land

MDPI

Article

Examining the Impact of China's Poverty Alleviation on Nighttime Lighting in 831 State-Level Impoverished Counties

Yiguo Shen, Xiaojie Chen, Qingxin Yao, Jiahui Ding, Yuhan Lai and Yongheng Rao *

School of Public Administration, Sichuan University, Chengdu 610065, China
* Correspondence: raoyongheng@126.com or raoyongheng@scu.edu.cn

Abstract: China's poverty alleviation projects have made significant contributions to global poverty eradication. This study investigates the impact of China's poverty alleviation projects on nighttime lighting in 831 state-level impoverished counties using the "NPP-VIIRS-like" dataset and discusses the difference of land use change under different nighttime light clusters in order to provide reference for future policy formulation and implementation. Our results show that the growth of total intensity of nighttime lighting (GRTNL) and the year-on-year growth rate of total intensity of nighttime lighting (YGRTNL) in China's impoverished counties are 103.74% and 9.69% from 2013 to 2021, respectively, which are both higher than the average levels of all counties (67.16%, 6.77%) and non-poor counties (64.68%, 6.56%) in China during the same period. Additionally, we discovered that impoverished counties that lifted out of poverty earlier had significantly higher nighttime lighting intensity than those later. Regional analysis reveals that the growth of nighttime lighting intensity shows a trend of decreasing from the central (1550.89 nW$\cdot$cm^{-2}$\cdot$sr^{-1}) to the eastern (924.57), western (762.57), and northeastern regions (588.07), while the growth rate decreases from western regions (282.46%) to the eastern (189.13%), central (178.56%), and northeastern (108.07%). We also identified that Gini coefficient of nighttime lighting has a trend of "slow and short-term rise-rapid and continuous decline". Moreover, nighttime lighting growth had similar trends with land use change, especially construction land. Overall, our study provides novel insights into the relationship between poverty alleviation effects and nighttime lighting in China's impoverished counties, which could inform future policy-making and research in this area.

Keywords: nighttime lighting; poverty alleviation; land use change; China

Citation: Shen, Y.; Chen, X.; Yao, Q.; Ding, J.; Lai, Y.; Rao, Y. Examining the Impact of China's Poverty Alleviation on Nighttime Lighting in 831 State-Level Impoverished Counties. *Land* **2023**, *12*, 1128. https://doi.org/10.3390/land12061128

Academic Editor: Dingde Xu

Received: 16 April 2023
Revised: 19 May 2023
Accepted: 22 May 2023
Published: 25 May 2023

1. Introduction

The overarching goal of the United Nations Sustainable Development Goals (SDGs) is to eradicate poverty from every corner of the world permanently [1]. Poverty is a serious challenge faced by countries worldwide, particularly in developing nations [2], and includes energy [3], global carbon emissions [4,5], climate change [6,7], human health [8], and even social and psychological barriers [9]. China's rural areas have undergone significant transformations over the past four decades, with per capita real income of rural households increasing almost 22 times [10]. China's poverty alleviation strategy and rural revitalization strategy are two national measures to promote the rapid growth of rural household income [11]. China completely eradicated rural poverty by the end of 2020, becoming the first developing country to achieve the United Nations Sustainable Development Goal of eradicating poverty by 2030, ten years ahead of schedule. However, the most prominent social issues in China today are the widening rich-poor gap and the inequality between urban and rural areas [12,13]. With the transfer of the main social contradictions, the biggest imbalance in China currently is the imbalance between urban and rural development, and the biggest deficiency is insufficient rural development [14]. Focusing on the economic development level of rural China in the context of policy implementation is significant in achieving the overall goal of China's agricultural and rural modernization, as well as agricultural development and rural reform in other developing countries.

Countries worldwide generally used several key economic indicators in the past, such as GDP, per capita income, and consumption capacity, to calculate the level of regional economic development [15–17]. However, most of this kind of data is obtained using traditional statistical methods, which has many problems such as strong lag, high acquisition cost, and vulnerability to human factors [18]. Nighttime lighting can detect weak artificial light at night and obtain surface information completely different from that in the daytime, so it is widely used to monitor various information and changes related to human activities [19,20]. In recent years, there have been some remote sensing satellites of nighttime lighting and the data products, such as Luojia-1, JL1-3B, DMSP-OLS, NPP-VIRS, etc. [21–25]. The progress of human activity reflected by the change of nighttime lighting in a long time series relies on the Defense Meteorological Satellite Program's Operational Line Scan (DMSP-OLS) data available since 1992 and the Suomi National Polar-orbiting Partnership's Visible Infrared Imaging Radiometer Suite (NPP-VIIRS) data available since 2012 [24]. The research hotspots mainly focus on the application of nighttime lighting in socioeconomic studies, which has expanded rapidly during the last two decades with focus on a range of topics, including mapping urban expansion and population dynamics [26–30], tracking electricity consumption [31,32], estimating GDP [23,33,34], poverty [35–37], and the environmental impacts of light emissions (light pollution) [38], including the impact on human health [39]. The research has the advantages of low acquisition cost, guaranteed update cycle, long time series, effective avoidance of administrative boundary change, and human interference [40]. It was an important replacement and reverse evolution of the classic GDP indicator, which could better measure the level of regional economic development and gradually become an important means for monitoring urban economic activities [41].

Many researchers have studied the correlation between nighttime lighting data and the economy, such as directly exploring the correlation between nighttime lighting data and GDP [33,42,43], or using nighttime lighting data to explore the authenticity of economic data [41,44]. These research results show that the brightness of night lights could be used as a substitute variable for GDP and could be used to measure the actual economic growth rate. Indeed, especially for rural areas, it has also been demonstrated in Colombia that nighttime lighting is a good proxy for economic activity [45]. In other words, it is reasonable to use nighttime lighting data to characterize the economic development in rural areas. At the same time, LUCC information is usually associated with and mainly driven by socioeconomic factors and is also a direct reflection of economic activities [46–48]. It is well documented that the relationship between economic growth and LUCC information is not a one-way effect, but rather a complex relationship of interactions [49,50]. On the one hand, economic activities have profoundly changed the surface morphology of the Earth. On the other hand, the variation process of land use and land cover has significant impacts on the economy. As the foundation for economic activities, land is an indispensable production factor for economic development, and the input of land resources plays an important role in promoting economic growth [51–53].

China has made great efforts to develop the rural economy, since the Targeted Poverty Alleviation policy proposed in 2013. Assessing the effectiveness of poverty alleviation in China is crucial to developing management approaches to economic and social sustainability. Research has indicated the correlation between nighttime lighting data and the economy, and revealed that LUCC information is usually associated with and mainly driven by socioeconomic factors. To understand the effectiveness of the poverty alleviation policy in China, we could analyze nighttime lighting data to indicate economic development and reveal how land use changes in impoverished areas for further maintenance and development in impoverished areas. Therefore, the purpose of this study is to map the nighttime lighting directly in 831 state-level impoverished counties in China from 2013 to 2021 to examine the impact of poverty alleviation on the rural economy, and to further discuss the LUCC at different impact levels. Specifically, it includes (1) assessing the economic development of impoverished counties based on nighttime lighting data; (2) studying the temporal and spatial variation characteristics of nighttime lighting in impoverished counties, including spatial equilibrium and cluster/outlier analysis; (3) using K-means clustering based on the DTW distance algorithm to identify clusters of impoverished counties with similar time series characteristics of nighttime lighting data; and (4) analyzing the land use change laws of impoverished counties with different clusters of nighttime lighting. Applying nighttime lighting data to measure the effectiveness of policies will help ensure objectivity and is of great significance for subsequent policy proposals, though without the combination with socioeconomic data.

2. Materials and Methods

2.1. Description of the Study Area

The study area encompasses all of China, located in the southeastern part of Eurasia, between latitudes 4°15′ to 53°31′ N and longitudes 73°34′ to 135°5′ E. The region is characterized by complex geomorphological types, and the mountainous area is very large, accounting for 2/3 of the national area. For historical and environmental reasons, a large number of impoverished people live in mountainous areas of China. Accurately identifying the impoverished and key support counties is an important way for China to target poverty alleviation and the development of rural areas, concentrate efforts on ensuring adequate supply, and prevent the scattered use of poverty alleviation funds. In 2014, the former State Council Leading Group of Poverty Alleviation and Development proposed a list of 831 impoverished counties in China. The year of poverty alleviation for these counties varied, with 3.4% announcing poverty alleviation in 2016, 15.1% in 2017, 34.1% in 2018, 41.1% being lifted out of poverty in 2019, and 6.3% declaring poverty alleviation in 2020. This data, as well as other information, was obtained from the National Rural Revitalization Administration (http://nrra.gov.cn/, accessed on 24 August 2022).

To address the significant spatial differences in the development of impoverished counties, we divided the study area into four major regions, including the eastern and central parts as well as the west and the northeast, following the classification standard of the "Intermediate and Northeast Regional Division" published by the National Bureau of Statistics in 2011 (Figure 1). The eastern region comprises 10 provinces and municipalities, including Beijing, Jiangsu, Shanghai, and others. The central region includes 6 provinces: Shanxi, Anhui, Jiangxi, and others. The western region covers 12 provinces, municipalities, and autonomous regions, such as Guangxi, Sichuan, Guizhou, and others. The northeast region includes Liaoning, Jilin, and Heilongjiang provinces. Among the four regions, the western region has the highest proportion of impoverished counties, accounting for 68%, followed by the central region at 23%, and the northeast region has the lowest number of impoverished counties, accounting for only 3%.

2.2. Data Source

2.2.1. Nighttime Lighting Dataset

To identify temporal and spatial changes in nighttime lighting across the entire study area, we utilized the "NPP-VIIRS-like NTL Data" from 2000–2021 at a global 500 m resolution for the years 2013–2021 [54]. The accuracy of this dataset was verified by the data producer and was found to be qualitatively akin to NPP-VIIRS nighttime lighting data, effectively capturing detailed information about the interior of the town and its temporal variation.

2.2.2. Land Cover Datasets

The land cover data used in this study were derived from the annual China Land Cover Dataset (CLCD) based on Google Earth Engine [55]. The dataset provides annual land cover information for China from 1985–2021. The data producers compared the CLCD with existing thematic land cover products and found that it showed good agreement with global forest change, global surface water, and impervious surface time series datasets.

This dataset is one of the few publicly available long time series year-by-year land cover data with a 30 m resolution, and it has potential applications in annual land cover change studies in China.

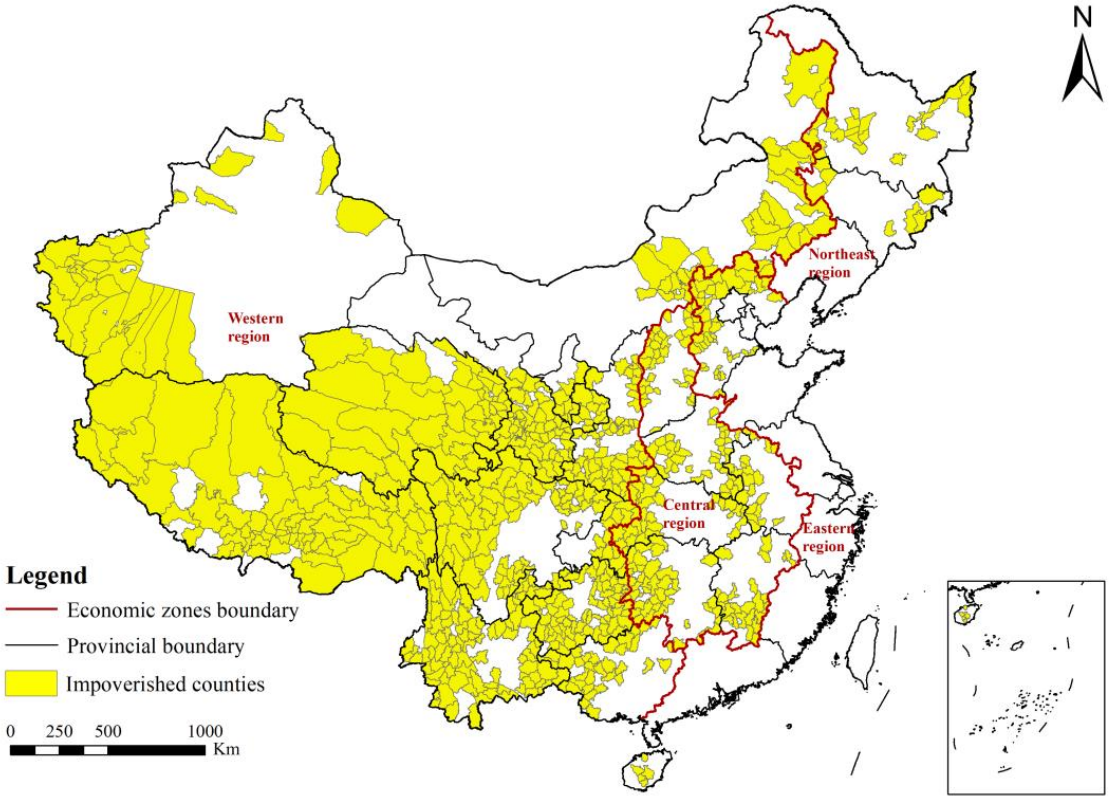

Figure 1. Distribution of impoverished counties in China, 831 in total.

2.3. Methods

2.3.1. Research Framework

To examine the impact of China's poverty alleviation on nighttime lighting in 831 state-level impoverished counties, we utilized the "NPP-VIIRS-like" nighttime lighting remote sensing dataset from 2013 to 2021 to obtain revised national nighttime lighting data and generate a map of nighttime lighting distribution for these counties (Figure 2). To explore the temporal and spatial characteristics of economic development, we analyzed the inter-annual variation of nighttime lighting intensity and constructed the Gini coefficient of urban nighttime lighting to examine the spatial equilibrium of economic development.

Additionally, we used K-means clustering based on the DTW distance algorithm to identify clusters of impoverished counties with similar time series characteristics of nighttime lighting data. We selected typical impoverished counties with different nighttime lighting cluster characteristics as research objects and constructed a land use change transfer matrix in the research period. By analyzing the land use change laws of impoverished counties with different clusters of nighttime lighting, while considering their own land resource endowments, we obtained insights into the impact of poverty alleviation on economic development. It should be clear that our results presented are indications of covariance in the variables, and that there is no triangulation of the nighttime lighting data and, also, that our results are not affected by data precision.

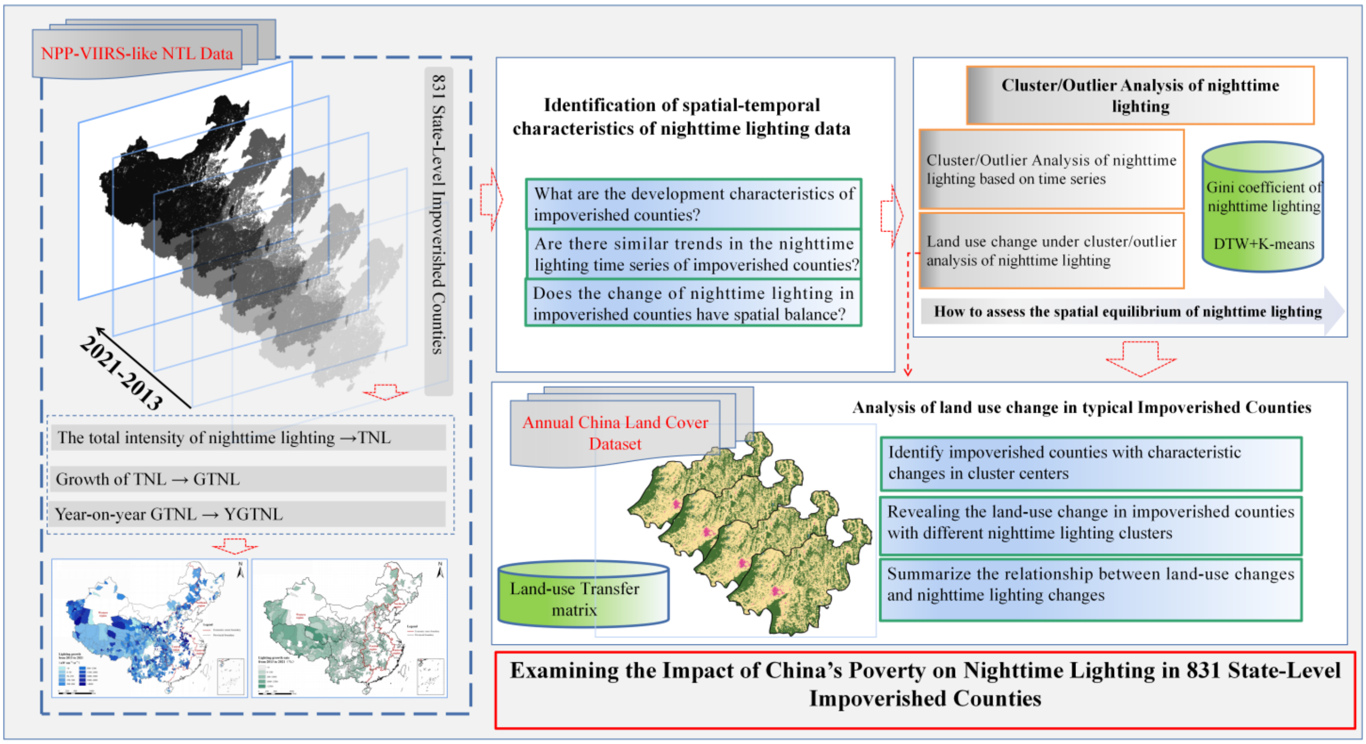

Figure 2. Research framework basic data, main methods, and purposes.

2.3.2. Identification of Spatial–Temporal Characteristics of Nighttime Lighting Data

Previous studies have established a strong positive correlation between nighttime lighting data and the level of economic development [24]. In this study, we aim to evaluate China's economic development from 2013 to 2021 at the state level using state-scale nighttime lighting data and the NPP-VIIRS nighttime lighting annual synthetic data to capture the temporal and spatial variation of nighttime lighting.

The total intensity of nighttime lighting (TNL) was calculated for 831 impoverished counties and other non-impoverished counties in China to assess the level of nighttime lighting from 2013 to 2021. Additionally, we used the growth of total intensity of nighttime lighting (GTNL) and the growth rate of total intensity of nighttime lighting (GRTNL) to analyze the nighttime lighting change trend in the study area, with a particular focus on impoverished counties. Furthermore, we chose the year-on-year growth rate of total intensity of nighttime lighting (YGRTNL) to indicate the year-by-year changes in nighttime lighting intensity in the study areas.

2.3.3. The Spatial Equilibrium of Nighttime Lighting in Impoverished Counties

The spatial equilibrium of human production activities is closely linked to the spatial distribution of nighttime lighting [56]. This study employs the urban nighttime lighting Gini coefficient [57] as a measure of research. The measurement values obtained by this method show significant consistency with the traditional Gini coefficient used to measure income inequality.

The urban nighttime lighting Gini coefficient ranges from 0 to 1. Values closer to 1 indicate more pronounced differences in economic scale among regions and greater imbalances in development. Conversely, lower values indicate smaller differences in economic scale and more balanced development. When the measurement value exceeds 0.5, it suggests a significant gap in social development within the region.

2.3.4. Cluster/Outlier Analysis of Nighttime Lighting

The study aimed to investigate the temporal homogeneity of nighttime lighting data in impoverished counties, and to analyze the relationship between nighttime lighting trends and land use changes. To achieve this, the K-means clustering method based on the dynamic time warping (DTW) distance algorithm [58] was used to group the nighttime lighting trends of 831 impoverished counties into five clusters based on their sequential similarities. Each cluster's characteristics were analyzed to identify similarities and differences in their trends (Figure 3).

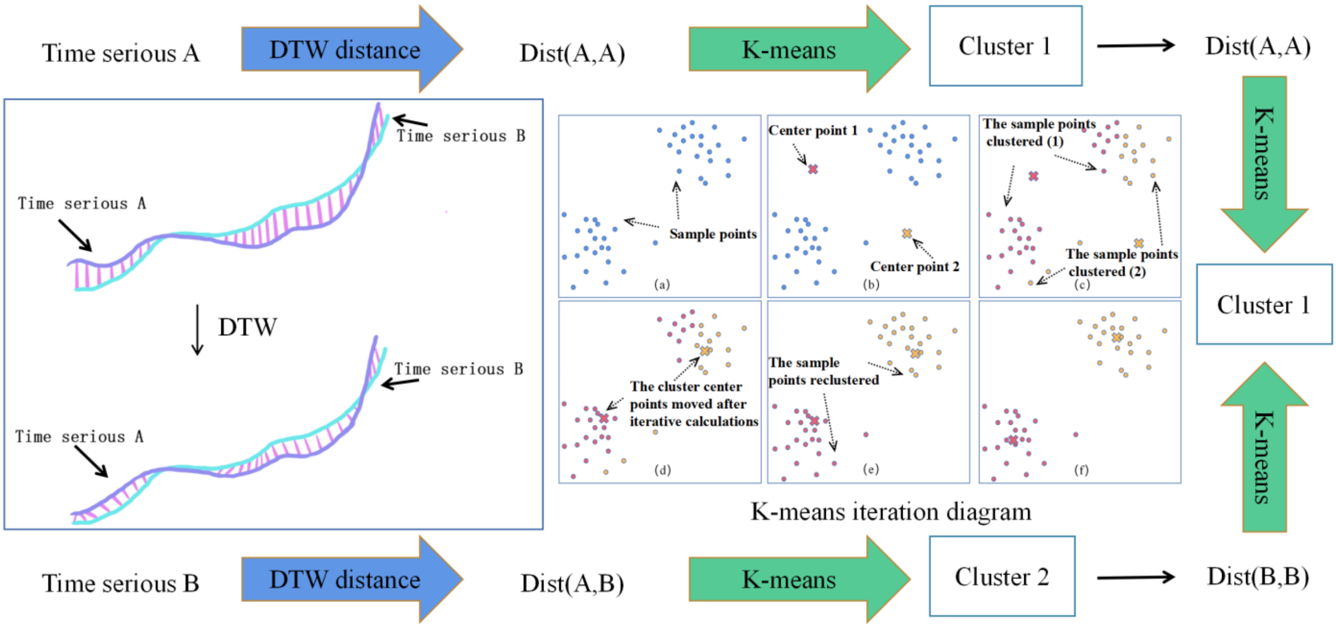

Figure 3. The basic steps of the DTW+K-means algorithm.

To better understand the relationship between land use change and economic development in impoverished counties, we selected typical impoverished counties with the highest fit degree in each cluster as representative cases in order to analyze the current status and characteristics of land use changes under different nighttime lighting clusters.

Our results provide insights into the temporal changes of nighttime lighting data in impoverished counties, and the associated land use changes [59]. The K-means clustering method helped identify distinct nighttime lighting trends, and the representative cases revealed the relationship between nighttime lighting and land use changes. This information could help policymakers and researchers develop effective poverty alleviation strategies and promote sustainable urban development.

3. Results

3.1. Amount Identification of the Nighttime Lighting

During the entire study period, the nighttime lighting intensity in impoverished counties in China exhibited a significant increasing trend (Figure 4). Despite having a relatively small base of total nighttime lighting intensity (TNL), the intensity steadily increased. The growth of total nighttime lighting intensity (GTNL) in impoverished counties averaged 942.89 nW$\cdot$cm$^{-2}\cdot$sr^{-1}, accounting for approximately 33.95% of the national average county growth. In terms of growth rate, the growth rate of total nighttime lighting intensity (GRTNL) in impoverished counties was 103.74%, far exceeding the total growth rate of 67.16% in counties and 64.68% in non-impoverished counties, and it peaked from 2016 to 2018. Additionally, the average year-on-year growth rate of total nighttime lighting in impoverished counties (YGRTNL) was 9.69%, exceeding both the national average annual growth rate of 6.77% and the average annual growth rate of non-impoverished counties of 6.56%. Therefore, the study demonstrates that impoverished counties outperformed non-impoverished counties throughout the study period.

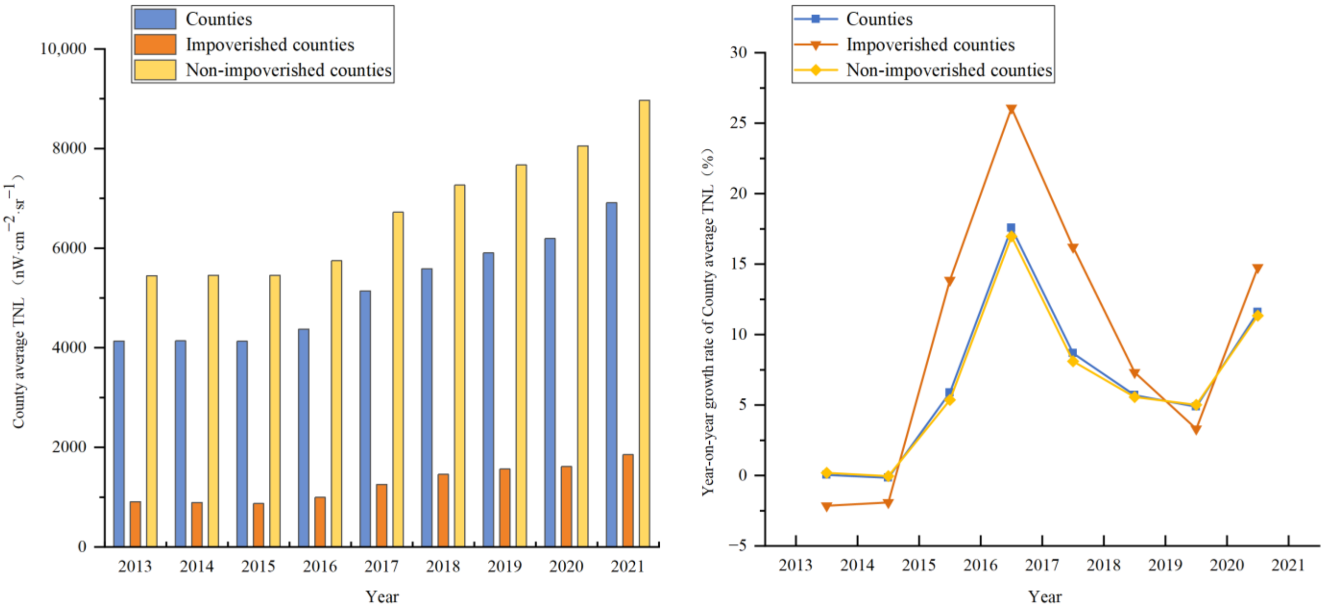

Figure 4. Amount identification of the nighttime lighting of nationwide, impoverished, and nonimpoverished counties based on TNL and YGRTNL.

We investigated the relationship between the year-on-year growth rate of nighttime lighting and poverty alleviation years in different impoverished counties (Figure 5). The growth rate in impoverished counties exhibited significant fluctuations across different years, displaying an overall N-shaped pattern characterized by a gradual slowdown from 2015 to 2017, followed by a continued deceleration until 2020, and a subsequent recovery from 2020 to 2021, thus showing an "acceleration-slowdown-rebound" trend. Notably, all impoverished counties achieved their highest growth rate during 2016–2017. Between 2019 and 2020, the growth rate of nighttime lighting in all impoverished counties dropped to the lowest. However, from 2020 to 2021, the growth rate of nighttime lighting in all impoverished counties rebounded significantly, with some surpassing the levels during 2017–2018. Furthermore, the impoverished counties that were lifted out of poverty that year exhibited a significantly higher growth rate than those that were lifted out of poverty in other years. Furthermore, as depicted in the figure, there is a positive correlation between the year of poverty alleviation and the intensity of nighttime lighting data, with the earlier poverty alleviation year corresponding to higher lighting intensity. Moreover, the trend of nighttime lighting change after poverty alleviation did not significantly slowdown but continued to grow.

3.2. Spatial Identification of the Nighttime Lighting

The changes in nighttime lighting in impoverished counties exhibit significant spatial variability, with an overall trend of decreasing intensity from the central region to the eastern, northeastern, and western regions (Figure 6). The growth rate of nighttime lighting exhibits a similar trend, with a decreasing rate from the western region to the central and eastern regions (Figure 7).

Specifically, the western region, which accounts for 68% of China's impoverished counties, has a slightly smaller average increase in nighttime light intensity than the central region, at 762.57 $nW \cdot cm^{-2} \cdot sr^{-1}$. However, there are striking internal differences, with the maximum growth reaching 7919.34 $nW \cdot cm^{-2} \cdot sr^{-1}$, while the minimum growth is only -1910.82 $nW \cdot cm^{-2} \cdot sr^{-1}$. Impoverished counties with nighttime light growth rates exceeding 2000% are concentrated in the western region, while 66% of impoverished counties with negative growth rates in nighttime light intensity are also in this region.

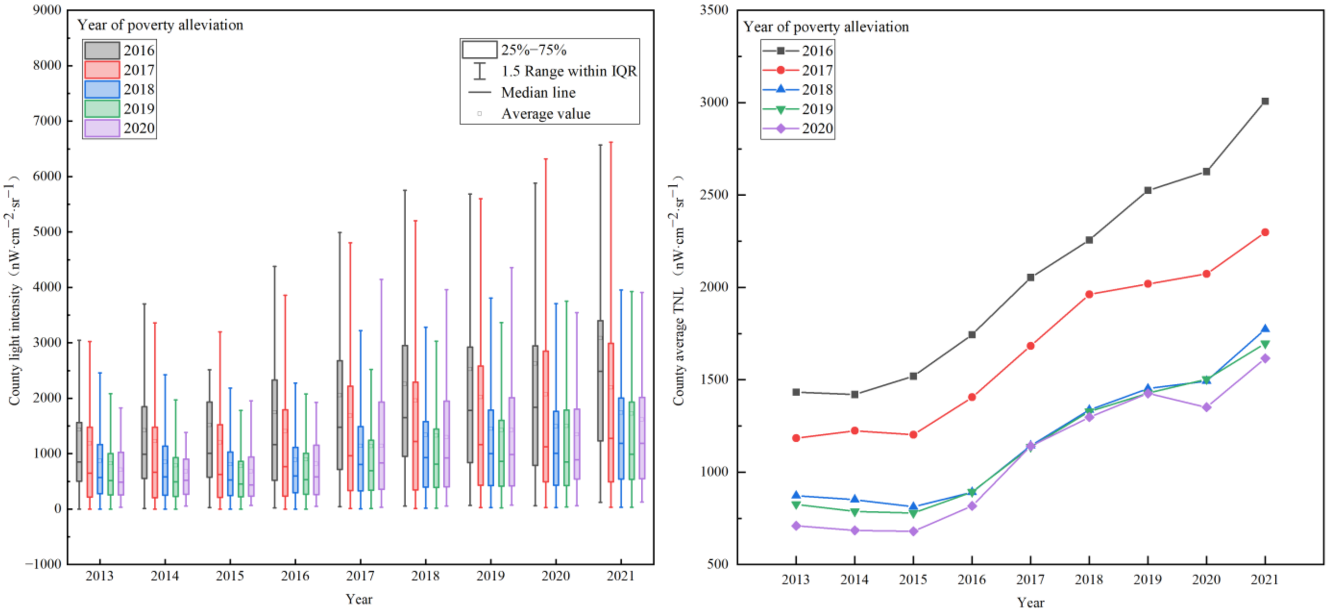

Figure 5. The relationship between nighttime lighting and time in counties with different poverty alleviation years is shown in the following figure. The left graph shows the nighttime lighting intensity of impoverished counties with different poverty alleviation years over time, while the right graph shows the average lighting intensity of impoverished counties with different poverty alleviation years over time.

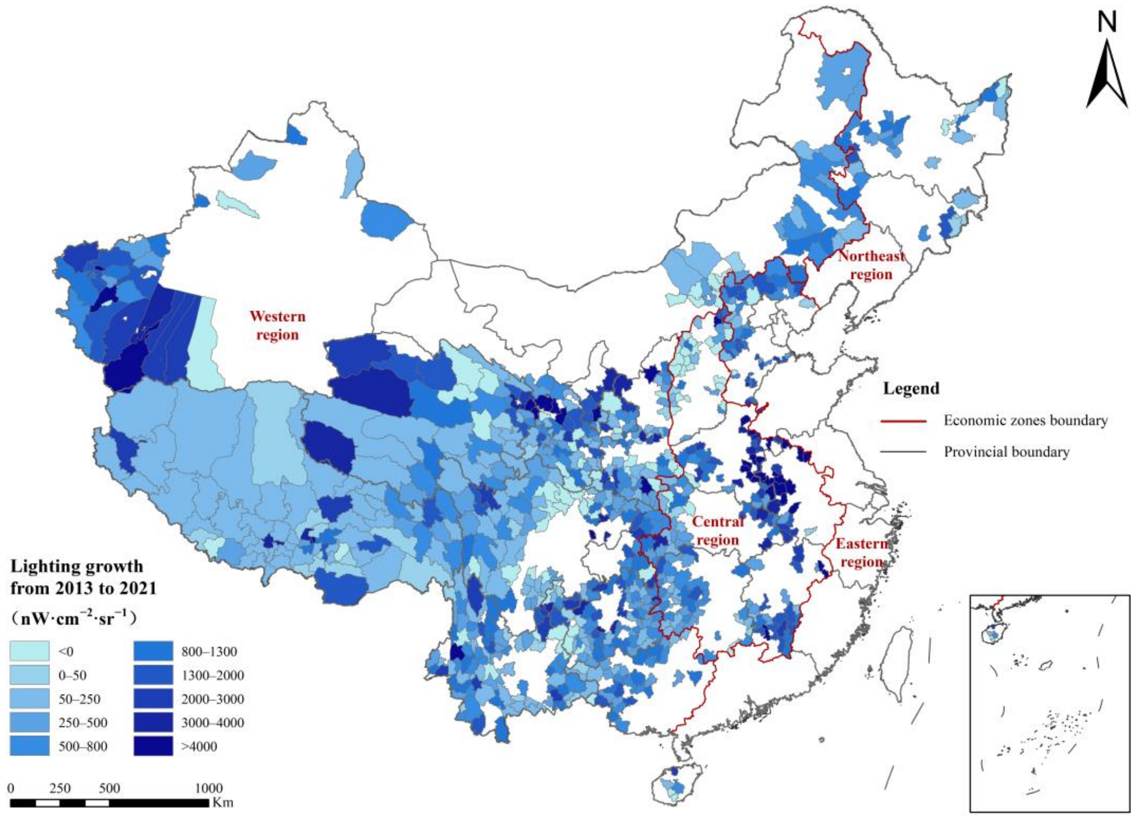

Figure 6. Spatial distribution of nighttime lighting growth in impoverished counties.

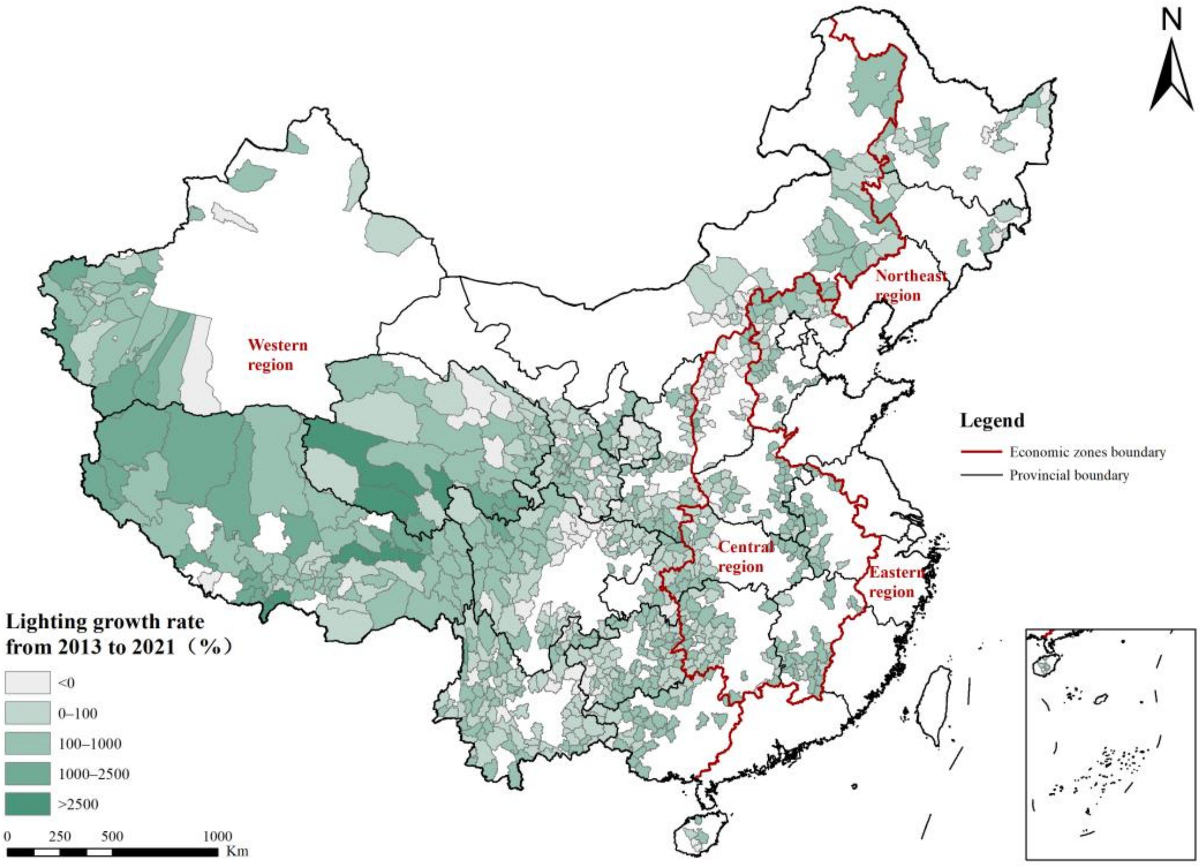

Figure 7. Spatial distribution of nighttime lighting growth rate in impoverish counties.

The central region, which accounts for 23% of China's impoverished counties, has the highest average increase in nighttime light intensity at 1550.89 nW$\cdot$cm$^{-2}\cdot$sr^{-1}. The increase in different impoverished counties is relatively different, with the maximum at 9892.43 nW$\cdot$cm$^{-2}\cdot$sr^{-1} and the minimum at $-$1112.23 nW$\cdot$cm$^{-2}\cdot$sr^{-1}, and the internal differences are not particularly obvious. The growth rate is at a medium level, with an average growth rate slightly lower than that of the western region, at 178.56%, and the internal spatial differences are small.

The eastern region has only 50 impoverished counties, accounting for 6% of the total. The overall increase in nighttime light intensity is slightly higher than that of the western region, at 924.57 nW$\cdot$cm$^{-2}\cdot$sr^{-1}, but the growth rate is lower than that of the western region, at 189.13%. Similarly, the northeastern region has only 28 impoverished counties (accounting for 3%), with the smallest increase in nighttime light intensity data, at 588.07 nW$\cdot$cm$^{-2}\cdot$sr^{-1}, and a growth rate that is only half of that in the western region, at 108.07%.

To further analyze the spatial differences in the growth rates of nighttime lighting in different economic regions of China, the nighttime light data of each impoverished county was subtracted from the national average growth rate of nighttime lighting to characterize the real development speed of impoverished counties (Figure 8). There are 487 impoverished counties with a growth rate greater than the national average, scattered throughout the country. However, the 319 impoverished counties with a growth rate less than the national average are mainly located in the western region, indicating spatial differences in the effectiveness of poverty alleviation effects across the country.

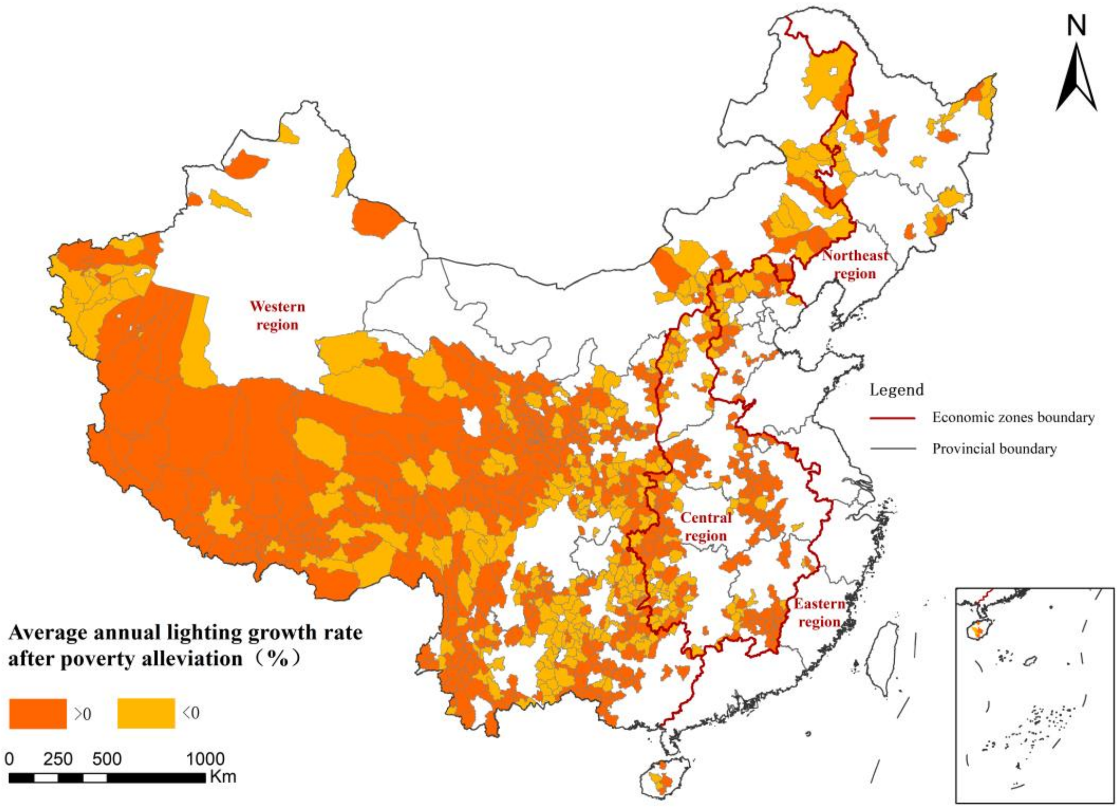

Figure 8. Average annual lighting growth rate after poverty alleviation in impoverished counties. If average annual lighting growth rate in the figure greater than 0 means that the growth rate of nighttime lighting in the impoverished counties is greater than the national average, and less than 0 means that it is lower than the national average.

3.3. The Spatial Equilibrium of Nighttime Lighting in Impoverished Counties

We used the Gini coefficient to assess the spatial equilibrium of nighttime lighting in impoverished counties, and the results showed that the Gini coefficient of nighttime lighting in impoverished counties exhibited a "slow, temporary rise, continuous decline" trend during the study period (Figure 9). Notably, internal differences in impoverished areas have decreased, indicating improved coordination in development. Nevertheless, in 2013, the Gini coefficient of nighttime lighting in urban impoverished counties surpassed the "warning line" for regional balanced development (0.4), reaching 0.54. From 2013 to 2015, the Gini coefficient of nighttime lighting in impoverished counties increased, followed by a continuous decline from 2015 to 2017, and it stayed stable from 2017 to 2020. Finally, there was a significant decrease from 2020 to 2021. Interestingly, the gap between impoverished counties and non-impoverished areas in China has been narrowing, and the disparity in regional development has been decreasing. From 2013 to 2021, the difference decreased from 0.07 to 0.03, and the Gini coefficient gradually became similar.

3.4. Cluster/Outlier Analysis of Nighttime Lighting Based on Time Series and Land Use Change

3.4.1. Cluster/Outlier Analysis of Nighttime Lighting Based on Time Series

The DTW+K-means algorithm (k = 5) was utilized to group 831 impoverished counties into five distinct clusters based on their temporal similarity in nighttime lighting changes, based on a time series (Figure 10). Cluster 1 comprises 385 impoverished counties, Cluster 2 has 279, Cluster 3 has 106, Cluster 4 has 51, and Cluster 5 has 10. Comparing the cluster centers of each cluster reveals the temporal characteristics of nighttime lighting changes in the five clusters.

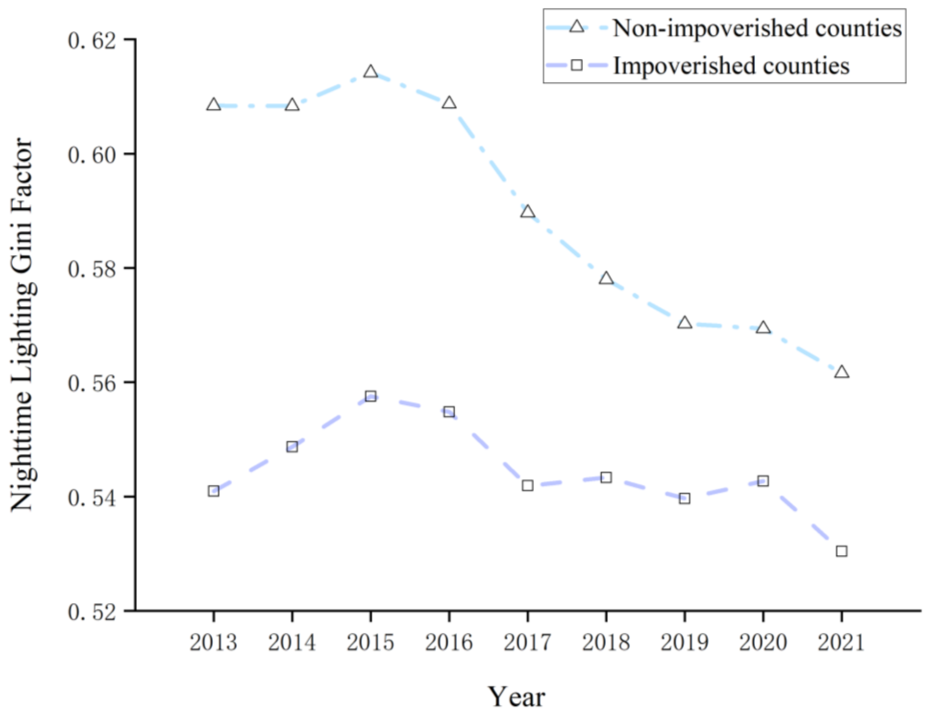

Figure 9. Gini coefficient shows the spatial equilibrium of nighttime lighting in impoverished and non-impoverished counties.

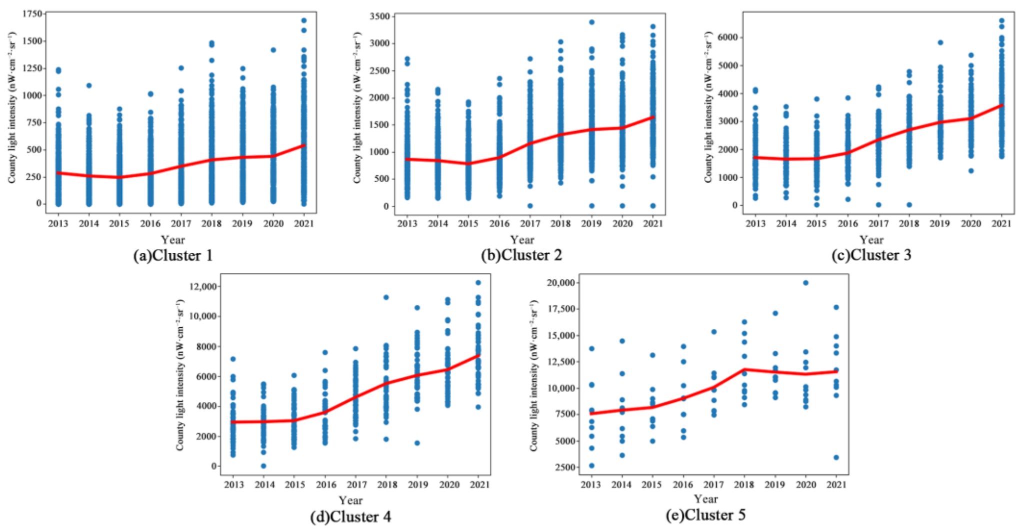

Figure 10. Nighttime lighting cluster analysis of impoverished counties. The five clusters include low base-slow growth type, low base-steady growth type, medium base-rapid growth type, high base-rapid growth type, and high base-slow growth type.

The temporal characteristics of nighttime lighting changes in each impoverished county cluster are as follows (Figure 11): low base-slow growth (66.67% growth rate), low base-steady growth (88.46% growth rate), medium base-rapid growth (94.44% growth rate), high base-rapid growth (150.02% growth rate), and high base-slow growth (46.67% growth rate). Impoverished counties in low base-slow growth and low base-steady growth exhibit a relatively small nighttime lighting base, particularly low base-slow growth cluster with nighttime lighting intensity less than 500 nW·cm^{-2}·sr^{-1} from 2013 to 2021. The nighttime lighting intensity base of medium base-rapid growth cluster is less than 2000 nW·cm^{-2}·sr^{-1}, but shows a rapid growth trend during the poverty alleviation stage. For high base-rapid growth cluster, it has a large nighttime lighting base, and has grown rapidly since 2017, with a much higher growth rate than other clusters. A high base-slow growth cluster exhibits the largest nighttime lighting intensity base, far exceeding other types, and it maintained a upward trend from 2013 to 2018, with a slight decrease for two consecutive years after 2018 to 2021, followed by a return to an upward trend. This cluster has the lowest growth rate during the research period.

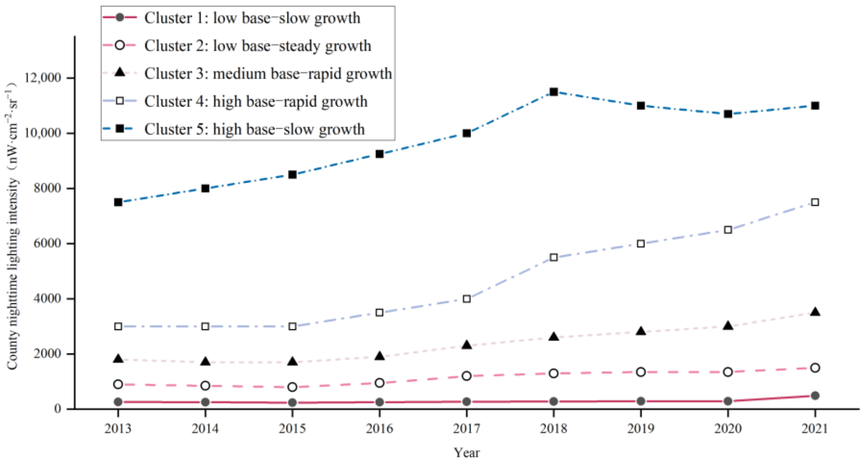

Figure 11. Nighttime lighting timing characteristic map of impoverished county.

3.4.2. Land Use Change under Cluster/Outlier Analysis of Nighttime Lighting

To provide a more nuanced understanding of the varying trends in land use changes across different clusters of nighttime lighting data, we selected five representative cases of typical impoverished counties that exhibited the highest degree of fit in each cluster for further analysis (Figure 12).

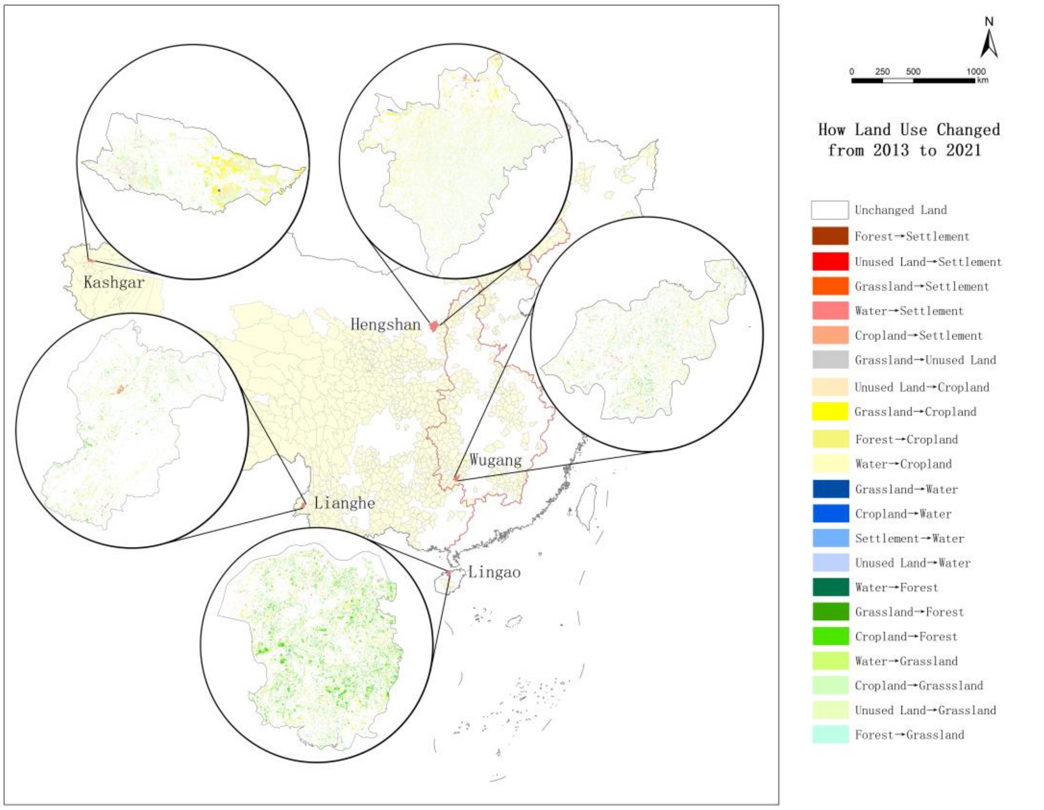

Figure 12. How land use changed from 2013 to 2021 in five representative cases of typical impoverished counties that exhibited the highest degree of fit in each cluster.

Lianghe, located in Yunnan province, demonstrated a low base-slow growth of nighttime lighting. During the study period, there was minimal land conversion occurring between forest and cropland, while grassland and cropland were gradually converted to settlement; Wugang, located in Hunan province, experienced a low base-steady growth of nighttime lighting, with a high proportion of cropland and forest (98.34%). The conversion of forest and cropland was steady, while the conversion of other land use type to settlement was relatively slow (around 0.53 square kilometers per year), resulting in a steady increase in nighttime lighting; Lingao, located in Hainan province, exhibited a medium base-rapid growth of nighttime lighting, with a high proportion of cropland and forest initially (96.03%). However, the flow of other land use types into settlement was one-way and the conversion rate was relatively high (around 0.51 square kilometers per year), resulting in a rapid increase in nighttime lighting during the study period. Kashgar, located in Xinjiang province, showed a high base-slow growth of nighttime lighting, with a significant amount of existing settlement and a slow rate of conversion of other land types into settlement. Finally, Hengshan, located in Shanxi province, exhibited a high base-rapid growth of nighttime lighting, with a relatively high initial proportion of settlement (0.63%). There was a significant conversion of cropland and grassland to settlement, leading to a sharp increase in nighttime lighting.

We found that the nighttime lighting growth rate and the variation trend of land use change are similar in many counties. A high nighttime lighting growth rate is always with the high land use change rate. Specifically, different nighttime lighting intensity has various initial structures of land use types and increasing rates of the settlement. Generally, the higher the nighttime lighting intensity, the larger the base of settlement, and the faster the growth rate of the nighttime lighting intensity shows a faster increase in settlement.

4. Discussion and Conclusions

4.1. Discussion

Nighttime lighting data from China's impoverished counties have a correlation with the effectiveness of China's poverty alleviation policies. In the critical period of evaluating the effect of phased poverty alleviation, preventing people who have been lifted out of poverty from falling back into poverty, and alleviating relative poverty, is of positive significance to reflect the implementation effect of China's policies through nighttime lighting data. Therefore, the main purpose of this study is to process the nighttime lighting data of China's impoverished counties from 2013 to 2021, analyze the impact of Chinese policies on it, and test the effectiveness of China's poverty alleviation policy implementation.

We analyzed the nighttime lighting data from time and spatial dimensions by using the interannual variation index of county nighttime lighting. It is found that the growth of total intensity of nighttime lighting (GRTNL) and the year-on-year growth rate of the total intensity of nighttime lighting (YGRTNL) in China's impoverished counties are both higher than the average levels of all counties and non-poor counties in China during the same period. However, according to data from the National Bureau of Statistics of China, the growth rate of infrastructure investment in China has slowed down since 2018, which may lead to a decline in the growth rate of total nighttime lighting intensity in both impoverished and non-impoverished counties. In addition, that decline in support at the end of poverty alleviation policies or the influence of environmental factors, such as the epidemic, may also lead to the nighttime lighting intensity in some impoverished counties showing a downward trend in 2020. Some impoverished counties are at risk of falling back into poverty after being declared out of poverty but continue to achieve economic growth after the implementation of the rural revitalization strategy. By analyzing regional characteristics based on the division of China's four major economic regions, we found that the growth of nighttime lighting intensity shows a trend of decreasing from the central to the eastern, northeastern, and western regions (central region has average increase in nighttime light intensity at 1550.89 $nW \cdot cm^{-2} \cdot sr^{-1}$, eastern at 924.57 $nW \cdot cm^{-2} \cdot sr^{-1}$, northeastern at 588.07 $nW \cdot cm^{-2} \cdot sr^{-1}$ and western at 762.57 $nW \cdot cm^{-2} \cdot sr^{-1}$), while the growth rate decreases from the western to the eastern, the central, and northeastern regions (the northeastern region has the growth rate of nighttime lighting at 108.07%, the central at 178.56%, the eastern at 189.13%, and the western at 282.46%). The most probable reasons for these results are that the western region that integrates border areas, ethnic minority areas, and areas prone to natural disasters has relatively slow poverty alleviation policies, which are based on the premise of environmental protection. While the central region has a convenient transportation network and abundant resources, and its poverty alleviation policies attach importance to the consolidation and development of industries so that it shows a better result. In addition, we also found that impoverished counties that were lifted out of poverty earlier had significantly higher nighttime lighting intensity than those lifted out of poverty later. In other words, the earlier a county was lifted out of poverty, the greater its nighttime lighting intensity, which indirectly confirms the reliability of nighttime lighting data as an indicator of economic activity. At the same time, early poverty alleviation does not necessarily mean a weakening of the growth rate of nighttime lighting data. In a considerable period, impoverished counties that were lifted out of poverty earlier were able to maintain a relatively fast growth rate of nighttime lighting intensity, which confirms the effectiveness and sustainability of China's poverty alleviation effects.

Based on spatial equilibrium and cluster/outlier analysis of nighttime lighting, it was found that the results showed a trend of "slow and short-term rise-rapid and continuous decline" after we introduced the Gini coefficient of nighttime lighting, indicating that China's poverty alleviation policy and work tend to be mature after long-term exploration. We then built a K-means clustering algorithm based on DTW similarity to divide 831 impoverished counties into five categories, and found that they have different characteristics during the study period. The growth rate of some clusters declined after the end of the Targeted Poverty Alleviation policy, but it increased, instead, after the implementation of the rural revitalization strategy, which is another policy from the Chinese government to help rural areas develop.

As land factors are closely related to economic development, we selected five typical impoverished counties that exhibited the highest degree of fit in each cluster and analyzed their land use transfer matrix. We found that the nighttime lighting growth rate and the variation trend of land use change are similar in many counties. A high nighttime lighting growth rate is always with the high land use change rate. Specifically, different nighttime lighting intensity has various initial structure of land use types and increasing rates of the settlement. Generally, the higher the nighttime lighting intensity, the larger the base of settlement, and the faster the growth rate of the nighttime lighting intensity shows a faster increase in settlement. The main reason for this is that settlement is a human-dominated land use type, and the greater its proportion and growth rate, the more intense human activities are, which is consistent with previous research [60]. At the same time, the study also found that impoverished counties with a low base and slow changes in nighttime light (that is, weak economic activities) often have high proportions of forest lands or other types that are less involved in human activities. Therefore, considering the performance of different land use types at different levels of economic development, future poverty alleviation and rural revitalization work should give preference to land use policies in economically backward areas in order to maintain and improve the local economic development level.

4.2. Conclusions

Our research indicates that the growth of nighttime lighting intensity in impoverished counties is directly correlated with economic growth. Counties with higher nighttime lighting intensity tend to achieve poverty alleviation earlier, confirming the effectiveness of using objective indicators such as nighttime lighting data to assess poverty alleviation policies and gain deeper insights into economic activity in impoverished areas. The economic level of China's national impoverished counties is steadily improving, and poverty alleviation and rural revitalization policies have a sustainable impact on nighttime lighting and economic development in these counties, emphasizing a sustained balance between time and space. Additionally, we found different nighttime lighting intensity has various initial structure of land use types and increasing rates of the settlement. Generally, the higher the nighttime lighting intensity, the larger the base of the settlement, and the faster the growth rate of the nighttime lighting intensity shows the faster increase in settlement. This finding emphasizes the importance of effective land resource management to promote economic growth and eradicate poverty.

It can be concluded that effective poverty alleviation policies can promote a country's economic growth and development, while targeted policies for impoverished areas can have a positive impact on their economic growth and help prevent people from falling back into poverty.

4.3. Limitations and Uncertainties

Our research provides evidence for the positive impact of China's poverty alleviation policies on the nighttime lighting data of impoverished counties, reflecting the progress made in poverty alleviation and economic development. Additionally, the findings suggest that nighttime lighting data can serve as a valuable indicator for evaluating poverty alleviation policies and their implementation.

However, the study only focuses on the impact of poverty alleviation policies on nighttime lighting data and does not consider different poverty alleviation models' effectiveness and sustainability. Future research could combine nighttime lighting data with social surveys and spatial statistics to fully understand the effectiveness and sustainability of poverty alleviation effects. It could also explore the relationship between other indicators and poverty alleviation policies to provide a more comprehensive evaluation of different poverty alleviation models' effectiveness and sustainability, which could focus on two main aspects. First, analyzing the drivers behind spatial pattern changes in relation to actual field surveys may help in a better understanding of real-life problems. Second, incorporating data from land surveys as the third-party verification factor could decrease the deviation from the coupling of different remote sensing data products (such as lighting and land use) due to varying resolutions and the scale effect of geographic studies.

Author Contributions: Conceptualization, Y.R. and X.C.; methodology, Y.R., X.C., Q.Y. and J.D.; software, Y.S., Q.Y., J.D. and Y.L.; validation, Q.Y., J.D. and Y.L.; formal analysis, Y.S., X.C., Q.Y., Y.L., J.D. and Y.R.; investigation, Y.R., Y.S., X.C., Q.Y., J.D. and Y.L. ; resources, Y.R.; data curation, Q.Y., J.D. and Y.L.; writing—original draft preparation, Y.S.; writing—review and editing, Y.R.; visualization, Y.S., Q.Y., J.D. and Y.L.; supervision, Y.R.; project administration, Y.S.; funding acquisition, Y.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (grant number 42101268).

Acknowledgments: The authors are grateful to the anonymous reviewers for their comments and suggestions which contributed to the further improvement of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fritz, S.; See, L.; Carlson, T.; Haklay, M.; Oliver, J.L.; Fraisl, D.; Mondardini, R.; Brocklehurst, M.; Shanley, L.A.; Schade, S.; et al. Citizen science and the United Nations Sustainable Development Goals. *Nat. Sustain.* **2019**, *2*, 922–930. [CrossRef]
2. Sun, Y.; Wang, Y.; Huang, C.; Tan, R.; Cai, J. Measuring farmers' sustainable livelihood resilience in the context of poverty alleviation: A case study from Fugong County, China. *Humanit. Soc. Sci. Commun.* **2023**, *10*, 75. [CrossRef] [PubMed]
3. Di Falco, S.; Lynam, G. New evidence on the rural poverty and energy choice relationship. *Sci. Rep.* **2023**, *13*, 3320. [CrossRef] [PubMed]
4. Bruckner, B.; Hubacek, K.; Shan, Y.; Zhong, H.; Feng, K. Impacts of poverty alleviation on national and global carbon emissions. *Nat. Sustain.* **2022**, *5*, 311–320. [CrossRef]
5. Hubacek, K.; Baiocchi, G.; Feng, K.; Patwardhan, A. Poverty eradication in a carbon constrained world. *Nat. Commun.* **2017**, *8*, 912. [CrossRef]

6. Marotzke, J.; Semmann, D.; Milinski, M. The economic interaction between climate change mitigation, climate migration and poverty. *Nat. Clim. Chang.* **2020**, *10*, 518–525. [CrossRef]
7. Soergel, B.; Kriegler, E.; Bodirsky, B.L.; Bauer, N.; Leimbach, M.; Popp, A. Combining ambitious climate policies with efforts to eradicate poverty. *Nat. Commun.* **2021**, *12*, 2342. [CrossRef]
8. Xu, X.; Yang, H. Elderly chronic diseases and catastrophic health expenditure: An important cause of Borderline Poor Families' return to poverty in rural China. *Humanit. Soc. Sci. Commun.* **2022**, *9*, 291. [CrossRef]
9. Bossuroy, T.; Goldstein, M.; Karimou, B.; Karlan, D.; Kazianga, H.; Parienté, W.; Premand, P.; Thomas, C.C.; Udry, C.; Vaillant, J.; et al. Tackling psychosocial and capital constraints to alleviate poverty. *Nature* **2022**, *605*, 291–297. [CrossRef]
10. Huang, J.K.; Shi, P.F. Regional rural and structural transformations and farmer's income in the past four decades in China. *China Agric. Econ. Rev.* **2021**, *13*, 278–301. [CrossRef]
11. Guo, Y.Z.; Liu, Y.S. Sustainable poverty alleviation and green development in China's underdeveloped areas. *J. Geogr. Sci.* **2022**, *32*, 23–43. [CrossRef]
12. Xu, R.; Yue, W.; Wei, F.; Yang, G.; Chen, Y.; Pan, K. Inequality of public facilities between urban and rural areas and its driving factors in ten cities of China. *Sci. Rep.* **2022**, *12*, 13244. [CrossRef] [PubMed]
13. Wu, S.; Zheng, X.; Wei, C. Measurement of inequality using household energy consumption data in rural China. *Nat. Energy* **2017**, *2*, 795–803. [CrossRef]
14. Wang, H.; Zhuo, Y. The Necessary Way for the Development of China's Rural Areas in the New Era-Rural Revitalization Strategy. *Open J. Soc. Sci.* **2018**, *06*, 97–106. [CrossRef]
15. Shu, H.; Xiong, P.P. The Gini coefficient structure and its application for the evaluation of regional balance development in China. *J. Clean. Prod.* **2018**, *199*, 668–686. [CrossRef]
16. Bowles, S.; Carlin, W. Inequality as experienced difference: A reformulation of the Gini coefficient. *Econ. Lett.* **2020**, *186*, 108789. [CrossRef]
17. Park, J.W.; Kim, C.U. Getting to a feasible income equality. *PLoS ONE* **2021**, *16*, e0249204. [CrossRef] [PubMed]
18. Chen, Y.; Zheng, Z.; Wu, Z.; Qian, Q. Review and prospect of application of nighttime light remote sensing data. *Prog. Geogr.* **2019**, *38*, 205–223. [CrossRef]
19. Elvidge, C.D.; Baugh, K.; Zhizhin, M.; Hsu, F.C.; Ghosh, T. VIIRS night-time lights. *Int. J. Remote Sens.* **2017**, *38*, 5860–5879. [CrossRef]
20. Levin, N.; Kyba, C.C.M.; Zhang, Q.L.; de Miguel, A.S.; Roman, M.O.; Li, X.; Portnov, B.A.; Molthan, A.L.; Jechow, A.; Miller, S.D.; et al. Remote sensing of night lights: A review and an outlook for the future. *Remote Sens. Environ.* **2020**, *237*, 111443. [CrossRef]
21. Jiang, W.; He, G.J.; Long, T.F.; Guo, H.X.; Yin, R.Y.; Leng, W.C.; Liu, H.C.; Wang, G.Z. Potentiality of Using Luojia 1-01 Nighttime Light Imagery to Investigate Artificial Light Pollution. *Sensors* **2018**, *18*, 2900. [CrossRef] [PubMed]
22. Zheng, Q.M.; Weng, Q.H.; Huang, L.Y.; Wang, K.; Deng, J.S.; Jiang, R.W.; Ye, Z.R.; Gan, M.Y. A new source of multi-spectral high spatial resolution night-time light imagery-JL1-3B. *Remote Sens. Environ.* **2018**, *215*, 300–312. [CrossRef]
23. Li, X.; Xu, H.M.; Chen, X.L.; Li, C. Potential of NPP-VIIRS Nighttime Light Imagery for Modeling the Regional Economy of China. *Remote Sens.* **2013**, *5*, 3057–3081. [CrossRef]
24. Zhao, C.C.; Cao, X.; Chen, X.H.; Cui, X.H. A consistent and corrected nighttime light dataset (CCNL 1992-2013) from DMSP-OLS data. *Sci. Data* **2022**, *9*, 12. [CrossRef]
25. Bennie, J.; Davies, T.W.; Duffy, J.P.; Inger, R.; Gaston, K.J. Contrasting trends in light pollution across Europe based on satellite observed night time lights. *Sci. Rep.* **2014**, *4*, 3789. [CrossRef] [PubMed]
26. Alvarez-Berrios, N.L.; Pares-Ramos, I.K.; Aide, T.M. Contrasting Patterns of Urban Expansion in Colombia, Ecuador, Peru, and Bolivia between 1992 and 2009. *Ambio* **2013**, *42*, 29–40. [CrossRef] [PubMed]
27. Imhoff, M.L.; Lawrence, W.T.; Stutzer, D.C.; Elvidge, C.D. A technique for using composite DMSP/OLS "city lights" satellite data to map urban area. *Remote Sens. Environ.* **1997**, *61*, 361–370. [CrossRef]
28. Small, C.; Pozzi, F.; Elvidge, C.D. Spatial analysis of global urban extent from DMSP-OLS night lights. *Remote Sens. Environ.* **2005**, *96*, 277–291. [CrossRef]
29. Zhou, Y.Y.; Smith, S.J.; Zhao, K.G.; Imhoff, M.; Thomson, A.; Bond-Lamberty, B.; Asrar, G.; Zhang, X.S.; He, C.Y.; Elvidge, C.D. A global map of urban extent from nightlights. *Environ. Res. Lett.* **2015**, *10*, 054011. [CrossRef]
30. Zhu, Z.; Zhou, Y.Y.; Seto, K.C.; Stokes, E.C.; Deng, C.B.; Pickett, S.T.A.; Taubenbock, H. Understanding an urbanizing planet: Strategic directions for remote sensing. *Remote Sens. Environ.* **2019**, *228*, 164–182. [CrossRef]
31. Min, B.; Gaba, K.M.; Sarr, O.F.; Agalassou, A. Detection of rural electrification in Africa using DMSP-OLS night lights imagery. *Int. J. Remote Sens.* **2013**, *34*, 8118–8141. [CrossRef]
32. Min, B.; Gaba, K.M. Tracking Electrification in Vietnam Using Nighttime Lights. *Remote Sens.* **2014**, *6*, 9511–9529. [CrossRef]
33. 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]
34. Forbes, D.J. Multi-scale analysis of the relationship between economic statistics and DMSP-OLS night light images. *GIScience Remote Sens.* **2013**, *50*, 483–499. [CrossRef]
35. Elvidge, C.D.; Sutton, P.C.; Ghosh, T.; Tuttle, B.T.; Baugh, K.E.; Bhaduri, B.; Bright, E. A global poverty map derived from satellite data. *Comput. Geosci.* **2009**, *35*, 1652–1660. [CrossRef]

36. Wang, W.; Cheng, H.; Zhang, L. Poverty assessment using DMSP/OLS night-time light satellite imagery at a provincial scale in China. *Adv. Space Res.* **2012**, *49*, 1253–1264. [CrossRef]
37. Yu, B.L.; Shi, K.F.; Hu, Y.J.; Huang, C.; Chen, Z.Q.; Wu, J.P. Poverty Evaluation Using NPP-VIIRS Nighttime Light Composite Data at the County Level in China. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2015**, *8*, 1217–1229. [CrossRef]
38. Weber, D.C. Ecological Consequences of Artificial Night Lighting. *Environ. Entomol.* **2008**, *37*, 1371–1372. [CrossRef]
39. Lunn, R.M.; Blask, D.E.; Coogan, A.N.; Figueiro, M.; Gorman, M.R.; Hall, J.E.; Hansen, J.; Nelson, R.J.; Panda, S.; Smolensky, M.H.; et al. Health consequences of electric lighting practices in the modern world: A report on the National Toxicology Program's workshop on shift work at night, artificial light at night, and circadian disruption. *Sci. Total Environ.* **2017**, *607*, 1073–1084. [CrossRef]
40. Li, X.C.; Zhou, Y.Y.; Zhao, M.; Zhao, X. A harmonized global nighttime light dataset 1992-2018. *Sci. Data* **2020**, *7*, 9. [CrossRef]
41. Zhou, N.; Hubacek, K.; Roberts, M. Analysis of spatial patterns of urban growth across South Asia using DMSP-OLS nighttime lights data. *Appl. Geogr.* **2015**, *63*, 292–303. [CrossRef]
42. Lazar, M.M. Shedding Light on the Global Distribution of Economic Activity. *Open Geogr. J.* **2010**, *3*, 147–160. [CrossRef]
43. Fu, H.Y.; Shao, Z.F.; Fu, P.; Cheng, Q.M. The Dynamic Analysis between Urban Nighttime Economy and Urbanization Using the DMSP/OLS Nighttime Light Data in China from 1992 to 2012. *Remote Sens.* **2017**, *9*, 416. [CrossRef]
44. Xu, K.; Chen, F.; Liu, X. The Truth of China Economic Growth:Evidence from Global Night-time Light Data. *Econ. Res. J.* **2015**, *9*, 17–29.
45. Pérez-Sindín, X.S.; Chen, T.-H.K.; Prishchepov, A.V. Are night-time lights a good proxy of economic activity in rural areas in middle and low-income countries? Examining the empirical evidence from Colombia. *Remote Sens. Appl. Soc. Environ.* **2021**, *24*, 100647. [CrossRef]
46. Rounsevell, M.D.A.; Pedroli, B.; Erb, K.H.; Gramberger, M.; Busck, A.G.; Haberl, H.; Kristensen, S.; Kuemmerle, T.; Lavorel, S.; Lindner, M.; et al. Challenges for land system science. *Land Use Policy* **2012**, *29*, 899–910. [CrossRef]
47. Dang, A.N.; Kawasaki, A. Integrating biophysical and socio-economic factors for land-use and land-cover change projection in agricultural economic regions. *Ecol. Model.* **2017**, *344*, 29–37. [CrossRef]
48. Li, J.Y.; Zhang, C.X.; Zheng, X.Q.; Chen, Y.M. Temporal-Spatial Analysis of the Warming Effect of Different Cultivated Land Urbanization of Metropolitan Area in China. *Sci. Rep.* **2020**, *10*, 17. [CrossRef]
49. Serra, P.; Pons, X.; Sauri, D. Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Appl. Geogr.* **2008**, *28*, 189–209. [CrossRef]
50. Li, C.; Zhu, H.L.; Ye, X.Y.; Jiang, C.; Dong, J.; Wang, D.; Wu, Y.J. Study on Average Housing Prices in the Inland Capital Cities of China by Night-time Light Remote Sensing and Official Statistics Data. *Sci. Rep.* **2020**, *10*, 20. [CrossRef]
51. Liu, Z.F.; He, C.Y.; Zhang, Q.F.; Huang, Q.X.; 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]
52. Shu, C.; Xie, H.L.; Jiang, J.F.; Chen, Q.R. Is Urban Land Development Driven by Economic Development or Fiscal Revenue Stimuli in China? *Land Use Policy* **2018**, *77*, 107–115. [CrossRef]
53. Singh, S.K.; Srivastava, P.K.; Gupta, M.; Thakur, J.K.; Mukherjee, S. Appraisal of land use/land cover of mangrove forest ecosystem using support vector machine. *Environ. Earth Sci.* **2014**, *71*, 2245–2255. [CrossRef]
54. Chen, Z.Q.; Yu, B.L.; Yang, C.S.; 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]
55. Yang, J.; Huang, X. The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. *Earth Syst. Sci. Data* **2021**, *13*, 3907–3925. [CrossRef]
56. Wu, J.H.; Tu, Y.; Chen, Z.Q.; Yu, B.L. Analyzing the Spatially Heterogeneous Relationships between Nighttime Light Intensity and Human Activities across Chongqing, China. *Remote Sens.* **2022**, *14*, 5695. [CrossRef]
57. Gastwirth, J.L. The Estimation of the Lorenz Curve and Gini Index. *Rev. Econ. Stat.* **1972**, *54*, 306–316. [CrossRef]
58. Niennattrakul, V.; Ratanamahatana, C.A. On Clustering Multimedia Time Series Data Using K-Means and Dynamic Time Warping. In Proceedings of the 2007 International Conference on Multimedia and Ubiquitous Engineering (MUE'07), Seoul, Republic of Korea, 26–28 April 2007; pp. 733–738.
59. Fan, J.F.; Liu, Q.Y.; Ren, Z.P.; Chen, Z.; Li, W.Q.; Yu, Y.; Zhou, Y.K. Nighttime luminosity transitions are tightly spatiotemporally correlated with land use changes: A pixelwise case study in Beijing, China. *Ecol. Indic.* **2022**, *145*, 16. [CrossRef]
60. Rao, Y.; Zhang, J.; Wang, K.; Jepsen, M.R. Understanding land use volatility and agglomeration in northern Southeast Asia. *J. Environ. Manag.* **2021**, *278*, 111536. [CrossRef]