Preliminary analysis of factors affecting economic well-being based on SDGSAT-1 nighttime light remote sensing and household survey data

Wei Jiang [1], Jie Liu[1,3]*, Tengfei Long[2], Ming Liu[3], Zhiguo Pang[1], Gan Luo[1],Elhadi Adam[4], Xiaohui Ding [5], Shiai Cui[2], Chunhui Wen[2],Longfei Wang[2]

[1] China Institute of Water Resources and Hydropower Research, Beijing, 100038, China - jiangwei@iwhr.com, liujie2000y09@163.com, Pangzg@iwhr.com, luogan_jxsr@163.com

[2] Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China - longtf@aircas.ac.cn, cuisa@aircas.ac.cn, wench@aircas.ac.cn, wanglf@aircas.ac.cn

[3] School of Architecture and Fine Art, Dalian University of Technology, 2 Linggong Road, Dalian 116024, China - liumingyitj@163.com

[4] School of Geography, Archaeology and Environmental Studies, University of The Witwatersrand, Jan Smuts Ave, Johannesburg, South Africa - Elhadi.Adam@wits.ac.za

[5] School of Software and Internet of Things Engineering, Jiangxi University of Finance and Economics, 665 Yuping Road, Nanchang 330013, China, dingxiaohui@gdas.ac.cn

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Abstract:

Economic well-being is an important indicator for measuring the happiness of national residents and is of great significance for poverty assessment in the United Nations 2030 Sustainable Development Goals. Since economic well-being is a multidimensional indicator involving multiple aspects of economic development level and individual residents' perception, its influencing factors are complex and lack empirical research. In order to explore the influencing factors of economic well-being, this study proposed an economic well-being factor analysis framework combining nighttime light remote sensing and household survey data. Taking Bazhou City, Hebei Province, China as an example, a household survey of economic well-being indicators was conducted in towns, and the spatial distribution feature of economic well-being in each town were statistically analyzed. Further, the Sustainable Development Satellite (SDGSAT-1) nighttime light remote sensing data and socioeconomic statistical data were used to conduct an analysis of the influencing factors of economic well-being. The results showed that: (1) there is spatial heterogeneity in economic well-being among towns, among which Dongduan has the highest economic well-being and Wangzhuangzi has the lowest economic well-being. The average economic well-being value of Bazhou City is 9.04; (2) A preliminary analysis of economic well-being and nighttime light remote sensing feature shows that the economic well-being of Dongduan and Tang'erli and other towns are consistent with the nighttime light remote sensing feature, but not in Bazhou and Shengfang. This indicates that the impact of economic well-being is multi-factorial, and there is no significant relationship between economic development level and economic well-being in local scale areas. This study is the first to use nighttime light remote sensing data and household survey data to analyze the factors affecting socioeconomic well-being, providing important support for subsequent large-scale global socioeconomic well-being modeling and poverty assessment.

1. Introduction

Poverty eradication is related to the progress and development of human civilization and is a global problem. Among the United Nations' 2030 Sustainable Development Goals (SDGs), "NO Poverty "is an important goal that needs to be achieved. At present, developing countries represented by China have successively carried out a large number of poverty reduction practices and achieved historic achievements about poverty eradication, but the research on the impact factor of economic well-being under poverty reduction measures lacks a deep cognition.

Research on economic well-being mainly includes human well-being and poverty monitoring and evaluation indicator systems based on statistical data, estimation of Gross Domestic Product (GDP) based on nighttime light remote sensing, and poverty measurement based on multi-source geo-spatial data. The Human Development Index(HDI) constructed by the United Nations Development Program provides a powerful tool for exploring the issue of human well-being. Some literature have used this index to study people's livelihood and well-being issues (Liu et al., 2021; Wang et al., 2022). These poverty monitoring methods based on statistical data have limitations such as data lag and high cost, making it difficult to carry out large-scale and high-frequency assessments.

Satellite remote sensing is an important means of monitoring human activities on the earth's surface(Li, 2024). A large number of studies have shown that nighttime light remote sensing data has a high correlation with GDP(Leng et al., 2019; Li et al., 2016), and remote sensing technology provides opportunities for large-scale poverty assessment. Li et al. used the nighttime light data of Luojia-1-01 to conduct research on the identification of multidimensional poverty(Li et al., 2020); Another studies combined nighttime light data, land cover data, digital elevation model, normalized difference vegetation index and points of interest data, and used machine learning methods to assess the economic status of Bangladesh and Chongqing, respectively(Shi et al., 2020; Zhao et al., 2019). In recent years, China has launched a number of nighttime light remote sensing satellites, such as Jilin-1 Video 03/07, Luojia-1-01, and SDGSAT-1 satellites, which have great potential in finely depicting the nighttime light structure and economic development status of cities.

Considering that night light data can reflect the socioeconomic level, the economic level is only a partial indicator of economic well-being, which is affected by many factors such as income and education. Therefore, socioeconomic indicators, population density maps, land cover, open street view data, auxiliary information such as terrain variables, remote sensing derivatives such as spectral vegetation indices, and surface temperature data are used in combination with nighttime light remote sensing data for poverty and economic well-

* Corresponding author

being assessment(Guojin et al., 2018; K et al., 2020; Liao et al., 2022; Pokhriyal and Jacques, 2017; Puttanapong et al., 2022; Steele et al., 2017). With the continuous enrichment of satellite remote sensing data and the rapid development of machine learning theory and methods, economic well-being assessment research based on satellite remote sensing has achieved many remarkable progresses. For example, Jean et al. used high-precision remote sensing images, convolutional neural networks, and transfer learning methods to predict the regional economic levels of five African countries with relatively limited data (Jean et al., 2016); McCallum et al. used more than 2 million household survey data (DHS) and nighttime light data to assess global economic well-being(McCallum et al., 2022) . With the successful launch of the SDGSAT-1 satellite, high-resolution nighttime light data is used in urban monitoring and disaster assessment, and helps to depict detailed human activities(Guo et al., 2023; Li et al., 2023; Yu et al., 2023). Currently, high-resolution SDGSAT-1 nighttime light data is still not well studied in areas such as poverty and economic well-being assessment.

In general, current research on economic well-being focuses on the measurement of well-being using multi-source geospatial data. Economic well-being is a multi-dimensional indicator that involves multiple aspects of economic development level and individual residents' perception. Its influencing factors are complex and lack empirical research. Therefore, this study focuses on the following three aspects: (1) A framework for analyzing economic well-being factors that combines nighttime light remote sensing and household survey data is proposed, and economic well-being questionnaire is designed to collect economic well-being data using household survey in Bazhou City, China; (2) Combined with economic well-being survey data, economic well-being statistics are conducted on a township scale, and the spatial distribution feature of economic well-being in each town are analyzed; (3) High-resolution SDGSAT-1 nighttime light remote sensing data and socioeconomic statistical data are used to analyze the factors affecting economic well-being.

2. Study Area and Datasets

2.1 Study Area

Bazhou City, a county-level city under the jurisdiction of Hebei Province, is located in the central part of Hebei Province. Bazhou City has 9 towns (Bazhou, Shengfang, Xin'an, Jianchapu, Nanmeng, Tangerli, Yangfengang, Kangxianzhuang, Wangzhuangzi), 3 townships (Chaheji, Dongyangzhuang, Dongduan), 1 provincial economic development zone (Bazhou Economic Development Zone) and 1 office (Yuhua Sub-district Office), 361 administrative villages and streets, 22 communities, and a permanent population of 800,000 and the town boundary is showed in Figure1.

In 2023, the gross domestic product of Bazhou City reached 45.2 billion yuan, covering the entire industrial chain including steelmaking and furniture. The living environment has been continuously optimized. Measures to improve residents' well-being such as roads, gas supply, and water supply have been implemented. Residents' well-being has been continuously improved. Among them, the per capita disposable income of urban residents reached 55,956 yuan; the per capita disposable income of rural residents reached 24,739 yuan.

Bazhou has made full use of the opportunities of the coordinated development of Beijing, Tianjin and Hebei to build a modern industrial system. At the same time, it has promoted the construction of a livelihood security system and improved the medical security mechanism to improve people's well-being. However, due to the large east-west span of Bazhou City, there are still large differences in economic development and significant spatial heterogeneity, and economic well-being needs to be further improved.

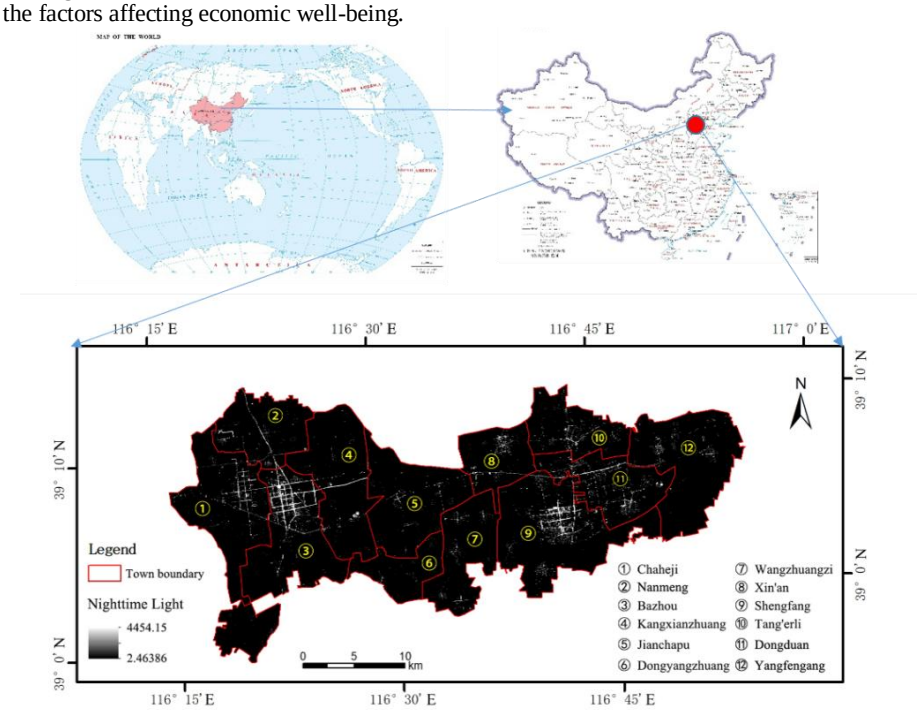

Figure 1. Study area with SDGSAT-1 nighttime light image

2.2 Datasets

SDGSAT-1 is China's first scientific satellite designed specifically for the SDGs. It is equipped with a night-light remote sensor to monitor light pollution and human activities on the earth's surface(Guo et al., 2023). SDGSAT-1 has many significant advantages over previous satellites (VIIRS-DNB and DMSP) in the field of nighttime light remote sensing.

First of all, SDGSAT-1 is equipped with a high-sensitivity night-light imager, which can detect and capture economic activities in low-brightness areas (remote villages). At the same time, SDGSAT-1 can perform dynamic time series analysis on the same area and quickly capture changes in nighttime lights to facilitate an in-depth understanding of the rhythm and intensity of economic activities. Secondly, SDGSAT-1’s global coverage capability combined with high sensitivity enables it to monitor economic dynamics on a global scale. Finally, the spatial resolution of SDGSAT-1 in nighttime remote sensing can reach 10 meters. This high resolution enables it to more accurately assess the urban microeconomic structure at a more detailed spatial scale, such as streets, communities, etc. Therefore, when SDGSAT-1 is combined with nighttime light remote sensing for economic evaluation, it has higher sensitivity, resolution and application breadth than traditional satellites such as VIIRS-DNB and DMSP.

The nighttime light remote sensing data uses the satellite image of SDGSAT-1 satellite on April 16, 2024. In order to reduce the influence of sensor feature and atmosphere, the nighttime light remote sensing image is corrected using relative radiation normalization and the filtering is used to eliminate noise data to ensure the accuracy of the nighttime light data and the comparability of data between different regions. The SDGSAT-1 image of the study area is shown in Figure 1.

3. Methodology

3.1 Technical framework

In order to explore the influencing factors of economic well-being, this study combined household survey economic well-being data, high-resolution nighttime light remote sensing data and socio-economic statistics to design a research framework. The technical roadmap is shown in Figure 2. It mainly includes three steps: data acquisition, data processing and factor analysis. (1) Data acquisition. Obtain economic well-being-related data through questionnaires and household surveys, including data aggregation and subsequent economic well-being calculation and spatial feature analysis. Obtain socio-economic data such as economic output and population using statistical yearbooks, and perform data analysis to analyze the influencing factors of economic well-being. Obtain nighttime light images with the help of sustainable development satellites, extract nighttime light features after preprocessing, including calculating the mean and standard deviation of nighttime lights, and analyzing the spatial features of nighttime lights. (2) Data processing. Summarize and calculate the economic well-being data obtained from questionnaires and household surveys, and analyze their spatial features. Analyze the statistical yearbook data to clarify the relationship between economic output, population and economic well-being, and analyze the influencing factors. Preprocess and extract features of nighttime light image data, and analyze its mean, standard deviation and spatial features. (3) Factor analysis. Taking into account the economic well-being questionnaire and household survey data, the socioeconomic data from the statistical yearbook, and the nighttime light image data, we conducted an analysis of the factors affecting economic well-being and explored the impact of various factors on economic well-being.

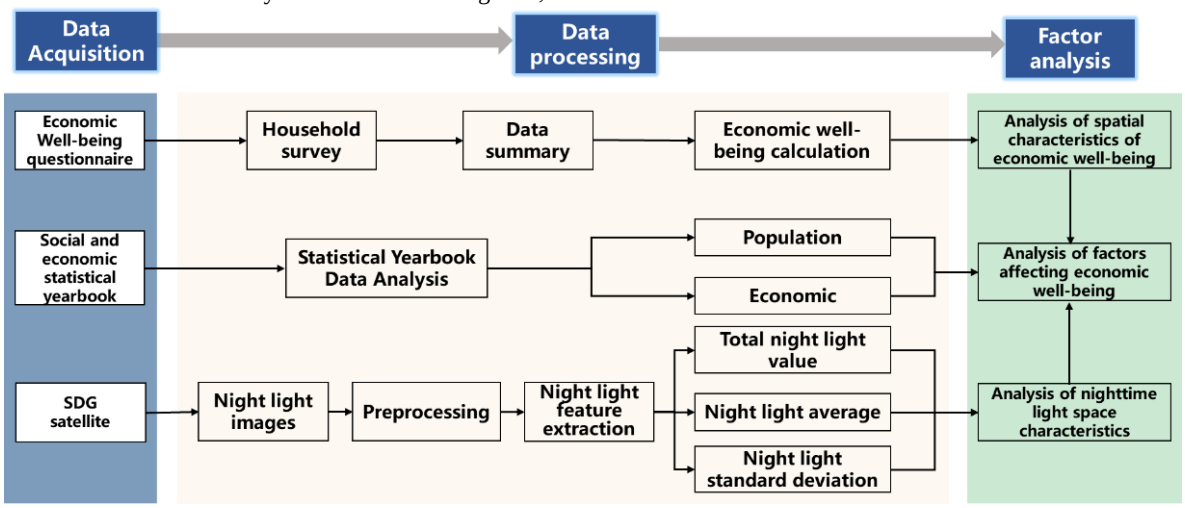

Figure 2. Technical flow chart

3.2 Economic well-being household data collection

By investigating the design of economic well-being indicator systems at home and abroad, combined with the poverty reduction practices that China has already carried out, the economic well-being indicators of this study mainly include income, work, housing, health, education, quality of life, happiness. Commonly, indicators are an important means of quantifying subjective happiness satisfaction(Wang et al., 2024). Therefore, the questionnaire also sets some basic information, including: gender, age, education level, number of children, and annual family income.

In order to facilitate respondents to fill in the questionnaire objectively and accurately, four options are set for each question: strongly agree, somewhat agree, somewhat disagree, and strongly disagree. Each option is assigned with equal weights, and then the economic well-being score of each surveyed individual is obtained. The economic well-being of the surveyed subjects in each town is counted separately, and the average economic well-being is obtained, which is used as the economic well-being value E of the town. The formula is as follows:

$$E = \frac{\sum_{i=0}^{n} e_i}{n} \quad (1)$$

$e_i$is the economic well-being calculated for each household survey subject, and n is the number of household surveys for each town.

3.3 Nighttime light feature extraction

In order to quantify the feature of nighttime light at each town scale, we constructed three nighttime light characteristic indicators, namely, the total nighttime light value (TNL), the nighttime light mean value (NLM) and the nighttime light standard deviation (NTSD), to reflect the total amount, average level and spatial difference of the economic vitality of the town area (Jiang et al., 2018).

TNL represents the sum level of night-time light within country and it can be expressed as follows:

$$TNL = \sum_{i=1}^{n} C_i \times DN_i \quad (2)$$

where DN_i is the ith gray level, C_i is the number of pixels that correspond to the gray level and n is the maximum gray level.

NLM denotes the average level of night-time light within country and the formula is as follows:

$$NLM = TNL / \sum_{i=1}^{n} C_i \quad (3)$$

where DN_i is the ith gray level, C_i is the number of pixels that correspond to the gray level and n is the maximum gray level.

NTSD represents the nighttime light spatial distribution difference, and the calculation formula is as follows:

$$NTSD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(DN_i - NTM)^2} \quad (4)$$

Refers to the differentiation level of light pollution in the statistical area. DN_i is the i-th gray level, NTM is the nighttime light mean.

4. Results

4.1 Analysis of economic well-being data based on household surveys

The survey questionnaire integrates a multi-dimensional indicator system of economic well-being, covering objective economic factors, environmental factors, social factors, as well as subjective well-being perception and happiness. The questionnaire contains 21 questions in 8 parts, including basic information, income, work, housing, health, education, quality of life, and subjective happiness, and comprehensively and systematically investigates residents' economic well-being satisfaction. In the questionnaire design, 15 economic well-being-related questions were answered with four options: strongly agree, somewhat agree, somewhat disagree, and strongly disagree.

In this study, the answers to 15 economic well-being-related questions in the questionnaire were analyzed based on a four-point Likert scale. The scale assigns specific scores to the options of "strongly agree", "somewhat agree", "somewhat disagree" and "strongly disagree" for quantitative analysis. "Strongly agree" and "somewhat agree" are assigned values of 2 and 1, respectively, while "somewhat disagree" and "strongly disagree" are assigned values of -1 and -2, respectively, for later statistical analysis. The collected questionnaires were assigned values and statistically graded. Among them, residents with economic well-being satisfaction scores in the range of [-30, -18) are very dissatisfied; residents with economic well-being satisfaction scores in the range of [-18, -6) are relatively dissatisfied; residents with economic well-being satisfaction scores in the range of [-6, 6) have no attitude; residents with economic well-being satisfaction scores in the range of [6, 18) are relatively satisfied; and residents with economic well-being satisfaction scores in the range of [18, 30] are very satisfied.

In the survey of nine towns and three townships in Bazhou City, a total of 160 survey questionnaires were collected, and the average economic well-being satisfaction score was 9.04. Data analysis of the nine towns and three townships in Bazhou City shows that the economic well-being satisfaction from high to low is Dongduan, Yangfengang, Dongyangzhuang, Tangerli, Bazhou, Jianchapu, Nanmeng, Chaheji, Xin'an, Shengfang, Kangxianzhuang, and Wangzhuangzi. Among them, the economic well-being satisfaction of Dongduan reached 15.58, the highest among the townships in Bazhou City, and the lowest satisfaction was Wangzhuangzi, with an average of 2.17. The distribution of economic well-being satisfaction of township residents in Bazhou City is shown in Figure 3.

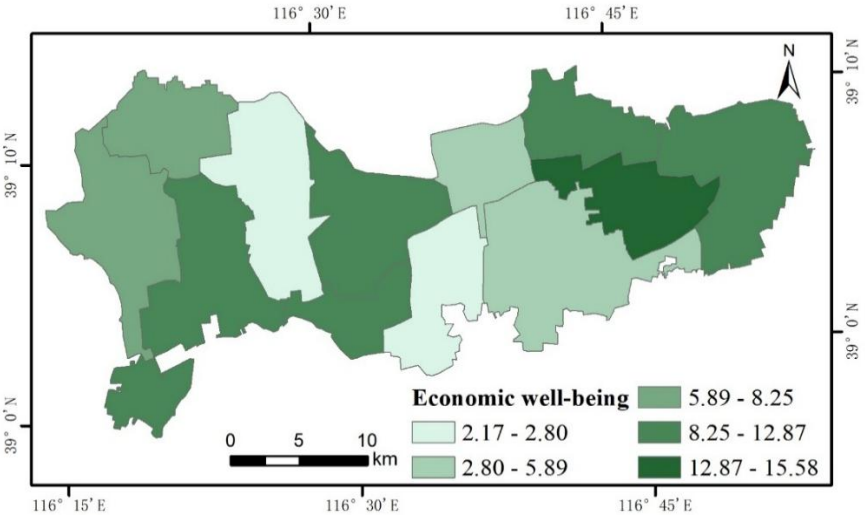

Figure 3. Economic well-being of Bazhou city at township scale

4.2 Preliminary analysis of economic well-being and nighttime light remote sensing feature

The administrative division vector data of Bazhou City and the nighttime light data are superimposed, and the nighttime light remote sensing spatial feature of each township light data are extracted separately, and the total nighttime light value (TNL), the nighttime light mean value (NLM) and the nighttime light standard deviation (NTSD) are summarized, respectively, which is showed in figure4.

As to the total nighttime light value, the total nighttime light value in Bazhou and Shengfang is far ahead of other towns and villages, and the total nighttime light value in Dongduan is the lowest.

The nighttime light mean value of Bazhou is the highest, reaching 7.47. The nighttime light mean value of Shengfang and Dongduan is more than 6 and the nighttime light mean value of Dongyangzhuang is the lowest, only 2.89. The NTSD in Bazhou is the most drastic, reflecting the obvious difference in light intensity between the county town and the surrounding villages, followed by Shengfang, and Dongyangzhuang has the lowest fluctuation.

Judging from the spatial feature of nighttime light remote sensing, Bazhou is far ahead in terms of nighttime light intensity, mean, standard deviation and total value, followed by Shengfang. The nighttime light intensity of Dongyangzhuang has the lowest mean, standard deviation and total value.

The analysis of economic well-being and spatial feature of nighttime light remote sensing shows that the economic well-being satisfaction of Dongduan, Tangerli is highly related to the total nighttime light value and nighttime light mean value. Bazhou and Shengfang are affected by other factors, resulting in economic well-being that is inconsistent or opposite to nighttime light remote sensing, as shown in Figure 4.

From the nighttime light mean value, there is a significant relationship between the nighttime light mean value and economic well-being satisfaction in Dongduan, Tangerli, Nanmeng, Chahe, Xin'an, Kangxianzhuang, and Wangzhuangzi; the nighttime light mean value in Yangfengang, Dongyangzhuang, and Jianchapu is low, but the economic well-being satisfaction is high; the nighttime light mean value in Bazhou and Shengfang is high, but the economic well-being satisfaction is low.

Regarding to the total nighttime light value, there is a significant relationship between the total nighttime light value and economic well-being satisfaction in Dongduan, Yangfenggang, Tang'erli, Jianchapu, Nanmeng, Xin'an, and Wangzhuangzi; the total nighttime light value in Dongyangzhuang is low, but the economic well-being satisfaction is high; the total nighttime light value in Bazhou, Chaheji, Shengfang, and Kangxianzhuang is high, but the economic well-being satisfaction is low.

The other influencing factors of economic well-being in towns and villages in Bazhou City are analyzed:

1) Income impact. The mean and total values of nighttime light intensity in Dongyangzhuang Township are the lowest, but its economic well-being satisfaction is relatively high. Among the 11 residents surveyed, five families have an annual income of 100,000-200,000 yuan, which is a relatively high income. Therefore, the economic well-being satisfaction in this area is relatively high.

2) Impact of natural disasters. The average and total values of nighttime light intensity in Bazhou Town and Shengfang Town are the two towns with the highest total values among the nine towns and three townships in Bazhou City. However, due to the impact of floods and waterlogging disasters, the houses and incomes of some families have been affected to varying degrees, resulting in a low economic well-being satisfaction.

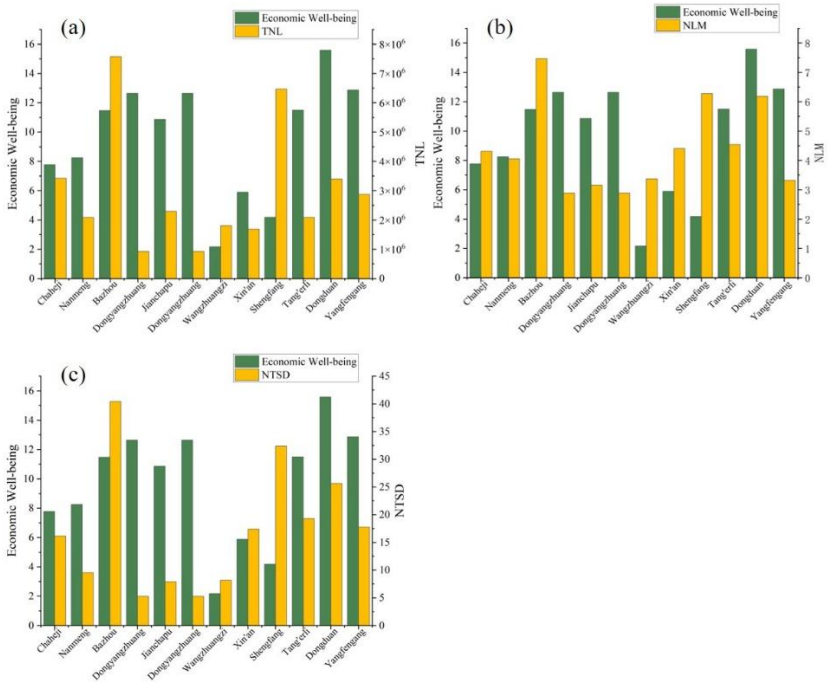

Figure4. Preliminary analysis of the relationship between economic well-being and TNL (a), NLM (b) and NTSD (c)

In general, there are differences in the connection between economic well-being and nighttime light remote sensing feature in towns and villages, and the economic well-being of some towns and villages shows an unrelated trend with the nighttime light remote sensing feature. Therefore, the economic development status represented by nighttime light remote sensing cannot fully reflect the economic well-being at township scale.

5. Conclusion

In order to explore the influencing factors of economic well-being, this study innovatively constructs an analysis framework for economic well-being factors that combines nighttime light remote sensing and household survey data. It first designs a set of socio-economic well-being questionnaires after poverty reduction in China, and Taking Bazhou City in China as the research area, a household survey on economic well-being was carried out and 160 valid questionnaire data were obtained. Further analysis of the economic well-being of towns in Bazhou City found that there is significant spatial heterogeneity in economic well-being, among which economic well-being is the highest is Dongduan, the lowest is Wangzhuangzi, and the average economic well-being value of Bazhou City is 9.04. Finally, using high-resolution SDGSAT-1 nighttime light remote sensing data and socioeconomic statistical data, an analysis of factors affecting economic well-being was carried out. The economic development status and economic well-being does not have a significant relationship in township scale, confirming that economic well-being is affected by multiple factors and does not entirely depend on the level of economic development. In the future, optical remote sensing data will be further combined to conduct research on the level of economic well-being affected by the synergy of multiple factors.

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