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Study of Urban Expansion and Urban Connection Characteristics of the Beijing–Tianjin–Hebei Region

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It is of great significance for coordinated development to analyze the urban expansion process and urban connection characteristics of urban agglomeration. We studied urban expansion extraction and urban connection analysis methods for urban agglomeration based on remote sensing satellite sensors of thematic mapper (TM), enhanced thematic mapper (ETM+), operational land imager (OLI) and visible infrared imaging radiometer suite (VIIRS), and urban area extraction and multidata analysis technologies. Using the relevant materials of domestic land cover data and nighttime light data combined with population and economic data, we analyzed urban agglomeration characteristics of the Beijing–Tianjin–Hebei region, which is one of the most important urban agglomeration areas in China. The expansion characteristics of the Beijing–Tianjin–Hebei region from 2000 to 2021, as well as urban connection characteristics and their changes among the cities, and the three axes of Beijing–Tianjin, Beijing–Baoding–Shijiazhuang, and Beijing–Tangshan–Qinhuangdao were studied. The results show that: (1) the Beijing–Tianjin–Hebei region expanded largely during 2000–2021 and the comprehensive development gap narrowed. (2) A development trend has occurred around Beijing marked by an obvious border construction feature. The expansion speed of the capital metropolitan area was faster in the east and north and weaker in the southwest. (3) The connection of the three development axes was significantly strengthened since 2017, with two cores of Beijing and Tianjin. Some problems of uneven urban connection and uncoordinated development were noted in the Beijing–Tianjin–Hebei region and some suggestions have been addressed.

1. Introduction

Urbanization is part of the natural evolution of non-agricultural industries and rural populations converging into cities and towns with the development of industrialization. It is an

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objective trend of human social development and an important symbol of national modernization.[1] With the development of remote sensing satellite sensors such as thematic mapper (TM), enhanced thematic mapper (ETM+), operational land imager (OLI), and visible infrared imaging radiometer suite (VIIRS), and information extraction technologies, urban area expansion can be extracted and analyzed at a regional scale. With the proposal of the Beijing–Tianjin–Hebei coordinated development strategy, more and more attention has been paid to Beijing–Tianjin–Hebei urban agglomeration. Thus, it is crucial to quantify and analyze the urban expansion process of this region.

In recent years, many scholars have conducted studies on the expansion characteristics of different cities and the analysis of connections between cities. Research on urban expansion has focused on the spatiotemporal characteristics of the expansion,[2–4] driving force analysis,[5–7] and predictive models.[8] Huang *et al.*[2] studied the method of monitoring urban expansion using multisource nighttime light data, optimized the method of selecting fitting samples in the integration process of multisource nighttime light data, and carried out monitoring of urban expansion in the Chengdu–Chongqing area over the last 15 years. Xia *et al.*[6] used a series of Landsat remote sensing images as data sources, identified urban construction land, combined this with a series of urban expansion evaluation indicators and socio–economic statistical data, and analyzed the temporal and spatial characteristics and driving forces of urban expansion in Hefei in the past 20 years. On the basis of the Artificial Neural Network–Agent Based Model–Cellular Automata (ANN–ABM–CA) coupling model, Tao *et al.*[8] simulated the expansion of the main urban area of Wuhan from 2005 to 2015 by considering the decision–making behavior of agents at the macro and micro levels and combining that with 10 driving forces of urban expansion. The research on urban spatial connections primarily includes three areas: research on the strength and direction of urban spatial connections,[9,10] research on the analysis of regional urban functions using an urban flow intensity model,[11] and research on the analysis of regional spatial connections based on a combination of these two areas.[12] On the basis of the revised gravity model, Li and Xiang[10] measured the strength of spatial connections between Xi'an and other central cities in central and western China and other cities with respect to their urban agglomeration and compared and analyzed the gap in and causes of spatial connection ability between Xi'an and other central cities in central China. An *et al.*[12] made comprehensive use of a gravity model, a fracture point model, and an urban flow intensity model to analyze the overall characteristics of the spatial linkages of cities within the Beijing–Tianjin–Hebei urban agglomeration.

In summary, although many studies have been carried out on urban spatial expansion and urban connection, few studies have integrated these two concepts and analyzed the connection of the Beijing–Tianjin–Hebei urban agglomeration from the perspective of an axis of development. On the basis of domestic land cover data, nighttime light data, and population and economic data, we analyzed the expansion characteristics of the Beijing–Tianjin–Hebei urban agglomeration from 2000 to 2021 as well as the characteristics of the connections between the three axes of Beijing–Tianjin, Beijing–Baoding–Shijiazhuang, and Beijing–Tangshan–Qinhuangdao. We studied urban area extraction technologies on the basis of data from remote sensing satellite sensors of TM, ETM+, OLI, and VIIRS, geographic information system (GIS) analysis, and multidata analysis technologies to reveal the rules of changes in urban expansion and existing problems in the current development of the Beijing–Tianjin–Hebei region. We then offer some administrative suggestions for strengthening the spatial connections and promoting the coordinated development of the Beijing–Tianjin–Hebei urban agglomeration.

2 Study Area and Materials

2.1 Study area

We selected the Beijing–Tianjin–Hebei urban agglomeration as our study area. This region consists of Beijing, Tianjin, and Hebei Province and has a total area of 218000 km^2. It is located in the northern part of the North China Plain, adjacent to Taihang Mountain in the west, Yanshan Mountain in the north, and the Bohai Sea in the east. The region enjoys a warm temperate continental monsoon climate.(5) The Beijing–Tianjin–Hebei urban agglomeration, together with the Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration, is one of the three major urban agglomerations, is the center of social and economic development in the North of China, and is the bellwether of the Bohai Sea economic circle.(13)

2.2 Materials

(1) Domestic land cover data

GlobeLand30 is a global geographic information public product provided by China. Generated from Landsat data, GlobeLand30 contains information from 2000, 2010, and 2020, and includes 10 first–level land cover categories:(14) artificial surfaces, cultivated land, woodland, grassland, shrub land, wetland, water bodies, tundra, bare land, glaciers, and permanent snow cover. The artificial surfaces are mainly cement, asphalt, and other hardened surfaces, and cultivated land consists of agricultural planting surfaces containing all cash crops.

(2) Nighttime light data

Annual composite National Polar–orbiting Partnership–Visible Infrared Imaging Radiometer Suite (NPP–VIIRS) nighttime light data were used in the study; these data excluded the effects of lightning, moonlight exposure, cloud coverage, and random noise. The annual nighttime light data of the Beijing–Tianjin–Hebei area from 2012 to 2021 were used for spatiotemporal analysis.

(3) Population and economic data

GDP and permanent resident population data were obtained from the national economic and social development bulletins and statistical yearbooks of cities in the Beijing–Tianjin–Hebei region.

3. Methods

3.1 Urban expansion analysis

Urban expansion analysis methods used in this study include urban area extraction, urban expansion rate, expansion intensity, average light intensity, light growth rate, and total light intensity variation coefficient.

(1) Urban area extraction

The category of artificial surface in GlobeLand30 was used as the urban area. By registration, cutting, and threshold extraction of the nighttime light data with GlobeLand30, results for the urban area in the years 2000, 2010, and 2012–2021 were obtained.

(2) Urban expansion rate

Urban expansion rate is the ratio of the difference between the area of artificial surface during the period of interest and the immediately previous period to the area of the immediately previous period.

(3) Urban expansion intensity

Urban expansion intensity is the ratio of the difference between the area of artificial surface of the period of interest and the previous period to the total area being studied.

(4) Average light intensity

The average light intensity of a region is calculated by multiplying the light brightness value by the area over which the light brightness was determined and dividing that product by the total area of the region. The equation is as follows:

$$DN_{mean} = \frac{\sum_{DN_i=DN_{min}}^{DN_{max}} DN_i \times n_i}{N_j}, \tag{1}$$

where DN_{mean} represents the average value of the light brightness, DN_{min} represents the minimum value of light brightness, DN_{max} represents the maximum value of light brightness, n_i represents the number of pixels whose brightness is DN_i , and N_j represents the total number of pixels.

(5) Light growth rate

The regional light growth rate is calculated by subtracting the average light intensity of the current period from the average light intensity of the previous period and then dividing that difference by the average light intensity of the previous period. The equation is as follows:

$$R_{DN\_m} = \frac{DN_{mean\_m} - DN_{mean\_n}}{DN_{mean\_n}}, \tag{2}$$

where R_{DN_m} represents the light growth rate, and DN_{mean_m} and DN_{mean_n} represent the average light brightness of year m and n, respectively.

(6) Variation coefficient of light intensity

The variation coefficient of regional total light intensity is obtained by dividing the standard deviation of the regional total lighting by the average value of the regional total lighting. The equation is as follows:

$$TNL = \sum_{DN_i=DN_{min}}^{DN_{max}} DN_i \times n_i, \tag{3}$$

$$CV\left(TNL\right)=\frac{S\left(TNL\right)}{M\left(TNL\right)}, \tag{4}$$

where TNL represents the total light intensity, DN_i represents the light brightness, n_i represents the number of pixels whose brightness is DN_i, $S(TNL)$ is the standard deviation of the total light intensity, and $M(TNL)$ is the average value of the total light intensity.

3.2 Correlation analysis

Previous studies(15,16) have proved that nighttime light correlates strongly with GDP and population. A regression analysis was carried out with the average nighttime light intensity of 13 cities in Beijing, Tianjin, and Hebei Province from 2012–2021 and the regional gross economic product and population.

3.3 Analysis of inter-city connection strength

(1) Inter-city connection strength

The inter-city connection strength is calculated using the city scale index and the actual travel distance between cities. The city scale index is calculated using the city light intensity, which represents the intensity of human activities in the cities, and the inter–city travel distance represents the accessibility between the cities by road. The equations for the gravity model and action potential model of inter–city connection strength are as follows:(17)

$$Scale_i = I \times B = \left[\sum_{k=m}^{n}\left(N_k \times S_k\right)\right] \times \frac{A_i}{A_0}, \tag{5}$$

where $Scale_i$ is the city scale index; N_k is the gray value of the Kth pixel in the city. The term S_k is the total number of pixels with the grayscale value of the Kth pixel in the city, m is the initial threshold point ($m = min = 1$), n is the end threshold point ($n = max$), A_i is the area of the grayscale value of i pixel of the city between the initial threshold and the end threshold, and A_0 is the total area of all cities that meet the grayscale threshold range of the pixels.

$$VCSI_{ij} = K\frac{Scale_i^a\,Scale_j^b}{D_{ij}^c}\left(i \neq j; i \in \left[1, p\right]; j \in \left[1, q\right]\right), \tag{6}$$

where $VCSI_{ij}$ is the connection strength index between city i and city j. The value K is the proportion coefficient; $Scale_i$ and $Scale_j$ are the regional size indices of the starting and destination cities, respectively. The values a and b are the potential indices of urban factor flow generating internal aggregation and external diffusion; D_{ij} is the actual travel distance between city i and city j, and c is the damping coefficient of the distance effect, which is reflected as the distance decay rate of the interregional attraction force of cities.

(2) Total urban connection strength

The total connection strength refers to the sum of the connection strengths between the city of interest and the other cities.

The actual travel time between two city centers was adopted as the distance between cities, and the shortest time required by high-speed rail or highway was selected for the calculation using Baidu map route planning.

Owing to the large gap in economic development levels and accessibility of various cities, significant differences arise in the connection strength among the cities. The value of connection strength is divided into four levels: first-, second-, third-, and fourth-level connection degrees by the ninth, eighth, seventh, and sixth power of 10, respectively.

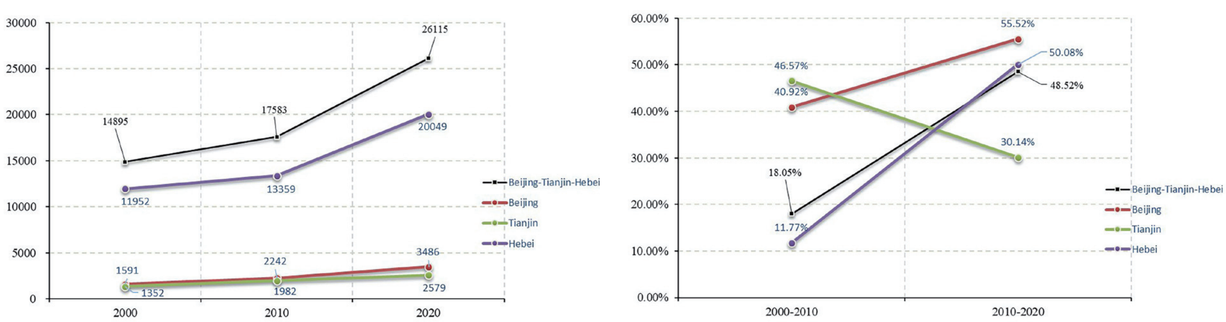
4. Results

4.1 Spatiotemporal characteristics of urban expansion of the Beijing–Tianjin–Hebei region

Figures 1 and 2 show urban expansion statistics and spatial distribution in the Beijing–Tianjin–Hebei region. In terms of urban expansion scale and rate, compared with the 2000–2010 period, the expansion rate of Beijing, Tianjin, and Hebei increased by 42.52% in the past 10 years, which is nearly 2.7 times that of the 2000–2010 period. Beijing is gradually stabilizing, Hebei is in the stage of rapid expansion, and Tianjin is in the stage of decelerating expansion. The east and south areas of the Beijing–Tianjin–Hebei region show stronger urban expansion than the areas of other directions.

The nighttime light is highly correlated with GDP and population. For example, Fig. 3(a) shows a strong linear correlation between nighttime light intensity and GDP; the coefficient of determination (R^2) is above 0.7. Therefore, nighttime light data can be used to comprehensively reflect the development of urban space.

From the perspective of the brightness of nighttime light, the growth rate of cities around Beijing is relatively faster than those around other cities. Langfang and Baoding have shown the



(a) (b)

Fig. 1. (Color online) (a) Surface area and (b) expansion rate of artificial land in Beijing, Tianjin, and Hebei from 2000 to 2020.

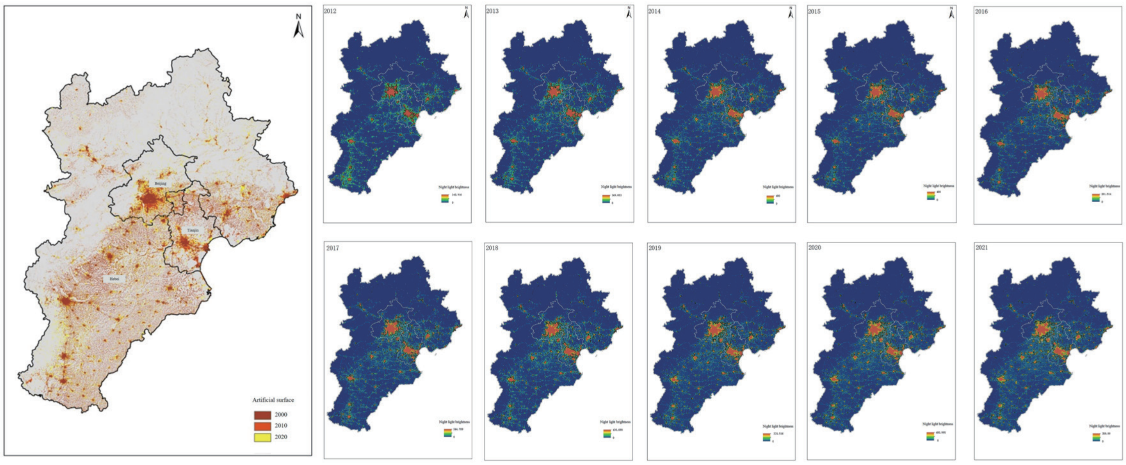
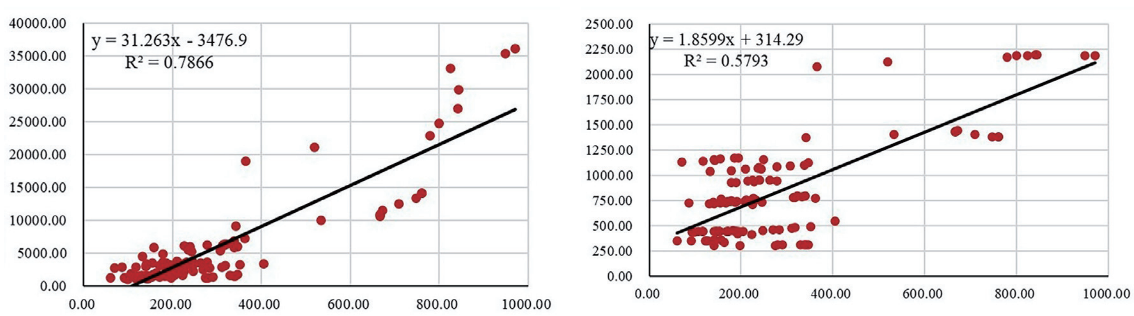


Fig. 2. (Color online) Urban expansion map of the Beijing–Tianjin–Hebei region from 2000 to 2021.



(a) (b)

Fig. 3. (Color online) Correlation between (a) nighttime light and GDP and (b) nighttime light and population.

most significant average growth in the past 10 years, exceeding those of Beijing and Tianjin (Fig. 4). In addition, the overall brightness of Beijing has increased, especially in key areas such as the Yanqing Winter Olympic Zone and Daxing Airport in the south. A small number of areas, such as the cities of Handan and Xingtai, showed negative growth of light, which may be due to the reduction of human activities in the southern urban area caused by the reduction of overcapacity in key industries, production reduction in industrial areas, and demolition of buildings.

The coefficient of variation of regional nighttime light can reflect the synergy of development within the region, and a decrease in the coefficient means a decrease in the gap between the comprehensive development of areas within the region. In the past 10 years, the overall development gap within the Beijing–Tianjin–Hebei region has been narrowed. The development gap between cities increased from 2012 to 2016, and the coefficient of variation of total light intensity decreased steadily after 2016 (Fig. 5). This variation reflects that the implementation of the Beijing–Tianjin–Hebei coordinated development strategy has enhanced the driving role of the region's urban agglomeration, and that the spatial heterogeneity has gradually weakened, narrowing the gap between the cities.

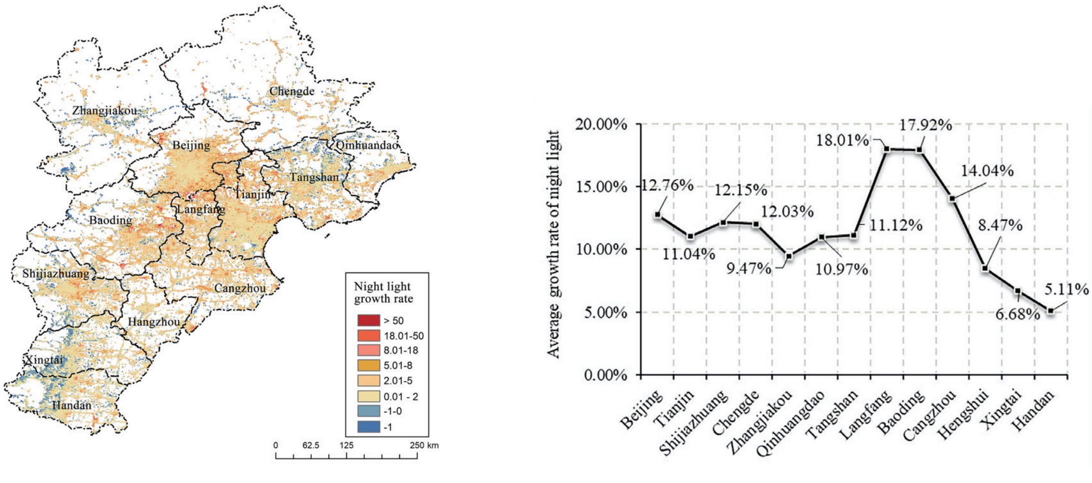


Fig. 4. (Color online) Spatial distribution of (a) nighttime light growth rate and (b) average growth rate of nighttime light by city in the Beijing–Tianjin–Hebei area from 2012 to 2021.

Fig. 5. Coefficient of variation of total light intensity in the Beijing–Tianjin–Hebei region from 2012 to 2021.

4.2 Characteristics of expansion around Beijing and in the capital metropolitan area

As shown in Fig. 4, the growth rate of cities around Beijing was faster owing to urban expansion as reflected in measurements of nighttime light brightness. For the border area between Beijing and the surrounding provinces and cities (in the buffer zones 1, 2, and 5 km around Beijing) as shown in Fig. 6, there is an obvious feature arising from construction at the borders.

The capital metropolitan area, which is 50 km from Tian'anmen (the center point of Beijing) showed the highest expansion intensity and showed a circle-like expansion trend. In the recent 10 years, the capital metropolitan area has been expanding in directions east and north, showing a spindle-like structure [Fig. 7(a)]. From 2000 to 2010, the intensity of the expansion of the capital metropolitan area was higher in the southeast but lower in the northwest. From 2010 to 2020, the intensity in the northeast and north was high, whereas it was low in the west.

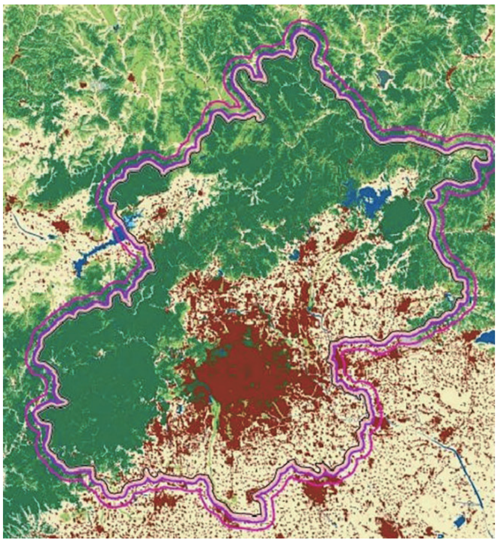
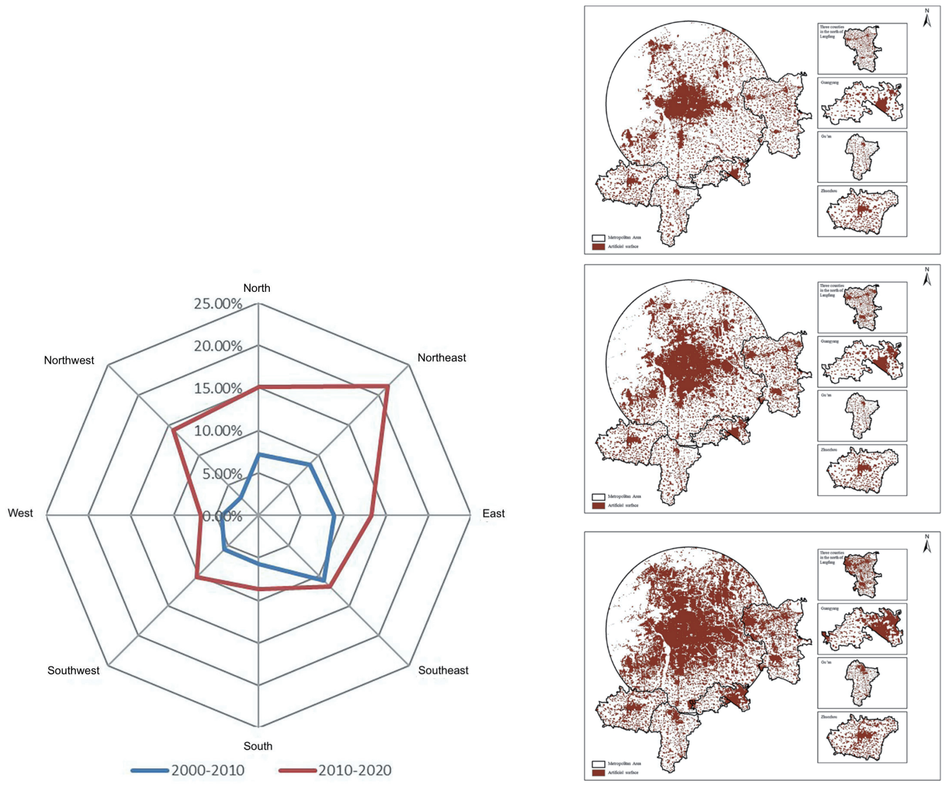


Fig. 6. (Color online) A spatial distribution map for the buffer zones 1, 2, and 5 km around Beijing in 2020.



(a) (b)

Fig. 7. (Color online) The intensity of expansion of the metropolitan area (a) in all directions and (b) as shown in expanded spatial distribution maps of artificial surface in the capital metropolitan area (years 2000, 2010, and 2020 from top to bottom).

In the metropolitan area, three counties in the north of Langfang (Sanhe, Dachang Hui Autonomous County, and Xianghe County), Gu'an, Guangyang, and Zhuozhou in Hebei have a strong momentum of expansion, which indicates the overall role of integration and development in the capital metropolitan area. Among them, Gu'an County's expansion rate in the past 10 years was about 10 times that in 2000–2010, and Guangyang District's expansion rate doubled in the past 10 years.

4.3 Analysis of urban connection in the Beijing–Tianjin–Hebei region

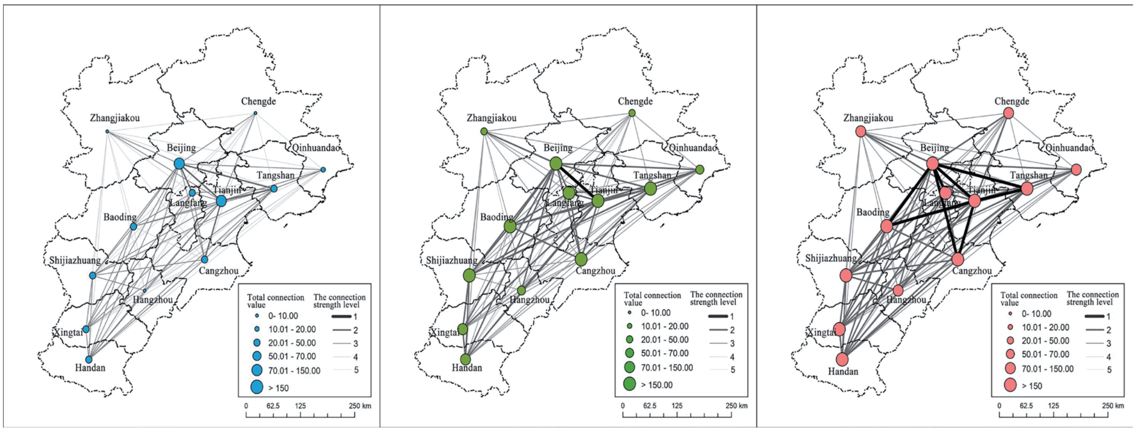
Beijing and Tianjin show the spatial agglomeration mode of dual-core and multicenter development, and the dual-core status is very stable. Relying on its unique regional advantages in the Beijing–Tianjin corridor, Langfang has experienced rapid urban expansion. Tianjin displays a tendency to expand to the northeast and southwest, and the size of the cities of Langfang and Tangshan has been expanded. The northeast region formed a coastal cluster development area with Tianjin as the core. Different degrees of urban clusters have been formed in the southwest region, with Shijiazhuang as the core city. A large gap still exists between Baoding, Shijiazhuang, and Tangshan and Beijing and Tianjin, but the development trend is obvious.

Compared with 2012, the total urban connection value of the Beijing–Tianjin–Hebei region increased significantly in 2021 (Table 1). The number of cities whose total connection value exceeded 150 increased from 0 in 2012 to 9, and the number of city pairs with first-level connections increased from 0 to 8. After 2017 [the year of the release of the "Beijing Urban Master Plan (2016–2035)"], the number of city pairs with first-level connections increased from only Beijing and Tianjin to 8 city pairs (Fig. 8).

Driven by the Beijing–Tianjin axis, Beijing–Baoding–Shijiazhuang axis, and Beijing–Tangshan–Qinhuangdao axis, the development trend of artificial surfaces in surrounding

Table 1
Ranking of the values of total urban connection in 2012 and 2021.

2012			2021		
No	City	Total connection value (10^7)	No	City	Total connection value (10^7)
1	Beijing	120.43	1	Beijing	1300.45
2	Tianjin	108.68	2	Tianjin	1062.66
3	Tangshan	47.22	3	Langfang	451.54
4	Handan	37.56	4	Tangshan	440.25
5	Shijiazhuang	34.08	5	Baoding	424.01
6	Xingtai	28.55	6	Cangzhou	405.87
7	Cangzhou	27.66	7	Shijiazhuang	352.10
8	Langfang	24.81	8	Handan	245.48
9	Baoding	24.74	9	Xingtai	211.28
10	Qinhuangdao	10.97	10	Qinhuangdao	108.41
11	Zhangjiakou	9.64	11	Hengshui	107.65
12	Hengshui	9.44	12	Zhangjiakou	95.66
13	Chengde	7.14	13	Chengde	95.06



(a) (b) (c)

Fig. 8. (Color online) Connection strength level and total connection value between Beijing, Tianjin, and Hebei; number of city pairs with first-level connection strength. (a) 0 in 2012, (b) 1 (Beijing–Tianjin) in 2017, and (c) 8 (Beijing–Tianjin, Beijing–Baoding, Beijing–Cangzhou, Beijing–Langfang, Beijing–Tangshan, Tianjin–Baoding, Tianjin–Cangzhou, Tianjin–Tangshan) in 2021.

cities is obvious. The average light intensity of each development axis city increased year by year from 2012 to 2021, and the average light intensity of Beijing was much higher than that of other cities. Beijing has the highest driving effect on the Beijing–Tianjin axis, and in 2021, it reached the first level of connection with other cities. In 2021, the connection strength between the cities of the Beijing–Baoding–Shijiazhuang axis reached the second level or above. Among them, Baoding is the city most influenced by Beijing on the axis, and the strength of the Beijing–Baoding connection has reached the first level. In 2021, the connection strength between cities in the Beijing–Tangshan–Qinhuangdao axis reached the second level or above, within which the connection level between Beijing and Langfang and between Beijing and Tangshan reached the first level.

5. Discussion

5.1 Urban spatial expansion and population growth of Beijing–Tianjin–Hebei region

On the whole, the urban spatial expansion of the Beijing–Tianjin–Hebei region correlated well with the growth of the population of permanent residents during 2000–2010, but the urban spatial expansion was significantly faster than the population growth during 2010–2020. In the past 10 years, the growth rate of the permanent resident population of Beijing, Tianjin, and Hebei was 4.09%, and the urban space expansion rate was 48.52% (Table 2). The urban space expansion speeds of Beijing, Hebei, and Tianjin are about 5 times, 33 times, and 4 times the population growth rate, respectively.

Table 2
Comparison of urban spatial expansion and rate of population change in Beijing–Tianjin–Hebei region in the recent 20 years.

	Rate of change in 2000–2010 (%)		Rate of change in 2010–2020 (%)	
	Population	Urban space	Population	Urban space
Beijing–Tianjin–Hebei region	15.87	18.05	4.09	48.52
Beijing	44.54	40.92	11.63	55.52
Tianjin	31.37	46.57	7.17	30.14
Hebei	7.75	11.77	1.48	50.08

Note: The urban space here is represented by the actual artificial surface area.

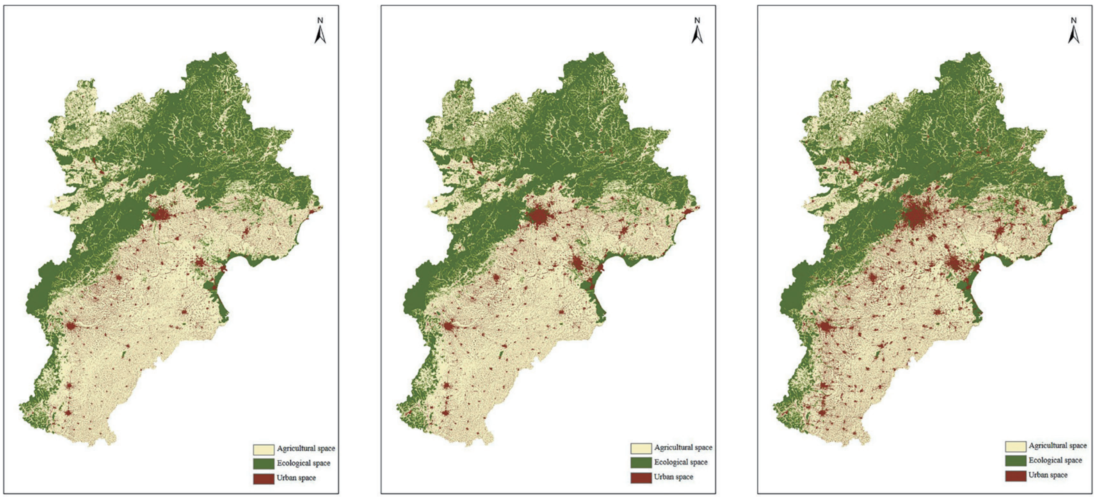
5.2 Spatial structure changes in the Beijing–Tianjin–Hebei region

The urban space, agricultural space, and ecological space of the Beijing–Tianjin–Hebei region were statistically analyzed. On the whole, the urban space of this region gradually expanded, and the agricultural space gradually was reduced (Fig. 9). The ecological space of Beijing decreased slightly from 2000 to 2010, but increased from 2010 to 2020, indicating that the effects of promoting ecological construction and green development gradually emerged after 2010. The ecological space of Hebei and Tianjin decreased slightly. The coordinated governance of ecological space needs to be strengthened.

5.3 Uneven connectivity and uncoordinated development of the cities of Beijing, Tianjin, and Hebei

The urban connections in 2021 between Beijing, Tianjin, and Hebei (Fig. 8) show the characteristics of a double core of Beijing and Tianjin, and uneven relationship between cities. In the Beijing–Tianjin–Hebei region, Beijing and Tianjin are double centers, accounting for the dominant position in the degrees of connection. The total urban connection value of Beijing and Tianjin is more than 1000×10^7, far exceeding other cities. The total urban connection value of Shijiazhuang is even lower than that of Langtang and Changzhou. In addition, except for Beijing and Tianjin, the connection between other cities is weak, and the role of node cities is lacking. On the development axes of Beijing–Tianjin, Beijing–Baoding–Shijiazhuang, and Beijing–Tangshan–Qinhuangdao, the intercity connection strength is the strongest near Beijing and gradually declines outward, and the northern cities are weaker than the central and southern cities. The transportation connection between the northern cities and the central and southern regions is insufficient, and the connection degree is weak. Some cities, such as Zhangjiakou, Hengshan, Qinhuangdao, and Chengde, have relatively weak connection levels with other cities, and the total connection value is relatively small.

In recent years, the capital metropolitan area has expanded rapidly toward the east and north. From the perspective of the surrounding area of Beijing, although the development of the northwest area of Beijing–Tianjin–Hebei has accelerated in recent years, it is still relatively weak compared with the northeast, southwest, and southeast.



(a) (b) (c)

Fig. 9. (Color online) Spatial distribution map of land surface in the Beijing–Tianjin–Hebei region. (a) 2000, (b) 2010, and (c) 2020.

6. Conclusions and Suggestions

We studied urban area extraction technologies based on data from remote sensing satellite sensors of TM, ETM+, OLI, and VIIRS, GIS analysis, multidata analysis technologies for urban expansion extraction, and urban connection analysis of urban agglomeration. Using the relevant materials, including land cover product, nighttime light data, as well as socioeconomic data, urban expansion and urban connection characteristics of the Beijing–Tianjin–Hebei region during 2000–2021 were analyzed. The methods in this paper can be used for other urban agglomeration analyses.

6.1 Conclusions

We conclude that the urban expansion and urban connection characteristics of the Beijing–Tianjin–Hebei region are as follows:

(1) The urban space of the Beijing–Tianjin–Hebei region continues to expand. The urban expansion trend around Beijing is significant, and the expansion speed in the east and north is fast, while the southwest and southeast are still weak in comparison.

(2) The connections between the Beijing–Tianjin, Beijing–Baoding–Shijiazhuang, and Beijing–Tangshan–Qinhuangdao development axes have been significantly strengthened since 2017, reflecting the remarkable achievements of coordinated development in the Beijing–Tianjin–Hebei region. Urban connections in the Beijing–Tianjin–Hebei region has two cores, namely, Beijing and Tianjin, leading to the development of the surrounding areas, and the connection in the southern areas is weaker than elsewhere, because of the absence of nodal cities.

(3) On the whole, the urban space of the Beijing–Tianjin–Hebei region is gradually expanding, while the agricultural space is gradually shrinking. The ecological space in Hebei and Tianjin showed a small reduction; thus, the collaborative governance of ecological spaces needs to be strengthened.

6.2 Administrative suggestions

(1) The northwest area around Beijing can be further promoted by driving the effect of the Winter Olympics on regional development. Taking advantage of the road system for the Winter Olympics, those areas can actively undertake the transfer of high-quality elements and industries from Beijing and cultivate snow- and ice-related industries.
(2) Regarding the problems of uneven urban connection and uncoordinated development, both accelerating the cultivation of key node cities (e.g., Shijiazhuang) and promoting coordinated regional development are necessary.
(3) To optimize the spatial pattern, land use efficiency and the coordination of ecological planning and management in the Beijing–Tianjin–Hebei region should be strengthened.

We studied methods of urban expansion extraction and urban connection analysis based on multisensor data for urban agglomeration, and the urban expansion and connection characteristics of the Beijing–Tianjin–Hebei region were analyzed. Other world-class urban agglomerations can be studied using these methods and, by comparing different urban agglomeration characteristics, more useful information can be provided for urban agglomeration development, and additional suggestions for the Beijing–Tianjin–Hebei region to build a world-class urban agglomeration can be offered.

Acknowledgments

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