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Accelerated nighttime light growth in China and its relationship with socioeconomic development

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Dear Editor,

Nighttime light (NTL), a direct indicator of human activities, captures multi-dimensional interactions between social systems and the natural environment.[1] Over the past decades, NTL has grown globally at an annual rate exceeding 2%, reflecting rapid urbanization and increasing human activity.[2,3] Previous work has suggested that expenditure on artificial lighting tends to scale with GDP and accounts for approximately 0.7% of economic output.[2] Artificial lighting supports nighttime mobility and economic activity and enhances public safety in urban areas.[4] However, excessive artificial lighting simultaneously generates light pollution, which can disrupt ecological balance at night, interfere with astronomical observations, and pose risks to human health.[5] These trade-offs highlight the need to balance societal benefits with environmental constraints. China, one of the world's most populous and rapidly growing economies, is undergoing the largest-scale urbanization in human history.[6] However, despite extensive NTL-based studies in China, the long-term evolution of China's total NTL magnitude and its relationship with major socioeconomic variables remain insufficiently characterized using a physically integrated metric.

NTL is typically characterized by spatial extent and radiance, but neither alone adequately represents overall NTL intensity. The spatial extent of NTL varies with the resolution of remote sensing data, and measurements of areal extent lack stability due to scale effects and the "blooming" phenomenon.[7] Radiance (Unit: W/m^2/sr) is defined as a physical quantity per unit projected area per unit solid angle. However, it cannot effectively and intuitively reflect changes in total NTL intensity while preserving its physical meaning (Figure S1 in the Figshare deposit, https://doi.org/10.6084/m9.figshare.34206819). To address these issues, Zeng et al.[8] proposed a new metric, radiant flux (Unit: W), which integrates both radiance and area, providing a more intuitive and accurate representation of total NTL. Radiant flux is therefore particularly suitable for large-scale aggregation and long-term comparison, where pixel-area differences affect radiance-based measurements. Building on this framework, we integrated original SNPP-VIIRS observations with a simulated dataset (pixel-level validation for China in 2012 showed an R^2 of 0.94; Figure S2 & Table S1 in the Figshare deposit).[9] We quantified changes in radiant flux across China from 1995 to 2020 and systematically examined the contributions of economic growth, population dynamics, and urban expansion to these changes (Figure 1). Detailed data descriptions and methods are also available in the Figshare deposit.

The total radiant flux across China increased from 56,812,465 W in 1995 (Figure 1A) to 144,655,975 W in 2020 (Figure 1B), with an overall growth rate of 155%. This trajectory comprises two growth phases (Figure 1C): a period of relatively slow growth from 1995 to 2010 and a phase of rapid acceleration from 2010 to 2020. During 1995-2010, the average annual increment was approximately 1.0×10^6 W (1.69% yr^{-1}). Total NTL rose by 4,858,665 W between 1995 and 2000 (8.55% relative to 1995; 1.65% yr^{-1}), by 7,038,838 W between 2000 and 2005 (11.41% relative to 2000; 2.18% yr^{-1}), and by only 4,370,602 W between 2005 and 2010 (6.36% relative to 2005; 1.24% yr^{-1}), indicating a gradual deceleration toward the end of this period. In contrast, growth accelerated markedly during 2010-2020. From 2010 to 2015, radiant flux increased by 25,539,970 W (34.95%), corresponding to an average annual growth rate of 6.18% yr^{-1}. Growth intensified during 2015-2020, when NTL increased by 46,035,434 W, a 46.68% increase relative to 2015, with an average annual growth rate of 7.96% yr^{-1}. Notably, the increase during 2015-2020 alone exceeded the cumulative growth of the previous two decades (1995-2015).

Variations in NTL are associated with socioeconomic development, population dynamics, and urban expansion, reflecting both intensified lighting within existing built-up areas and the creation of new illuminated urban infrastructure.[2] To examine these relationships, we used China's 1995-2020 raster data for gross domestic product (GDP) and population (POP), which were obtained from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (https://www.resdc.cn/), as well as urban built-up area (UBA) data from Tsinghua University.[10] The totals and changes in China's NTL, GDP, POP, and UBA are shown in Figures 1D-E.

In contrast to trends reported for other countries, China's NTL has grown rapidly but significantly more slowly than its economy and urban built-up area. A cornerstone NTL study reported that during 2012-2016, the global median growth rate of national-level NTL (15%) slightly exceeded the median GDP growth rate (13%), suggesting a tendency toward disproportionate or inefficient expansion of nighttime lighting in most countries.[2] In China (Figure 1E), GDP and UBA increased by more than 1,600% and 500%, respectively, between 1995 and 2020, whereas NTL increased by only 155%, markedly lagging behind the rates of economic development and urban expansion. Within a given region, GDP may continue to grow substantially, whereas nighttime light (NTL) emissions are unlikely to increase indefinitely and may eventually approach saturation. Such comparisons should therefore serve as reference indicators, interpreted alongside regional socioeconomic development and the spatial distribution of economic activities. Notably, during the 2015-2020 period, China's NTL growth rate (47%) exceeded its GDP growth rate (39%) for the first time, potentially reflecting a combination of slower economic expansion and intensified investment in large-scale infrastructure. This exceedance marks a meaningful shift in China's lighting trajectory. Nevertheless, NTL growth remained substantially lower than UBA expansion during the same period.

Changes in aggregate ratios cannot directly capture the absolute relationship between NTL and socioeconomic parameters. We therefore calculated NTL, GDP, POP, and UBA totals for each prefecture-level city at six time points: 1995, 2000, 2005, 2010, 2015, and 2020. We then derived radiant flux per unit GDP, POP, and UBA for each city (Figure S3A, C & E in the Figshare deposit). Linear correlation analysis shows that NTL/GDP (Figure S3B in the Figshare deposit) and NTL/UBA (Figure S3F in the Figshare deposit) are both negatively correlated with year at a high level of statistical significance. This further indicates relatively slow NTL growth compared with China's economic development and urban expansion. Overall, China's nighttime lighting did not exhibit inefficient expansion beyond that warranted by its economic and urban development.

To investigate the influencing factors of NTL changes, we quantified variations in NTL (D_{NTL}), GDP (D_{GDP}), POP (D_{POP}), and UBA (D_{UBA}) at the prefecture-level city scale (Figures S4-S5 in the Figshare deposit), and used random forest models to assess the explanatory importance of D_{GDP}, D_{POP}, and D_{UBA} in predicting NTL changes (Figures 1F-J; see Table S2 in the Figshare deposit). Model performance and ranking robustness were assessed using OOB validation, response-permutation tests, and comparisons with XGBoost and Extra Trees (Tables S2-S3 in the Figshare deposit). UBA increases consistently had high predictive importance for NTL growth. During the 1995-2005 period (Figures 1F-G), UBA was the highest-ranked explanatory variable for changes in NTL. After 2005, however, GDP caught up with or even surpassed UBA in explanatory importance, becoming one of the key variables associated with NTL dynamics (Figures 1H-J). The increase in POP importance during 2015-2020 should be interpreted cautiously. Figure 1E shows national aggregate population change, whereas the random forest model captures prefecture-level variation in D_{POP}. Thus, even when national population growth was close to zero, population redistribution among cities may still help explain spatial differences in D_{NTL}. However, POP remained less important

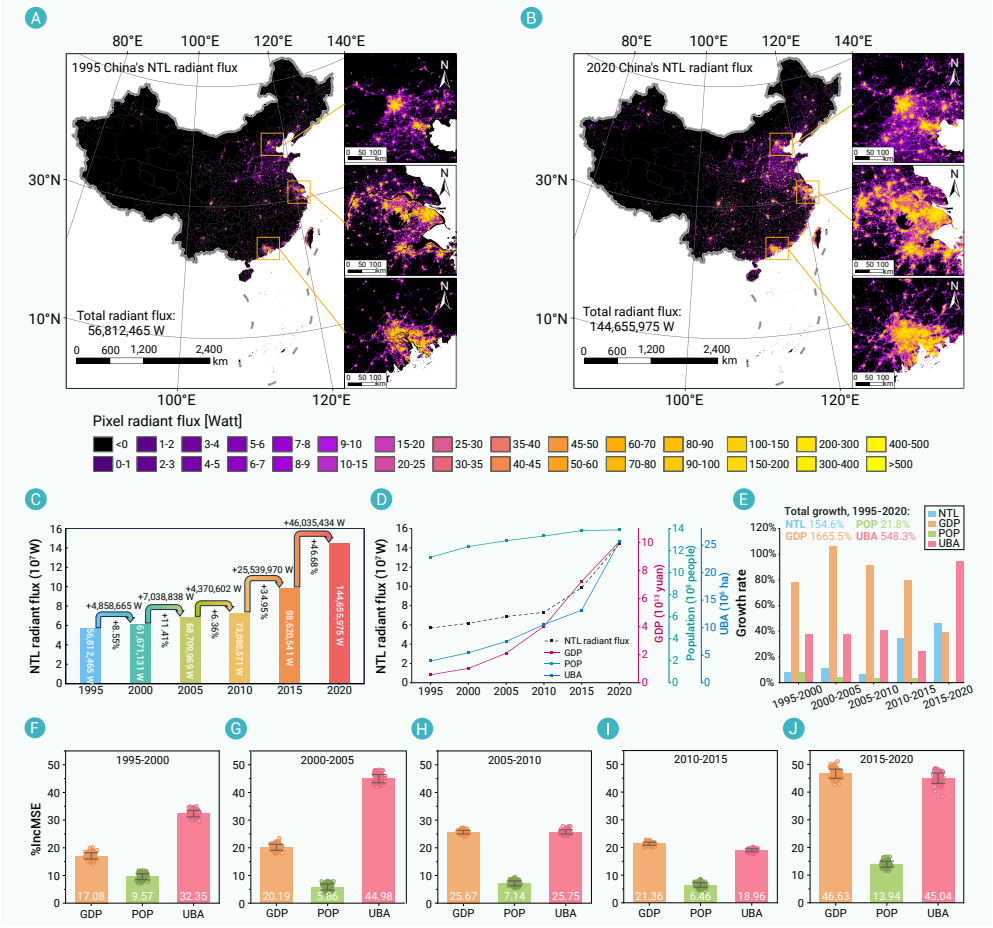


Figure 1. Growth and influencing factors of nighttime light radiant flux in China, 1995-2020 (A-B) Spatial distributions of NTL radiant flux in China in 1995 and 2020. (C) National NTL radiant flux totals and changes, 1995-2020. (D) The total amounts and changes in China's GDP, POP, and UBA. (E) Growth rates of China's NTL, GDP, POP, and UBA in each time period. (F-J) Random forest feature importance rankings for each period, based on prefecture-level changes. Bars represent the mean feature importance across 100 random forest runs, and error bars indicate ±1 standard deviation (%IncMSE is a variable-importance metric in random forest models. It indicates the percentage increase in model prediction error when a given variable is randomly permuted).

than GDP and UBA, indicating that it was not the main explanatory variable. The three selected variables represent long-term, consistently quantifiable factors closely associated with NTL changes throughout the study period. Other factors, such as natural disasters, unexpected events, public awareness, and policies or regulations, may also affect NTL variation, but they are often episodic, spatially heterogeneous, and difficult to quantify consistently across China over the long temporal span of this study.

We advance the quantitative assessment of NTL dynamics using radiant flux as an integrated and physically meaningful metric, enabling a robust reconstruction of China's NTL evolution from 1995 to 2020. We reveal a two-phase trajectory, characterized by prolonged moderate growth followed by rapid acceleration after 2010, reflecting China's broader socioeconomic transformation. Comparisons with GDP, population, and urban built-up area further show that NTL changes were closely associated with socioeconomic growth and urban expansion, but the strength and direction of these relationships varied across periods and variables. Collectively, these findings provide a quantitative basis for understanding the long-term evolution of artificial lighting in China and its relationship with major socioeconomic variables. China's NTL trajectory and its associated socioeconomic factors provide comparative information for studies in other rapidly urbanizing regions. The dataset and analytical framework may also support future studies on urban development, light pollution, energy use, and ecological impacts, where additional policy, ecological, or health-related data are needed to further evaluate sustainability and conservation implications. To facilitate broader cross-disciplinary applications, we share the global radiant flux dataset spanning 2012-2024 (https://doi.org/10.5281/zenodo.17847442).

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

1. Jia M., Zeng H., Chen Z., et al. (2024). Nighttime light in China's coastal zone: The type classification approach using SDGSAT-1 Glimmer Imager. *Remote Sens. Environ.* **305**:114104. DOI:10.1016/j.rse.2024.114104
2. Kyba C.C.M., Kuester T., Sánchez de Miguel A., et al. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. *Sci. Adv.* **3**:e1701528. DOI:10.1126/sciadv.1701528
3. Li T., Wang Z., Kyba C.C.M., et al. (2026). Satellite imagery reveals increasing volatility in human nighttime activity. *Nature* **652**:379–386. DOI:10.1038/s41586-026-10260-w
4. Boyce P.R. (2019). The benefits of light at night. *Build. Environ.* **151**:356–367. DOI:10.1016/j.buildenv.2019.01.020
5. Zielinska-Dabkowska K.M., Schernhammer E.S., Hanifin J.P., et al. (2023). Reducing nighttime light exposure in the urban environment to benefit human health and society. *Science* **380**:1130–1135. DOI:10.1126/science.adg5277
6. Bai X. and Shi P. (2025). China's urbanization at a turning point-challenges and opportunities. *Science* **388**:eadw3443. DOI:10.1126/science.adw3443
7. Wang C., Chen Z., Yang C., et al. (2020). Analyzing parcel-level relationships between Luojia 1-01 nighttime light intensity and artificial surface features across Shanghai, China: A comparison with NPP-VIIRS data. *Int. J. Appl. Earth Obs. Geoinf.* **85**:101989. DOI:10.1016/j.jag.2019.101989
8. Zeng H., Jia M., Ning X., et al. (2025). Quantitative characterization of global nighttime light: A method for measuring energy intensity based on radiant flux and SNPP-VIIRS data. *Remote Sens. Environ.* **318**:114576. DOI:10.1016/j.rse.2024.114576
9. Guo W., Zhao Y., Kyba C.C.M., et al. (2025). Using a deep learning method to establish 500 m resolution non-saturation nighttime light time series from 1992 to 2022. *Int. J. Appl. Earth Obs. Geoinf.* **143**:104771. DOI:10.1016/j.jag.2025.104771
10. Li X., Gong P., Zhou Y., et al. (2020). Mapping global urban boundaries from the global artificial impervious area (GAIA) data. *Environ. Res. Lett.* **15**:094044. DOI:10.1088/1748-9326/ab9be3

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AUTHOR CONTRIBUTIONS

Haihang Zeng: Conceptualization, Methodology, Data curation, Software, Visualization, Writing - original draft; Mingming Jia: Conceptualization, Methodology, Visualization, Project administration, Writing - review & editing; Wei Guo: Conceptualization, Methodology, Data curation, Writing - review & editing; Chuanpeng Zhao and Rong Zhang: Methodology, Writing - review & editing; Yeqiao Wang and Zongming Wang: Conceptualization, Writing - review & editing. All authors contributed to manuscript preparation and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.