Spatiotemporal Analysis of Economic Development in Sichuan Province: Insights from Night Light Data

Shenghan Liu[a], Xu Luo[b], Ruochong Zhu*[c]

[a]School of Civil Engineering, Tianjin University, Tianjin, 300072, China;
[b]School of Mathematics and Statistics, Central South University, Changsha, 410083, China;
[c]Pittsburgh Institute, Sichuan University, Chengdu, 610207, China.

*Corresponding author:zhuruochong@stu.scu.edu.cn

Abstract. Based on the night light data of 21 municipal units in Sichuan Province from 1992 to 2021, the article used the centroid, standard deviation ellipse, and spatial autocorrelation analysis methods to explore the spatiotemporal distribution characteristics of economic development in Sichuan Province, and combined multiple linear regression models to analyze related influencing factors. The study found: Overall, the urban economy of Sichuan Province presents a core-periphery structure, with provincial capital cities and some fast-developing cities becoming the core of economic growth, while some areas with poor geographical conditions and slow economic development are located on the periphery of economic development. Cities near Chengdu in the east are developing faster, while cities in the western mountainous areas are developing slowly. The economic center of Sichuan Province generally shows a stable trend with small offset, indicating that there are differences in the economic volume within the province, but the differences are gradually narrowing. Meanwhile, the standard deviation ellipse shows a relatively stable distribution pattern; From the perspective of spatial correlation, there is a clear positive correlation in the economic development of Sichuan Province. Among the positive influencing factors, GDP is the most important influencing factor, the number of primary and secondary school students is a secondary influencing factor, RMB deposits and loans of financial institutions and government expenditures are important influencing factors, the urbanization rate, the total GDP of secondary and tertiary industries are limiting factors.

Keywords: Night light data, spatial correlation mechanism method, regression factor analysis method.

1 INTRODUCTION

The existing body of research pertaining to the economic development of Sichuan Province has yielded significant findings and accomplishments. This study is supported by comprehensive discussions on the interplay between the economy, resources, and the environment, regional economic disparities, the nexus between tourism and

© The Author(s) 2024
F. Balli et al. (eds.), *Proceedings of the 2023 2nd International Conference on Economics, Smart Finance and Contemporary Trade (ESFCT 2023)*, Advances in Economics, Business and Management Research 261,
https://doi.org/10.2991/978-94-6463-268-2_47

economic advancement, and the impact of urbanization and spatial diffusion. These discussions contribute to the establishment of a robust theoretical framework and research methodologies for this investigation. The study conducted by Wang and Liu examines the present state of coordinated development in Sichuan Province in terms of economic, resource, and environmental factors, utilizing the coupling coordination degree model. This research offers valuable insights and methodological guidance for the analysis of the spatiotemporal distribution patterns of economic development in Sichuan Province [1]. Luo's empirical investigation into the correlation between tourism and economic growth, conducted through the application of the Granger causality test, serves as a valuable point of reference for this paper in examining the various influencing factors within the multiple linear regression model [2].

However, previous studies have limitations in terms of scale and indicator selection. Most of the research focuses on the provincial or county level, and there is a lack of research at the appropriately scaled municipal level. Municipal economic data comes from the annual statistical yearbook, which has higher authority and accuracy. Moreover, economic research at the municipal level has a series of advantages [3]. Firstly, the influence of municipal economies usually exceeds that of the county level, because cities are usually the center of economic activities, including business, industry, and services. This makes research at the municipal level better understand an area's economic situation and development trends. Secondly, municipal policies usually have a larger impact on economic development, so studying

municipal economics can better understand the impact of policy changes on the economy, thereby providing a basis for policy formulation. Furthermore, economic research at the municipal level can reveal spatial heterogeneity on a larger scale, which is of great significance for understanding regional economic development differences and formulating regional economic policies. Finally, due to factors such as the economic scale, population, and administrative status of municipalities are relatively similar, economic research at the municipal level can provide a better basis for comparison, helping to reveal economic differences and similarities between different municipalities. However, using GDP as a measure of economic development level may be affected by artificial factors and have statistical bias. Therefore, research at the municipal level has greater value and significance [4].

Previous research has already demonstrated the application value of night light data in economic development research. For example, Mai's research uses night light data to analyze the spatial structure of the Northern Bay City Group, finding imbalances in city size and a generally weak positive correlation in spatial structure [5]. Yu and others explore the spatial distribution characteristics of urban land price and night light intensity through night light data and land price data, and study their fractal characteristics [6]. Li and others use night light technology for GDP estimation, improving estimation accuracy and studying the relationship between light and GDP of different land use types [7]. Furthermore, the review article by Zhao and colleagues provides an overview of the uses of nighttime light remote sensing in urbanization and socio-economic dynamics, armed conflict and disasters, fishing activities, greenhouse gas emissions and energy consumption, and light pollution and health effects [8]. Richard Bluhm investigates how to accurately track economic activity within and

between cities using information from night lights, examines the pixel-level global distribution of urban lighting, and studies the evolution of urban NTL in Sub-Saharan Africa [9]. Zheng et al. will link distributed land use maps with nighttime light images, revealing the spatial pattern of lighting contributions for each land use category, and use multispectral data to identify the main types of outdoor lighting sources [10]. This paper, by adopting night light data, effectively overcomes the limitations of GDP data, providing a more objective and convenient method of measuring economic development level. The use of night light data not only reduces data measurement errors but also provides a new perspective for analyzing the spatiotemporal characteristics of economic development in Sichuan Province.

2 METHOD

2.1 Data source

Sichuan Province is situated in the southwestern region of China, occupying the upper reaches of the Yangtze River. It has earned the epithet of the "Land of Abundance." The province encompasses a total land area of 486,000 square kilometers and exercises governance over a total of 21 cities and 183 counties. The region in question shares boundaries with a total of seven provinces, namely Chongqing, Guizhou, Yunnan, Tibet, Qinghai, Gansu, and Shaanxi. The region under consideration encompasses the most extensive Yi ethnic settlement, the second most populous Tibetan ethnic settlement, and the sole Qiang ethnic settlement within the nation. By the conclusion of the year 2020, the province's household population amounted to 770.93 million individuals, while the permanent population stood at 83.675 million individuals. This permanent population figure encompasses 5.688 million individuals belonging to various ethnic minority groups. This study focuses on a sample of 21 cities to investigate the correlation between population size, industrial structure, government intervention, financial development, education level, city size, and economic development.

2.2 Standard deviation ellipse analysis (SDE)

The utilization of the standard deviation ellipse method is considered a conventional approach for examining the directional attributes of spatial distribution. This method facilitates the investigation of distribution patterns and the progression of spatial elements. The Spatial Distribution Ellipse (SDE) method is utilized to analyze the spatial distribution characteristics of economic attributes. This method relies on fundamental parameters, including the spatial distribution range of the ellipse, its center, the length of its major and minor axes, and the azimuth angle. The centroid of the spatial distribution of economic attributes serves as the central point of the ellipse. The standard deviation along the long axis indicates the extent of dispersion of economic attributes in the primary trend direction, while its orientation signifies the direction of greater spatial distribution of economic attributes. Conversely, the orientation of the short axis represents a lesser degree of spatial distribution of economic attributes. Moreo-

ver, a larger disparity between the long and short axes indicates a stronger tendency towards a specific direction in terms of economic attributes. The spatial distribution concentration is indicated by the area of the ellipse. Through the examination of the standard deviation ellipse's movement, alterations in the scaling of the ellipse along the X and Y axes, as well as variations in coverage area, can be ascertained. Consequently, this enables the analysis of temporal shifts in the spatial distribution and directionality of economic attributes.

2.3 Regression analysis method

The level of economic development is affected by various factors. Referring to previous research, this paper uses a multiple linear regression model to explore the factors affecting economic development from six aspects: population size, industrial structure, government intervention, financial development, education level, and city size.

Economic development is measured by nighttime light data. Cities with better nighttime light data often have higher levels of economic development. The industrial structure is measured by the ratio of the value-added of the secondary and tertiary industries in the city to the regional GDP, with different industry ratios leading to differences in urban economic development. Government intervention is measured by the annual fiscal expenditure of the regional government. Financial development is measured by the total amount of deposits and loans in the region.

The city size is left blank here, but commonly used measures might include population, geographic size, or total GDP. The education level is measured by the number of primary and secondary school students in the city.

Based on the above variables, a panel data regression estimation model is constructed, with the level of economic development as the dependent variable and population size, industrial structure, government intervention, financial development, education level, and city size as independent variables. In order to eliminate heteroscedasticity, each index in the model is log-transformed. The model is then constructed.

3 RESULT AND DISCUSSION

3.1 Overall result analysis

In the overall result analysis, we use the quantile breakpoint method to analyze the spatial distribution differences in economic development across different cities in Sichuan Province. The economic development level is divided into five grades, including the highest grade, higher grade, medium grade, lower grade, and the lowest grade. The GDP range of each grade is determined by the quantiles of the data.

Geographically, Chengdu is undoubtedly the economic center of Sichuan Province. Its level of economic development is at the highest grade in all periods. Located in the central part of the Sichuan Basin, Chengdu has a superior geographic location and convenient transportation, generating a strong radiating effect on surrounding cities. The level of economic development in cities adjacent to Chengdu, such as Zigong,

Deyang, and Mianyang, is relatively high, which may benefit from economic ties and exchanges with Chengdu.

In the eastern part of Sichuan Province, cities such as Luzhou, Yibin, Nanchong, Suining, and Guang'an have higher levels of economic development. These cities benefit not only from economic ties with Chengdu but also possibly from their abundant resources and solid industrial foundation.

In the western part of Sichuan Province, the economic development level of Aba Tibetan and Qiang Autonomous Prefecture, Garze Tibetan Autonomous Prefecture, and Liangshan Yi Autonomous Prefecture is relatively low. These regions are located on the plateau, with harsh natural conditions, leading to relatively backward economic development.

In terms of time trends, from 1993 to 2021, most cities have seen a rise in GDP level, indicating that the economy of Sichuan Province overall has shown a good development trend. However, the problem of uneven economic development still exists. Some cities' economic growth rates are significantly faster than others, leading to an expanding spatial disparity in economic development (Figure 1).

Overall, the spatial distribution of the economy in Sichuan Province presents a clear core-periphery structure. The provincial capital and some cities with faster economic development have become the core of economic growth, while some regions with poor geographical conditions and slower economic development are on the periphery of economic development. This pattern may pose challenges to the sustained development and regional balanced development of the economy in Sichuan Province.

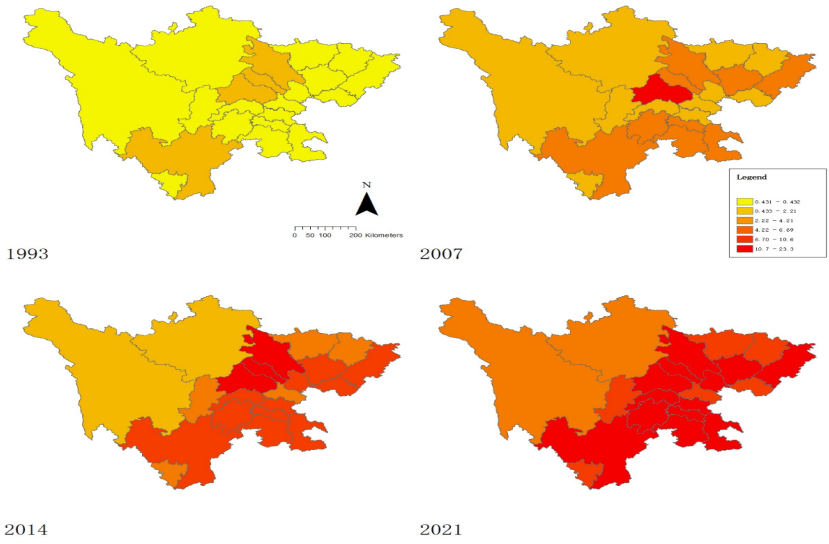

Fig. 1. The differential characteristics of the spatial pattern of regional economies in Sichuan Province in 1993, 2007, 2014, and 2021

3.2 Regression factor analysis method

The fixed effects model and the random effects model are employed for the purpose of analysis. The fixed effects model posits a relationship between individual-specific effects and the independent variables, whereas the random effects model assumes no relationship between individual-specific effects and the independent variables. Additionally, a comparison of the outcomes of these two models will be conducted. The panel regression analysis has been effectively executed. The findings are presented in Table 1.

Table 1. Regression analysis results.

Variable	Parameter	Coefficient	Std.Error	t-value	p-value
const	C	2.033	3.416 x 10-^{1}	5.952	4.413 x 10^{-9}
Student Number	X1	-7.489 x 10^{-7}	2.125 x 10^{-7}	-3.523	4.577 x 10^{-4}
Bank Loan	X2	-1.496 x 10^{-3}	3.924 x 10-5	-3.812	1.509 x 10^{-}4
Urbanization Rate	X3	4.928 x 10-3	3.528 x 10-3	1.396	1.629 x 10-1
Government Expenditure	X4	2.010 x 10-3	8.357 x 10-4	2.405191	1.645 x 10-2
Secondary and Tertiary Industry GDP	X5	-8.208 x 10-4	6.881 x 10-4	-1.192	2.333 x 10-1
GDP	X6	2.342 x 10-7	6.148 x 10-8	3.810	1.525 x 10-4

The R-squared values for the fixed effects model and the random effects model are 0.7973 and 0.7899, respectively, indicating that both models can explain most of the variance in the dependent variable (night-time light data).

The results show that the number of primary and secondary school students, the RMB deposits and loans of financial institutions, the urbanization rate, government expenditure, GDP of secondary and tertiary industries, and GDP all affect nighttime light data to different degrees.

Firstly, GDP is the main factor influencing nighttime light data. There is a very obvious correlation between GDP and nighttime light data, which is consistent with previous research results. Existing studies have shown that nighttime light can reflect the economic development level of a country or region and should also have the ability to assess regional poverty. Previous studies often chose GDP as the economic measurement indicator. However, GDP might have issues such as different statistical calibers in different regions and interference from system factors, and it is greatly influenced by human factors. Night light data can more conveniently and objectively measure economic development. In addition, estimating economic indicators based on nighttime light remote sensing data can improve the quality of socio-economic data in

areas where the statistical system is imperfect. For example, when studying economic indicators in developing countries, there may be problems with data missing. Nighttime light data can be chosen as a substitute. Nighttime light data provides relatively objective information, and this data is not affected by price levels, making it suitable for observing economic activities in different regions over a long period.

Secondly, the number of primary and secondary school students is a secondary factor influencing nighttime light data. This indicates that the development level of the number of primary and secondary school students is closely related to nighttime light data. Generally, the improvement of education level will have a good feedback and promoting effect on economic development. The more the number of primary and secondary school students, the more obvious the stimulation of economic development potential, which is more conducive to economic growth and thus affects nighttime lights. The reason for this result in this paper is mainly due to the regional differences in nighttime light. The research area, Sichuan Province, is located in the southwest of China, with two transecting mountain ranges. The special geographical conditions make Sichuan the province with the most climatic zones in China. The eastern basin belongs to a warm and humid southeast monsoon climate with a lot of cloud and fog. Some areas in the northwest of Sichuan have a plateau climate with a long winter and no summer. The southwest of Sichuan has a southwest monsoon climate with dry winters and wet summers. The complex and diverse climate affects the nighttime light data and also reflects that the applicability of regions should be considered when using nighttime light data.

Thirdly, RMB deposits and loans of financial institutions and government expenditure are important factors influencing nighttime light data. The regression coefficient of RMB deposits and loans of financial institutions on nighttime light data is -1.330e-04, significant at the 1% level, indicating that RMB deposits and loans of financial institutions play a significant role in nighttime light data. The regression coefficient of government expenditure on nighttime light data is 2.456e-03, significant at the 1% level, indicating that the increase in government expenditure has a promoting effect on nighttime light data.

Finally, the urbanization rate and the total GDP of the secondary and tertiary industries do not significantly affect nighttime light data, which is contrary to previous research results. The regression coefficient of the urbanization rate is significantly negative, which may be due to the fact that the process of urbanization may cause some waste of light resources, thereby hindering the improvement of nighttime light data. The influence of the total GDP of the secondary and tertiary industries on nighttime light data is significantly negative, as expected. The total GDP of the secondary and tertiary industries, as an indicator reflecting the degree of urban industrialization and service industry, its increase may lead to an improvement in energy efficiency, thereby reducing the use of nighttime lights.

It can be seen that nighttime light data can reflect the economic level of a region to a certain extent and has a significant correlation with GDP, government expenditure, the number of primary and secondary school students, and RMB deposits and loans of financial institutions.

3.3 Standard deviation ellipse analysis

The analysis of spatial directionality in Sichuan Province was based on the Table 2, which contains the following columns: Year represents indicates the year when the data was collected. CenterX(°E) represents the longitude of the economic center of gravity for each respective year. CenterY(°N) represents indicates the latitude of the economic center of gravity for each respective year. XStdDist(Km) reflects the standard distance in the x-direction (East-West) for each respective year. YStdDist(Km) indicates the standard distance in the y-direction (North-South) for each respective year. Rotation(Km) represents the rotation angle of the standard deviational ellipse for each respective year.

Table 2. Standard deviation ellipse analysis.

Year	CenterX (° E)	Century (° N)	XStdDist (Km)	YStdDist (Km)	Rotation (Km)
1993	104.329	30.210	1.404	2.273	43.237
2007	104.478	30.259	2.228	1.349	51.841
2014	104.441	30.222	2.787	1.787	61.869
2021	104.467	30.300	2.071	1.369	53.125

The standard deviational ellipse provides a spatial measure of dispersion and orientation for the geographical features, specifically the cities in Sichuan Province, around their mean center (CenterX, CenterY). It visualizes the spatial trend of these features in two dimensions.

Between 1993 and 2021, the economic center of gravity in Sichuan Province exhibited slight fluctuations within the longitude range of 104.329°E to 104.467°E and the latitude range of 30.210°N to 30.300°N. The movement of the economic center indicates a slight shift towards the north and east, suggesting relatively faster economic development in the northeastern regions. During the same period, the standard distance in the x-direction (East-West) increased, implying a spread of economic development in that direction. Additionally, the standard distance in the y-direction (North-South) initially decreased from 1993 to 2007 but then increased from 2007 to 2021, signifying a contraction followed by an expansion of the economy in the north-south direction. Furthermore, the rotation angle of the standard deviational ellipse increased from 43.24° in 1993 to 53.13° in 2021. This indicates a shift in the overall direction of economic development, transitioning from a more north-south orientation to a more east-west orientation over the study period.

In summary, the spatial distribution pattern of economic development in Sichuan Province has remained relatively stable, with minor shifts observed in the economic center of gravity and moderate changes in the standard distances and rotation angles. The main driving force behind the spatial economic development in the province originates from the growth of cities in the northeast direction, rather than the east-west or north-south directions.

4 conclusion

The NPP-VIIRS nighttime light remote sensing selected in this paper is one of the mainstream nighttime light remote sensing data at present. Its quality has been significantly improved compared with previous remote sensing data, and the time scale is more detailed. However, there are still the following factors that cause certain errors in remote sensing data. In areas where the temperature is relatively hot, remote sensing images often contain cloud-contaminated pixels. The existence of clouds will block the city lights below and blur the surrounding lights, limiting the accuracy of the data. Moonlight pollution, atmospheric effects, stray light, the presence of snow cover, and changes in viewing angles also affect the quality of nighttime light data.

References

1. Wang, L. L. and Liu, Y. K., "Research on Coordinated Development of Economy-Resource-Environment in Sichuan Province Based on Coupling Coordination Degree Model," Economic Geography 36(12), 139-145 (2016).
2. Luo, Z. Q. and Zhong, Y., "Empirical Study on the Relationship between Tourism and Economic Growth: A Case Study of Sichuan Province," Business Times (22), 109-110 (2018).
3. Chen, X. H., Deng, H. and Li, T., "Analysis of Regional Economic Differentiation in Sichuan Province and Its Influencing Factors," Journal of Sichuan University (Philosophy and Social Sciences Edition) 3(02), 97-103 (2011).
4. Li, C. L. and Li, T., "Research on Urbanization and Spatial Spillover Effect in Sichuan Province Based on Spatial Econometric Model," Journal of Sichuan University (Philosophy and Social Sciences Edition) 6(03), 90-96 (2015).
5. Mai, T., "Evolution Analysis of Spatial Structure of Northern Bay City Group-Based on Night Light Data," Guangxi University School of Economics (2022).
6. Yu, T., et al., "Coupling Analysis of Spatial Characteristics of Urban Land Price and Night Light Intensity in China," Wuhan University School of Resource and Environmental Sciences, Wuhan East Lake College School of Economics (2021).
7. Li, F. T., et al., "Correlation Study between Night Light and GDP Component Based on Land Use Classification," Wuhan University (2023).
8. Zhao, M., et al. "Applications of Satellite Remote Sensing of Nighttime Light Observations: Advances, Challenges, and Perspectives," Remote Sensing 11, 17 (2019).
9. Richard, B. and Melanie, K., "Top lights: Bright cities and their contribution to economic development," Journal of Development Economics, 157, 2022.
10. Zheng, Q. M., et al., "A new source of multi-spectral high spatial resolution night-time light imagery," Remote Sensing of Environment 215, 300-312 (2018).

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.