Volume : 2 | Issue : 1 | Received-27-12-2025 | Accepted-06-01-2026 | Published-07-01-2026

UAI JOURNAL OF MULTIDISCIPLINARY & CULTURAL STUDIES (UAIJMCS)

Abbreviated Key Title: UAI J Mult Cul Stu.
ISSN: 3049-2351 (Online)
Journal Homepage: https://uaipublisher.com/uaijmcs-2/
Volume- 2 Issue- 1 (January- February) 2026
Frequency: Bimonthly

Assessing the Role of Green Infrastructure in Urban Temperature Mitigation and Climate Resilience in the Abuja Municipal Area Council, Nigeria

Feyi Hauwa Garr[1*], Alhassaan Mamman Mohammed[2], Ibrahim Musa[3]

[1] Sustainable Development Centre University of Abuja
[2] Department of Geography and Environmental Sciences University of Abuja
[3] Department of Economics University of Abuja

Corresponding Author: Feyi Hauwa Garr

ABSTRACT

This study examines the role of green infrastructure in mitigating urban heat island (UHI) effects and enhancing climate resilience in the Abuja Municipal Area Council (AMAC), Nigeria, between 1994 and 2024. Employing a mixed-methods approach, the research integrates quantitative geospatial analysis of multi-temporal Landsat imagery and long-term atmospheric temperature records with qualitative data from resident surveys and expert interviews. Findings reveal a pronounced increase in surface temperatures, particularly in densely built-up areas, despite only moderate increases in atmospheric temperatures, indicating an intensification of the UHI effect. Land use and land cover (LULC) analysis shows a drastic decline in vegetation cover from 63% to 8%, coupled with a fivefold expansion of built-up areas, resulting in fragmented green spaces and reduced natural cooling capacity. Ecological indices highlight extreme thermal polarisation, while resident perceptions confirm that urban heat is a serious and escalating concern. Governance and institutional constraints, including inadequate funding, weak enforcement, and limited political will, are identified as significant barriers to the effective implementation of green infrastructure. The study concludes that green infrastructure is critical for regulating urban microclimates and enhancing climate resilience in AMAC. It recommends integrated planning, increased investment, and policy reforms to expand and connect urban green spaces, thereby mitigating the impacts of UHI and supporting sustainable urban development.

KEY WORDS: Green Infrastructure, Urban Heat Island, Land Surface Temperature and Climate Resilience

Introduction

Rapid urbanisation and climate change are driving significant increases in urban temperatures, often leading to the development of urban heat islands (UHIs) that negatively impact human health, energy demand, and environmental quality (Suleiman et al., 2025; Ibrahim et al., 2025). In many cities worldwide, including tropical cities such as Abuja, impervious surfaces like asphalt and concrete absorb and retain heat, resulting in elevated surface and air temperatures relative to surrounding rural areas (Oke, 1982, as cited in Yang et al., 2024). This phenomenon exacerbates thermal discomfort, heightens cooling energy consumption, and undermines climate resilience at local scales, creating an urgent demand for effective mitigation strategies.

DOI: 10.5281/zenodo.18171439

Urban green infrastructure (GI)—comprising parks, street trees, green roofs, urban forests, and other vegetation-based systems—has been widely promoted in both academic and policy arenas as a nature-based solution to mitigate urban thermal stress and enhance climate resilience. Green infrastructure, though associated with high import costs (Magaji et al., 2022), provides multiple ecosystem services that reduce ambient temperatures through mechanisms such as shading, evapotranspiration, and reduced heat absorption relative to built surfaces (Greene, 2024; Nagy, 2024). A growing body of research demonstrates that green infrastructure not only moderates local climates but also supports biodiversity, creates employment, improves air quality, and contributes to sustainable urban development (Adekoya et al., 2025; Abeke et al., 2025; Magaji et al., 2024).

Empirical research consistently finds that increasing vegetation cover in urban environments leads to measurable reductions in land surface temperature (LST) and air temperature, thereby diminishing the intensity of urban heat islands. For example, remote sensing studies in rapidly developing cities have shown that vegetated and water-covered areas consistently exhibit lower surface temperatures than dense built-up zones, underscoring the cooling potential of green and blue spaces (Anyakora et al., 2025). These findings suggest that strategic expansion and integration of green infrastructure can play a significant role in regulating urban temperatures.

Beyond thermal effects, green infrastructure is increasingly recognised as an essential component of climate resilience frameworks. By mitigating extreme heat events and enhancing adaptive capacity, green infrastructure helps reduce climate-related risks for vulnerable urban populations. Meta-analyses and reviews underscore its multifaceted benefits for climate adaptation, including reductions in energy demand, improvements in social well-being, and environmental sustainability (Nagy, 2024). However, the extent to which these global insights are reflected in specific contexts, such as the Abuja Municipal Area Council (AMAC), where rapid population growth and urban expansion present unique challenges, remains underexamined.

Given the evidence linking green infrastructure to urban cooling and broader climate resilience benefits, there is a need to investigate how these dynamics manifest within AMAC's specific geographic and socio-ecological context. Studies focused on AMAC have begun to document spatial patterns of vegetation and temperature regulation, indicating that green and blue spaces contribute to local cooling effects (Anyakora et al., 2025). Evaluating the contribution of green infrastructure to temperature mitigation and resilience in AMAC will therefore provide empirical grounding to inform urban planning and climate adaptation strategies in the Federal Capital Territory of Nigeria.

Theoretical Framework and Literature Review

Conceptual Review

Green Infrastructure

Green infrastructure refers to a strategically planned network of natural and semi-natural elements, including parks, urban forests, green roofs, permeable surfaces, and wetlands, designed to provide a range of ecosystem services that address environmental, climatic, and social challenges in urban areas (Abiola et al., 2025; Magaji et al., 2025). Such infrastructure operates by harnessing natural processes to manage stormwater, improve air quality, enhance biodiversity, and mitigate heat stress, functioning as an alternative or complement to traditional "grey" infrastructure such as concrete drainage systems and paved surfaces (Green infrastructure is defined broadly to include natural and engineered vegetative systems; a key benefit is reduction of heat stress and climate adaptation) (Wikipedia).

Urban Temperature

Urban temperature, particularly in the context of the urban heat island (UHI) phenomenon, denotes the localized warming observed in cities relative to surrounding rural areas, resulting from extensive impervious surfaces, reduced vegetation, and concentrated anthropogenic heat emissions; this temperature elevation affects both surface and air temperatures within urban environments, contributing to thermal discomfort, increased energy demand for cooling, and heightened public health risks during extreme heat events.

Climate Resilience

Climate resilience refers to the capacity of systems whether ecological, infrastructural, or social—to anticipate, absorb, adapt to, and recover from the impacts of climate change and related hazards, such as extreme temperatures, storms, and flooding (Abubakar et al., 2025; Olusola et al.,2025; Magaji & Musa, 2024), while maintaining essential functions and structures; within urban contexts, resilience encompasses planning and design strategies that strengthen infrastructure and communities against both current climate variability and future climate stressors (Tanko et al., 2025).

Theoretical Framework

Urban Ecosystem Services Theory

Urban Ecosystem Services Theory, which explains how natural and semi-natural components within urban areas provide essential ecological functions that support human well-being and climate adaptation. The theory posits that integrating green infrastructure into urban planning enhances ecosystem services such as temperature regulation, stormwater management, air purification, and biodiversity conservation, thereby reducing the negative impacts of urbanisation and climate change (Bolund & Hunhammar, 1999). In the context of the Abuja Municipal Area Council (AMAC), applying this theory helps to conceptualise how strategically planned green spaces—parks, street trees, and vegetated corridors—can mitigate urban heat island effects, lower ambient temperatures, and improve local climate resilience, ultimately contributing to sustainable urban development and the health and comfort of residents.

Empirical Review

An empirical study analyzing green parks in Abuja demonstrated measurable cooling effects on the local urban microclimate using geospatial techniques; Millennium Park, Abuja Recreational Park, and Zone 6 Neighbourhood Park exhibited mean land surface temperatures (LST) that were significantly lower than surrounding built environments, with results showing strong negative correlations between LST and vegetation cover as indicated by Normalized Difference Vegetation Index (NDVI) values (Armson et al., 2018). The analysis also found that larger park size and more complex shapes enhanced cooling potential around buffer zones up to 350 m, suggesting that urban park design is critical for mitigating urban heat island (UHI) effects in hot and humid cities like Abuja (Armson et al., 2018). These findings provide concrete evidence from the Federal Capital Territory that green spaces help regulate local temperatures, supporting their role in climate adaptation strategies.

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Recent empirical research on green roofs showed that vegetated roofs can substantially reduce both surface and ambient air temperatures when compared with conventional roofing, with reductions of approximately 3.1 °C in surface temperature and 0.6 °C in air temperature confirmed through paired t-tests and regression analyses (International Journal of Civil Engineering and Architecture Engineering, 2025). Utilising ENVI-met simulations, the study further demonstrated that the cooling effects of green roofs extended beyond the roof surface into surrounding urban canopy zones, highlighting the broader microclimate mitigation potential of such infrastructure (International Journal of Civil Engineering and Architecture Engineering, 2025). The results validate green roofs as practical components of urban climate resilience, emphasising the importance of optimised substrate depth and moisture management.

An empirical investigation into micro-scale urban green infrastructure, focusing on trees, green roofs, and green facades, revealed that planting trees had the most significant impact on reducing Physiological Equivalent Temperature (PET) in high-density residential areas, lowering PET by approximately 13 % under existing and future climate conditions (Frontczak et al., as cited in UCLIM, 2025). The study found green facades offered moderate mitigation (5 %–10 %), while green roofs had negligible effects on thermal comfort at the pedestrian level, indicating that vegetation placement and type are crucial determinants of mitigation performance (Frontczak et al., as cited in UCLIM, 2025). These results empirically underscore the differentiated contributions of green infrastructure types to microclimate regulation and point to trees as priority investments for urban heat mitigation.

A multi-scale empirical synthesis revealed that urban green infrastructure impacts vary with spatial scale; large green spaces exceeding 250 ha were associated with city-wide temperature reductions of 3.5–4.6 °C, while smaller scale interventions such as street trees and green roofs delivered localized cooling of 1.1–2.6 °C and reduced building cooling energy demand by up to 51 % (Renewable and Sustainable Energy Reviews, 2025). These findings, derived from cross-study comparisons, remote sensing, and in situ measurements, emphasise that both the extent and configuration of green infrastructure determine its effectiveness in urban climate regulation (Renewable and Sustainable Energy Reviews, 2025). This empirical evidence supports the argument for integrated green planning across scales to maximise climate-resilience outcomes.

An empirical review examining integrated green infrastructure strategies such as green roofs, facades, and street trees found that combined greenery systems can achieve up to a 2 °C reduction in ambient urban temperatures while improving thermal comfort indices by over 10 °C under certain conditions, in addition to lowering building cooling energy demand by roughly 15 % (Sustainability, 2025). The study synthesised quantitative findings from multiple case studies. It highlighted the synergistic effects of integrated green infrastructure relative to isolated greening interventions, reinforcing the value of holistic solutions for sustainable and climate-resilient cities (Sustainability, 2025). These empirical results demonstrate that multi-component green infrastructure strategies can significantly contribute to urban thermal regulation and energy efficiency.

Gaps in the Literature

Despite extensive empirical evidence demonstrating the cooling effects of green infrastructure at multiple scales, ranging from micro-scale interventions such as street trees and green facades to large urban parks and integrated green systems, most studies have focused on temperate or coastal cities, with limited attention to tropical inland urban centres like Abuja. While research in Abuja has begun to document localised cooling effects of urban parks (Armson et al., 2018), there remains a lack of comprehensive empirical studies examining the combined contribution of diverse green infrastructure components (e.g., parks, green roofs, street trees, and vegetated corridors) to urban temperature regulation and climate resilience at both neighbourhood and city-wide scales. Additionally, few studies have integrated land surface temperature measurements, thermal comfort indices, and socio-environmental assessments to evaluate the effectiveness of green infrastructure in enhancing adaptive capacity in rapidly urbanising tropical contexts. Therefore, a focused study assessing the multi-dimensional impacts of green infrastructure on urban heat mitigation and climate resilience in the Abuja Municipal Area Council (AMAC) is necessary to fill this knowledge gap and provide evidence-based recommendations for urban planning and climate adaptation strategies in the Federal Capital Territory.

Methodology

Research Design

This study employed a mixed-methods research design, combining quantitative geospatial analysis with a structured social survey to investigate the role of green infrastructure in moderating urban heat island (UHI) effects and enhancing climate resilience in AMAC. The mixed-methods approach facilitated triangulation, integrating objective satellite-derived measurements of land-use/land-cover (LULC) and land surface temperature (LST) with subjective insights from residents and environmental professionals, thereby enhancing both the reliability and contextual relevance of the findings (Creswell & Plano Clark, 2018). Multi-temporal satellite imagery spanning 1994–2024 was analysed for geospatial patterns, while the social survey captured perceptions of UHI, green space utility, and climate adaptation strategies.

Study Area

The research was conducted in the Abuja Municipal Area Council (AMAC), the administrative and economic centre of Nigeria's Federal Capital Territory (FCT), located between latitudes 8°40′N–9°20′N and longitudes 7°10′E–7°40′E, covering approximately 1,769 km² (Balogun, 2001). AMAC includes the Federal Capital City districts (Garki, Wuse, Maitama, Asokoro) and rapidly expanding satellite settlements such as Karu, Nyanya, and Lugbe, which provide critical contexts for urban expansion and thermal dynamics. The area experiences **a** tropical wet and dry climate (Köppen Aw), with elevations ranging from 70–760 m above sea level, and has undergone significant vegetation loss due to urbanisation, resulting in fragmented green spaces such as Millennium Park (Musa et al., 2019; Okoye & Martins, 2023).

Reconnaissance Survey

A reconnaissance survey preceded data collection to gather preliminary information on urban microclimates, land-use patterns, and logistical considerations within selected districts (Garki, Wuse, Maitama, Asokoro). The survey facilitated observations of temperature variations, shading patterns, and green space distribution, informed the refinement of survey instruments, and guided sampling strategies. Key institutions such as the Abuja Geographic Information System (AGIS), the Nigerian Meteorological Agency (NiMet), and Abuja Development Control were consulted to support data acquisition and verification.

DOI: 10.5281/zenodo.18171439

Population and Sample Size

The study population included AMAC residents, urban planners, and environmental professionals involved in UHI management. Using the Krejcie and Morgan (1970) formula, a sample size of 384 was recommended for a projected 2024 population of 3.6 million. However, due to logistical constraints, a purposive sample of 150 respondents was selected, with 135 valid responses retained after data cleaning. The respondents were proportionally distributed across AMAC to capture diverse urban experiences.

Data Sources and Collection

The study utilised geospatial, meteorological, and primary survey data. Landsat satellite imagery (Landsat 5 TM, 7 ETM+, 8 OLI/TIRS, and 9 OLI/TIRS) for the years 1994, 2000, 2006, 2012, 2018, and 2024 was acquired from the United States Geological Survey (USGS) for LULC classification and LST retrieval. Historical air temperature records (1990–2024) from NiMet provided ground-truth validation for satellite-derived temperature trends.

Remote Sensing and Geospatial Analysis

Satellite images underwent geometric and radiometric corrections to ensure temporal and spatial consistency. Data were projected to Universal Transverse Mercator (UTM) Zone 32N using the Minna Datum. Spectral bands were stacked to generate false-colour composites and clipped to AMAC boundaries using ArcGIS's "Extract by Mask" tool. Image enhancement and classification procedures were applied to improve interpretability and accuracy (Congalton & Green, 2019).

Statistical Analysis

Quantitative analyses were conducted in SPSS v26.0. Linear regression examined long-term temperature trends using NiMet data. At the same time, Pearson's correlation analysis assessed relationships between LST and LULC variables, particularly vegetation cover and built-up density, to quantify associations and determine their statistical significance.

Accuracy Assessment

The reliability of LULC classifications was evaluated using accuracy assessment based on field verification points, high-resolution imagery from Google Earth Pro and Sentinel-2, and geospatial datasets from AGIS and the Office of the Surveyor-General of the Federation. Metrics such as overall accuracy, producer's accuracy, user's accuracy, and kappa coefficient were calculated, with interpretation guided by Landis and Koch (1977) thresholds and standards from Foody (2002) and Congalton and Green (2019).

Ethical Considerations and Data Presentation

Ethical approval was obtained, and informed consent was secured from all participants. Confidentiality and voluntary participation were ensured, and data were securely stored. Results were presented using tables, charts, graphs, and thematic maps to illustrate spatial and temporal patterns of LULC, LST, and climate indices across AMAC.

Data Presentation and Analysis of Results

This section presents and interprets the empirical findings on the contribution of green infrastructure to urban temperature moderation and climate resilience in AMAC between 1994 and 2024. The analysis integrates long-term atmospheric temperature records, Landsat-derived land surface temperature (LST) data, land-use and land-cover (LULC) transformations, ecological indices, and resident perceptions. Findings are structured around the study objectives, moving from climatic trends to surface thermal dynamics, landscape changes, ecological performance, and socio-institutional factors that influence the effectiveness of green infrastructure. Ecosystem services and urban ecology frameworks guide the interpretation, linking biophysical data to human experiences (Bolund & Hunhammar, 1999; Oke, 1982).

Atmospheric Temperature Trends in Abuja (1994–2024)

Table 4.1 Annual Atmospheric Temperature Profile for Abuja (1994–2024)

Year	Max Temp (°C)	Min Temp (°C)	Avg Temp (°C)
1994	33.3	21.1	27.2
…	…	…	…
2024	33.6	22.1	27.9

Source: Author's Analysis (2025), NiMet data

Table 4.1 indicates a persistent warming trend, particularly in minimum (night-time) temperatures, which increased by ~1.0 °C over 30 years. Maximum daytime temperatures remained relatively stable. This pattern demonstrates reduced nocturnal cooling and confirms the development of UHI effects, highlighting the urban environment's inability to dissipate heat during night hours (Oke, 1982).

Land Surface Temperature Dynamics in AMAC (1998–2024)

Table 4.2 Summary of Land Surface Temperature Statistics

Year	Max LST (°C)	Mean LST (°C)	Min LST (°C)
1998	32.2	32.2	32.2
2000	36.0	32.7	29.7
2006	37.9	32.8	26.2
2012	36.3	34.2	31.6
2018	43.5	34.2	21.4
2024	47.1	37.0	20.7

Source: Author's Analysis (2025), Landsat data

Table 4.2 demonstrates significant surface warming, with maximum LST increasing by ~15 °C between 1998 and 2024. The widening range between maximum and minimum LST highlights spatial thermal heterogeneity, where built-up areas retain heat while vegetated patches provide limited cooling. This escalation confirms intensifying surface-level UHI effects (Voogt & Oke, 2003).

Land Use and Land Cover (LULC) Dynamics (1994–2024)

Table 4.3 LULC Distribution in AMAC (km²)

Year	Cropland	Vegetation	Bare Surface	Water Body	Built-up
1994	453.73	1110.52	51.86	5.78	128.83
2000	461.12	1094.95	59.96	3.80	130.89
2006	227.00	289.70	1038.55	2.60	192.85

DOI: 10.5281/zenodo.18171439

Year	Cropland	Vegetation	Bare Surface	Water Body	Built-up
2012	733.15	579.61	42.67	3.20	392.07
2018	493.95	383.92	514.62	2.43	486.57
2024	498.41	140.45	383.83	2.20	725.82

Source: Author's Analysis (2025), Landsat imagery

Table 4.3 shows a drastic decline in vegetation (from 63% in 1994 to 8% in 2024) alongside a more than fivefold increase in built-up areas. Bare surfaces spiked in 2006, reflecting pre-construction land clearing. These changes illustrate the loss of natural cooling capacity and the replacement of ecological buffers with impervious surfaces, explaining elevated surface temperatures (Armson et al., 2018).

Table 4.4 Average Annual LULC Change Rate

Class	Change (km²)	Rate (km²/year)
Cropland	+44.68	+1.49
Vegetation	−970.07	−32.34
Bare Surface	+331.97	+11.07
Water Body	−3.58	−0.12
Built-up	+596.99	+19.90

Source: Author's Analysis (2025)

Table 4.4 highlights accelerated vegetation loss compared to built-up growth. Land clearing prior to development expands bare surfaces, amplifying surface heating and stressing urban ecological systems (Voogt & Oke, 2003).

Relationship Between LULC, LST, and Air Temperature

Table 4.5 Combined Indicators

Year	Built-up	Vegetation	Air Tmax	LST Max	Thermal Gap
2000	130.89	1094.95	33.1	36.0	+2.9
2006	192.85	289.70	33.0	37.9	+4.9
2012	392.07	579.61	32.4	36.3	+3.9
2018	486.57	383.92	32.9	43.5	+10.6
2024	725.82	140.45	33.6	47.1	+13.5

Source: Author's Analysis (2025), combined NiMet, LST, and LULC data

Table 4.5 confirms an inverse relationship between vegetation and surface temperature. As built-up density increases, the gap between air temperature and LST widens, emphasising the importance of green infrastructure in mitigating surface heat (Oke, 1982; Armson et al., 2018).

Ecological Performance of Green Infrastructure (EEI and UTFVI)

Table 4.6 EEI and UTFVI Distribution (2004–2024)

Year	Excellent (%)	Worst (%)	Mean UTFVI (Excellent)	Mean UTFVI (Worst)
2004	48.82	50.02	−0.836	+0.816
2014	42.18	56.66	−0.947	+0.704
2024	44.99	53.74	−0.844	+0.706

Source: Author's Analysis (2025)

Table 4.6 reveals ecological polarisation, with over half of AMAC in the "Worst" category. Green infrastructure remains fragmented, reducing overall resilience against heat stress and indicating insufficient connectivity in cooling networks (Bolund & Hunhammar, 1999).

Resident Perceptions of Urban Heat and Green Infrastructure

Table 4.7 Perception of UHI Severity

Perception	Percentage
Very serious	45
Somewhat serious	41
Not a problem	0
Unsure	14

Source: Author's Field Survey (2025)

Table 4.7 shows strong alignment between empirical evidence and lived experiences. Most residents perceive urban heat as a critical issue, corroborating LST and atmospheric data (Armson et al., 2018).

Table 4.8 Barriers to Green Infrastructure Implementation

Barrier	Percentage
Lack of political will	65
Insufficient funding	56
Weak enforcement	52
Limited awareness	52
Technical constraints	41

Source: Author's Field Survey (2025)

Table 4.8 identifies governance and institutional failures as primary constraints to green infrastructure implementation. Respondents indicate that political commitment, funding, and enforcement challenges, rather than technical feasibility, impede effective urban cooling (Okoye & Martins, 2023).

Discussion of Findings

Findings indicate a strong relationship between urban expansion, declining green infrastructure, and increasing surface thermal stress in AMAC. While atmospheric temperatures show moderate increases, LST escalates sharply in built-up areas. LULC analysis confirms vegetation loss at the expense of urban growth, weakening the city's natural cooling capacity. Ecological indices and resident

DOI: 10.5281/zenodo.18171439

surveys further demonstrate fragmented green networks and governance barriers that limit the potential of green infrastructure to enhance climate resilience. Collectively, the evidence underscores that UHI in AMAC is both an environmental and governance challenge requiring integrated urban planning and policy interventions (Bolund & Hunhammar, 1999; Oke, 1982; Armson et al., 2018).

Conclusions and Recommendations

The study demonstrates a clear and compelling link between urban expansion, declining green infrastructure, and intensifying thermal stress in the Abuja Municipal Area Council (AMAC). Empirical evidence from long-term atmospheric records, satellite-derived land surface temperatures (LST), and land-use/land-cover (LULC) analysis indicates that, while atmospheric temperatures have increased moderately over the past three decades, surface temperatures in built-up areas have risen sharply. Vegetation loss, green-space fragmentation, and the proliferation of impervious surfaces have significantly reduced the city's natural cooling capacity, intensifying the urban heat island (UHI) effect. Ecological indices further reveal extreme spatial polarisation between thermally stressed built-up zones and isolated cooling areas, underscoring the limited effectiveness of current green infrastructure in providing comprehensive climate resilience. Resident perceptions corroborate these findings, emphasising that urban heat is a serious and growing concern within daily life in AMAC.

To mitigate urban heat and enhance climate resilience, AMAC is recommended to adopt a comprehensive, integrated green infrastructure strategy that prioritises expanding and connecting vegetated areas, including parks, street trees, green corridors, and green roofs. Urban planning policies should mandate the incorporation of green spaces in new developments while retrofitting existing built-up areas with cooling vegetation. Strengthening institutional frameworks, increasing funding allocations, and promoting community awareness are essential to overcome governance barriers identified in this study. Additionally, periodic monitoring using geospatial and thermal data should be institutionalised to track progress and inform adaptive management strategies, ensuring that green infrastructure interventions effectively moderate urban heat and enhance the city's capacity to withstand future climate-related risks.

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DOI: 10.5281/zenodo.18171439