



# Population-land urbanization and comprehensive development evaluation of the Beijing-Tianjin-Hebei urban agglomeration

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## Abstract

As the main form of the new urbanization strategy, urban agglomeration promotes inter-regional economic development, population flow, and industrial cooperation. It is not only an important platform for the country to participate in international competition, but also an important carrier to explore the multiple influencing factors of urbanization. Based on the Beijing-Tianjin-Hebei urban agglomeration, the temporal and spatial characteristics of its evolution from 1990 to 2020 are analyzed by using the models of urban evolution and industrial transfer. The results show that at the level of urban land use evolution intensity, Beijing > Tianjin > Hebei, and the evolution of urban land use showed an obvious pattern of concentration of resources in central cities (districts) and weak development in sub-central cities (counties). The overall level of urban sprawl showed a downward trend, and only 0.50% of districts and counties were in the stage of high sprawl. Before 2010, the urban sprawl of Beijing, Tangshan, and southern Hebei province remained at a high level, and after 2010, the urban sprawl of central Hebei province remained at a high level. In terms of comprehensive development, the index of cities decreased, including Beijing, Tianjin, and Tangshan, while the index of cities increased including Shijiazhuang, Handan, Xingtai, and Baoding. There is a trend of agglomeration and diffusion of regional industries in geographical space. Middle- and high-end manufacturing industry and service industry gather in the first city, and middle- and low-end processing industry, labor-intensive industry, and agriculture move to surrounding cities. The research results can provide policy suggestions for the coordinated development of regional integration in developing countries.

**Keywords** Landsat data · Urbanization · Population mobility · Industrial transfer · Coordinated development · The Beijing-Tianjin-Hebei urban agglomeration

## Introduction

Since reform and opening up in the 1980s, under the guidance of socialism with characteristics, the urbanization and industrialization of the Beijing-Tianjin-Hebei urban agglomeration has made rapid progress, rising from 22.13% in the early stage of reform to 68.39% by the end of 2020, and is expected to reach about 80% by the middle of the twenty-first century (Gu 2019; Shen et al. 2017). After 40 years

of urbanization development, the current socio-economic and urban construction of the Beijing-Tianjin-Hebei urban agglomeration has been in an important stage of transformation (Zhao et al. 2017, 2018; Wang 2022). How to effectively solve the urban development problems caused by rapid urbanization, such as uncoordinated urban and rural development, extensive expansion of urban boundaries, ecological environment quality reduction, and loss of cultivated land, and put forward a new path of sustainable social development has become the focus of the current government departments and academia.

Factors such as economic activities, land use, and population agglomeration form continuous regional agglomeration at the geographical level, and land use is the most drastic and obvious factor in urban development (Wang and Cao 2022). At present, many scholars have carried out multi-level research on urban construction and social development and achieved some research results (Parjanen et al. 2018).

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The content of the research mainly focuses on three aspects: on the one hand, based on land use change, the functional transformation, space–time expansion, and supply–demand relationship of urbanization land are studied, including the intensity of urban land expansion, utilization efficiency, and sustainable development (Gennaio et al. 2009). On the other hand, the urban land expansion form and landscape distribution characteristics are described, and predict its future development trend through the model (Krähmer 2020; Silva Neiva et al. 2021). The third aspect explores the interactive coupling relationship between urban land use and population flow, economic development, and ecological quality, and explores its influencing mechanism and environmental effects (Krähmer 2020). The research scale mainly covers macro, medium, and micro levels. The macro level focuses on urban development (Dempsey et al. 2011, Tan and Lu 2018); the medium level focuses on provinces, urban agglomerations, and river basins (McCormick et al. 2013; Prakash et al. 2020); and the micro level focuses on the transformation of various land use functions within cities (Li et al. 2016). At the research data level, the statistical yearbook and social development statistics released by third-party institutions were mainly used at first (Buckley and Kallergis 2019). It has the advantages of easy data acquisition, small amount of data, and strong operability. However, it also has some shortcomings, such as inconsistent statistical caliber and lack of geographical temporal and spatial attributes. With the further intensification of the diversification, three-dimensional, and complexity of urban development, the statistical data cannot fully reflect the characteristics of urbanization development. With the launch of space satellite and the social application of data, its global, all-weather, visualization, and high-precision characteristics are favored by scholars. Scholars used satellite data to study the expansion path, space–time dynamics, and heterogeneity of urban development, which promoted the research on urbanization development from two-dimensional space to three-dimensional space (Shao et al. 2021; Tu et al. 2021). In general, the expansion dynamics of land use change in urban development as an important carrier of urban physical space are gradually revealed by scholars, but the complexity of geographical space makes its expansion law and theoretical framework still need to be further summarized and summarized.

City is a highly developed living space for human beings. It is the region with the most vitality and development potential. It is also the support for countries to participate in global competition and industrial division of labor (Bruneckiene et al. 2012). Although there are abundant research results, there are still some shortcomings in relevant literature. It mainly includes that the existing literature mainly focuses on the dominant factors such as expansion area and speed, and lacks the comprehensive research on the

multi-dimensional population, economy, and area factors of urban development. The existing literature mainly focuses on regions or individual cities, and lacks the induction and in-depth summary of the common laws of urban land expansion in urban agglomerations. The existing literature lacks the overall consideration of comprehensive factors such as economy, population, and location in the process of urban development. The existing literature lacks the comparison between developed and developing countries, especially the summary of the development characteristics of developing countries. Based on this, the main contributions of this study are as follows: ① The characteristics of urban land expansion in cities are measured in detail, and the common laws of urban land expansion in cities with different locations are summarized. ② The spatial and temporal dynamics of urban circulation among economy, population, and industry in the Beijing-Tianjin-Hebei urban agglomeration are analyzed, which is helpful to the cooperation and division of labor among cities under the market economy.

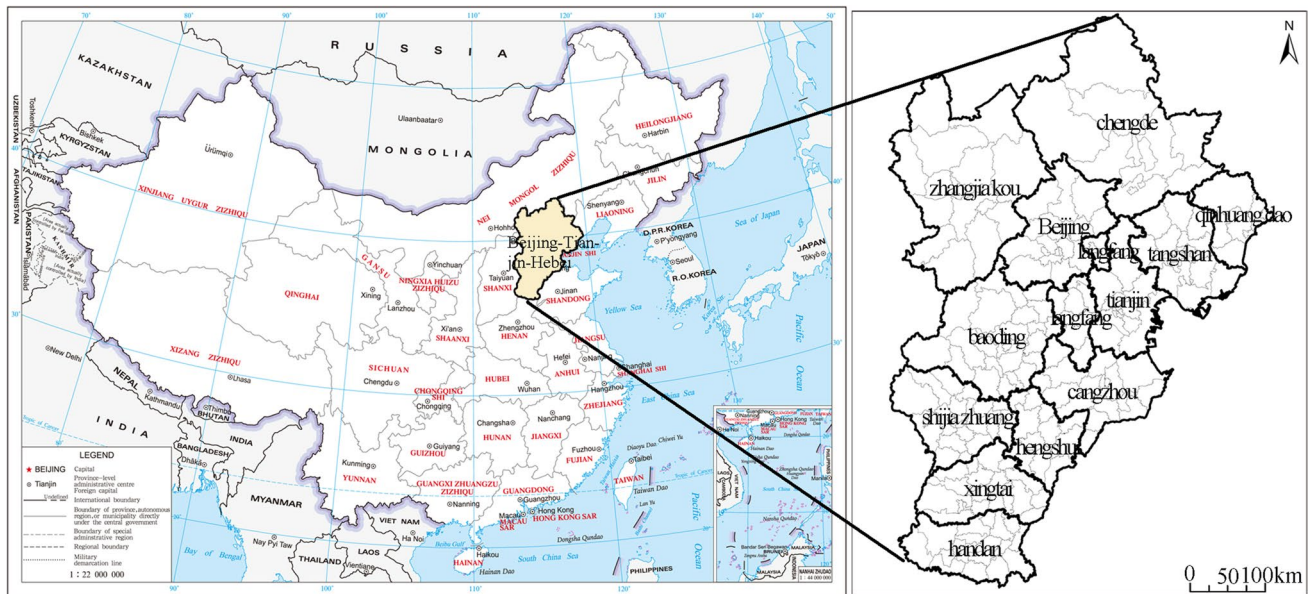
## Study area and data source

### Study area

The Beijing-Tianjin-Hebei urban agglomeration mainly consists of 13 cities and 200 districts and counties in Beijing, Tianjin, and Hebei province. It is the largest urban agglomeration in northern China and the third largest urban agglomeration and economic growth pole after the Yangtze River Delta and the Pearl River Delta. It is the political center and important economic center of China (Fig. 1). By the end of 2020, the total GDP of the Beijing-Tianjin-Hebei region was 8.64 trillion yuan, accounting for 8.50% of the national GDP in the same period. The total population of the region was 113 million people, accounting for 8.07% of the national GDP. The total land area of the region was 21,800 km<sup>2</sup>, accounting for 2.27% of the national GDP. About 84% of the Beijing-Tianjin-Hebei region's land has been utilized, and its development intensity is much higher than the national average level, with limited potential and lack of reserve land resources. Therefore, the Beijing-Tianjin-Hebei city cluster is a typical representative area to carry out urbanization spatial research.

### Data source

The socio-economic data in this paper are from The Annual Statistical Mirror of Beijing, Tianjin, and Hebei and the Annual Statistical Mirror of Chinese Cities (1990–2020). Urban land evolution data are mainly collected from Landsat TM/ETM Remote Sensing Images in summer between 1990, 2000, 2010, and 2020, and a series of adjustments



**Fig. 1** Location map of the Beijing-Tianjin-Hebei urban agglomeration

and corrections are made to the spatial information such as image band, ground control point, and geodetic datum on GEE geographic cloud platform. According to the information of spectral reflectance, background, and topography, human-computer interactive interpretation and expert knowledge are used to determine the land use type of the corrected image. According to the standard of Classification of Land Use Status (GB/T 2017), land use types are preliminarily classified into six types: construction land, cultivated land, forest land, grassland, water area, and unused land. According to the needs of this study, the impervious land such as large, medium, and small urban construction land in construction land is classified as the urban land area of this study. Compared with the data of the China Urban Statistical Yearbook, the overall accuracy of the sorted urban land has reached 87.35–94.26%, which basically meets the requirements of this study.

## Method

In the process of quantitative research on the evolution dynamics and influencing factors of urban land use in the Beijing-Tianjin-Hebei urban agglomeration, this paper follows the principle from part to whole, and chooses the geo-spatial index (land use evolution intensity index, evolution hot spot index, and influencing factor model) and industrial structure transfer model (Tian et al. 2019). The land use evolution intensity index takes the total land area of the research object as the framework and uses the area change value in the first and last years of the research stage as the

variable to quantify the change and proportion of different cities in the urban agglomeration (Gong et al. 2014). The evolution hot spot index adopts the spatial autocorrelation principle and takes the area change value of cities and towns in different stages as the variable to visually display the aggregation of evolution hot spots and the distribution of cold spots in urban agglomeration at the spatial level. The spatio-temporal evolution of urban land use in the Beijing-Tianjin-Hebei urban agglomeration can be quantified through two geospatial models. In order to further analyze the long-term changes of cities in the urban agglomeration system, the comprehensive development index is introduced. The comprehensive development index covers the three most important factors in urban development—population, urban land, and economic aggregate, which can accurately quantify the comprehensive development level of a city (Fang et al. 2015). Finally, the most representative changes in the output value of the secondary and tertiary industries in the process of urbanization are selected to analyze the industrial transfer situation of different cities in the urban agglomeration with the model.

## Evolution intensity index of land use ( $E$ )

$E$  refers to the percentage of urban land expansion area in the total area within the research framework of city  $i$  within the research period. Its advantage lies in the standardized treatment of the average annual growth rate of urban land within the research framework. It makes the growth rate in different periods comparable, and can characterize the form and

development quality of urban expansion in different stages. Its expression is as follows:

$$E = \frac{(S_b - S_a)}{S_{total} \times \Delta t} \times 100 \tag{1}$$

where  $E$  represents the urban land evolution intensity index of the city  $i$ ,  $S_a$  and  $S_b$  respectively represent the urban land area of the city  $i$  at the beginning and end of the research cycle,  $S_{total}$  represents the total land area of city  $i$ , and  $\Delta t$  represents the interval from  $a$  year to  $b$  year.

### Urban sprawl index

At the beginning of the twentieth century, European scholars defined enclave development of industrialized towns and urban boundary expansion as urban sprawl (Wang and Cao 2022). With the development of social economy, the influencing factors of urban sprawl are no longer limited to the urban spatial form. At present, academia believes that the phenomenon that the growth rate of urban population is less than that of urban built-up area is the main index of urban sprawl. The expression is as follows:

$$SI = \left( \frac{BA_m - BA_n}{BA_n} \right) / \left( \frac{PO_m - PO_n}{PO_n} \right) \tag{2}$$

where  $PO_m$  represents the total permanent urban residents in the  $m$  year,  $PO_n$  represents the total permanent urban residents in the base year  $n$ ,  $BA_m$  represents the area of urban construction land in the  $m$  year, and  $BA_n$  represents the area of urban construction land in the base year  $n$ . When  $SI \leq 1$ , there is no urban sprawl. When  $SI > 1$ , there is urban sprawl, and the greater the  $SI$  value, the higher the degree of sprawl.

### Comprehensive development index (D)

$D$  index can reflect the comprehensive strength, space–time dynamics, and development quality of each city within the overall framework. According to the idea of the first law of geography, the three most important elements in the process of urban development—urban land area, total economic volume, and urban resident population, are selected to determine the comprehensive development potential and ranking of cities. Its expression is as follows:

$$d_i = \sqrt[3]{P_i \times S_i \times E_i} \tag{3}$$

$$D_i = d_i / \sum_{i=1}^n d_i \tag{4}$$

where  $P_i$  represents the permanent urban population of the city,  $S_i$  represents the urban land area,  $E_i$  represents the gross

national economic product, and the greater  $D_i$  represents the stronger comprehensive urbanization level of city  $i$ .

### Model of industrial structure transfer (I)

$I$  can represent different stages of city  $I$ 's development, and the composition and transfer of its internal industrial structure, and reflect the development quality level of city  $I$ , mainly including the city's economic aggregate and the output value of the secondary and tertiary industries. The expression is as follows:

$$I_i = \frac{G_3 - G_2}{G_{total}} \times 100 \tag{5}$$

where  $G_3$  represents the output value of the tertiary industry of city  $i$  in the  $n$  year,  $G_2$  represents its output value of the secondary industry, and  $G_{total}$  represents its total output value.

## Results

The evolution of urban land use in the Beijing-Tianjin-Hebei urban agglomeration from 1990 to 2020 was accurately quantified, and the spatio-temporal characteristics of urban land use evolution in different cities were analyzed.

### Analysis of urban land use evolution intensity

On the whole, the evolution intensity of urban land use in the Beijing-Tianjin-Hebei urban agglomeration showed a trend of rising first and then decreasing, and showed obvious staged differences (Table 1). At the provincial level, the area of urban construction land in each city has continued to grow in the past 30 years. The  $E$  index of Beijing > Tianjin > Hebei is 0.27, 0.19, and 0.02, respectively. Among them, the index  $E$  of Beijing rose first and then declined, rising continuously from 0.16 to 0.44 from 1990 to 2010, and then falling from 0.44 to 0.17 from 2010 to 2020. On the whole, the index  $E$  of Tianjin shows a stable trend, rising continuously from 0.05

**Table 1** Urban land expansion intensity index

	Time/year			
	1990–2000	2000–2010	2010–2020	1990–2020
Beijing	0.16	0.44	0.17	0.27
Tianjin	0.05	0.24	0.21	0.19
Hebei	0.02	0.03	0.02	0.02
Central (district)	0.36	1.24	0.25	0.38
Sub-centers (counties)	0.03	0.06	0.03	0.04

to 0.24 from 1990 to 2010, but falling to 0.21 from 2010 to 2020. Compared with the rapid evolution of urban land use in Beijing and Tianjin, the index  $E$  of Hebei increased slowly from 1990 to 2020 with a low level of 0.02–0.03. From the analysis of district and county level, the evolution of urban land use in the Beijing-Tianjin-Hebei urban agglomeration shows an obvious pattern of central city (district) resource concentration and sub-central city (county) development weakness. From 1990 to 2010, the evolution of central cities remained at a high level, and the index  $E$  continued to rise from 0.36 to 1.24. From 2010 to 2020, although the index  $E$  declined from 1.24 to 0.25, it still remained at the average level of 0.38 in the whole 30 years. The sub-central city index  $E$  has been at a low level of 0.03–0.06, and the index  $E$  has maintained an average level of 0.04 during the whole 30 years.

From the analysis of the index  $E$  change trend and spatial evolution of the cities in the Beijing-Tianjin-Hebei region in the past 30 years, Beijing and Tianjin have been the two core driving cities of the Beijing-Tianjin-Hebei region, while Hebei is at a lower level of development. After the rapid development from 1990 to 2005, Beijing took the initiative to shut down and relocate some high pollution and low energy efficiency enterprises and industrial chains to Tianjin and Hebei due to industrial pollution, inefficient land use, ecological damage, and other reasons. Due to the refined development and the relocation of a large number of industrial chains, Beijing has been in the later stage of industrialization since 2005. Urban evolution pays more attention to the improvement of space quality, and its index  $E$  shows a downward trend (Lu et al. 2018). Tianjin is in the accelerated stage of industrialization, and its economic development is still dominated by industry, which requires a large amount of construction land for sustainable development. Hebei is in the primary stage of industrialization, its economic development mainly depends on agriculture and heavy industry, and the evolution of urban land is relatively slow.

### Analysis of urban sprawl and evolution

From the perspective of time series, the overall level of urban sprawl of 200 districts and counties in the Beijing-Tianjin-Hebei urban agglomeration shows a downward trend. The number of districts and counties in the low-value area increased, while the number of districts and counties in

the high-value area gradually decreased, and only 0.50% of the districts and counties were in the high spreading stage (Table 2). Specifically, the number of sprawl cities with negative population growth increased from 33 to 85, while the non-sprawl cities remained stable in the fluctuation. The number of low-spread districts and counties decreased from 49 in 1990–2000 to 38 in 2010–2020, the number of medium-spread districts decreased from 74 to 38, and the number of high-spread districts decreased from 7 to 1 (Fig. 2). At the beginning of the twenty-first century, with the acceleration of industrialization and urbanization of the Beijing-Tianjin-Hebei urban agglomeration, its economic structure has been constantly improved and optimized, and the course of economic development experienced a turning point in 2010. Before 2010, most districts and counties showed a moderate level of sprawl, indicating that the growth of urban built-up area was much higher than that of the total population of the region, and it was in a state of extensive development. After 2010, with the national policies of energy conservation and emission reduction and advocating clean energy, Beijing and Tianjin in the Beijing-Tianjin-Hebei urban agglomeration have optimized their industrial structure. The governments of Beijing and Tianjin have taken the initiative to shut down many industrial chains with high pollution and low efficiency, resulting in the slowdown of urban economic growth and the reduction of jobs. During this period, the intensity of urban construction decreased in most districts and counties, even lower than the regional population growth rate, and no urban sprawl occurred. The number of spreading cities with negative population growth increased, indicating that the population outflow of the Beijing-Tianjin-Hebei urban agglomeration and the attractiveness of regional central cities increased, while the population attractiveness of small- and medium-sized cities decreased.

From the perspective of spatial pattern, the urban sprawl of Beijing, Tangshan, Shijiazhuang, Handan, and other cities in southern Hebei province remained at a high level before 2010. The middle part of Hebei is mainly moderately spreading. With the continuous improvement of urban transportation and other infrastructures, the spreading degree continues to extend, which promotes the increase of the flow of factors such as population, resources, and investment. The growth rate of construction land in northern Hebei is slow, population urbanization is higher than land urbanization,

**Table 2** Sprawl classification of the Beijing-Tianjin-Hebei urban agglomeration

Spread level	Negative spread $SI < 0 \text{ \& } P_j < P_i$	Not yet spread $0 \leq SI \leq 1$	Low spread $1 < SI \leq 5$	Moderate spread $5 < SI \leq 50$	High spread $SI > 50$
1990–2000	16.50	18.50	24.50	37.00	3.50
2000–2010	16.00	7.50	22.50	48.00	6.00
2010–2020	42.50	19.00	19.00	19.00	0.50

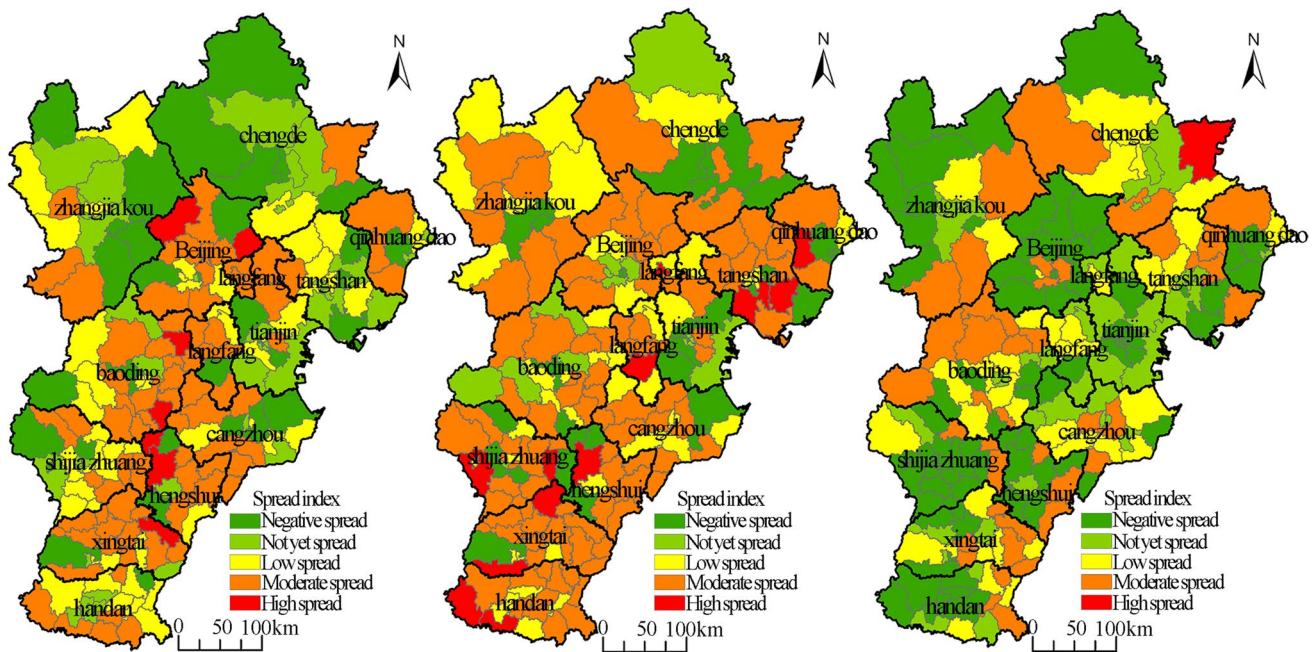


Fig. 2 Spatial distribution of sprawl in the Beijing-Tianjin-Hebei urban agglomeration. a 1990–2000. b 2000–2010. c 2010–2020

and there is no spreading phenomenon on the whole. After 2010, with the economic structural reform of the Beijing-Tianjin-Hebei urban agglomeration and the reduction of industrial chains such as heavy industry, the development of southern Hebei slowed down. Relying on the advantages of policy, social geography, and location, the cities in central Hebei have undertaken the medium- and low-end industrial chain transferred from Beijing and Tianjin, and attracted part of the employed population. The scale of land use in the northern part of Hebei is also increasing, and man-land relationship shows a trend of coordinated development, with a low degree of urban sprawl. In view of the fact that the Beijing-Tianjin-Hebei urban agglomeration is gradually promoting the optimization of industrial structure, driving the transformation of urban economic structure, strengthening resource management, promoting the integrated development of urban and rural areas and regions, etc., it will remain in a medium–low degree of spread development for a long time in the future.

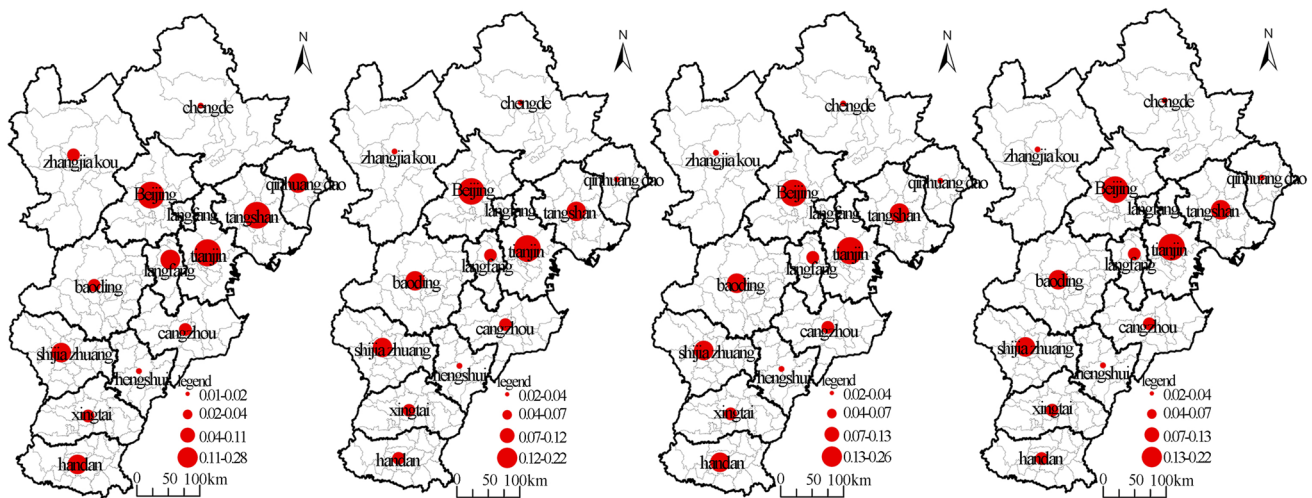
**Analysis of comprehensive urban development**

The index *D* can reflect the relative comprehensive strength of each city in the urban agglomeration and the change of its development proportion on a spatio-temporal scale (Table 3; Fig. 3). From the perspective of temporal and spatial evolution, cities with declining index *D* include Beijing, Tianjin, and Tangshan. Among them, the index *D* of Beijing continues to decrease by 0.22 from 0.27. The main factor is the decline in the evolution growth rate of population and urban

Table 3 Urban comprehensive development index

	Time/year			
	1990	2000	2010	2020
Beijing	0.27	0.22	0.25	0.22
Tianjin	0.23	0.15	0.16	0.17
Shijiazhuang	0.06	0.10	0.10	0.09
Tangshan	0.11	0.08	0.08	0.08
Qinhuangdao	0.04	0.03	0.03	0.03
Handan	0.04	0.07	0.07	0.07
Xingtai	0.02	0.04	0.05	0.05
Baoding	0.05	0.09	0.07	0.08
Zhangjiakou	0.03	0.04	0.03	0.03
Chengde	0.02	0.02	0.03	0.04
Cangzhou	0.03	0.05	0.06	0.06
Langfang	0.05	0.04	0.04	0.05
Hengshui	0.01	0.05	0.03	0.04

land. The decline in population growth rate is mainly caused by the rise in social living cost, which weakens its attractiveness to the surrounding population. The index *D* of Tianjin continued to drop from 0.23 to 0.17. The main reason for the decline was the weak economy, which mainly resulted from the high proportion of the secondary industry in Tianjin’s economic structure and low short-term added value. The index *D* of Tangshan continued to decrease by 0.08 from 0.11, which was mainly due to the decrease in population growth. The decrease in population growth mainly resulted from the difficulty in obtaining the population diverted from



**Fig. 3** Temporal and spatial evolution of urban comprehensive development. **a** 1990. **b** 2000. **c** 2010. **d** 2020

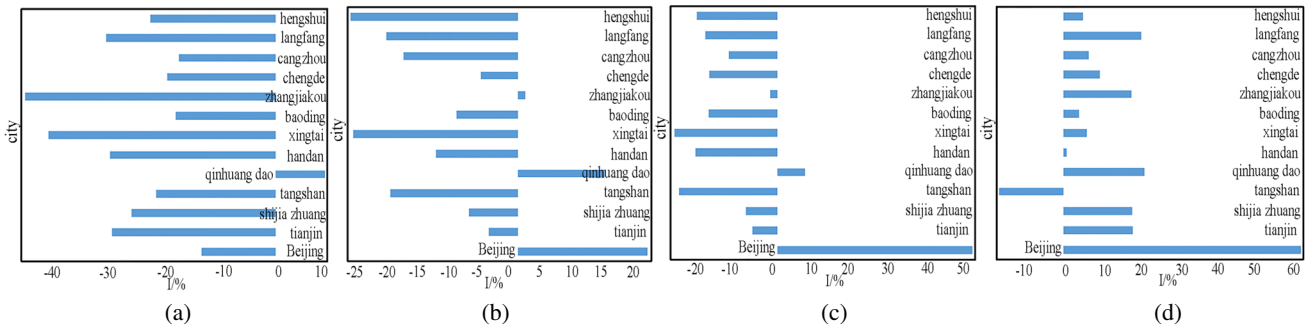
Beijing and Tianjin as well as the population inflow from the vast hinterland of central and southern Hebei as its economic attraction.

Cities with increased index  $D$  include Shijiazhuang, Handan, Xingtai, Baoding, Cangzhou, and Hengshui, among which Shijiazhuang and Baoding are emerging cities in Hebei (Tang et al. 2015). The index  $D$  of Shijiazhuang continued to rise from 0.06 to 0.09, mainly due to the increase of population and urban land use evolution. It is mainly due to the superiority of the provincial capital. In terms of population, it has attracted a large number of people in central and southern Hebei. At the same time, it has greater policy dividends in urban construction. The index  $D$  of Baoding continued to rise from 0.05 to 0.08, mainly due to the increasing growth rate of economic and urban land use evolution. It is mainly due to the strong state support for the construction of Xiongan New Area in recent years, which has accelerated its economic development. Handan's index  $D$  continued to rise from 0.04 to 0.07, mainly due to the rising growth rate of economy and urban land evolution. It mainly comes from the heavy industry in Handan's secondary industry, which drives its economic development. At the same time, the mining also promotes the construction of small- and medium-sized towns. The index  $D$  of Cangzhou continued to rise from 0.03 to 0.06, mainly due to higher economic growth. Cangzhou is the only seaport city in the central and southern part of Hebei. The vast hinterland in the southern part of the central part of Hebei stimulates the growth of its marine industry and transportation industry and promotes economic development. The index  $D$  of Hengshui and Xingtai continued to rise from 0.01 to 0.04, and from 0.02 to 0.05. The two cities are located between Cangzhou and Handan, and their economies have promoted common development. The cities with stable index  $D$  include Qinhuangdao, Zhangjiakou, Chengde, and

Langfang. Their location distribution is located in the urban circle surrounding Beijing, Tianjin, and Tang, and their common characteristics are slow population, urban land use, and economic development, which are basically stable.

## Discussions

According to the analysis of relevant data such as GDP and primary, secondary, and tertiary industries and enterprises in the urban statistical yearbook of the Beijing-Tianjin-Hebei urban agglomeration from 1990 to 2020, the industrial structure of the Beijing-Tianjin-Hebei urban agglomeration has the trend of agglomeration and diffusion in space. In particular, the middle- and high-end manufacturing industry and service industry are clustered in the first city, while the middle- and low-end processing industry, labor-intensive industry, and agriculture are transferred to the surrounding cities. The industrial upgrading and transfer of the Beijing-Tianjin-Hebei urban agglomeration have formed classification and division of labor among different cities. In order to quantify the upgrading and transfer of industrial structure of different cities in the Beijing-Tianjin-Hebei urban agglomeration from 1990 to 2020, this paper uses the data of the secondary and tertiary industries of 13 prefecture-level cities in the Beijing-Tianjin-Hebei urban agglomeration to calculate their industrial changes with Formula 6 (Fig. 4). The variation trend of the difference between the secondary and tertiary industries in 13 cities in 1990, 2000, 2010, and 2020 was compared. In 1990, the industrial difference of all cities was negative, with an average of  $-23.96\%$ , and only Qinhuangdao ( $9.11\%$ ) had a positive industrial difference. In 2000, the industrial difference of all cities was negative as a whole, and the average difference was  $-8.88\%$ . The number



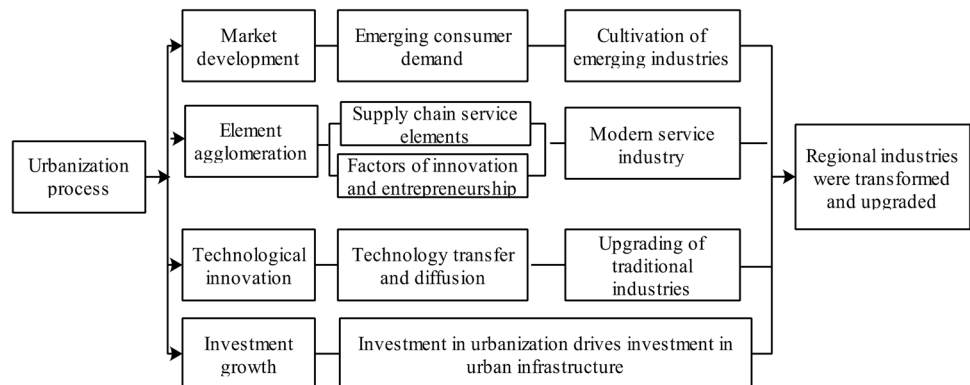
**Fig. 4** Spatio-temporal evolution of urban industrial structure transfer. **a** 1990. **b** 2000. **c** 2010. **d** 2020

of cities with positive difference increased to 3, including Beijing (20.2%), Qinhuangdao (13.5%), and Zhangjiakou (1.10%). In 2010, the industrial differential value of all cities was negative on the whole, with an average of  $-9.25\%$ . The positive differential value decreased to two cities, namely Beijing (51.1%) and Qinhuangdao (7.33%). In 2020, the industrial differential value of all cities is generally positive, with an average value of  $13.31\%$ . The number of cities with positive differential value increases to 12, including Beijing (62.35%), Qinhuangdao (21.29%), Tianjin (18.16%), and Shijiazhuang (17.94%).

From 1990 to 2020, the change of industrial difference between different cities can basically reflect the transfer of the secondary and tertiary industries among different cities, and reveal the structural differences of economic development among cities in the Beijing-Tianjin-Hebei urban agglomeration (Chen et al. 2017). As shown in Fig. 4, in 1990, the spatial distribution of industrial structure in all cities was relatively balanced, and the overall difference was small. There were 6 cities below the average value. As the economic aggregate of the Beijing-Tianjin-Hebei urban agglomeration continues to grow, the division of labor among cities becomes closer, and the industrial structure in the economy also changes accordingly. In 2020, there are obvious differences in the spatial distribution of industrial

structure among cities, and only Tangshan has a negative difference. It shows that Beijing has completely formed an economic structure with high added value and low pollution, mainly in the tertiary industry (service industry), and Tianjin has initially formed an economic structure with both secondary industry (industry) and tertiary industry (service industry). Among the cities of Beijing, Tianjin, and Tangshan, the proportion of the secondary industry (industry) in Tangshan’s economic structure is far higher than that of the tertiary industry (service industry), indicating that Tangshan has accepted part of the industrial enterprises and industry chains transferred from Beijing and Tianjin. Although its economic aggregate is the first in Hebei province, it is still in the stage of accelerated development of industrial society, with high energy consumption per unit and serious pollution (Martinat et al. 2016). Hebei is close to Beijing and Tianjin, and has undertaken most of their industrial transfer. The change of industrial difference value of Hebei cities in the past 30 years also confirms the change of industrial structure (Fig. 5). However, it mainly undertakes the secondary industry with high pollution and part of the tertiary industry with low added value, which leads to the deterioration of its ecological environment. Its economy is still dominated by the primary industry (agriculture), which mainly provides raw materials and rough processing for the development

**Fig. 5** Urbanization and industrial cooperation mechanism





of Beijing and Tianjin, but its economic aggregate is not high. In view of the current situation, the government should timely adjust the industrial structure and change the strategy of attracting investment, focusing on the introduction of high-tech and high value-added industries to promote the technological innovation of polluting enterprises. At the same time, to reduce the dependence on resource exploitation, it should not only develop at a low speed, but should actively integrate into the Beijing-Tianjin-Hebei urban agglomeration and develop together under the guidance of Beijing and Tianjin.

## Conclusions and recommendations

### Conclusions

Based on Landsat remote sensing data and social and economic data of the Beijing-Tianjin-Hebei urban agglomeration from 1990 to 2020, this paper comprehensively applied econometric and geospatial models and other methods, and drew the following conclusions: Long time series remote sensing data provide reliable data sources for monitoring large-scale urban land use evolution and population flow. This paper analyzes the urban spatial evolution and economic activities in the Beijing-Tianjin-Hebei region. At the level of urban land use evolution intensity, Beijing > Tianjin > Hebei, and the evolution of urban land use showed an obvious pattern of concentration of resources in central cities (districts) and weak development in sub-central cities (counties). The overall level of urban sprawl showed a downward trend, with the low-value area increasing and the high-value area gradually decreasing. Only 0.50% of the districts and counties were in the stage of high sprawl. Before 2010, the urban sprawl of Beijing, Tangshan, and southern Hebei province remained at a high level, while after 2010, the urban sprawl of central Hebei province remained at a high level. In terms of comprehensive development, the index of cities decreased including Beijing, Tianjin, and Tangshan, while the index of cities increased including Shijiazhuang, Handan, Xingtai, and Baoding. There is a trend of agglomeration and diffusion of regional industries in geographical space. Middle- and high-end manufacturing industry and service industry gather in the first city, and middle- and low-end processing industry, labor-intensive industry, and agriculture move to surrounding cities.

### Recommendations

According to the evolution process of urban land use and the characteristics of industrial transfer in the Beijing-Tianjin-Hebei urban agglomeration from 1990 to 2020, and combined with the current difficulties of the

Beijing-Tianjin-Hebei urban agglomeration, the following policy suggestions are put forward:

- (1) To strengthen the comprehensive development level of urban agglomeration, it is necessary to improve the matching degree of urban economy, population, and land. At present, relying solely on policy preference and land auction can improve the city's economic level and promote its population growth in the short term, but it is inconsistent with the current concept of high-quality development and urban development transformation put forward by the Chinese government. Beijing, Tianjin, and Shijiazhuang have inherent policy and economic advantages in the urban development of the Beijing-Tianjin-Hebei urban agglomeration. In terms of talent introduction, the restrictions on urban settlement can be gradually relaxed so that talents can continue to gather and promote the comprehensive development of the city.
- (2) Improve the radiation driving capacity of core cities and promote the integrated development of urban agglomerations. While strengthening the comprehensive development level of urban agglomerations, it should highlight the leading role of core cities in regional cities, rather than relying on preferential policies to absorb provincial resources and form a dominant situation of one city. The government should base itself on the resource endowment conditions of different cities in urban agglomerations; take overall consideration of natural resources, social economy, population distribution, and other factors; and construct dislocation development in different fields.
- (3) Optimize the social management function of urban agglomeration and strengthen the transformation and innovation ability of science and technology. Give full play to the scale effect of central cities, improve the development quality of urban stock space, and improve the input-output ratio. The government should pay attention to the intensive development of production and employment functions, update and transform the parts with low efficiency of urban space utilization in the old city in an orderly manner, and transform the vacant and idle spaces to create high-tech and low-pollution industrial parks.

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## Declarations

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## References

- Bruneckiene J, Činčikaitė R, Kilijonienė A (2012) The specifics of measurement of the urban competitiveness at the national and international level. *Géocarrefour* 23:45–54
- Buckley RM, Kallergis A (2019) The sustainable development goal for urban sanitation: Africa's statistical tragedy continues? *J Urban Health* 96:123–130
- Chen L, Xu L, Yang Z (2017) Accounting carbon emission changes under regional industrial transfer in an urban agglomeration in China's Pearl River Delta. *J Clean Prod* 167:110–119
- Dempsey N, Bramley G, Power S, Brown C (2011) The social dimension of sustainable development: defining urban social sustainability. *Sustain Dev* 19:289–300
- Fang C, Wang Y, Fang J (2015) A comprehensive assessment of urban vulnerability and its spatial differentiation in China. *J Geog Sci* 26:153–170
- Gennaio M-P, Hersperger AM, Bürgi M (2009) Containing urban sprawl—evaluating effectiveness of urban growth boundaries set by the Swiss Land Use Plan. *Land Use Policy* 26:224–232
- Gong J, Chen W, Liu Y, Wang J (2014) The intensity change of urban development land: implications for the city master plan of Guangzhou, China. *Land Use Policy* 40:91–100
- Gu C (2019) Urbanization: processes and driving forces. *Sci China Earth Sci* 62:1351–1360
- Krähmer K (2020) Are green cities sustainable? A degrowth critique of sustainable urban development in Copenhagen. *Eur Plan Stud* 29:1272–1289
- Li X, Li C, Parriaux A, Wu W, Li H, Sun L, Liu C (2016) Multiple resources and their sustainable development in urban underground space. *Tunn Undergr Space Technol* 55:59–66
- Lu N, Wei H, Fan W, Xu Z, Wang X, Xing K, Dong X, Viglia S, Ulgiati S (2018) Multiple influences of land transfer in the integration of Beijing-Tianjin-Hebei region in China. *Ecol Ind* 90:101–111
- Martinat S, Dvorak P, Frantal B, Klusacek P, Kunc J, Navratil J, Osman R, Tureckova K, Reed M (2016) Sustainable urban development in a city affected by heavy industry and mining? Case study of brownfields in Karvina, Czech Republic. *J Clean Prod* 118:78–87
- McCormick K, Anderberg S, Coenen L, Neijl L (2013) Advancing sustainable urban transformation. *J Clean Prod* 50:1–11
- Parjanen S, Hyypiä M, Martikainen SJ, Hennala L (2018) Elements of socially sustainable innovation processes in Finnish urban development. *Sustain Dev* 27:281–288
- Prakash M, Ramage S, Kavvada A, Goodman S (2020) Open earth observations for sustainable urban development. *Remote Sens* 12:1646
- Shao Z, Wu W, Li D (2021) Spatio-temporal-spectral observation model for urban remote sensing. *Geo-Spatial Information Science* 24:372–386
- Shen L, Shuai C, Jiao L, Tan Y, Song X (2017) Dynamic sustainability performance during urbanization process between BRICS countries. *Habitat Int* 60:19–33
- Silva Neiva S, Prasath RA, Amorim WS, Andrade Lima M, Barbosa SB, Ribeiro JMP, Ceci F, Schneider J, Deggau AB, Andrade Guerra JBSO (2021) Sustainable urban development: can the balanced scorecard contribute to the strategic management of sustainable cities? *Sustain Dev* 29:1155–1172
- Tan F, Lu Z (2018) The impact of urban compactness on urban sustainable development in China: the case of Nanjing. *Sustain Dev* 27:270–280
- Tang B, Hu Y, Li H, Yang D, Liu J (2015) Research on comprehensive carrying capacity of Beijing–Tianjin–Hebei region based on state-space method. *Nat Hazards* 84:113–128
- Tian Y, Jiang G, Zhou D, Ding K, Su S, Zhou T, Chen D (2019) Regional industrial transfer in the Jingjinji urban agglomeration, China: an analysis based on a new “transferring area-undertaking area-dynamic process” model. *J Clean Prod* 235:751–766
- Tu W, Zhang Y, Li Q, Mai K, Cao J (2021) Scale effect on fusing remote sensing and human sensing to portray urban functions. *IEEE Geosci Remote Sens Lett* 18:38–42
- Wang Y (2022) Development characteristics, influencing mechanism and coping strategies of resource-based cities in developing countries: a case study of urban agglomeration in Northeast China. *Environ Sci Pollut Res Int* 29:25336–25348
- Wang Y, Cao H (2022) Study on ecological adaptability construction characteristics of residential buildings in Kangba area, Tibet, China. *Environ Sci Pollut Res Int* 29:573–583
- Zhao W, Gu C, Tang Y (2017) Urbanization and rural development in the Beijing-Tianjin-Hebei metropolitan region: coupling-degree model. *J Urban Plann Dev* 143:4016028.1
- Zhao Z, Bai Y, Wang G, Chen J, Yu J, Liu W (2018) Land eco-efficiency for new-type urbanization in the Beijing-Tianjin-Hebei Region. *Technol Forecast Soc Chang* 137:19–26

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