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Research article

Human activities along southwest border of China: Findings based on DMSP/OLS Nighttime light data

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A R T I C L E I N F O

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A B S T R A C T

Human activities along southwest border of China exert significant influences on sustainable development of regional economy, politics, and environment among countries Vietnam, Laos, and Myanmar. However, related empirical studies remain very limited due to the low availability and comparability of small-scale statistic data in that region. Fortunately, Nighttime light (NTL) images provide uniform, consistent and valuable data sources. Using NTL data from 1992 to 2013, this article seeks to contribute the literature by investigating the trend of relative intensity of human activities between China and her southwest neighborhoods. We find that the human activities intensity of Chinese borderland maintained advantage over her neighborhoods, and the trend of this advantage is nonlinear. Regional development policy launched by Chinese government is considered to be a possible explanation.

1. Introduction

Due to the relatively underdeveloped infrastructure, backward production technology and other geographical factors, great regional disparity exists between the east and the southwest regions within China [1–3]. On the one hand, high speed growth of economic development in the eastern China attracts labor, capital and other production factors move from the southwest to the east, results in further enlargement of regional disparities and even fewer inhabitants in the southwest border region. On the other hand, by implementing favorable policies, countries along the southwest of China, Vietnam, Laos, and Myanmar, achieved stable development in the border regions [4,5]. Survey shows that people living in the Chinese border even migrate to neighboring countries, leaving farmland abandoned or even subleased to foreigners and environment deteriorated. In the Chinese southwest border region, a problem so called “dual emptiness”, which means the border region is becoming more and more “empty” compared both with hinterland of China and with the neighbor countries, has been a great concern to Chinese policy makers as well as regional scientists. Many of them believe the “dual emptiness” may seriously impede sustainable development of regional economy, politics and environment.

In essence, the problem is directly associated with intensity of human activities along the borderland, which play unique roles in promoting sustainable development of regional economy, environment, as well as foreign politics among bordering countries. The southwest of China borders on Vietnam, Laos, and Myanmar. This region contains cross-border mountains, rivers, and accommodates multi-ethnic residents. There exists complex and historic competition-cooperation among residents within that region. A sustainable development in that region exerts great influences on multilateral economic, political, and environmental issues among the bordering countries. However, due to its relatively low level of economic development, small-scale statistic data of that region is not available.

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Therefore, the disparities and relative strength of economic activities across borers are unknown. This article investigates the relative intensity of human activities in the past several decades between China and her southwest neighborhoods by using the Nighttime Light (NTL) Data.

The novelty of this study lies in the reasonable handling of data comparability issues between China's southwest border area and neighboring Laos, Myanmar, and Vietnam through the use of NTL data. At the same time, differences from the case studies and questionnaire surveys in the region, the combination of NTL data and ARIMA model can systematically present the differences in human activities along the border at different regions and times.

2. Literature review

Existing studies are limited to descriptive statements, case studies or policy program plannings. These studies have made corresponding contributions to the characteristics of population mobility and residence intentions, observation of individual cases of empty towns and villages, urbanization and tourism development, and regional economic planning in the southwest border area. Based on questionnaire survey, Li and Liang [6] and Chen [7] analyze the space structure of population and migration across southwest border of China. Luo and Ge [8] and Luo and Zhu [9] analyzed the influencing factors of residence intentions among locals and the floating population in southwest border areas through questionnaire surveys. Yang [10] and Wei et al. [11] investigate the urbanization process across the southwest border by case studies. Wang [12] and Fang [13] conducted case studies to observe the issue of urban emptiness in the southwest border region. Li [14] and Zhang [15] put forward development strategies and regional economic corporations plannings. Zhang [16] and Wang et al. [17] analyzed the construction of cross-border trade cooperation mechanisms in the southwest border region. Zhong [18] and Mu et al. [19] evaluated the development of the tourism industry and issues related to poverty governance in the region. Theoretically, Yang and Pan [20] use the Core-Periphery model [21,22] to investigate the spatial economic distribution along southwest border of China. Related scientific surveys or empirical studies remain very limited. To the best of our knowledge, using satellite remote sensing data, Wang [23] analyze the human settlements along southwest border of China and shows a T-shaped pattern of settlement distribution. However, the analyses are static because the data are limited to the year of 2012. Zhang and Li [24] empirically examine regional economic disparities within southwest border of China using TOPSIS approach, however, the disparities and relative strength of economic activities across borers are unknown. Generally, we lack a distinct portrait of the relative intensity of human activities in the past several decades along the southwest border of China, which makes policymakers difficult to adopt appropriate regional strategies and regional corporation policies that help to promote sustainable regional development.

In order to fill this gap, this article investigates the relative intensity of human activities in the past several decades between China and her southwest neighborhoods by using the Nighttime Light (NTL) Data published by the National Oceanic and Atmospheric Administration (NOAA), which reflects the light brightness of the earth surface (eliminating the accidental factors like cloud, moonlight, and fire light). Since the data is less biased by human factors than traditional survey and census method, it reflects the intensity of human activities much more scientifically and has a higher international comparability. The NTL data are widely used to estimate urban spatial structure and development dynamics [25–28], population density [29–31], spatialization of GDP parameters [32–35], identification of impoverished areas [36–38], energy consumption [39–42] and environmental pollution [43–45], as well as other major events such as disasters [46–48] and wars [49–51]. Furthermore, with high international comparability, NTL data also posses unique value in studying the less developed countries and regions where the statistical system are immature. However, the annual NTL data by NOAA are available only from 1992 to2013.[1]

To better understand the generated time series data, we use the Auto Regressive Integrated Moving Average (ARIMA) model to analyze the NTL data. ARIMA model is a very intuitive method commonly used in time series analysis in recent years, which has been extensively applied in practical production for enterprises. Because of its reliance only on endogenous variable and not requiring assistance from other exogenous variables, it can be effectively combined with NTL data. The ARIMA model has not been widely combined with NTL data, so it has only been applied to predict the GDP of various provinces in China [52,53]. In other fields, the combination of the ARIMA model and NTL data still holds great potential for application, so we are applying it to predict human activities along border areas.

We used the ARIMA model to predict the relevant results before the COVID-19 epidemic from 2014 to 2019 to draw a more complete portrait of the trend in the relative intensity of human activities over the past several decades along that region. Our results show that, contrary to the concern of "dual emptiness", the intensity of human activities of Chinese borderland maintained advantage over Vietnam, Laos, and Myanmar in the past several decades. Furthermore, the trend of this advantage is nonlinear. Generally, the trends show somewhat U-shaped pattern, and the turning points appeared around year 2000, when the Chinese government launched several regional policies to promote the development of the western border region, including the "Western Development Policy" and the "Action of Prospering Frontier and Enriching People".[2] Although further empirical examination is, however, limited due to the poor availability of local economic data, by conducting a time series analysis with NTL data, this study tries to show the unique value of NTL data in less developed regions where the availability and comparability of statistic data are usually not satisfactory.

[1] After 2013, NOAA provides monthly image data based another satellite system VIIRS, which are uncomparable with previous annual data.

[2] The China's "Western Development Policy" and "Action of Prospering Frontier and Enriching People" are the two most important policies to boost its less developed western and border regions, adopted by the central government, that continue to this day.

3. Methodology

3.1. Data

Nighttime Light Data is collected by a series of meteorological satellite from the U.S. air force, these satellites belong to the United States Defense Meteorological Satellite Program (DMSP). The satellites are equipped with OLS (Operational Linescan System) sensors. Different from the ordinary sensors, the OLS sensor is designed to observe the cloud at night under the moonlight, thus has a higher photoelectric magnification ability that can detect low intensity lights, such as the lamplights, fire and the traffic on the earth surface. From 1992, the U.S. National Oceanic and Atmospheric Administration (NOAA) using this original observation data, established and released a series of annual nighttime light remote sensing data products.[3] Among these data products, Stable Lights is widely used in the field of geography and social science. This product removed the forest fires and other short and unstable lights, and the background noise is also identified and replaced with 0. Therefore, the Night-time Light data contains only the city, town and other relatively stable lights. The data is provided annually from 1992 to 2013, covers the full range of longitude and most range of latitude, the accuracy is 1 square kilometer. Because it is less biased by human factors than traditional survey and census method, the use of NTL Data to evaluate human activities shows its unique value, especially in the areas that lack of traditional statistical data or the quality of statistical data is low. Besides, the NTL Data also has a higher international comparability.

3.2. Study area

The southwest of China (Guangxi Autonomous Region, Yunnan Province, Tibet Autonomous Region) borders on Vietnam, Laos, and Myanmar as shown by Fig. 1.

This region contains cross-border mountains, rivers, and accommodates multi-ethnic residents. There are complex and historic competition-cooperation among residents within that region. In terms of physical geography, southwest China and the land countries of Southeast Asia form an organically interconnected whole. The Himalayas and Hengduan Mountains, known as the “Roof of the World”, shape the geographical features of the land countries in southwest China and Southeast Asia. The Himalayas and Hengduan Mountains serve as the skeletal framework, and the Lancang-Mekong River, Dulong River-Enmeikai River-Irrawaddy River, Nu River-Sa The Erwen River and the Red River are blood vessels. The nature has created an organically connected stage for human activities [54].

Before the formation of modern nation-states, this land became a treasure trove for numerous ethnic groups to thrive, including the Tibeto-Burman language group of the Sino-Tibetan language family, the Zhuang-Tao language group, the Miao-Yao language group, and the Mon-Khmer language family of the Austro-Asiatic language family, leaving traces of many ethnic groups’ mobilities and interactions. With the conclusion of the Southeast Asian nation-state movement and the founding of the People’s Republic of China in the 1940s, the ownership of the region’s territory was gradually clearly demarcated, establishing a clear and stable connection between the land and national sovereignty, and between residents and state power. The intersection and interweaving of the natural space of geography, the social and cultural space of ethnic groups, and the political space of the country exerts great influences on multilateral economic, political, and environmental issues among the bordering countries [55].

From the Han Dynasty to the Ming and Qing Dynasties, the southwest border area has always been an important part of the “Southern Silk Road” that connects to Southeast Asia and South Asia [56]. In modern times, countries such as Vietnam, Myanmar, and Laos, which border China’s southwest border areas are also important docking areas for China’s “Belt and Road Initiative” [57]. The region still preserves many cross-border folk religious and cultural exchanges [58].

The basic indicators of this region are shown in Fig. 2.

In particular, the human activities along the southwest border of China also play an important role in regional sustainable development issues, such as border trade, cross-border migration, and regional stability.

Accordingly, we set the study area as 50 km wide band-shaped zones between China and her southwest neighborhoods along the border line as shown in Fig. 3. We choose 50 km mainly because it roughly indicates scale of country level in China. As shown in Fig. 3, we set 50 km wide band-shaped zones for Vietnam, Myanmar, and Laos respectively. The solid curve band-shaped zones are in China, the dashed curve band-shaped zones are in Vietnam, Myanmar, and Laos respectively, the overlaps of the curves are the border lines.

3.3. Time series of relative human activities intensity

The raw data are processed by ArcGIS 10.1. With the Night-time Light Data 1992–2013 we analyze the relative intensity of human activities between China and her neighborhoods in the study area illustrated above. In the study area, we use the average night-time light of China to represent the average intensity of human activities in China and that of the neighboring countries to represent the average intensity of human activities in corresponding neighboring countries. Finally, a ratio between the above two is calculated to represent the relative intensity of human activities between China and her neighborhoods in the study area.

The average night-time light in our study area is generated by adding gray values of all pixels and dividing it by the area of the region (square km). We use the ratio of average night-time lights of the two adjoining band-shaped zones as the index of the relative

[3] All data product can be downloaded freely from the NOAA website: http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

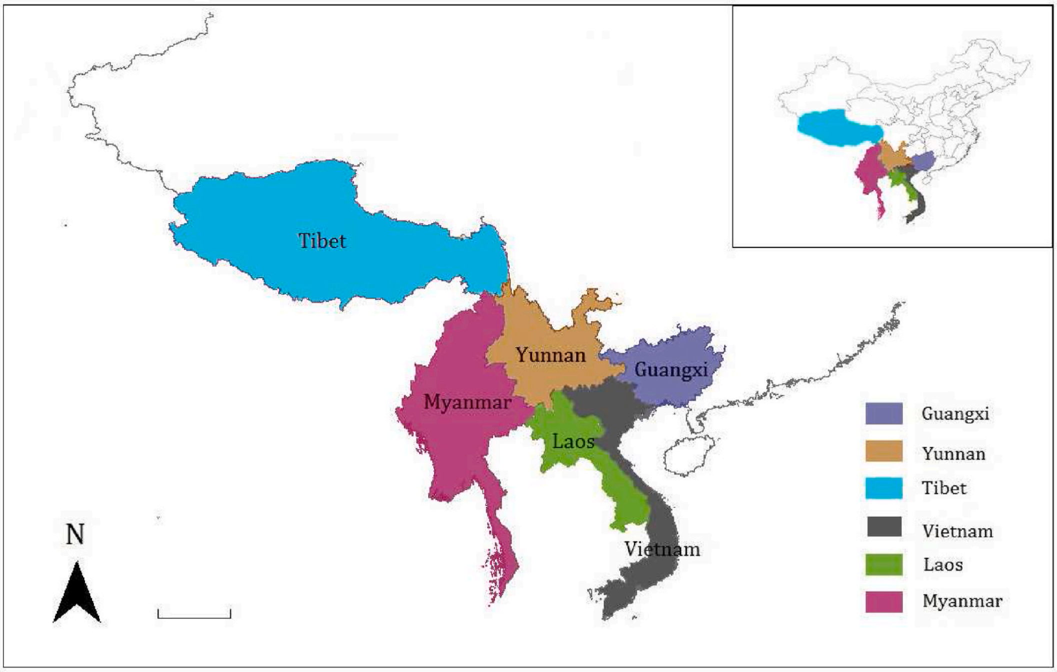

Fig. 1. Location of the southwest border of China.

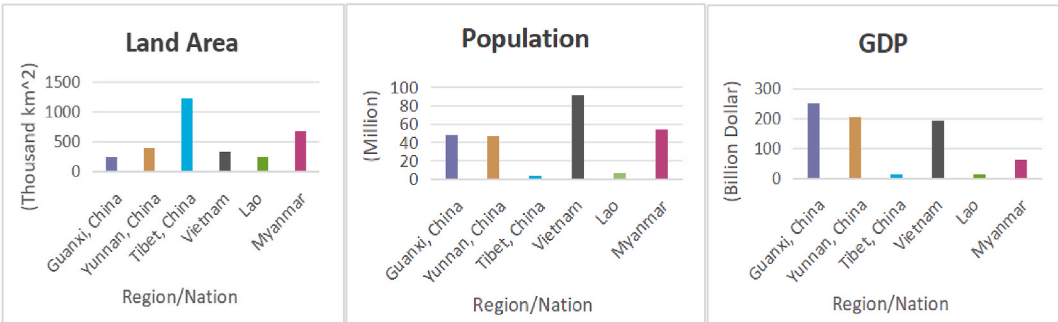

Fig. 2. Location of the southwest border of China.

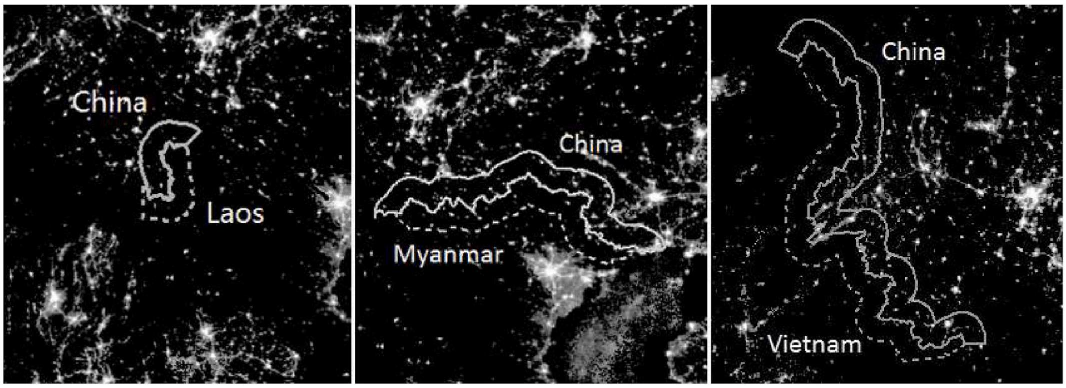

Fig. 3. The study area shown by the band-shaped zones.

level of human activities between China and the corresponding countries denoted by HL, HV, and HM (HL is China vs Laos, HV is China vs Vietnam, and HM is China vs Myanmar. See Supplementary Materials for details.). The index larger than 1 indicates the intensity of human activities is higher in China. On the contrary, the index smaller than 1 indicates that the intensity of human activities is lower in China. We analyze the index by time series approach and show the trend of the relative intensity of human activities in the past several decades along the study area.

3.4. ARIMA model

There are a number of approaches available for fitting and forecasting time series. Autoregressive integrated moving average (ARIMA) modelling is a specific subset of univariate modelling, in which a time series is expressed in terms of past values of itself (the autoregressive component) plus current and lagged values of a “white noise” error term (the moving average component). ARIMA modelling takes into account changing trends, periodic changes, and random disturbances in time series, and are very useful in modelling the temporal dependence structure of a time series. Specifically, the form of ARIMA (p, d, q) is defined as [59]:

$$\Phi_p(B)(1-B)^d x_t = \Theta_q(B)\xi_t, \tag{1}$$

where, p denotes the order of autoregressive, q denotes the order of moving average terms, d denotes the degree of difference, B is the backshift operator (such that $BX_t = X_{t-1}$, $B^2X_t = X_{t-2}$, …) and [59]:

$$\Phi_p(B) \equiv 1 - \Phi_1 B - \Phi_2 B^2 - \ldots - \Phi_p B^p, \tag{2}$$

$$\Theta_q(B) \equiv 1 - \Theta_1 B - \Theta_2 B^2 - \ldots - \Theta_q B^q. \tag{3}$$

In particular, if the original time series is stationary ($d = 0$), the ARIMA models reduce to ARMA models. The core problem lies in ensuring the series is stationary (determine the differencing order d) and in determining the order of p and q that adequately describes the time series being examined. ARIMA modelling process can be illustrated graphically by Fig. 4.

3.5. Model identification and estimation

After data preparation, we first examine whether the time series is stationary by conducting the unit root test or plotting its autocorrelogram which shows the autocorrelation between differing lag lengths of the time series. If the series is not stationary, we difference the series by d times until it is stationary. Then the probably most important tasks are the successful determination of the predictor's order (p, q) and the estimation of the coefficients Φ_i, Θ_j.

We use Autocorrelation function (ACF) graph and Partial autocorrelation function (PACF) graph to identify the order of moving average and autoregressive terms included in the ARIMA model. On the other hand, substantial literature has contributed to the determination of the order (p, q) and various different criteria, such as Akaike's, Rissanen's, Schwarz's have been proposed to implement the order selection process. In this article, we use the Akaike Information Criterion (AIC) to compare the goodness-of-fit among ARIMA models, and choose the one that minimizes the AIC. Estimation of the model's parameters were obtained by ordinary least squares method.

3.6. Diagnostic checking and forecast

The derived model must be checked for adequacy by diagnostic checking. A common way is to check whether the residuals from an ARIMA model is normally and randomly distributed. Usually, an overall check of the model adequacy is provided by Ljung-Box [60] Q statistics. The test statistics Q is given as [61]:

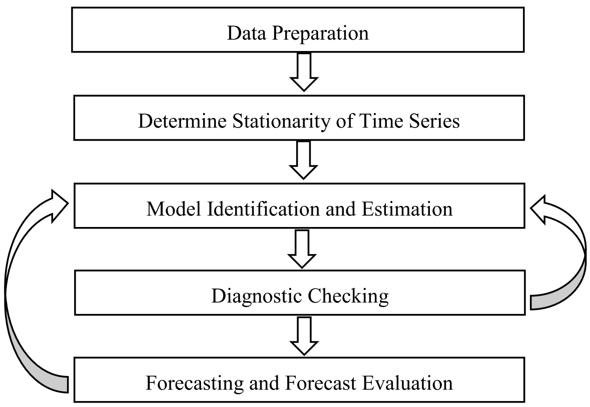

Fig. 4. Flow chart for ARIMA modelling procedure.

$$Q(m) \equiv N(N+2)\sum_{h=1}^{m}\frac{\hat{\rho}_h^2}{N-h}, \tag{4}$$

where N is the number of residuals, m denotes the number of time lags and $\hat{\rho}_h$ is the residual autocorrelation at lag h. Under the null hypothesis $H_0: \rho_1 = \rho_2 = \ldots = \rho_m = 0,\ Q(m)$ follows a χ_m^2 distribution. Usually, if the p-value associated with the Q Statistics is small (p-value$< \alpha$), the estimated model is considered inadequate and a modification is necessary. Finally, the fitted ARIMA model is used for a short-term forecasting. Here, in order to improve the accuracy, we use one-step static forecast which takes observed values instead of previously forecast values to make next step forecast.

4. Results

4.1. China and Laos

The original series past the unit root test and is considered to be stationary. Based on the distribution characteristics, we conducted three models, ARIMA (1, 0, 0), ARIMA (1, 0, 1) and ARIMA (1, 0, 2). The AIC values of these three models are 5.92, 5.41 and 5.52 respectively. Of all the models, results indicate that ARIMA (1, 0, 1) is the best fit for the data. The parameter estimates for the optimum ARIMA (1, 0, 1) model are shown in Table 1.

The model's fitted (1992–2013) values are presented in Fig. 5. The forecast values of the years 2014, 2015, 2016, 2017, 2018 and 2019 were 2.5015, 1.6671, 1.1783, 0.8051, 0.5524 and 0.3768 respectively.

4.2. China and Vietnam

After differencing the original series one time ($d = 1$), we obtain a stationary time series ranged from 1992 to 2013. Based on the distribution characteristics, we conducted three models, ARIMA (1, 1, 2), ARIMA ((3), 1, 2) and ARIMA (2, 1, 2). The AIC values of these three models are 0.93, 0.57 and 0.85 respectively. Of all the models, results indicate that ARIMA ((3), 1, 2) is the best fit for the data. The parameter estimates for the optimum ARIMA ((3), 1, 2) model are shown in Table 2.

The model's fitted (1992–2013) values are presented in Fig. 6. The forecast values of the years 2014, 2015, 2016, 2017, 2018 and 2019 were 2.6204, 2.3992, 2.4049, 2.3497, 2.3776 and 2.3899 respectively.

4.3. China and Myanmar

After differencing the original series one time ($d = 1$), we obtain a stationary time series ranged from 1992 to 2013. Based on the distribution characteristics, we conducted three models, ARIMA (1, 1, 0), ARIMA (1, 1, 1) and ARIMA (0, 1, 2). The AIC values of these three models are 3.32, 2.41 and 3.11 respectively. Of all the models, results indicate that ARIMA (1, 1, 1) is the best fit for the data. The parameter estimates for the optimum ARIMA (1, 1, 1) model are shown in Table 3.

The model's fitted (1992–2013) values are presented in Fig. 7. The forecast values of the years 2014, 2015, 2016, 2017, 2018 and 2019 were 7.1820, 7.2105, 7.2258, 7.2344, 7.2387 and 7.2266 respectively.

4.4. Further prediction

In order to further understand the trend of human activity on the southwest border of China, the ARIMA model is used in this article to predict the intensity of human activities in China compared with Laos, Vietnam and Myanmar in 2030 and 2050. The three values obtained in 2030 are 0.0058, 2.5626, and 7.2112, respectively. When predicting for 2050, the value of China compared to Laos is negative, which is not intuitive. Therefore, the article only provides predictions for China compared to Vietnam (2.5364) and Myanmar (7.2065) in 2050. Although the accuracy of further prediction is insufficient, some trends can be speculated. In other words, China's advantage in human activities on the border of Laos is continuously declining, or may not even have a relative advantage. China's advantage over Vietnam tends to stabilize at around 2.5, while China still maintains a significant advantage over Myanmar.

5. Discussion and conclusions

The intensity of human activities plays a unique role in promoting sustainable development of regional economy, environment, as well as foreign politics among bordering countries. The southwest of China borders on Vietnam, Laos, and Myanmar. This region contains cross-border mountains, rivers, and accommodates multi-ethnic residents. There exists complex and historic competition-

Table 1
Parameters for ARIMA (1, 0, 1) model.

Parameter	Coefficient	*Standard error*	*t* statistic	*p value*
AR1	0.6781	0.1165	5.8208	<0.0001
MA1	0.9726	0.0470	20.6765	<0.0001

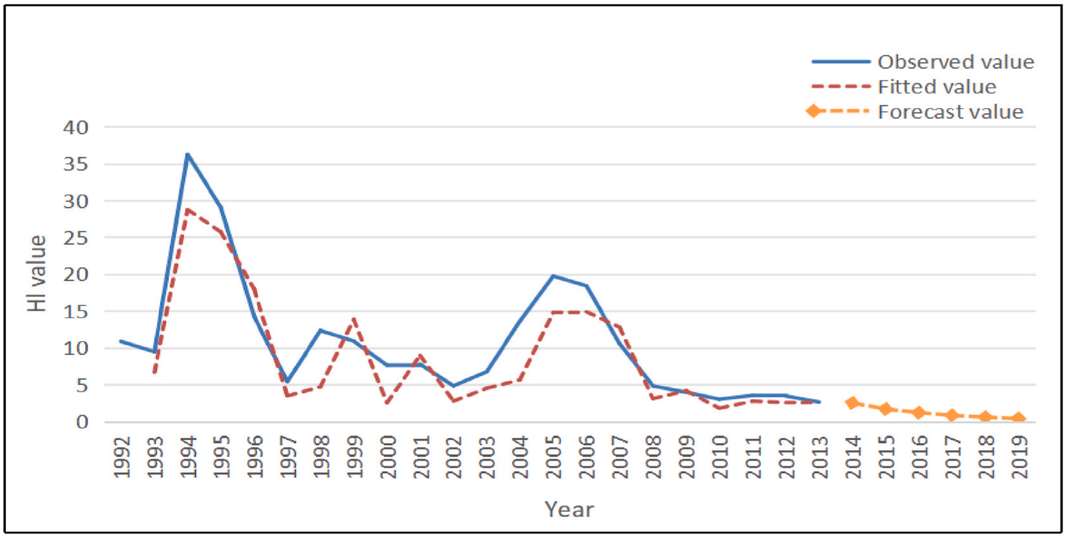

Fig. 5. Black dots present the observed values (1992–2013), the dash curve presents ARIMA (1, 0, 1)'s fitted values (1993–2013) and the triangles present the predicted (2014–2019) values.

Table 2
Parameters for ARIMA ((3), 1, 2) model.

Parameter	Coefficient	*Standard error*	*t* statistic	*p value*
AR1	1.2173	0.0870	13.9890	<0.0001
AR3	−0.4093	0.0866	−4.7246	0.0003
MA1	−1.7385	0.0545	−31.8781	<0.0001
MA2	0.8150	0.0516	15.8005	<0.0001

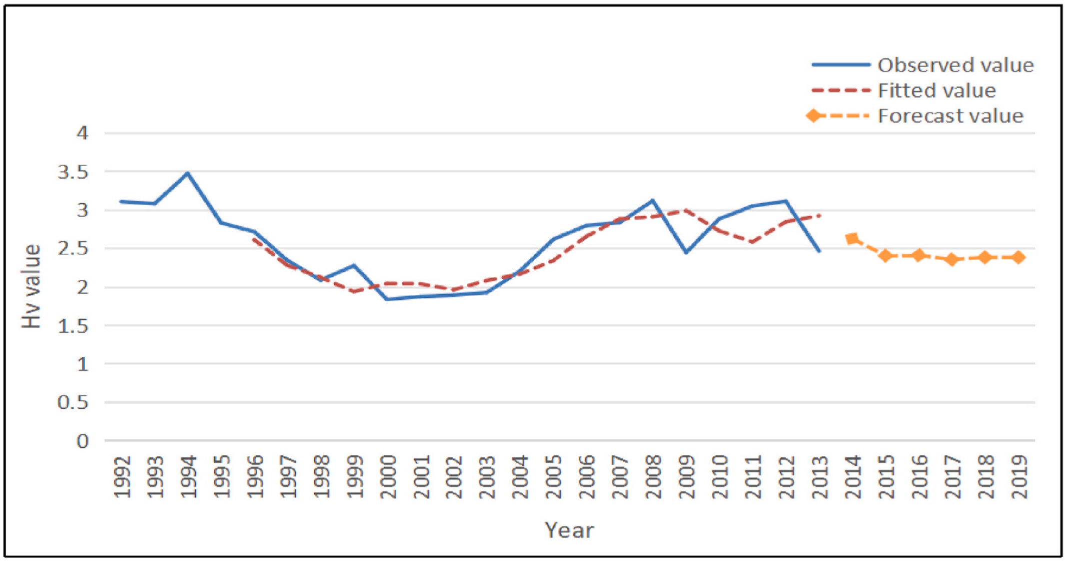

Fig. 6. Black dots present the observed values (1992–2013), the dash curve presents ARIMA ((3), 1, 2)'s fitted values (1996–2013) and the triangles present predicted (2014–2019) values.

cooperation among residents within that region. A sustainable development in that region exerts great influences on multilateral economic development, political stability, and multilateral cooperation in environmental improvement among the bordering countries. However, on the one hand, due to its relatively low economic development level, labors, capital and other production factors move out of the southwest of China to the eastern coast regions; on the other hand, surveys show that people living in the Chinese

Table 3
Parameters for ARIMA (1, 1, 1) model.

Parameter	Coefficient	*Standard error*	*t* statistic	*p value*
AR1	0.6842	0.0741	9.2277	<0.0001
MA1	−1.7212	0.5093	−3.3795	0.0033

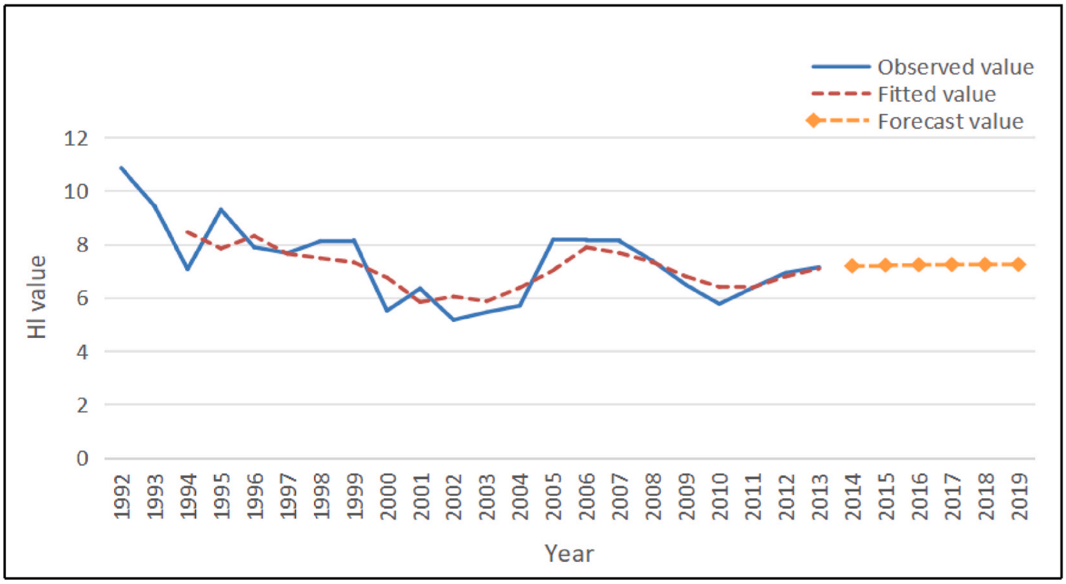

Fig. 7. Black dots present the observed values (1992–2013), the dash curve presents ARIMA (1, 1, 1)'s fitted values (1994–2013) and the triangles present predicted (2014–2019) values.

southwest boarder even migrate to neighboring countries, leaving farmland abandoned or subleased to foreigners and environment deteriorated. It results in a problem called "dual emptiness", which impedes sustainable development of regional economy, politics and environment, and has been a great concern to Chinese policy makers as well as regional scientists.

This problem is, in essence, directly related with the intensity of human activities along the region. However, related empirical studies or scientific surveys remain very limited due to the low availability and comparability of small-scale statistic data in that region. Existing studies are limited to descriptive statements, case studies or policy program plannings. Generally, we lack a relatively clear and complete portrait about the trend of relative intensity of human activities along the southwest border of China in the past several decades. By using the NTL data, we generate the index of human activity intensity and analyze the time series data by ARIMA model. Our results indicate that, contrast to the concern of "dual emptiness", in regions bordering on Vietnam, Laos, and Myanmar, the intensity of human activities in China maintained advantage over the past two decades. Furthermore, the trend of the relative intensity is nonlinear. In particular, we find that the trend show somewhat U-shaped pattern with the turning points appeared around year 2000, when the Chinese government launched several regional policies to promote the development of the western border region, including the "Western Development" and the "Action of Prospering Frontier and Enriching People". A further empirical examination of the relation between the regional policy adoption and the trend of relative intensity of human activities is, however, limited due to the low availability of local economic data.

Complementing NTL data with human development indicators, land use change variables, block wise statistical data and other data would greatly improve this study. However, our data structure includes not only China but also Vietnam, Laos and Myanmar, making it hard to obtain corresponding data in the border regions of these three countries. As a result, it is difficult for us to accurately supplement our current data with the above data. Therefore, we have reviewed and introduced some studies conducted only using Chinese data to support and complement our work. We have used other important data sources and variables from China to enhance our evidence concerning the impact of China's "Western Development" and "Action of Prospering Frontier and Enriching People" policies on the economic development of China's border areas. Based on the county-level statistical data, Liang [62] used DID method to evaluate the impact of the "Western Development" and the "Action of Prospering Frontier and Enriching People" policies on the economic growth of China's border area. He found that since 2001, the short-term economic growth effect of the implementation of the "Action of Prospering Frontier and Enriching People" in China's border areas has been significant, but the long-term effect has been insufficient, which is consistent with the observations made in this article. Wang [63] applied DID method to confirm that the "Action of Prospering Frontier and Enriching People" has facilitated the development of tourism and improved living standards of urban residents in the border areas of Guangxi, China, using data from the "Guangxi Statistical Yearbook". Zhang [64] combed the economic growth situation of border areas from 2000 to 2018, and found that after the implementation of the policy of "Action of Prospering Frontier and Enriching People", compared with the national average growth level, the main economic indicators of the border areas in the period of 2000–2005 and 2006–2010, including GDP, investment in social fixed assets, fiscal expenditure and value-added of the three major industries, were significantly higher than the national average. For example, between 2000 and 2005, the average GDP growth rate in China was 13.31 %, while the average GDP growth rate in the border areas was 17.01 %. During the period from 2011 to 2015, the growth rate of economic and social indicators in China's border areas remained relatively consistent with the national level. During the period from 2016 to 2018, the economic growth in China's border areas was significantly weaker than the national average. During the period from 2016 to 2018, the average GDP growth rate in China was 10.10 %, while in the border areas it was only 2.53 %. This indirectly confirms our NTL-based prediction that human activities along China's borders have not been significantly better than that of its neighbors in recent years.

Regarding the fundamental causes or influencing variables behind emptiness of border, specific analysis is still required in conjunction with other relevant research methods. First, natural environmental factors. Many border areas in China are located in highlands, mountainous areas, deserts, and other challenging terrains, and the relatively difficult living conditions in these areas have forced residents in borders to migrate [65]. The second factor is economic development. Although China has implemented policies such as the "Action of Prospering Frontier and Enriching People" and the "Western Development" to promote economic development in border areas, but the weak economic foundation of these areas has resulted in severe issues of poverty and employment [66]. Therefore, migration for employment to improve their lives has become a choice for many border residents. At the same time, the underdevelopment of the border economy poses challenges for primary-level governance in the border in terms of policy authority, talent supply, and securing adequate funding for public services [67]. The third factor is geopolitical or political factor. The border governance of a country will have a significant impact on residents of the border regions in the neighboring countries. For example, in the 1990s, as a result of Vietnam's preferential border policies, irregular migration of border residents was observed in certain areas of Yunnan [68]. The fourth factor is the psychological and cognitive factor of border residents. Many border residents have an unclear understanding of their nation and country [69], and their national consciousness is relatively weak, making it difficult to fundamentally understand the importance of guarding and consolidating borders.

Common methods for studying this region include case studies and questionnaire surveys. The advantage of case studies is that they are easier to observe and can provide in-depth descriptions of an object. However, The disadvantage is that case studies have a certain degree of randomness, making it difficult to see the whole picture from a narrow perspective. Questionnaire surveys have the advantage of an exploratory design with questions, allowing for understanding the respondents' comprehensive attitude towards a certain topic. Questionnaire surveys often have limited sample sizes, and it is necessary to control the quality of the questionnaire and the authenticity of the respondent's information. In addition, case studies and questionnaire surveys often find it difficult to systematically compare and present differences between different regions and years. Through the observation of the emptiness of the southwest border of China, it can be seen that NTL data can provide reliable data and image support for studying the emptiness of land borders, with advantages such as high reliability and strong data comparability. Especially in areas with limited statistical data availability and comparability, NTL data holds unique value, and can serve as an important basis for monitoring and evaluating the emptiness of land borders. Meanwhile, NTL data has some issues that need to be addressed and improved, such as insufficient resolution and data accuracy, sensor element mutation, limited grayscale range, saturation of lighting in urban centers, and the influence of local government "lighting engineering" on nighttime light.

Subsequent research can use NTL data to explore human activities along the northwest and northeast borders of China. For example, Xinjiang Province in northwest China shares borders with several countries such as Russia, Mongolia, Kazakhstan, Tajikistan, Pakistan, etc. Analyzing it can also provide valuable discoveries. Additionally, it is worth exploring the possibility of integrating different nighttime light datasets to uncover more comprehensive conclusions.

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Data availability statement

The integrated data used for predictive analysis in this article are included in Table S1. Raw Nighttime Light Data product can be downloaded freely from the NOAA website: http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html, accessed on December 16, 2023.

CRediT authorship contribution statement

Lili Tan: Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Guofu Jin:** Writing – review & editing, Writing – original draft, Visualization, Software, Funding acquisition, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24324.

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