactness of economic factors (0.0546) and municipal facilities (0.0460) is higher, while the compactness of transportation (0.0285) and land for production (0.01720) is lower. More attention in urban spatial planning is given to the utilization and development of economic factors and municipal facilities, while the economical use of productive land and optimization of transportation are insufficiently considered (see Figure 4).

As the capital of China, Beijing is a densely populated area with developed transportation, but its level of transportation development per capita is far below the levels of municipal facilities and economic development. As the second largest city in Jingjinji, the level of development of transportation and municipal facilities is modest and unbalanced in Tianjin. Therefore, it is necessary to optimize traffic layout on limited traffic land, increase traffic accessibility and links with other provinces and cities, and promote both the construction of high standard municipal facilities and development of economic factors. In Shijiazhuang, the capital of Hebei Province, transportation development is better than the development of municipal facilities. Therefore, there is still room for development of infrastructure, public transport system, drainage system and taxi layout. Cangzhou, Xingtai and Langfang have excellent transportation and municipal facilities, while Hengshui, Tangshan and Chengde have poor municipal facilities and transportation, and still need to increase investment. Baoding, Qinhuangdao and Zhangjiakou should also

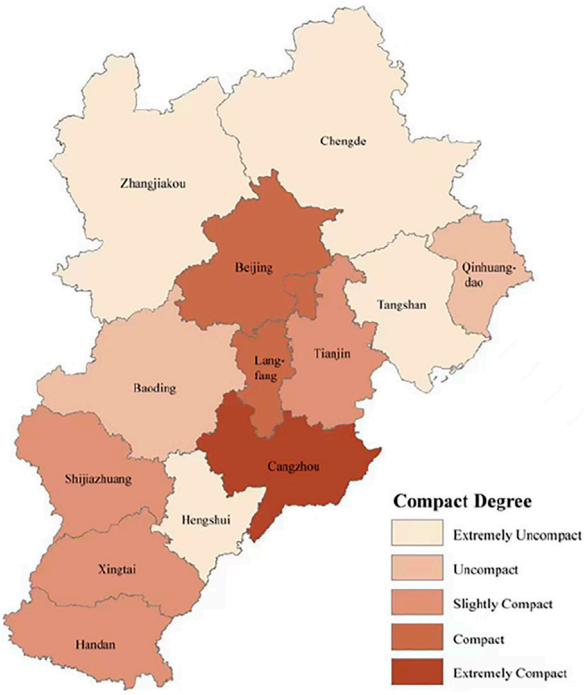

FIGURE 1
Degree of Compactness of production-living-ecological space in Beijing-Tianjin-Hebei.

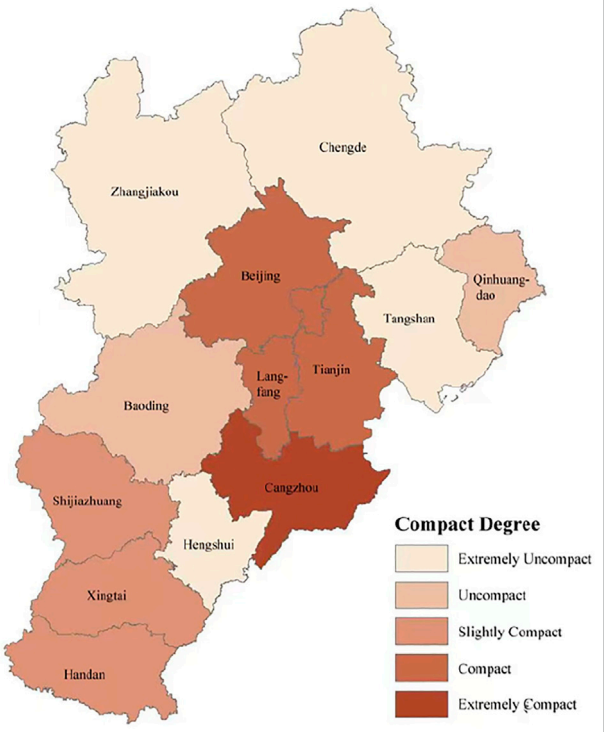

FIGURE 3
Degree of Compactness of production space in Beijing-Tianjin-Hebei.

FIGURE 2
Compact development degree of production-living-ecological space in Beijing-Tianjin-Hebei.

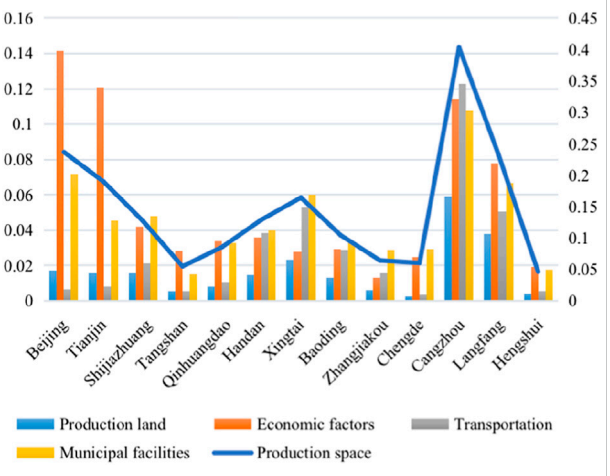

FIGURE 4
Secondary indicators of Degree of compactness of production space in Beijing-Tianjin-Hebei.

promote the development of transportation and municipal facilities. The obtained results show that cities with compact production space in the Jingjinji urban agglomeration made better use of production land, while other cities with low compactness of production space ignored compact development of production land.

There is a big difference between the compactness of city's economic factors and city's overall compactness. However, the top four cities in the economic factor compactness are all central cities of the urban agglomeration and their surrounding cities, which is in line with the strength of their social and economic development. In terms of transportation, due to the unbalanced development of passenger and freight transport and dense population, the compactness of transportation is quite different from the compactness of urban production space. As a foundation for urban development, sufficient attention has been paid to the compact development of municipal facilities. Developed megacities have a better allocation of economic factors based on good municipal facilities, but the conditions of municipal facilities impede the allocation of economic factors in underdeveloped cities.

6.2.2 Comparative analysis of living space compactness

The development of compactness of living space in the Jingjinji urban agglomeration is relatively unbalanced with standard deviation of 0.0769, which indicates that there is a small difference in the compactness. The compactness of social life is higher, while the compactness of residential land and public services is lower. Cities of higher urban compactness have a low degree of social life compactness, which shows that the supply of residential land in most small and medium-sized cities is relatively adequate, while in large cities it is limited. Cities of high urban compactness give importance to the compact development of public services, while underdeveloped areas do not provide sufficient support to public services (see Figure 5).

In terms of social life, the rankings of urban compactness and compactness of living space are similar. Most cities in the central and eastern parts of the urban agglomeration have a higher compactness of social life compared to the lower compactness of economic factors of production space. The compactness of living space is lower than that of the production space in southern and northwestern cities. However, the compactness of social life is higher than that of the production space, although lower than that in central and eastern cities. It can be seen that the government pays more attention to the correct operation, function and development of living space, but pays less attention to the layout of living space and guaranteed supply of public services for residents. Moreover, although some small and medium-sized cities have a low level of economic development, their social living space is relatively compact and livable (see Figure 6).

6.2.3 Comparative analysis of ecological space compactness

In this study, the ecological space is not a natural ecological environment, but an ecologically compact space represented by ecological development and efficiency due to human interventions in urban planning. Low ecological compactness shows that it is very difficult to restore the natural ecological environment. The results show that the compactness of the ecological space in the Jingjinji urban agglomeration is relatively low. In particular, central, eastern and southern cities have relatively higher

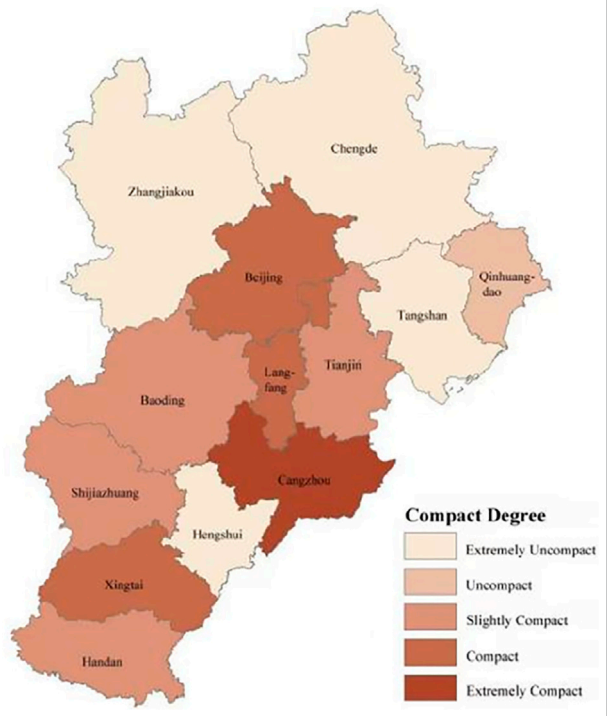

FIGURE 5
Degree of Compactness of living space in Beijing-Tianjin-Hebei.

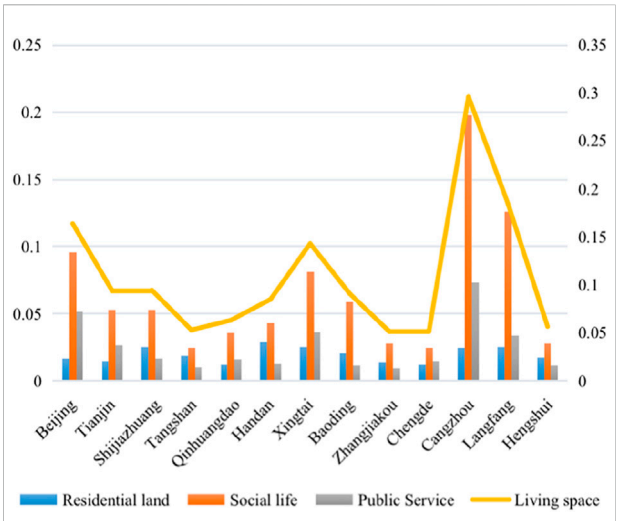

FIGURE 6
Secondary indicators of Degree of Compactness of living space in Beijing-Tianjin-Hebei.

compactness, while northwest cities as ecological conservation areas have lower compactness. To some extent, this shows that the compact development of ecological space in northwest cities is still low due to good ecological environment, poorly developed production space base and lower demand for construction and restoration of ecological environment (see Figure 7).

The calculation results show that the compactness of green land (0.0106) is slightly lower than that of pollution treatment (0.0154). This indicates that with the advocacy of green development, pollution emissions were treated in a certain form, but the reservation of green land needs to be strengthened (see Figure 8).

7 Conclusion

Compactness of urban space refers to the degree of agglomeration or compactness of related elements in PLES according to the specific economic and technological links in the process of urbanization. The efficiency of urban operations is directly affected by urban space compactness, and the appropriate urban compactness will maximize the overall benefits in urban agglomerations. However, too high or too low compactness can become an obstacle to healthy and sustainable urban development.

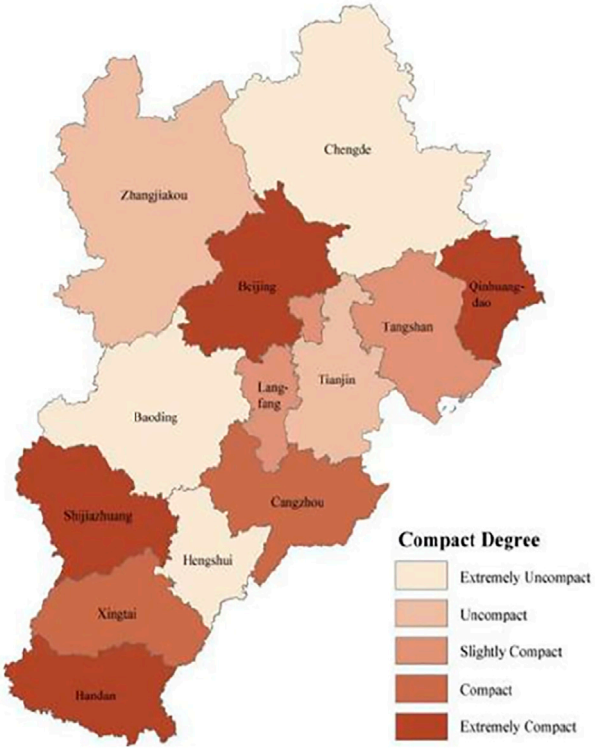

FIGURE 7
Degree of Compactness of ecological space in Beijing-Tianjin-Hebei.

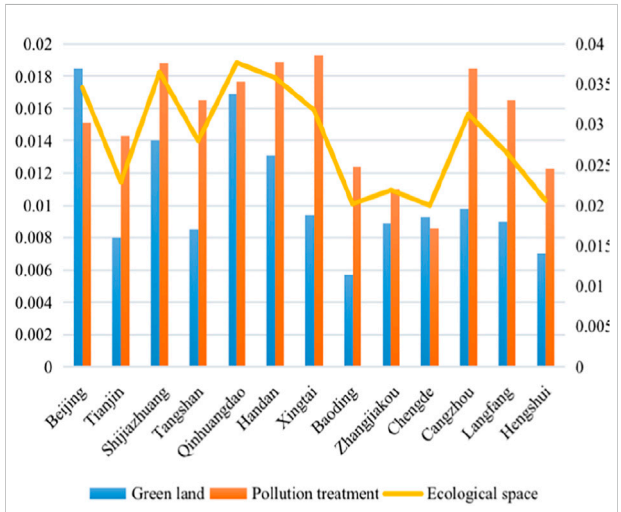

FIGURE 8
Secondary indicators of Degree of compactness of ecological space in Beijing-Tianjin-Hebei.

By measuring and calculating the compactness of 13 cities in the Jingjinji urban agglomeration in terms of production, living and ecological spaces, the following conclusions are obtained: (1) from the perspective of an urban agglomeration, the overall development advantages of Beijing, Tianjin and Shijiazhuang is highly ranked, but the compactness of the production land is low; (2)in terms of economic factors and the resources of production space, Beijing and Tianjin have played the role of central cities and enabled the compact development of economic factors. Relying on the location near the neighboring central cities, Cangzhou and Langfang optimized the business environment of small and medium-sized enterprises (SME), which contributed to high technology penetration and conversion rate and improved the accessibility of financing and financial liquidity of SMEs. As far as investments in transportation and municipal facilities are concerned, the development of municipal facilities is better than that of transportation, so more attention should be given to transportation in the future; (3)in terms of living space, it is necessary to relieve residential density in compact agglomeration areas and improve the use of public resources and services per capita. The fact is that there is a large gap in the level of public services between cities in the Jingjinji urban agglomeration. As a result, small and medium-sized cities cannot quickly reduce the development gap between them and core cities; and 4) in terms of the ecological space of the urban agglomeration, the green space in the Jingjinji urban agglomeration consists mainly of green land and parks.

Based on a comparative analysis of compactness, there are problems in the Jingjinji urban agglomeration, such as

unbalanced compactness of PLES and cities. Accordingly, it is necessary to solve the problems of unbalanced compactness through land governance. However, each city in the Jingjinji urban agglomeration is at a different stage of development and faces different compactness problems. Thus, it is necessary to scientifically and rationally address local compactness problems according to specific local conditions. Ultimately, the compact development of the entire urban agglomeration can be achieved.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found in "China City Statistical Yearbook, Urban social and Economic Survey Department of National Bureau of Statistics 2020, http://www.stats.gov.cn".

Author contributions

HyW and HmW performed data analysis and wrote the manuscript. HmW assisted in manuscript editing and article review. HyW designed the study and assisted in data analysis. XX provided the initial data and instruments.

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Conflict of interest

Author XX was employed by Development Holdings Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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