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Spatio-Temporal Dynamics of Non-Grain Production of Cultivated Land in China

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Abstract: Non-Grain Production is verycommon to see in many areas in China, which threatens food security. To understand the spatio-temporal characteristics of NGP is helpful in mitigating it. This study has applied a new approach to measure the NGP rate. Results show that, the NGP rate reached the peak of 1.49 in 2003 across the 20 selected years. Moreover, the NGP rate was revealed to be higher in the north and the east compared to the south and the west. Additionally, the NGP rate is shown to move from north to south with a total of 68.78 km whenapplying the centroid migration model. The patterns of NGP are shown usingspatial heterogeneity: the high-high agglomeration pattern was revealed mainly in the north, while there are less provinces of this pattern as time goes by. In addition, the Theil index of the NGP rate indicates that the equity of NGP remains at a low level in the first ten years and getslarger and larger in the later ten years.

Keywords: spatio-temporal dynamics; non-grain production; cultivated land

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1. Introduction

Land use change is common to see everywhere in the world. This not only appears in land cover, but also land use practices and management. It is witnessed that more and more famers plant trees and dig ponds in cropland or choose to plant non-grain products rather than grain products mainly because of the higher profits of planting cash crops [1]. If the phenomenon continues, it can be expected that less grains would be grown and the pressure on food security will be intensified [1,2]. This would absolutely threaten food security when we are facing the challenge of foods hortages due to the limit of the quantity of cultivated land, soil pollution, and the degradation of cultivated land [3]. What is even more concerning is the increasing population and upgrading of food demand. Seen from COVID-19 and the war between Russia and Ukraine, an increasing pressure is exerted on food security worldwide [4]. Moreover, it has been documented that the rapid expansion of cash crops would influence human society and the ecosystem, sometimes innegative ways [5]. Therefore, non-grain production not only threatens food security, but also has some other far-reaching influence on the farmers' livelihoods, land degradation, and ecosystem deterioration [6,7].

NGP is often measured as "the ratio between the area of grain and the area of cash crops", "the proportion of sowing area of non-grain in the sowing area of agricultural products" [7,8], or "the proportion of transfer in (out) area of non-grain in the transfer in (out) area of agricultural land" [9,10]. There are stricter definitions of NGP that only regard planting agricultural products other than the staple foods that are limited to rice, wheat, and corn.

The aforementioned measurements of calculating the NGP index can be generally classified in two ways, one is based on statistical data of grain production and the other one is a visual interpretation according to remote sensing images combined with field investigation [11]. These measurements mainly contribute to revealing the NGP by reflecting the cropping system. However, these measurements have shortages in presenting

NGP when there is poultry farming, forestry and fruit farming, and lawn planting [12,13]. The measurement of the visual interpretation and field survey indeed increases the accuracy of recognizing NGP in terms of type and extent, but it is largely limited by the development of remote sensing and is thus unfriendly to apply in a large-scale area. Therefore, this study proposed an approach that measures NGP in reflecting the structure of agricultural production.

China is a country with a broad area and huge population. This indicates an intensified stress on food security, especially when a 27% NGP was witnessed across the country [13]. Furthermore, crop planting can be limited by the different cropland endowments across the county [14]. There are more precipitation, sunshine, and higher temperatures that are favorable for cultivation in the south compared to the north. Similarly, the west is less likely to be favorable for cultivation since the higher elevation and higher proportion of mountains and hilly landscapes contrasts with the flat landscapes in the east. It is documented that cultivation suitability is important in influencing the NGP [15]. Therefore, it can be expected there is a variance of NGP across the whole country.

There are some other studies that claim the socio-economic factors play a more important role in NGP [16]. Since more developed areas tend to have higher income from non-farming jobs [17], a higher NGP rate is generally found in the south and east compared to the north and west. More specifically, eastern China tends to have a higher NGP as a more developed area compared to western China. In addition, southern China has a higher NGP compared to northern China despite the more favorable agricultural production conditions.

As seen from previous studies, the spatio-temporal characteristics of NGP variations are mainly revealed at provincial or city levels [5,18]. For the limited studies that are conducted at a national level, they fail in revealing the NGP across time. Therefore, it is necessary to understand the spatio-temporal characteristics of NGP in China. This study calculates the NGP of China from2000 to 2019 at a provincial scale. Revealing the spatio-temporal characteristics of the NGP of China is of great importance in understanding the trend of NGP as well as the spatial characteristics across the country.

2. Materials and Methods

2.1. Study Area

China is located in the east of Asia and to the west coast of the Pacific Ocean (3°51′ N–53°33′ N, 73°33′ E–135°05′ E). It covers an area of more than 9.6 million km^2, which ranks it as the third largest country in the world. In such a broad area, the natural conditions vary significantly from the south to the north, from the west to the east (Figure 1). Among which is the precipitation, sunshine, temperature, and terrain. These various natural conditions foster significantly different agricultural conditions. There are many plains such as Northeast Plain, North China Plain, Yangtze Plain, and Pearl River Delta Plain, which fosters the “Granary of China”. For example, the sufficient light and heat conditions of four northeastern provinces in northeast China with black soil contributes to about one-third of China’s total grain output. The North China Plain has deep and fertile soil layers. The multiple cropping index ranks first in north China.

Figure 1. Illustration of study area.

Despite the fact that China is a traditional cultivated country with a history of thousands of years, the agriculture of China has been under stressful pressure in recent decades. In the meantime, China is one of the most densely populated countries with more than 1.4 billion people, which accounts for almost one-fourth of the total population in the world. Moreover, a higher NGP is driven by the higher cost of non-farming job opportunities. Farming is low profit and less farmers tend to continue farming once they have the opportunity to work in the second and third industries.

2.2. Measurement of "Non-Grain Production" Index

2.2.1. "Non-Grain Production" Index

The non-grain level calculation based on statistical data mainly adopts "grain ratio" and "non-grain crop sown area ratio to crop sown area ratio" as indicators for analysis. "Grain ratio" refers to the proportion of the sowing area of grain crops in the sowing area of crops. The two indicators add up to 1.

The NGP is often measured with an index of "The ratio between grain and non-grain products", but it fails in reflecting the "non-grain" agricultural production structure. When the cultivated land used to grow cash crops is changed to "non-grain" activities, such as livestock breeding and fruit farming, the sown area of food crops on the cultivated land remains unchanged and the sown area of crops decreases. At this time, the ratio of grain to crop increases, indicating that the degree of "non-grain" has been improved, but the actual level of "non-grain" has not changed. When the sown area of grain crops and the sown area of crops are reduced simultaneously, the "grain-to-crop ratio" performance is relatively stable. Still, the actual "non-grain-oriented" level is exacerbated. Similarly, the "grain-to-crop ratio" cannot reflect the influence of the change of cultivated land area on the level of "non-grain".

Accordingly, this study proposes a "non-grain production" index to measure the extent of non-grain production. This index can be derived as:

$$K = \left[1.5 + \frac{(S_{cropland} - S_{grain})}{S_{cropland}}\right] \times 100\% \quad (1)$$

where $S_{cropland}$ indicates the area of cropland and S_{grain} refers to the sowing area of grain. In ensuring a positive value of K (>=0), the proportion between $S_{cropland}$ and S_{grain} is transferred by adding 1.5. According to Equation (1), a higher K value indicates a higher extent of non-grain production.

2.2.2. Theil Index

This study applies the Theil index to measure the equity of the non-grain production index within a unit and between the units. The Theil index can be expressed as follows:

$$\mathrm{T} = \sum_{p=1}^{n}\left[\left(\frac{1}{n}\right) \times \left(\frac{y_p}{u_y}\right) \times ln\left(\frac{y_p}{u_y}\right)\right] \quad (2)$$

where y_p indicates the non-grain production index of the province of p; u_y is the non-grain production index of the whole of China; and n refers to the number of provinces in the study area (units). The value of the Theil index (T) ranges from 0 to $ln(n)$. Specifically, 0 represents no gap between the provinces, while the $ln(n)$ indicates a large gap between the provinces.

The T is composed of T_{br} and T_{wr}:

$$T = T_{br} + T_{wr} \quad (3)$$

The formula between the region is expressed as:

$$T_{br} = \sum_{i=1}^{n}\left[\left(\frac{p_i}{P}\right) \times \left(\frac{y_i}{\mu}\right) \times ln\left(\frac{y_i}{\mu}\right)\right] \quad (4)$$

where n indicates the number of units in a specific domestic region; p_i is the number of provinces in the region of i; p is the total amount of provinces in the study area; y_i is the non-grain production index of the province of i; μ is the non-grain production index of the whole of China. A more significant index indicates a greater regional difference.

2.2.3. Spatial Autocorrelation Analysis

The spatial autocorrelation model includes global spatial autocorrelation and local spatial autocorrelation [19]. In this study, the global Moran's I is used to judge the aggregation or dispersion degree of the NGP level of cultivated land at a provincial scale, as denoted by I_{global}. A positive Moran index represents an agglomeration distribution, while a negative one indicates a discrete distribution. If the Moran index is 0, it means a random distribution and no correlation. However, the global Moran index can only reflect the overall spatial distribution characteristics of factors but fails in measuring the aggregation and spatial heterogeneity. In this study, the local Moran's I index was used to explore the spatial location of the "non-grain" level of cultivated land aggregation at the regional scale and to identify the agglomeration characteristics, as denoted by I_{local}. The calculation formula is as follows [20]:

$$I_{global} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \quad (5)$$

$$I_{local} = \frac{(x_i - \overline{x}) \sum_{j=1}^{n} W_{ij} (x_j - \overline{x})}{\frac{1}{n} \times \sum_{i=1}^{n} (x_i - \overline{x})^2} \quad (6)$$

where, W_{ij} is the spatial weight value of province i and province j, and $\overline{x}$ is the average value. The value of I ranges from -1 to 1. A negative value indicates a negative correlation, while a positive value indicates a positive correlation, 0 indicates no correlation.

2.3. Data Sources

This study is mainly based on the following data: area of cropland and sowing area of grain from the statistics and spatial data of administrative boundary (Table 1).

Table 1. Data Sources.

Data	Data Source	Data Type	Year
Area of cropland	Yearly statistics of China	Statistical data	2000–2019
Sowing area of grain	Yearly statistics of China	Statistical data	2000–2019
Administrative boundary	Data Centre of Resources and Environment, Chinese Academy of Science [21]	Shapefile	2000–2019

3. Results

3.1. Spatio-Temporal Characteristics of NGP

3.1.1. Spatial Characteristics

Seen from the result, the average NGP rate of the study area ranges from 1.88 (in 2015) to 1.96 (in 2005). Generally, a higher NGP appears in the northwest of China, while it is lower in the southeast across the study period (Figure 2). The highest NGP mainly dominates in the Xinjiang, Qinghai, Gansu, Ningxia, and Liaoning provinces. Contrastingly, lower NGP is mainly distributed in coastal provinces such as Zhejiang, Anhui, and Fujian. Moreover, the Xizang Autonomous region was revealed with the lowest NGP and even a negative value in early years, for example in 2000 and 2005 (Figure 2a,b). The decrease in NGP has been expanding from north to south since 2000 and has alleviated since 2015 (Table 2).

Table 2. NGP of each province in China.

Province	2000	2005	2010	2015	2019
Beijing	1.9349	2.1248	2.0156	2.2582	2.3870
Tianjin	2.0307	2.0906	2.0355	1.9428	1.9608
Hebei	1.7556	1.8050	1.7577	1.6909	1.7363
Shanxi	1.9713	1.9829	1.9222	1.9156	1.9451
Inner Mongolia	2.1835	2.1708	2.0576	2.0253	2.0064
Liaoning	2.1182	2.0840	2.0587	2.0022	2.0165
Jilin	2.0826	2.0256	1.9810	1.8927	1.8864
Heilongjiang	2.1230	2.0770	1.8880	1.8174	1.8110
Shanghai	2.0011	2.1480	2.0461	2.0768	2.2251
Jiangsu	1.8227	1.8564	1.7701	1.7206	1.7389
Zhejiang	1.6386	1.8949	2.0286	2.0941	2.0956
Anhui	1.8048	1.7623	1.6830	1.6349	1.6287
Fujian	1.3359	1.5136	1.7335	1.9467	1.9840
Jiangxi	1.7976	1.7675	1.7054	1.7095	1.7482
Shandong	1.8782	1.9212	1.8391	1.7287	1.7271
Henan	1.7298	1.7044	1.6122	1.4865	1.5134
Hubei	2.0167	2.0274	2.0022	1.9109	1.9320
Hunan	1.7677	1.8093	1.8360	1.7959	1.8534
Guangdong	1.8662	1.9448	1.9822	2.0262	2.0292

Table 2. *Cont.*

Province	2000	2005	2010	2015	2019
Guangxi	1.8763	1.9538	1.9947	1.9925	2.0203
Hainan	1.9526	2.1146	2.0273	2.1877	2.2310
Chongqing	1.7930	1.8493	1.9212	1.9590	1.9447
Sichuan	1.9409	1.9559	1.9818	1.9685	1.9579
Guizhou	1.9648	1.9994	2.0129	2.0025	2.0507
Yunnan	1.9915	1.9963	2.0018	2.0087	2.0119
Xizang	0.4528	0.3973	0.7220	0.9349	1.0440
Shaanxi	1.8737	1.9434	1.9252	1.9287	1.9076
Gansu	2.0303	2.0542	2.0208	2.0054	2.0290
Qinghai	2.0467	2.1306	2.0851	2.0514	2.0053
Ningxia	1.9769	1.8944	1.9044	1.9293	2.0102
Xinjiang	2.2960	2.3086	2.2753	2.2642	2.2809

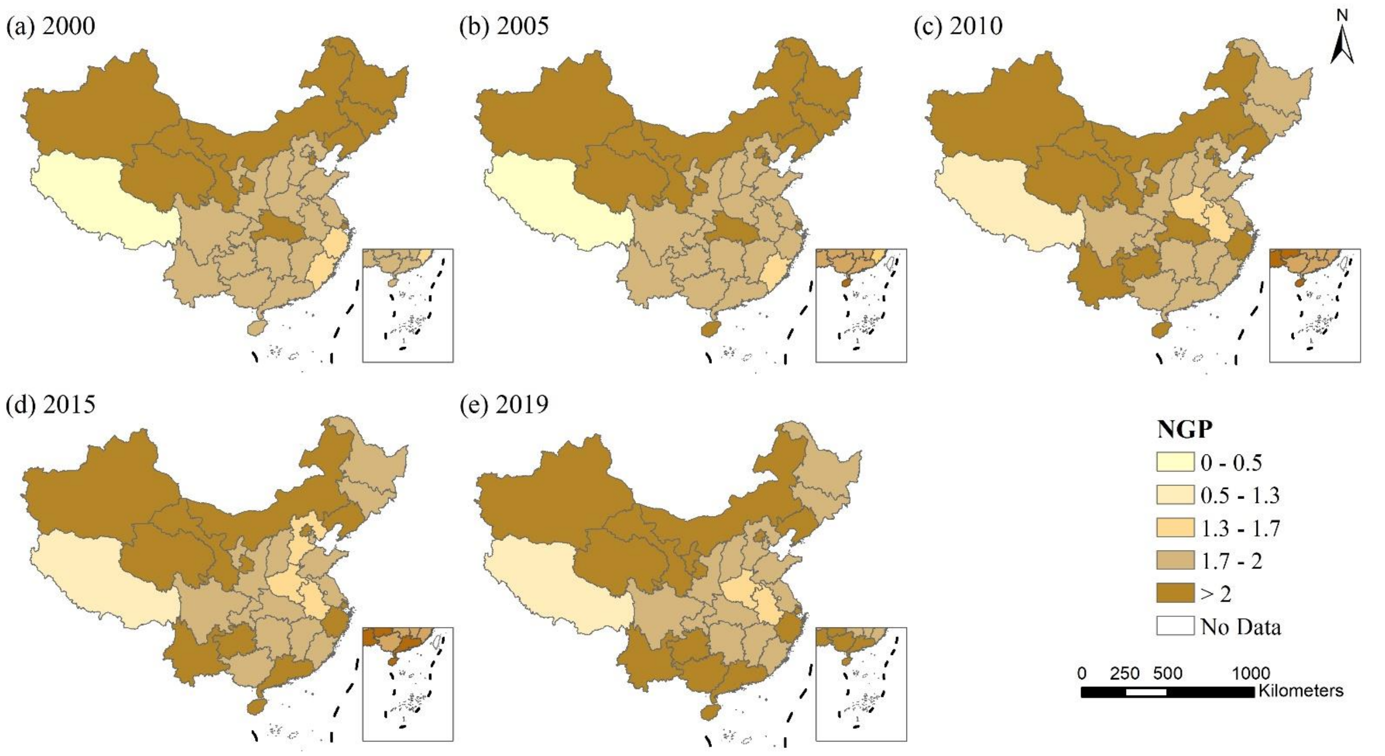

Figure 2. Spatial characteristics of NGP (2000–2019).

3.1.2. Theil Index of NGP

The overall Theil index of NGP is revealed as stable between 2000 (0.0744) and 2002 (0.0719). Then, a decrease was found from 2002 to 2003 (0.0697) (Figure 3). Then, it remained stable from 2004 (0.0725) to 2005 (0.0716), followed by a decline in 2006 (0.0693). After that, the overall Theil index continued to increase ever since. The average overall Theil index of NGP reached 0.0771. The increase was moderate between 2006 and 2012 and then significant until2016. Generally, this indicates that the equity of NGP remained at a low level in the first ten years and got larger and larger in the later ten years. More specific to the Theil index of NGP between the units, its change shows a fluctuant trend with a peak of 0.0430 in 2005 and 0.0643 in 2018 (averaged at 0.0526).

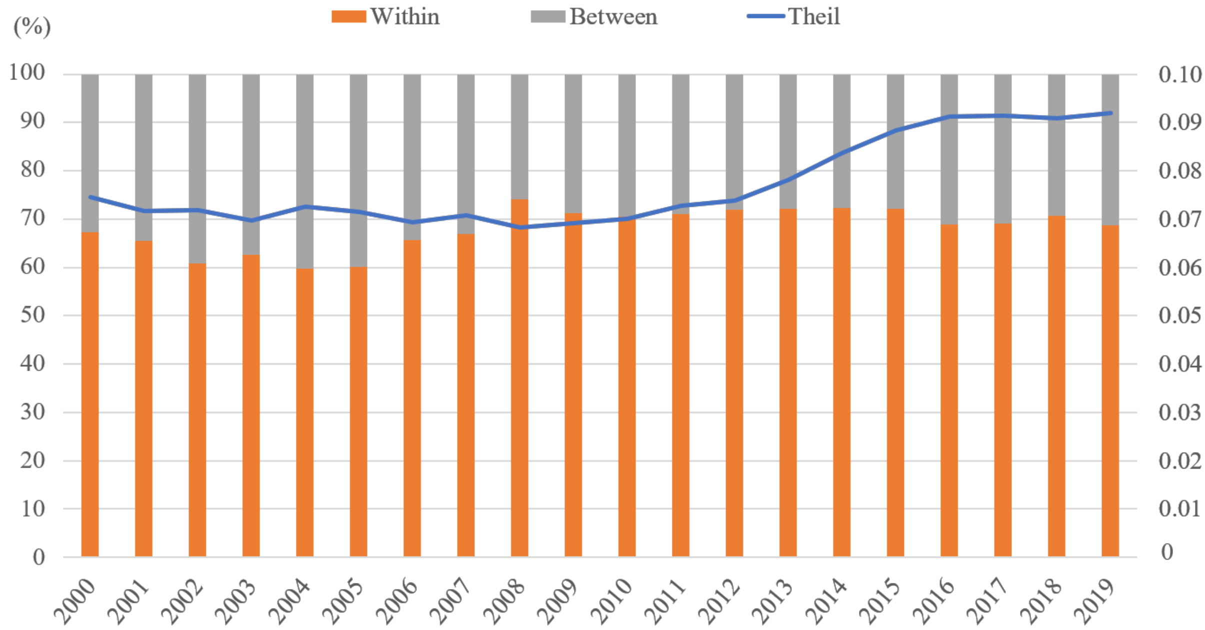

Figure 3. Theil index of NGP rate.

3.1.3. Local Moran's I Index of NGP

Seen from Figure 4, the Moran's I index showed a high-high agglomeration pattern in the north part (Gansu, Inner Mongolia, Heilongjiang, and Jilin). There were less areas that showed a high-high agglomeration pattern from 2005. Xizang was the only province with a low-high agglomeration pattern in the whole study area and it showed from 2000 to 2015. In addition, Shandong was the only province with a low-low agglomeration pattern, which only appeared from 2015.

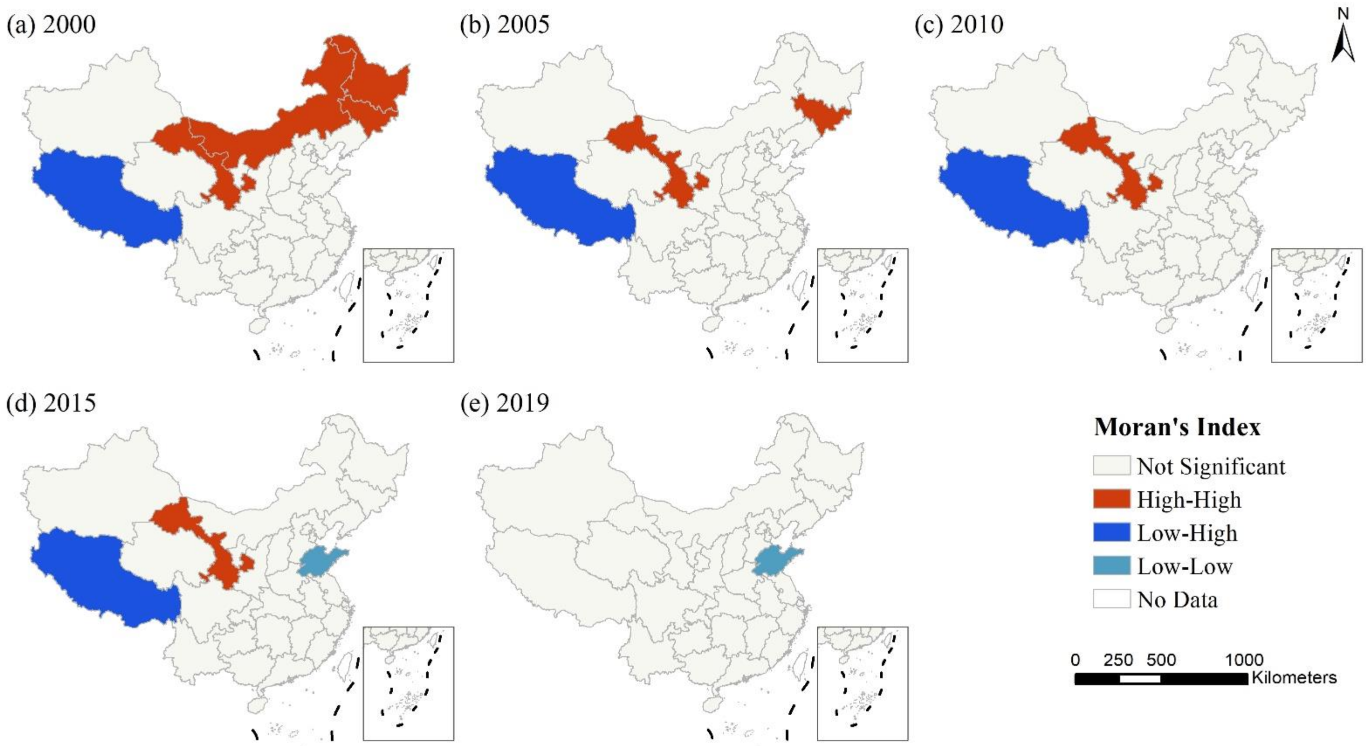

Figure 4. Spatial agglomeration patterns of the NGP rate.

3.2. Spatio-Temporal Characteristics of Change of NGP

3.2.1. Changes of NGP between 2000 and 2019

Further observing the changes of NGP during the study period, there weresignificant differences among the regions (Figure 5). Generally, the NGP of more than 1/3 of the provinces showed a downward trend. Among them, Tianjin, Jiangsu, Shandong, Hubei, and Qinghai had the most significant NGP in 2005 and then showed a downward trend. In 2010, the NGP in Tianjin, Shanghai, Hainan, and Ningxia declined to a certain extent and maintained an increasing trend. From 2000 to 2019, the NGP in Zhejiang, Fujian, Guangdong, and Yunnan kept increasing, while the NGP in Hebei, Shanxi, Jiangxi, and Gansu decreased from 2010 to 2015 and then increased.

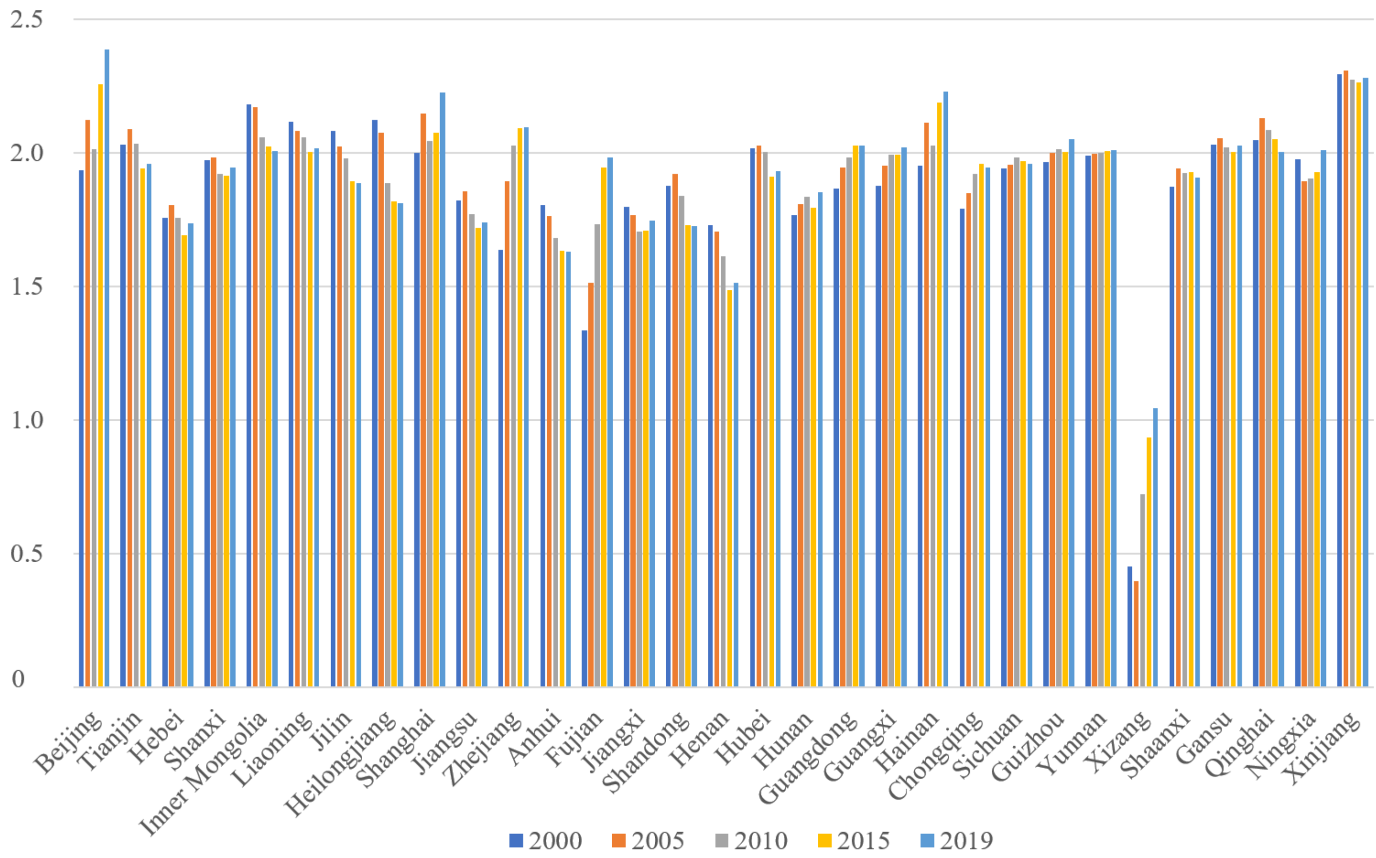

Figure 5. The NGP value of each province.

Figure 6 shows the spatial variation of NGP. The NGP in Xizang always kept a significant growth trend. Generally, the NGP decreased in the north and increased in the south from 2000 to 2019. In specific, the NGP decreased most in Heilongjiang and Henan. In contrast, areas in Tianjin and Xizang as well as the southern parts of Fujian, Zhejiang, and Hainan showed the most dramatic increase in NGP. Seen from specific provinces, some provinces in the north showed an increasing trend of fluctuation (such as Xinjiang and Gansu) and the NGP of some provinces first increased and then decreased in the early stage, such as Qinghai. NGP continued to increase in southern China, such as in Xizang and Fujian.

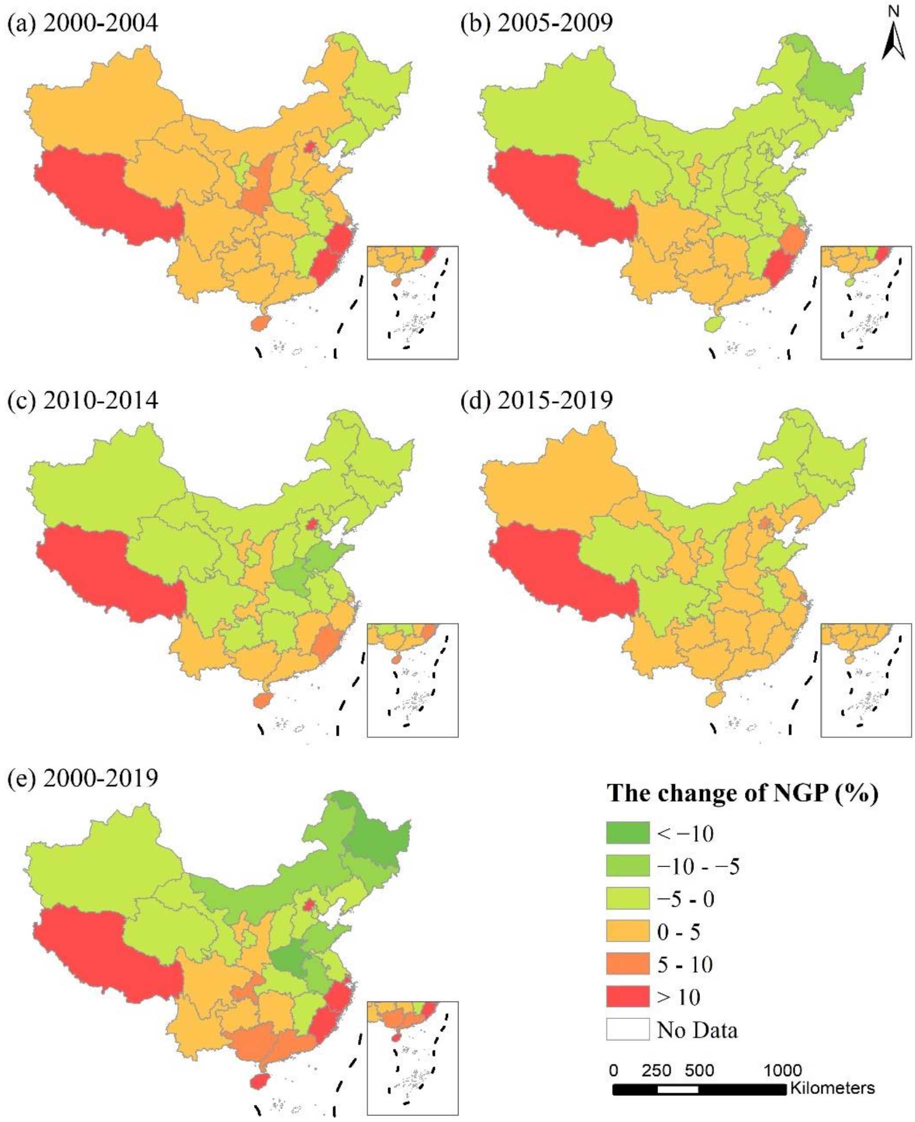

Figure 6. The change of NGP rate.

3.2.2. Centroid Migration of NGP

According to the centroid migration model, the centroid migration of NGP tookplace within the Henan province during the study years (Figure 7). The centroid of NGP migrated from the north to the south year by year. More specifically, during 2000–2005, the centroid of NGP migrated by 15.07 km, and was followed by 24.02 km and 16.60 km in 2005–2010 and 2010–2015. However, this migration decreased to 2.02 km between 2015 and 2019. A total of 50.41 km migrated from 2000 to 2019.

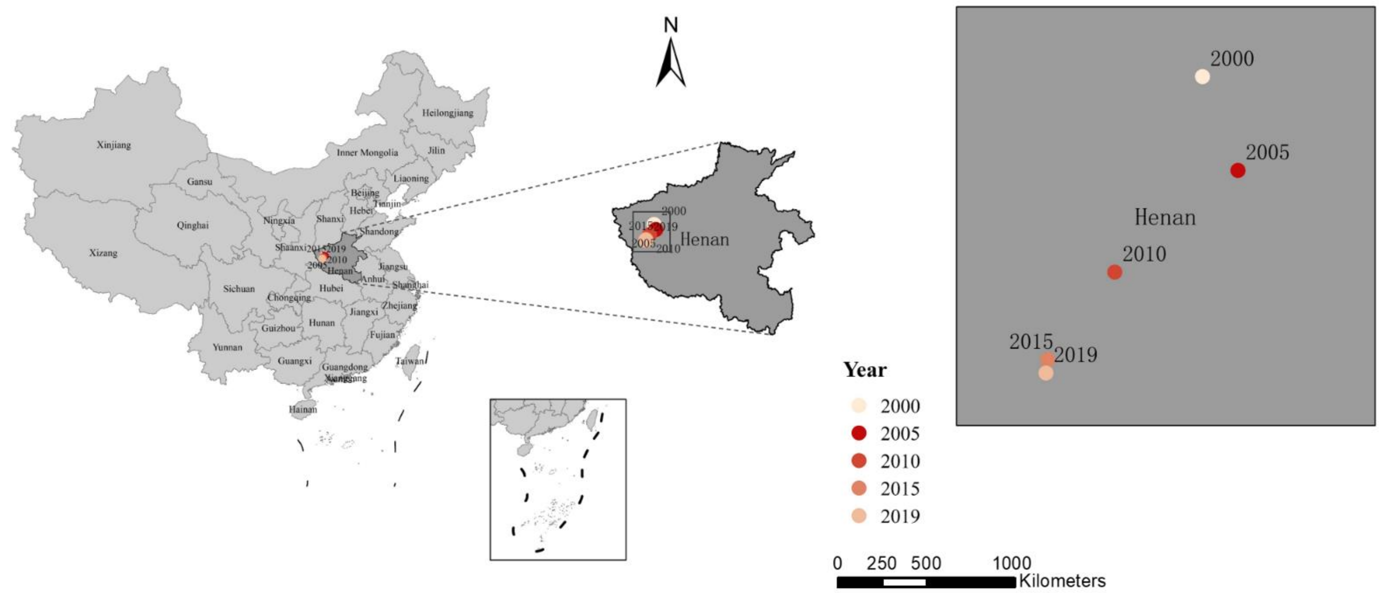

Figure 7. Illustration of the centroid migration of NGP (2000–2019).

4. Discussion

4.1. Dynamics of Spatial Characteristics of NGP

Generally, the NGP was revealed to be higher in the north compared to the south. The lower NGP in the south indicates that a higher area of grain sowing area in this region, which can result from the sufficient sunshine, precipitation and suitable temperatures that are good for agricultural production [22–24]. Contrastingly, croplands in the south of China enable two and even three harvests in a year, while only one harvest is possible in the north [25,26].

More specific to the provinces, the north area tends to have croplands that are flatter and more connected, which is favorable for scale farming and the utilization of agricultural machinery [27–29]. Examples include "The Plain of North China" (including Beijing, Tianjin, Hebei, Henan, Shandong, and Shanxi) [30–32] and the "Three Rivers Plain" (Heilong River, Songhua River, and Wusuli River) [33,34]. In addition, areas with scarce black soil (named as "Panda soil") such as Heilongjiang and Jilin are found with a lower NGP. Another example is the cotton planting in Xinjiang (northwest of China) [35,36]. In the southern parts, there are more vegetables, subtropical fruits, flowers, and tobacco that request more intensive labor input than machines [37].

The spatial characteristics of NGP of China can be also explained by the relation among the sowing area of grain, sowing area of non-grain, and area of cropland (Figure 8). Specific to the provinces, all the sowing areas of grain, sowing areas of non-grain, and the areas of cropland are revealed the lowest in the southwest, particularly in Xizang, Qinghai, and Xinjiang. Contrastingly, provinces including Henan, Shandong, Hubei, Hunan, Sichuan, and Anhui have a relative higher sowing area of grain and sowing area of non-grain. More specifically, Henan, Sichuan, and Hebei are shown with higher NGP with a higher sowing area of non-grain and a lower sowing area of grain.

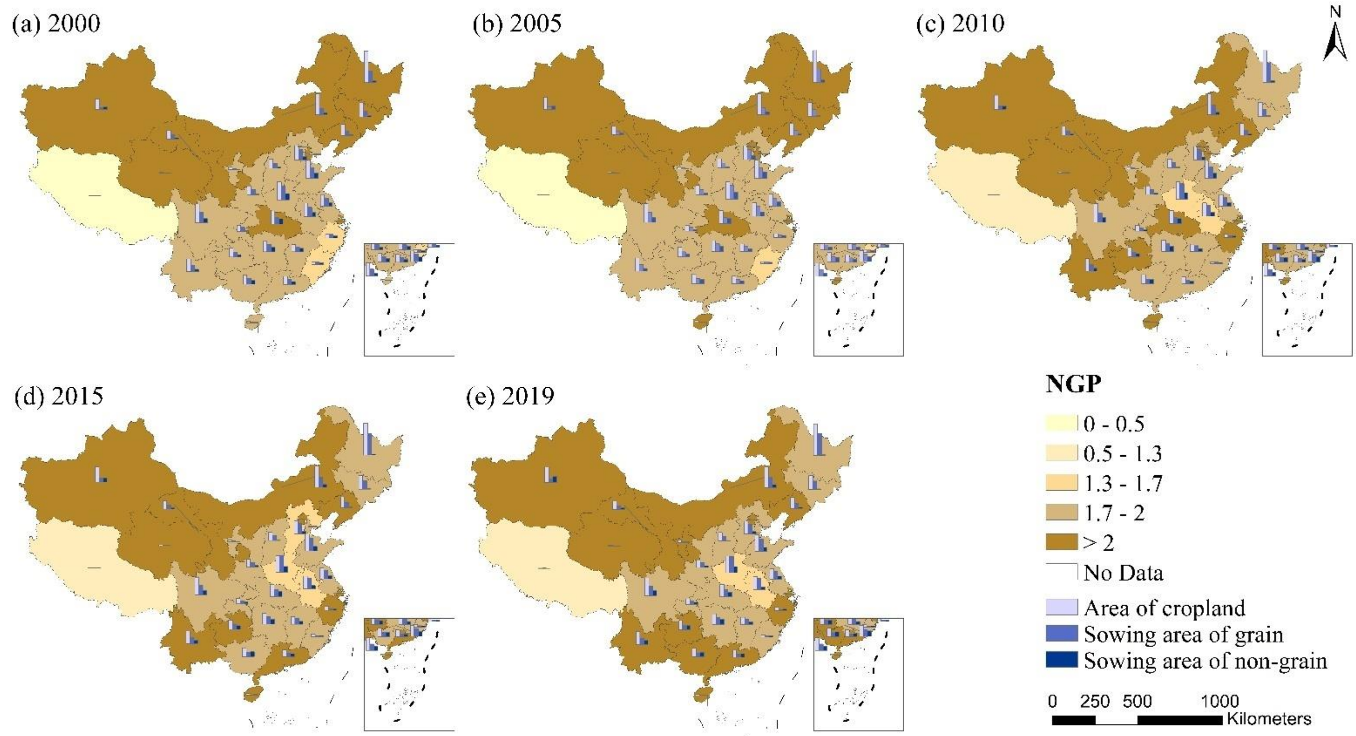

Figure 8. Spatial distribution of sowing area of grain, sowing area of non-grain, and area of cropland (at a provincial level).

4.2. Dynamics of Temporal Characteristics of NGP

Seen through the whole of China, the area of cropland remains stable across the 20 years (Figure 9). The sowing area of grain is almost two times as many as the sowing area of non-grain. More specifically, the sowing area of grain is the lowest around the year of 2003 and reaches the peak in 2016. However, the sowing area of non-grain ranks highest in 2003 and remains at a stable level with a slight decrease since 2006. Therefore, the overall NGP wasthe highest in 2003 and has kept decreasing even since.

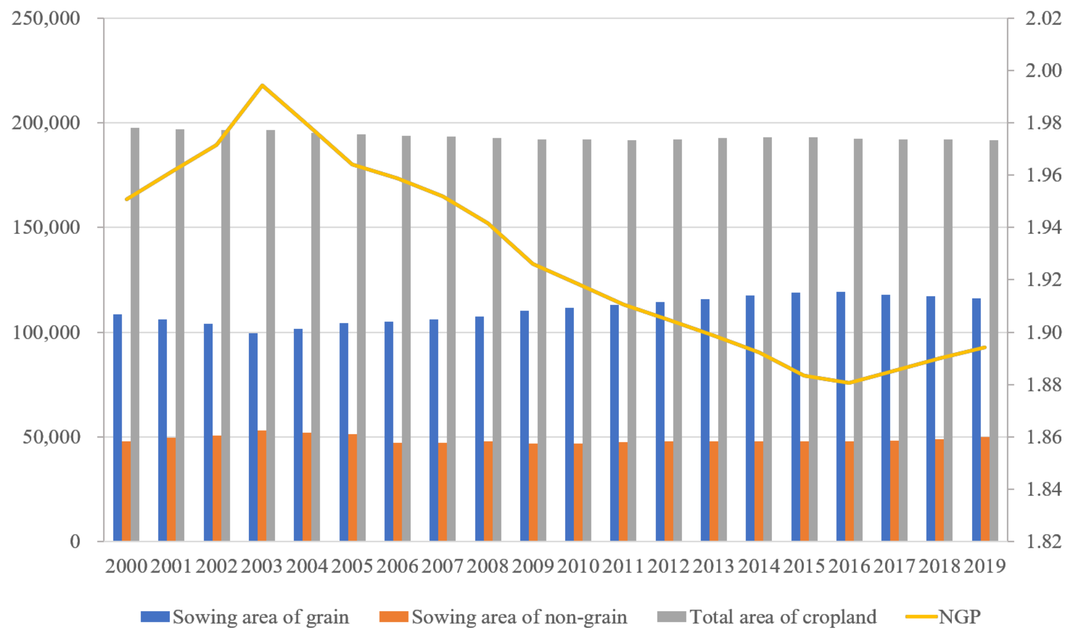

Figure 9. Comparison of sowing area of grain, sowing area of non-grain, and area of cropland (2000–2019).

Seen across the study years, the NGP in the north decreases while that in the south increases. With social-economic development, the opportunity cost of non-farming employment increases [37,38]. This is particular true in the southern parts where there is a higher proportion of tertiary industries that attract more farmers to conduct non-farming jobs [39]. A more significant change of NGP in the south compared to the north can be related to the adjustment of agricultural industry policies [40,41]. For example, the demand for staple food (such as rice, wheat, and corn) is decreasing while that for fruits and vegetables are increasing year by year.

The NGP reaching the peak of 1.99 in 2003 across the 20 years may be influenced by the application of land transfer policies since 2002. Land transfer only takes place if there are profits. Therefore, farmers are prone to choose cash crops rather than staple food. The NGP continues to drop from 2003 to 2016, which can result from the implementation of cropland protection policies. It is forbidden to create fishponds or plant fruit trees in the cropland, especially on the superior cropland. Furthermore, the agricultural subsidy also promotes staple food cultivation. This is related to specific agricultural policies from local governments [42–44].

The high-high agglomeration pattern was revealed mainly in the north, but there are less provinces of this pattern as time progresses (Figure 4). In particular, Gansu, Inner Mongolia, Heilongjiang, and Jilin were shown with high-high agglomeration patterns in 2000, but only Gansu and Jilin were left by 2005 and Gansu since 2010. Comparatively, Xizang, the only low-high agglomeration pattern, was revealed from 2000 to 2015. In addition, Shandong is shown with a low-low agglomeration pattern, but only during 2015 and 2019.

5. Conclusions

NGP is paid an increasing amount of attention because of the potential risk of it threatening food security. China has a vast territory and significant differences in land resource endowments; therefore, various measures should be adopted specifically at a local level to alleviate NGP. This study uses31 provinces in China as research objects and explores spatio-temporal evolution characteristics of NGP during the past 20 years, from 2000 to 2019. Through the study, we can know that the situation of NGP in different regions is different and measures should adopt various countermeasures according to different situations to alleviate NGP: (1) Attach importance to the innovation of agricultural science and technology. Mechanized agriculture can be actively promoted where land is flat and concentrated as well as with fertile soil, such as the northeast and the south of China. The bottleneck of agricultural science and technology innovation needs to be solved through sustainable industrialization and modern agricultural development, for example, to cultivate and popularize new grain crops that adapt to the harsh climate and environment. (2) Ensuring economic returns from growing grain. This is particularly true in the northwest where there is less precipitation and high elevations. Subsidies should be allocated more effectively to promote grain crop planting.

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