GeoHealth

RESEARCH ARTICLE
10.1029/2024GH001034

Key Points:
- Nighttime light in the central area of Zhengzhou decreased by at least 18%
- The reduction in nighttime light was observed within a 15-km radius of the central area
- Lockdown measures significantly impacted economic activities in Zhengzhou

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Citation:
Jiang, L., & Liu, Y. (2024). Spatiotemporal dynamics of COVID-19 pandemic city lockdown: Insights from nighttime light remote sensing. *GeoHealth*, *8*, e2024GH001034. https://doi.org/10.1029/2024GH001034

Received 19 FEB 2024
Accepted 28 MAY 2024

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Spatiotemporal Dynamics of COVID-19 Pandemic City Lockdown: Insights From Nighttime Light Remote Sensing

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Abstract The global COVID-19 outbreak severely hampered the growth of the global economy, prompting the implementation of the strictest prevention policies in China. Establishing a significant relationship between changes in nighttime light and COVID-19 lockdowns from a geospatial perspective is essential. In light of nighttime light remote sensing, we evaluated the spatiotemporal dynamic effects of COVID-19 city lockdowns on human activity intensity in the Zhengzhou region. Prior to the COVID-19 outbreak, nighttime light in the Zhengzhou region maintained a significant growth trend, even under regular control measures. However, following the October 2022 COVID-19 lockdown, nighttime light experienced a substantial decrease. In the central area of Zhengzhou, nighttime light decreased by at least 18% compared to pre-lockdown levels, while in the sub-center, the decrease was around 14%. The areas where nighttime light decreased the most in the central region were primarily within a 15 km radius, while in the sub-center, the decrease was concentrated within a 5 km radius. These changes in both statistical data and nighttime light underscored the significant impact of the COVID-19 lockdown on economic activities in the Zhengzhou region.

Plain Language Summary China implemented some of the strictest COVID-19 control measures globally, yet research on large-scale city lockdowns in China remains limited. Zhengzhou, being one of China's major cities with stringent control measures and a global hub for electronic goods processing and production, has seen significant impacts on the global electronic goods supply chain due to these measures. Our research offers a new approach to assessing the impact of pandemic transmission in urban systems, providing valuable insights from a geographic spatial perspective. The utilization of nighttime light data highlights how computer-based data analysis enhances our understanding of the spatial scope and dynamics of large-scale pandemics in urban areas.

1. Introduction

Since the emergence of Severe Acute Respiratory Syndrome (SARS) in 2003, Corona Virus Disease 2019 (COVID-19) has evolved into the most perilous global pandemic (Deng et al., 2022; Y. Zhang et al., 2022). COVID-19 exhibits a wider transmission, a prolonged duration of spread, and a greater geographical reach compared to previous public health crises. Its global outbreak has significantly impeded the growth of the world economy, leading to escalated losses for numerous nations and corporations (Bi, 2023; Zhao et al., 2022). Consequently, the imperative of controlling and preventing pandemics has ascended to the forefront, prompting some nations to initiate Level I responses to major public health catastrophes (Cai & Mason, 2022; Wu et al., 2023).

The first case of COVID-19 in China was identified in Wuhan in December 2019. Within a mere two months, the virus spread rapidly across the nation, affecting 31 of China's provincial administrative regions (Z. Zhang et al., 2023). The pandemic's propagation, exacerbated by significant periods of population mobility such as the Spring Festival, has compounded its adverse effects on economic growth. The Chinese government has implemented stringent prevention and control measures, effectively curbing the spread of COVID-19. Since 29 April 2020, China's pandemic prevention and control efforts have reverted to a state of normalcy, with sporadic and localized outbreaks being the general experience.

An essential area of research concerning abrupt public safety crises is the evaluation of pandemic management impacts (Abid et al., 2022; Alalawi et al., 2022; Murugesan et al., 2022). Effective assessment of pandemic management effects is critical for post-pandemic economic recovery and growth. A frequently employed technique for evaluating the impact of pandemic management across various dimensions is the utilization of statistical data. Many scholars conduct research on pandemics utilizing statistical data for geographic analysis (Filonchyk et al., 2021; Mărgărint et al., 2023; Masters et al., 2022), establishing evaluation criteria (Wen et al., 2022), analyzing variations in pandemic transmission (Ning et al., 2023), elucidating diverse control strategies (F. Guo et al., 2022), scrutinizing the spatiotemporal progression of the pandemic (Gaisie et al., 2022), and delineating the spatiotemporal pattern (Wadhwa & Thakur, 2022). However, statistical data may lag due to limitations within the statistical system, and simultaneously, the representativeness or accessibility of the data may be inadequate.

As a globally standardized measure of nocturnal observation, nighttime light data uniquely delineates the level of regional economic activity (Louw et al., 2022), thereby mitigating the influence of regional disparities. Methods based on nighttime light remote sensing data can compensate for the deficiencies of conventional socioeconomic census techniques. Globally, varying degrees of nighttime light reduction in urban areas following city closures have been observed (Rowe et al., 2022; G. Xu et al., 2022). As a consequence of statewide travel restrictions implemented early in 2020, 82% of residential areas experienced diminished lighting, while 87% of the Indian population encountered reduced light due to lockdown measures (Elvidge et al., 2020; Ghosh et al., 2020). In Africa's natural reserves, which represent tourist economic zones, 75% experienced a decrease in nocturnal light intensity due to the COVID-19 pandemic (Anand & Kim, 2021; G. Li et al., 2023; Y. Li et al., 2023). Nighttime light data has been extensively utilized across various domains, including the estimation of statistical indicators, urbanization, energy consumption, ecological environment, economic development, and the analysis of natural disasters and conflicts (Argentiero et al., 2021; Z. Wang et al., 2021; Zheng et al., 2022).

Some studies have utilized nighttime lighting data to evaluate the impact of pandemic disasters. For instance, nighttime lighting data has been employed to analyze the effects of the “closure” policy (Miller et al., 2021), the temporal and spatial progression of confirmed cases (G. Xu et al., 2021), monthly fluctuations in nocturnal illumination (Beyer et al., 2023), the repercussions on human life and the natural environment (Jamei et al., 2022), the influence on economic activities (Roberts, 2021), power consumption (Rowe et al., 2022), and energy usage (Beyer et al., 2021; Çelik et al., 2022; Yu et al., 2022). However, current research has yet to thoroughly investigate the sudden, widespread, and stringent lockdowns implemented during the pandemic. This study aims to address this scientific gap by exploring the impact of public health policies (COVID-19 lockdowns) on nocturnal light alterations, which diverges from previous methodologies in the health field.

Consequently, our research focused on four main aspects: (a) Examining the spatiotemporal alterations in Zhengzhou's nighttime illumination from September to October 2022; (b) Investigating natural variations in nighttime light prior to the COVID-19 outbreak; (c) Comparing variations in nighttime light before and after the onset of the COVID-19 pandemic; (d) Analyzing the spatial gradients of nighttime light variation. The innovation of our study lies in offering a novel approach to assessing the impact of pandemic transmission in urban systems, with a geographic spatial perspective. Utilizing nighttime light data demonstrated how computer-based data analysis enhances comprehension of the spatial extent and dynamics of large-scale pandemics in urban areas.

2. Materials and Methods

2.1. Study Area

Zhengzhou, a major transportation hub in China, is centrally located within the country (Figure 1). Encompassing a total area of 7,567 km^2 (G. Li et al., 2023; Y. Li et al., 2023), Zhengzhou comprises six districts, five county-level cities, and one county: Zhongyuan District (ZYD), Erqi District (EQD), Guancheng District (GCD), Jinshui District (JSD), Shangjie District (SJD), Huiji District (HJD), Gongyi City (GYC), Xingyang City (XYC), Xinmi City (XMC), Xinzheng City (XZC), Dengfeng City (DFC), and Zhongmu County (ZMC). By the end of 2022, Zhengzhou's permanent population exceeded 12.828 million (G. Li et al., 2023; Y. Li et al., 2023). In 2022, Zhengzhou's Gross Domestic Product (GDP) reached 1293.47 trillion yuan (J. Guo et al., 2024), ranking it 16th among China's urban GDPs. Over the past decade, Zhengzhou's growth has been closely linked to the electronic information industrial chain, with Xinzheng Airport Area (XZA) serving as the world's largest iPhone processing base, responsible for 50% of Apple's total production.

China initiated COVID-19 control measures on 19 January 2020, imposing temporary home quarantines for its citizens (Deng et al., 2022). Through measures such as border closures, nucleic acid testing, and health green codes, China effectively contained the spread of COVID-19. Presently, domestic travel within China is permitted under “Regular prevention and control” practices. However, after 2022, with the variation of COVID-19

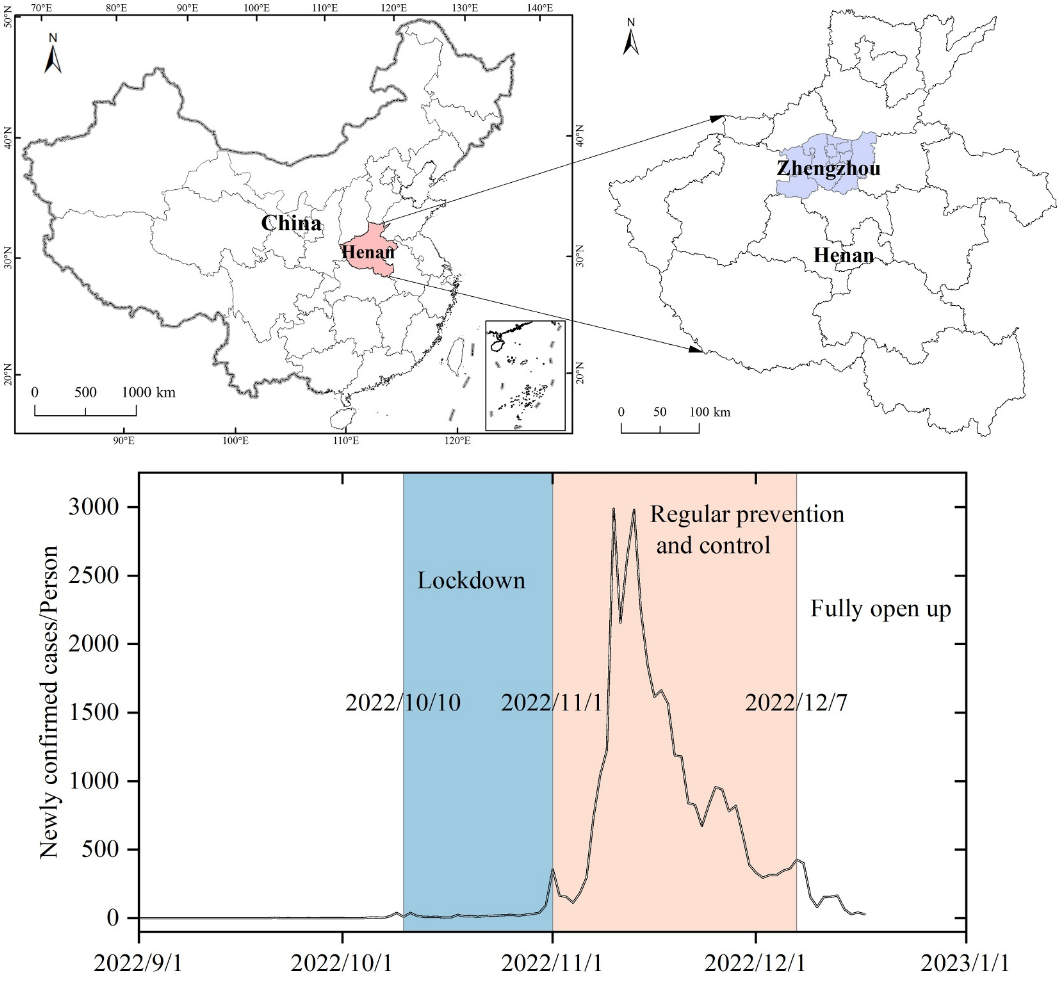

Figure 1. Location of Zhengzhou in China and situation of newly confirmed cases. Lockdown refers to imposing strict restrictions on social activities and public spaces; Regular prevention and control refers to basically restoring normal life and work while taking protective measures (normal nucleic acid test and health codes).

(Omicron virus), the infectivity and transmission range rapidly increase. Certain major cities, including Zhengzhou, have experienced significant COVID-19 outbreaks. In response, local governments have implemented strict restrictions on residents' movements, referred to as "Lockdown." Zhengzhou witnessed varying degrees of pandemic transmission in January, May, and October 2022, with the most severe outbreak occurring in October, resulting in a lockdown lasting over a month. On 4 October 2022, the pandemic was initiated by truck drivers from other areas, subsequently spreading through various channels, including train stations, hospitals, and schools. Strict control measures were implemented in Zhengzhou on 10 October 2022 (Figure 1), with the entire region returning to normalcy on 1 November 2022, restoring orderly production and daily life. Notably, during the Zhengzhou pandemic, Foxconn employees from the main factory at Xinzheng Airport returned home on foot.

2.2. Materials

There are two primary types of frequently used night light remote sensing data: the first is the night-time light data captured by the US Military Meteorological Satellite (DMSP), which suffers from low spatial resolution and oversaturation; the second is provided by the Suomi National Polar Orbiting Partnership Satellite (SUOMI-NPP), which offers a spatial resolution of 500 m and a broader range of radiation detection and onboard calibration. In April 2012, the National Oceanic and Atmospheric Administration released the night light data, resolving the issue of oversaturated pixel DN (Digital Number) values in metropolitan centers. We obtained monthly night-time light data for September and October from 2019 to 2022 from the EOG Group's official website, hosted by the Colorado School of Mines in the US (https://eogdata.mines.edu/products/vnl/). We selected the VIIRS Cloud Mask (VCM) version data, which is immune to the influence of stray light. The raw data from NPP-VIIRS uses the WGS-1984 coordinate system, which may result in image size reduction as latitude increases. Therefore, all NPP-VIIRS image data are processed using the Alberts Equal Area Projection to mitigate image area distortion and simplify area computation. The Resource and Environmental Science and Data Center of the Chinese Academy of Sciences indicates that administrative division data in China primarily consists of provinces, cities, and counties.

2.3. Methods

2.3.1. COVID-19 Lockdown and Night-Time Light Changes

To demonstrate the correlation between night light changes and the COVID-19 lockdown, we first collected and calculated the daily average night light and the number of newly confirmed cases in September and October 2022. We analyzed the trend changes and calculated the correlation coefficient using Spearman's rank correlation. Second, we gathered spatial distribution data sets of major air pollutants (CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}) (Wei et al., 2023), analyzed the trends from September to October 2022, and further examined whether there were co-benefits of changes in major air pollutants.

2.3.2. Calculation of Night-Time Light Indicators

1. Intuitive representations of the effect of urban night-time light radiation include the Sum of Night-time Light Radiation (SNLR) and Average of Night-time Light Radiation (ANLR) (Jiang & Liu, 2023).

$$\mathrm{SNLR} = \sum_{i}^{n} \mathrm{DN}_i \tag{1}$$

$$\mathrm{ANLR} = \frac{\mathrm{SNLR}}{n} \tag{2}$$

DN_i represents the DN value of the *i*th pixel, and n is the total number of pixel values in the study area.

2. The Effect of Night-time Light Radiation (ENLR) and Difference of Night-time Light Radiation (DNLR) are metrics used to assess the impact of pandemic control on cities.

$$\mathrm{DNLR} = \mathrm{ANLR}_j - \mathrm{ANLR}_r \tag{3}$$

$$\mathrm{ENLR} = \mathrm{DNLR}_{2022} - \mathrm{DNLR}_{2019,2020,2021} \tag{4}$$

The formula represents the monthly DNLR, where j and r represent various months, and ENLR is the difference in DNLR between 2022 and 2019, 2020, and 2021. An ENLR < 0 indicates a negative impact of pandemic control on night-time light changes, while an ENLR > 0 suggests a beneficial impact of pandemic control on night-time light variations. A higher ENLR indicates a more severe impact. In line with the control period in October 2022, there was no significant COVID-19 pandemic in October 2019. The years 2020 and 2021 can be considered as the regular control period (Figure 2).

2.3.3. Analysis of Night-Time Light

1. Initially, we analyzed the changes in night-time light during the COVID-19 lockdown period, followed by an analysis of the changes during the same timeframe before the COVID-19 pandemic outbreak. Subsequently, we addressed the years 2020 and 2021, post-COVID-19 outbreak, but not subjected to the strictest control measures (Regular control). Lastly, we accounted for natural variations in monthly night-time lights by constructing the ENLR to mitigate the influence of these fluctuations.
2. Employing buffer zones with 1-km rings, we examined the relationship between night-time light changes and the distance from the city center. We segmented the counties in the Zhengzhou region into centers and sub-centers, analyzed the night-time light gradient changes in each county, and compared the trends observed in 2022 to those in 2019, 2020, and 2021.

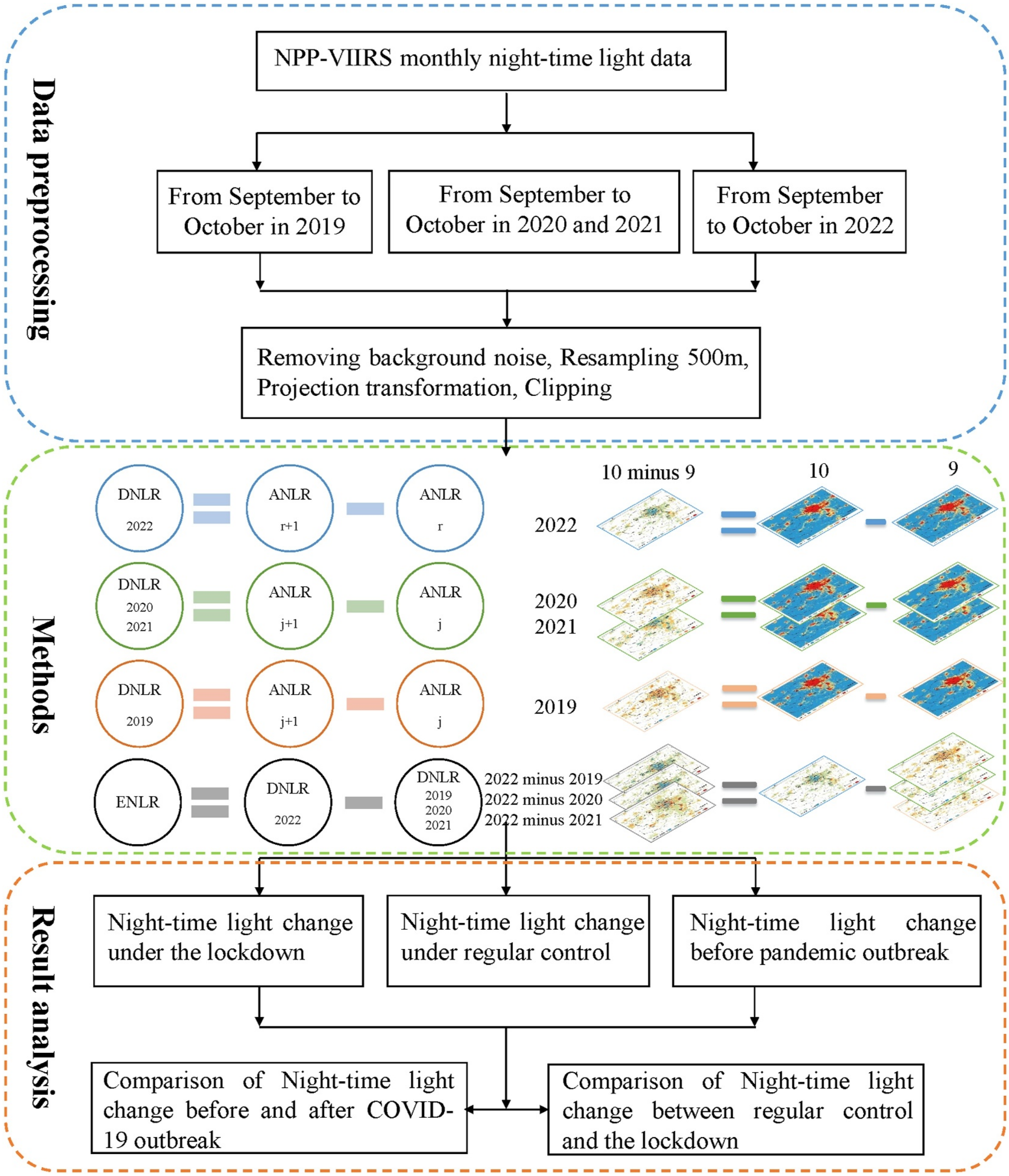

Figure 2. Workflow of this study.

3. The industrial park most impacted by the pandemic was Foxconn Zhengzhou Industrial Park (hereafter referred to as "Foxconn"), also Apple's largest manufacturing facility. The early release of new iPhone models in October significantly influenced production capacity.

3. Results

3.1. Relationship Between Night-Time Light and COVID-19 Lockdown

In Figure 3a, the daily fluctuations of night-time lights and newly confirmed COVID-19 cases are depicted. Prior to a notable surge in newly confirmed cases, decisive measures were taken in the Zhengzhou region to enforce city closures. During the stringent lockdown period, there was a significant decrease in average night-time light ($P < 0.05$), attributed to citizens adhering to pandemic prevention policies and reducing nonessential production activities. Concurrently, the number of newly confirmed cases saw a significant increase ($P < 0.05$). A

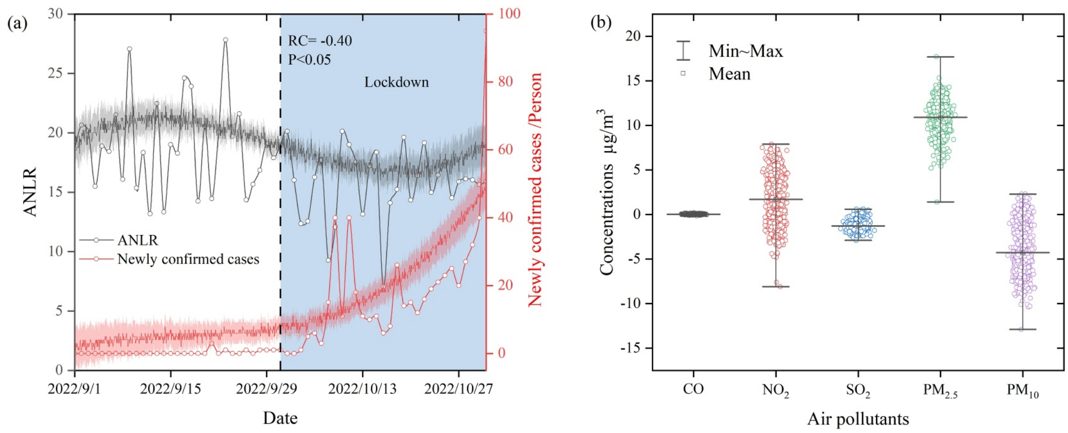

Figure 3. Spillover effects of COVID-19 pandemic during lockdown and unlockdown: (a) Change trend of night light and COVID-19 newly confirmed cases; (b) Change trends of major air pollutants: CO, NO_2, SO_2, $PM_{2.5}$, and PM_{10}. RC represents the related coefficient.

noteworthy negative correlation was observed between night-time light and newly confirmed cases (RC = −0.40, $P < 0.05$), indicating a substantial spillover effect of COVID-19.

Figure 3b illustrates the trend of major air pollutants in the Zhengzhou region. The changes before and after the lockdown (from September to October 2022) indicate stable concentrations of CO, increasing concentrations of NO_2 and $PM_{2.5}$ (average concentration increases of 2 and 10 μg/m^3, respectively), and decreasing concentrations of SO_2 and PM_{10} (average concentration decreases of 2 and 5 μg/m^3, respectively). This disparate trend in main air pollutants suggests that the reduction in night light intensity is not attributable to a synergistic effect with the reduction in air pollutant concentration but rather to the strict control of COVID-19.

3.2. Spatiotemporal Variation of Night-Time Light

3.2.1. Under Lockdown

During October 2022, Zhengzhou implemented stringent pandemic control policies, marking the period of greatest impact on social and economic activities. As depicted in Figure 4d, the DNLR notably decreased ($p < 0.01$) when strict control measures were enforced in the Zhengzhou region in October 2022. From a district-specific perspective, strict control commenced in October, with central districts of Zhengzhou (EQD, JSD, ZYD, HJD, and GCD) experiencing the greatest impact, while surrounding urban districts had relatively minor impacts (SJD, GYC, XYC, XMC, XZC, DFC, and ZMC). DNLR ranged from high to low in JSD, GCD, ZYD, EQD, HJD, SJD, XZD, ZMC, XMC, XYC, GYC, and DFC, with variations ranging from −7 to −0.1 (Figure 5d). Notably, three regions consistently exhibited high brightness, identified as the Huis resettlement region in GCD, the Longzihu University City at the junction of JSD and ZMC, and the airport in XZC, confirmed through high-resolution image comparison.

3.2.2. Under Regular Control

Figures 4b and 4c depict distinct trends for 2020 and 2021 under regular control. From September to October 2020, nocturnal light in the Zhengzhou region exhibited a significant increase ($p < 0.01$, DNLR of all urban districts exceeded 0), whereas from September to October 2021, there was a notable decrease in nocturnal light ($p < 0.01$, DNLR of all urban districts was below 0). The differing outcomes can be attributed to the widening spread of the pandemic and the gradual strengthening of preventive measures during the middle and later stages of regular control. However, the control measures in 2021 had not yet reached their strictest phase. From a district-specific perspective, the majority of districts witnessed an increase in nocturnal light from September to October 2020. The DNLR order, from largest to smallest, was ZYD, JSD, GCD, EQD, HJD, XZC, SJD, ZMC, XMC, XYC, GYC, and DFC, with a range of variation from 0.2 to 5.0. Conversely, from September to October 2021, the majority of districts experienced a decrease in nocturnal light radiation, with DNLR ranking from smallest to

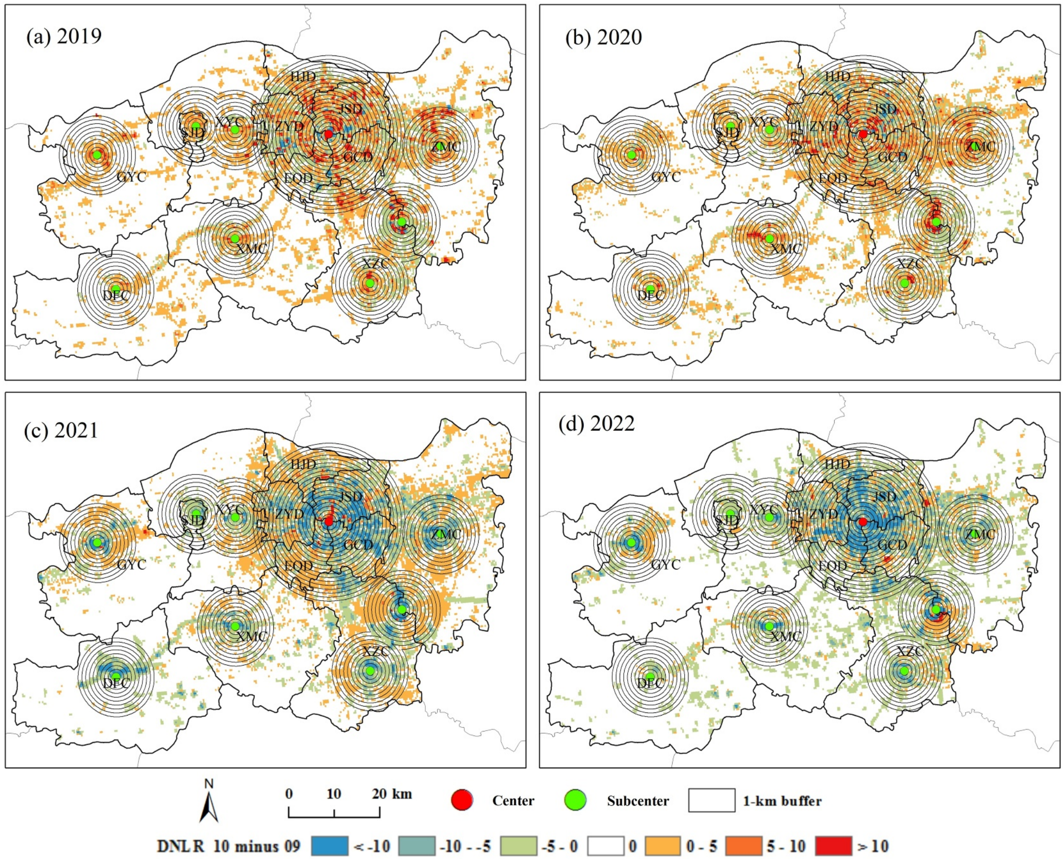

Figure 4. Spatiotemporal distribution of DNLR in Zhengzhou region from September to October. (a) 2019, (b) 2020, (c) 2021, and (d) 2022. DNLR were calculated in a series of 1-km buffer rings with concentric ring analysis.

largest in GCD, JSD, ZYD, SJD, EQD, XZC, HJD, ZMC, XYC, GYC, DFC, and XMC, ranging from −0.1 to −7 (Figures 5b and 5c).

3.2.3. Before COVID-19 Pandemic Outbreak

Figure 4a illustrates that the pixel increase in nocturnal light in Zhengzhou from September to October 2019 was overwhelmingly dominant ($p < 0.01$, DNLR in all districts exceeded 0), with the industrial park and central urban districts being the primary locations of this increase before the widespread outbreak of the COVID-19 pandemic. From a district-specific standpoint, the majority of districts experienced an increase in nocturnal light from September to October 2019 (DNLR with a range of variation from 0.1 to 5.2) (Figure 5a). The upper limit and number of DNLR positive extreme values in 2019 are notably larger than those in 2020, 2021, and 2022, while the lower limit and number of DNLR negative extreme values are considerably smaller. The positive DNLR values in ZYD, JSD, GCD, EQD, and XZC were mostly above 30, whereas the negative extreme values were mostly below −30. The positive DNLR values in the surrounding counties were primarily above 10, while the negative extreme values were mostly below −10. This indicates that in certain urban core regions, the economy was relatively active under normal conditions.

3.3. Comparative Analysis of Night-Time Light Variation

3.3.1. Before and After COVID-19 Pandemic Outbreak

Figures 6a and 7a demonstrate that even after accounting for natural changes, the pandemic lockdown in Zhengzhou significantly impacted nocturnal light in various urban regions. Compared to changes in 2019, nocturnal light in 2022 exhibited a predominantly negative trend. The ENLR in all districts was negative, with a range of variation from −7.9 to −0.2. While the nocturnal light changes from September to October in 2019 were

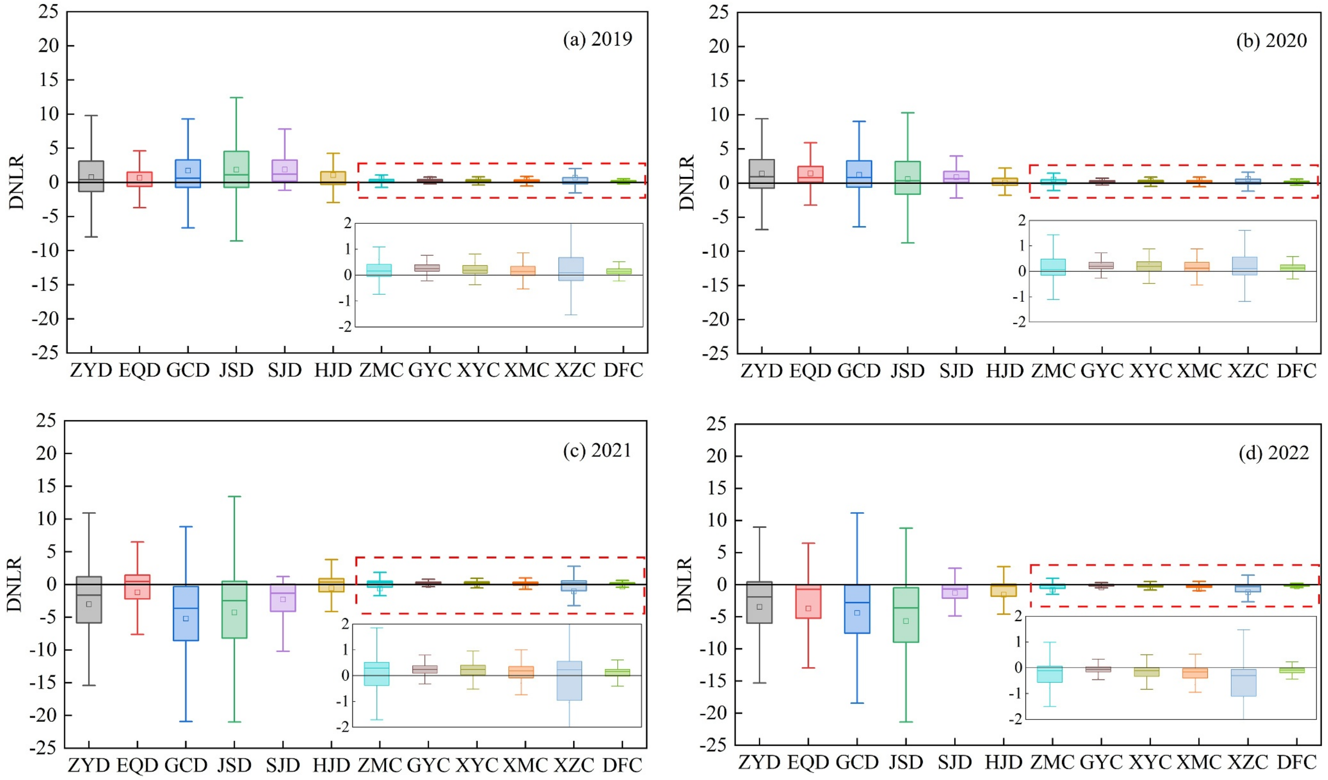

Figure 5. DNLR statistics in different counties in Zhengzhou region from September to October: (a) 2019, (b) 2020, (c) 2021, and (d) 2022.

relatively minor, those in 2022 far surpassed them. Although some regions of Zhengzhou also experienced decreases in nocturnal light under normal circumstances, the extent and intensity of nocturnal light reduction were notably less extensive than during the pandemic lockdown. In comparison to October 2019 before the epidemic, nocturnal light in the city center of Zhengzhou decreased by at least 18%, and in surrounding counties, it decreased by at least 14% during the October 2022 lockdown period.

3.3.2. Lockdown and Regular Control

Figures 6b and 7b reveal that in comparison to October 2020, the fluctuations in nocturnal light remained consistent in 2022, albeit with a notably higher decrease area than increase area. Across all districts, a declining nocturnal light trend was observed (with ENLR variation ranging from −8.1 to −0.1). The intensity of pandemic control in 2022 surpassed that of 2020 significantly. During the October 2022 lockdown period, the nocturnal light in Zhengzhou's city center decreased by at least 16%, while that in surrounding counties dropped by a minimum of 18%. Similarly, compared to October 2021, the nocturnal light patterns in 2022 displayed a consistency in increase and decrease, though the decrease area slightly outweighed the increase area (Figures 6c and 7c). Notably, districts like GCD, SJD, ZMC, XZC, and DFC witnessed an increasing trend in nocturnal light (with ENLR ranging from 0.1 to 1.4), while other districts experienced a decrease (with ENLR ranging from −2.4 to −0.1). The pandemic control measures in 2022 were more stringent than in 2021, and the central urban districts were particularly affected by the 2021 lockdownCompared to 2020, 2021, and 2022, night-time light did not decrease during the initial stages of regular control, but rather showed a notable increase in 2020. This suggests that regular control measures did not significantly inhibit human activities. However, as the intensity of pandemic control escalated, this impact became more evident in 2021. The pandemic control measures implemented in Zhengzhou in 2022 undoubtedly reached the peak of intensity. This underscores the importance of maintaining a certain degree of flexibility in pandemic control measures.

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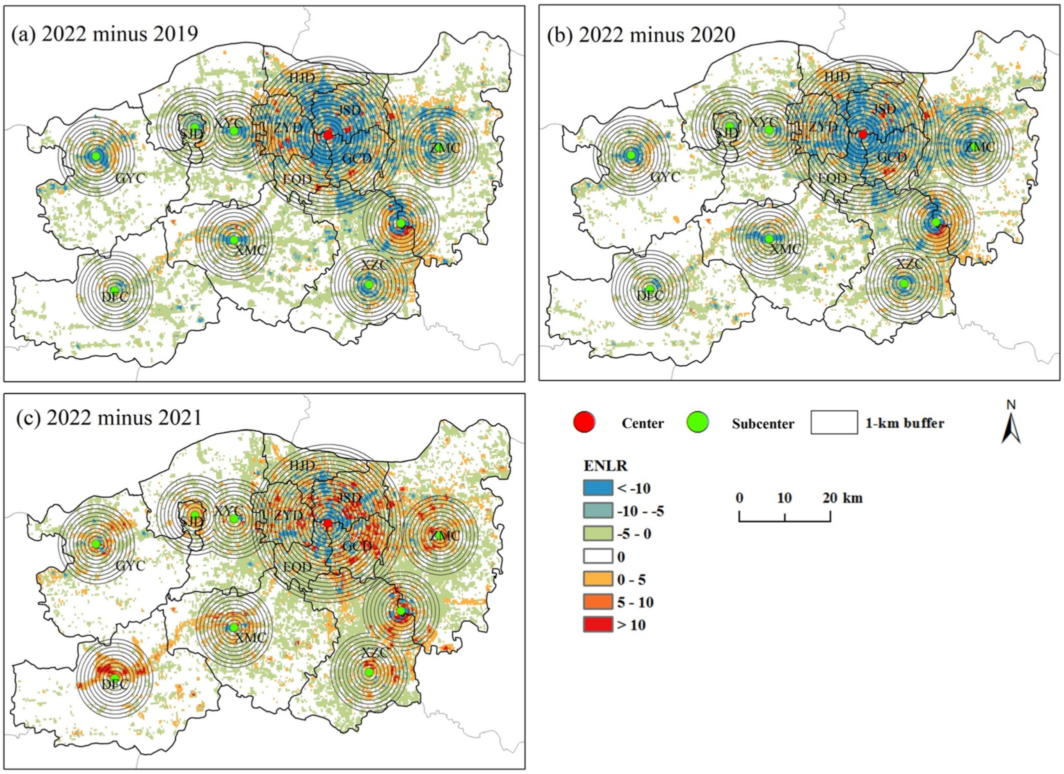

Figure 6. Spatiotemporal distribution of ENLR in Zhengzhou region from September to October. (a) Comparison between 2019 and 2022. (b) Comparison between 2020 and 2022. (c) Comparison between 2021 and 2022.

3.4. Spatial Gradients of Night-Time Light Variation

Figure 8 illustrates that as the distance from the city center increased, the impact of nocturnal light changes gradually diminished. The city center exhibited the largest impact area, with significant reductions in nocturnal lighting within a 15-km radius, while regions beyond this radius experienced lesser impact. Sub-center counties like XMC and XZA were also notably affected by the lockdown, with impacts mainly concentrated within a 5-km range. Annual comparative analysis indicates that in 2022, nocturnal light exhibited the largest decrease compared to 2019 and 2020, yet the smallest decrease compared to 2021, suggesting that epidemic management in 2021 began to markedly affect human activity intensity. Notably, while nocturnal light in the city center decreased significantly in 2022 compared to 2021, some counties and districts (DFC, SJD, XZC, ZMC) in the sub-center showed slight increases in a small range. This implies that the 2022 epidemic lockdown had a significant impact on the city center compared to surrounding areas, which were less sensitive to the lockdown measures directed at the city center.

3.5. Industrial Park's Night-Time Light Variation

From a nocturnal light perspective alone, it is apparent that Foxconn's production capacity has been significantly affected (Figure 9). In October 2022, the industrial park's nocturnal light predominantly decreased significantly (DNLR < -10), with a slight increase in a small area ($0 <$ DNLR < 5), potentially corresponding to necessary living facilities. Before the COVID-19 pandemic, October 2019 witnessed a significant increase in nocturnal light (DNLR > 5), aligning with a high productivity time node. Even after excluding natural increases from September to October, Foxconn's park still exhibited a significant decrease in nocturnal light (ENLR < -10).

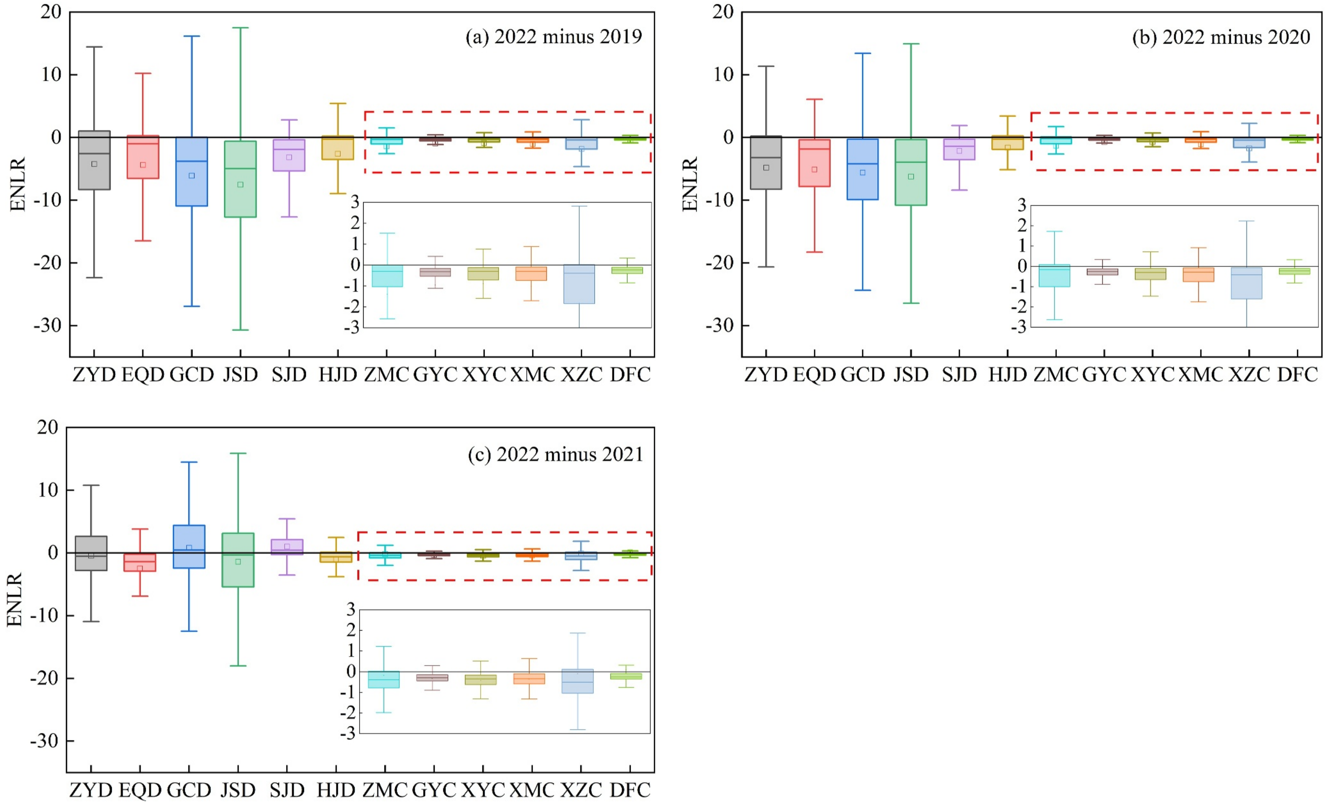

Figure 7. ENLR statistics in different counties in Zhengzhou region: (a) Comparison between 2019 and 2022. (b) Comparison between 2020 and 2022. (c) Comparison between 2021 and 2022.

4. Discussions

4.1. Mechanism of Night-Time Light Changes

Before the implementation of stringent pandemic control measures, economic activity in Zhengzhou was still on the rise. These developments were closely intertwined with the imposition of strict limitations. There exists a causal link between the mechanisms of pandemic control and nocturnal light (Kim, 2022; Ning et al., 2023). The primary reason behind the overall decrease in nocturnal light was the reduction in nighttime illumination from residential, commercial, and industrial establishments on the ground (Zhao et al., 2022). The COVID-19 lockdown restricted residents' mobility and vehicular movement while prohibiting the operation of public places such as factories, malls, and shops (Deng et al., 2022). These actions were inevitably impacted by the lockdown, leading to observable changes in nocturnal light.

Although precise monthly economic data are currently unavailable due to delays in economic statistics, insights can still be gleaned from the National Economic Development Report of Zhengzhou in 2022. The wave of COVID-19 transmission affected several industries in Zhengzhou, with the tourism industry bearing a particularly evident impact. The lockdown coincided with the peak tourism period, exacerbating the impact on tourism-related activities. Before the epidemic lockdown, the growth rates of consumer goods retail, accommodation and catering, tourist arrivals, and total tourism revenue in Zhengzhou in 2019 stood at 9.5%, 7.4%, 14.5%, and 15.2%, respectively. However, in 2022, these growth rates plummeted to −3.3%, −12.8%, −12.2%, and −11.0%, respectively (data sourced from the National Economic Development Report of Zhengzhou). This underscores the significant economic repercussions of stringent epidemic management measures in Zhengzhou.

4.2. Comparison With Existing Research

The study of urban challenges related to nighttime light remote sensing data has rapidly advanced, thanks to the increasing spatial, temporal, and spectral resolution of nighttime light satellites (Jechow & Hölker, 2020;

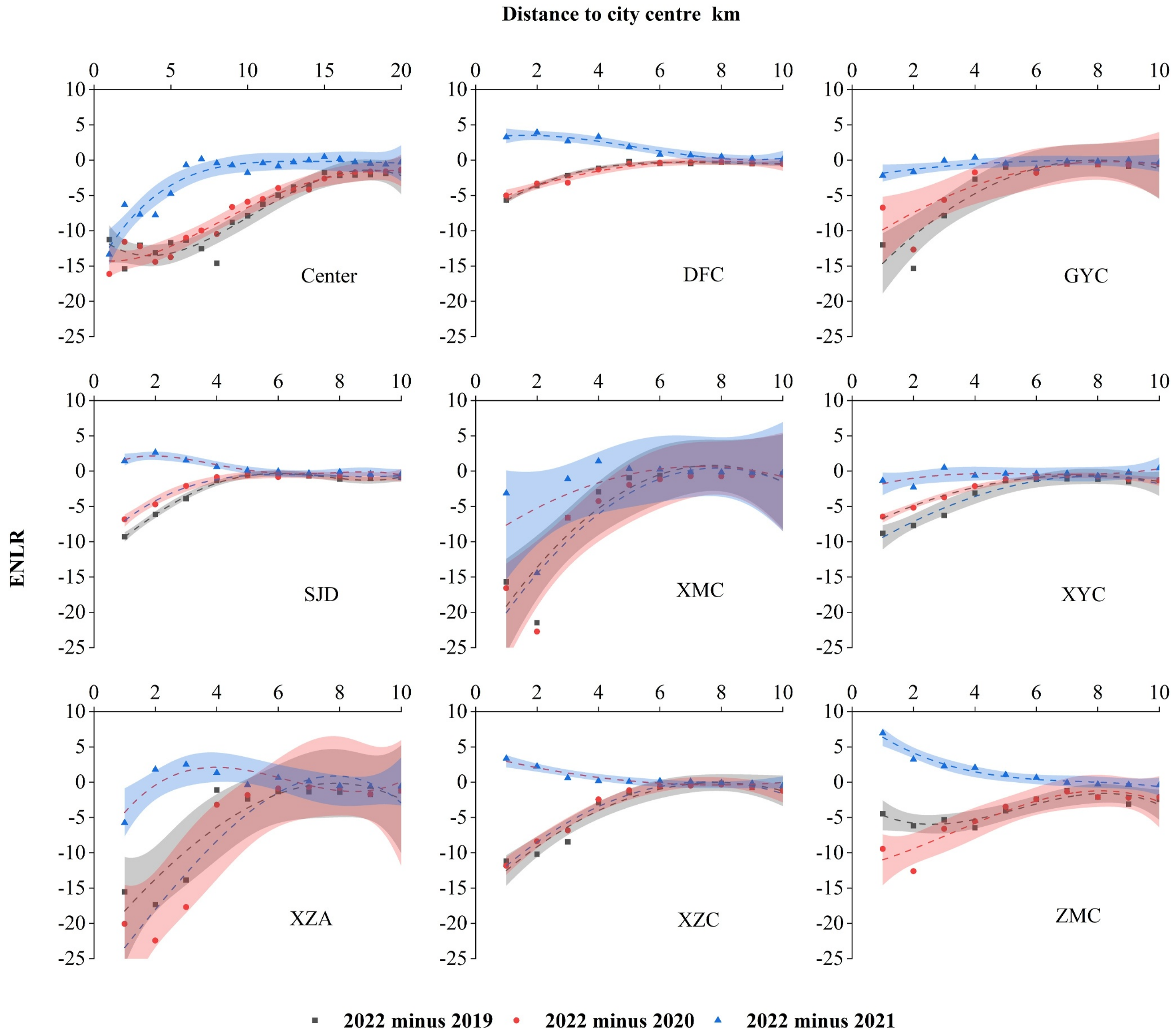

Figure 8. Spatial gradients of ENLR. ENLR were calculated in a series of 1-km buffer rings with concentric ring analysis. Center represented 5 districts in the center of Zhengzhou: ZYD, EQD, GCD, JSD, and HJD. In addition to the administrative districts, we added a concentric ring analysis of Xinzheng Airport Area (XZA).

Kim, 2022). Urban public safety domains, including natural disasters, conflicts, environmental health, and pandemics, have all benefited from the use of nighttime light data (C. Li et al., 2022; J. Li et al., 2022). Findings from numerous studies suggest that nighttime light remote sensing can play a crucial role in urban public safety (Anand & Kim, 2021; C. Li et al., 2022; J. Li et al., 2022; Straka et al., 2021; Zheng et al., 2021). Policies such as lockdowns and stay-at-home orders, frequently employed internationally to mitigate and manage the COVID-19 pandemic, have a significant impact on urban residents' productivity and quality of life (Hayakawa et al., 2022). Nighttime remote sensing serves as an effective tool for monitoring changes in urban socioeconomic activity. Our study offers a fresh perspective on assessing the socioeconomic effects of the COVID-19 pandemic by demonstrating how nighttime light remote sensing can efficiently track changes in urban socioeconomic activities resulting from public health prevention and control measures. Consistent with the findings of many other researchers (Ma et al., 2023; Xue et al., 2022; Yang et al., 2021), our research indicates that pandemic control measures implemented in Zhengzhou from September to October 2022 significantly dampened economic activity. Our study stands as a valuable resource for China and other regions as they evaluate the effectiveness of pandemic prevention and control methods.

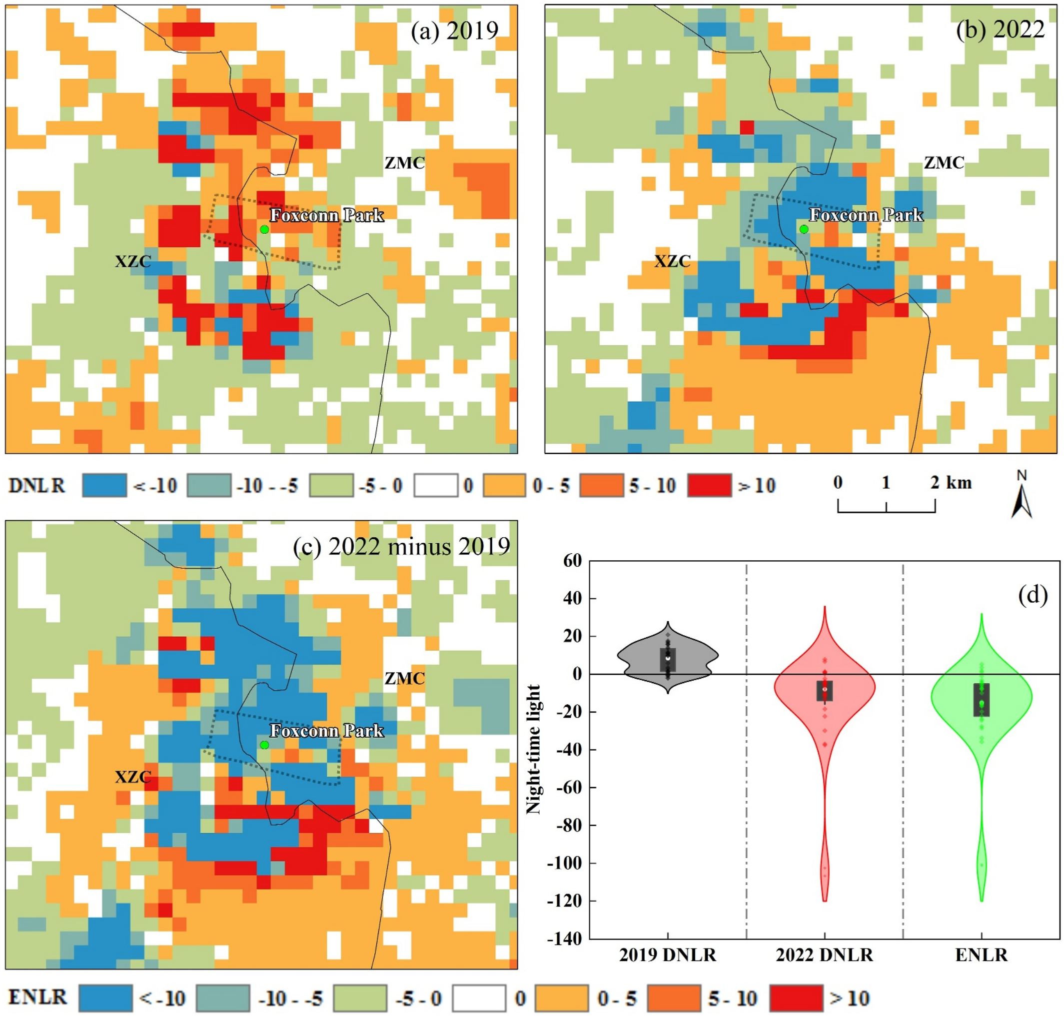

Figure 9. Night-time light change in Foxconn between 2022 and 2019: (a) DNLR distribution in 2019, (b) DNLR distribution in 2022, (c) ENLR distribution, and (d) DNLR and ENLR statistics.

4.3. Study Innovation

In the realm of health research, previous approaches focused on analyzing nighttime light as a potential contributor to health risks (Lu et al., 2023). Numerous epidemiological studies have demonstrated that the intensity of nighttime light can impact human health (Côté-Lussier et al., 2020). For instance, disruptions in circadian rhythm caused by nighttime light have been linked to a variety of human diseases, including coronary heart disease, diabetes, obesity, and cancer (Stevens et al., 2013; T. Wang et al., 2023; Y.-X. Xu et al., 2024). However, research on the influence of nighttime light on the incidence rate and mortality of COVID-19 has typically been limited to individual-level disease risk (Y. Zhang et al., 2022). Presently, there is a lack of research assessing the broader impact of the macro COVID-19 pandemic. This gap exists because studies focused on individual health fail to adequately capture the effects of macro public health event management. Our research introduces a novel approach by utilizing nighttime light data to investigate changes in nocturnal illumination resulting from COVID-19 epidemic control policies, diverging from the traditional view of nighttime light as a pathogenic factor. This represents a significant departure from previous health research methodologies.

5. Conclusions

Our study aimed to analyze spatiotemporal changes in nighttime light using monthly data and compare differences before and after the COVID-19 outbreak in the Zhengzhou region. The COVID-19 pandemic lockdown in

Zhengzhou in October 2022 persisted for an extended period as part of China's pandemic prevention efforts. Spatiotemporal analysis based on nighttime light remote sensing data revealed that prior to the pandemic outbreak, nighttime light in Zhengzhou exhibited a significant upward trend. Even under regular control measures, nighttime light continued to increase. However, by 2021, the intensity of pandemic control measures reached a critical level, impacting human activities. Following the October 2022 COVID-19 lockdown, there was a notable overall decrease in nighttime light throughout Zhengzhou. As a key indicator of human activity intensity, nighttime light in the central area of Zhengzhou decreased by at least 18%, while the surrounding counties experienced a decrease of over 14%.

Concentric circle analysis indicated that as distance from the city center increased, the decrease in nighttime light gradually diminished, highlighting a more pronounced response to pandemic control measures in the city center. The area where nighttime light decreased most significantly in the central area of Zhengzhou was primarily within a 15 km radius, while changes in nighttime light in the surrounding counties were concentrated within a 5 km radius.

Examining data on consumer goods retail, accommodation and catering, tourist arrivals, and total tourism revenue in Zhengzhou revealed comprehensive decreases in 2022 compared to 2021 (with the four indicators decreasing by −3.3%, −12.8%, −12.2%, and −11.0% respectively), while 2019 still demonstrated significant growth compared to 2018 (with the four indicators increasing by 9.5%, 7.4%, 14.5%, and 15.2% respectively). These statistical and nighttime light data changes underscore the significant impact of the lockdown on economic activity in the Zhengzhou region.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The NPP/VIIRS monthly products that support the findings of this study are openly available at Elvidge et al. (2017). The air pollutants products are openly available at Wei et al. (2023).

Acknowledgments
This study was funded by the National Natural Science Foundation of China, Grant 42071253. The authors thank the editors and anonymous referees for their valuable comments on this study.

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