Temporal and Spatial Pattern Changes of Regional Economic Development Based on Night-time Light Data

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Abstract. To realize coordinated regional development is a prerequisite for sound, efficient and steady development of the national economy. In this paper, DMSP/OLS night light data of Shandong Province from 2000 to 2013 are adopted to analyze spatial and temporal pattern changes of regional economic development. Research results suggest that: The overall economic development of Shandong has been fluctuating. The economic development gap of different cities is large and a cross-regional economic coordination framework has not yet been put in place. Eastern coastal cities have been enjoying a sound development momentum, which can effectively drive the economic development of the surrounding cities.

1. Introduction
Since regional coordinated development is a prerequisite for sound, efficient and steady development of national economy, coordinated regional economic development has been an issue of great concern to scholars. Previous scholars mainly adopted per capita GDP as a measure of economic development. Little attention has been paid to employing other statistical indexes as proxy variables of economic development. With the constant development of technologies, the satellite remote sensing data represented by DMSP/OLS night-time light data have been increasingly applied to economic studies both at home and abroad (Mellander, 2015; Bickenbach et al., 2016), which has helped address defects of manual statistics and provide more objective data. On the one hand, the regional economic development level and the night-time light illuminance are closely connected, thereby turning light data into a reliable proxy variable to measure economic development. On the other hand, the night-time illuminance data, obtained from satellite remote monitoring, can maximally eliminate the disturbance of artificial factors, provide relatively objective data, and reduce the influence of data measurement errors on research findings. In this paper, DMSP/OLS night-time light illuminance data, which can reflect the economic development status of different regions, are chosen. With Shandong Province in China as a case study, the regional difference of regional economic development is examined at an attempt to investigate the regional economic evolution from the dynamic perspective of time and space.

2. Overview of the Research Region and Data Preprocessing

2.1 Overview of the Research Region
Shandong is a representative object for research into regional economic differences and coordinated regional development. There are 17 cities in Shandong Province, whose regional conditions, resource endowments, and initial development conditions are different. In this paper, three time nodes, chiefly 2000, 2006, and 2013, are selected to study dynamic changes of regional economy in different places.
of Shandong Province over a span of 14 years.

2.2 Data Preprocessing
The DMSP/OLS data from the National Oceanic and Atmospheric Administration (NOAA) and the National Geographic Data Center (NGDC) are adopted as the night-time light illuminance data for this research. So far, the NOAA has published the night-time illuminance data from 1992 to 2013. On the basis of this data, Landsat 8 images are used as the benchmark to calibrate the global lamplight data and to obtain the global light map. After tailoring, the night-time lamp data of 17 cities in Shandong Province are acquired. DMSP/OLS stable light time series data have a high spatial and temporal resolution ratio, which is suitable to observe economic activities in different regions over a long period. Meanwhile, no artificial control is required during the process of data collection, and the relatively objective information can be gained to provide a unique perspective for review of the regional economic development.

3. Night-time Light Data Extraction
The statistical data comparison method is used to extract city information. The threshold dichotomy is combined to reflect the total quantity and characteristics of city land. For example, the maximum and minimum of the night-time light images in a city is $\text{DN}_{\text{MAX}}$ and $\text{DN}_{\text{MIN}}$, respectively, which is denoted by the value of the official built-up area, $S$. Then, the DNT of the built-up area can be written as below:

$$\text{DNT} = \text{int}\left[\frac{(\text{DN}_{\text{MAX}} - \text{DN}_{\text{MIN}})}{2}\right]$$

The built-up area of Shandong Province is $S(DN_T)$, where $\Delta S(DN_T)$ is the absolute value of the difference between $S(DN_T)$ and $S$. After constant adjustment, the threshold value can be finally obtained, which can ensure $\Delta S(DN_T)$ to be the minimum, and the optimal value can be worked out. The specific process chart is shown in Fig. 1.

![Figure 1. Light data extraction process chart of the city built-up area.](image-url)

According to the above steps, the urban built-up area data of 2000, 2006 and 2013 can be obtained. Compared with the official data, results obtained by this method are more in line with the practical situations.

4. Analysis of Urban Spatial Sprawl and Light Index
4.1 Analysis of Urban Expansion Ratio and Range
Urbanization of a city can be taken into consideration to measure the city’s social and economic development level. According to the annual city area changes, the urban sprawl degree can be evaluated.

Within a short period of time, the annual average sprawl area of the same city is known as the city land use sprawl degree. Below is the equation for calculation.
Where, $V$ denotes the degree of urbanization; $U_t$ and $U_0$ denote the urban land use area of Shandong Province in late 2013 and early 2016; $t$ denotes the interval of years.

Since the samples collected are at a large interval of time, development speeds in different cities in Shandong vary from each other. In order to ensure comparability and scientificity of results, nominalization is a necessary step, which can be realized by the following formula:

$$X = \frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}}$$

Eq. (2) and Eq. (3) are used to calculate data. The statistical results suggest. The distribution of 17 cities in the province suggests that Jinan and Qingdao are two regions with the fastest urbanization. The urbanization in eastern coastal areas is faster than that in West China. It is apt to say that the social and economic development of East China is faster than that of West China, and the overall economic development is at a balance, which is reflected as a radiating distribution pattern with Qingdao at the core. Within the research time and scope, Jining City, Linyi City, Yantai City, Dezhou City, Laiwu City, and Heze City are enjoying an increasingly sound development momentum. This can also reflect bettering of social and economic status.

From the perspective of time series, the overall urbanization of Shandong Province from 2000 to 2006 is balanced. The social and economic dynamic changes are almost synchronous. From 2006 to 2013, their development is uneven, slightly showing signs of polarization. Analysis of the two periods of time can lay a scientific data basis for the follow-up research and preliminarily explore Shandong’s economic development trend based on the time series.

### 4.2 Selection of Night-time Remote Indexes and Statistical Indexes

The light illuminance data and the light area are key factors directly influencing night-time remote sensing value and also major factors to demonstrate the night activeness of a region. Since the economic development level and the activeness degree are positively correlated, the night-time remote sensing images can be used to acquire information, thus exploring their social and economic development level and direction in the future.

The data of three time nodes are combined to compute the relationship between the remote sensing variables and the official statistical data variables. Meanwhile, correlation analysis of night-time remote sensing indexes and official statistical data is conducted. The results are shown in Table 1.

| Second Industry/Third Industry | Gross Domestic Product $N_1$ | GDP $N_2$ | Fiscal Revenue $N_3$ | Per Capita Net Income $N_4$ | Total Brightness $M$ | Total Area $S$ | Relative Brightness $M'$ | Relative Area $S'$ |
|-------------------------------|-------------------------------|-----------|---------------------|---------------------------|---------------------|-----------------|----------------------|------------------|
|                               | 0.912                         | 0.523     | 0.937               | 0.536                     | 0.527               | 0.517           | 0.552                | 0.634            |
| Total Brightness $M$          | 0.923                         | 0.505     | 0.917               | 0.514                     |                     |                 |                      |                  |
| Relative Brightness $M'$      | 0.343                         | 0.893     | 0.558               | 0.730                     | 0.552               |                 |                      |                  |
| Relative Area $S'$            | 0.302                         | 0.981     | 0.465               | 0.823                     | 0.634               |                 |                      |                  |

Analysis results suggest that 90% of the numerical value is higher than 0.500, meaning that there is an obvious correlation between the night-time remote sensing indexes and statistical indexes. Horizontally, the value of $N_1, N_2, N_3, N_4$ is high on the whole, indicating a strong correlation; the value of $N_5$ ranges from 0.500 to 0.600, indicating a low degree of correlation, which is not taken into consideration. Vertically, the numerical value of $M$, $M'$, $S$ and $S'$ is relatively high and fluctuates slightly in the process, but it is on the whole consistent. This suggests that the night-time
remote sensing indexes are indeed inseparably correlated with the official statistical data.

4.3 Research and Evaluation of Night-time Light Index

On the basis of comparative research of remote sensing indexes and statistical indexes, statistical indexes from the official website are summarized. The statistical index P computing model is built to verify objectivity and correctness of various index values.

\[ P = 0.357N_1 + 0.095N_2 + 0.320N_3 + 0.134N_4 \]  

**Table 2.** Characteristic and contribution rate of official statistics.

| Indexes Value          | Characteristic | Contribution (%) | Total Contribution (%) | First Principal Component | Second Principal Component |
|------------------------|----------------|------------------|------------------------|---------------------------|----------------------------|
| Gross Domestic Product \(N_1\) | 3.376          | 87.981           | 87.981                 | 0.356                     | 0.823                      |
| GDPN\(N_2\)            | 0.983          | 26.536           | 96.421                 | 0.473                     | -0.635                     |
| Fiscal Revenue \(N_3\) | 0.125          | 1.898            | 99.012                 | 0.398                     | 0.427                      |
| Per Capita Net Income \(N_4\) | 0.102 | 1.167            | 99.902                 | 0.365                     | -0.502                     |

By analyzing the statistical indexes, a theoretical night-time light computing model can be built.

\[ P = MW_1 + M'W_2 + SW_3 + S'W_4 \]  

Where, \(P\) denotes the social and economic dynamic level; \(M\) denotes the total illuminance of Shandong Province; \(S\) denotes the total light area of Shandong Province; \(M'\) denotes the relative light illuminance of Shandong Province; \(S'\) denotes the relative area of Shandong Province; \(W\) denotes the light index weight of Shandong Province.

After the social and economic dynamic effect of Shandong Province is statistically analyzed, the next step is to calculate the total intensity of Shandong Province. Below is the formula.

\[ M = \sum_{i=1}^{63} M_i N_i \]  

Where, the illumination, \(M_i\), of grade \(i\) is multiplied by the \(N_i\), the total number of pixels in Shandong Province.

Under the condition that the average light illuminance index, \(M'\), is already known, the outcome is the actual light illuminance, and below are the specific steps.

\[ M' = \frac{M}{63N} = \frac{\sum_{i=1}^{63} M_i N_i}{63N} \]  

Where, \(N\) is the total number of light illuminance pixels in Shandong (63 \(\geq M_i \geq 1\)), and 63 is the maximum illuminance of the night-time light data.

Finally, the total area of all light pixels in Shandong Province’s light area and their percentage in the whole province are calculated, which can be obtained by dividing the light pixel area, \(a\), with the total area of Shandong, \(A\). The result can be written as below.

\[ S' = \frac{a}{A} \]  

To identify the night-time light index weight is an important step. Only in this way can the night-time light index accurately reflect the dynamic social and social changes of Shandong Province.
This paper calculates the relation matrix. The equation of the first main principal component is built: \( Y_1 = 0.345X_1 + 0.334X_2 + 0.276X_3 + 0.283X_4 \). The equation of the second principal component is built: \( Y_2 = -0.402X_1 - 0.466X_2 - 0.523X_3 + 0.503X_4 \). Combining Eq.(1) and Eq.(2), \( Y = 0.703Y_1 + 0.299Y_2 \) can be obtained. The three equations can be combined to obtain the equation to calculate the light index, \( P \).

\[
P = 0.123M + 0.098S + 0.352M' + 0.347S'
\]

(9)

The eigenvalue, contribution ratio and main principal component value of various remote sensing indexes are shown in Table 3.

**Table 3.** Characteristic and contribution rate of remote sensing data.

| Indexes Value | Characteristic | Contribution (%) | Total Contribution (%) | First Principal Component | Second Principal Component |
|---------------|----------------|------------------|------------------------|--------------------------|---------------------------|
| Total Brightness M | 2.897 | 69.647 | 69.647 | 0.423 | -0.502 |
| Total Area S | 1.423 | 30.673 | 93.823 | 0.376 | -0.498 |
| Relative Brightness M' | 0.345 | 9.674 | 98.536 | 0.319 | 0.504 |
| Relative Area S' | 0.011 | 0.067 | 99.123 | 0.302 | 0.533 |

### 4.4 Computing Results of Night-time Light Index and Statistical Indexes

The light index is statistically analyzed within the research period of time, and the broken line graph is drawn as below.

![Figure 2. Map of changes in light index by city, 2000, 2006, 2013.](image)

The annual change trend of light index and statistical indexes is consistent with each other. This suggests that the night-time light illuminance of the research area demonstrates a consistent growth trend in numerical value and spatial distribution. This also indirectly reflects the overall annual economic development of the research area. However, the development level in different parts of the research area has been disproportional, of which Qingdao ranks No. 1, directly followed by Jinan. Other cities also witnesses development to different degrees.

In order to examine reliability of this research, regression analysis is conducted to obtain the regression relationship between the light index, \( P \), and the statistical index, \( Q \).

As one observes in Fig. 4, the light index \( P \) and the statistical index \( Q \) basically remain nearby the regression line, but the individual deviation is huge. This proves that the numerical values in this
research are scientific and accurate. The night-time light data can provide solid evidence for research into the latest trends of economic development in Shandong Province, and allow users to analyze and explore temporal and spatial pattern changes from the remote sensing data layer.

![Figure 3. Regression relationship between light index P and statistical index Q.](image)

5. Conclusions
Based on the above research results, the following conclusions can be reached.

(1) From 2000 to 2013, the regional economic development levels of 17 cities in Shandong Province varies to different degrees and shows slight fluctuations. Nevertheless, the overall economic development is on an upward trend both in temporal and spatial distribution.

(2) Seen from intraregional difference, coastal regions in East China demonstrate striking advantages, whose development is obviously faster. For example, the development of eastern coastal cities represented by Yantai and Qingdao is fast. Particularly the development momentum from 2006 to 2013 significantly accelerates, compared with that from 2000 to 2006. This reflects the promoting effect of coastal cities’ regional advantages on economic development. In inland cities of Shandong Peninsula, the economic growth rate starts to slow down.

(3) The regional economic development is influenced by the spatial effect to a large margin. Cities with a high development level can radiate their development momentum to surrounding places. For example, as the largest city in Shandong Province, Qingdao has played a vital role in driving regional development, for its neighboring cities have been moving to a higher development level. The development level of the provincial capital Jinan slows down in 2006. Due to its insignificant radiation effect, its neighboring cities are all at a low development level.

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