A spatially-explicit assessment on equality of Urban Green Space Coverage across 32 major cities in China

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Abstract

Greenspace is an important urban component for providing ecosystem service and protecting human health. And the need for "providing universal access to greenspace for urban residents" has been specified in the 11th Sustainable Development Goals (SDGs11.7). Yet, the inequality of per-capita urban green space has not well understood in a spatially-detailed way. Therefore, in this study, we estimated per-capita urban green space at 30-meter sub-pixel level from our generated urban green vegetation fractions dataset, which exhibited a generally consistent agreement with estimated fractions from high-spatial resolution Google earth images (RMSE ranged from 10.41%~12.09%). And then quantified the spatial gradient change along the urban center-edge for 32 major cities in China, as well as their inequal access for urban residents. Our results indicate: 1) Urban green space generally decreases along the gradient from city centers to the urban fringe. However, the trends vary among 32 cities, exhibiting either monotonic, power-law decline or hump-shaped patterns. 2) Per capita urban green space in the urban core are generally lower than those in fringe for over 80% of case cities. 3) For 32 major cities, per capita urban green space inequality in eastern coastal China (e.g., Guangzhou) were lower than other central and western cities (e.g., Guiyang and Zhengzhou), due to better spatial alignment between green spaces supply and population demands. 4) Economic development (GDP) and urbanization (built-up area) are two key factors influencing the distribution of green space. These findings highlight the necessity of balancing efficiency and equity for urban planning, particularly through optimized greening policies for mitigating ecosystem service disparities and achieving sustainable development goals.

1. Introduction

Green space is a crucial component of urban environments, offering a wide range of ecosystem services such as air and water purification, temperature regulation, and carbon sequestration, in addition to promoting human health by providing spaces for recreation and social interaction (Zhou et al., 2014; Huang et al., 2021; Song et al., 2021). As urbanization continues to accelerate globally, the need for accessible green space has gained significant attention. In response, the United Nations' 11th Sustainable Development Goal (SDG 11.7) highlights the importance of ensuring "universal access to green space for urban residents," recognizing its potential to improve quality of life and support social equity (Chen et al., 2022; Wu et al., 2023). Given the growing urban populations and the associated pressures on urban ecosystems, effective monitoring of green space could help track the spatial distribution, quality, and availability of greens paces, thus providing an improved understanding that can inform policy decisions to enhance urban sustainability and resilience.

Despite its importance, the equity of green space distribution, particularly in terms of per capita urban green space coverage,

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has not been sufficiently addressed in a spatial detailed way. While some cities have made efforts in improving green infrastructure, disparities in access to green space remain, often concentrated in more affluent or centrally located areas. Measuring the equality of green space allocation requires a nuanced understanding of its spatial patterns, which can be captured using metrics such as the Gini coefficient to quantify the level of inequality in its distribution (Catalano, et al., 2009; Martin and Conway, 2025). However, current methods of assessing this inequality are often too generalized and fail to account for micro-level needs within interior urban space. The reason is, the lack of high-spatial resolution datasets make it difficult to assess spatial disparities in green space availability accurately. Currently, vegetation fractions products from spectral mixture analysis offer significant advancements in addressing such challenges related to spatiotemporal continuity of vegetation data (Sun et al., 2024; Zhang et al., 2022). These products provide consistent and up-to-date measurements of vegetation cover across large urban areas, which are capable of a detailed understanding of both the quantity and quality of urban green spaces. This is particularly important for assessing green space accessibility and ensuring that equitable distribution aligns with the needs of urban populations.

Here, we use our generated fractional estimates of urban green vegetation (GV) at the sub-pixel level using Landsat OLI images from a spectral mixture analysis model. We then quantified the spatial transitional change of urban green space and per-capita urban green space along the urban center-to-edge gradients for 32 major cities in China, employing a concentric ring methodology. In addition, the Gini coefficient for both overall green space coverage and per capita green space was adopted to quantify the inequity in access to green space within these cities. This measurement allows for a detailed assessment of the spatial inequality in human green space exposure across urban areas. Our findings provide a comprehensive understanding of how green space is distributed within population and how the spatial equity of human green spaces exposure vary between the central and peripheral urban zones.

2. Materials and methods

2.1 Study area

In this study, a total of 32 cities across China were selected as the research sites. These cities encompass the administrative centers of 23 provinces and 5 autonomous regions, in addition to the 4 directly governed municipalities. The selection of these cities was based on their representativeness in terms of geographical distribution, socio-economic development levels, and environmental characteristics.

2.2 Data Sources and preprocessing

(1) The experiment utilized four existing datasets to derive an accurate and reliable urban surface boundary. These datasets include GlobeLand30 (GISD30), and annual China Land CoverDataset (CLCD) from the year 2020, along with China Land Use/Cover Change Dataset (CLUD) from the year 2018. To enhance the accuracy and consistency of the final dataset, a majority voting algorithm was applied to integrate the four datasets. This fusion approach ensures that the derived impervious surface dataset better reflects the actual urban conditions by minimizing discrepancies and leveraging the strengths of each source.

(2) Population data for the year 2020 were obtained from the WorldPop project. This dataset provides high-resolution (~3 arc-seconds, approximately 100 meters at the equator) gridded population distribution data, which is widely used in demographic and environmental studies due to its fine spatial resolution and global coverage. The downloaded population data were preprocessed by clipping the raster images to match the spatial extent of the fused urban impervious surface dataset for the selected target cities. This preprocessing step ensures spatial consistency across the datasets, facilitating subsequent analyses and improving computational efficiency. The data processing workflow involved georeferencing, projection conversion where necessary, and resampling to ensure uniform spatial resolution across all datasets.

(3) Green space data were derived from the 2020 Landsat satellite imagery, utilizing a spectral mixture analysis approach to generate a spatiotemporally continuous GV abundance product. This dataset, characterized by a 30-meter spatial resolution, provides detailed insights into vegetation distribution and abundance. The dataset was sourced from Zhang et al. (2022), ensuring its scientific validity and applicability for urban ecological studies. The unmixed fractions of urban green vegetation exhibited a generally consistent agreement with

estimated fractions from high-spatial resolution Google earth images (RMSE ranged from 10.41%~12.09%), demonstrating its high suitability and reliability. Similar to the population data, the green space dataset was clipped to the spatial extent of the urban impervious surface area for the further analysis.

2.3 Methods

2.3.1 Concentric ring analysis: Concentric ring analysis was conducted to explore the spatial gradients of green space coverage. This approach follows the methodology proposed by Zhang et al. (2023) , which divides urban areas into equidistant buffer zones from a defined city center. The geographic center or municipal government location of each city was defined as the urban center based on OpenStreetMap (OSM) data. This method ensures consistency across all study areas. Equidistant concentric rings were generated from the city center at fixed intervals (5-kilometer), ensuring full coverage of the major urban areas considering urban surface boundary, which as illustrated in Figure 1. Green space density within each concentric ring was defined as the ratio of the total green space area to the total area of the corresponding buffer zone. Alternatively, the green space density can be interpreted as the average GV abundance within the buffer zone, obtained through spectral mixture analysis of Landsat 2020 imagery. Population density within each concentric ring was computed as the ratio of the total population to the total area of the buffer zone, defined by the equation,

$$Pop_{deni} = \frac{Pop_{sumi}}{Areai} \quad (1)$$

Where $\mathrm{Pop_{sumi}}$ is total population in ith ring，Areai is built-up area in such ring; Per capita green space is a critical indicator for assessing the availability of urban green infrastructure relative to the population distribution. It reflects the balance between urban ecological resources and human well-being, offering insights into environmental sustainability and livability. In this study, the per capita green space for each concentric buffer ring was calculated to evaluate human greenspace exposure across different urban zones.

2.3.2 Gini coefficient: To assess the spatial inequality in the distribution of green space and per capita green space across the study areas, the Gini coefficient was employed as a measure of spatial disparity. This approach follows the modeling process outlined by Song et al. (2021). The Gini coefficient is widely used in urban studies to quantify the degree of inequality in resource allocation and socio-economic factors across spatial units. The Gini coefficient ranges from 0 to 1, where a value of 0 represents absolute equality and a value of 1 signifies absolute inequality. In this study, the Gini coefficient is defined as the ratio of the area between the line of equality (the 45-degree line) and the Lorenz curve (area A) to the total area under the line of equality (area A + area B). This relationship is mathematically expressed as:

$$\mathrm{Gini} = \frac{\mathrm{A}}{\mathrm{A+B}} \quad (2)$$

The area under the Lorenz curve, specifically area B, is a key component in the calculation of the Gini coefficient. Area B represents the portion of the area under the line of equality that is not captured by the Lorenz curve. This area reflects the cumulative distribution of the variable (e.g., green space and per capita green space) that is considered to be "unequal" or disproportionately distributed across the spatial units. For a discrete set of data points representing spatial units (e.g., concentric buffer rings), area B can be approximated as the following:

$$\mathrm{B} = \frac{\sum_{i=1}^{n}(\mathrm{B_i}-\mathrm{B_{i-1}})(\mathrm{G_i}+\mathrm{G_{i-1}})}{2} \quad (3)$$

where $\mathrm{G_i}$ and $\mathrm{B_i}$ represent the cumulative proportion of the variable (e.g., green space) and the cumulative percentage of spatial units (ranked from lowest to highest), respectively, for the *i*-th unit. n is the total number of spatial units (e.g., concentric rings or grid cells).$(\mathrm{B_i} - \mathrm{B_{i-1}})$ represents the difference in the cumulative percentage of spatial units between the *i*-th and *(i−1)*-th units.

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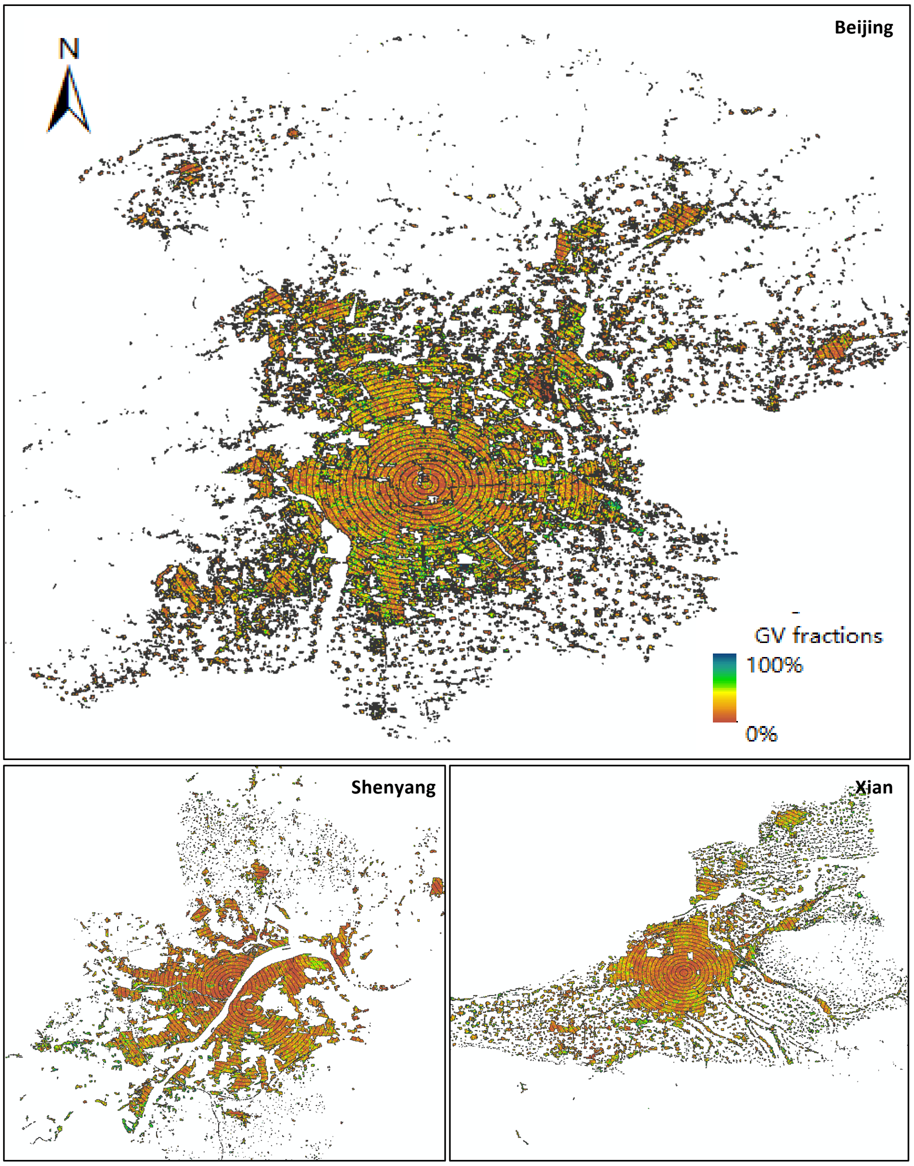

Figure 1. Example of concentric ring analysis

3. Results

3.1 Green space and per capita green space across concentric ring

The analysis of green space density across 32 cities reveals an overall declining trend in urban green space coverage. However, distinct patterns of green space distribution were observed in different cities, which can be classified into 3 primary types: inverted U-shaped, monotonically increasing, and small-scale fluctuation. In about 62.5% cities, green space density exhibited a inverted U-shaped distribution, where the density increased initially with distance from the city center, peaked at a certain point, and then decreased as the distance further increased. This pattern suggests the presence of green spaces in intermediate areas, with a decline in green space density in the peripheral zones. Such patterns may indicate well-planned intermediate green areas and parks, followed by a reduction in green space as urban sprawl intensifies at the city’s edge. For a few cities (15.6%), green space density showed a consistent increase as the distance from the city center grew. This upward trend indicates that green spaces are more concentrated in suburban and peripheral areas than in the urban core. Such a pattern may be a result of urban planning strategies that emphasize green space development in suburban zones, contributing to a more balanced distribution of green infrastructure across the urban-rural gradient. In addition, green space density in some city exhibited small-scale fluctuations, with slight increases and decreases observed at varying distances from the city center. This pattern suggests irregular or fragmented green space distribution.

The relationship between per capita green space and the distance from the city center across 32 cities is depicted in the figure 3. The results suggest that the distribution of per capita green space follows an exponential growth trend with respect to the distance from the city center. This trend indicates that urban green space distribution follows an exponential function, where the spatial availability of green space either grows or decays slowly in the early stages of distance but tends to sharply increase beyond a certain point.

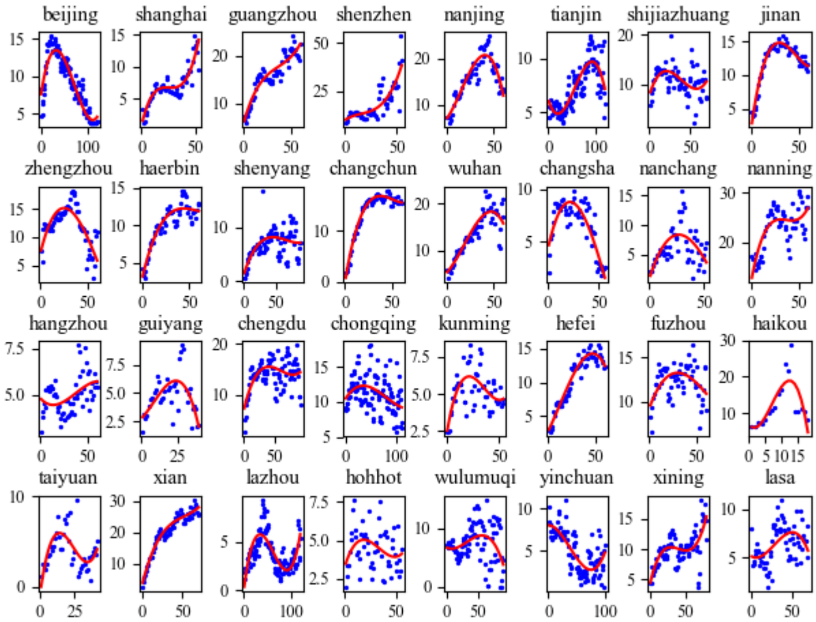

Figure 2. green space across concentric ring

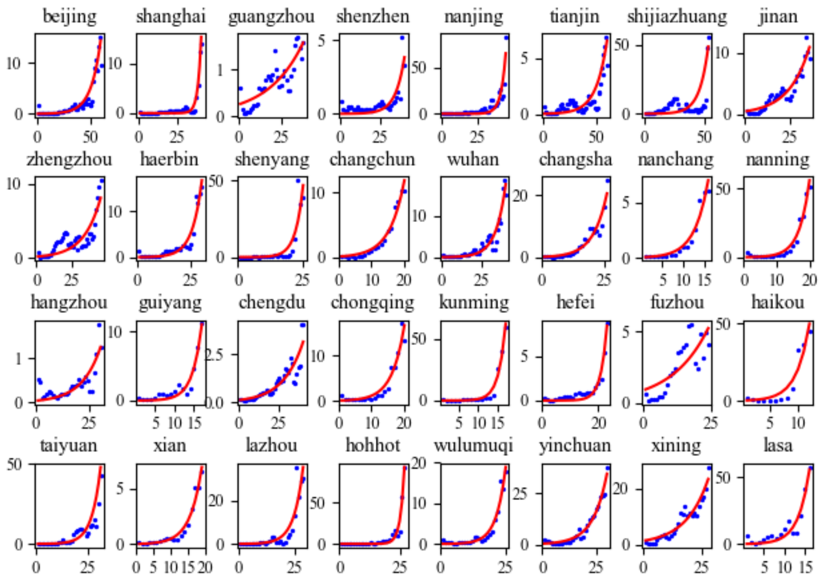

Figure 3. per capita green space across concentric ring

3.2 Inequity analysis of green spaces

The analysis presented in the figure visualizes the relationship between green space distribution and per capita green space equality across urban areas, using two key indicators: the Gini coefficient for green space distribution and the Gini coefficient for per capita green space. The Gini coefficient for green space area shows higher values in the Central and Northeast regions of China. These regions exhibit significant inequality in the distribution of green space, with a concentration of green areas in certain urban zones, while other areas remain underserved. This indicates a disproportionate allocation of green spaces, where some cities or districts may benefit from substantial green areas, while others, particularly in rural or peripheral zones, may experience limited access to green infrastructure. The high Gini coefficient values in these regions suggest that green space planning may not adequately address the needs of all urban areas, with some regions benefiting more from urban parks, recreational areas, and green belts than others. This pattern highlights the need for more equitable green space policies that aim to redistribute green spaces more evenly across urban areas, especially in less developed regions.

The Gini coefficient for per capita green space is notably lower in Central and Western China, indicating greater equity in the distribution of green space relative to population size. In these regions, the spatial alignment between green space supply and population demand appears to be more balanced, with residents in both urban and suburban areas having more equal access to green space. This pattern suggests that green space development in these regions may be more aligned with the needs of the population, ensuring that green areas are distributed proportionally to population density. Lower Gini coefficients for per capita green space in these regions indicate that urban planners may be focusing on improving green space availability in response to population growth and urbanization, ensuring a more even distribution of green spaces in relation to the population. This can be seen as a positive outcome of strategic urban planning that aims to meet the needs of both urban and rural populations, fostering social equity in green space access.

The regional disparities in the Gini coefficients for green space area and per capita green space reflect differences in urban planning and the spatial distribution of green infrastructure across China. While regions in the Central and Northeast areas show higher inequality in green space distribution, regions in the Central and Western areas exhibit more equitable access to green space per capita. These findings highlight the importance of region-specific urban policies that address the unique challenges of green space allocation in both densely populated and less urbanized areas. Future urban planning should aim to balance green space supply with population needs to ensure sustainable and inclusive green infrastructure development across all regions.

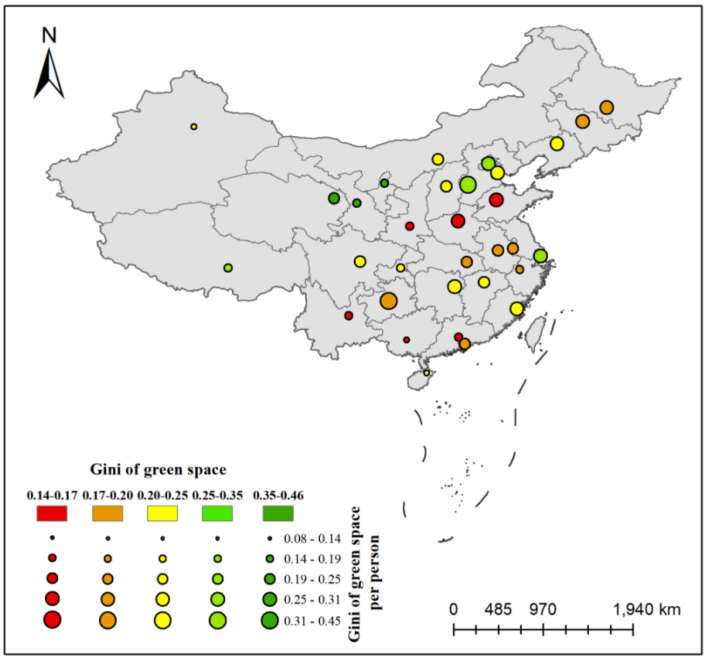

Figure 4. Spatial pattern of Gini coefficients for green space distribution and per capita green space across 32 cities

3.3 Relationship between inequity of green spaces with socio-economic factors

The scatter plots in the figure 4 illustrate the relationship between the Gini coefficient for green space (both total and per capita) and two key socioeconomic factors. The quadratic fit suggests a u-shaped relationship (Figure 5a). This implies that cities with medium economic development tend to have more equitable green space distribution. The reason for this relationship could be that these cities have the space and economic strength to develop and maintain public green spaces more uniformly across different areas, ensuring more equal access for the population. On the contrary, low developed cities do not have the economic strength to support the development of green space, and highly developed Mega Cities present a lot of spatial constraints, resulting in poorer spatial equity of green space as well. This economic characterization is also reflected in the relationship between built-up area and the Gini coefficient, in which also medium-sized cities have a better equilibrium compared to low-sized cities with high spatial extent (Figure 5c).

The fitted model of Gini coefficient of per capita green space and GDP suggests a slight negative correlation. This relationship indicates that as GDP increases, the distribution of green space per capita becomes slightly more equitable (Figure 5b). Higher-income cities likely have better urban planning policies and greater funding for green infrastructure, which helps balance the availability of green space relative to the population size, reducing disparities. This negative linear trend between the Gini coefficient of per capita green space and built-up area indicates the same patterns, In other words, cities with larger built-up areas tend to distribute green space more evenly in relation to their population, possibly due to the integration of green spaces into the urban planning process and the need to address population density through targeted infrastructure investments.

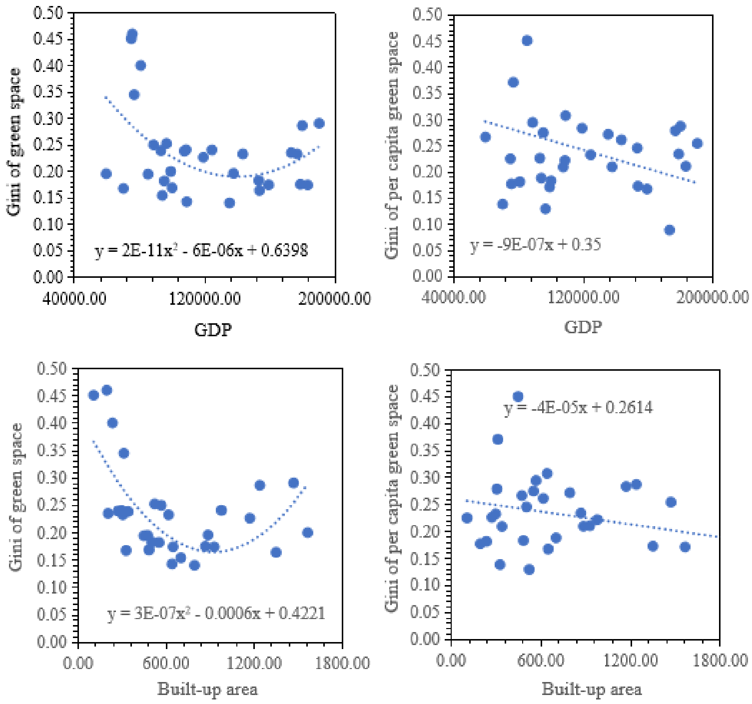

Figure 5. Relationship between Inequity of green spaces with socio-economic factors

4. Conclusions

This study employed the Gini coefficient to quantify the inequity in access to green space along spatial gradient change from urban center to edge within 32 major cities in China, based on our generated urban GV fractions dataset and concentric ring methodology. The regional disparities in the Gini coefficients for green space area and per capita green space reflect differences in urban planning and the spatial distribution of green infrastructure across China. While regions in the Central and Northeast areas show higher inequality in green space distribution, regions in the Central and Western areas exhibit more equitable access to green space per capita. Besides, the analysis reveals that economic development (GDP) and urbanization (built-up area) are key factors influencing the distribution of green space. These findings highlight the importance of region-specific urban policies that address the unique challenges of green space allocation in both densely populated and less urbanized areas.

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