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Spatiotemporal Characteristics of Urbanization in the Taiwan Strait Based on Nighttime Light Data from 1992 to 2020

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Abstract: Urbanization is a crucial indicator which reflects the socio-economic development of a country or region. The regions across the Taiwan Strait (TSR) have garnered attention worldwide as being representative of typical urbanization development along the southeastern coast. Currently, research in the TSR predominantly focuses on individual regions, with limited academic achievements comparing urbanization paths across the strait. In particular, the domain of comparative analysis of the spatiotemporal characteristics of urbanization dynamics in TSR by using long time series of nighttime light data remains largely underexplored. Therefore, this study focused on comparing the urbanization paths in the TSR and analyzing the spatiotemporal characteristics of urbanization by using the long-term nighttime light data from 1992 to 2020. Additionally, some methods such as Theil–Sen median trend analysis, Mann–Kendall significance test, Hurst exponent, spatial statistics, and time series were used to quantitatively analyze the spatial distribution patterns and temporal trends of nighttime lights in the TSR since 1992. The results were as follows: (1) From 1992 to 2020, the spatial distribution of nighttime light data in TSR exhibited significant spatial heterogeneity, with high-value areas mainly located in southeastern Fujian and northwestern Taiwan, while low-value areas were concentrated in Fujian's inland regions; (2) During this period, nighttime lighting data increased from 729,863 in 1992 to 2,729,052 in 2020, and the percentage of its high-value (40–063) increased from 2.59% in 1992 to 12.22% in 2020; (3) Comparison of nighttime light data across representative cities from Taiwan (Taipei, Hsinchu) and Fujian (Xiamen, Fuzhou) uncovered distinct growth patterns—while Taiwanese cities had a high initial brightness value (the lowest value in the last 30 years was 518,379.4), their growth was relatively slow (average growth rate of 17%); Fujian cities, on the other hand, started from lower initial brightness value (the lowest value in the last 30 years was 35,123.1), but displayed substantial growth vigor (average growth rate of 222%); (4) During the study period, the nighttime light data of the vast majority of cities in the TSR demonstrated a significant increasing trend, particularly in coastal areas and urban centers; (5) Predictions of future trend variation suggest that the significantly increasing trend of cities surrounding Taiwan's primary metropolitan areas will intensify, whereas metropolitan regions such as Keelung may witness a decline in future trend variations. However, only a mere 0.03% of the nighttime light data show a significant decreasing trend. Additionally, there are distinct differences in the urbanization development stages of the TSR. Fujian is currently undergoing rapid urbanization, while Taiwan's urbanization has entered a stable stage. The study reveals that factors such as geographical location, natural resources, transportation infrastructure, population size, and industrial structure collectively influence the urbanization characteristics of the TSR. This research bears substantial significance for deepening the comprehension of the patterns and processes of urbanization development in the TSR and provides valuable insights for urban construction and development across the strait.

Keywords: urbanization; nighttime light; spatiotemporal characteristics; trend analysis; future trend; Taiwan Strait

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1. Introduction

Urbanization is a crucial indicator that reflects the socio-economic development of a country or region. It is closely related to multiple factors, such as population composition, economic growth, land resources, and social well-being [1–4]. Under the background of accelerated urbanization, the global urbanization system has undergone an unprecedented transformation and reconstruction [5]. Urbanization in developed regions has essentially entered a mature stage, and the urbanization level has stabilized. The focus of world urbanization had shifted to the developing world [6–9]. In the realm of geography, the definition of urbanization places greater emphasis on the evolution of geographical space across spatiotemporal factors [10–12]. Urbanization is a global concern, especially for developing countries, such as those in Southeast Asia and East Asia [13,14].

The Taiwan Strait (TSR), an important waterway located in the waters of southeastern China, connects the East China Sea and the South China Sea as a natural ribbon. With a length approaching 400 km and an average width of approximately 180 km that narrows to a mere 130 km at its smallest expanse, it stands as the principal maritime artery between mainland China and Taiwan [15]. Its presence conveys an abundance of natural resources to cities on both sides of the Taiwan Strait and gives these areas unparalleled geographical advantages [16]. The regions across the Taiwan Strait, namely, Fujian of Mainland China and Taiwan, have garnered attention worldwide as being representative of typical urbanization development along the southeastern coast [17]. The TSR shares similarities in terms of geographical location, natural conditions, and sociocultural aspects. Moreover, the urbanization development in both regions has experienced a complex process and pattern [18–21]. Since 1992, Fujian has experienced a rapid and continuous process of urbanization, including the 1994 "Economic Cooperation of the Five Cities in Southwest Fujian", the 2004 "Strait West Coast Economic Zone Development Plan" and "Urbanization Development of the Min Triangle", and becoming a pivotal starting point for the "21st Century Maritime Silk Road" in 2013. As a critical juncture on the north–south route of the Pacific west coast, Fujian witnessed the official launch of the "Fujian Free Trade Zone" in 2014. These policies and initiatives all contributed to the development of Fujian's urbanization [22]. Differently from developed regions, Fujian faces challenges such as a lower urbanization rate and great urban–rural inequality at the current development stage. In contrast, Taiwan's urbanization has entered a relatively advanced stage, owing to its unique history, cultural background, and specific geographical location. Consequently, Taiwan exhibits characteristics of high urbanization levels and balanced regional development [23]. In the current context of "comprehensive moderately prosperous society" in 2020, it is of paramount importance to conduct long time series analyses to understand and synthesize the evolutionary process and patterns of urbanization in the TSR. By comparing the urban development characteristics of both regions, valuable insights can be gained for urban construction in mainland China, while also providing crucial guidance for sustainable urban development and future planning in both areas.

A growing number of studies have been devoted to analyzing the spatiotemporal evolution of urbanization in the TSR. Chen [24] combined macrolevel analysis based on statistical data with field research to comprehensively evaluate the urbanization process in Fujian. Liu [25], through an in-depth analysis of Taiwan's historical data and policy evolution, elucidated the close connection between urbanization and development in the process of rural-to-urban transformation. Li [26], on the other hand, explored the differences and lessons learned between mainland China and Taiwan, in terms of integrated urban and rural development, by comparing policies, data, and practical cases from both sides of the strait. Obviously, traditional quantitative urbanization research based on statistical data can, to a certain degree, capture the spatiotemporal evolution of urbanization and provide a comprehensive portrayal of the urbanization process. However, traditional statistical data, such as those derived from statistical yearbooks and land census records, are generally constrained by administrative boundaries, hindering the research of urbanization's spatial characteristics from a fine-grained perspective. Additionally, from a temporal perspective, conventional data are subject to long update cycles and other limitations, making it difficult to examine the spatiotemporal features of urbanization across long time series from a macroscopic standpoint. In contrast to traditional methods, remote sensing technology, with its cost-effectiveness, timeliness, and extensive spatial coverage, enables rapid and accurate monitoring of the spatiotemporal characteristics of urbanization over long time series [27–29]. During the night, a majority of passive remote sensing applications tend to focus on the thermal or microwave spectral regions, aiming to measure parameters related to thermal radiation [30]. Such a setup enables sensors and platforms to conduct remote sensing monitoring of nighttime illumination within the visible range. Novel remote sensing sensors, such as satellite-based, airborne, and ground sensors, have been developed to quantify nighttime illumination, providing new research opportunities in the field of remote sensing [31,32]. Additionally, nighttime light remote sensing, an optical remote sensing technology capable of detecting faint light at night, acquires data unattainable by daytime remote sensing [33]. Boasting advantages such as wide coverage, rapid acquisition, and easy access, this technology has been extensively employed in the study of multi-scale, long-term urban issues [34–38]. Thus, an extensive number of studies have applied remote sensing images of nighttime light to the analysis of urbanization, for example, revealing the characteristic of urban infrastructural transitions [39], performing experiments to show the scope of the city [40], detecting urban centers and their spatial structure [41], and exploring indicators such as urbanization population [42] and socio-economic data [43]. At the same time, some scholars use remotely sensed nighttime light data to study the urbanization development on both sides of the Taiwan Strait. For instance, Liu et al. [44] used the nighttime light data to estimate ethnic disparity in economic well-being in mainland China and Taiwan. Lu et al. [45] used nighttime light data from 1992 to 2013 to monitor changes in the expansion of the West Coast urban agglomeration and to explore the coupled coordination between the expansion of the West Coast agglomeration and the quality of urbanization. Chen et al. [46] employed nighttime light data and combined it with Landast time series to detect long-term landslide activities in Taiwan from 1998–2017. Chai et al. [47], on the other hand, utilized nighttime light data to investigate the spatiotemporal characteristics of urbanization in the Xiamen Special Economic Zone. Meanwhile, Nie [48] conducted a specialized study on the spatiotemporal evolution of urban built-up areas in Fujian Province using multi-source data. At present, research in the TSR predominantly focuses on individual regions, with limited academic achievements which compare urbanization paths in the TSR. In particular, the domain of comparative analysis of the spatiotemporal characteristics of urbanization dynamics in the TSR, by using long time series of nighttime light data, remains largely underexplored. Overall, nighttime light data possess the capacity to analyze the relationship between urbanization processes and socioeconomic development levels. However, there is a need to expand the scope and depth of research, particularly in exploring the spatiotemporal patterns and long-term evolution of these processes. This expansion will facilitate a more comprehensive understanding of urbanization and balanced social development in the TSR.

Based on this, the objectives of this study were as follows: (1) analyze the spatial distribution patterns and temporal trends of nighttime light data in the TSR from 1992 to 2020; (2) predict the future variation in urbanization trends and spatiotemporal characteristics; (3) elucidate the evolutionary process and patterns of urbanization in the TSR; (4) explore the similarities and differences development of urbanization in the TSR. This analysis provides valuable insights for urban policymakers and planners to formulate urban development strategies on both sides of the strait. To fulfill these objectives, time series nighttime light data in the TSR from 1992 to 2020 and comprehensive evaluation methods such as Theil–Sen median trend analysis, Mann–Kendall significance test, spatial statistics, and time series analysis were used to explore the evolutionary process and patterns of urbanization in the TSR. The future variation in urbanization trends was described using the Hurst exponent.

The remainder of this paper is organized as follows: in Section 2, we present our research methodology, the study area, data, and model; Section 3 presents the results of the spatiotemporal characteristics and the future trend variation, as well as a comparison of typical cities; Section 4 performs an in-depth analysis based on the results of the nighttime lighting data; and Section 5 is the conclusion. This is shown in a flowchart in Figure 1.

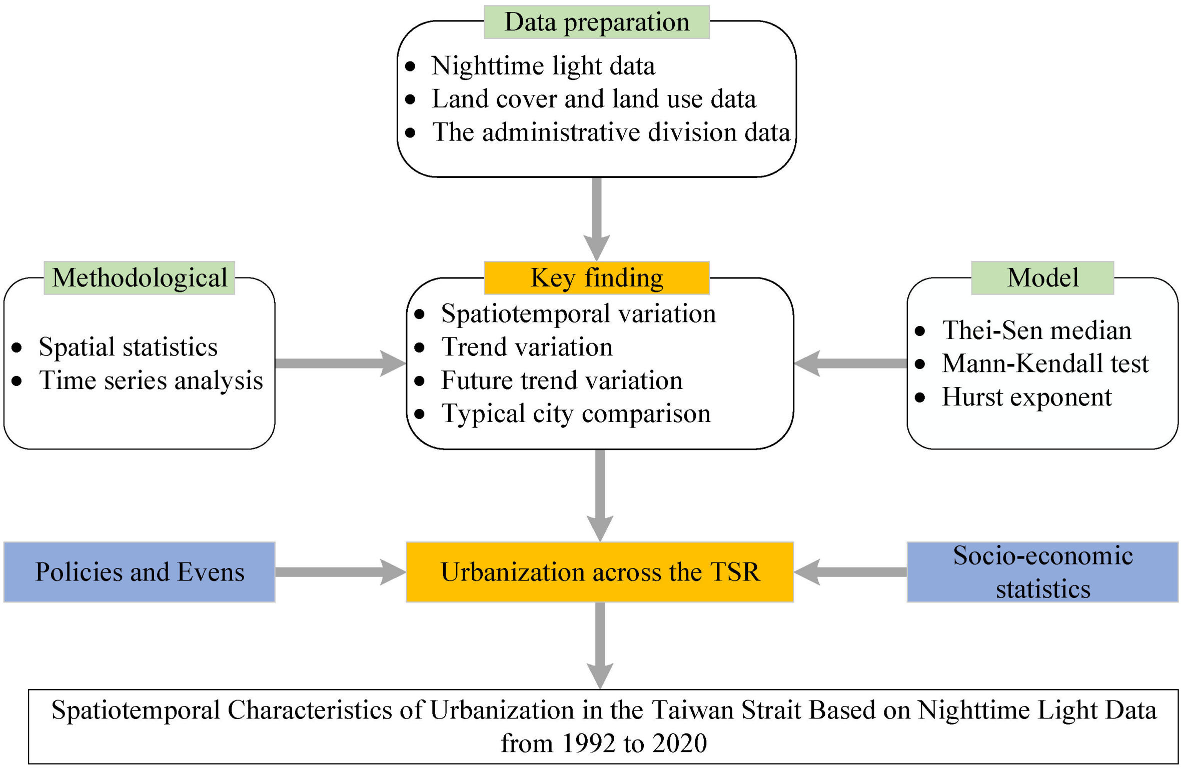

Figure 1. The flowchart used to analyze the spatiotemporal characteristics of urbanization in the TSR.

2. Materials and Methods

2.1. Study Area

The TSR is in the southeast of China (Figure 2a). The TSR shares similarities in terms of geographical location, natural conditions, and sociocultural aspects [19]. Situated on the western shore of the Taiwan Strait, Fujian province is delineated by water ridges on its northern, western, and southern borders. Fujian province, a crucial starting point of the 21st-century Maritime Silk Road, was among the earliest Chinese provinces engaged in international trade and is a renowned ancestral homeland for overseas Chinese and Taiwanese compatriots. Taiwan, situated on the continental shelf off the southeastern coast of China, is bordered by the Pacific Ocean to the east, faces Fujian province across the Taiwan Strait to the west and the East China Sea to the north, and is neighbored by the Philippine Islands across the Bashi Channel to the south. Based on the demographic and economic statistics found in the 2020 Fujian Statistical Yearbook [49] and the records from Taiwan's Ministry of the Interior's Department of Household Registration [50], it is evident that both Fujian and Taiwan have undergone significant growth from 1992 to 2020. In Fujian, the total population swelled from 31.16 million to 41.61 million, alongside a remarkable increase in per capita GDP, which jumped from 2500 yuan to 105,100 yuan. During the same period, Taiwan's population grew at a lower rate, with its total population rising from 20.80 million to 23.56 million. Simultaneously, Taiwan's per capita GDP underwent a substantial surge, escalating from 77,100 yuan to an impressive 203,100 yuan.

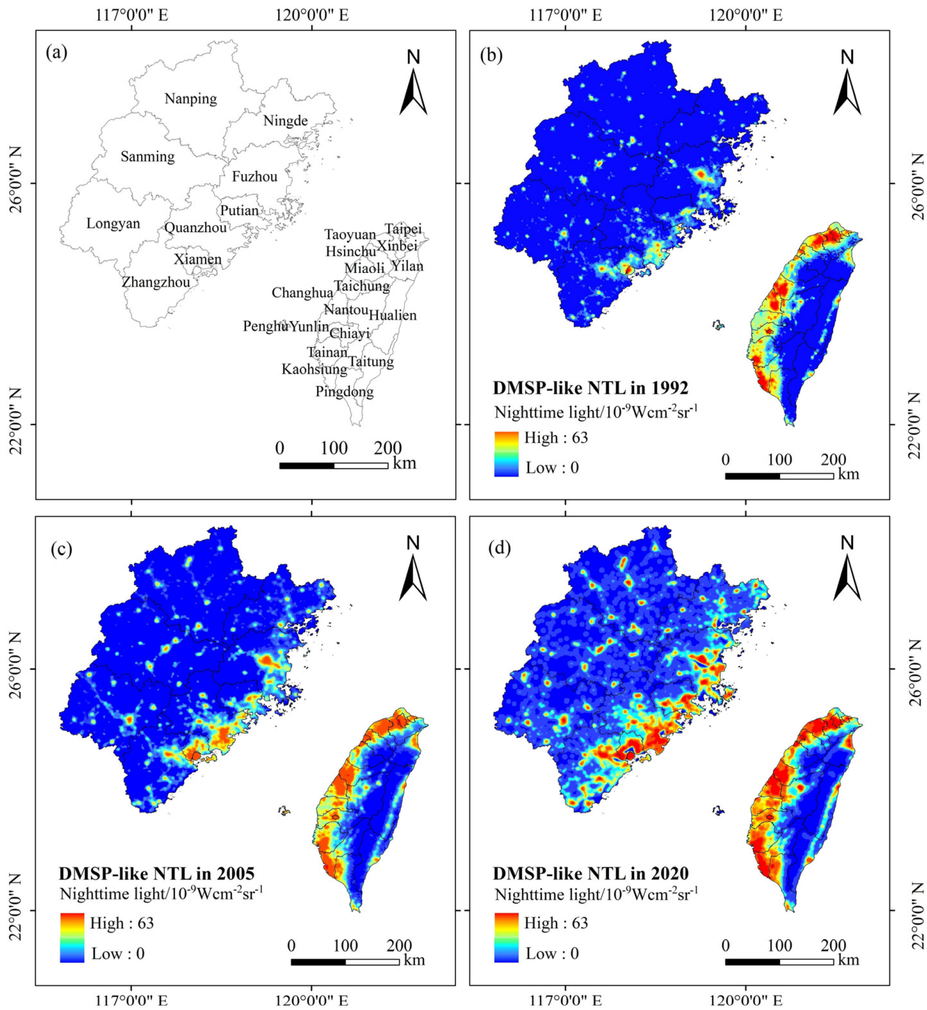

Figure 2. The (**a**) location, and the "DMSP−OLS-like" nighttime light images in (**b**) 1992, (**c**) 2005, and (**d**) 2020 of the TSR.

2.2. Dataset

2.2.1. Nighttime Light Data

As shown in Figure 2b–d, the nighttime light dataset employed within the context of this research was formulated by Li et al. [51], with an appreciable spatial resolution of 30 arc-seconds. Deposited in the Figshare repository (https://doi.org/10.6084/m9.figshare.9828827.v2 (accessed on 5 January 2022)), the data bear the mark of the GEOTIFF file format, facilitating processing with GIS software, such as QGIS. The dataset's primary feature is the harmonized global nighttime light (NTL) time series data, comprising sequentially calibrated stable DMSP NTL observations from 1992 to 2013, distributed as follows: F10 (1992–1994), F12 (1995–1996), F14 (1997–2003), F16 (2004–2009), and F18 (2010–2013). The dataset was further enhanced with the inclusion of simulated DMSP-like DNs derived from the VIIRS radiance data from the period of 2014 to 2018. The simulated data was created from the annual VIIRS NTL data, synthesized post-denoising the monthly observation data procured from VIIRS. Another integral aspect of the dataset is the inferred relationship between VIIRS data, quantified by the Sigmoid function of 2013, and DMSP data. This element permitted the creation of DMSP-like NTL data from VIIRS data. Significantly, this dataset not only extends the time series length of the two types of original nighttime light remote sensing data but also exhibits superior time series consistency and data quality. Collectively, these attributes offer valuable data support for analyzing and researching the spatiotemporal characteristics of large-scale urbanization over a long-term series. Moreover, the acquired nighttime light data, after being trimmed according to the requisite administrative division data (the administrative division data are based on a 1:4 million national database provided by the National Geographic Center of China), is employed in subsequent research. In this study, the collected nighttime light data undergo uniform processing on the ArcGIS 10.6 software platform developed by the Environmental Systems Research Institute (Redlands, CA, USA).

2.2.2. Land Cover and Land Use Data

The land use data utilized in this study were developed by Jie et al. [52] and are available for download at https://doi.org/10.5281/zenodo.5816591 (accessed on 5 January 2022). They constructed the first annual Landsat-based land cover product (CLCD) for China, from 1985 to 2019, using 335,709 Landsat images on Google Earth engine. They collected training samples by combining stable samples extracted from the China Land Use/Cover Dataset (CLUD), with samples visually interpreted from satellite time series data, Google Earth, and Google Maps. Several temporal metrics were constructed from all available Landsat data and provided to a random forest classifier to obtain classification results. A post-processing method combining temporal filtering and logical inference was further proposed to improve the temporal consistency of CLCD.

2.3. Methods

2.3.1. Theil–Sen Median

The Theil–Sen Median was used to analyze dynamic trends in remote sensing-derived nighttime light data. The median value of the slope series was used as the basis for determining trend, which reduces the influence of missing or abnormal data [53,54]. It is known as the most widely used linear non-parametric trend prediction model. For time series NTL, its specific calculation formula is as shown:

$$\text{slope} = \text{median}((\text{NTL}_j - \text{NTL}_i)/(j - i))\ 1992 \leq i \leq j \leq 2020 \tag{1}$$

Slope is the variation trend in nighttime light remote sensing data in the TSR from 1992 to 2020, calculated by Theil–Sen Median. Slope > 0 indicates that the change in nighttime light data shows an increasing trend, while slope < 0 is a decreasing trend, and a greater absolute value of slope indicates a greater changing trend.

Theil–Sen Median was used to calculate the brightness change trend in luminous remote sensing data in a long time series, while the Mann–Kendall non-parametric statistical test was used to evaluate the significance of the trend.

2.3.2. Mann–Kendall Test

The Mann–Kendall statistical test (MK) is a non-parametric statistical test that is versatile in its application, providing strong practicability and convenience in calculation. It is undisturbed by outliers and is suitable for both type and order variables, without requiring any specific distribution or particular order, making it highly adaptable to a variety of data structures [55–57]. Furthermore, this robustness makes it a particularly effective method for handling complex datasets such as nighttime light data, which can exhibit significant trends over time due to various factors, such as urban development or policy changes. The MK test not only identifies the presence and direction of a trend but also remains unaffected by noise or incomplete data points, enhancing the reliability of the analysis. In combination with the Theil–Sen estimator, a complementary method that quantifies the magnitude of the trend, the MK test provides a comprehensive perspective on trend analysis. This synergy of these two methods bolsters their suitability for diverse datasets and amplifies their ability to detect, quantify, and validate significant trends. Therefore, the choice of the Mann–Kendall test in this study was not merely convenient but strategic, providing an insightful analysis of significant trends within the data. In this paper, this method was also used to realize the brightness trend analysis of long time series remote sensing-derived nighttime light data. The calculation formula is as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(s)}}, \ S > 0 \\ 0, \quad S = 0 \\ \frac{S+1}{\sqrt{var(s)}}, \ S < 0 \end{cases} \tag{2}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(NTL_j - NTL_i) \tag{3}$$

where var(s) is as follows:

$$var(s) = \frac{n(n-1)(2n+5)}{18} \tag{4}$$

$$sign(NTL_j - NTL_i) = \begin{cases} 1, \ NTL_j - NTL_i > 0 \\ 0, \ NTL_j - NTL_i = 0 \\ -1, \ NTL_j - NTL_i < 0 \end{cases} \tag{5}$$

in which NTL_j and NTL_i are the nighttime light data in the study year i and j, respectively, n is the sequence length (the number of years in the study period), sign refers to the sign function, and Z is the statistical value of the significance test of nighttime light data series, with range $(-\infty, +\infty)$. At the given significance level, $p = 0.05$, the threshold of the normal distribution is $Z_{1-\alpha/2}$. When $|Z| \leq Z_{1-\alpha/2}$, the null hypothesis can be accepted (the trend is insignificant), and when $|Z| > Z_{1-\alpha/2}$, the null hypothesis is rejected and the trend is significant ($Z_{1-\alpha/2} = Z_{0.975} = 1.96$).

2.3.3. Hurst Exponent

The Hurst exponent, proposed by the hydrologist Hurst in 1951 [58], is used to quantify the sustainability of time data series. Initially, this method was primarily employed within the domain of hydrology, serving as a tool to comprehend and forecast the intricate dynamics between reservoir and river flow rates. Through careful processing and analysis of historical flow data, Hurst parameter is calculated using the least squares method. This approach provides an effective way to capture and quantify the long-term memory inherent in the data sequence, thereby facilitating the prediction of its future autocorrelation. Furthermore, the application of the Hurst exponent is not confined solely to the realm of hydrology. In fact, given its unique theoretical advantages, the Hurst exponent has found wide-ranging applications in numerous other fields, including meteorology [59], ecology [60], and economics [61]. Therefore, this paper employs the Hurst exponent to investigate future variations in nighttime light data. Firstly, we defined the time series of nighttime light remote sensing data {NTLt}, t = 1, 2, . . . , n. Then, the following formula was used to calculate the average brightness value of the remote sensing data of nighttime light:

$$\overline{NTL_{(\tau)}} = \frac{1}{\tau} \sum_{t=1}^{\tau} NTL_{(\tau)}, \ \tau = 1, 2, \ldots, n \tag{6}$$

The cumulative deviation was calculated as follows:

$$X_{(t,\tau)} = \sum_{t=1}^{\tau} NTL_t - \overline{NTL_{(\tau)}}, \ 1 <= t <= \tau \tag{7}$$

The extreme deviation sequence was calculated as below:

$$R_{(\tau)} = \max_{1 \leq t \leq \tau} X_{(t,\tau)} - \min_{1 \leq t \leq \tau} X_{(t,\tau)}, \ \tau = 1, 2, \ldots, n \tag{8}$$

The standard deviation sequence was calculated as shown:

$$S_{(\tau)} = \left[\frac{1}{\tau} \sum_{t=1}^{\tau} \left(NTL_t - \overline{NTL_{(\tau)}}\right)^2 \right]^{\frac{1}{2}}, \ \tau = 1, 2, \ldots, n \tag{9}$$

Taking the ratio of $R_{(\tau)}$ and $S_{(\tau)}$, we arrived at the following:

$$\frac{R_{(\tau)}}{S_{(\tau)}} = (c\tau)^{H} \tag{10}$$

The value of H is the Hurst Index, which can be fitted by least squares. When the value of H is close to 1, this means that the continuity of the future change trend is stronger; when the value of H is 0.5, the change in time series of nighttime light remote sensing data is more random; and when $0 < H < 0.5$, the future change trend in nighttime light remote sensing data is contrary to the past change trend, i.e., is anti-persistent. When H approaches 0, the future change trend in nighttime light remote sensing data is not consistent with the past change trend, which shows that the anti-persistence of remote sensing data of nighttime lighting is stronger.

3. Results

3.1. Spatial Distribution Characteristics of Nighttime Light Data in the TSR

Figure 3 illustrates the spatial distribution of nighttime light data in the TSR from 1992 to 2020. As can be seen from Figure 3, the spatial distribution of nighttime light data in the TSR is markedly distinct, with the brightness of nighttime lights in coastal regions being significantly higher than that in inland areas. More specifically, the nighttime light data can be categorized into three levels: low-value (0–15), mid-value (15–40), and high-value (40–63), which account for 85.27%, 9.22%, and 5.51% of the total, respectively. As depicted in Figure 4, high-value data are primarily concentrated in Changhua, Hsinchu, Chiayi, Taipei, Keelung, Xinbei, Taoyuan, Xiamen, and Quanzhou, covering the southeast of Fujian and the northwest of Taiwan. Mid-value data are predominantly located in Yunlin, Tainan, Quanzhou, Putian, Fuzhou, and Zhangzhou. Meanwhile, low-value nighttime light data are primarily found in inland areas of Fujian, such as Longyan, Nanping, and Sanming.

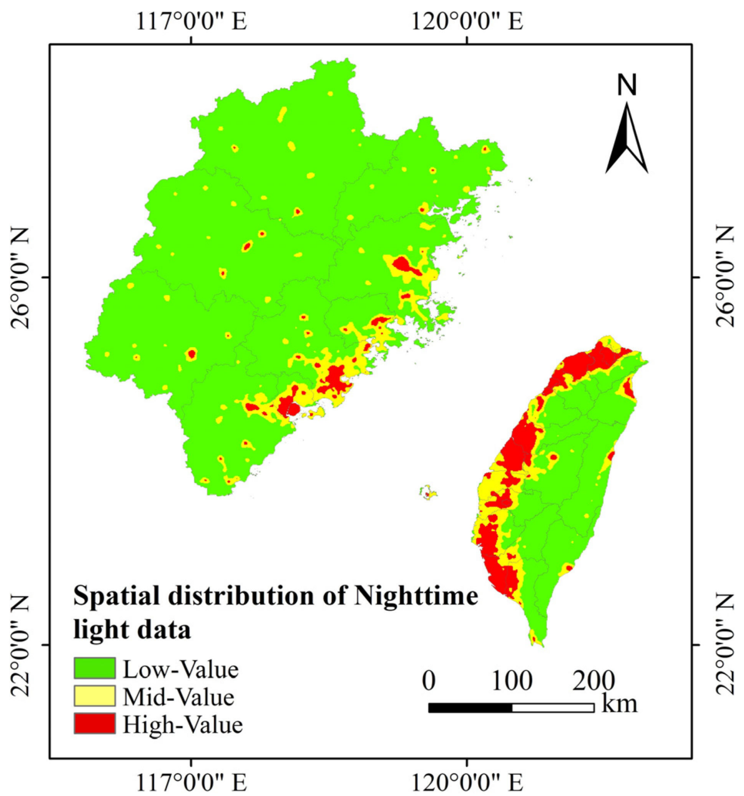

Figure 3. The annual values of nighttime light data in the TSR from 1992 to 2020.

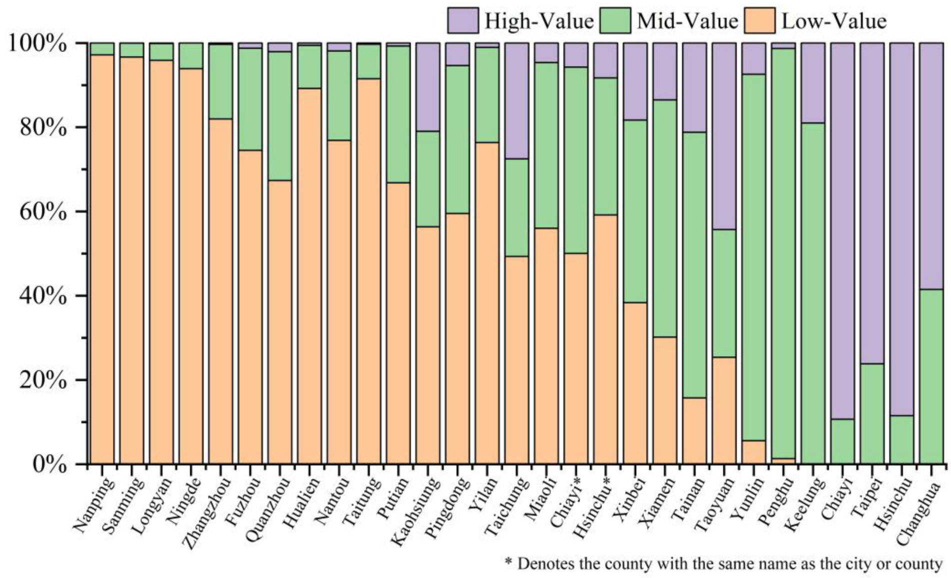

Figure 4. Nighttime light data proportion of the TSR in different cities from 1992 to 2020.

3.2. Time Variation Characteristics of Nighttime Light Data in the TSR

According to the changing trends in nighttime light data in the TSR, the timeline can be roughly divided into three phases: a stable growth stage from 1992 to 2004, a fluctuating transition stage from 2004 to 2010, and a substantial increase stage from 2010 to 2020. As shown in Figure 5, the nighttime light data gradually increased from 729,863 in 1992 to 1,433,594 in 2004, with an average annual growth rate of 5.79%. Subsequently, the data fluctuated between 1,326,874 and 1,535,755 from 2004 to 2009, and then rapidly grew to 1,476,409 between 2009 and 2014, with an average annual growth rate of 8.76%. Afterward, the nighttime light data remained stable at 2,270,000 between 2014 and 2016, and then experienced a significant increase in the following three years, but it decreased from 2,950,627 to 2,729,052 in 2020. In summary, despite some fluctuations in the early stages, the overall trend indicates that the nighttime light data in the TSR was continuously increasing from 1992 to 2020.

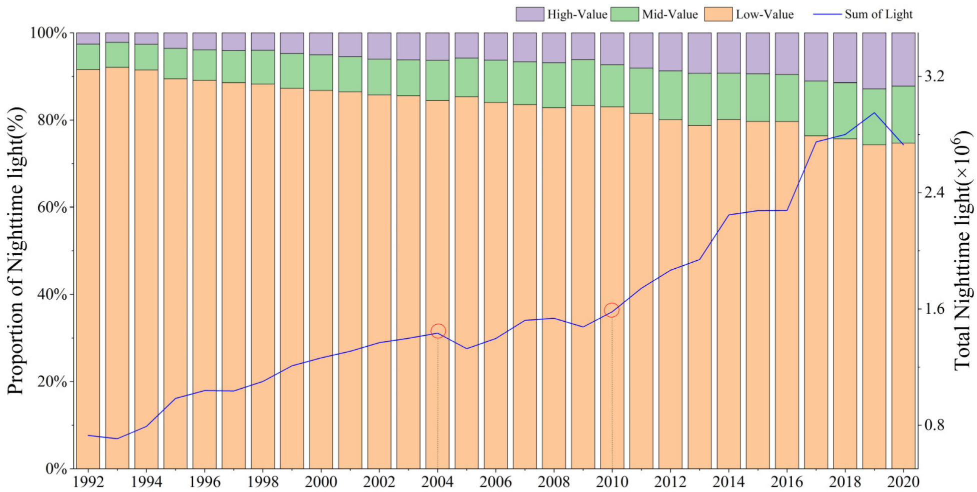

Figure 5. Area proportion of the TSR under different nighttime light data from 1992 to 2020.

Based on the previously mentioned classification criteria for nighttime light data, it was divided into three levels to quantify the changes in nighttime light data in the TSR from 1992 to 2020. Figure 5 illustrates the proportions of each level of nighttime light data in the total area for different years and the curve of the sum of light values from 1992 to 2020. As can be seen from Figure 5, from 1992 to 2020, the proportion of low-value decreased year by year, while that of mid-value and high-value gradually increased. Specifically, the proportion of low-value areas significantly dropped from 91.6% in 1992 to 74.75% in 2020. Conversely, the proportion of high-value areas increased from 2.59% in 1992 to 12.22% in 2020.

3.3. Trend Variation in Nighttime Light Data in the TSR

In order to scrutinize the evolving patterns of nighttime light data in the TSR between 1992 and 2020, this research employed the non-parametric Mann–Kendall and Theil–Sen's methods to ascertain the presence of significant positive or negative change trends in nighttime light data. This trend variation can be categorized into four levels: significant decreasing trend, low-significance increasing trend, mid-significance increasing trend, and high-significance increasing trend (Table 1), which account for 0.03%, 12.37%, 5.43%, and 0.57%, respectively.

Table 1. Categories of nighttime light data.

Categories	Theil–Sen Median	Mann–Kendall Test
Significant decreasing trend	Slope < 0	$\lvert Z \rvert > 1.96$
Low-significance increasing trend	$0 <$ Slope ≤ 1	$\lvert Z \rvert > 1.96$
Mid-significance increasing trend	$1 <$ Slope ≤ 2	$\lvert Z \rvert > 1.96$
High-significance increasing trend	$2 <$ Slope ≤ 3	$\lvert Z \rvert > 1.96$

According to the Figure 6, the spatial distribution of the variation trend in nighttime light data was heterogeneous in the TSR. A significant proportion of cities, amounting to 18.36%, displayed a substantial increasing trend in nighttime light data, predominantly in coastal regions and urban centers. In contrast, a mere 0.03% of the nighttime light data revealed a significant decreasing trend. Specifically, high-significance increasing trends were primarily concentrated in Xiamen, Fuzhou, and Quanzhou, i.e., the southeast of Fujian. Mid-significance increasing trends were predominantly located in Quanzhou, Fuzhou, and Zhangzhou. Low-significance increasing trends in nighttime light data were essentially found in Tainan and Xinbei. On the other hand, only a few areas exhibited a significant decreasing trend, almost exclusively observed in Fuzhou and Kaohsiung.

3.4. Future Trend Variation in Nighttime Light Data in the TSR

In the present study, we employed the Theil–Sens median trend analysis model and the Mann–Kendall significance test model for an in-depth and detailed exploration of the significant trends in long time series data of nighttime light brightness. This procedure facilitated the unveiling of urbanization evolution scenarios across both shores of the TSR. However, to attain a more comprehensive and detailed understanding, we opted to further utilize the Hurst exponent. Leveraging the history of long time series nighttime light brightness fluctuations, we performed predictive analysis of future brightness variations. Our analysis results indicated an average Hurst value of 0.53. This suggests that the nighttime light brightness variation across both shores of the TSR will maintain a significant growth trend, implying that urbanization along the TSR will persist along its established developmental path. In addition, using $H = 0.5$ as the threshold value, the predicted trend in nighttime light data change can be divided into two categories: $H > 0.5$, which indicates that future nighttime light data trend will remain consistent with current trends, and $H < 0.5$, which indicates that future nighttime light data trends will reverse from current trends. As can be seen in Figure 7, regions where nighttime light data trends are expected to remain consistent with the current state account for 9.81% of the total area of the TSR, while 7% of the area is predicted to see a reversal of the current nighttime light data trends.

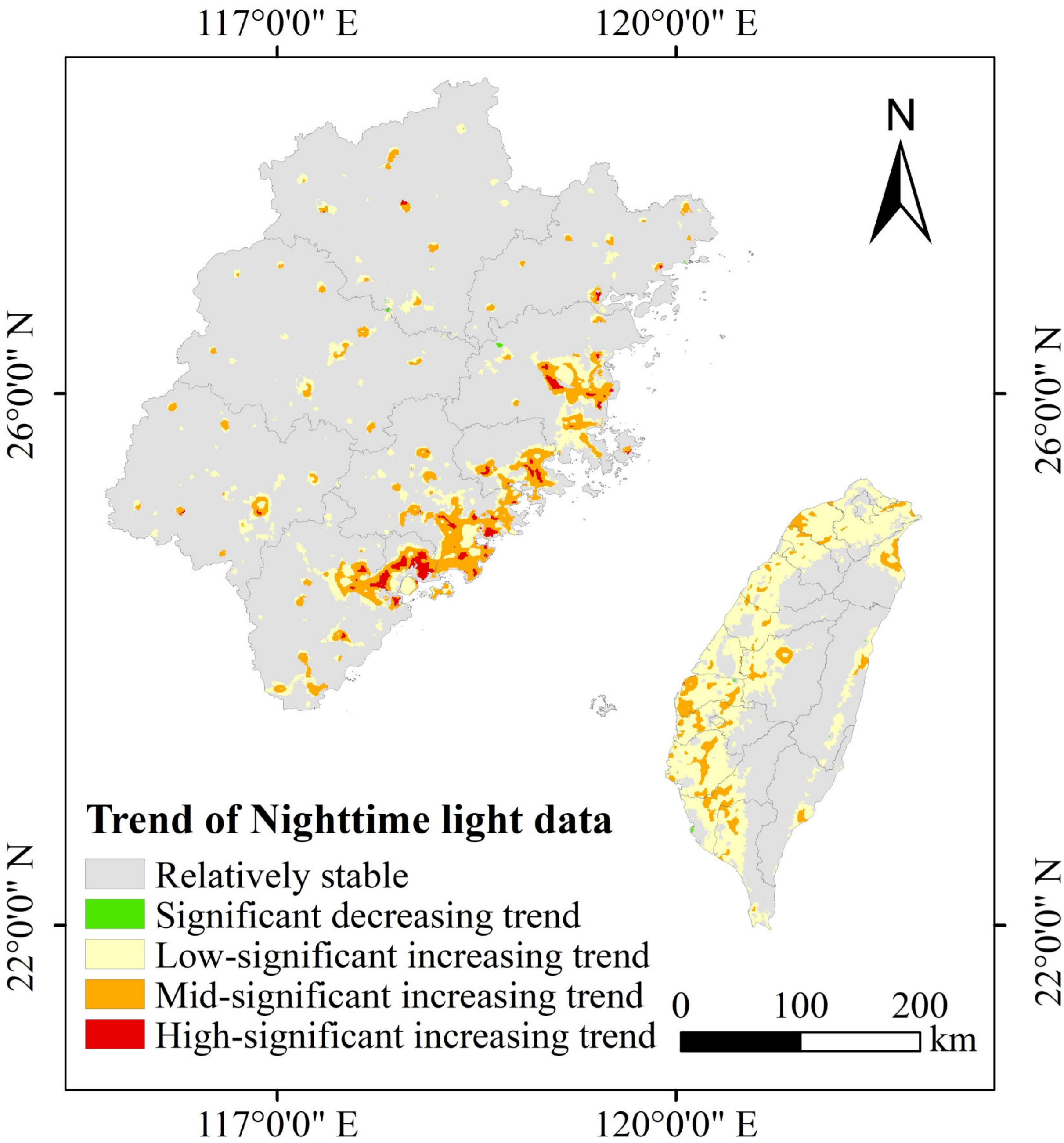

Figure 6. Spatial distribution of the nighttime light data trend of the TSR from 1992–2020.

By employing the Hurst exponents model and combining the results of the Theil–Sen trend analysis model and Mann–Kendall significance test model, the trend of future changes in nighttime brightness was explored. Based on the calculation results, the future change trends in nighttime brightness were divided into six categories: low-significance decreasing trend, mid-significance decreasing trend, high-significance decreasing trend, low-significance increasing trend, mid-significance increasing trend, and high-significance increasing trend (Table 2).

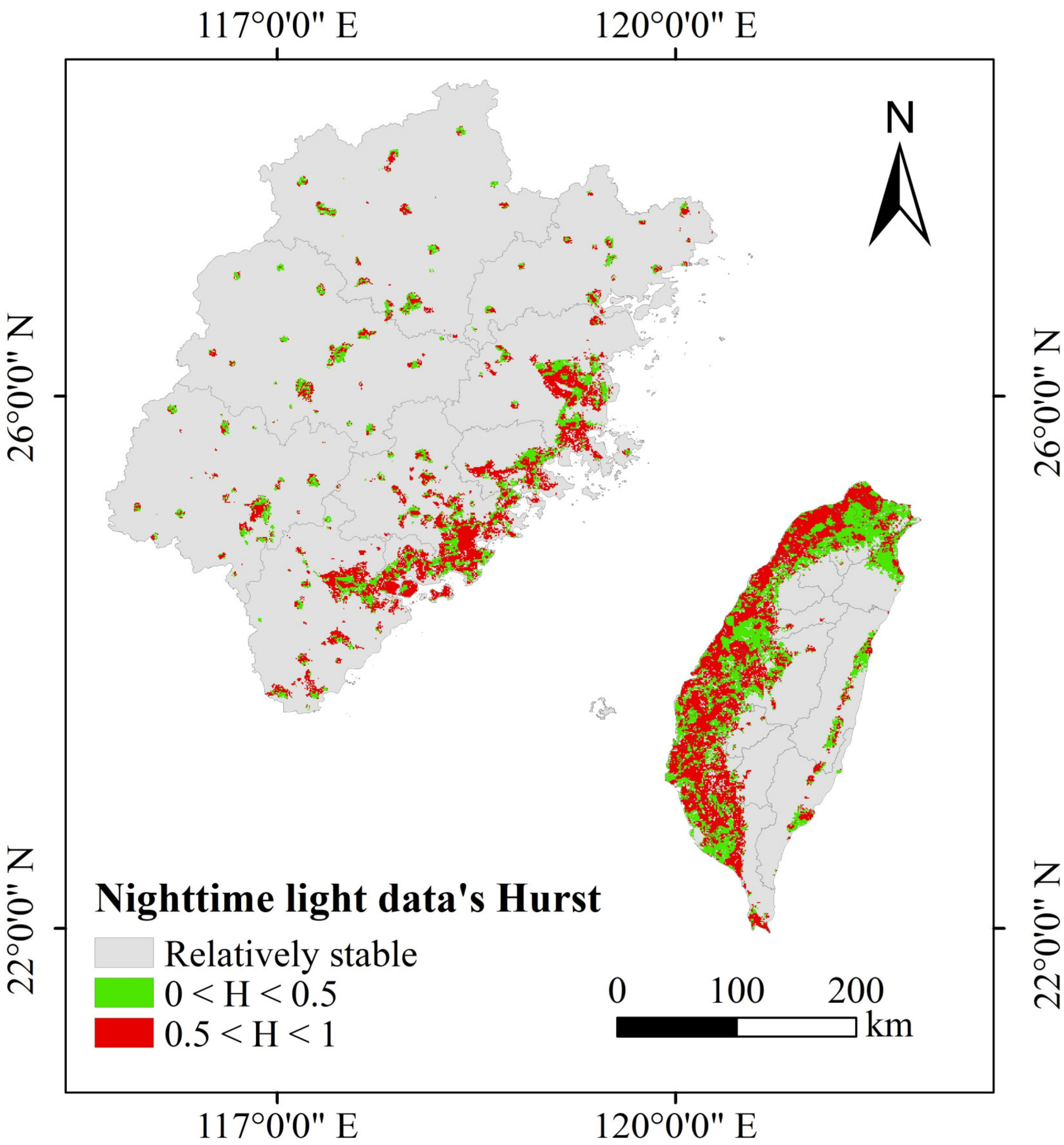

Figure 7. Future nighttime light data trends based on the Hurst exponent.

Table 2. Categories of future trend in nighttime light data.

Historical Brightness Changes	Hurst	Future Trend
Significant decreasing trend	0–0.5	Low-significance increasing trend
	0.5–1	Low-significance decreasing trend
Low-significance increasing trend	0–0.5	Low-significance decreasing trend
	0.5–1	Low-significance increasing trend
Mid-significance increasing trend	0–0.5	Mid-significance decreasing trend
	0.5–1	Mid-significance increasing trend
High-significance increasing trend	0–0.5	High-significance decreasing trend
	0.5–1	High-significance increasing trend

Figure 8 presents the distribution of future change trends in nighttime brightness in the TSR. Over the total area of the TSR, it is expected that 9.22% of the region will exhibit a significant increasing trend in future nighttime light data, while 6.39% of the region is predicted to display a significant decreasing trend. Moreover, it is projected that over 50% of the area in Taoyuan, Tainan, Hsinchu, and Yunlin will show a significant increasing trend, while 67.27% of the area in Keelung is anticipated to demonstrate a significant decreasing trend.

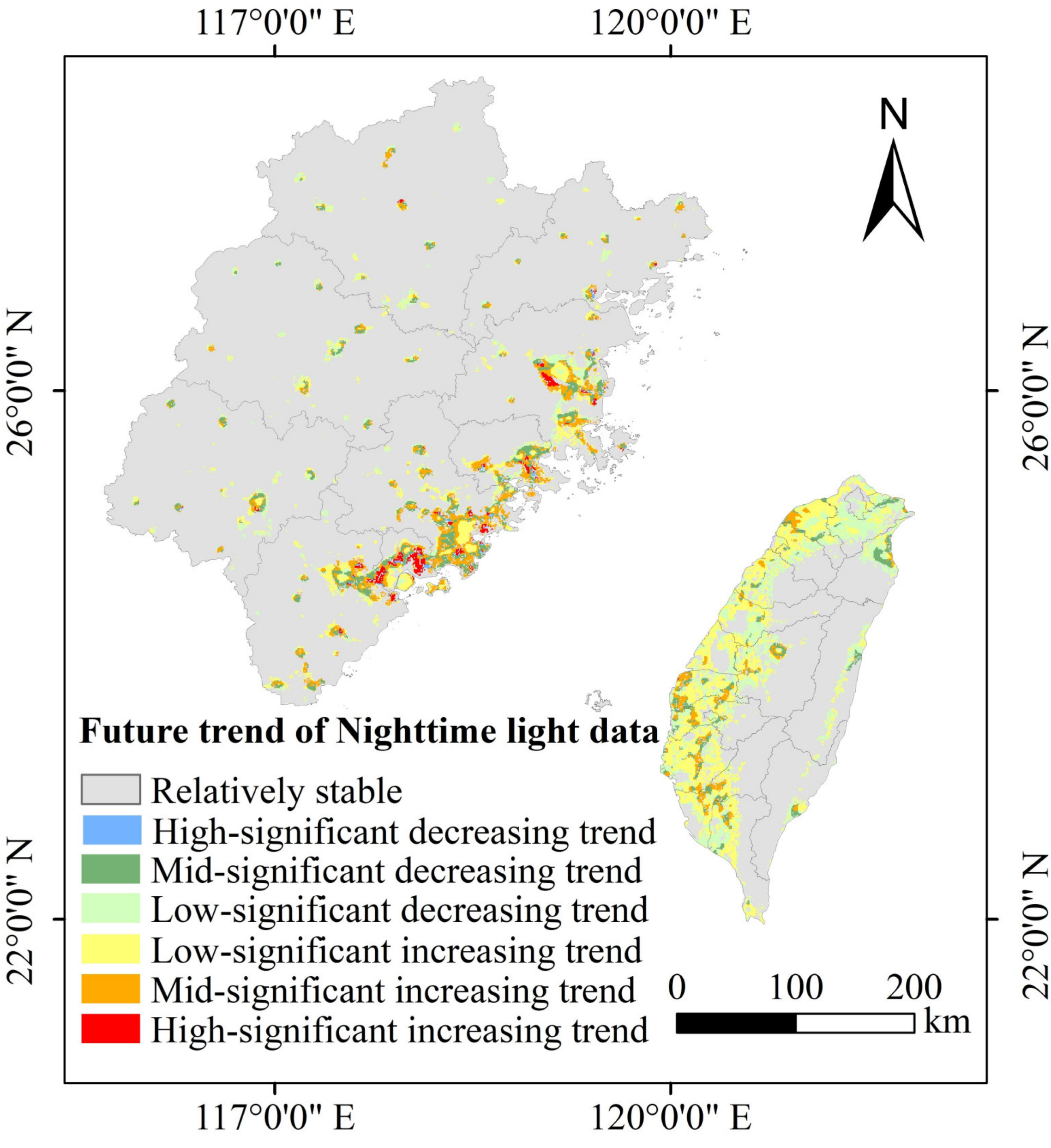

Figure 8. Future trend in nighttime light data in the TSR during 1992–2020.

3.5. Comparing Nighttime Light Data and Land Use Data in Typical Cities across the TSR

In order to conduct a profound analysis and comparison of the nighttime lighting differences within the regions across the TSR, this study chose representative cities for examination. These cities included Taipei, which serves as Taiwan's political, economic, and cultural hub; the coastal city of Hsinchu in Taiwan; Fuzhou, the provincial capital of Fujian; and Xiamen, a special economic zone. The choice of these locations allowed for a comprehensive investigation into the diverse lighting scenarios and underlying regional disparities. We selected nighttime lighting data and land use data for comparative analysis. The results show the following:

For nighttime light data per unit area, Figure 9 shows the trends of these four cities from 1992–2020. Notably, Taipei and Hsinchu had significantly higher nighttime light data per unit area than Fuzhou and Xiamen. Remarkably, the lowest values recorded for Taipei and Hsinchu over this period (518,379.4) were almost on par with the maximum values in the Fujian cities during the same time frame (556,723.5);

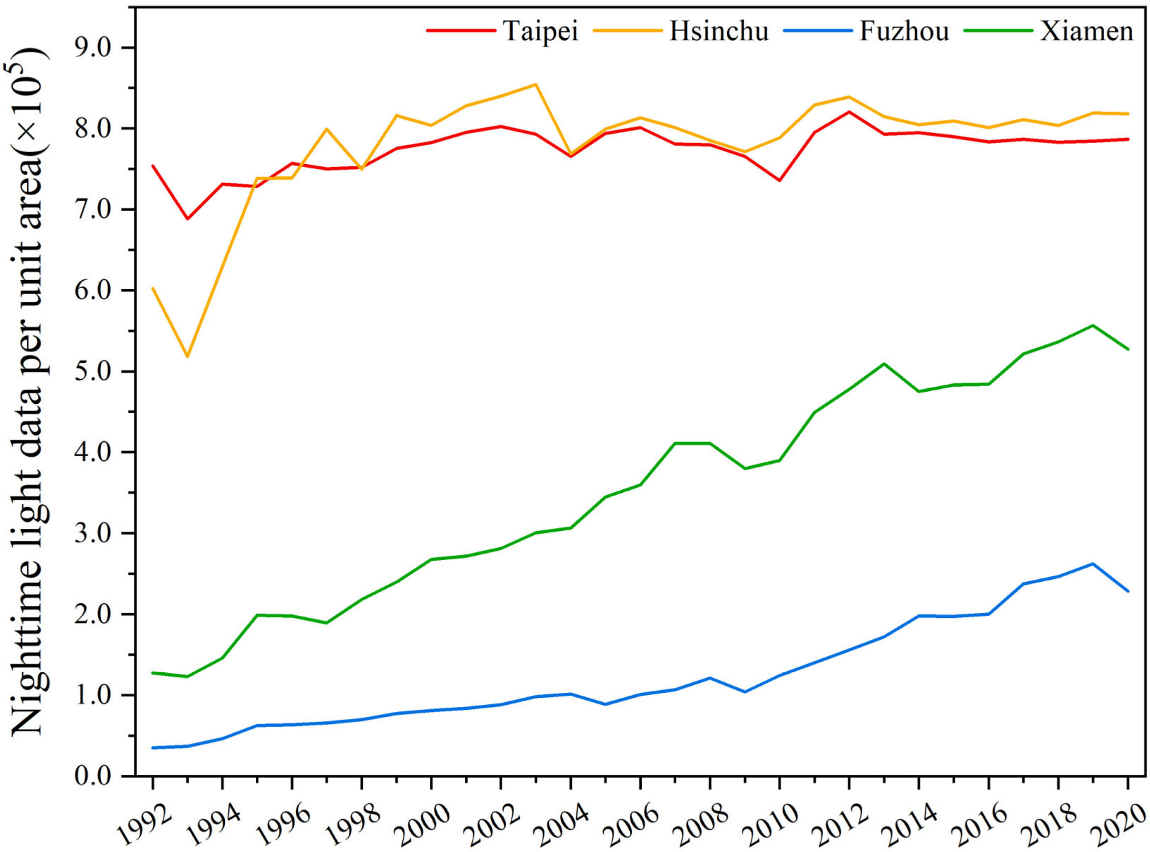

Figure 9. Nighttime light data per unit area in Fuzhou, Xiamen, Taipei, and Hsinchu from 1992 to 2020.

For the growth rates, Figure 10 further illustrates the growth rate trends of these four cities from 1992–2020. It is clear that, although Taipei and Hsinchu reported higher nighttime light data in per-unit areas, their growth rates were relatively lower, fluctuating by around 5% and 30%, respectively. Conversely, the growth rates in Fuzhou and Xiamen greatly surpassed those in Taipei and Hsinchu, with Fuzhou peaking at approximately 650% and Xiamen reaching a high of 350%. This analysis signifies that, despite the higher initial nighttime light data in the Taiwanese cities, the Fujian cities exhibited a stronger vigor in the dynamics of nighttime light data growth.

Furthermore, this study integrated a comparison between the nighttime light data and the land use and land cover data (CLCD) from 1992 to 2020 for both sides of the TSR. As illustrated in Figure 11, the trend in land use data for impervious surfaces area was akin to that of the nighttime light data during the research period. Both the land use and land cover for impervious surfaces per unit area in Taipei and Hsinchu were considerably higher than those in Xiamen and Fuzhou in Fujian. In terms of growth rate, as shown in Figure 12, the cities in Fujian showed a significant increasing trend, while the growth trend in Taiwan was gradually slowing down.

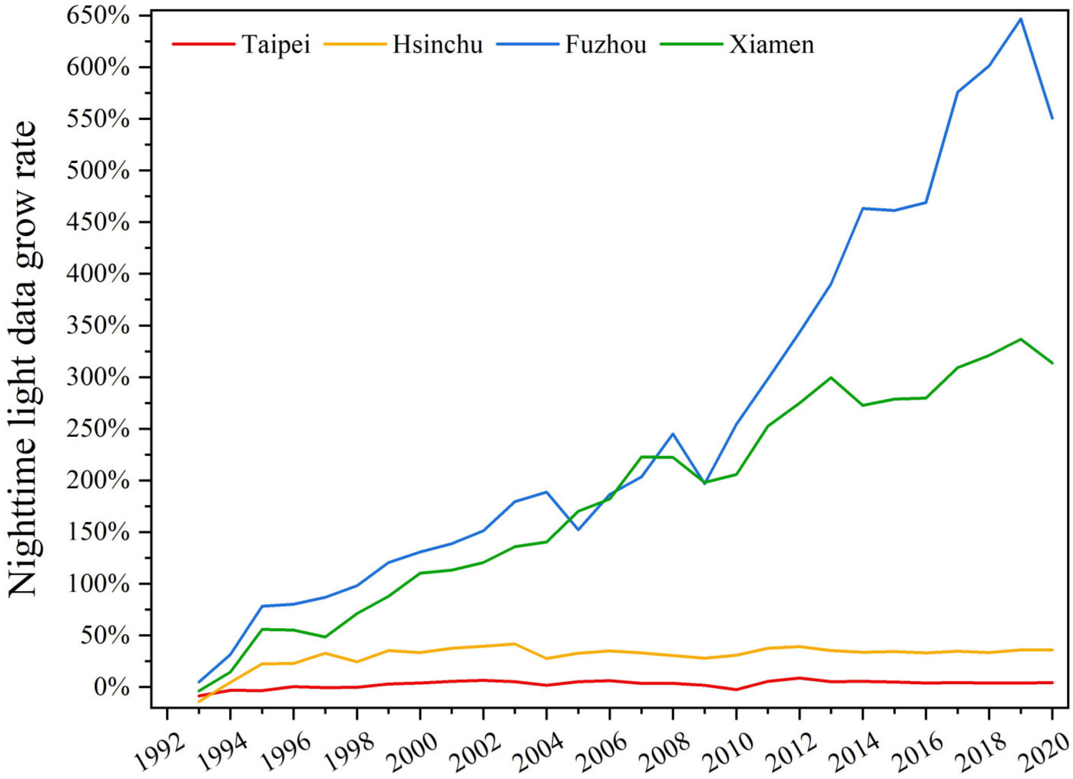

Figure 10. The growth rate of nighttime light data per unit area in Fuzhou, Xiamen, Taipei, and Hsinchu from 1992 to 2020.

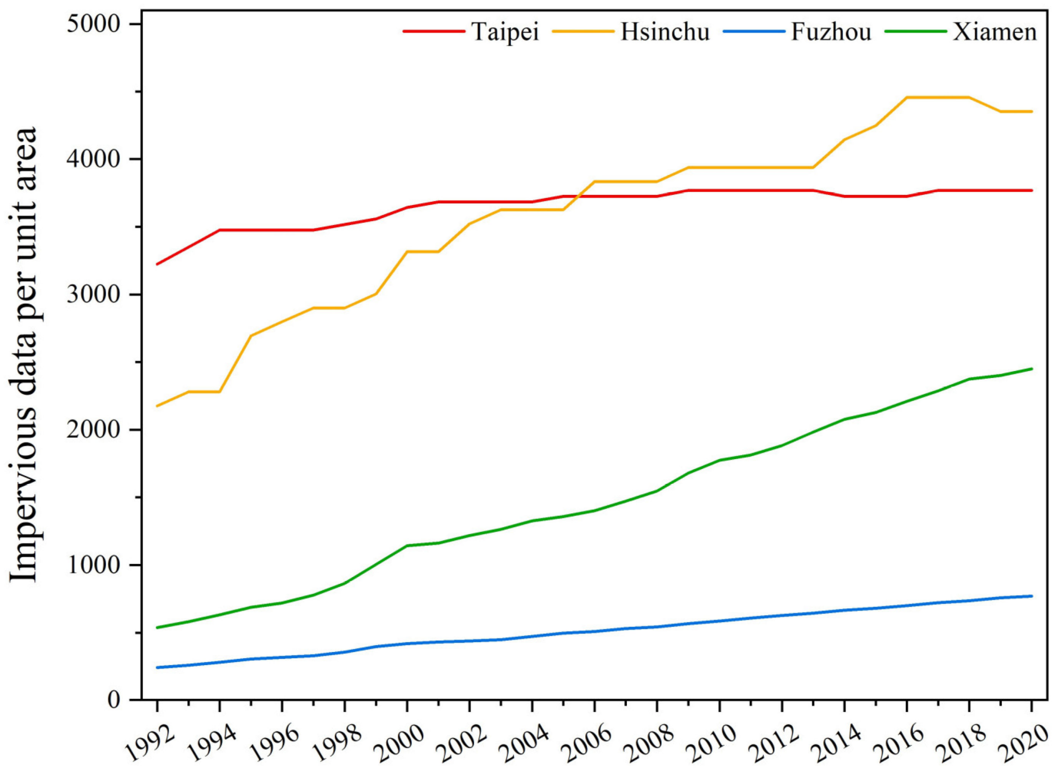

Figure 11. Impervious surface per unit area in Fuzhou, Xiamen, Taipei, and Hsinchu from 1992 to 2020.

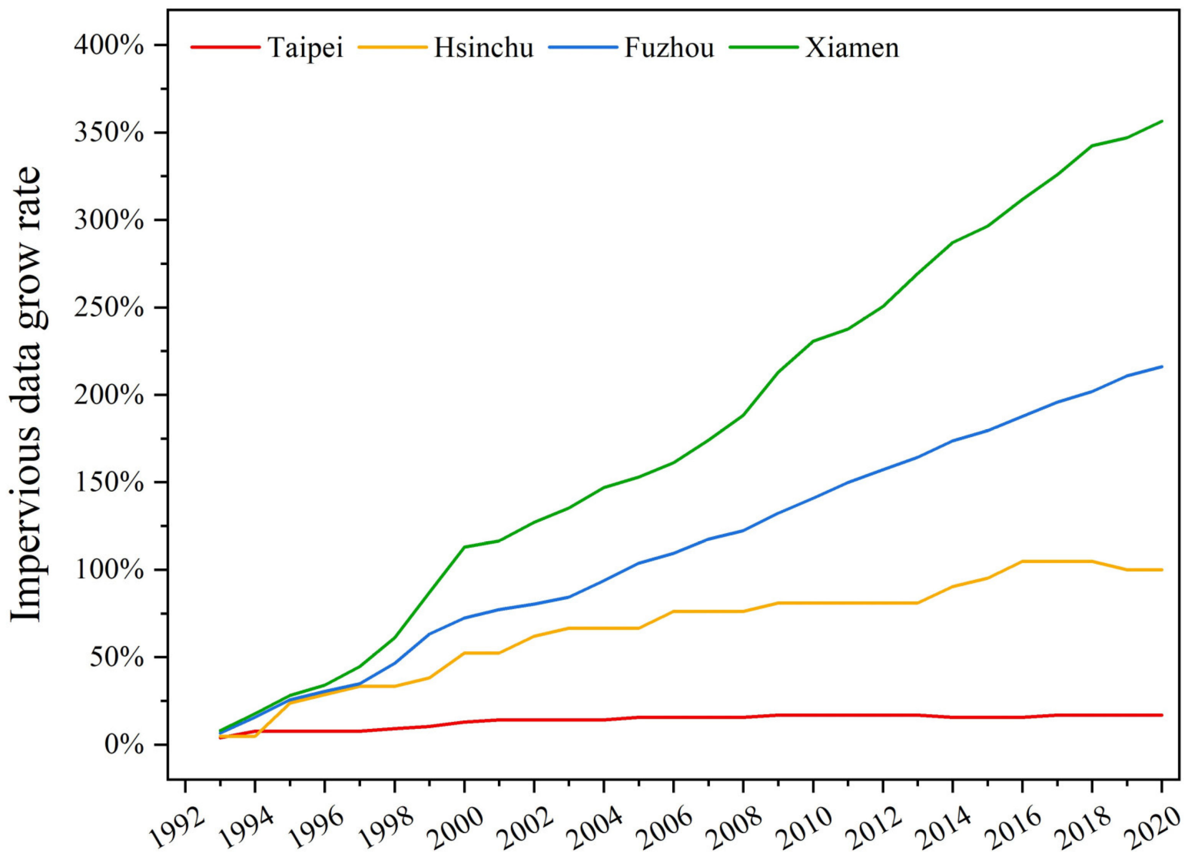

Figure 12. The growth rate of impervious surface per unit area in Fuzhou, Xiamen, Taipei, and Hsinchu from 1992 to 2020.

By conducting an in-depth comparative analysis of nighttime lighting data and land use data, we were able to delve into the interplay between the growth dynamics of nighttime light data in cities across the TSR and their economic development. Firstly, Taipei and Hsinchu City demonstrated higher per-unit area nighttime light and impervious surface area compared to Fuzhou and Xiamen, as corroborated by both datasets we examined. This indicates a greater degree of urbanization in Taiwanese cities. However, despite the high initial values for Taiwanese cities, the growth rate in Fuzhou and Xiamen significantly surpassed that of Taipei and Hsinchu City. This suggests that cities in Fujian Province were exhibiting a stronger growth momentum in these respects, whereas the growth trend in Taiwanese cities was relatively slowing down. This examination not only uncovered the differences in nighttime light data growth between Taiwan and Fujian, but also provided a solid foundation for understanding the economic development status of these regions over the past 30 years.

4. Discussion

4.1. Spatiotemporal Variation Characteristics of Nighttime Light Data in the TSR

Nighttime light data variations across different regions reveal a pronounced spatial heterogeneity in the TSR. High-value (40–63) data are predominantly located in Taipei, Hsinchu, and Chiayi, whereas low-value (0–15) data are mainly found in Nanping, Sanming, Longyan, and Ningde. Specifically, the proportions of high-value areas are 76.16%, 88.49%, and 89.33%, respectively, of the aforementioned regions, while the low-value areas account for 97.19%, 96.68%, 95.89%, and 93.92%, respectively. Notably, high-value data in Nanping and Ningde were non-existent, while those in Longyan and Sanming only accounted for 0.11% and 0.03%, respectively. This could be attributed to the cities' predominantly rugged, mountainous terrain and rolling hills, which contribute to their complex natural environments and impede transportation, consequently constraining urban development. Moreover, these cities possess a relatively weak economic foundation and lack the competitive advantages necessary to attract talent and capital, rendering it difficult to unlock their market potential [62]. According to the 2020 Fujian Statistical Yearbook, the Gross Regional Product of Nanping, Ningde, Sanming, and Longyan cities comprised a mere 4.57%, 5.96%, 6.15%, and 6.53% of the entire province, substantially lower than coastal regions in Fujian, such as Fuzhou (22.8%), Xiamen (14.53%), and Quanzhou (23.11%). Owing to their remote locations, sparse populations, and low levels of economic development, these cities exhibit diminished population mobility, resulting in relatively low population densities. According to the 2020 Fujian Statistical Yearbook, the population densities of Sanming, Nanping, Longyan, and Ningde were 107.4, 120, 143 and 234.4 persons/km^2. In contrast, the population densities of southern Fujian regions such as Zhangzhou, Quanzhou, and Xiamen were 392.3, 778, and 3048.2 persons/km^2, respectively, markedly higher than eastern and northern Fujian.

In comparison, the nighttime brightness in Taipei, Hsinchu, and Chiayi in Taiwan predominantly fell within the high-value range (40–63). This is primarily because Taipei, as the political, economic, and cultural center of Taiwan, has a developed finance, commerce, technology and cultural industry, and its transportation system is also three-dimensional (with a road density of up to 6100 m/km^2, which is the highest in Taiwan) [63–65]. Hsinchu serves as a vital base for Taiwan's technological industry, housing world-renowned semiconductor industries and technology parks. According to Hsinchu's municipal statistical report, in 2021, the city's average business revenue was 7.885 million New Taiwan Dollars (TWD) per capita, ranking first among all counties and cities in Taiwan. Within this, the manufacturing industry constituted the largest proportion (69.02%), and, among the manufacturing sectors, the revenue of electronic components reached a staggering 2.19 trillion TWD, accounting for 61.30% of the city's total revenue [66]. Chiayi is situated in a fertile river plain, with two converging streams providing favorable irrigation conditions. Its privileged subtropical monsoon climate, abundant sunlight, and rainfall offer a conducive environment for agricultural development. As one of the earliest developed regions in Taiwan, Chiayi is also Taiwan's most important timber distribution and processing center, earning the reputation of a "Timber Metropolis" [67].

Consequently, these cities' nighttime brightness predominantly fell within the high-value range, indicating a higher degree of urbanization, more advanced economic development and transportation networks, and relatively higher population densities. According to Taiwan's Ministry of the Interior's Department of Household Registration, the population densities in 2020 for Taipei, Chiayi, and Hsinchu were 9557, 4432, and 2768 persons/km^2, respectively, while their per capita disposable income was 472,710, 364,317, and 430,002 TWD, respectively. Furthermore, the percentages of the population within the urban planning areas of Taipei and Chiayi amounted to 100% [68]. In summary, the distribution characteristics of nighttime lights in the TSR are determined by a combination of factors, including geographical location, natural resources, transportation facilities, population size, and industrial structure [69].

In addition, we have also found that, between 1992 and 2020, the nighttime light data of coastal cities in the TSR has shown a significant growth trend, with a remarkable growth in regions comprising up to 18.36% of the total area. This trend was mainly concentrated in cities such as Xiamen, Quanzhou, Zhangzhou, and Fuzhou, among which Xiamen exhibited the highest significant growth trend, reaching 18.33%. According to the 2020 Fujian Statistical Yearbook, the GDP of Fuzhou, Quanzhou, Xiamen, and Zhangzhou amounted to 1002.002 billion, 1015.87 billion, 638.4 billion, and 454.56 billion RMB, respectively, far exceeding the GDP of inland cities in Fujian, such as Nanping (200.74 billion RMB), Longyan (287.09 billion RMB), and Sanming (270.22 billion RMB). This is mainly due to these cities being located in Fujian's coastal areas, benefiting from favorable geographical locations and natural resource advantages. Their unique natural landscapes and rich tourism resources provide robust support for urban development. For example, Xiamen has consistently ranked among the top three domestic tourist destinations, successively winning titles such as “Most Influential City in China’s Tourism”, “Global Most Popular Tourist Destination”, “Top Ten Domestic Tourist Destination”, “Most Anticipated Travel Destination”, “Excellent City for ‘Internet+’ Tourism in China”, and “Hot Spring Capital of China”. Fujian’s port cluster, as one of the five major port clusters in the national plan, is an essential strategic fulcrum for the “One Belt, One Road” initiative, adjacent to the Yangtze and Pearl River Deltas and facing the Taiwan Strait. It has the second-longest coastline in mainland China, stretching 3752 km, with an island shoreline of 2804 km [70]. Thus, these coastal cities can rely on marine resources, ports, and other natural conditions to engage in extensive economic cooperation and cultural exchanges. Furthermore, the government has introduced a series of policy measures, such as the establishment of the Xiamen Special Economic Zone [71], the creation of the Xiangyu Free Trade Zone [72], the expansion of Special Economic Zones [73], the BRICS Summit [74], the planning of the Fuzhou Min River Delta Golden Triangle Economic Circle [75], the organization of the first International Investment Promotion Month [76], the completion and commissioning of the Strait International Convention and Exhibition Center [77], the opening of the Quanzhou Comprehensive Pilot Zone [78], and the implementation of the Golden Bridge Project [79]. These measures have jointly promoted the rapid development of urbanization in Fujian’s coastal areas. As a result, the nighttime light data and the urbanization development changes in Fujian’s coastal cities are more prominent [80].

By comparison, Taiwan’s overall significant growth trend in nighttime brightness was relatively low, with less than 1% of the region exhibiting high significant growth (Yunlin), and no other cities or counties showing a noticeable growth trend. This is mainly attributed to Taiwan’s urbanization process entering a stable stage (with an annual average growth rate of only 0.2% in urbanization over the past 30 years), slower urban development, and a gradually decelerating urban population growth rate [19]. Simultaneously, the development of the economy, society, and culture in cities was relatively stable (according to Taiwan’s statistical report, the economic growth rate in 2020 was only 3.39%). However, the trend in suburbanization is becoming increasingly apparent. The production and social resources in metropolitan areas are gradually migrating to surrounding satellite cities, further accelerating the process of population suburbanization. This has led to a gradual decrease in the population in urban areas and a dispersion of urban functions [81].

In addition, future predictions of nighttime light data from the TSR show that more than 50% of the areas in Taiwan, such as Taoyuan, Tainan, and Yunlin, are expected to exhibit a significant increasing trend. This phenomenon can largely be attributed to the proximity of these cities to highly urbanized cities such as Taipei, Xinbei, and Chiayi. The influence of the proliferation of these traditionally developed cities predicts a significant growth trend in the future [82]. Concurrently, most regions in Xiamen, Fuzhou, Quanzhou, Zhangzhou, and Putian in Fujian also exhibit an upward trend, demonstrating the pattern of urban cluster development [83]. Thus, for these cities showing a clear increasing trend, we predict a persistent advancement of the urbanization process. Concurrently, the potential increase in light pollution should be noted. Rigorous light pollution control measures need to be implemented, and lighting facilities should be upgraded, for instance, through the adoption of low-light-pollution LEDs.

However, for Keelung, Chiayi, Taipei, and Xinbei, the predicted nighttime light data might not demonstrate a significant increasing trend. This is mainly due to the continuous improvement and enhancement of urban planning and management in Taiwan, along with the ongoing refinement and optimization of urban environments and social structures [84]. Thus, for these cities, urban planning should prioritize maintaining the current level of development, optimizing city structure, and enhancing public facilities. Simultaneously, the promotion of environmental policies, such as green building and green transportation, should be continued.

For Nanping, Sanming, and Longyan in inland Fujian, the projected growth trends are expected to be lower. As such, urbanization developments in these regions warrant sufficient attention. Appropriate policy adjustments and investments should be made to facilitate further development and enhancement in these cities. It is advisable to prioritize the development of infrastructure, improvement of public services, and enhancement of living standards to attract more population and investment.

Therefore, by predicting future trends in nocturnal lighting, urban planners and policy makers can gain a better understanding of urbanization trends, anticipate areas that may require more policy investment, avoid over-development in some areas, and prevent developmental lag in others, thereby minimizing regional disparities. Additionally, this allows environmental organizations to comprehend light pollution trends and formulate corresponding protective measures. Overall, this study provides valuable reference for the formulation of future regional urbanization development strategies.

4.2. Variation Characteristics in Nighttime Light Data in the TSR at Different Stages of Development

Between 1992 and 2020, the total nighttime brightness in the TSR exhibited a continuous growth trend, increasing from 729,863 to 2,729,052, a 3.7-fold increase, with an average annual growth rate of 4.82%. The growth trend can be roughly divided into three phases: a stable growth phase from 1992 to 2004, a fluctuating transition phase from 2004 to 2010, and a substantial growth phase from 2010 to 2020. The growth characteristics of different phases are closely related to the urbanization process of cities along the straits and the implementation of relevant policies (Figure 13). Specifically, during the first phase (1992–2003), the urbanization process of the cities along the straits gradually advanced, with an annual average growth rate of nighttime light data reaching 5.79%. In 1992, Taiwan implemented the “Economic Transformation” plan to promote the shift of economic structure towards high-tech and service industries, reducing reliance on traditional manufacturing [85]. In 1993, the “Master Plan for Fujian Coastal Economic Development Zone” included Sanming, Nanping, Longyan, Fu’an, and Fuding as part of the coastal economic opening zone [86]. In 1994, the “Economic Cooperation of Five Cities in Southwest Fujian” was implemented, aiming to build a modern international city cluster [87]. In 1995, the “Asia-Pacific Financial Center Plan” was implemented as Taiwan’s long-term financial development plan, promoting economic development in both regions [88]. During the second phase (2004–2009), in 2004, Fujian implemented the “West Coast Economic Zone Strategic Plan” to strengthen economic cooperation between Fujian and Guangdong, Hainan, Taiwan, and other regions, jointly constructing a new pattern of regional economic development [89]. In 2009, the “Meizhou Bay Port Integration” transformed Meizhou Bay Port into a comprehensive hub for cross-strait maritime direct routes, providing transit services for Taiwan and creating a gateway port and base facing the Asia-Pacific region [90]. During the third phase (2010–2020), policies such as “Xia-Zhang-Quan Urban Integration” [91] and “Fu-Pu-Ning Urban Integration” [92] in Fujian were implemented, with large cities at the core driving the development of surrounding small- and medium-sized cities, promoting urbanization construction. This caused the annual average growth rate of nighttime light data to fluctuate between 3% and 4%. Furthermore, the proposal and implementation of policies such as “The 18th National Congress: Accelerating the Construction of New Urbanization” in 2012 [93], “Precision Poverty Alleviation” in 2013 [94], and “21st Century Maritime Silk Road: Fujian Province’s Master Plan for Main Functional Zones” in 2013 [95] also promoted the rapid advancement of urbanization across the straits. In 2017, Fujian implemented the “Fujian Free Trade Pilot Zone” plan, aiming to promote the transformation and upgrading of foreign trade, as well as innovative development, creating an open gateway and strategic hub for the 21st Century Maritime Silk Road [96]. Taiwan also implemented the “Forward-looking Infrastructure Development Program”, aiming to strengthen infrastructure construction in areas such as railways, highways, ports, and environmental protection [97]. The implementation of these policies not only promoted the urbanization process in both regions, but also led to an annual growth rate of nighttime light data as high as 20.73% in 2017. Moreover, we found that, between 1992 and 2020, the total nighttime light data fluctuated in some years, which might be attributed to the impact of natural disasters and epidemics such as "Feiyan" in 2001, "Sangmei" in 2006, "Moranti" in 2016, and the COVID-19 pandemic in 2019 [98–100].

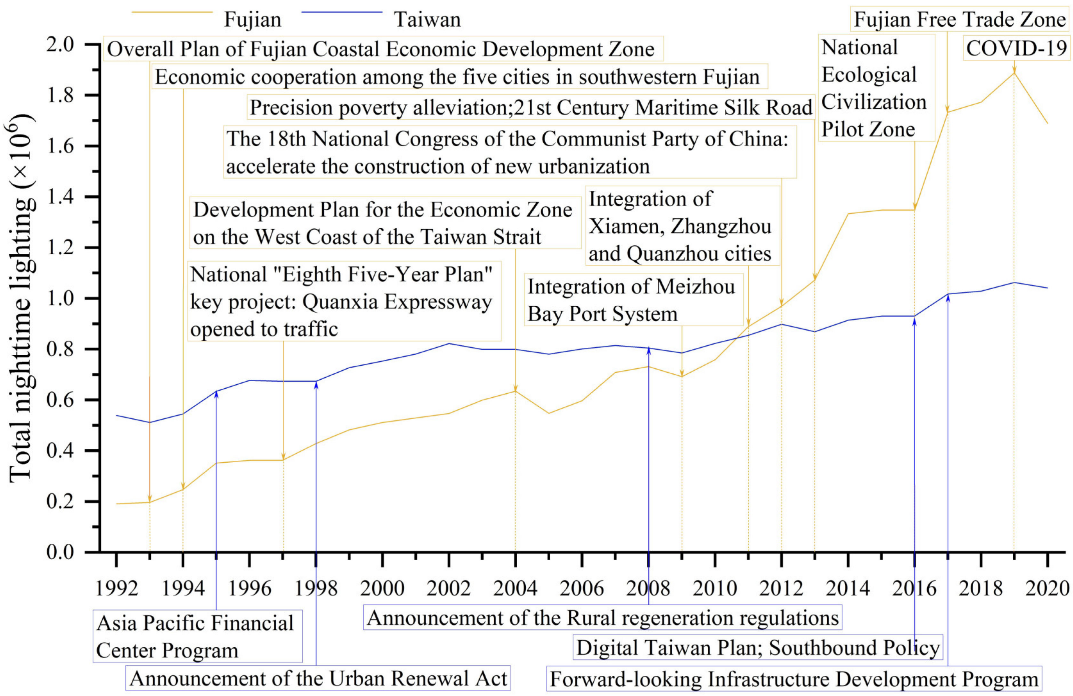

Figure 13. Trends in nighttime light data and associated urbanization policies from 1992 to 2020.

The characteristics of urbanization in the TSR are determined by a combination of factors, such as geographical location, natural resources, transportation infrastructure, population size, and industrial structure. Fujian is currently in a rapid urbanization phase, and the province has increased its investment in infrastructure construction and public services. It has also strengthened its management of urban planning and land use, leading to a steady growth of urbanization in Fujian Province at the beginning of the 21st century. The urbanization rate increased fourfold from 17.14% in 1992 to 68.76% in 2020 [101]. By contrast, Taiwan, situated across the sea, has already reached a mature stage of urbanization, with its urbanization rate experiencing a slight increase from 74.4% in 1990 to 78.9% in 2020 [102]. Owing to the enactment of a series of policies, Taiwan has circumvented the issues faced by many Latin American and Asian countries during their modernization processes, such as excessive metropolitan expansion leading to an influx of rural populations into cities and heightened social stratification. Taiwan has effectively averted the "big city disease" commonly observed in the urbanization processes of developing countries and regions, maintaining stable population growth and a moderate urban scale [103].

Although the two areas in the TSR are at distinct stages of urbanization, they share numerous similarities in terms of geographical location, natural conditions, and sociocultural aspects. Enhanced communication and cooperation between the two regions would facilitate the exchange of urban development experiences and practices, as well as the sharing of success stories. Fujian could draw upon Taiwan's advanced technologies and experiences in urban development, such as urban planning, environmental protection, and transportation management, and apply these insights to its own urbanization endeavors, thereby augmenting the province's comprehensive urban competitiveness.

While our study delves into the spatiotemporal characteristics of urbanization across the TSR, there are still some limitations. One of the important limitations is that we did not include the analysis of light pollution. Rapid urbanization often accompanies a swift rise in artificial light proportion [104]. In recent years, light pollution has escalated as the global proportion of nighttime artificial illumination has grown rapidly [105]. Artificial light can disrupt circadian rhythms, affect species counts or behaviors [106], and negatively impact human health through the suppression of melatonin production [107]. Although remote sensing of nighttime lights can play a key role in monitoring light pollution [108], spatial resolution limitations have prevented us from analyzing the urbanization trends in light pollution in our study. The data resolution we utilized was 30 arc-seconds (equivalent to about 1 km). This resolution may encapsulate numerous light sources and their corresponding light pollution within each data pixel. Although this level of spatial resolution suffices for some macro-level urbanization studies, it may pose constraints for nuanced light pollution analysis [109]. Therefore, data limitations prevented a detailed analysis within our study. We look forward to opportunities to access higher resolution nighttime light remote sensing data in the future so that light pollution analysis can be incorporated into the study of the spatiotemporal characteristics of urbanization across the TSR.

5. Conclusions

As the acceleration of economic globalization continues, the global urbanization system is undergoing an unprecedented transformation and reconstruction. This not only induces profound changes in regional economic structures and social lifestyles, but also accentuates the importance of comprehensively understanding the spatiotemporal characteristics of urbanization. The TSR, characterized by numerous similarities in geographical location, natural conditions, and social culture, as well as having experienced complex stages and patterns of urbanization, has emerged as a focal area for urbanization research. Fujian, currently in a stage of rapid urbanization, grapples with issues such as a low degree of urbanization and significant urban–rural disparities. In contrast, Taiwan's urbanization, fortified by its historical and cultural background and distinct geographical location, has advanced into a relatively developed stage, exhibiting characteristics of high urbanization levels and balanced regional development. Therefore, in the current context of "building a moderately prosperous society in all respect", it becomes an imperative research area to conduct long-term time series analysis to understand and summarize the evolution and laws of urbanization on both sides of the TSR. A comparison of the urbanization development characteristics of the two places can provide some reference for urbanization construction in mainland China. Simultaneously, this provides significant insights for sustainable urban development and future planning and construction on both sides of the TSR. Consequently, this paper utilized Theil–Sens median trend analysis models, Mann–Kendall significance test models, Hurst exponent, spatial statistics, and time series analyses, based on nearly 30 years of nighttime light data from 1992 to 2020. It comprehensively examined the spatial distribution patterns and temporal trends of nighttime light data in the TSR since 1992, as well as the analysis and prediction of future trends, reaching the following conclusions:

(1) From 1992 to 2020, the total nighttime brightness in various regions in the TSR increased to varying degrees. Spatially, coastal regions exhibited markedly higher nighttime brightness than inland areas. Additionally, Taiwan's overall nighttime brightness was noticeably greater than that of Fujian. In terms of development stages, Taiwan has reached a mature phase of urbanization, while Fujian remains in a stage of rapid urban development;
(2) Over the past 29 years, the total nighttime brightness in the TSR exhibited a rapid growth trend, increasing 3.7-fold. This process can be divided into three phases: a stable growth phase from 1992 to 2004, a fluctuating transition phase from 2004 to 2010, and a substantial growth phase from 2010 to 2020. As urbanization accelerated, the substantial growth period displayed a 1.99-fold increase over the fluctuating transition period. However, nighttime brightness exhibited minor fluctuations due to various natural disasters and pandemic influences;
(3) According to the trend analysis model, there was a significant increase in the brightness of nighttime light data in the coastal and inland areas of the TSR between 1992 and 2020. Notably, the coastal cities of Xiamen, Quanzhou, Zhangzhou, Fuzhou,

and Putian in Fujian showed a high and significant increase in brightness trend. In contrast, the overall change in brightness in the inland areas was relatively small, with a slower increase in trend;

(4) Utilizing the Hurst exponent model to predict future trends across the TSR, the study indicates that, due to the diffusion effect from traditionally developed cities, places in Taiwan such as Taoyuan, Tainan, and Yunlin are forecasted to display a marked growth trend in the future. On the other hand, the urbanization process in areas such as Keelung, Chiayi, Taipei, and Xinbei seems to have reached a stable stage, with a projected downward trend in the future. Simultaneously, influenced by the trend in urbanization cluster development, most regions in Xiamen, Fuzhou, Quanzhou, Zhangzhou, and Putian in Fujian are expected to demonstrate an increasing trend, while the future rising trend is expected to be lower in Nanping, Sanming, and Longyan in the interior of Fujian;

(5) From a comparative analysis of nighttime light data for representative cities in Taiwan and Fujian (Taipei, Hsinchu, Xiamen, Fuzhou), it is evident that, although Taiwanese cities displayed higher initial brightness, their growth rate was comparatively lower. Fujian cities, despite starting with lower brightness levels, demonstrated a higher growth rate. Further research revealed a consistency between the trend of change in nighttime light data and the patterns of variation in land cover and land use data.

In summary, an in-depth study of the spatiotemporal characteristics of urbanization in the TSR based on nighttime light data from 1992 to 2020 provides a powerful and effective tool for urban planners, policymakers, and environmental organizations. This not only enables them to deeply understand and predict the dynamic trends of urbanization, but also assists in accurately identifying areas of particular concern and devising targeted strategies for future urban development. This study provides guidance for seizing policy opportunities in urbanization development across the TSR, as well as maximizing the utilization of its unique resources and locational advantages. Simultaneously, by strengthening infrastructure construction and comprehensively planning and streamlining the development blueprint for the TSR, these regions' holistic development can be effectively propelled. In particular, by promoting urban–rural integration and further driving the full development of rural areas, balanced and sustainable progress in urbanization across the TSR can be realized. Therefore, the insights and strategic suggestions presented in this study for the development of urbanization across the TSR bear profound theoretical significance and practical value.

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References

1. Chen, M.; Lu, D.; Zhang, H. Comprehensive evaluation and the driving factors of China's urbanization. *Acta Geogr. Sin.* **2009**, *64*, 387–398.
2. Lu, M.; Chen, Z. Urbanization, Urban-Biased Economic Policies and Urban-Rural Inequality. *Econ. Res. J.* **2004**, *6*, 50–58.
3. Friedmann, J. Four theses in the study of China's urbanization. *Int. J. Urban Reg. Res.* **2006**, *30*, 440–451. [CrossRef]
4. Yun, G.; Zhao, S. The imprint of urbanization on PM2. 5 concentrations in China: The urban-rural gradient study. *Sustain. Cities Soc.* **2022**, *86*, 104103. [CrossRef]
5. Wang, H.; He, Q.; Liu, X.; Zhuang, Y.; Hong, S. Global urbanization research from 1991 to 2009: A systematic research review. *Landsc. Urban Plan.* **2012**, *104*, 299–309. [CrossRef]
6. Chen, M. Research progress and scientific issues in the field of urbanizatio. *Geogr. Res.* **2015**, *34*, 614–630.
7. Dewan, A.M.; Yamaguchi, Y. Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Appl. Geogr.* **2009**, *29*, 390–401. [CrossRef]
8. Wei, Y.D.; Ye, X. Urbanization, urban land expansion and environmental change in China. *Stoch. Environ. Res. Risk Assess.* **2014**, *28*, 757–765. [CrossRef]
9. Chan, R.C.; Shimou, Y. Urbanization and sustainable metropolitan development in China: Patterns, problems and prospects. *Geojournal* **1999**, *49*, 269–277. [CrossRef]
10. Antrop, M. Changing patterns in the urbanized countryside of Western Europe. *Landsc. Ecol.* **2000**, *15*, 257–270. [CrossRef]
11. Wang, X.S.; Liu, J.Y.; Zhuang, D.F.; Wang, L.M. Spatial-temporal changes of urban spatial morphology in China. *Acta Geogr. Sin.* **2005**, *60*, 392–400.
12. Yun, G.; He, Y.; Jiang, Y.; Dou, P.; Dai, S. PM2.5 spatiotemporal evolution and drivers in the Yangtze River Delta between 2005 and 2015. *Atmosphere* **2019**, *10*, 55. [CrossRef]
13. Xu, G.; Jiao, L.; Liu, J.; Shi, Z.; Zeng, C.; Liu, Y. Understanding urban expansion combining macro patterns and micro dynamics in three Southeast Asian megacities. *Sci. Total Environ.* **2019**, *660*, 375–383. [CrossRef] [PubMed]
14. Thuzar, M. Urbanization in Southeast Asia: Developing smart cities for the future? *Reg. Outlook* **2011**, *183*, 96–100.
15. Cui, J. *Oceanography*; China Youth Publishing Group: Beijing, China, 2012.
16. Wang, L.; Bi, J.; Meng, X.; Geng, G.; Huang, K.; Li, J.; Tang, L.; Liu, Y. Satellite-based assessment of the long-term efficacy of PM2.5 pollution control policies across the Taiwan Strait. *Remote Sens. Environ.* **2020**, *251*, 112067. [CrossRef]
17. Wu, Q.; Liu, S.; Chen, P.; Liu, M.; Cheng, S.; Ke, H.; Huang, P.; Ding, Y.; Cai, M. Microplastics in seawater and two sides of the Taiwan Strait: Reflection of the social-economic development. *Mar. Pollut. Bull.* **2021**, *169*, 112588. [CrossRef]
18. Tang, Y. Preliminary Study on the Development of Urbanization in Taiwan. *J. Chang. Univ.* **2011**, *21*, 10–13.
19. Chen, X. Comparison and Reflection on Urbanization Across the Taiwan Strait. *Glob. City Geogr.* **2017**, *12*, 6–8.
20. Luo, Z. Analysis of urbanization characteristics and influencing factors across the Taiwan Strait. *J. Fuzhou Univ.* **2011**, *25*, 128–132.
21. Qiu, R.; Wang, S.; Zhu, C. On Urbanization of Fujian Province. *J. Southwest Agric. Univ.* **2005**, *4*, 68–71.
22. Liu, S.; Jiang, F.; Zhang, Q. Regional Differences and Coordinated Development Strategies of Urbanization Development in China. *Popul. Res.* **2007**, *3*, 7–19.
23. Wang, J. Discrepancies of Social Development of Both Sides across the Taiwan Strait and Their Respective Counterstrategies. *Cross Taiwan Strait Stud.* **2014**, *1*, 29–39.
24. Chen, A. Urbanization in China and the Case of Fujian Province. *Mod. China* **2006**, *32*, 99–130. [CrossRef]
25. Liu, P. *Urbanization and Development: The Rural-Urban Transition in Taiwan*; Routledge: Oxfordshire, UK, 2019.
26. Li, Q. Comparative Research on the Balanced Development between Urban and Rural Areas across the Taiwan Strait. Ph.D. Thesis, Central China Normal University, Wuhan, China, 2015.
27. Zhang, F.; Shao, Y.; Huang, H.; Bahtebay, J. Review of urban remote sensing research in the last two decades. *Acta Ecol. Sin.* **2021**, *41*, 3255–3276.
28. Yun, G.; Zuo, S.; Dai, S.; Song, X.; Xu, C.; Liao, Y.; Zhao, P.; Chang, W.; Chen, Q.; Li, Y. Individual and interactive influences of anthropogenic and ecological factors on forest PM2. 5 concentrations at an urban scale. *Remote Sens.* **2018**, *10*, 521. [CrossRef]
29. Valjarević, A.; Djekić, T.; Stevanović, V.; Ivanović, R.; Jandziković, B. GIS numerical and remote sensing analyses of forest changes in the Toplica region for the period of 1953–2013. *Appl. Geogr.* **2018**, *92*, 131–139. [CrossRef]
30. Weng, Q. Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. *ISPRS J. Photogramm. Remote Sens.* **2009**, *64*, 335–344. [CrossRef]
31. Hänel, A.; Posch, T.; Ribas, S.J.; Aubé, M.; Duriscoe, D.; Jechow, A.; Kollath, Z.; Lolkema, D.E.; Moore, C.; Schmidt, N. Measuring night sky brightness: Methods and challenges. *J. Quant. Spectrosc. Radiat. Transfer.* **2018**, *205*, 278–290. [CrossRef]
32. Kyba, C.C.; Garz, S.; Kuechly, H.; De Miguel, A.S.; Zamorano, J.; Fischer, J.; Hölker, F. High-resolution imagery of earth at night: New sources, opportunities and challenges. *Remote Sens.* **2014**, *7*, 1–23. [CrossRef]
33. Levin, N.; Kyba, C.C.; Zhang, Q.; de Miguel, A.S.; Román, M.O.; Li, X.; Portnov, B.A.; Molthan, A.L.; Jechow, A.; Miller, S.D. Remote sensing of night lights: A review and an outlook for the future. *Remote Sens. Environ.* **2020**, *237*, 111443. [CrossRef]
34. Yu, B.; Wang, C.; Gong, W.; Chen, Z.; Shi, K.; Wu, B.; Hong, Y.; Li, Q.; Wu, J. Nighttime light remote sensing and urban studies: Data, methods, applications, and prospects. *J. Remote Sens.* **2021**, *25*, 342–364.
35. Doll, C.H.; Muller, J.; Elvidge, C.D. Night-time imagery as a tool for global mapping of socioeconomic parameters and greenhouse gas emissions. *Ambio A J. Hum. Environ.* **2000**, *29*, 157–162. [CrossRef]

36. Doll, C.N.; Muller, J.; Morley, J.G. Mapping regional economic activity from night-time light satellite imagery. *Ecol. Econ.* **2006**, *57*, 75–92. [CrossRef]
37. Small, C.; Elvidge, C.D.; Balk, D.; Montgomery, M. Spatial scaling of stable night lights. *Remote Sens. Environ.* **2011**, *115*, 269–280. [CrossRef]
38. Zhang, Q.; Seto, K.C. Mapping urbanization dynamics at regional and global scales using multi-temporal DMSP/OLS nighttime light data. *Remote Sens. Environ.* **2011**, *115*, 2320–2329. [CrossRef]
39. Stokes, E.C.; Seto, K.C. Characterizing urban infrastructural transitions for the Sustainable Development Goals using multi-temporal land, population, and nighttime light data. *Remote Sens. Environ.* **2019**, *234*, 111430. [CrossRef]
40. Zhu, Z.; Zhou, Y.; Seto, K.C.; Stokes, E.C.; Deng, C.; Pickett, S.T.; Taubenböck, H. Understanding an urbanizing planet: Strategic directions for remote sensing. *Remote Sens. Environ.* **2019**, *228*, 164–182. [CrossRef]
41. Chen, Z.; Yu, B.; Song, W.; Liu, H.; Wu, Q.; Shi, K.; Wu, J. A new approach for detecting urban centers and their spatial structure with nighttime light remote sensing. *IEEE Trans. Geosci. Remote Sens.* **2017**, *55*, 6305–6319. [CrossRef]
42. Wu, B.; Yang, C.; Wu, Q.; Wang, C.; Wu, J.; Yu, B. A building volume adjusted nighttime light index for characterizing the relationship between urban population and nighttime light intensity. *Comput. Environ. Urban Syst.* **2023**, *99*, 101911. [CrossRef]
43. Addison, D.M.; Stewart, B. Nighttime lights revisited: The use of nighttime lights data as a proxy for economic variables. In *World Bank Policy Research Working Paper*; World Bank: Washington, DC, USA, 2015.
44. Liu, J.; Li, W. A nighttime light imagery estimation of ethnic disparity in economic well-being in mainland China and Taiwan (2001–2013). *Eurasian Geogr. Econ.* **2014**, *55*, 691–714. [CrossRef]
45. Lu, C.; Li, L.; Lei, Y.; Ren, C.; Su, Y.; Huang, Y.; Chen, Y.; Lei, S.; Fu, W. Coupling coordination relationship between urban sprawl and urbanization quality in the West Taiwan Strait urban agglomeration, China: Observation and analysis from DMSP/OLS nighttime light imagery and panel data. *Remote Sens.* **2020**, *12*, 3217. [CrossRef]
46. Chen, T.K.; Prishchepov, A.V.; Fensholt, R.; Sabel, C.E. Detecting and monitoring long-term landslides in urbanized areas with nighttime light data and multi-seasonal Landsat imagery across Taiwan from 1998 to 2017. *Remote Sens. Environ.* **2019**, *225*, 317–327. [CrossRef]
47. Chai, C.; He, Y.; Yu, P.; Zheng, Y.; Chen, Z.; Fan, M.; Lin, Y. Spatiotemporal Evolution Characteristics of Urbanization in the Xiamen Special Economic Zone Based on Nighttime-Light Data from 1992 to 2020. *Land* **2022**, *11*, 1264. [CrossRef]
48. Nie, Y. Study on Spatial-Temporal Changes of Urban Built-Up Areas in Fujian Province Based on Multi-Source Data. Master's Thesis, Fujian Normal University, Fuzhou, China, 2019.
49. Fujian Provincial Statistical Yearbook 2021. Available online: http://tjj.fujian.gov.cn/tongjinianjian/dz2021/index.htm (accessed on 5 January 2022).
50. Taiwan's Ministry of the Interior's Department of Household Registration. Available online: https://www.ris.gov.tw/app/portal/674 (accessed on 5 January 2022).
51. Li, X.; Zhou, Y.; Zhao, M.; Zhao, X. A harmonized global nighttime light dataset 1992–2018. *Sci. Data* **2020**, *7*, 168. [CrossRef] [PubMed]
52. Yang, J.; Huang, X. The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. *Earth Syst. Sci. Data* **2021**, *13*, 3907–3925. [CrossRef]
53. Sen, P.K. Estimates of the regression coefficient based on Kendall's tau. *J. Am. Stat. Assoc.* **1968**, *63*, 1379–1389. [CrossRef]
54. Fensholt, R.; Langanke, T.; Rasmussen, K.; Reenberg, A.; Prince, S.D.; Tucker, C.; Scholes, R.J.; Le, Q.B.; Bondeau, A.; Eastman, R. Greenness in semi-arid areas across the globe 1981–2007—An Earth Observing Satellite based analysis of trends and drivers. *Remote Sens. Environ.* **2012**, *121*, 144–158. [CrossRef]
55. Kendall, M.G. *Rank Correlation Methods*; Hafner: London, UK, 1948.
56. Tošić, I. Spatial and temporal variability of winter and summer precipitation over Serbia and Montenegro. *Theor. Appl. Climatol.* **2004**, *77*, 47–56. [CrossRef]
57. Yun, G.; Yang, C.; Ge, S. Understanding Anthropogenic PM2.5 Concentrations and Their Drivers in China during 1998–2016. *Int. J. Environ. Res. Public Health* **2022**, *20*, 695. [CrossRef]
58. Hurst, H.E. Long-term storage capacity of reservoirs. *Trans. Am. Soc. Civ. Eng.* **1951**, *116*, 770–799. [CrossRef]
59. Tatli, H. Detecting persistence of meteorological drought via the Hurst exponent. *Meteorol. Appl.* **2015**, *22*, 763–769. [CrossRef]
60. Wang, Y.; Li, B.; Wang, R.; Su, J.; Rong, X. Application of the Hurst exponent in ecology. *Comput. Math. Appl.* **2011**, *61*, 2129–2131. [CrossRef]
61. García, M.D.L.N.; Requena, J.P.R. Different methodologies and uses of the Hurst exponent in econophysics. *Stud. Appl. Econ.* **2019**, *37*, 96–108. [CrossRef]
62. Zhu, Z.; Luo, D. The spatiotemporal differences and evolution trends of urbanization level in Fujian Province. *Co Oper. Econ. Sci.* **2014**, *8*, 4–6.
63. Zhang, Y. After 28 Years of Three-Dimensional Railway Construction in the Greater Taipei Area. Available online: http://www.taihainet.com/news/twnews/twsh/2011-10-22/763375.html (accessed on 5 January 2022).
64. Wei, R. The Experience on Developing Urban Cultural Industry in Taibei. *Asia Pac. Econ. Rev.* **2010**, *3*, 122–126.
65. Wang, Y. Analysis on the Characteristics of Urbanization Development in the Greater Taipei Region. *Mod. Taiwan Stud.* **2017**, *6*, 46–51.

66. Lee, W.; Yang, W. The cradle of Taiwan high technology industry development—Hsinchu Science Park (HSP). *Technovation* **2000**, *20*, 55–59. [CrossRef]
67. Ren, J. Investigation of the Green Space Landscape in Chiayi, Taiwan. Master' Thesis, Northwest A&F University, Xianyang, China, 2016.
68. Sheng, J. The Study of the Interaction of Taiwan's Urbanization and its Economic Development. *World Econ. Study* **2009**, *7*, 81–86.
69. Zheng, W.; Chen, G. Development ideas of urbanization in Fujian. *Dev. Res.* **2005**, *6*, 53–55.
70. Cao, W.; Su, B. Study on the Status, Problems and Countermeasures of Port Resource Integration in Fujian. *J. Tonghua Norm. Univ.* **2018**, *39*, 58–65.
71. Tang, Y. The Advantages and Functions of Xiamen Special Economic Zone in Improving Cross-straits Relations: Review & Rethinking. *Taiwan Res. Q.* **2007**, *3*, 63–71.
72. Wei, Z. Xiangyu Free Trade Zone Leverages the Investment Fair Platform to Boost Wine Enterprise Development. *Port Econ.* **2014**, *10*, 52.
73. Cao, W.; Wu, J. Research in Urban Traffic Strategy Planning on the Background of Xiamen Special Economic Zones Dilatation to City Wide. *Urban Dev. Stud.* **2011**, *18*, 108–114.
74. Zhan, S. BRIC summit and Xiamen international fan urban environmental improvement. *Sci. Manag. Res.* **2017**, *35*, 114–116.
75. Dong, R. Fuzhou Municipal Party Committee Secretary Xi Jinping on: Minjiangkou Golden Triangle Economic Circle Development Strategy. *Outlook* **1993**, *16*, 17–18.
76. Zhang, Y.; Xiong, L. 2011 China Fuzhou International Investment Promotion Month and the Third Strait Science and Technology Achievement Fair was successfully held. *China Mark.* **2001**, *7*, 67.
77. Xiao, L.; Li, Z.; Liu, M. Research on Strait International Convention and Exhibition Center and Fuzhou's Economy from the Perspectives of Influence, Development and Prospect. *Trade Fair Econ.* **2022**, *2*, 12–14.
78. Wu, Y.; Wu, Z.; Cai, H. Quanzhou Explores the Way for "Financial Reform". *Faren Mag.* **2013**, *9*, 35–37.
79. Vigorously, O.R. The "Golden Bridge Project" to serve the "Two Pioneers" in Haixi. *Fujian Science and Technology Daily*, 2008.
80. Lin, S.; Wang, X.; Wu, X.; Jiang, Q. Quality measurenment of urbanization and improvement path of the coastal economic belt in Fujian province. *J. Guizhou Norm. Univ.* **2016**, *34*, 10–16.
81. Sheng, J. The Discriminate of Taiwan's Experience and Flaw in Urbanization Development Process. *Taiwan Res. J.* **2010**, *5*, 57–63.
82. Wang, M.; Derudder, B.; Liu, X. Polycentric urban development and economic productivity in China: A multiscalar analysis. *Environ. Plan. A* **2019**, *51*, 1622–1643. [CrossRef]
83. Guo, Q.; He, Z.; Li, D.; Marcin, S. Analysis of Spatial Patterns and Socioeconomic Activities of Urbanized Rural Areas in Fujian Province, China. *Land* **2022**, *11*, 969. [CrossRef]
84. Xiang, W. Procedures, Patterns and Trends of Development in Taiwan's Rural Areas. *Taiwan Stud.* **2021**, *4*, 80–87.
85. Shi, F. Cross-Straits Perspective for Reviewing Transformation of Taiwan's Regional Economy. *Taiwan Res. Q.* **2004**, *4*, 55–60.
86. Council, T.S. The State Council on the further opening of Fujian Province to the outside world of the issue of approval. *Gaz. State Counc. People's Repub. China* **1993**, *2*, 69–70.
87. Lin, S. Five Cities in Southwest Fujian Continue to Strengthen Regional Cooperation. *Fujian Daily*, 2007.
88. Cao, X. Background and Prospects of Taiwan's "Asia Pacific Operations Center Plan". *Taiwan Stud.* **1996**, *4*, 43–49.
89. Yang, P. Economic development in the west of Taiwan strait looks forward to direct maritime transport between Taiwan and Mainland. *China Ship Surv.* **2006**, *7*, 48–51.
90. Liu, J. Meizhou Bay port integration launched. *Meizhou Daily*, 2009.
91. Li, B. Analysis of the mode of developing enclave economy in the same city of Xiamen-Zhangzhou-Quan. *Spec. Zone Econ.* **2012**, *11*, 17–19.
92. Zhu, S. The Research on Spatial Development Strategies of Fupuning. Master's Thesis, Beijing Forestry University, Beijing, China, 2014.
93. Xu, Y. Some Countermeasures to Accelerate the Development of New Urbanization in Fujian. *China Circ. Econ.* **2013**, *20*, 11.
94. Tao, J.; Liu, S.; Liu, Y.; Sun, Y. Fujian Experience in Precise Poverty Alleviation and Poverty Eradication. *People's Trib.* **2017**, *18*, 102–106.
95. Wu, C. Analysis on Advantages and Countermeasures of Fujian's Integrating into the Strategy "21st Century Marine Silk Road". *Asia Pac. Econ. Rev.* **2014**, *6*, 109–113.
96. Zhang, H.; Huang, M. Analysis on the Integrated Development between Fujian Pilot Free Trade Zone and the Core Area of 21st Century Maritime Silk Road. *J. Fujian Norm. Univ.* **2015**, *4*, 1–7.
97. Liu, X. Comments on Tsai Ing-wen's "New Southward Policy". *Taiwan Stud.* **2015**, *6*, 23–32.
98. Zeng, B. Evaluation of China's Provincial Economic Resilience Under the Impact of COVID-19 Epidemic. *J. Ind. Technol. Econ.* **2021**, *40*, 127–133.
99. Elvidge, C.D.; Ghosh, T.; Hsu, F.; Zhizhin, M.; Bazilian, M. The dimming of lights in China during the COVID-19 pandemic. *Remote Sens.* **2020**, *12*, 2851. [CrossRef]
100. Xu, G.; Xiu, T.; Li, X.; Liang, X.; Jiao, L. Lockdown induced night-time light dynamics during the COVID-19 epidemic in global megacities. *Int. J. Appl. Earth Obs. Geoinf.* **2021**, *102*, 102421. [CrossRef]
101. Chen, Y. "Creating" a more beautiful city. *Strait Commun.* **2020**, *1*, 50–51.
102. Tang, Y. *Study of Taiwan's Urbanization and Its Mechanism: An Empirical Analysis Based on Spatial Econometrics*; Zhejiang University Press: Hangzhou, China, 2011.

103. Lin, Z. Taiwan's Urbanization Development Experience and Implications for the Mainland. *Fujian Financ.* **2014**, *8*, 22–26.
104. Green, J.; Perkins, C.; Steinbach, R.; Edwards, P. Reduced street lighting at night and health: A rapid appraisal of public views in England and Wales. *Health Place* **2015**, *34*, 171–180. [CrossRef]
105. Cinzano, P.; Falchi, F.; Elvidge, C.D. The first World Atlas of the artificial night sky brightness. *Mon. Not. R. Astron. Soc.* **2001**, *328*, 689–707. [CrossRef]
106. Hölker, F.; Wolter, C.; Perkin, E.K.; Tockner, K. Light pollution as a biodiversity threat. *Trends Ecol. Evol.* **2010**, *25*, 681–682. [CrossRef] [PubMed]
107. Kumar, P.; Ashawat, M.S.; Pandit, V.; Sharma, D.K. Artificial Light Pollution at Night: A risk for normal circadian rhythm and physiological functions in humans. *Curr. Environ. Eng.* **2019**, *6*, 111–125. [CrossRef]
108. Bennie, J.; Duffy, J.P.; Davies, T.W.; Correa-Cano, M.E.; Gaston, K.J. Global trends in exposure to light pollution in natural terrestrial ecosystems. *Remote Sens.* **2015**, *7*, 2715–2730. [CrossRef]
109. Li, J.; Xu, Y.; Cui, W.; Wu, Y.; Wang, J.; Su, B.; Ji, M. Monitoring of nighttime light pollution in Nanjing City based on Luoia 1-01 remote sensing data. *Remote Sens. Nat. Resour.* **2022**, *34*, 7.