Spatio-Temporal Dynamics of National Characteristic Towns in China Using Nighttime Light Data

Haipeng Song and Tingting He *

School of Public Affairs, Zhejiang University, Hangzhou 310058, China; shp0808@zju.edu.cn
* Correspondence: tthe@zju.edu.cn

Abstract: Characteristic towns have emerged along with China’s economic and social development. As a new model of small-town development, they have played an essential role in promoting industrial transformation and upgrade, improving the living environment, and promoting regional innovation and development. Accurate identification of the expansion characteristics of National Characteristic Towns (NCTs) is vital for optimizing the spatial layout of characteristic towns and adjusting the policies of characteristic towns. This study used a dataset on nighttime light to identify expanding NCTs and measure their expansion from 2000 to 2020. In total, 233 expanding NCTs were identified, accounting for 58.25% of the NCTs in China. The areas with the most significant intensity of expansion are primarily located in the East, South, and North economic regions. The critical period of NCTs expansion primarily occurred in the periods 2008–2011 and 2011–2014. Our results show that NCTs are highly consistent with the spatial distribution of urban agglomerations, and the development of NCTs is inherently related to the development of urban agglomerations in the region. The implementation of NCT policies has significantly promoted the development of NCTs in the Central and Western economic regions, which face challenging development issues and differ from those in the Eastern region. The method proposed in this study can effectively identify the ‘hot spots’ of expanding NCTs and the critical periods of their expansion.

Keywords: nighttime lights; national characteristic town; urbanization; China

1. Introduction

Urbanization is a global socio-economic and geographical phenomenon, especially for Asia, Africa, and Latin America, characterized by lagging development and predominantly rural population [1,2]. The main manifestations of urbanization are urban expansion and migration of people from rural to urban areas [3,4]. Compared to large cities, small towns lack economic efficiency with social–economic development and suffer from economic decline and population loss, resulting in a spatial form of inequality [5–10]. As a bridge connecting the city and the village, small towns have caused widespread attention, especially in China [11–14].

As a new model of small-town development, characteristic towns emerge with China’s economic and social development and play a significant role in promoting industrial transformation and upgrading, improving the living environment, and promoting regional innovation and development. It has a critical multi-dimensional agglomeration of population, industry, and culture. In 2015, Zhejiang province was the first to promote construction in characteristic towns [15,16]. After learning from the experience of Zhejiang province and considering the uneven development of different regions, the Ministry of Housing and Urban-Rural Development, the National Development and Reform Commission, and the Ministry of Finance issued a joint notice on the development of National Characteristic Towns (NCTs). There were 403 NCTs recognized by the Ministry of Housing and Urban-Rural Development. Given the number of NCTs at the provincial and county levels
established by local governments, the number of NCTs planned for construction is more than 1000 [17].

Characteristic towns have attracted the attention of many scholars in recent years. Four aspects of NCT research have been recognized. First, the connotation research of NCTs [18,19]. NCTs are not a single platform for industrial gathering, but a form of spatial organization of emerging industries that integrate innovation, production, sales, and services of characteristic industries [20,21]. Second, the functions of NCTs were examined. NCTs are an important carrier and development mode of urbanization [22]. The third point is the construction and development path of the NCTs. It includes construction principles, cultural construction, industrial transformation, and other dimensions [23–26]. Fourth, the spatial structure of NCTs was discussed. Current research generally states that NCTs are developing rapidly [27,28]. However, previous research has failed to use reliable data and methods to reflect the status of NCT development [15,25,27].

Are characteristic towns expanding? This paper attempts to explain and elaborate on this question. This study introduced a new method that uses long-time series calibration integral DMSP/OLS and NPP/VIIRS NL data to identify expanding NCTs and measure their expansion. The objectives of this study are to answer several scientific questions. First, what were the spatiotemporal patterns of NCT expansion? Furthermore, what were the spatiotemporal patterns of NCT expansion intensity and the expansion ratio during the study periods? Finally, has the expected goal of expansion been achieved after implementation of NCT policies? This study provides assistance for optimizing the spatial layout of characteristic towns and guiding the adjustment of NCT policies in China.

2. Materials and Methodology

2.1. Study Area

The two main types of characteristic towns include Zhejiang and NCTs in China. Zhejiang characteristic towns are not traditional administrative towns, but integrate industry, community culture, and tourism. NCTs are organized towns with traditional administrative divisions, including distinctive industries, specific populations, and economic scales. In essence, they are an extension of the small-town concept. Small towns refer to communities of a specific size inhabited by people mainly engaged in non-agricultural production activities that differ from large and medium-sized cities and villages. They include state-approved institutional towns and relatively developed rural market towns that have not yet been established.

The main difference between the two versions of characteristic towns is that NCTs focus on organic towns, while Zhejiang characteristic towns focus on industrial development. NCTs have originated from small town development strategies. They are the product of a particular phase of urbanization development. NCTs are proposed from the top down based on the administrative boundaries of organized towns and around their functional positioning [29].

This study focuses on NCTs in mainland China. There are two reasons for this. As a typical representative of small towns, NCTs are the most urbanized small towns (see Table S1 in Supplementary Materials). Second, NCTs are a relatively independent policy target. Identifying the characteristics of NCT expansion is helpful in evaluating the effects of NCTs policy implementation in China.

The NCTs include the first batch of 127 towns in October 2016 [30] and the second batch of 276 towns in August 2017 [31]. The list of NCTs is taken from the official website of the Ministry of Housing and Urban-Rural Development in China. For this study, 400 NCTs were selected to be the focus of research in this article. Three NCTs were not used because of lack of relevant geographic information. Based on the previous studies [32,33], eight economic regions of China were used in this study (Figure 1). Zhejiang province has the highest number of NCTs (23), followed by Jiangsu province and Shandong province, each with 22 NCTs.
2.2. Data Sources

Presently, two types of data are used to analyze dynamic information about characteristic towns. The first type of data refers to social and economic statistics based on administrative units. The second is remote sensing data with medium resolution provided by Landsat Thematic Plotter images [34]. There has always been an objective problem in the research of characteristic towns, i.e., the imperfect mechanism of township statistics leads to a lack of research data, which hinders the development of quantitative research such as model evaluation and quantitative measurement [35].

Nighttime lights across the Earth’s surface provide a distinctive and effective perspective for observing human activities [36–39]. Remotely sensed nighttime lights have been shown to correlate with socioeconomic parameters such as population [40–42], economic activity [43], poverty [44,45], and urbanization dynamics [46]. Remote sensing and nighttime light data are beneficial for their fast acquisition and updating, strong anti-interference ability, high resolution, lack of light overflow, and intuitive reflection of spatial development dynamics [46].

DMSP/OLS and NPP/VIIRS data show significant differences in sensor parameters, spatial resolution, and spectral response mode between different years, so they cannot be used directly for comparative analysis. Therefore, this study requires the systematic correction and integration of DMSP/OLS and NPP/VIIRS NL data from 2000 to 2020. In turn, the integration of nighttime light data correction includes DMSP/OLS nighttime light data correction, NPP/VIIRS nighttime light data correction, DMSP/OLS and NPP/VIIRS nighttime light data integration (Table 1). This study adopted a dataset corrected by Chen [48]. This dataset provides long-term stable nighttime light data and is recorded as a digital number (DN).

**Table 1.** Description of data used in this study.

| Data       | Data Description                                                                 | Time Range  | Data Source                                                                                                                                 |
|------------|----------------------------------------------------------------------------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| DMSP/OLS   | Annual nighttime stable light data from Version 4 DMSP/OLS Nighttime Light Time Series datasets | 2000–2020   | https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/YGIVCD (accessed on 20 October 2021)                             |
| NPP/VIIRS  | Monthly nighttime light data from Version 1 VIIRS Day/Night Band Nighttime Light datasets | 2019        | National Catalogue Service for Geographic Information (https://www.webmap.cn/commres.do?method=result100W) (accessed on 20 October 2021) |
| Boundaries | Shape file of county, provincial, and national level regions                      |             |                                                                                                                                           |
2.3. Overview Methods

Figure 2 shows the main steps in this study. First, we identified the expansion of NCTs throughout the study period and focused on the expansion of each town every three consecutive years by proposing an Expanding NCTs Identification Index (ECII) (Section 2.4). This paper used adjusted and integrated nighttime lights datasets from 2000 to 2020. Then, to further quantify the degree of expansion of characteristic towns, we measured the expansion of NCTs, as well as analyzed their expansion patterns in China. For this, we used two indices named the Characteristic towns Expansion Intensity Index (CEII) and the Characteristic towns Expansion Ratio Index (CERI) (Section 2.5).

![Figure 2](image.png)

**Figure 2.** Procedures for quantification of expanding NCTs using nighttime light data.

2.4. Identification of Expanding Characteristic Towns

Population loss and economic recession are the two most commonly used indicators to identify expanding cities [49]. Thus, the basic assumption is that changes in nighttime
lights reflect changes in population and economy. Based on previous studies on long-term nighttime light data, we defined an expanding characteristic town as one with a substantial amount of light brightness that is constantly growing. There are two criteria for these towns: annual growth of over 0.01 for more than three consecutive years or more than half of the study period. We decided to use these criteria for the following reasons. First, with regard to research [44], it seems reasonable to set 0.01 as the threshold. Second, due to accidental errors, it is necessary to perform analyses on DN ranging from 0 to 63 years by year in order to exclude occasional expansion of NCTs. Third, based on a previous study [50], we set continuous growth over more than three consecutive years as the standard for the continuously expanding characteristic towns and over one-third of the study period for frequently expanding characteristic towns.

To comprehensively understand expanding characteristic towns, we proposed to expand the Characteristic Towns Identification Index (ECII), which is calculated from year to year based on Total Digital Numbers (TDN) from 2000 to 2020. This approach helps to ensure reliable results. Equation (1) applies to nighttime lights data from 2000 to 2020:

\[
ECII_{(t,t+1)}(c) = \frac{TDN_{t+1}(c) - TDN_t(c)}{TDN_t(c)}
\]  

where \( ECII_{(t,t+1)}(c) \) is the ECII of the NCTs \( c \) from the \( t \)th year to \( (t+1) \)th year; and \( TDN_{t+1}(c) \) and \( TDN_t(c) \) are the TDN values of the characteristic towns \( c \)th in \( (t+1) \)th year and \( t \)th year, respectively.

Based on the previously mentioned definition of expanding characteristic towns, we set three years as the study period. We identified expanding characteristic towns covering 21 years (2000–2020) as well as every three-years between 2000 and 2020, respectively.

During the study period, we examined each characteristic town year by year to identify whether the characteristic towns were expanding between two adjacent years using Equation (2) as follows:

\[
M_{(t,t+1)}(c) = \begin{cases} 
1, & \text{if } ECII_{(t,t+1)}(c) > 0.01 \\
0, & \text{if } ECII_{(t,t+1)}(c) \leq 0.01
\end{cases}
\]  

where \( M_{(t,t+1)}(c) \) is set as 1, and the characteristic town \( c \) is expanding in these two years.

Furthermore, we calculated the expansion of characteristic towns on a time scale of three consecutive years in order to identify the continuously expanding characteristic towns and during the whole study period in order to identify the frequently expanding characteristic towns. Then, we used Equation (3) to check whether the characteristic towns were actually expanding characteristic towns:

\[
EC(c) = \begin{cases} 
1, & \text{if } M_{(t,t+1)}(c) = 1 \& M_{(t+1,t+2)}(c) = 1 \& M_{(t+2,t+3)}(c) = 1 \\
0, & \text{if } M_{(t,t+1)}(c) = 1 \& M_{(t+1,t+2)}(c) = 1 \& M_{(t+2,t+3)}(c) \neq 1
\end{cases}
\]  

where \( EC(c) = 1 \), the characteristic town \( c \) can be regarded as expanding characteristic towns. \( M_{(t,t+1)}(c) \) is built on Equation (2), where \( t \) refers to the consecutive year in the study period. Furthermore, \( x \) is the number of one-year units in the study period. When the calculation is from 2000 to 2020, then \( x \) is 21. When it is 2000–2002, 2002–2005, . . . , 2017–2020, then \( x \) is 3. When \( x \) is the total number of periods in 1-year units from 2000 to 2020, as the value of \( x/2 \) shall be an integer, we set the value of this study as 10 (10.5).
2.5. Measuring the Expansion of Characteristic Towns

For nighttime light data, it is common to see non-expanding and expanding pixels in the same town. Every characteristic town also displays both pixels. In this study, we mainly focused on expanding pixels. We experimented with values of 0.1, 0.15, 0.2, 0.25, and 0.3 and finally selected 0.15 as the optimal threshold value. Pixels with a DN increase of over 0.15 compared to the previous year are defined as expanding pixels, otherwise as non-expanding pixels. The sum of DN increase in NCTs is defined as the characteristic town expansion intensity. Meanwhile, the characteristic town expansion ratio defined the proportion of these expanding pixels to the total number of lit pixels in NCTs.

Initially, we identified a pixel \( i \) in characteristic towns as an expanding pixel in cases where its DN increased by more than 0.15 from year to year. The Expanding Pixel Identification Index (EPII) in characteristic towns is calculated as follows:

\[
EPII_{t(t+1)}(i) = \begin{cases} 
1, & \text{if } \frac{DN_{i(t+1)}(i) - DN_{i(t)}(i)}{DN_{i(t)}(i)} > 0.15 \\
0, & \text{if } \frac{DN_{i(t+1)}(i) - DN_{i(t)}(i)}{DN_{i(t)}(i)} \leq 0.15 
\end{cases}
\]  

where if the DN of pixel \( i \) in the characteristic towns \( i \) increased above 0.15 from \( t \) year to \( (t + 1) \) year, then the value of \( EPII_{t(t+1)}(i) \) is 1, meaning that pixel \( i \) was an expanding pixel in characteristic towns.

To qualify the expansion intensity of each characteristic town, we proposed the Characteristic Towns Expansion Ratio Index (CERI). In that case, we undertook the annual calculation of each characteristic town using Equation (5) on nighttime lights data from 2000 to 2020.

\[
CERI_{t(t+1)}(n) = \sum (DN_{i(t)}(n) - DN_{i(t+1)}(n)) 
\]

\( CEII_{t(t+1)}(n) \) is the \( CEII \) of the characteristic towns \( n \)th from the \( t \)th year to the \( (t + 1) \)th year. The \( DN_{i(t)}(n) \) and \( DN_{i(t+1)}(n) \) represent the DN values of the \( t \)th expansion pixel in the characteristic towns \( n \)th in the \( t \)th year and \( (t + 1) \)th year.

We proposed the Characteristic Towns Expansion Ratio Index (CERI) to measure the characteristic towns’ expansion ratios. Therefore, we calculated the expansion ratio of each characteristic town with Equation (6) on nighttime lights data from 2000 to 2020.

\[
CERI_{t(t+1)}(n) = \frac{NEP_{t+1}(n)}{NP_{t}(n)} \times 100\%
\]

\( CERI_{t(t+1)}(n) \) shows the \( CERI \) of characteristic towns \( n \)th from the \( t \)th year to \( (t + 1) \)th year. \( NEP_{t+1}(n) \) represents the number of expanding pixels of the characteristic towns from the \( t \)th year to the \( (t + 1) \)th year in the characteristic towns \( n \)th. \( NP_{t}(n) \) represents the total number of lit pixels of the characteristic towns in the \( t \)th year.

To understand the patterns of expansion of characteristic towns, we calculated the average \( CEII \) of each characteristic town during 2000–2020:

\[
M_{CEII(n)} = \frac{\sum_{i=1}^{y} CEII_{t(t+1)}(n)}{y}
\]

where \( M_{CEII(n)} \) is the average \( CEII \) of characteristic towns \( n \) from 2000 to 2020. \( CEII_{t(t+1)}(n) \) is \( CEII \) from \( t \) year to \( (t + 1) \). For \( t \in [1, 21], y \) represents the 21 years (2000–2020) in this study. Moreover, this study includes the CERI averages of each characteristic town from 2000 to 2020, which were calculated using Equation (8) as follows.

\[
M_{CERI(n)} = \frac{\sum_{i=1}^{y} CERI_{t(t+1)}(n)}{y}
\]
where $M_{CERI(t)}$ is average CERI of expanding characteristic towns $n$ from 2000 to 2020. $CERI_{t}(n)$ is CERI from $t$ year to $(t+1)$. For $t \in [1,21]$, $y$ represents the 21 years (2000–2020) in this study.

For the convenience of subsequent analysis, we classified CEII into five categories (low, relatively low, moderate, relatively high, and high) using the natural breaks method. This classification method has the advantage of generating minor variances among categories without the influence of artificial factors [51,52]. Meanwhile, we used the natural breaks method to classify CERI into five categories: less than 10%, 10–15%, 15–20%, 20–25%, and more than 25%.

3. Results

3.1. Spatial Distribution of Expanding NCTs

To analyze the spatio-temporal dynamics of NCTs in China over 21 years, we identified expanding NCTs using nighttime light data from 2000 to 2020. There are 233 expanding NCTs, which account for 58.25% of the total of 400 NCTs. Typical characteristics of the spatial agglomeration are mainly distributed in the coastal areas, especially the three major urban agglomerations in the eastern zones (Figure 3).

![Figure 3. Spatial distribution of expanding NCTs in China.](image)

There are 77 expanding NCTs in the first batch of NCTs, or more specifically 19.25% (the first batch of NCTs accounted for 31.5%). In total, 156 expanding NCTs are recognized in the second batch of NCTs, or more specifically 39% (the second batch of NCTs accounted for 68.5%).

Regarding the types of expanding NCTs, there are 204 continuous expanding NCTs and 149 frequently expanding NCTs. They are located in the East, South, and North economic regions and make up more than 50% of continuously expanding and frequently expanding NCTs (see details in Table S2 in Supplementary Materials).

At the level of economic regions, regional differences in the spatial distribution of national expanding NCTs are evident. Expanding NCTs are mainly located in the East (48), North (35), and South economic regions (33). Expanding NCTs in the SW account for 20.6%, followed by 15.02% in the MYR and 14.16% in the Central region. The economic regions of NCTs are unevenly distributed, which shows that the characteristics of spatial distribution are more present in the East, and less frequent in the Central and West regions. Among the
eight economic regions, the proportional expansion of NCTs is the highest in the leading economic regions such as East (88.889%), South (80.488%), and North (76.087%).

Table 2 shows that Zhejiang province, Jiangsu province, Guangdong province, Shandong province, and Fujian province ranked among the top five. The number of expanding NCTs in provinces is as follows: 20 in Zhejiang province, 20 in Jiangsu province, 18 in Guangdong province, 15 in Shandong province, and 11 in Fujian province (Table 2). The proportion of expanding NCTs (B) is as follows: 8.584% in Jiangsu province, 8.584% in Zhejiang province, 7.725% in Guangdong province, 6.438% in Shandong province, and 4.721% in Fujian province. The spatial distribution of expanding NCTs shows a decreasing trend from the East and South economic regions to the Central and NW economic regions.

Table 2. Statistics on the expanding NCTs in China.

| Economic Region | Province     | Number of Expanding NCTs | Proportion of Expanding NCTs A (%) | B (%) |
|-----------------|--------------|--------------------------|-----------------------------------|-------|
| NE              | Jilin        | 2                        | 6.061                             | 0.858 |
|                 | Liaoning     | 8                        | 24.242                            | 3.433 |
|                 | Heilongjiang | 4                        | 12.121                            | 1.717 |
|                 | Total        | 14                       | 42.424                            | 6.009 |
| North           | Beijing      | 7                        | 15.217                            | 3.004 |
|                 | Tianjin      | 4                        | 8.696                             | 1.717 |
|                 | Hebei        | 9                        | 19.565                            | 3.863 |
|                 | Shandong     | 15                       | 32.609                            | 6.438 |
|                 | Total        | 35                       | 76.087                            | 15.021|
| East            | Shanghai     | 8                        | 14.815                            | 3.433 |
|                 | Jiangsu      | 20                       | 37.037                            | 8.584 |
|                 | Zhejiang     | 20                       | 37.037                            | 8.584 |
|                 | Total        | 48                       | 88.889                            | 20.601|
| South           | Guangdong    | 18                       | 43.902                            | 7.725 |
|                 | Hainan       | 4                        | 9.756                             | 1.717 |
|                 | Fujian       | 11                       | 26.829                            | 4.721 |
|                 | Total        | 33                       | 80.488                            | 14.163|
| MYR             | Shanxi       | 10                       | 18.868                            | 4.292 |
|                 | Shaanxi      | 5                        | 9.434                             | 2.146 |
|                 | Henan        | 6                        | 11.321                            | 2.575 |
|                 | Inner Mongolia | 8                  | 15.094                            | 3.433 |
|                 | Total        | 29                       | 54.717                            | 12.446|
| Central         | Anhui        | 9                        | 15.254                            | 3.863 |
|                 | Jiangxi      | 3                        | 5.085                             | 1.288 |
|                 | Hubei        | 8                        | 13.559                            | 3.433 |
|                 | Hunan        | 4                        | 6.780                             | 1.717 |
|                 | Total        | 24                       | 40.678                            | 10.3  |
| SW              | Sichuan      | 8                        | 10.667                            | 3.433 |
|                 | Guangxi      | 8                        | 10.667                            | 3.433 |
|                 | Yunnan       | 7                        | 9.333                             | 3.004 |
|                 | Guizhou      | 4                        | 5.333                             | 1.717 |
|                 | Chongqing    | 5                        | 6.667                             | 2.146 |
|                 | Total        | 32                       | 42.667                            | 13.734|
| NW              | Gansu        | 5                        | 12.821                            | 2.146 |
|                 | Qinghai      | 3                        | 7.692                             | 1.288 |
|                 | Ningxia      | 3                        | 7.692                             | 1.288 |
|                 | Xizang       | 1                        | 2.564                             | 0.429 |
|                 | Xinjiang     | 6                        | 15.385                            | 2.575 |
|                 | Total        | 18                       | 46.154                            | 7.725 |

Note: A represents the proportion of expanding NCTs in the region in relation to the total number of NCTs in the region, while B represents the proportion of expanding NCTs in the region in relation to the number of expanding NCTs in China.

3.2. Temporal Changes in the Number of Expanding NCTs

Over time, the number of expanding NCTs changed from 2000 to 2020. The expansion trend began with 10 expanding NCTs in the period between 2002 and 2005, rising to 32 between 2005 and 2008, followed by a decline to 30 between 2008 and 2011. Later, there
was an increase to 55 between 2011 and 2014, followed by a final increase to 101 between 2017 and 2020. In other words, the number of expanding NCTs peaked during two periods: 2005–2008 and 2017–2020 (Figure 4).

![Figure 4. Temporal changes in expanding NCTs in China.](image)

Figure 4 shows the cyclical change in the increase and decrease in the number of expanding NCTs. In the period between 2002 and 2005, economic regions had the fastest expansion of NCTs. These are NE, NW, North, and South economic regions, all having two expanding NCTs. Between 2005 and 2008, the expanding NCTs were primarily concentrated in the South (19 expanding NCTs) and East (13 expanding NCTs) economic regions. Later, for the 2008–2011 period, the expanding NCTs were located mainly in the South (8 expanding NCTs) and MYR (6 expanding NCTs) economic regions. Compared to the 2005–2008 period, the number of expanding NCTs appears to have declined rapidly. However, the number of expanding NCTs continued to grow in the 2011–2014 period, reaching its peak in the 2017–2020 period (Figure 4).

Figure 5 shows that expanding NCTs are primarily located in three major urban agglomerations, i.e., in the urban agglomerations of the Pearl River Delta, the Yangtze River Delta, and the Beijing–Tianjin–Hebei area. The location of expanding NCTs is highly correlated with the development of urban agglomerations. This study presents a development model linking NCT development with urban agglomerations.
Figure 5. Spatiotemporal changes in expanding NCTs in China: (a) 2002–2005, (b) 2005–2008, (c) 2008–2011, (d) 2011–2014, (e) 2014–2017, (f) 2017–2020. Period from 2000 to 2002 was not mapped because there were no expanding NCTs.
3.3. NCT Expansion Intensity and Ratio

NCT expansion intensity includes low, relatively low, intermediate, relatively high, and high levels. Among the expanding NCTs in China from 2000 to 2020, the expansion intensity was predominantly concentrated at low levels. The number of NCTs with different types of expansion intensity (CEII) is as follows: low (314), relatively low (44), intermediate (30), relatively high (7), and high (5), which accounts for 78.5%, 11%, 7.5%, 1.75%, and 1.25% of all NCTs, respectively.

The number of NCTs with different types of expansion ratio (CERI) is as follows: less than 10% (345), 10–15% (30), 15–20% (15), 20–25% (8), and more than 25% (2), which accounts for 86.25%, 7.5%, 3.75%, 2%, 0.5% of the total number of NCTs, respectively. The expansion intensity of NCTs is mostly at a low level, with an NCT expansion ratio of less than 10%.

NCTs with high expansion intensity and high expansion ratio are mainly located in the South, East, and North economic regions, which have significantly higher expansion intensity and ratio compared to other economic regions in China. The characteristics of NCT expansion are mainly in line with the distribution of the three major urban agglomerations in the east. The NCT expansion intensity shows a high degree of agglomeration in the eastern regions. Furthermore, the NCT expansion intensity in the central and western regions is relatively high, while the expansion ratio is generally low (Figure 6).

![Figure 6](image-url)

**Figure 6.** NCT expansion intensity and expansion ratio in China: (a) CEII-based distribution by economic regions; (b) CERI-based distribution by economic regions.

NCTs in the East economic regions have the highest average expansion intensity (146.568), followed by the South regions (127.921). In addition, CEII in the North, NW, and NE economic regions is 47.835, 38.529, and 35.111, respectively. CEII in the MYR economic regions is only 5.696, which is less than 4% of the East economic regions (Figure 7A). For the level of characteristic towns, the NCT expansion intensity (accumulative annual CEII) is as follows: Anting (1122.78), Lecong (1006.198), Beijiao (894.974), Xiqiao (792.922), Guzhen (506.29), Wujing (478.842), Luzhi (434.942), Lujia (407.269), Funing (403.567), and Shawan (399.116). Additionally, it is worth noting that out of all of the top 10 towns, only Funing (Heilongjiang) is in the NE economic region. Other NCTs are mainly concentrated in the South and North economic regions (Figure 7B).
As shown in Figure 7C, the NCTs in Shanghai have the highest average expansion intensity 347.775. The next is the NCT expansion intensity in Guangdong province with 219.279. The Jiangsu province, Tianjin, Beijing, Zhejiang province, Xinjiang, Ningxia, and Fujian provinces exceed the national average level of 49.219. It should be noted that from the point of the average expansion intensity of NCTs, Xinjiang and Ningxia rank in the top 10, ahead of other provinces. In addition, the expansion of NCTs in Liaoning province and Heilongjiang province was notable between 2000 and 2020, with an average CEII value exceeding 45.

To further analyze the expansion characteristics of NCTs, we adopted the annual average of the expansion intensity of characteristic towns to identify critical expansion periods in eight economic zones. The annual average CEII is 19,411.779 and peaked (27,560.018) during the period from 2011 to 2014. CEII increase was primarily concentrated in two time periods (2008–2011 and 2011–2014). The NCTs expansion intensity was significantly higher than the average level (Figure 8).

For economic regions, the time of distribution of the NCT expansion intensity is different among the eight economic regions. The expansion intensity of NCTs in the NE economic regions was mainly concentrated in the period 2008–2011 (2820.825) and was significantly higher than the national average. Consequently, the expansion intensity in the NE economic regions was significantly lower (1155.488) than the national average during
other periods. The NCT expansion intensity in the North was primarily identified in two periods, i.e., between 2008 and 2011 (2753.062) and between 2017 and 2020 (2944.962).

Figure 8. Temporal changes in CEII in China and its economic regions.

The intensity of NCT expansion in the East economic regions is significantly higher than the national average and is mainly concentrated in the period 2011–2014 (13,447.379). In the East economic regions, the NCT expansion intensity in any other period was also significantly higher than the national average, and the NCT expansions were evident. The intensity of NCT expansion in the South economic regions was primarily concentrated between 2002 and 2005 (7145.08) and between 2008 and 2011 (7624.593). During these periods, the expansion intensity was significantly higher than the national average in other periods. In the MYR economic regions, the NCT expansion intensity was concentrated in two time periods, the period 2011–2014 (1541.372) and the period 2017–2020 (1571.826). The NCT expansion intensity during the entire research cycle was significantly lower than the national average. In addition, compared to the other seven economic regions, the NCT expansion intensity in the Central economic regions was significantly lower. Moreover,
the expansion intensity was primarily concentrated in the period between 2017 and 2020 (1022.244) and was at the level of the national average.

The NCT expansion intensity in the SW economic regions was concentrated in the period 2014–2017 (1792.125). The expansion intensity is significantly lower than the national average. Furthermore, the NCT expansion intensity in the NW economic regions was largely concentrated in periods 2011–2014 (2347.784) and 2017–2020 (3754.511). In addition, it should be noted that the NCT expansion intensity was significantly higher than the national average, while the expansion intensity in other periods was significantly lower than the national average.

Since 2016, China has been implementing the NCT policies at the national level. The most obvious areas of NCT expansion intensity are the North, MYR, Central, SW, and NW economic regions in the period 2017–2020. Compared to the eastern region, the implementation of NCT policy has significantly promoted the development of NCTs in the central and western regions.

4. Discussion

4.1. Are Characteristic Towns Expanding?

Characteristic towns are a new type of industrial organization in social and economic development, which plays a vital role in optimization of industrial structure, distribution of productive forces, allocation of spatial resources, and promotion of supply-side structural reforms [53, 54]. Based on the critical role of characteristic towns in promoting urbanization, improving the rural living environment, and promoting regional innovation and development, some scholars advocate promoting characteristic towns [17, 26]. The expansion of characteristic towns reflects the regional factor mobility and the changing patterns of urbanization. It is not necessary to promote the development of all characteristic towns, but characteristic towns with excellent growth potential and high quality of development. Therefore, it is crucial to identify the characteristic towns that are expanding.

At present, research on characteristic towns is mainly focused on spatial distribution characteristics [26, 55]. Current research generally believes that NCTs are developing rapidly. However, previous research has failed to use reliable data and methods to reflect the status of NCT development [15, 25, 27, 54].

The innovation of this paper is the discovery of spatial and temporal characteristics of the expanding characteristic towns during different periods with the application of nighttime light data. The expansion of characteristic towns may intensify the trend of internal differentiation of characteristic towns, and location and policy will also change the expansion trajectory of the characteristic towns. NCT expansion is common in China, but also shows regional or temporal disparities. More than half of the NCTs have expanded in China. The number of expanding NCTs peaked in two periods. The first period was between 2005 and 2008 and the second period was between 2017 and 2020. NCT expansion intensity and expansion ratio predominantly occurred in the East, South, and North economic regions. The above research findings can provide a reference for decision makers to implement advanced planning in response to the differentiated development of NCTs.

4.2. Advantages of Identifying Expanding NCTs Using Nighttime Light Data

There has always been an objective problem in the research of characteristic towns; that is, the imperfect township statistics lead to a lack of data, which hinders the quantitative research [35]. Using nighttime light data can provide a large amount of information that is difficult to obtain by traditional methods, which compensates for the difficulties brought by the lack of data for the study of characteristic towns.

This study proposes a method for identifying expanding NCTs in China using nighttime light data from 2000 to 2020. The results show that nighttime light data have significant advantages in identifying expanding NCTs. The scientific method proposed in this study can effectively identify the ‘hot spots’ of expanding NCTs and the critical periods of their expansion. NCTs are still a relatively new phenomenon, and most are still being created or
developed in China. In this study, expanding NCTs and non-expanding NCTs were successfully classified during the investigated period, which is the most significant difference compared to other studies.

The method in this study was also used to evaluate NCT policy before and after its implementation. The results show that the implementation of the NCT policy has promoted the rapid development of characteristic towns in the central and western regions. Therefore, the used method has significant advantages in identifying expanding NCTs in China.

4.3. Limitations and Future Work

It should be noted that there are still several aspects that were not addressed in this study. First, although nighttime light data can better represent the development characteristics of NCTs, the development of these towns is not manifested solely through spatial expansion, but also in economic aspects of development. As nighttime light data are unlikely to reflect these characteristics, it may be necessary to include statistical data in future studies. Furthermore, there are obvious differences between the NCT regional developments and the influencing factors. The differentiation of the NCT regional development differences have not been studied and further research is needed. Third, this paper aimed to reveal the development process of NCTs, but there is no quantitative contribution of NCTs to regional development. This paper failed to quantify the impact of NCT development on the region. Future research should use econometric models to describe NCTs and their locations, population, and policies. The relationship between the aforementioned factors is crucial to a better understanding of the development of NCTs in China.

5. Conclusions

NCTs are typical representatives of small towns in China. This study proposes a method for identifying expanding NCTs in China according to nighttime light data from 2000 to 2020. The accuracy of the identification of expanding NCTs was verified, and the results show that the NCT expansion is a common phenomenon in China, but there are regional or temporal differences. More than half of the NCTs have expanded in China. The expanding NCTs are mainly located in the East, South, and North economic regions. The number of expanding NCTs peaked in two periods. The first period was between 2005 and 2008 and the second period was between 2017 and 2020. NCT expansion intensity and expansion ratio occurred predominantly in the East, South, and North economic regions.

NCTs are highly consistent with the spatial distribution of cities, and the development of NCTs is inherently related to the development of urban agglomerations in the region. The implementation of the NCT policy has promoted the rapid development of the NCTs in central and western regions. Thus, policies should focus on the development of expanding NCTs in the eastern urban agglomerations and the development of non-expanding NCTs in the central and western regions.

In this study, the proposed method is practical and accurate for the identification of the expanding NCTs using nighttime light data. This method can effectively identify the ‘hot spots’ of expanding NCTs and the critical expansion periods. The results from this method can help to optimize the spatial layout of characteristic towns and guide the adjustment of NCT policies in China.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/rs14030598/s1, Table S1: Comparison of primary data of NCTs and small towns in 2016, Table S2. Types of expanding NCTs

Author Contributions: H.S. designed the research and wrote the manuscript. T.H. performed the experiment and analyzed evaluation results. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (72004197).

Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Yin, X.; Wang, J.; Li, Y.; Feng, Z.; Wang, Q. Are small towns really inefficient? A data envelopment analysis of sampled towns in Jiangsu province, China. Land Use Policy 2021, 109, 105590. [CrossRef]
2. Feng, Y.; Wang, R.; Tong, X.; Shaﬁzadeh-Moghadam, H. How much can temporally stationary factors explain cellular automata-based simulations of past and future urban growth? Comput. Environ. Urban Syst. 2019, 76, 150–162. [CrossRef]
3. Seto, K.C.; Sanchez-Rodriguez, R.; Fragiakos, M. The new geography of contemporary urbanization and the environment. Annu. Rev. Environ. Resour. 2010, 35, 167–194. [CrossRef]
4. Torbick, N.; Corbiere, M. Mapping urban sprawl and impervious surfaces in the northeast United States for the past four decades. GIScience Remote Sens. 2015, 52, 746–764. [CrossRef]
5. Binns, T.; Nel, E. The village in a game park: Local response to the demise of coal mining in KwaZulu-Natal, South Africa. Econ. Geogr. 2003, 79, 41–66. [CrossRef]
6. Malý, J. Small towns in the context of “borrowed size” and “agglomeration shadow” debates: The case of the south moravian region (Czech republic). Eur. Cty. 2016, 8, 333–350. [CrossRef]
7. Filipović, M.; Kokotović, K.; Drobnjaković, M. Small towns in Serbia-The “bridge” between the urban and the rural. Eur. Cty. 2016, 8, 462–480.
8. Broadway, M. Implementing the slow life in southwest Ireland: A case study of Clonakilty and local food. Geogr. Rev. 2015, 105, 216–234. [CrossRef]
9. Mayer, H.; Knox, P. Small-town sustainability: Prospect in the second modernity. Eur. Plan. Stud. 2010, 18, 1545–1565. [CrossRef]
10. Wirth, P.; Elis, V.; Müller, B.; Yamamoto, K. Peripheralisation of small towns in Germany and Japan-Dealing with economic decline and population loss. J. Rural Stud. 2016, 47, 62–75. [CrossRef]
11. Wu, Y. The controversy and definition of the concept of small towns in China. Dev. Small Cities Towns 2014, 32, 50–55.
12. Tong, Y.; Liu, W.; Li, C.; Zhang, J.; Ma, Z. Understanding patterns and multilevel influencing factors of small town shrinkage in Northeast China. Sustain. Cities Soc. 2021, 68, 102811. [CrossRef]
13. Kühn, M. Small towns in peripheral regions of Germany. Ann. Univ. Pedagog. Crac. Studia Geogr. 2015, 8, 29–38.
14. Nel, E.; Connelly, S.; Stevenson, T. New Zealand’s small town transition: The experience of demographic and economic change and place based responses. N. Z. Geog. 2019, 75, 163–176. [CrossRef]
15. Miao, J.T.; Phelps, N.A. ‘Featured town’ fever: The anatomy of a concept and its elevation to national policy in China. Habitat Int. 2019, 87, 44–53. [CrossRef]
16. Wu, Y.; Chen, Y.; Deng, X.; Hui, E. Development of characteristic towns in China. Habitat Int. 2018, 77, 21–31. [CrossRef]
17. Wang, D.W.; Li, Y. Typical problems of characteristic town development and sustainable promotion strategies. Econ. Rev. J. 2019, 8, 69–75.
18. Li, Y.F.; Ma, H.D. Cold Thinking in the Construction of characteristic town: Cultural absorption and inheritance in the construction of characteristic town. Gen. Res. 2018, 3, 113–121.
19. Fu, X.D.; Fu, J.S. The Theory Origin and Enlightenment of Leading Industrial Embeddedness. Reg. Econ. Rev. 2017, 33, 26–32.
20. Sheng, S.H.; Zhang, W.M. Characteristic town: A form of industrial spatial organization. Zhejiang Soc. Sci. 2016, 19, 36–38.
21. Yao, S.J. Governance Confluence in the Integration of Urban and Rural Areas: Policy Issues Based on ‘characteristic towns’. Soc. Sci. Rev. 2017, 39, 45–50.
22. Zeng, J.; Ci, F. The construction of characteristic towns under the background of new urbanization. Macroecon. Manag. 2016, 12, 51–56.
23. Zhang, J.F. The path and model of characteristic town construction: Taking Datong City, Shanxi Province as an example. China Agric. Resour. Reg. Plan. 2017, 38, 145–151.
24. Zhou, X.H. Industry Transformation and Cultural Reconstruction: The Path of Creating characteristic towns. Nanjing Soc. Sci. 2017, 28, 12–19.
25. Xie, H.; Li, Y.H.; Wei, Y.Y. Study on the spatial structure characteristics and influencing factors of characteristic towns in Zhejiang Province. Sci. Geogr. Sin. 2018, 38, 1283–1291.
26. Fang, Y.L.; Huang, Z.F.; Li, J.L.; Wang, F. The spatial distribution and industrial characteristics of Chinese characteristic towns. J. Nat. Resour. 2019, 34, 1273–1284.
27. Ma, R.F.; Zhou, X.J.; Li, Q. The regional types of characteristic towns in the Yangtze River Delta and their adaptive construction paths. J. Geogr. 2019, 39, 912–919.
28. Zou, Y.; Zhao, W. Searching for a new dynamic of industrialization and urbanization: Anatomy of China’s characteristic town program. Urban Geogr. 2018, 39, 1060–1069. [CrossRef]
29. Liu, T. Characteristic town: New exploration in the process of Zhejiang’s new urbanization. Zhejiang Econ. 2017, 9, 8–10.
30. Ministry of Housing and Urban-Rural Development of the People’s Republic of China. Notice on the Publication of the National Characteristics Towns Demonstration List (First Batches) by Ministry of Housing and Urban-Rural Development of the People’s Republic of China. 14 October 2016. Available online: http://www.mohurd.gov.cn/gongkai/fdzdgknr/tzgg/20161014_229170.html (accessed on 20 October 2021).

31. Ministry of Housing and Urban-Rural Development of the People’s Republic of China. Notice on the Publication of the National Characteristics Towns Demonstration List (Second Batches) by Ministry of Housing and Urban-Rural Development of the People’s Republic of China. 22 August 2017. Available online: http://www.mohurd.gov.cn/gongkai/fdzdgknr/tzgg/201708/20170828_233078.html (accessed on 20 October 2021).

32. Liang, Q.M.; Fan, Y.; Wei, Y.M. Multi-regional input-output model for regional energy requirements and CO2 emissions in China. Energy Policy 2007, 35, 1685–1700. [CrossRef]

33. Deng, J.X.; Liu, X.; Wang, Z. Characteristics analysis and factor decomposition based on the regional difference changes in China’s CO2 emission. J. Nat. Resour. 2014, 29, 189–200.

34. Liu, Z.; He, C.; Zhang, Q.; Huang, Q.; Yang, Y. Extracting the dynamics of urban expansion in China using DMSP-OLS nighttime light data from 1992 to 2008. Landsc. Urban Plan. 2012, 106, 62–72. [CrossRef]

35. Wang, X.Q.; Qi, W.; Liu, S.H. Spatial distribution characteristics and related factors of small towns in China. Geogr. Res. 2020, 39, 319–336.

36. Huang, Q.X.; Yang, X.; Gao, B.; Yang, Y.; Zhao, Y. Application of DMSP/OLS nighttime light images: A meta-analysis and a systematic literature review. Remote Sens. 2014, 6, 6844–6866. [CrossRef]

37. Peng, J.; Lin, H.X.; Chen, Y.Q.; Blaschke, T.; Luo, L.W.; Xu, Z.H.; Hu, Y.N.; Zhao, M.Y.; Wu, J.S. Spatiotemporal evolution of urban agglomerations in China during 2000–2012: A nighttime light approach. Landsc. Ecol. 2020, 35, 421–434. [CrossRef]

38. Sharma, R.C.; Tateishi, R.; Harai, K.; Gharechelou, S.; Iizuka, K. Global mapping of urban built-up areas of year 2014 by combining MODIS multispectral data with VIIRS nighttime light data. Int. J. Digit. Earth 2016, 9, 1004–1020. [CrossRef]

39. Zhao, M.; Zhou, Y.; Li, X.; Cao, W.; He, C.; Yu, B.; Li, X.; Elvidge, C.D.; Cheng, W.; Zhou, C. Applications of satellite remote sensing of nighttime light observations: Advances, challenges, and perspectives. Remote Sens. 2019, 11, 1971. [CrossRef]

40. Elvidge, C.D.; Baugh, K.E.; Kihn, E.A.; Kroehl, H.W.; Davis, E.R.; Davis, C.W. Relation between satellite observed visible-near infrared emissions, population, economic activity and electric power consumption. Int. J. Remote Sens. 1997, 18, 1373–1379. [CrossRef]

41. Zhuo, L.; Ichinose, T.; Zheng, J.; Chen, J.; Shi, P.J.; Li, X. Modelling the population density of China at the pixel level based on DMSP/OLS non-radiance calibrated nighttime light images. Int. J. Remote Sens. 2009, 30, 1003–1018. [CrossRef]

42. Chen, X. Nighttime Lights and Population Migration: Revisiting Classic Demographic Perspectives with an Analysis of Recent European Data. Remote Sens. 2020, 12, 169. [CrossRef]

43. Bernt, M. The limits of shrinkage: Conceptual pitfalls and alternatives in the discussion of urban population loss. Int. J. Urban Res. 2015, 40, 441–450. [CrossRef]

44. Doll, C.N.H.; Muller, J.P.; Morley, J.G. Mapping regional economic activity from night-time light satellite imagery. Ecol. Econ. 2006, 57, 75–92. [CrossRef]

45. Jean, N.; Burke, M.; Xie, M.; Davis, W.M.; Lobell, D.B.; Ermon, S. Combining satellite imagery and machine learning to predict poverty. Science 2016, 353, 790–794. [CrossRef] [PubMed]

46. Ma, T.; Zhou, C.H.; Pei, T.; Haynie, S.; Fan, J. Quantitative estimation of urbanization dynamics using time series of DMSP/OLS nighttime light data: A comparative case study from China’s cities. Remote Sens. Environ. 2012, 124, 99–107. [CrossRef]

47. Huang, Q.; He, C.; Gao, B.; Yang, Y.; Liu, Z.; Zhao, Y.; Dou, Y. Detecting the 20-year city-size dynamics in China with a rank clock approach and DMSP/OLS nighttime data. Landsc. Urban Plan. 2015, 137, 138–148. [CrossRef]

48. Chen, Z.; Yu, B.; Yang, C.; Zhou, Y.Y.; Yao, S.J.; Qian, X.J.; Wang, C.X.; Wu, B.; Wu, J.P. An extended time series (2000–2018) of global NPP-VIIRS-like nighttime light data from a cross-sensor calibration. Earth Syst. Sci. Data 2021, 13, 889–906. [CrossRef]

49. Oswald, P.; Rieniets, T. Atlas of Shrinking Cities; Hatje Cantz: Ostfildern, Germany, 2006.

50. Wu, K.; Li, Y.C. Research progress of urban land use and its ecosystem services in the context of urban shrinkage. J. Nat. Resour. 2019, 34, 1121–1134. [CrossRef]

51. Zhao, J.C.; Ji, G.X.; Yue, Y.L.; Dai, Z.Z.; Chen, Y.L.; Yang, D.Y.; Yang, X.; Wang, Z. Spatio-temporal dynamics of urban residential CO2 emissions and their driving forces in China using the integrated two nighttime light datasets. Appl. Energy 2019, 235, 612–624. [CrossRef]

52. Liu, J.W. Current situation, hotspot and trend of characteristic town research: Visual analysis based on CNKI and CiteSpace. Chin. J. Agric. Resour. Reg. Plan. 2021, 42, 107–117.

53. Sun, Z. Spatial distribution characteristics and influencing factors of characteristic towns in China. Chin. J. Agric. Resour. Reg. Plan. 2020, 41, 205–214.

54. Lu, P.; Zhang, J.H.; Wang, C.; Zhao, L. Classification and spatial distribution features of characteristic towns in China. Econ. Geogr. 2020, 40, 52–62.

55. Wang, Z.F.; Liu, Q.F. The spatial distribution and influencing factors of national characteristic towns in China. Sci. Geogr. Sin. 2020, 40, 419–427.