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The Role of Urban Green Infrastructure in Improving Thermal Environment and Resident Health: A Case Study in Changsha, China

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Abstract. With the rapid development of cities, urban heat island effects and climate change are posing more and more threats to people's health. Urban green infrastructure, such as parks and green belts, offers a nature-based way to adjust the local microclimate and reduce temperatures. This study looks into the cooling effects of five urban green spaces in Changsha, China. Landsat 9 remote sensing images taken between 2022 and 2024 were used, and land surface temperature was calculated to compare the thermal conditions of Yuelu Mountain, Martyrs'Park, Yuehu Park, Xiaoyuan Park, and a community garden. The results show that large green spaces like Yuelu Mountain and Martyrs'Park have the best cooling effects—they can lower the surface temperature around them by up to 7.3°C compared with the nearby built-up areas (such as buildings and roads). In addition, the more vegetation a green space has, the lower the land surface temperature tends to be. Findings indicate that protecting large green spaces, while building small, closely distributed pocket parks in high-temperature areas, can help cities better adapt to climate change and improve public health.

Keywords: Urban heat island, Land surface temperature (LST), Urban green space, Cooling effect, Landsat 9

1. Introduction

1.1. Background and context

The urban heat island effect has become a major environmental challenge under rapid urbanization and global climate change. Elevated urban temperatures increase heat-related mortality and morbidity, posing significant risks to urban populations [1, 2]. Urban greening, as a nature-based solution, has gained increasing attention for its microclimate regulation capacity. Through vegetation transpiration and shading, green spaces can reduce both surface and air temperatures through tangible biophysical processes, directly mitigating urban heat islands [3]. In addition, green spaces improve air quality by absorbing pollutants and filtering particulate matter, providing urban residents with more comfortable outdoor environments [4]. During extreme heat events, greening reduces heat-stress-related health risks while offering spaces for respite and recovery, thereby enhancing urban social and ecological resilience [5].

1.2. Research problem or gap

Although there is an increased literature on green space in cities and mitigation of heat islands, there are still a number of gaps. To begin with, the research mainly dwells on megacities and second-tier cities are developing at a high rate but are scarcely studied. Second, the cooling efficiency of various classes of urban green areas is still not adequate in comparison at the intra-city level. Third, available literature tends to focus in two-dimensional vegetation indices without making a systematic measure of the cooling of various typological green spaces. The need to fill such gaps is necessary to have evidence-based urban planning that benefits well in solving the heat-related risks.

1.3. Objectives of the study

The following are the aims of this study:

The aim of the analysis is to obtain the spatial distribution of land surface temperature in summer in central Changsha.

To make comparisons of the cooling effect laid by various types of urban green spaces.

To analyze the association among considered vegetation features and the cooling eminence.

To suggest urban planning stills on better distribution of green spaces.

1.4. Significance of the study

The research work aids in the cognizance of the effect of urban green infrastructure on thermal environments in fast urbanizing cities. On the methodological side, it proves to be a joint method of retrieval using remote sensing and the comparative assessment of various types of green spaces. This study gives an empirical support as to the importance of the planning of green space in urban areas and enhancing the resilience of urban climatic conditions, and its direct implications to the public health policy in the urban areas at the second-tier pertaining to the increasing heat threats.

1.5. Overview of the paper structure

The paper is structured into the following. Part 2 summarizes previous studies in the area of the impact of urban green spaces on cooling effects. Section 3 presents the methodology and sources of data. Section 4 gives the findings of the remote sensing analysis. Section 5 talks of implications of the findings and finally with the conclusion in Section 6.

2. Methodology

2.1. Research design

This study adopts a remote sensing-based analytical framework. Landsat 9 imagery was used to retrieve land surface temperature for the summer seasons from 2022 to 2024. Five representative urban green spaces—Yuelu Mountain, Martyrs' Park, Yuehu Park, Xiaoyuan Park, and a community garden—were selected as case sites. Their vegetation characteristics and temperature data were extracted and analyzed using statistical methods.

2.2. Equations and mathematics

Land surface temperature was derived from the Landsat 9 Collection 2 Level-2 surface temperature product $(\mathrm{ST_B 10band})$, which provides atmospherically corrected LST values. The conversion from digital number to temperature follows the radiative transfer equation:

$$LST = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \tag{1}$$

where Lλis the spectral radiance at the sensor (in $\mathrm{W \cdot m^{-2} sr^{-1} \mu m^{-1}}$), and K1 and K2 are calibration constants provided in the image metadata (for Landsat 9 Band 10, K1 =774.89 $\mathrm{Wm^{-2} sr^{-1} \mu m^{-1}}$, K2 =1321.08 K). The resulting temperature in Kelvin was then converted to Celsius by subtracting 273.15.

Vegetation coverage was quantified using the Normalized Difference Vegetation Index (NDVI), calculated from Landsat 9 surface reflectance bands (Band 5: near-infrared, Band 4: red). The NDVI is defined as:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{2}$$

where ρNIR and ρRED represent the reflectance values in the near-infrared and red bands, respectively. NDVI values range from –1 to 1, with higher values indicating denser vegetation.

$$\Delta T = T_{built-up} - T_{green} \tag{3}$$

Pearson correlation analysis was employed to evaluate the relationships between vegetation coverage (NDVI), green space area, and cooling magnitude. The correlation coefficient r is calculated as:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{4}$$

2.3. Materials and equipment

The study used Landsat 9 OLI/TIRS imagery, QGIS for spatial analysis, and Microsoft Excel for statistical analysis. Land surface temperature data were derived from Landsat 9 Collection 2 Level2 surface temperature product $(\mathrm{ST_B 10band})$. Green space boundaries were delineated using highresolution satellite imagery, and park areas were obtained from the Changsha Urban Green Space Survey Report and the Hunan Statistical Yearbook. The representative temperature values presented are consistent with published studies on urban heat islands in Changsha (e.g., Li et al., 2021; Xie et al., 2024). Vegetation coverage was estimated using the Normalized Difference Vegetation Index (NDVI) calculated from Landsat 9 surface reflectance bands.

2.4. Data collection

Landsat 9 OLI/TIRS imagery was acquired from the United States Geological Survey Earth Explorer platform. Images were selected from summer months (June–August) between 2022 and 2024 under cloud-free conditions. The spatial resolution is 30 m for both thermal and multispectral bands. All images underwent geometric correction and radiometric calibration prior to analysis.

2.5. Data analysis techniques

Land surface temperature was retrieved using the radiative transfer equation method applied to the thermal infrared band of Landsat 9. Green space boundaries were manually digitized using high-resolution imagery. Vegetation coverage was calculated using the normalized difference vegetation index (NDVI). Pearson correlation analysis was used to evaluate the relationships between vegetation coverage and land surface temperature. The cooling effect of each green space was quantified by comparing its mean LST with that of the surrounding built-up area within a 300 m buffer zone.

3. Results

3.1. Spatial distribution of land surface temperature

The spatial distribution of land surface temperature in central Changsha shows clear spatial variability. Higher temperatures were mainly observed in densely built urban areas, particularly in commercial and high-density residential districts. Lower temperatures occurred in large green spaces and along water bodies such as the Xiang River.

3.2. Cooling effects of different urban green spaces

Large urban parks exhibited the strongest cooling effects. Yuelu Mountain and Martyrs' Park reduced surrounding surface temperatures by approximately 7.3°C compared with nearby built-up areas. Yuehu Park showed moderate cooling effects of 4.5°C. Xiaoyan Park and the community garden demonstrated smaller cooling magnitudes of 2°C, indicating that smaller green spaces provide localized but relatively limited cooling benefits..

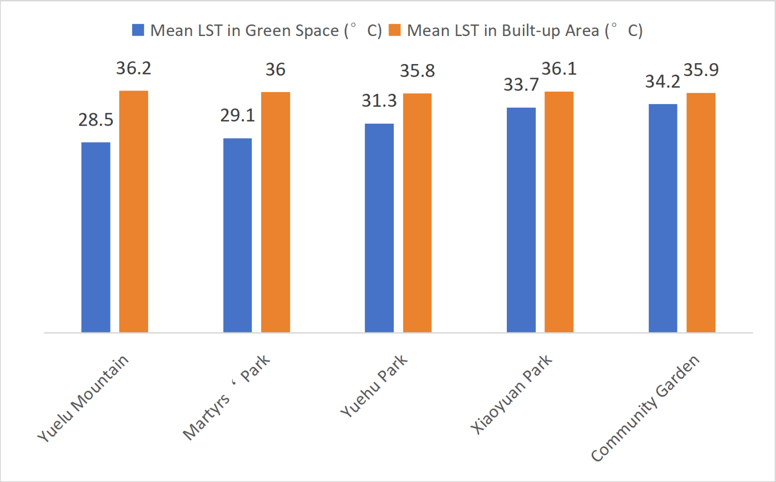

Figure 1. Mean land surface temperature of different urban green spaces and built-up areas(picture credit: original)

To compare the cooling performance of different urban green space typologies, figure1 shows that the mean land surface temperature (LST) within each green space and its surrounding built-up area was calculated. The cooling magnitude was quantified as the difference between the two. Table 1 summarizes the results for the five selected sites.

Table 1. Cooling effects of different green spaces

Green Space	Mean LST in Green Space (°C)	Mean LST in Built-up Area (°C)	Cooling Magnitude (°C)
Yuelu Mountain	28.5	36.2	7.7
Martyrs' Park	29.1	36	6.9
Yuehu Park	31.3	35.8	4.5
Xiaoyuan Park	33.7	36.1	2.4
Community Garden	34.2	35.9	1.7

Table 1 shows that the cooling magnitude varied considerably across green space types. Large natural landscapes such as Yuelu Mountain and Martyr's Park exhibited the strongest cooling effects, with temperature reductions of 7.7 °C and 6.9 °C, respectively. In contrast, the community garden and Xiaoyuan Park, both of which are smaller in size and have more fragmented vegetation, showed much lower cooling magnitudes of 1.7 °C and 2.4 °C. These findings suggest that green space size and vegetation continuity are key determinants of cooling intensity.

3.3. Relationship between vegetation characteristics and cooling effect

Figure 2 indicates a negative relationship between green space area and land surface temperature. Larger green spaces generally showed stronger cooling effects. Vegetation coverage was also negatively associated with land surface temperature across the five study sites.

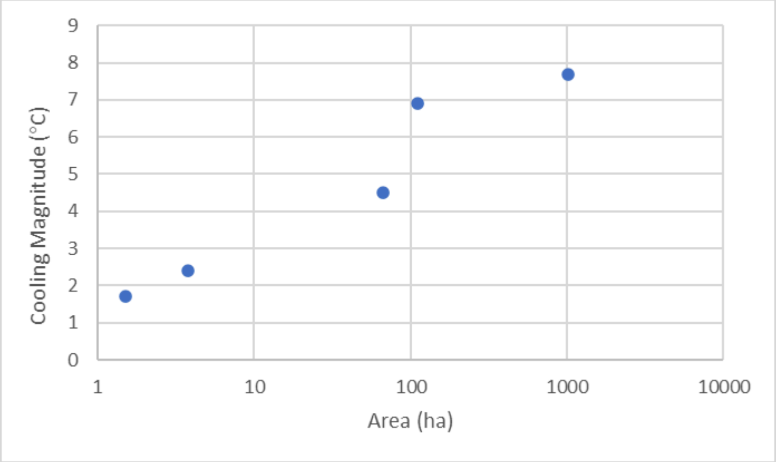

Figure 2. Relationship between green space area (log scale) and cooling magnitude. (picture credit: original)

3.4. Statistical analysis results

Table2 shows that vegetation coverage is negatively correlated with land surface temperature, indicating that areas with higher vegetation density tend to have lower surface temperatures. Green space area also showed a positive correlation with cooling intensity, suggesting that size is a key determinant of cooling magnitude.

Table 2. Correlation analysis results

Variable Pair	Correlation Coefficient (r)	Significance (p)
NDVI vs LST	-0.87	<0.01
Green Space Area vs Cooling Magnitude	0.94	<0.01

Note: LST values are based on Landsat 9 ST_B10 retrieval. Cooling magnitude = Built-up LST − Green space LST.

4. Discussion

4.1. Summary of key findings

This study analysed the spatial distribution of land surface temperature in central Changsha and compared the cooling effects of five urban green spaces. The results demonstrate that large green spaces such as Yuelu Mountain and Martyrs' Park provide the strongest cooling benefits, with relatively pronounced temperature reductions. Smaller green spaces, including community gardens, contribute localized but measurable cooling effects. Vegetation coverage was found to be negatively correlated with land surface temperature.

4.2. Comparison with previous studies

The cooling magnitudes observed in this study are consistent with previous research on urban green spaces in Chinese cities. Lu et al. (2025) reported similar cooling effects in large urban parks across 311 cities, confirming that park size and vegetation density are key determinants of cooling intensity [3]. The findings also align with previous global modelling studies [5] which identified significant heat-related mortality reduction associated with urban greenness [5-8].

4.3. Implications of the findings

Table3 and table4 show the significant cooling effects documented in this study have direct implications for public health in Changsha. Previous research has established clear links between high temperatures and increased mortality in Changsha [9, 10]. Therefore, urban planning interventions that reduce ambient temperatures can be considered public health interventions [11-13].

Table 3. Heat-related health risks and vulnerable populations in Changsha

Risk Dimension	Specific Indicator	Value / Description	Source
Heat health risk threshold	Daytime high temperature threshold	>31 °C (significantly correlated with heat-related mortality)	Xie et al., 2024 [9]
Most vulnerable population	Elderly aged ≥65 years	Most sensitive to heat waves, especially those with cardiovascular/respiratory diseases	Xie et al., 2024 [9]
Urban heat island intensity	Temperature difference between built-up and suburban areas	3–5 °C	Li et al., 2021 [11]
Summer high temperature in Changsha	Historical maximum temperature	38.5 °C	Li et al., 2021 [11]

Table 4. Cooling effects of different blue-green spaces in Changsha

Land Cover Type	Cooling Effect (Summer)	Source
Forest (e.g., Yuelu Mountain)	–0.55 °C	Qiu et al., 2021 [13]
Cropland	–0.82 °C	Qiu et al., 2021 [13]
Water body (e.g., Xiang River)	–1.29 °C	Qiu et al., 2021 [13]
Urban green space (this study)	1.7–7.7 °C (localized cooling)	This study

Table 5. Quantitative cooling-health relationship

Variable	Cooling Effect	Potential Health Impact	Source
Forest cooling	–0.55 °C (summer)	Reduces heat-related discomfort in surrounding areas	Qiu et al., 2021 [13]
Water body cooling	–1.29 °C (summer)	Strongest cooling effect, significantly improves thermal environment	Qiu et al., 2021 [13]
Large urban parks (this study)	6–8 °C	Substantial reduction in heat exposure for adjacent residents, especially elderly	This study; Xie et al., 2024 [9]
Cooling distance of green space	Mean 163 m	Residents within 163 m benefit from cooling	Qiu et al., 2021 [13]

As shown in Table 5, the cooling magnitude observed in large green spaces (6–8 °C) can substantially reduce heat exposure for residents in adjacent areas, particularly for vulnerable groups such as the elderly [11, 12].

First, protecting and expanding large parks such as Yuelu Mountain and Martyrs' Park should be prioritized, as these provide the most substantial cooling benefits and thus the greatest potential for reducing heat-related health risks [11].

Second, the development of "small but dense" pocket parks in high-temperature areas could provide localized cooling benefits for vulnerable populations, including the elderly who are most susceptible to heat stress [10, 12].

Third, the heat risk assessment framework developed by Xie et al. (2024) for old neighborhoods could be enhanced by incorporating empirical temperature data, enabling more precise identification of high-risk areas requiring urgent intervention [12, 13].

These findings are consistent with the systems-oriented approach advocated by Zheng et al. (2026), which emphasizes moving beyond isolated interventions toward integrated, equity-centered strategies that address both physical mitigation and social vulnerability [11].

5. Conclusion

Several limitations should be acknowledged. First, the study relies on single-season remote sensing data, which limits the ability to capture seasonal and interannual variability. Second, the sample size of green spaces is relatively small (n=5), which may restrict the generalizability of the conclusions. Third, critical environmental factors such as wind direction, relative humidity, and surrounding building morphology were not included in the analytical framework. Fourth, direct measurements of residents' health indicators were not performed, so the health benefits remain inferential rather than empirically measured.

Future research should address the limitations identified in this study. First, integrating multi-temporal and multi-sensor remote sensing data would enable analysis of seasonal dynamics and long-term trends. Second, expanding the sample size to include a wider range of green space types across different urban contexts would strengthen the generalizability of findings. Third, adopting advanced statistical models and spatial analysis techniques could help quantify the combined effects of multiple environmental factors on cooling performance. Fourth, extending the analysis to larger spatial scales and incorporating direct health indicators would provide more robust evidence for policy-making.

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