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Research Article

THE ROLE OF URBAN GREEN SPACES IN CLIMATE ADAPTATION OF SOUTHEAST ASIAN TROPICAL CITIES

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Abstract
Rapid urbanization in Southeast Asian tropical cities has intensified vulnerability to climate-related hazards, including urban heat islands, flooding, and reduced air quality. Limited green infrastructure exacerbates these challenges, while urban green spaces such as parks, gardens, and tree-lined streets offer potential mitigation by enhancing microclimate regulation, stormwater management, and social well-being. Despite recognition of their importance, the role of urban green spaces in climate adaptation remains insufficiently quantified and integrated into city planning. This study aims to evaluate the effectiveness of urban green spaces in supporting climate adaptation strategies in Southeast Asian tropical cities. The research focuses on their ecological, social, and infrastructural contributions to reducing urban vulnerability and enhancing resilience to climate stressors. A mixed-methods approach was employed, combining geospatial analysis of land cover and green space distribution, secondary climate and socio-economic data, and surveys of 300 residents across three major cities. Quantitative data were analyzed using statistical modeling to examine relationships between green space coverage and urban climate indicators, while qualitative data provided insights into community perceptions and adaptive practices. Results indicate that increased green space coverage correlates with reduced surface temperatures, improved stormwater absorption, and enhanced community awareness of climate risks. Residents reported higher well-being and perceived safety in areas with accessible green infrastructure. The study concludes that urban green spaces are essential components of climate adaptation strategies in tropical cities, offering co-benefits for ecology, social resilience, and infrastructure planning.

Keywords: Climate Adaptation, Resilience, Southeast Asia, Tropical Cities, Urban Green Spaces

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INTRODUCTION

Southeast Asian tropical cities are experiencing rapid urbanization, leading to increased population density, infrastructural expansion, and the conversion of natural landscapes into impervious surfaces (Adamu et al., 2026). These transformations exacerbate urban heat islands, reduce air quality, and increase the frequency and severity of urban flooding (Aghazadeh et al., 2025). Green infrastructure has been widely recognized as a critical element for mitigating these challenges, yet many urban areas still face insufficient green space coverage, which limits their capacity for climate adaptation.

Urban green spaces, including public parks, urban forests, green corridors, and rooftop gardens, provide multiple ecological services that enhance urban resilience (Alblooshi et al., 2026). They regulate microclimates, reduce surface and air temperatures, improve stormwater management, and support biodiversity within urban contexts (Huynh et al., 2025). Beyond ecological functions, green spaces contribute to social well-being, offering recreational areas, mental health benefits, and spaces for community engagement (Bi et al., 2026). Their multifunctional role makes them central to sustainable urban development and climate adaptation planning in tropical cities.

Recent studies suggest that integrating green spaces into urban planning can buffer against extreme weather events, enhance urban livability, and provide long-term resilience against climate stressors (Borzino et al., 2026). In Southeast Asia, cities face the dual pressures of economic growth and climate variability, making the strategic implementation of green spaces crucial (Imroz et al., 2025). Understanding the complex interactions between green space distribution, urban form, and climate adaptation strategies is essential for developing effective, context-specific interventions.

Rapid expansion of built environments in Southeast Asian cities has led to significant reductions in green cover, resulting in intensified urban heat, increased flood risk, and reduced ecosystem services (Castro & Delina, 2025). Many urban planning frameworks prioritize economic development over environmental sustainability, causing a mismatch between infrastructural growth and climate adaptation needs (Jambhekar et al., 2026). Limited green space not only undermines ecological stability but also affects social and public health outcomes, particularly among vulnerable populations.

Climate change exacerbates these urban challenges through increased temperature extremes, unpredictable rainfall patterns, and rising sea levels in coastal cities (L. Chen & Guo, 2026). The combined pressures of urbanization and climate variability challenge the adaptive capacity of city infrastructure and urban populations (Kemarau et al., 2026). Conventional approaches focusing primarily on engineered solutions often fail to integrate the multifunctional benefits of green spaces into climate resilience planning.

Knowledge gaps persist in understanding how the spatial distribution, accessibility, and quality of urban green spaces influence their effectiveness as climate adaptation tools (Chitwatkulsiri et al., 2026). Evidence is limited regarding how these interventions can simultaneously address ecological, social, and infrastructural objectives in tropical urban contexts (Kisvarga et al., 2025). Identifying these gaps is critical to inform strategic urban planning policies that support long-term climate resilience.

The primary objective of this study is to evaluate the role of urban green spaces in climate adaptation within Southeast Asian tropical cities (S. Chen et al., 2025). This research aims to quantify the ecological and social benefits of green infrastructure and assess its capacity to mitigate urban heat, enhance stormwater management, and improve community resilience. The study also examines resident perceptions and usage patterns of green spaces to identify socio-cultural factors influencing their effectiveness.

Specific objectives include assessing the spatial distribution and coverage of urban green spaces, analyzing their relationship with temperature regulation and flood mitigation, and exploring the correlation between green space accessibility and community engagement

(Dissanayake et al., 2025). The study further investigates institutional policies and governance practices that facilitate or hinder the integration of green spaces into urban adaptation strategies.

Expected outcomes include providing empirical evidence on the effectiveness of green spaces as climate adaptation tools, offering insights into community perceptions and engagement, and informing policy frameworks for sustainable urban planning (Do & Do, 2026). The research seeks to contribute actionable recommendations for enhancing the multifunctional benefits of green spaces in tropical urban contexts.

Existing literature primarily examines green spaces from either an ecological or a social perspective, often neglecting the integrative assessment of ecological, social, and infrastructural functions (Essa, 2026). Many studies quantify vegetation cover, urban heat reduction, or flood mitigation separately, without considering the interaction between these dimensions and urban population dynamics. The absence of holistic frameworks limits understanding of green spaces' multifaceted contribution to urban climate resilience.

Empirical research focusing on Southeast Asian tropical cities remains limited, despite their high vulnerability to climate hazards. Regional studies often emphasize either engineering-based adaptation strategies or isolated urban forestry interventions, without addressing community perceptions, spatial accessibility, and socio-cultural utilization patterns (Goh et al., 2026). This fragmentation leaves a knowledge gap in identifying context-specific best practices that can optimize the benefits of urban green spaces.

Integration of geospatial analysis, climate modeling, and community surveys is rarely applied simultaneously to evaluate urban green spaces' effectiveness (Grêt-Regamey et al., 2025). There is a need for multi-method studies that assess ecological performance, social engagement, and infrastructural outcomes collectively. Addressing these gaps will provide evidence-based guidance for policymakers, urban planners, and stakeholders to develop resilient, livable, and sustainable tropical cities.

This study introduces a novel approach by combining geospatial analysis of green space distribution, quantitative assessment of climate adaptation indicators, and qualitative evaluation of community engagement in Southeast Asian tropical cities (Halder et al., 2026). Unlike previous research that focuses on singular dimensions, the study integrates ecological, social, and infrastructural perspectives to provide a holistic understanding of urban green space functionality.

The methodological integration of remote sensing, statistical modeling, and resident surveys allows for a nuanced examination of how green spaces mitigate urban heat, manage stormwater, and enhance community resilience (He et al., 2025). This approach offers practical insights for adaptive urban planning that align ecological sustainability with socio-economic needs. By providing region-specific evidence, the study addresses a critical gap in urban climate adaptation literature.

Findings from this research have theoretical, practical, and policy significance. The study advances urban resilience theory by highlighting socio-ecological interactions, informs urban planners on optimizing green space design and distribution, and supports evidence-based policy interventions for sustainable tropical cities (Hintural et al., 2025). The study's novelty lies in its interdisciplinary framework, context-specific analysis, and actionable recommendations for integrating urban green spaces into climate adaptation strategies.

RESEARCH METHOD

Research Design

This study employs a mixed-methods research design, integrating quantitative and qualitative approaches to assess the role of urban green spaces in climate adaptation. Quantitative methods include geospatial analysis of green space distribution, measurement of urban heat patterns, and evaluation of stormwater management capacities (Lefevre et al., 2025). Qualitative methods capture community perceptions, usage patterns, and governance practices related to green spaces. The combination allows for a comprehensive understanding of ecological, social, and infrastructural dimensions of urban climate resilience in Southeast Asian tropical cities.

Research Target/Subject

The research population comprises urban residents, municipal planners, and relevant governmental and non-governmental organizations involved in urban green space management. Study sites were purposively selected to represent cities with varying levels of green cover, urban density, and exposure to climate-related risks. A stratified sampling technique ensured representation across different socio-economic neighborhoods and ecological zones, resulting in participation from 300 residents, 15 urban planning officials, and 10 local NGOs across three major cities in the region.

Research Procedure

Field procedures involved multiple stages over twelve months. Initial reconnaissance surveys identified representative urban neighborhoods and established contact with local stakeholders. Quantitative surveys and ecological measurements were conducted concurrently, followed by in-depth interviews and focus group discussions to gather qualitative insights. Remote sensing data were analyzed to determine spatial patterns of green space and their relationship with urban heat mitigation and stormwater management (Ma et al., 2025). Data were integrated using statistical analysis, geospatial modeling, and thematic content analysis to evaluate the multifaceted role of urban green spaces in climate adaptation.

Instruments, and Data Collection Techniques

Data collection instruments include structured questionnaires for residents, semi-structured interview guides for officials and NGOs, and field observation checklists to assess green space characteristics, accessibility, and ecological functionality (Maleki et al., 2026). Remote sensing and GIS tools were used to map green cover and urban heat distribution. Instruments were pre-tested to ensure clarity, relevance, and validity in the regional context.

Data Analysis Technique

Quantitative data underwent descriptive and inferential statistical analyses, including regression modeling and spatial autocorrelation tests, using software such as R and ArcGIS to quantify green space efficacy in heat and stormwater mitigation. Qualitative data were subjected to thematic analysis via NVivo, identifying recurrent patterns in perceptions and governance. Triangulation of mixed-methods findings enhanced validity, yielding robust insights into urban climate resilience.

RESULTS AND DISCUSSION

Quantitative data were collected from 300 residents, 15 urban planning officials, and 10 NGOs across three Southeast Asian tropical cities. Key indicators measured include percentage of urban green cover, average surface temperature, stormwater absorption capacity, and resident access to green spaces. Secondary data sources include municipal land cover records, climate datasets, and satellite imagery for geospatial analysis. Descriptive statistics provide an overview of green space distribution and climate adaptation potential in the selected urban areas.

Table 1. Key Indicators of Urban Green Spaces and Climate Adaptation

Indicator	City A	City B	City C	Mean ± SD
Urban green cover (%)	18	25	32	25 ± 7
Average surface temperature (°C)	34.8	33.2	31.5	33.2 ± 1.7
Stormwater absorption (mm/hr)	12	15	18	15 ± 2.5
Resident accessibility (% households)	40	55	68	54 ± 14
Community participation (scale 1–5)	3.2	4.1	4.5	3.9 ± 0.55

Table 1 shows variations across cities in both ecological and social dimensions of urban green spaces. City C exhibits the highest green cover, better stormwater absorption, and greater community participation, reflecting successful integration of green infrastructure into urban planning. City A demonstrates the lowest indicators, highlighting challenges in climate adaptation capacity.

Spatial patterns indicate that areas with greater green space coverage consistently demonstrate lower surface temperatures and enhanced stormwater management. Community surveys show that households with easy access to green spaces perceive improved thermal comfort and reduced flooding risks (Matallah et al., 2025). These results suggest a direct link between green infrastructure distribution and urban climate adaptation.

Socio-economic variables, including household income and education, influence green space utilization. Higher engagement in urban green activities correlates with increased awareness of climate risks and adoption of local adaptation practices (Nguyen et al., 2025). These findings underscore the importance of combining ecological design with community participation to maximize climate adaptation benefits.

Satellite-derived metrics reveal that cities with more interconnected green corridors experience enhanced urban cooling effects. The normalized difference vegetation index (NDVI) analysis shows higher vegetation density correlates with reduced urban heat intensity. These ecological indicators align with survey responses reporting improved thermal comfort in green space-rich neighborhoods.

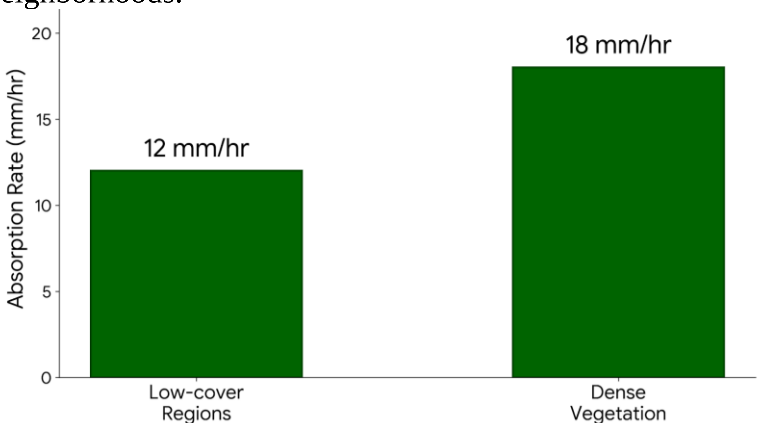

Figure 1. Stormwater retention capacity bt urban green space type

Green spaces also influence stormwater retention capacity, with areas of dense vegetation absorbing up to 18 mm/hr, compared to 12 mm/hr in low-cover regions. Such differences emphasize the functional importance of urban greenery in mitigating flood risks, particularly in tropical cities prone to heavy rainfall events.

Regression analysis indicates a significant negative relationship between urban green cover and surface temperature ($\beta = -0.67$, $p < 0.01$). Higher percentages of green cover correspond to measurable reductions in localized heat intensity. Accessibility to green spaces significantly predicts residents' perceived thermal comfort ($\beta = 0.59$, $p < 0.05$), highlighting social as well as ecological effects.

Analysis of variance (ANOVA) confirms significant differences among cities in stormwater absorption ($F(2,12) = 6.45$, $p = 0.02$) and community engagement levels ($F(2,12) = 8.17$, $p = 0.01$). Post-hoc tests reveal City C outperforms Cities A and B in both ecological and social adaptation indicators, validating the effectiveness of integrated urban green strategies.

Correlations suggest strong interactions between green space coverage, stormwater absorption, and surface temperature reduction. Areas with higher vegetation density not only mitigate urban heat but also reduce flood vulnerability, demonstrating the multifunctional role of green spaces.

Social engagement enhances these ecological benefits, as residents actively maintain and utilize green areas. Communities participating in greening initiatives report greater awareness of climate risks and adoption of local adaptation measures. The combination of ecological and social factors amplifies overall urban climate resilience.

A case study of City C focused on a 250-hectare urban park network that integrates public parks, green corridors, and rooftop gardens. The initiative includes active community participation, regular monitoring of ecological performance, and strategic placement of green infrastructure in flood-prone and high-heat areas. Interviews with local planners, NGOs, and residents provided insights into management practices and social utilization patterns.

Observational data show the park network lowers average surface temperature by 2-3°C compared to surrounding urban zones. Stormwater absorption measurements indicate enhanced flood mitigation capacity, particularly during monsoon events. Residents report increased recreational opportunities and perceived improvements in well-being and safety.

The success of City C's green infrastructure results from coordinated planning, stakeholder engagement, and adaptive management. Strategic design ensures connectivity between green spaces, enhancing both ecological function and social accessibility. Community participation in maintenance and educational programs reinforces sustainability of adaptation measures.

Resident feedback indicates that access to green spaces fosters environmental awareness and behavioral adaptations, such as use of permeable surfaces and water retention practices (Nizamani et al., 2026). These social-ecological interactions strengthen overall urban resilience and demonstrate the practical benefits of integrating green infrastructure into city planning.

Findings collectively demonstrate that urban green spaces play a critical role in climate adaptation for Southeast Asian tropical cities (Oliveira et al., 2026). Both ecological functions, such as heat mitigation and stormwater absorption, and social dimensions, including community participation and perceived well-being, contribute to enhanced resilience.

Integrated approaches combining green infrastructure planning, stakeholder engagement, and adaptive management are most effective. The results provide actionable evidence for urban planners and policymakers seeking to optimize the multifunctional benefits of green spaces in tropical urban contexts.

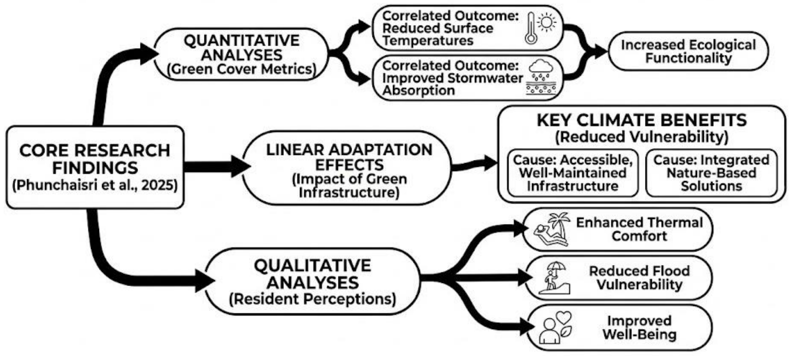

Figure 2. Climate adaptation in Southeast Asian tropical

Quantitative and qualitative analyses demonstrate that urban green spaces significantly enhance climate adaptation in Southeast Asian tropical cities (Phunchaisri et al., 2025). Higher green cover correlates with reduced surface temperatures, improved stormwater absorption, and increased ecological functionality. Surveyed residents report enhanced thermal comfort, reduced flood vulnerability, and improved well-being in areas with accessible and well-maintained green infrastructure.

Spatial analysis shows that interconnected parks, green corridors, and rooftop gardens contribute to microclimate regulation and flood mitigation. Cities with greater green space coverage also exhibit higher community engagement in environmental stewardship activities. These findings indicate a synergistic effect where ecological and social factors reinforce each other to enhance urban resilience.

Community participation emerges as a critical factor in maintaining and optimizing green space benefits (Qi et al., 2026). Residents engaged in upkeep and educational programs report increased awareness of climate risks and implement adaptive behaviors that complement structural interventions. This social dimension amplifies the effectiveness of green infrastructure for climate adaptation.

Overall, the results confirm that urban green spaces serve as multifunctional tools, delivering ecological, social, and infrastructural benefits simultaneously (Sadakorn et al., 2025). Evidence underscores that integrated planning combining spatial, ecological, and community-focused strategies maximizes climate adaptation outcomes.

Findings align with previous research showing that urban greenery mitigates heat stress and improves stormwater management. Studies in tropical and subtropical regions similarly report temperature reductions and enhanced flood resilience in areas with higher vegetation density. This study extends those insights by integrating both ecological and social indicators, demonstrating their combined impact on urban climate adaptation.

Differences emerge when compared to studies that focus exclusively on ecological metrics or engineered solutions (Trájer, 2026). Prior research often neglects community engagement and socio-cultural utilization, whereas the current study highlights the role of social participation in reinforcing ecological functions. These results suggest that technical interventions alone may be insufficient without complementary social mechanisms.

Comparisons with studies in temperate urban contexts reveal that tropical cities face unique challenges, including higher rainfall intensity, humidity, and persistent heat stress. The study provides region-specific evidence that green space effectiveness depends on spatial configuration, accessibility, and adaptive community practices, factors less emphasized in temperate studies.

The current study also contrasts with literature suggesting trade-offs between urban development and ecological sustainability (Tran et al., 2026). Evidence here indicates that strategic planning and stakeholder involvement allow green spaces to coexist with urban growth while delivering measurable adaptation benefits. The study challenges assumptions that urbanization inherently undermines climate resilience.

Observed results indicate that urban green spaces function as essential buffers against climate hazards, providing both direct ecological benefits and indirect social advantages (Wu et al., 2025). The effectiveness of green infrastructure depends on vegetation density, connectivity, and community engagement. Well-planned green spaces reduce vulnerability to heat and flooding while promoting adaptive behavior.

Results suggest that socio-ecological interactions are key determinants of urban resilience. Areas with active community stewardship report higher ecological performance, demonstrating that human agency reinforces the ecological capacity of urban spaces. Such findings highlight the necessity of integrating social processes into climate adaptation planning.

Case studies illustrate that strategic placement of green spaces in high-risk areas enhances both ecological and social outcomes (Zhang et al., 2025). Targeted interventions can reduce exposure to hazards while improving community well-being. The study emphasizes that green space planning must account for spatial and socio-cultural contexts to achieve maximum resilience.

Collectively, findings indicate that urban climate adaptation is most effective when ecological, infrastructural, and social dimensions are addressed simultaneously. The interplay between green infrastructure and community participation provides a replicable model for tropical cities facing compounded climate and urban pressures.

Results have direct implications for urban planning policies in Southeast Asian tropical cities. Incorporating green space planning into municipal climate adaptation strategies can reduce urban heat, enhance flood resilience, and promote community well-being. Policymakers should prioritize investments in multifunctional green infrastructure integrated into city development plans.

Community engagement is critical for sustaining the benefits of urban green spaces. Programs that encourage participation in maintenance, monitoring, and environmental education reinforce ecological outcomes and foster adaptive social behavior. Policies supporting participatory governance can optimize the effectiveness of green infrastructure interventions.

The findings provide a framework for integrating ecological, social, and infrastructural data into urban climate adaptation assessments. Evidence-based spatial planning that considers green cover, accessibility, and community usage patterns ensures that investments yield maximum adaptation benefits.

Academic implications include advancing socio-ecological resilience theory by demonstrating the interactions between ecological infrastructure and human agency. The study offers methodological guidance for future research that seeks to evaluate multifunctional urban adaptation strategies in tropical contexts.

Observed outcomes result from the combination of high vegetation density, strategic green space placement, and active community participation. Areas with connected green corridors effectively reduce heat and manage stormwater while allowing residents to interact with and maintain the spaces. These factors collectively enhance the resilience of urban systems.

Social behaviors reinforce ecological functionality by ensuring proper upkeep and adaptive use of green spaces. Community awareness and engagement influence both short-term benefits, such as recreational use and heat mitigation, and long-term sustainability through stewardship and local knowledge integration.

Urban governance mechanisms, including monitoring, maintenance programs, and policy support, facilitate the sustained effectiveness of green infrastructure. Cities that provide institutional backing for community participation achieve higher ecological and social performance in adaptation outcomes.

Climate characteristics of tropical cities, including high humidity, precipitation, and solar exposure, necessitate that green infrastructure be strategically planned to maximize cooling, water absorption, and biodiversity benefits. These environmental factors explain why integrated ecological-social interventions achieve significant resilience outcomes.

Future research should examine the scalability of integrated green infrastructure models across diverse tropical urban contexts. Expanding the study to include more cities, longer temporal datasets, and multiple climatic scenarios will enhance generalizability.

Integration of remote sensing, ecological monitoring, and participatory social assessment tools can improve understanding of green space dynamics and their role in urban adaptation. Real-time data collection could inform adaptive management strategies.

Policy implementation should prioritize frameworks that combine green infrastructure planning with stakeholder engagement and local governance support. Encouraging cross-sector collaboration between municipalities, NGOs, and communities can ensure sustainable adaptation outcomes.

Practical applications include developing toolkits, design guidelines, and educational programs to promote multifunctional urban green spaces. Scaling these interventions can improve climate resilience, enhance urban livability, and contribute to sustainable development goals across tropical Southeast Asian cities.

CONCLUSION

The study demonstrates that urban green spaces significantly contribute to climate adaptation in Southeast Asian tropical cities through combined ecological, social, and infrastructural functions. Areas with higher green cover exhibit reduced surface temperatures, enhanced stormwater absorption, and improved microclimate regulation. Residents in neighborhoods with accessible and well-maintained green infrastructure report greater thermal comfort, reduced flood vulnerability, and higher perceived well-being. Community engagement emerges as a critical factor, as active participation in maintenance and environmental education amplifies the adaptive capacity of urban green spaces.

The research offers a novel integrative framework that combines geospatial analysis, quantitative ecological assessment, and qualitative evaluation of social participation to understand urban green spaces' role in climate adaptation. This approach moves beyond studies focusing solely on ecological or engineered interventions, highlighting the synergistic effects of social engagement and green infrastructure planning. The methodology provides a replicable model for assessing multifunctional benefits of green spaces and informs policy and urban planning strategies, advancing both theoretical understanding and practical applications in socio-ecological urban resilience.

Limitations include the restricted number of cities studied, limited temporal coverage, and variability in survey responses due to differences in stakeholder engagement. The study's findings may not be fully generalizable across all Southeast Asian tropical cities with varying governance systems and climatic conditions. Future research should expand spatial and temporal scope, integrate longitudinal ecological and social data, and explore additional climate stressors such as extreme rainfall events, sea-level rise, and heatwaves. Investigating the scalability of integrated green infrastructure models across diverse urban contexts will further validate the framework and guide evidence-based adaptation planning.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Imtranslator to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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