Spatialisation of GDP based on NPP-VIIRS night lighting and urban utilization

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Abstract. Spatialisation of Gross Domestic Product combines GDP data with geospatial information can be used to visualize economic differences between regions. It allows for objective evaluation of economic disparities and can aid in identifying areas for targeted development. Besides, a city's economic level can be indicated by its energy consumption and population density, both of which are positively correlated with nighttime lighting data. Thus, the study builds a regression model of GDP and NPP-VIIRS nighttime light radiation value taking Beijing as an example, as the economic development of districts and counties in Beijing varies significantly. The lighting data from 2013-2020 was obtained from the database and processed to obtain the grayscale image element values. Ordinary Least Squares was used to model the regression of grey scale image element values with GDP for each year. The model fitting results indicated a positive linear correlation between GDP and nighttime lighting data. The correlation between GDP and nighttime lighting increased gradually from 2013 to 2020. During this period, the area of light and light intensity in Beijing increased simultaneously at night. From a spatial perspective, the intensity of nighttime lighting was higher in the central city than in the suburbs. This observation was consistent with the actual GDP level of Beijing. After pixel-by-pixel correction, the mean error was controlled between 1.02 to 1.15. Thus the level of economic development of the city can be predicted by the spatialisation of GDP used by the NPP-VIIRS night lights and the city. Besides, the study corrected special data points through error analysis, improving the accuracy of the application of the night light data and the ability to handle abnormal data.

Keywords: Specialization of GDP; Geospatial information; Energy consumption; Population density; Grayscale image element values;

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1 Introduction

Analysing the correlation between nocturnal illumination and the spatial distribution of GDP can aid in comprehending the economic situation and development level of various regions. Nocturnal illumination is closely linked to economic activities and the degree of urbanisation. Therefore, studying the relationship between nocturnal illumination and GDP can provide crucial information about the economic development of a region.

The study 'Analysis of Spatial Distribution Characteristics of GDP and Nighttime Light in Beijing' demonstrates a positive correlation between GDP and nighttime light in Beijing. The study analyzed nighttime light data and GDP data in different areas of the city. 'Spatial Analysis of Nighttime Light and GDP Distribution in Beijing' investigates the spatial distribution pattern of nighttime light and GDP in Beijing through spatial analysis using remote sensing data and statistical data. The study revealed that there are spatial clustering effects between nighttime light and GDP levels in Beijing. The central areas of the city and developed commercial areas have higher intensity of nighttime light and GDP levels. These results indicate a positive correlation[1] between the intensity of nighttime lighting and the level of GDP within Beijing. Furthermore, there is a clear spatial clustering effect between nighttime lighting and GDP[2], with higher levels of nighttime lighting intensity and GDP observed in urban centres and developed commercial areas.

However, existing research in Beijing shows that the accuracy of night-time lighting data in areas with less developed secondary and tertiary industries is not high. Additionally, remote sensing data acquired by satellites cannot be processed in a targeted manner. Thus, the study developed a regression model to reflect the spatial distribution of GDP in each urban area of Beijing by correlating the grey-scale image metric values with the GDP of each year. The NPP-VIIRS nighttime light data was Lamberts equirectangular conic projection[3] sampling and noise reduction was performed on the data images. Light intensity statistics were then conducted on the acquired data and outliers were corrected to obtain the base data image. The spatial boundaries of the existing images were vectored[4] and pickle film data processing was applied to obtain the image data with the boundary contour of each urban area in Beijing. The night Light Data Processing Principles is detailed in Section 2. The proposed methodology is expressed in Section 3. Experimental results and analyses are described in Section 4, and Section 5 presents our conclusions.

2 Materials and Methodology

2.1 Materials

The study area of this article is Beijing, which has 16 municipal districts with an area of 16410.54 square kilometres and a resident population of 21.843 million. After the reform and opening up, China's economy has gradually developed and urban construction has been accelerated, and the economic level of Beijing is in the leading position in mainland China. Since 2013, Beijing's GDP has been growing rapidly, and by 2023, Beijing's GDP has reached 24,899.3 billion yuan, an increase of 6.7% compared with the previous year. The

NPP-VIIRS nighttime light images used in this study are from the National Geophysical DataCenter (NGDC) of the United States, which were taken by Suomi-NPP satellite using VIIRS, about 824 km from the surface, with a polar orbit, and were obtained by splicing several cloud-free images. NPP-VIIRS does not filter the fire, though it does not filter the fire. Although NPP-VIIRS does not filter out interfering items such as firelight and fishing vessels, its resolution is extremely high and the detector used eliminates the phenomenon of oversaturation of light and improves detection sensitivity.

2.2 Methodology

2.2.1Acquisition of Night Light Data.

This study describes the direct acquisition of satellite images through the NPP-VIIRS night light database. However, the directly acquired images may contain flaws in data representation. Therefore, the study further process the night light data. Figure 1 shows the application of the mean filtering method[5] to reduce image noise. The filter size is defined, and the mean value of the neighboring pixels is calculated. This value is then applied to the current pixel value to smooth the image and reduce noise. Subsequently, the study create a grid based on the noise-reduced image to divide the data. The light intensities were counted, and the areas with the highest and lowest values were identified by comparing the light intensities. The text has been improved to adhere to conventional structure, clear and objective language, formal register, precise word choice, and grammatical correctness. Any subjective evaluations have been excluded. To identify outliers in the nighttime light data, a box-and-line plot of the data was visualized. Data points more than 1.5 times the upper and lower quartile spacing were considered outliers. After processing the images using the aforementioned methods, the study obtained more accurate nighttime lighting data for China. The study then used the administrative district map of Beijing to superimpose the image and carried out pickle film data processing to extract the night light data of Beijing as the data source.

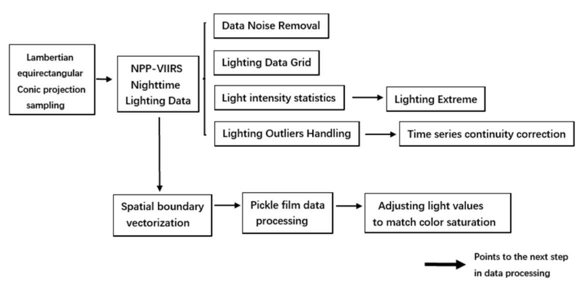

Fig. 1. Processing of nighttime light data

2.2.2Construction of Regression Models.

The total night-time light radiation value is the sum of the light DN values within the district administrative unit, calculated as follows

$$e = DN_i * n_i \tag{1}$$

where e is the nighttime light irradiance, DNi is the grey scale pixel value[6] at level i within the administrative unit, and ni is the number of pixels in the administrative unit.

$$E' = \sum_{DNmin}^{DNmax} e \tag{2}$$

Where E' is the total value of light radiation at night, DNmax and DNmin are the maximum and minimum values of light DN values in the district administrative unit respectively.

The average nighttime light radiation value is the ratio of the total nighttime light radiation value to the maximum light radiation value in the county administrative unit, calculated as follows

$$E = E'/（DNmax * N) \tag{3}$$

Where E is the average lighting radiation value, and N is the total number of image elements of the district administrative unit in the interval [DNmin, DNmax].

The lighting area ratio is the ratio of the lighting area of the district administrative unit to the administrative area of Beijing Municipality, and the calculation formula is

$$S_L = S_N/S \tag{4}$$

Where SL is the lighting area ratio, SN is the area of districts and administrative units in the interval [DNmin, DNmax] and S is the administrative area of Beijing.

The area light irradiance is the product of the average light irradiance and the light area ratio, calculated as

$$E_L = E * S_L \tag{5}$$

where EL is the value of light radiation in the area.

3 Experimentation and analysis

3.1 Night Light Distribution Map

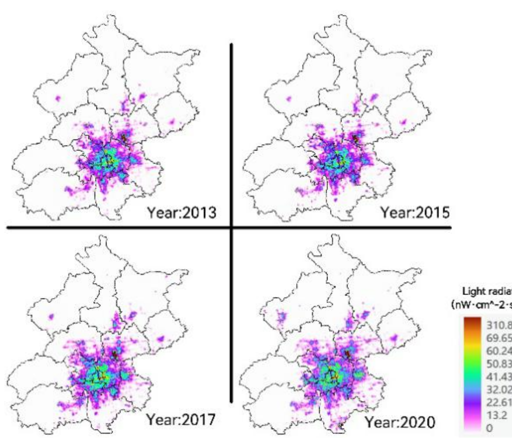

Fig. 2. Changes in Remote Lighting at Night in Beijing, 2013-2020

It can be seen from Figure 2 that the change of light radiation in the area of Beijing from 2013 to 2020. Its light area shows the trend of increasing from the center of Beijing to the surrounding area, which proves that the economic level of Beijing is continuously improving. This study proposes predicting the level of economic development in Beijing using the NPP-

VIIRS nighttime lighting database. The OLS[7] algorithm was used to construct the linear regression model shown in Figure 2 due to its minimal model requirements and ability to minimize the sum of squares of the distances from all observations on the scatter plot to the regression straight line. It also allows for more accurate prediction of the trend of NPP-VIIRS nighttime lighting data from 2013 to 2020 and changes in accuracy. The Beijing Municipal People's Government provided accurate values for Beijing's GDP for each year. The model data points were established by selecting representative months of each year and their corresponding DNi and GDP values. Upon analyzing the four sets of linear equations and their respective R2 values, it is evident that the DNi values extracted from the nighttime lighting data exhibit a positive linear correlation with the Beijing GDP[8]. The obtained R2 values range from 0.8751 to 0.9526 and tend to approach 1. This increasing correlation demonstrates that the NPP-VIIRS nighttime lighting data can accurately represent and predict the economic development level of Beijing.

3.2 Comparison of Simulated and Actual GDP Values

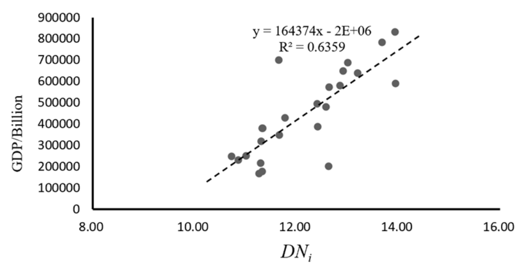

Fig. 3. Linear regression was used to model the relationship between the DN_i value of nighttime lighting and GDP in Beijing from 2013 to 2017.

As depicted in Figure 3, the study created a training set of DNi and GDP output values for the years 2013, 2015, and 2017. The study then applied ordinary least squares to fit the data, resulting in the regression equation y = 164374x - 2E+06. The analysis indicates a strong positive correlation between light intensity and GDP. The simulated output value of GDP in 2020 is obtained by substituting the DNi value of 2020 from the lighting data into the regression equation for calculation.

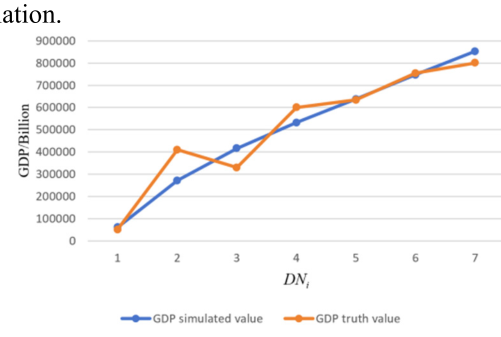

Fig. 4. Comparison of simulated and actual GDP values in 2020

Figure 4 illustrates that the simulated and real GDP values follow a similar overall trend, with a decreasing error. The regression equation for the true values is y = 79939x + 3925.6. Therefore, the regression model, based on the data from 2013 to 2017, can predict the future development of GDP.

3.3 Presentation and Analysis of Errors

Table 1. Relative error between simulation results and actual output value of Beijing's GDP from 2013 to 2020.

District	2013/%	2015/%	2017/%	2020/%
Dongcheng	0.06	0.06	0.03	0.01
Xicheng	0.05	0.05	0.04	0.03
Haidian	0.07	0.04	0.05	0.03
Shijingshan	0.02	0.02	0.03	0.02
Tongzhou	0.13	0.15	0.08	0.06
Chaoyang	0.34	0.31	0.28	0.25
Fengtai	1.27	1.98	1.23	1.11
Fangshan	1.35	1.44	1.23	1.19
Shunyi	1.23	1.45	1.33	1.42
Changping	1.56	1.51	1.67	1.47
Daxing	1.47	1.43	1.34	1.22
Huairou	2.04	1.83	1.89	1.66
Pinggu	2.01	2.08	2.11	2.01
Mentougou	2.14	2.01	1.94	1.97
Miyun	2.57	2.04	2.31	1.94
Yanqing	2.08	1.99	2.03	1.93
Average	1.15	1.14	1.09	1.02

4 Conclusion

It can be seen from Table 1 that indicate that the model, which spatialises Beijing's GDP using NPP-VIIRS night-time lighting data, is suitable for simulating and predicting regional GDP. However, the lighting data has a significant error in defining the output value of the primary industry in some areas and cannot accurately identify the production value that the area contributes to Beijing. Image-by-image correction is necessary in data processing[9] to enhance data accuracy. The simulation accuracy is high, and the generated GDP can reflect the actual development of Beijing, as evidenced by the average relative error of GDP for 2013-2020 falling within the range of 1.02 to 1.15.

The NPP-VIIRS night-time lighting data is commonly used. The univariate linear regression equations can be optimized by filtering out noise and eliminating incidental lighting factors[10]. Therefore, in future research, the study can further explore the economic development and spatial changes of the city and predict its future development through data simulation.

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