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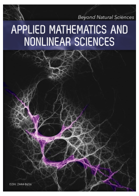

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Mapping Regional Economic Activity Using DMSP/OLS Nighttime Light Data

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Abstract

This paper extends the use of network theory to the study of region network modeling between China and five central Asian countries (Kazakhstan, Kirghiz Tanzania, Tajikistan, Turkmenistan, Uzbekistan) using the DMSP/OLS nighttime light data. In this paper, first, regional scale index and region interaction index are designed and calculated. Then based on these indices, the 0-1 region incidence matrix is obtained and the region network is constructed. Furthermore, the regional economic activity is identified by using the region network. This study deepens the application of complex network in the field of regional cooperation.

Keywords: Region Network; Modeling; DMSP/OLS Nighttime Light Data
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1 Introduction

Since China put forward "the Belt and Road" strategy, countries and regions along the Belt and Road have responded actively and enhanced cooperated with each other [1,2]. "Silk Road Economic Belt," as an important part of "the Belt and Road" strategy, promotes the economic development of Asian countries. The five Central Asian countries (Kazakhstan, Kirghiz Tanzania, Tajikistan, Turkmenistan, Uzbekistan) are located at the junction of the Asian and Eurasian continents. Since ancient times, they have been a zone with great economic interests and political significance. How to promote the development of cooperation between China and the five Central Asian countries has always been the focus of attention [3]. Therefore, it is of great significance to study the regional relationship between China and the five Central Asian countries. Region network is one of the most important methods to study the relationship between regions. Recent years, region network has received increasing attention from researchers [4–6].

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The existing studies are of great significance, but most research analyzed the regional economic activities using input-output data or trade data. However, in some regions, it is often difficult to obtain the official data. The five Central Asian countries are all developing countries, most of which are located in zones with high political and military relevance [7]. There are some deviations in the official statistics in five Central Asian countries, and it is often difficult to obtain the official data. Therefore, this paper studies the regional economic activities of these regions with the help of the night lighting data observed by satellite remote sensing DMSP/OLS. In the study of the region network structure of the Silk Road Economic Belt between China and the five Central Asian countries, we choose the modeling method of region network based on DMSP/OLS night lighting data. The data is used to evaluate the scale of China's provinces and the five Central Asian countries in order to form a network model. Based on the model, the 0-1 region incidence matrix is developed to reflect the region network of China and five central Asian countries along the "Silk Road Economic Belt." This study provides a basis for China and the five Central Asian countries to define the strategic positioning of the Silk Road Economic Belt, so as to jointly promote the multi-party cooperation and development of the Silk Road Economic Belt between both sides.

2 Method

2.1 Regional Scale Index

Official statistics with only single indicators are difficult to reflect the comprehensive strength of the region. The DMSP/OLS nighttime lighting data contains rich connotations [8–10], which can present not only economic aspects (GDP, urban agglomeration, urbanization, etc.), but also social aspects (population distribution, population size, etc.), as well as the ecological aspects (vegetation, energy consumption, CO2 emissions, etc.). Therefore, the regional scale index based on DMSP/OLS nighttime lighting data can comprehensively express the regional scale. The formula is as follows:

$$M_i = I \times B = \left[\sum_{e=g}^{f} (N_e \times S_e)\right] \times \frac{A_i}{A_o} \tag{1}$$

where M_i denotes region scale index, N_e denotes gray value of the e-level pixel in the region, that is, DN value of the e-level pixel, S_e denotes the total number of e-level pixel, $\sum_{e=g}^{f} (N_e \times S_e)$ denotes the total night light intensity of the e-level pixel, g and f denotes initial threshold and end threshold respectively, in this paper, $g = 1$, $f = 63$; A_i denotes the area between initial threshold and end threshold of the region i pixel gray value, A_o denotes the total area.

2.2 Region Interaction Index

Gravity model is based on Newton's classical mechanics. Through the universal gravity formula, it extends and expands continuously to form a complete and simple gravity model [11,12], which is mainly used to analyze and predict the regional interaction. Gravity model is widely used in regional interaction. In general, the gravity model can be simplified as:

$$M_y = K\frac{Y_i Y_j}{D_{ij}} \tag{2}$$

where K denotes constants, which generally represent gravitational coefficients, Y_i and Y_j denote endogenous variables, D_{ij} denotes spatial distance. The regional interaction model in this paper extends the use of gravity model to analyze the interaction between China and the five central Asian countries. The expanded formula is as follows:

$$I_{ij} = K\frac{M_i^a M_j^b}{d_{ij}^c} (i \neq j; i \in [1,n]; j \in [1,m]) \tag{3}$$

where I_{ij} denotes the region interaction index between region i and region j, K denotes proportionality coefficient, in this paper, K=1, M_i denotes the region scale of initial region i, M_j denotes the region scale of end region j. a and b are the potential indexes for cities to generate internal agglomeration and external diffusion of urban factor flows. In this paper, values of a and b are set at 1. $c$denotes the damping coefficient of the distance between regions, which is the rate at which the interaction between regions decreases as the distance increases between regions. The damping coefficient $c$is subject to factors like geographical environment and regional economic development. The damping coefficient is used to describe the scale difference of interaction between regions: when the value is 1, it represents the interaction between regions at the national scale; when the value is 2, it represents the interaction between regions at the regional scale. d denotes the distance between region i and region j.

2.3 The 0-1 Region Incidence Matrix

Based on region interaction index, define region incidence matrix$A = \begin{bmatrix} I_{11} & I_{12} & \cdots & I_{1n} \\ I_{21} & I_{22} & \cdots & I_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ I_{n1} & I_{n2} & \cdots & I_{nn} \end{bmatrix}$, I_{ij} denotes the region interaction index of region i and region j. In region incidence matrix, some information is not important, in order to keep important information and filter unimportant information,0-1 Region Incidence Matrix is needed. The inter-regional association is bounded by the critical value and divided into strong association and weak association. The weak association is set to 0 and the strong association is set to 1. Suppose matrix B is the 0-1 region incidence matrix and suppose α is the critical value. $b_{ij} = \begin{cases} 1 & I_{ij} > \alpha \\ 0 & I_{ij} < \alpha \end{cases}$ [13–15]. b_{ij}=1 denotes that there is strong interaction between region i and region j, b_{ij}=0 denotes that there is no strong interaction between region i and region j.

3 Empirical Analysis

The scale indices of provincial regions of China and five Central Asian countries were calculated, the regional interaction coefficients of China and five Central Asian countries were deduced, and the regional incidence matrix was then utilized for building the 0-1 region network matrix of China and five Central Asian countries in the Silk Road Economic Belt. At the same time, the region network of China and five Central Asian countries were visually displayed to effectively and empirically analyze the structure of this region network.

3.1 Data Source

DMSP/OLS nighttime light data was obtained by directly averaging the gray values of visible light and NVIR channels throughout the year, and the gray values of the data ranged from 1 to 63. The data used in this paper is downloaded from the web site (https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html). At present, there are six versions of DMSP satellites, F10, F12, F14, F15, F16 and F18, on the website. This paper downloads and uses the latest year's Nighttime Light Data.

3.2 The 0-1 Region Incidence Matrix of China and Five Central Asian Countries

To analyze the region network model of China and five Central Asian countries in the Silk Road Economic Belt based on DMSP/OLS nighttime light data, it was necessary to obtain the 0-1 region incidence matrix of China and five central Asian countries based on DMSP/OLS nighttime light data. In this step, strong interaction edges are retained and weak interaction edges are deleted. In this paper, the 0-1 matrix consists of 82 nodes. The incidence structure was visually displayed in the form of black and white grids with the help of Matlab, which vividly shows the relationship between regions. The black grid means that the value of the element in the matrix is "0" and the white grid means the value of the element in the matrix is "1," as shown in Figure 1.

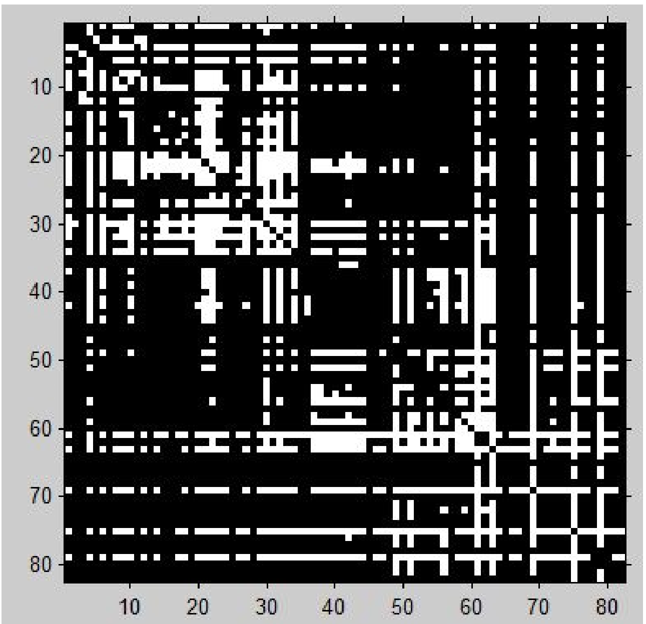

Fig. 1 The 0-1 matrix of China and five Central Asian countries.

3.3 Visualization of Region network of China and Five Central Asian Countries

3.3.1 Visualization of Regional Scale Index

The regional scale indices of 34 provinces of China and 48 regions of five Central Asian countries are calculated according to DMSP/OLS nighttime light data. The regional scale index of China and five Central Asian countries are generated by ArcGIS, as is shown in Figure 2 and Table 1.

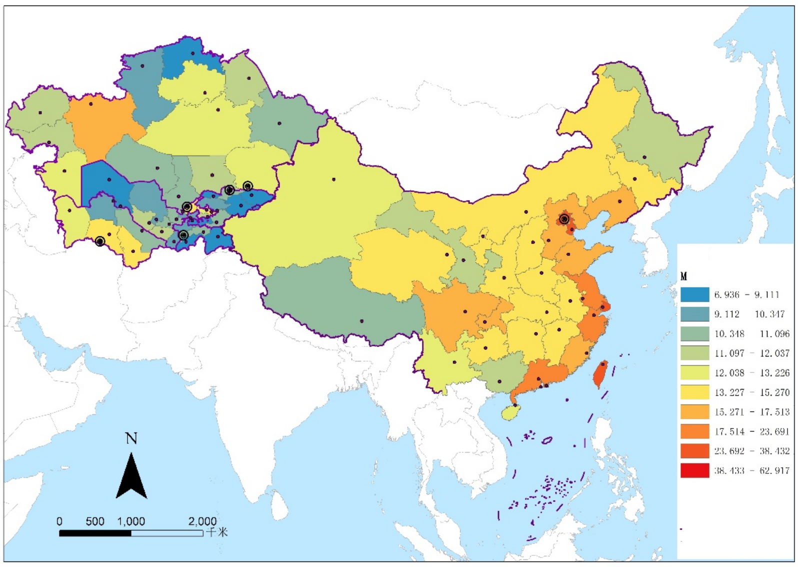

Fig. 2 Regional scale index of China and five Central Asian countries.

As Figure 2 shows, a higher regional scale index calculated by DMSP/OLS nighttime light data has a deeper shade in the map.

Table 1 Top 10 region of M_{ij}

Rank	Country	Region	M_{ij}
1	China	Macao	62.91666667
2	Turkmenistan	Ashgabat	62.37912088
3	Uzbekistan	Tashkent City	59.60437376
4	Kyrgyzstan	Osh	54.72527473
5	Kyrgyzstan	Bishkek	52.95424837
6	Tajikistan	Dushanbe	51.08333333
7	China	Shanghai	38.43164507
8	China	Beijing	35.26494465
9	China	Hong Kong	34.02559055
10	China	Taiwan	31.22040386

Table 1 lists the top ten regions of China and five Central Asian countries in terms of regional scale index. A regional scale index calculated based on DMSP/OLS nighttime light data can comprehensively represent a region's economy, population distribution, regional urban expansion. Macao has the highest regional scale index as the best-performing region. Ashgabat, the capital of Turkmenistan, comes in second. As Shanghai, Beijing, Hong Kong and Taiwan are among the top ten regions, half of the top regions are found in China. The last one of 82 regions of China and five Central Asian countries is Gorno-Badakhshan, Tajikistan.

3.3.2 Visualization of the Region network

The region network of China and five Central Asian countries is generated by ArcGIS, as is shown in Figure 3.

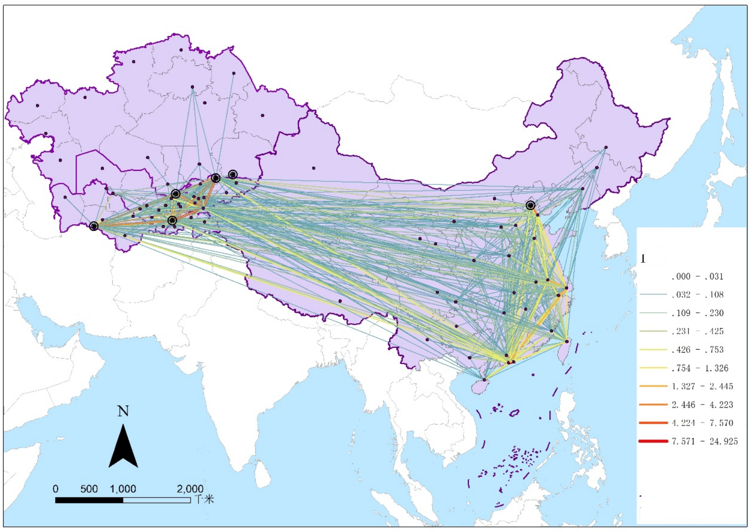

Fig. 3 The region network of China and five Central Asian countries.

It can be seen from Figure 3 that a closer regional connection between China and five Central Asia countries calculated based on DMSP/OLS nighttime light data (namely a greater value) has a deeper shade in the connecting line of the map.

Table 2 Top 10 region of I_{ij}

Rank	Target Region	Origin Region	I_{ij}
1	Macao	Hong Kong	24.92540010100
2	Dushanbe	Tashkent City	7.56993838894
3	Tashkent City	Osh	6.72447018732
4	Guangdong	Macao	6.07031147388
5	Osh	Bishkek	5.69402181089
6	Dushanbe	Osh	5.54157784865
7	Tashkent City	Bishkek	4.79227534775
8	Andijon	Osh	4.22313322944
9	Sirdaryo	Tashkent City	3.53646936683
10	Beijing	Tianjin	3.46988473097

Table 2 lists the top ten regions of China and five Central Asian countries in terms of I_{ij}. Macao and Hong Kong have the highest I_{ij} as calculated by DMSP/OLS nighttime light data, indicating that they have the closest connection among 82 regions of China and five Central Asian countries. Macao and Hong Kong are followed by Dushanbe, the capital of Tajikistan, and Tashkent, the capital of Uzbekistan. Macao is also in close contact with Guangdong. Beijing, the capital of China, and Tianjin, a municipality of China, are ranked tenth in regional interaction coefficient. The Tibet Autonomous Region, which is geographically connected to Central Asia, and Gorno-Badakhshan, Tajikistan, are ranked last of the 82 regions, showing that the two regions are the least closely connected. It can be seen that the geographical advantage is not the only advantage or the biggest factor in regional connections. If a region wants to enhance its connection with other regions, it must rely on its own economic, political and ecological strength to realize internal agglomeration and external radiation.

It is easy to learn from Table 2 that the top ten regions of the regional interaction coefficient do not include that of China and the areas of five Central Asian countries. They are all the regional interaction correlations among regions within a country. According to the normal logic, the correlation between regions within a country is definitely stronger than that that among countries. Due to the influence of geographic, national policy factors and international trade tariff, etc. it somewhat limits the connection between China's provinces and the five Central Asian countries. The correlation between Hong Kong and Macao is certainly stronger than that between Hong Kong and Tashkent. Therefore, the top ten regions of the regional interaction coefficient listed in Table 2 conform to the normal statistical phenomena. In order to further analyze the correlation between China and the five Central Asian countries included in the Silk Road Economic Belt, this paper calculates the top ten regions of I_{ij} between China's provinces (regions, municipalities) and the five Central Asian states (cities), as shown in Table 3 .

Table 3 Top ten regions of I_{ij} between China and five Central Asian countries

Rank	Target Region	Origin Region	I_{ij}
1	Tashkent City	Macao	0.66495933706
2	Osh (city)	Macao	0.65529039428
3	Bishkek	Macao	0.64100306532
4	Ashgabat	Macao	0.60616474567
5	Dushanbe	Macao	0.60107254390
6	Tashkent City	Hong Kong	0.32551366963
7	Osh (city)	Hong Kong	0.32045480667
8	Tashkent City	Shanghai	0.31889247694
9	Bishkek	Tianjin	0.31583358760
10	Tashkent City	Tianjin	0.31563198468

It can be seen from Table 3 that I_{ij} between China and the five Central Asian countries based on DMSP/OLS night light data is much lower than that within the country. I_{ij} of Tashkent City of Uzbekistan and Macau, about 0.665, is the highest among China and the five Central Asian countries. In China and the five Central Asian countries totaling 82 regions, the highest coefficient is Macao and Hong Kong, which is 24.925, with differing nearly 37.5 times. However, for the study of the correlation between China and the five countries of Central Asia, I_{ij} between China and the five regions of Central Asia is more meaningful. According to the analysis in the table, Macao, Hong Kong Autonomous Region, Shanghai and Tianjin in China have the closest connection with the five Central Asian countries compared with other provinces (districts and municipalities), of which Macau has the highest correlation with Tashkent, followed by the correlation of Osh city and Bishkek of Kyrgyzstan and Macau, Ashgabat of Turkmenistan and Macau, Daushanbe of Tajikistan and Macau, Hong Kong and Tashkent City and Osh, Shanghai and Tashkent, Tianjin and Bishkek and Tashkent. It is not difficult to learn that the key regions of the five Central Asian countries are Osh, Bishkek, Ashgabat, Dushanbe and Tashkent City. These regions have relatively strong correlation with China. Therefore, we should focus on the correlation among these regions, which is also the focus of this study.

4 Conclusion

This paper extends the use of network theory to the study of region network modeling between China and five central Asian countries (Kazakhstan, Kirghiz Tanzania, Tajikistan, Turkmenistan, Uzbekistan) using the DMSP/OLS nighttime light data. Since the "Belt and Road" strategy proposed in 2013, more and more domestic and foreign scholars have studied it. As is known to all, the five Central Asian countries are all developing countries, there are some deviations in the official statistics in the region, and it is often difficult to obtain the data. Therefore, it's difficult to study the regional economic activities of these regions. This paper conducted based on DMSP/OLS night light data. The results allow us to make inferences about the regional economic structures of China and five central Asian countries. It can be learnt from the research in this paper that, to some extent, the application of DMSP/OLS night light data to study regional correlation is scientific and effective. This study provides a basis for China and the five Central Asian countries to define the strategic positioning of the Silk Road Economic Belt, so as to jointly promote the multi-party cooperation and development of the Silk Road Economic Belt between both sides. Besides, it provides a new research perspective for the study of region cooperation, which has practical and theoretical significance.

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