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Article

# Exploring Divergent Patterns and Dynamics of Urban and Active Rural Developments

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**Abstract:** Analyzing urban-rural spatial structures and changes are of great significance for understanding the urban-rural relationship evolution. While previous studies mostly focused on the urban internal spatial structure evolution, less from the regional scale to explore the urban and rural evolution. Here, taking Dezhou city, a rapidly urbanization city in China as a case study, we employed the local contour tree method and nighttime light data to map urban and active rural regions' range during 2012-2020, and further explored the respective development processes of them. This study found that different from rural regions, internal structures of urban regions are more complex, and there are often multiple hot spots inside them. The urban-rural regions' area had increased significantly by 39.3% during 2012-2020 ( $p<0.05$ ). The urban and rural region rankings of the identified counties are basically consistent with the urban and rural population rankings. Particularly, different from perspectives of earlier land use (i.e., built-up land or impervious surface), this study identified urban and active rural regions in view of the scope of active human activities. This study therefore found populations were greatly responsible for affecting changes of urban and active rural region structures. These findings could be helpful for understanding urban-rural dynamics.

**Keywords:** nighttime light data; urban-rural regions; geospatial dynamics; local contour tree method; Dezhou city of China

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## 1. Introduction

Urban structure refers to the form and way of the relationship and interaction between the elements of urban organizations, including economic structure, social structure, the formation of various regions within the city and its distribution and configuration. In recent years, it has received more attention in urban research and planning circles [1,2]. Because of its relatively single internal organizational structure, there are few studies on rural regions' internal structure. Driven by urbanization and industrialization, the flow of materials, information, capital and people between urban and rural areas is more frequent, and the influence between them is gradually deepening [3-6]. The concept of urban-rural integrated development has been put forward. Urban-rural integrated development is the integration of urban-rural planning, industrial development, infrastructure construction, public services, employment market, social management, the gradual disappearance of urban and rural differences, and finally the process of integration [7-12]. Furthermore, relevant researches should not be limited to cities, but should also include rural areas in the research category. The concept of urban structure needs to be expanded to urban-rural structure. The urban-rural structure is mainly reflected in the population distribution, industrial structure, economic development and spatial structure between urban-rural regions. Urban-rural population [13,14], industry [15,16] and economic development issues [4,17] are often studied by scholars, but urban-rural spatial structure is less mentioned. Urban-rural spatial structure is the result of different development forces in a given region and is also a direct reflection of regional functions [18-20].

What is the specific scope of the urban-rural spatial structure? What is the development history of urban-rural spatial structure? What is the functional partition of urban-rural spatial structure? How will the flow of population, capital and material between urban-rural regions affect the urban-rural spatial structure? Studying these problems can help us to understand the process and mechanism of urban-rural integration, and help to solve a series of problems in the process of urban-rural integration, such as rural hollowing [21] and large urban-rural income gap [22].

In urban regions, there are kinds of data such as cell phone signaling, Point of Interest (POI), taxi trajectory data, and land use data can be employed to research urban structure. Sun and Fan [23] employed taxi trajectory data to identify urban centers and the results show that the taxi track data can be used to accurately identify the urban center of Shanghai in different periods. Meanwhile, they analyzed the spatial and temporal changes of its pattern. Deng et al. [24] used POI data to detect the city's primary and secondary centers, and the results showed good accuracy. The study found that most of the city's urban centers had comprehensive functions. In addition, a series of data such as housing, mobile signaling, road network and GPS location can be used to conduct urban studies [25-27].

However, in rural regions, researchers are often limited by data acquisition conditions and cannot carry out research well. When it comes to rural issues, previous researchers mostly get research data through field researches or statistical yearbooks [28-32]. Field research is the most commonly used method, but it requires a lot of manpower and material resources. It's not very convenient to carry out large-scale research. Statistics can only show the overall situation and are usually difficult to be used in geospatial rural issues.

With the development of remote sensing technology, researchers began to study urban-rural structure through remote sensing monitoring data of land use. For example, Hara used remote sensing interpretation technology to identify the changes of paddy fields in the suburbs of Bangkok to study the expansion of urban-rural mixed areas [33]. With GIS technology, Gu used land use data to explore the changes of urban-rural landscape pattern in Tianjin Binhai New District [34]. Although land use data has made a significant contribution to the study of urban-rural spatial structure, it is difficult to reflect the situation of urban-rural population, economy and industrial activity agglomeration, and ignores the role of human activities in urban and rural structure.

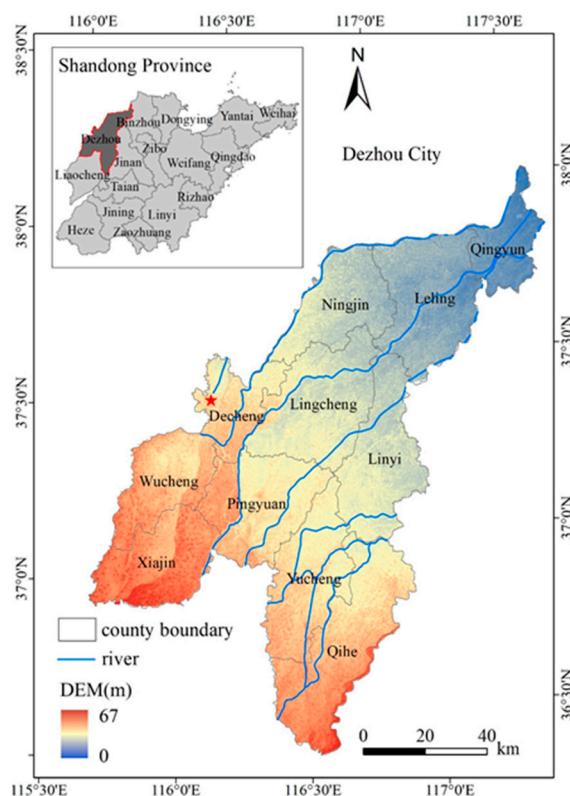
Fortunately, with the continuous advancement of remote sensing monitoring technology, satellites can directly monitor the state of human activity at night, that is, night light. Nighttime light data can be used to detect human activities, and is widely used in GDP, population, military conflict, urbanization monitoring and other research and analysis related to human activities [30,32,35-39]. Nighttime light data can be employed to monitor light changes when human activity changes in urban-rural regions, which can be used to monitor the change of urban and rural spatial morphology. However, studies on urban-rural regions' spatial morphology and its changes using nighttime light data are still lacking. This is mainly because the proximity of night light to human activities is rather weak in rural regions. Therefore, we tried to design an algorithm to improve the quality of nighttime light data to enhance the ability to identify rural regions. Inspired by the work of Wu [40], we employed the localized contour tree method to identify spatial urban and rural patterns in Dezhou city of China. In addition, the hierarchy and attributes of the detected centers were analyzed and calculated.

In this work, the following research questions are addressed: (1) How nighttime light data can be improved to highlight rural regions? and (2) How the urban-rural structure has changed and what are the mechanisms behind this change?

## 2. Materials and Methods

### 2.1. Study area

Dezhou city, with a total area of  $1.04 \times 10^4 \text{ km}^2$  and 5.6 million people locates in east China and the western part of the Shandong Province. Because of locating in the alluvial plain of the Yellow River, the Yellow River flooded frequently in the history of Dezhou city, resulting in the topography of high southwest and low northeast. Dezhou city is significantly affected by the monsoon climate and has the obvious cold-hot and dry-wet boundary which is suitable for agricultural production. At the same time, Dezhou city is also the transportation hub of China. Good agricultural planting conditions make 47% (2.63 million) of the population in Dezhou an agricultural population. Due to the limited cropland resources, the per capita cropland area is only  $0.0024 \text{ km}^2$ , which is far lower than the average level of China ( $0.007 \text{ km}^2$ ). Less per capita land resources and surplus rural labor force led to many rural populations into cities. Therefore, Dezhou is a typical representative of the dramatic changes in urban-rural relations in the process of urbanization in China (Figure 1).



**Figure 1.** Location map of Dezhou city of Shandong province, China.

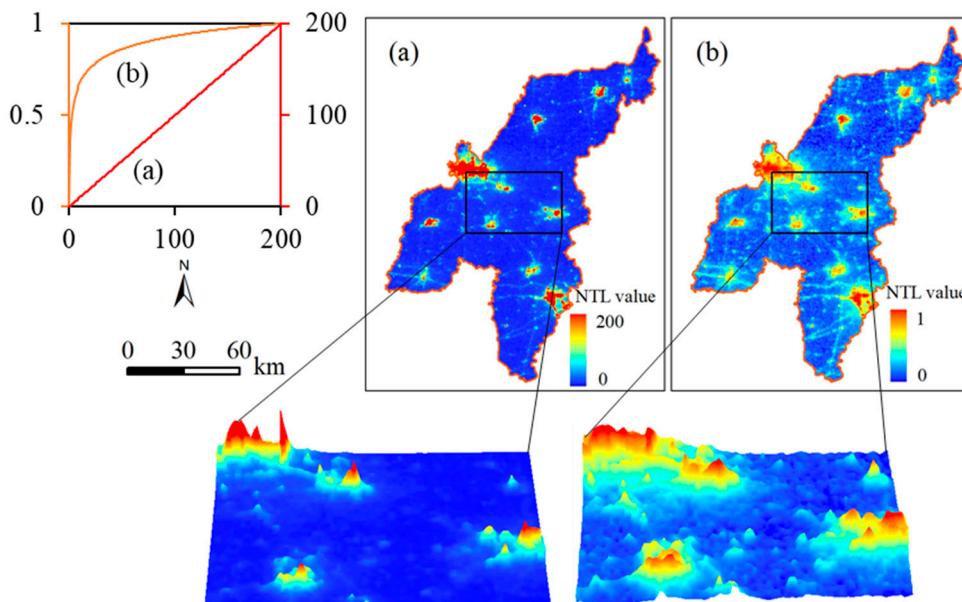
### 2.2. Data sources and processing

At present, the commonly used night light data mainly comes from two satellites. One is the Defense Meteorological Satellite Program (DMSP), which is the polar orbit satellite program of the United States Department of Defense. The spatial resolution of the sensor is 3000m. The spatial resolution of the night light products is usually 1000m, and the time series is 1992-2013. The other is the new generation of earth observation satellite Suomi NPP launched in 2011. The visible infrared imaging radiometer suit (VIIRS) carried by the satellite can obtain new nighttime light remote sensing images, and the spatial resolution is also improved to 750m. The spatial resolution of the nighttime light remote sensing products is 500m. Our study selected NPP-VIIRS nighttime light data during 2012-2020. The data comes from the National Ocean Center Meteorological Agency ([https://eogdata.mines.edu/nighttime\\_light/annual/v20/](https://eogdata.mines.edu/nighttime_light/annual/v20/)), the cloud cover pixel has been corrected.

To analyze the variation of urban and rural, the NPP-VIIRS data are utilized. Besides, nighttime light in rural regions is easily overlooked because of the huge difference in brightness between rural and urban regions. In our study, we employed conditional function model to reconstruct the monthly nighttime light data. The reconstructed nighttime light data can better highlight the rural regions (Figure 2). The calculation formula is as follows:

$$Y_i = \sqrt{\frac{\log_{10}(Y_i + 1)}{\log_{10}(X_{max} + 1)}} \quad (1)$$

where  $Y_i$  is the reconstructed nighttime light value;  $X_i$  is the original nighttime light value;  $X_{max}$  is the maximum nighttime light value in the region. In this study, we fixed  $X_{max}$  to 200. Based on reconstructed nighttime light data, a three-by-three Gaussian filter with sigma 1 was used to smooth the NPP-VIIRS nighttime light data to reduce noise. Besides, our study also uses the GDP and demographic yearbook data of Dezhou city from 2012 to 2020 to evaluate the results of urban-rural division and explore the driving mechanism of urban-rural spatial structure change.



**Figure 2.** Nighttime light data before (a) and after (b) conditional function model reconstruction.

### 2.3. Methods

#### 2.3.1. Localized contour tree of nighttime light data

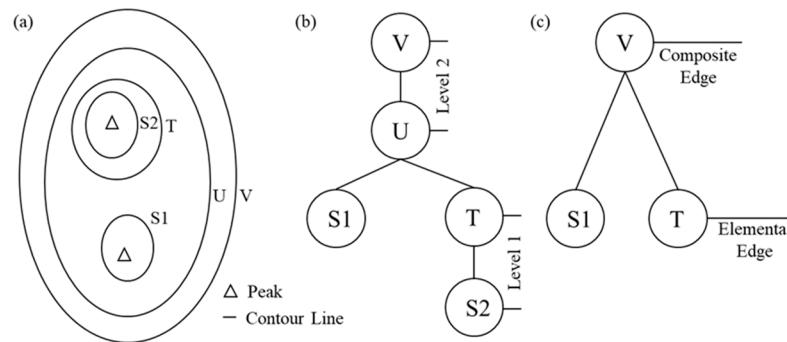
Urban-rural regions are the main bearing areas of human activities. Nighttime light is the most intuitive manifestation of human activities, and there is a high correlation with the strength of human activities. Therefore, the intensity distribution of nighttime light can be conceptualized as a continuous surface, representing the intensity of human activity, where the terrain corresponding to an urban or rural center is like a mountaintop.

Such a peak can be represented by a set of contour lines on a topographic map. Similarly, the identification of urban-rural spatial structures be the detection of a set of nighttime light density contour lines on the digital surface. The structural relationship of the contour lines can be represented by the contour tree. The initial use scenario of localized contour tree method is to explore and determine the surface depression through digital elevation model (DEM) [40,41]. Therefore, this study tried to apply the localized contour tree method to the structure determination of urban-rural regions through nighttime light.

The localized contour tree method uses one or more bifurcation trees (s) to represent a contour map. A contour tree is composed of Nodes and Links. A Node represents a contour line, and a Link

represents a topological relationship between two adjacent Nodes. The localized contour tree method mainly consists of three parts: (1) determine the position of seed contour; (2) generate regular contour tree; (3) simplify the contour tree. Figure 3 shows how to use the contour map of night light intensity to generate regular and simplified contour trees.

Firstly, we define the contour line that contain only one local nighttime light value peak and have no other contours inside as “seed contour line”. S1 and S2 are two seed contour lines in Figure 3a. In multi-center urban/rural regions, there are multiple nighttime light value peak points, and there will certainly be multiple seed contours. We define these seed contour lines as level 1 Nodes and identify the surrounding contours from level 1 Nodes outward. If the nearest contour of the seed contour contain line only its seed contour, the contour will be delimited at the same level as the seed contour line. If a contour line contains two or more individual seed contour lines, then we think the contour line’s level is higher than the seed contour lines it contains. For example, the contour line S1 and S2 in Figure 3a belong to the seed contour line, the contour line S2 and T belong to the same level 1 Node, and S1 belongs to other level 1 Node. Since there are two independent level 1 Node T and S1, the contour line U can be identified as a level 2 Node. The contour V contains U. Therefore, V also belongs to the level 2 Node. This recognition process will continue until all contour lines are identified, and finally construct a regular contour tree (Figure 3b). Then the regular contour tree of Figure 3b is simplified to reflect the hierarchical structure of different level nodes. In Figure 3b, contour line S2 and T belong to level 1 and can be considered as a branch in the contour tree map. Since there are no other seed contour line in this branch, we can consider this branch as an elemental region. The outermost contour line (T) of this branch represents the spatial range of this branch. Therefore, we only retain the contour line S1 and T in Figure 3b, representing two different branches. This identification method can be applied to the identification of all branches in the contour tree, such as the identification of branches belonging to the contour lines U and V in Figure 3b. In the identification of urban-rural spatial range, V (Figure 3c) can be regarded as a sub-tree, because it contains two independent level 1 Nodes, and no other contour line contains it. Meanwhile, V can be regarded as a two-node sub-tree.



**Figure 3.** Urban and rural region detection using localization contour tree method, referring to an earlier study[42]. (a) Nighttime light intensity contour map; (b) Regular contour tree; (c) Simplified contour tree.

It is possible for a single grid cell to be an urban/rural region, but the scope of urban/rural regions should not be too small. However, areas that are too small cannot be considered as an urban/rural region. Considering the above problem, we define the minimum urban/rural region as  $1\text{km}^2$ . Areas. Meanwhile, in our study, the extent of contour V is represented urban or rural regions. We believe that all major urban\rural regions can be detected with these preset parameters.

### 2.3.2. Calculation of urban and rural attributes

To further analyze the differences between urban-rural regions, we used five nighttime light statistics, including minimum light intensity (MIN), maximum light intensity (MAX), total night light intensity (TNTL), average light intensity (AI) and standard deviation of light intensity (STD).

Analogously, area (S) and compactness index (CI) were used to quantify the morphological and geometric characteristics of urban-rural regions. CI is a shape indicator defined by perimeter and area of urban / rural regions. In general, the circle is the most compact, CI value is 1. The definitions of the above seven urban / rural attributes are shown in Table 1.

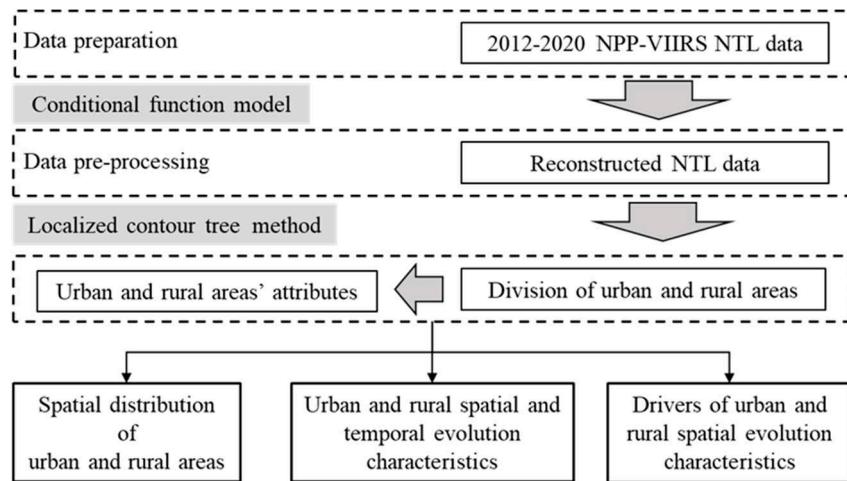
**Table 1.** Definitions of statistics of nighttime light value and morphometric characteristics.

Attribute	Definition
Minimum Intensity (MIN)	$\text{MIN} = \min_{i=1}^N \{x_i\}$ : $N$ is the number of pixels in an urban/rural region and $x_i$ is the nighttime light intensity value of the $i$ th pixel.
Maximum Intensity (MAX)	$\text{MAX} = \max_{i=1}^N \{x_i\}$
Total Nighttime Light Intensity (TNTL)	$\text{TNTL} = \sum_{i=1}^n x_i$
Area (S)	$S = N * \text{CS}$ : CS is the grid cell size. S is the area of an urban/rural region.
Average Intensity (AI)	$\text{AI} = \text{TNTL}/S$
Standard Deviation of Intensity (STD)	$\text{STD} = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2}$ : $\bar{x}$ indicates the average nighttime light value in a contour object.
Compactness index (CI)	$\text{CI} = 4\pi S/P^2$ : P is the perimeter of an urban/rural region.

### 2.3.3. Urban-rural division method

In China, the basic administrative unit is divided from top to bottom into province-city-county-township/town-village. Among them, the county seat is the most basic carrying unit of the urban region, while the township/town and village represent the vast rural region. At the same time, the intensity and scope of human and economic activities in urban regions are significantly higher than those in rural regions. Therefore, this can be used as a basis for the division of urban-rural regions in Dezhou city.

Firstly, we can obtain the spatial range of hot spots of human activities by using localized contour tree method. Then, taking the county as the smallest unit of the urban region, the hot spot area with the largest area of human activities within the county is designated as the city, and the other areas are designated as rural regions. Finally, specifically speaking, Dezhou city has 11 counties, so the top 11 hotspots are cities. However, in the continuous development of urban-rural regions, there may be the situation of the integration of the development of the two counties, resulting in the integration of the urban space scope of the two counties. In this case, we need to talk about the number of city limits separately, rather than just taking the first X bit of area as the city limits. The flow chart of this study is as follows in Figure 4.



**Figure 4.** Flowchart of the methodology adopted in this study.

### 3. Results

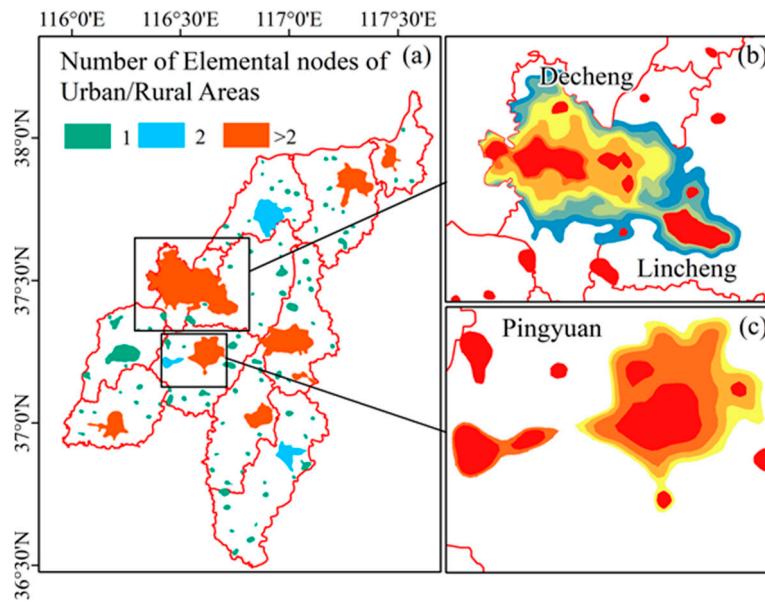
This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

#### 3.1. Identification and analysis of urban and active-rural regions

This study removed the closed lines with area less than 1 km<sup>2</sup> to eliminate potential urban-rural regions that were too small as mentioned in Section 2.3.1. Then we applied the localized contour tree method to generate contour trees during 2012-2020. Taking the simplified contour tree for 2020 as an example, Figure 5a shows the nighttime light contour maps and the nested hierarchical structures in Dezhou city. We obtained 105 sub-trees. Among them, 94 were one-node sub-trees (green features in Figure 5a), 3 were two-node sub-trees (blue features in Figure 5a), and the others belonged to three or more complex sub-trees (orange features in Figure 5a).

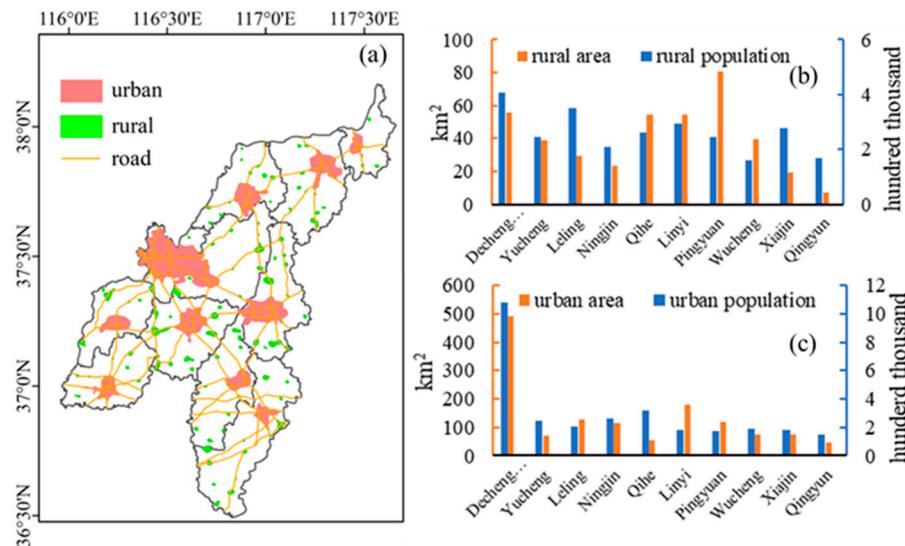
The largest sub-tree had 7 levels which is the economic center of Dezhou city located Decheng County and Lincheng County in the west, as shown in Figure 5b. And it turns out that the urban regions of the two counties are interconnected. Initially, regions with two or more nodes are basically urban regions, while regions with only one node are basically rural regions. Because urban regions tend to be more extensive, and there is often more than one area of intensive human activity. Human and socio-economic activities in rural regions tend to be homogeneous and generally concentrated in one place.

One-node sub-trees are the main part of the total. On the map, these areas are basically rural regions. One-node sub-trees mainly consist of town, factories and villages. The size of town is smaller than county and bigger than villages. For most towns in China, there are usually 1 or 2 main roads through the town at least. In some places, there could be a river through the town. Homes and other buildings often unfold along the road or river, which makes the construction of the town simpler than county (Figure A3a-g). Besides towns, factories are also extracted from nighttime light data. Figure A3h-g shows that the factory is far away from city and is surrounded by croplands. Industrial production consumes a lot of electricity, but cropland regions without lamplight make the factories the brightest spot(s) in these regions. Therefore, they can also be extracted when two or more villages are spaced together, producing nighttime lights that are close to the brightness of towns, though these cases are less common.



**Figure 5.** Nighttime light contour map of 2020. (a) Dezhou city, (b) Decheng and Lincheng county of Dezhou city and (c) Pingyuan county of Dezhou city.

This study divided urban-rural regions of 2020 according to the method 2.3.2. Spatial distributions of urban-rural regions in Dezhou city were showed in Figure 6. Overall, urban-rural regions showed uniform distribution patterns. Urban region of each county is well identified, and there is only one central region generally, and other areas as rural regions. Urban and rural regions are connected by roads, and most rural regions are distributed along roads (Figure 6a). Notably, the urban region of Lincheng County and Decheng District integration into a region. This is mainly because the county town of Lincheng County is close to Decheng District, and Decheng District is the economic center of the whole Dezhou city. The development direction of Lincheng County gradually expands westward until it is integrated with Decheng District.



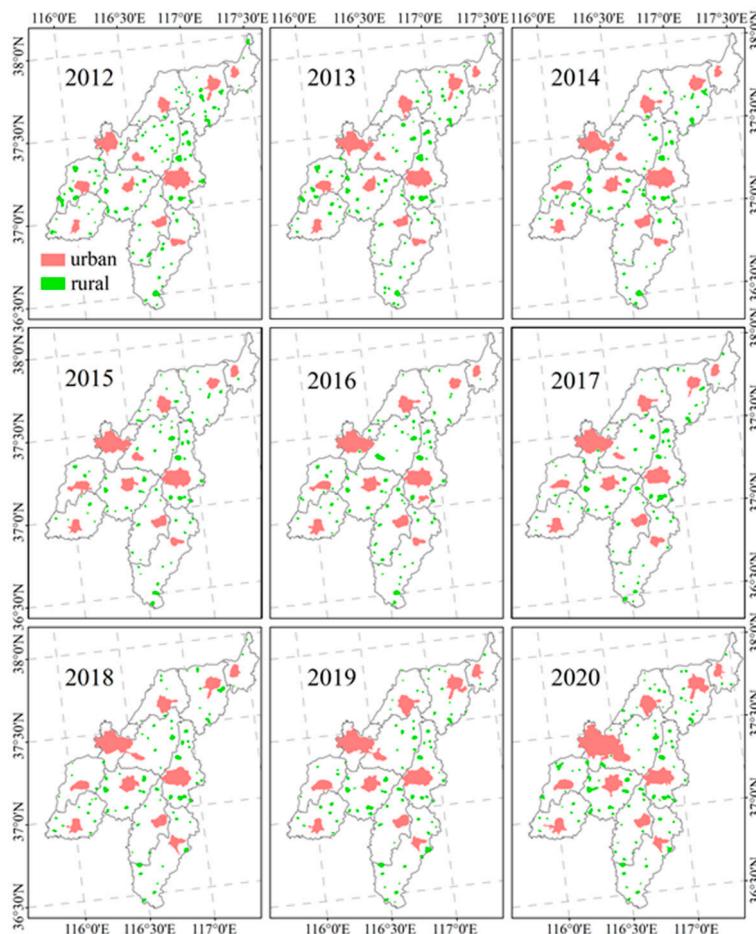
**Figure 6.** (a) Spatial distribution maps of urban-rural regions in 2020. (b) Histogram of rural region and rural population in each county. (c) Histogram of urban region and urban population in each county.

Rural regions are distributed in the periphery of the city, and their sizes are far less than the cities'. The number of urban regions in Dezhou city in 2020 is 10, but its area reaches 1354.5 km<sup>2</sup>, accounting for 79.13% of the total urban-rural regions. There are 95 rural regions, covering the area

of 357.3 km<sup>2</sup>, and 20.87% of the total urban-rural regions (Figure A1). Populations and urban/rural region of each county in Dezhou city also maintain high consistency (Figure 6b and c).

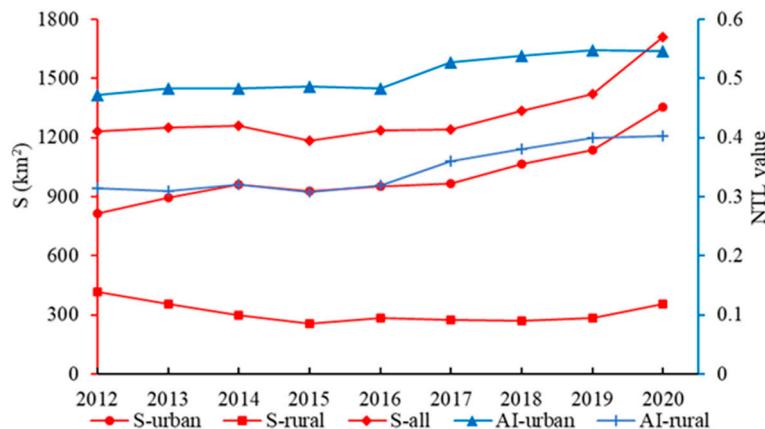
### 3.2. Spatial and temporal evolution characteristics of urban-rural regions

The spatial patterns of urban and rural in Dezhou city remained basically unchanged during 2012-2020 (Figure 7). It is noteworthy that the urban regions of Decheng District and Lingyi County were separated from each other in 2012-2017 and merged into the same area after 2018. Rural regions are scattered around urban regions, and the number is decreasing. The urban-rural regions of Dezhou city have increased significantly ( $p<0.05$ ) from 1229 km<sup>2</sup> in 2012 to 1711 km<sup>2</sup> in 2020 (Figure 8). Specifically, the large influx of rural populations into urban regions has led to the increasing demand for construction land. At the same time, the scope of human activities in urban regions has been expanded. For example, the urban region expanded from 813.44 km<sup>2</sup> to 1354.47 km<sup>2</sup>. The area of rural regions decreased first and then increased slightly, from 415.68 km<sup>2</sup> in 2012 to 357.26 km<sup>2</sup> in 2020.



**Figure 7.** Spatial and temporal evolution characteristics of urban-rural regions during 2012-2020.

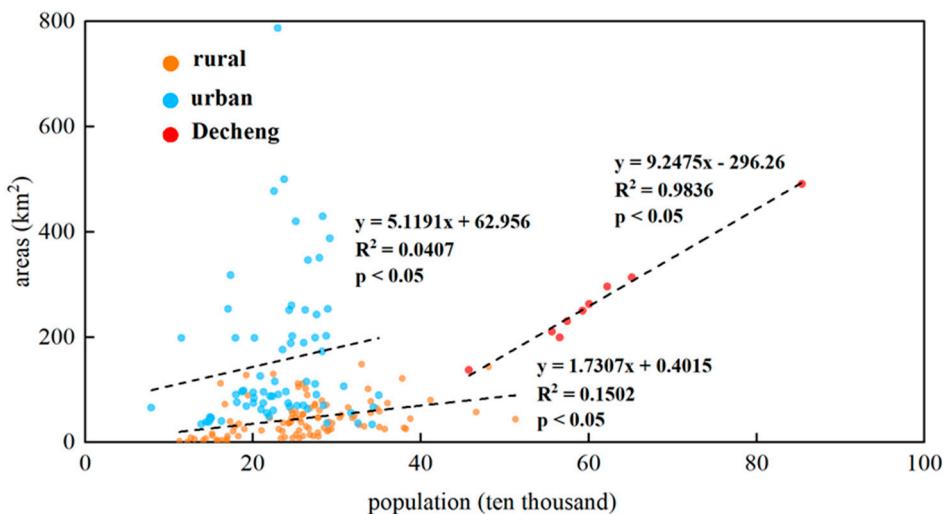
The nighttime light data can reflect the economic development level of a region to some extent. The night light brightness in urban regions is higher than that in rural regions, indicating that the development level of rural urban regions is higher than that of rural regions. The average nighttime light values in urban-rural regions of Dezhou city showed a significantly increasing trend ( $p<0.05$ ). The average nighttime light values in urban regions increased from 0.47 in 2012 to 0.55 in 2020 (slope =0.011,  $p<0.05$ ), and in rural regions increased from 0.31 in 2012 to 0.4 in 2020 (slope =0.013,  $p<0.05$ ). It suggests that levels of urban and rural developments in Dezhou city both improved in the past 9 years.



**Figure 8.** The area (red line) and nighttime light value (blue line) of urban-rural regions.

### 3.3. Drivers of spatial urban and rural evolution characteristics

Night light is the feedback of human activities. The intensity and scope of night light will be directly affected by human activities. To further investigate the influencing factors of spatial and temporal changes in urban-rural regions, this study combined the area (S) of urban-rural regions with the rural and urban populations. Then we counted the rural/urban area and corresponding populations at the county scale, and generated scatter plots to check their correlations at the rural/urban level, respectively (Figure 9). For the rural regions, the rural populations and area showed a significant positive correlation ( $p<0.01$ ). Every ten thousand people increase in rural regions, the rural regions will also expand 1  $\text{km}^2$ . But the rural populations of Dezhou city were significantly shrinking by  $1.2 \times 10^5$  people/a in 2012-2020 ( $p<0.05$ , Figure A2). For urban regions, the urban populations and corresponding areas showed a significant positive correlation ( $p<0.01$ ). Besides, Decheng District, as the economic center of Dezhou city, its urban populations and area show a more significant positive correlation ( $R^2=0.98$ ,  $p<0.01$ ). During 2012-2020, the urban populations of Decheng county increased from  $4.57 \times 10^5$  to  $8.54 \times 10^5$ , an increase of 86.8%. The area of urban regions increased from  $138 \text{ km}^2$  to  $492 \text{ km}^2$ .



**Figure 9.** Scatter plots of the urban (blue dots), rural (orange dots) and Decheng (red dots) populations and corresponding areas.

Overall, decreased rural populations led to the reduction of active-rural regions, especially before the year of 2015. By contrast, the influx of populations into cities is an important reason to lead to the continuous expansion of urban regions. The influx of rural population into urban regions has brought a lot of labor, promoted industrial expansion, and required more infrastructure and public

services to support more and more people, which has led to increasing urban human activities, urban structure tends to be more complex and expanding to the edge. For rural regions, although the population is declining, the links with the urban are increasing. Urban industries are partially transferred to rural regions through spillover effects. Infrastructure conditions in rural regions are also improving. This leads to increased nighttime light intensity in rural regions, but at a slower rate than in urban regions.

#### 4. Discussion

##### 4.1. Spatial structure of the urban-rural regions

Through the nighttime light data obtained from NPP/VIIRS and localized contour tree method, this study explored the polycentric structures of urban-rural regions in Dezhou city. Besides, we calculated the nighttime light intensity, location and morphological attributes of each urban-rural regions. Based on the identified results, we divide the identification results into urban-rural regions. Decheng district is the most predominant overall, both commercial center and public service center. The number of rural regions is predominant in Dezhou city, scattered across the counties and cities. Rural regions generally show the characteristics of small area and single function [43]. Lights emitted at night by some large factories far from urban regions are also identified as rural regions. Various roads are connected in series as intermediaries in various urban-rural regions. The development of transportation conditions is one of the important indicators to measure the urbanization of a region [44]. For relatively backward areas, towns tend to be distributed along roads and gradually connect with other surrounding towns.

##### 4.2. Spatial-temporal evolution of urban-rural regions

The spatial ranges of urban-rural regions extracted by night light can well match the real change process of human activities [37]. As we can see from Figure 8, rural regions first shrink and then expand while urban regions continue to expand. For China, urbanization makes urban regions need many labors, while rural regions face the problem of surplus labor. Therefore, most young and middle-aged rural people choose to move to cities to get better job opportunities and increase their income. As a result, human activities in rural regions are greatly reduced.

Interestingly, from the perspective of land use, China's urban-rural regions are showing a trend of expansion [45]. The reason for this difference can be considered that there are differences in the definition of rural regions. In our study, the rural regions are defined as active-rural regions. Nighttime lighting is an intuitive manifestation of human activities. Due to the outflow of rural populations, the intensity of human activities in many rural regions has weakened. However, rural houses will not decrease with the outflow of populations. On the contrary, when people make money in the city, they return to new houses in rural regions. Therefore, the rural changes in this study show different results from land use (i.e., built-up land or impervious surface).

In addition, we also found rural regions showed a trend of agglomeration. The number of rural regions in Dezhou city is decreasing, but the average nighttime light brightness in rural regions is increasing. This shows that the population loss in rural regions far from urban regions or inconvenient transportation is serious, resulting in human activities in the region not be detected. Most young rural workers choose to flow into urban regions to find jobs, while older people and children follow to cities or live in larger rural regions around cities [46].

##### 4.3. Localized contour tree method used in this study

In this study, we compared nighttime lighting data with topographic elevation data to explore the hotspots of human activities and divided them into urban-rural regions according to their attributes. The localized contour tree method has multiple advantages in spatial urban and rural form and internal structure detection. Firstly, the localized con-tour tree method identifies the spatial distribution range of urban-rural regions based on nighttime light data. It can help us understand where human activities are strong and where it's relative weak. Secondly, the attribute information

(area, density, orientation and elongation) of urban and rural areas can be identified by the local contour tree method. At the same time, the scope of urban-rural regions identified without administrative boundaries can better reflect the natural state of human activities. Thirdly, the method can also identify the spatial hierarchy of the initial urban region, which can be used for multi-center identification of urban areas. It is worth noting that when the local contour tree method is applied to different regions, the parameters selected are different in the extraction range. The value must be determined based on local conditions. Since the resolution of nighttime light data is only 500m, it is not able to identify small rural regions well. It is hoped that finer spatial resolution data will be available in the future to refine this study.

#### 4.4. Limitations and future perspectives

This study used nighttime light data to extract ranges in both urban-rural regions. However, the spatial resolution of nighttime light data is just 1km, which has limited ex-traction ability for small rural regions. In future studies, if the temporal and spatial resolution of data can be further improved, it will help refine the research results and further explore the mechanism of urban and rural spatial-temporal pattern evolution. Besides, in this study, nighttime light value was reconstructed in the range of 0-1. Besides, it is note that the localized contour tree method needs to debug parameters to achieve the best ex-traction effect, which limits its parameter application in other regions.

### 5. Conclusions

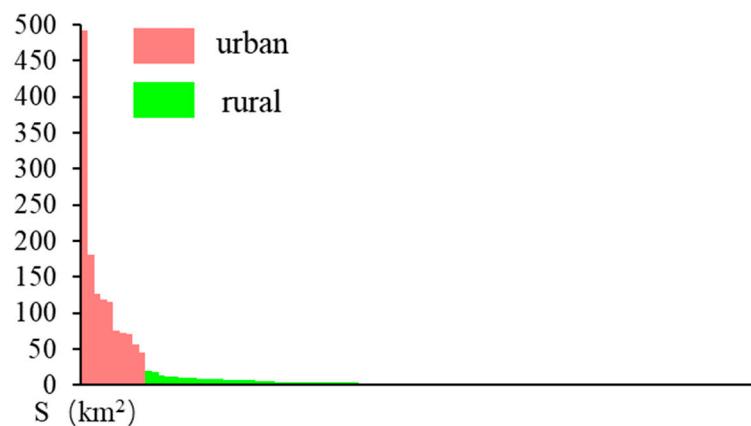
Based on the NPP/VIIRS yearly composite data, a reconstruction method of nighttime light was proposed to enhance the brightness of nighttime light value in rural regions. Subsequently, this study evaluated the application of the localized contour tree method to the identification of urban-rural regions in Dezhou city. Our results showed that the localized contour tree method could effectively identify the spatial scope and internal structure of urban-rural regions. Finally, with the help of urban-rural division method, the identified results are divided into urban-rural regions. Based on the division results, this study concluded that the expansion speed in developed regions was significantly higher than that in less developed regions. The rural regions showed a shrinking tendency. There are certain differences in the factors that affect urban-rural regions. It is mainly related to the populations. But in general, both urban-rural regions are growing, and the average intensity of human activity is increasing. The results show that urban-rural regions belong to the area of mutual influence. From the perspective of spatial scale, in the process of rural development, its boundary is constantly approaching the city, and the boundary of urban regions is also expanding. Therefore, in the future urban planning, it is not possible to limit the planning scope within the urban space, but to consider the coordination be-tween rural planning and urban planning; focus on urban-rural fringe spatial planning and other issues.

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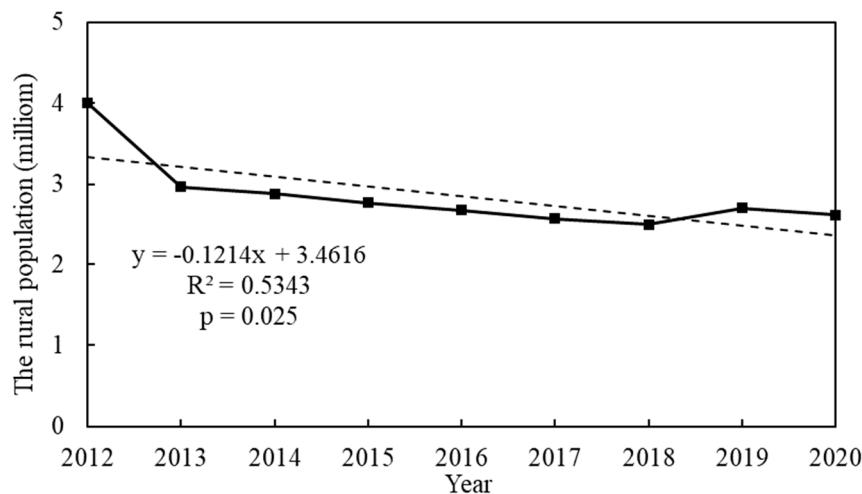
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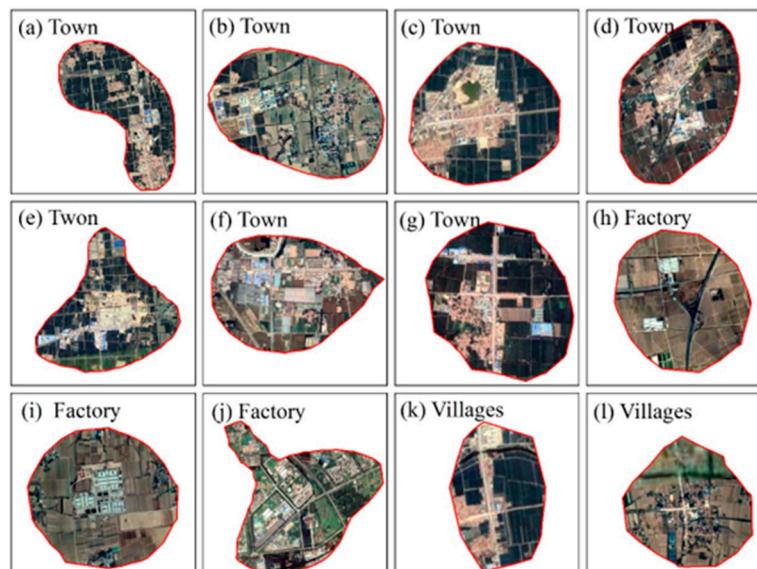
## Appendix A



**Figure A1.** The area of each urban and rural region in 2020.



**Figure A2.** The rural population change in Dezhou city during 2012-2020.



**Figure A3.** Satellite remote sensing images in some rural regions.

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