

XGBoost modelling of urban green space morphology and summer daytime land surface temperature

Fei Hou, Nooriati Taib^{*ID}, Massoomah Hedayati Marzbali^{ID},
Aldrin Abdullah^{ID}

School of Housing, Building and Planning, Universiti Sains Malaysia,
11800 Gelugor, Penang, Malaysia



ARTICLE INFO	ABSTRACT
<i>Article history:</i> Received April 01, 2026 Received in revised form June 08, 2026 Accepted July 22, 2026 Available online September 01, 2026 <i>Keywords:</i> Cooling effect Land surface temperature Land use and land cover Morphological spatial pattern analysis XGBoost *Corresponding author: Nooriati Taib School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Gelugor, Penang, Malaysia Email: nooriati@usm.my ORCID: https://orcid.org/0000-0001-7788-958X	<i>Rapid urbanisation has intensified summer daytime land surface temperature (LST) in many cities, yet the influence of detailed green space morphology on surface heat remains unclear. This study examines how different morphological classes of urban green space affect summer daytime LST in Shanghai. Land use and land cover data from ESRI and ECOSTRESS LST products for 2024 were aggregated into a 1 km × 1 km grid. Morphological Spatial Pattern Analysis was used to classify urban green space into core, edge and branch classes, and an explainable machine learning model with SHAP values was applied to quantify variable importance, nonlinear responses and interactions. The core and edge classes emerged as the main controls and together accounted for more than 60% of total importance, while the branch class provided additional, secondary cooling. Partial dependence results showed that higher values of core and edge classes were associated with an almost monotonic decrease in land surface temperature, and interaction analysis indicated that the lowest temperatures occurred where core and edge were both high. These findings highlight the central role of internal green space morphology in mitigating summer daytime surface heat and offer a structural basis for climate responsive urban planning.</i>

Introduction

Against the backdrop of rapid urbanisation, land use and land cover patterns are being continually reshaped (Dadashpoor, Azizi, and Moghadasi 2019). The expansion of built-up space and the growth of impervious surfaces make it easier for heat to accumulate at the land surface in cities (Wali et al. 2025). This effect is particularly evident during summer daytime, when intense solar radiation combines with complex urban spatial forms, leading to pronounced spatial differences in land surface temperature and the formation of persistent high-temperature clusters (Liang et al. 2025). Such thermal conditions not only heighten heat-exposure risks, but also place

long-term pressure on urban ecosystem stability, public health, and the efficiency of urban systems (Guo and Chen 2025). As a key indicator of surface thermal processes and heat-risk patterns, land surface temperature can directly reflect the thermal state of different spatial units and their distinct heat-accumulation characteristics (Z. Wang, Sun, and Wang 2026). Interpreting variations in land surface temperature from a spatial perspective is therefore fundamental to understanding the urban thermal environment and to developing targeted strategies for spatial governance.

Among the many factors that influence land surface temperature, urban green space is widely regarded as having considerable potential for

thermal regulation, yet its effects are often complex (Y. Wang and Ren 2025). With advances in quantitative research on landscape patterns, growing evidence shows that the morphological characteristics of urban green space commonly exhibit complex, non-linear relationships with land surface temperature (Vahid and Aly 2025; Zhu et al. 2025). Therefore, continuing to describe the relationship between urban green space and land surface temperature using linear assumptions, we risk underestimating or misjudging the true role of green-space morphology, thereby weakening the explanatory power of planning and the effectiveness of management actions. This study focuses on the nonlinear responses of morphological characteristics of urban green spaces to summer daytime land surface temperature. It seeks to provide clearer evidence of how green space form participates in urban thermal regulation in non-linear ways, and to lay a conceptual and methodological foundation for more fine-grained heat-mitigation research and subsequent spatial optimisation in practice.

Literature review research

Many studies have shown that, among the many factors shaping urban thermal environments, urban green space plays a leading role in surface cooling (Nur Ramdiana and Yola 2023; Wan Ali Yaacob 2024). Land surface temperature studies consistently report that the proportion of green space explains more variation in temperature than most built-up or sociological variables, and that increments in green cover are often associated with marked reductions in summer daytime land surface temperature (Arellano and Roca 2022). Recent studies further suggest the existence of practical thresholds: once the green space percentage exceeds certain values across different urban function zones, land surface temperature decreases rapidly and then plateaus, indicating that green space is the dominant driver of local cooling but with diminishing marginal returns (Jin et al. 2025; Zhang, Zhang, and Qi 2024).

With the development of morphological spatial pattern analysis, scholars have begun to look beyond simple green ratios to examine how specific morphological elements of green infrastructure support cooling (Budzik, Sylla, and Kowalczyk 2024; Y. Chen, Wang, and Zhou 2021). Morphological spatial pattern analysis classifies green patches into core, edge, bridge,

branch, islet, perforation, and loop classes, allowing researchers to link detailed spatial structure to thermal outcomes (Ali A. Shohan et al. 2024). Many studies have found that core green areas, characterised by compact, interior vegetation with limited edge exposure, generate the strongest cooling effect and show the most robust negative association with land surface temperature or urban heat island intensity. Edge and bridge elements also tend to contribute to temperature reduction by expanding effective cooling fronts and facilitating ventilation corridors, whereas small, isolated islets frequently exhibit weak or even negligible cooling performance (Nguyen et al. 2022; Liu et al. 2025).

Morphological spatial pattern analysis-based studies further highlight that the cooling role of green space is nonlinear (C. Huang et al. 2025). Increases in the proportion of core or connected morphological spatial pattern analysis classes produce pronounced cooling up to a critical point, beyond which further expansion yields diminishing returns. At the same time, the influence of each morphological spatial pattern analysis class varies across neighbourhoods and scales, reflecting interactions with surrounding built-up morphology and local ventilation conditions (Güller and Toy 2024). Overall, these findings converge on the view that urban green space, especially when organised as large, contiguous cores with functionally connected edges and corridors, is the primary structural lever for mitigating summer daytime surface heat, while fine-scale morphological composition determines how fully this cooling potential is realised.

Methods

Dataset

The land use and land cover dataset was obtained from Environmental Systems Research Institute, with a 10 m spatial resolution (Karra et al. 2021). It contains nine classes: water, trees, flooded vegetation, crops, built-up area, bare ground, snow/ice, clouds, and rangeland. Morphological spatial pattern analysis of urban green spaces in Shanghai was conducted using the GUIDOS Toolbox 3.2. By defining foreground and background, we extracted morphological units and finally derived seven morphological

spatial pattern analysis classes (e.g. core, edge, bridge, etc.).

Data processing

After acquiring the datasets, we generated a 1 km × 1 km regular grid based on the Shanghai boundary in ArcGIS to harmonise the spatial scale and to link green space morphology with summer daytime land surface temperature for subsequent analyses. This grid size has been shown to be suitable for examining the spatial extent of core functional areas in China (Fan et al. 2012), and avoids the heterogeneity and size variation that often affect administrative units. Using this grid

as the basic analysis unit, we overlaid the Morphological Spatial Pattern Analysis results and the ECOSTRESS land surface temperature data. For each cell, we calculated the mean summer daytime land surface temperature and the area proportion of the core, edge and branch classes of urban green space, while excluding cells with missing or invalid values. Figure 1 presents the spatial distribution of urban green space morphology and land surface temperature within the 1 km × 1 km grid across the study area, providing a consistent spatial framework for subsequent modelling and interpretation.

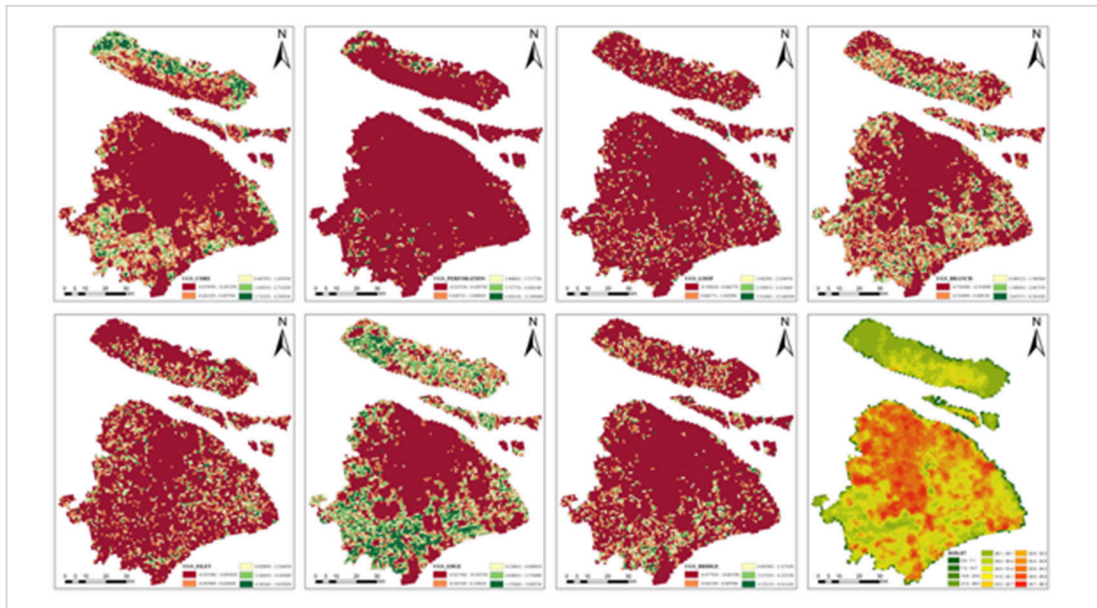


Figure 1. Morphology and land surface temperature in 1 km × 1 km grids

XGBoost

To explore the nonlinear links between urban green space morphology and summer daytime land surface temperature, we used an extreme gradient boosting model based on the XGBoost algorithm. The response variable was the mean summer daytime land surface temperature for each 1 km × 1 km grid cell, and the predictors were the area proportions of the core, edge and branch classes of urban green space derived from Morphological Spatial Pattern Analysis, together with basic land use and land cover attributes. After removing grids with missing or clearly erroneous values, all continuous predictors were standardised. The dataset was then randomly divided into a training set and a test set, using 70% of the samples for model training and 30% for

independent testing, and model hyperparameters were tuned on the training set to balance goodness of fit and overfitting risk. Based on the final model, SHAP values were calculated to quantify the relative importance of each morphological class and to interpret their marginal and joint effects, and partial dependence and interaction plots were used to describe the detailed response patterns of the core, edge and branch classes of urban green space.

Results and discussion

The importance analysis (figure 2) shows that summer daytime land surface temperature is mainly driven by the core class of urban green space (32.3%) and the edge class of urban green space (27.9%), which together account for more than 60% of the total contribution. This pattern indicates that large, contiguous core green areas and their surrounding edge zones are the key morphological components regulating surface temperature at the grid scale, forming the

structural backbone of the urban cooling system. The branch class of urban green space contributes a further 13.9%, suggesting that branch-like extensions of core patches provide additional, but secondary, cooling influence, mainly by extending the reach of cooling into neighbouring built-up areas. Overall, the ranking of importance highlights that consolidating core green spaces and maintaining well-developed edge belts is far more effective for mitigating summer daytime heat than simply increasing scattered or narrow green strips.

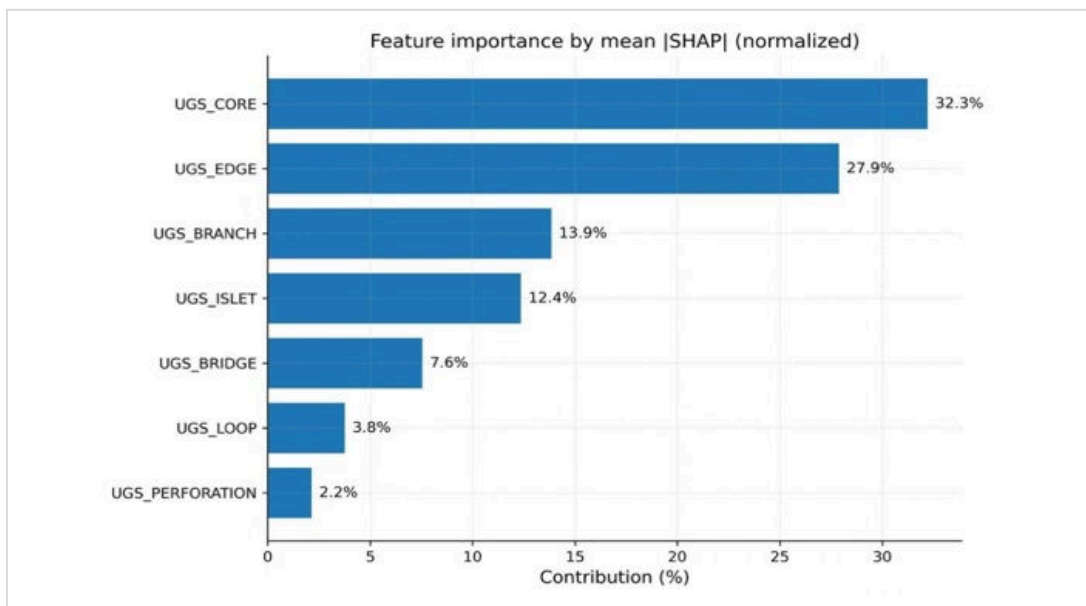


Figure 2. Feature importance analysis results

The partial dependence plots (figure 3) show that increases in the core class of urban green space are associated with a clear and almost monotonic decrease in summer daytime land surface temperature, with the cooling effect becoming stronger as core values enter the upper range, where each additional increase in core area yields a marked temperature drop. A similar downward pattern appears for the edge class of urban green space, indicating that enlarging edge zones around core patches also steadily reduces temperature and helps to transmit cooling from

interior vegetation to surrounding built up areas. By contrast, the branch class of urban green space displays a more fluctuating response at low and medium values, reflecting its greater sensitivity to local context and background land use, but still shows an overall downward tendency at higher values. This suggests that branch like extensions provide additional, though less stable, cooling benefits that depend on being connected to substantial core and edge structures rather than operating as an independent cooling source.

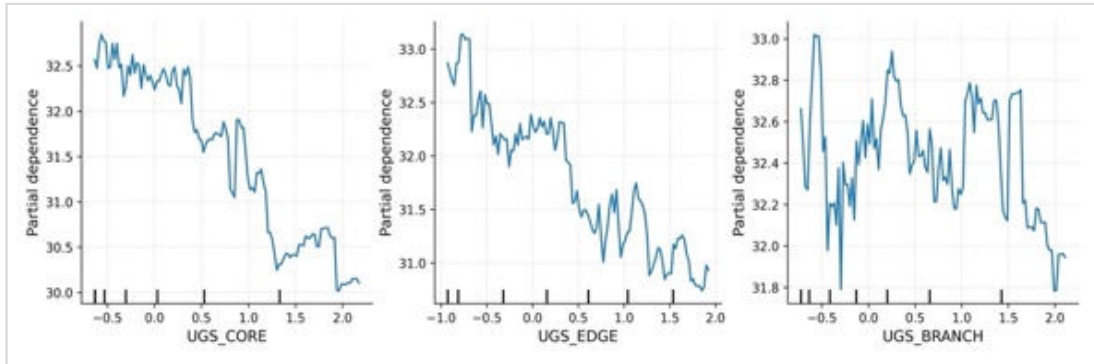


Figure 3. The partial dependence plots

The interaction plots (figure 4) show that summer daytime land surface temperature is lowest in grids where the core class of urban green space and the edge class of urban green space are both high, with strongly negative SHAP values indicating a pronounced joint cooling effect and a clearly synergistic relationship between interior and boundary vegetation. When the core class of urban green space interacts with the branch class of urban green space, core areas continue to provide the primary cooling, while moderate levels of branch structures add further reductions in temperature by extending cooling pathways

into adjacent built up cells, although this influence weakens where branch values are very low or very high. For the interaction between the edge class of urban green space and the branch class of urban green space, edge zones maintain a relatively stable cooling role that is partly strengthened by higher branch values, but the pattern is more scattered, suggesting that branch elements mainly reinforce the cooling generated by core and edge configurations and remain secondary compared with the dominant effect of large cores wrapped by well developed edges.

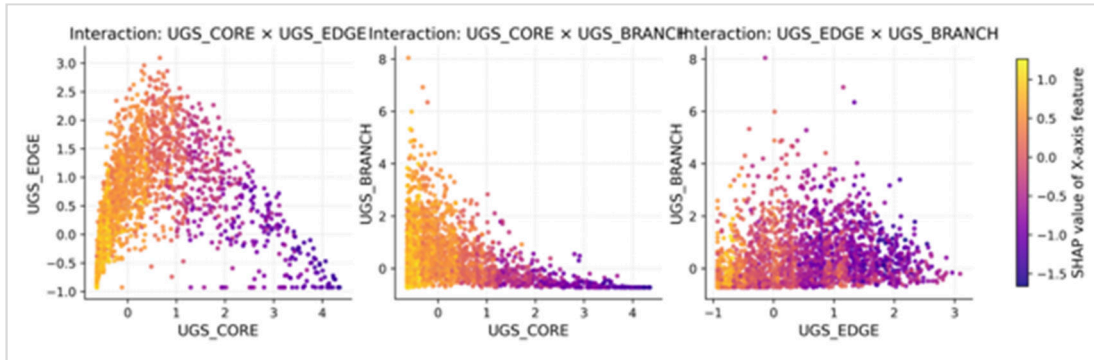


Figure 4. The interaction plots

Discussion

This study shows that the morphological structure of urban green space is a decisive factor in regulating summer daytime land surface temperature (Z. Huang et al. 2025). The importance analysis highlights the core class and the edge class of urban green space as the dominant drivers, together explaining more than 60% of the model contribution, with the branch class playing a secondary but still meaningful role. This hierarchy confirms that it is not only the presence of green space that matters, but also how

vegetation is organised within the urban fabric (Yuliani et al. 2026). Large, contiguous core areas appear to function as stable cooling effect, while their surrounding edges act as key transition zones where cooling can spread into adjacent built-up space (Hou et al. 2026).

The partial dependence results strengthen this interpretation. The almost monotonic decline in land surface temperature with increasing core and edge values indicates a robust cooling response once core green space becomes sufficiently extensive and well framed by edge zones. In

contrast, the more irregular pattern for the branch class suggests that linear extensions of green space do not guarantee cooling on their own; their effectiveness likely depends on being anchored to substantial core areas. Branch structures can improve the reach of cooling, but without a strong core and edge base their influence remains limited and unstable (Liu et al. 2025).

The interaction analysis further demonstrates that cooling is not simply the sum of individual morphological effects. The lowest temperatures occur where both the core and edge classes are high, pointing to a strong synergistic effect: compact, interior vegetation combined with broad edge belts creates a composite structure that maximises local cold-air production and diffusion (Yu et al. 2025). Interactions between the core and branch classes, and between the edge and branch classes, show that branch elements primarily reinforce the cooling created by cores and edges rather than acting as independent drivers (Xie et al. 2015; M. Chen et al. 2024).

These results have clear planning implications. Urban greening policies should prioritise the consolidation and protection of large core green spaces, while ensuring that these cores are wrapped by well-connected edges that interface effectively with surrounding streets and neighbourhoods (M. Chen et al. 2024; Liu et al. 2025). Branch elements can then be used to extend cooling corridors into densely built areas, but should be designed as complements to, rather than substitutes for, core and edge structures (Hsu, Sathianarayanan, and Gianoli 2025). By framing urban green space as a system of interacting morphological classes, this study provides a more operational basis for designing green infrastructure that targets surface heat where it is most critical.

Conclusions

This study demonstrates that summer daytime land surface temperature in Shanghai is controlled primarily by the core and edge classes of urban green space, with the branch class providing secondary support. Core areas act as the main cooling reservoirs, edge zones transfer this cooling to surrounding land, and branch elements extend the influence along linear paths. The strongest cooling emerges where core and edge values are both high, revealing a clear joint effect

and indicating that compact continuous vegetation combined with extensive edge belts forms the most effective configuration at the grid scale. These findings suggest that urban heat mitigation should prioritise protecting and enlarging core green areas, strengthening their edge interfaces with streets and neighbourhoods, and then using branch corridors in a complementary way to channel cooling into dense built-up districts. In doing so, planners can move from simply increasing green quantity to deliberately shaping green space structure for maximum thermal benefit.

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Author(s) contribution

- Fei Hou** contributed to the preparation of research concepts, methodologies, investigations, data analysis, visualizations, and article drafting.
- Nooriati Taib** contributed to the preparation of research concepts, literature reviews, data analysis, and the preparation and validation of article drafts.
- Massoomeh Hedayati Marzbali** contributed to methodologies, supervision, and validation.
- Aldrin Abdullah** contributed to methodologies, supervision, and validation.