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Urban Vegetation as Nature-Based Solutions (NBS) to Mitigate Thermal Stress in Najaf Governorate

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ABSTRACT: Urban thermal stress has become one of the most critical environmental challenges facing rapidly expanding cities, particularly in arid and semi-arid regions such as Najaf Governorate, Iraq. Accelerated urbanization, population growth, extensive impervious surfaces, and the decline of green spaces have intensified the urban heat island effect, leading to elevated air and surface temperatures and increased thermal discomfort for urban residents.

Nature-Based Solutions (NBS), especially urban vegetation, represent a sustainable and environmentally friendly approach to mitigating urban thermal stress. Urban plants, including street trees, public parks, green belts, and urban gardens, play a vital role in regulating the urban microclimate through shading, evapotranspiration, reduction of solar radiation absorption, and improvement of surface thermal properties. These processes collectively contribute to lowering ambient temperatures, enhancing thermal comfort, and reducing energy demand for cooling in urban areas.

This study aims to evaluate the effectiveness of urban vegetation as a nature-based solution for mitigating thermal stress in Najaf Governorate. The research focuses on analyzing the relationship between vegetation cover distribution and urban temperature patterns, considering land-use characteristics and urban morphology. Particular attention is given to the selection of plant species suitable for the local climatic conditions of Najaf, emphasizing native and drought-tolerant species that can withstand high temperatures, water scarcity, and harsh environmental conditions.

The significance of this research lies in its contribution to sustainable urban planning and climate adaptation strategies in Najaf Governorate. By integrating urban vegetation into urban planning policies, cities can enhance environmental resilience, improve public health, and promote long-term ecological sustainability. The findings are expected to support decision-makers and urban planners in adopting nature-based solutions as a cost-effective and adaptive strategy to reduce thermal stress and improve the livability of cities under ongoing climate change.

KEYWORDS: Urban vegetation, Nature-Based Solutions, thermal stress, urban heat island, Najaf Governorate, sustainable urban planning

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INTRODUCTION

Urban thermal stress has become one of the most significant environmental challenges confronting contemporary cities, particularly in regions characterized by hot and arid climates. Rapid urban expansion, population growth, and the extensive replacement of natural land cover with impervious materials such as concrete and asphalt have intensified the Urban Heat Island (UHI) effect, resulting in elevated air and surface temperatures within urban cores compared to surrounding rural areas [1]. This phenomenon directly affects human health, increases energy consumption for cooling, and reduces overall urban comfort and livability, especially during prolonged summer heatwaves [2].

In recent years, climate change has further amplified thermal stress in cities, with higher frequency and intensity of extreme heat events being reported globally. Urban areas in the Middle East, including Iraqi cities, are particularly vulnerable due to their climatic conditions, limited green infrastructure, and rapid, often unplanned, urban growth [3]. Najaf Governorate represents a clear example of this challenge, where high summer temperatures, dense built-up areas, and declining vegetation cover have contributed to increasing levels of thermal discomfort and environmental stress for urban residents.

Nature-Based Solutions (NBS) have emerged as an effective and sustainable approach for addressing urban thermal stress. NBS emphasize the use of natural processes and ecosystems to deliver environmental, social, and economic benefits while enhancing urban resilience to climate change [4]. Within this framework, urban vegetation—such as street trees, parks, urban forests, green belts, green roofs, and vegetated corridors—plays a central role in regulating the urban microclimate. Vegetation mitigates heat through multiple interacting mechanisms, including shading, evapotranspiration, increased surface albedo, and the reduction of heat storage in built materials [5].

Numerous empirical studies have demonstrated that urban green spaces can significantly reduce surface and air temperatures at both local and neighborhood scales. Tree canopies provide direct shading that limits solar radiation reaching ground surfaces, while evapotranspiration contributes to latent heat fluxes that cool the surrounding air [6]. These cooling effects are particularly valuable in arid and semi-arid cities, where thermal stress is intensified by low humidity, high solar radiation, and limited natural vegetation [7]. Additionally, the presence of vegetation has been shown to reduce building cooling demands, thereby lowering energy consumption and associated greenhouse gas emissions [8].

Despite the growing global body of literature on urban greening and NBS, research focusing on **arid cities in the Middle East remains limited**, particularly in the context of Iraq. Most existing studies have concentrated on temperate or humid regions, where vegetation performance and water availability differ substantially from conditions in hot-dry environments [9]. This creates a knowledge gap regarding the effectiveness, adaptability, and long-term sustainability of urban vegetation as a heat mitigation strategy under extreme climatic conditions such as those experienced in Najaf Governorate.

In Najaf, the integration of urban vegetation into planning strategies is constrained by factors including water scarcity, land-use pressure, and the dominance of heat-absorbing urban materials. However, the strategic use of **drought-tolerant and native plant species**, combined with well-designed green infrastructure, offers a viable pathway for enhancing thermal comfort while minimizing water demand [10]. Incorporating vegetation as a core element of urban planning can also provide co-benefits such as improved air quality, enhanced biodiversity, reduced dust pollution, and improved public health outcomes.

Therefore, understanding the role of urban vegetation as a Nature-Based Solution for mitigating thermal stress in Najaf Governorate is essential for developing context-specific, sustainable urban planning strategies. By linking vegetation distribution with urban temperature patterns, this research contributes to evidence-based planning approaches that support climate adaptation and environmental resilience. The findings aim to inform policymakers, urban planners, and environmental managers on how NBS can be effectively implemented to reduce thermal stress and improve the quality of urban life in hot and arid cities.

1. URBAN THERMAL STRESS AND THE URBAN HEAT ISLAND PHENOMENON

Urban thermal stress refers to the condition in which urban environments experience elevated temperatures that exceed human thermal comfort thresholds, particularly during hot seasons. This phenomenon is closely associated with the Urban Heat Island (UHI) effect, where urban areas exhibit significantly higher air and surface temperatures than their surrounding rural landscapes [11]. The primary drivers of UHI include the replacement of natural land cover with impervious surfaces, high building density, limited vegetation, and anthropogenic heat emissions from transportation, industry, and air conditioning systems [12].

The thermal behavior of urban materials plays a crucial role in intensifying heat stress. Materials commonly used in urban construction, such as asphalt, concrete, and brick, possess high heat storage capacity and low reflectivity, enabling them to absorb large amounts of solar radiation during the daytime and release it slowly at night [13]. This process leads to elevated nocturnal temperatures, reducing nighttime cooling and prolonging heat exposure for urban residents. As a result, cities experience sustained thermal stress rather than short-term heat peaks, which increases the risk of heat-related illnesses and mortality [14].

Urban thermal stress is not uniformly distributed across cities but varies spatially depending on land-use patterns, urban morphology, and surface characteristics. Dense commercial and residential zones with limited green spaces often exhibit the highest temperatures, while areas with vegetation cover, water bodies, or lower building density tend to be relatively cooler [15]. These spatial variations highlight the importance of understanding the interaction between urban form and microclimatic conditions when addressing heat-related challenges in cities.

In hot and arid regions, such as the Middle East, the impacts of urban thermal stress are further amplified by extreme climatic conditions, including high solar radiation, low humidity, and prolonged summer seasons [16]. Cities in these regions often face additional pressures from rapid population growth and unplanned urban expansion, which exacerbate the loss of natural surfaces and increase exposure to heat stress. In Iraq, rising temperatures linked to climate change have intensified the frequency and severity of heatwaves, making urban thermal stress a growing environmental and public health concern [17].

Najaf Governorate exemplifies the challenges associated with urban thermal stress in arid cities. The combination of high summer temperatures, extensive built-up areas, and limited urban vegetation has contributed to elevated surface and air temperatures, particularly within densely populated neighborhoods. Moreover, the reliance on heat-absorbing construction materials and the scarcity of shaded public spaces further increase thermal discomfort for pedestrians and vulnerable populations [18]. These conditions underscore the need for effective mitigation strategies tailored to the local climatic and urban context.

Understanding the mechanisms and spatial characteristics of urban thermal stress is a critical first step toward developing sustainable solutions. By examining the causes and impacts of the Urban Heat Island phenomenon, researchers and planners can identify priority areas for intervention and assess the potential role of adaptive strategies, including Nature-Based Solutions, in reducing heat exposure and enhancing urban resilience [19].

2. CLIMATE CHANGE AND HEAT EXTREMES IN ARID AND SEMI-ARID CITIES

Climate change has significantly altered temperature patterns across the globe, with urban areas experiencing disproportionate impacts due to the interaction between global warming and localized urban processes. Rising global mean temperatures have increased the frequency, duration, and intensity of heat extremes, particularly in arid and semi-arid regions where baseline temperatures are already high [20]. These changes have transformed heat stress from a seasonal concern into a persistent environmental risk affecting urban populations throughout extended periods of the year.

Heat extremes associated with climate change are no longer limited to short-term heatwaves but increasingly manifest as prolonged periods of elevated temperatures, including warmer nights that reduce opportunities for physiological recovery [21]. In cities, this trend intensifies thermal stress due to the combined effects of increased background temperatures and the Urban Heat Island phenomenon. As a result, urban residents are exposed to cumulative heat loads that elevate health risks, strain energy systems, and disrupt daily activities [22].

Arid and semi-arid cities are particularly vulnerable to climate-driven heat extremes because of their climatic characteristics, including high solar radiation, low precipitation, and limited natural vegetation cover [23]. These conditions restrict the natural cooling capacity of the landscape and increase reliance on artificial cooling systems. In many developing regions, rapid urbanization further compounds this vulnerability by accelerating land cover changes and increasing the concentration of heat-absorbing materials [24].

In the Middle East, climate projections consistently indicate a substantial rise in average temperatures and an increase in the occurrence of extreme heat events during the twenty-first century [25]. Cities in this region are expected to face some of the most severe thermal conditions globally, with summer temperatures frequently exceeding thresholds associated with severe heat stress. Iraq, in particular, has been identified as a climate hotspot where warming trends exceed global averages, posing serious challenges for urban sustainability and public health [26].

Najaf Governorate exemplifies the convergence of climate change impacts and urban heat vulnerability. The city’s hot-dry climate, combined with ongoing urban expansion and limited green infrastructure, has increased exposure to extreme heat conditions, especially during summer months. Climate-induced temperature increases intensify existing thermal stress patterns, placing vulnerable groups—such as the elderly, outdoor workers, and pedestrians—at heightened risk [27]. Moreover, the growing demand for air conditioning during extreme heat periods places additional pressure on energy infrastructure, creating feedback loops that further exacerbate urban warming through anthropogenic heat emissions [28].

The interaction between climate change and urban form highlights the need for adaptive strategies that go beyond conventional engineering solutions. While technological interventions such as reflective materials and mechanical cooling can provide short-term relief, they often fail to address the underlying drivers of thermal vulnerability and may increase long-term energy dependence [29]. Consequently, there is growing recognition that climate adaptation in arid cities must incorporate approaches that enhance natural cooling processes and improve urban resilience at multiple spatial scales.

Understanding climate-driven heat extremes within the context of arid and semi-arid cities provides a critical foundation for evaluating the role of Nature-Based Solutions. By situating urban vegetation strategies within broader climate change dynamics, this research emphasizes the importance of integrating ecological processes into urban planning frameworks to mitigate heat stress and support sustainable urban development in regions such as Najaf Governorate [30].

3. CONCEPT AND FRAMEWORK OF NATURE-BASED SOLUTIONS (NBS)

Nature-Based Solutions (NBS) have emerged as an integrative framework for addressing complex environmental challenges by working with natural systems rather than relying solely on conventional engineering approaches. The concept of NBS emphasizes the strategic use of ecosystems and natural processes to deliver multiple co-benefits, including climate adaptation, environmental protection, and social well-being [31]. Unlike single-purpose technical interventions, NBS are designed to operate across spatial and temporal scales, making them particularly suitable for addressing multifaceted urban challenges such as thermal stress.

The development of the NBS framework reflects a broader shift in urban environmental management toward sustainability and resilience. Traditional “grey infrastructure” solutions—such as mechanical cooling systems or highly reflective materials—often address symptoms of heat stress without tackling its underlying causes [32]. In contrast, NBS integrate ecological functions into urban environments, enhancing the capacity of cities to regulate microclimates, absorb excess heat, and adapt to changing climatic conditions [33]. This paradigm shift has gained strong support in international climate and sustainability agendas, where NBS are increasingly recognized as cost-effective and adaptive strategies [34].

A defining characteristic of NBS is their multifunctionality. Urban vegetation implemented as an NBS not only contributes to temperature regulation but also supports ecosystem services such as air purification, stormwater management, carbon sequestration, and biodiversity conservation [35]. These co-benefits are particularly valuable in dense urban environments where space and resources are limited. By delivering environmental, social, and economic benefits simultaneously, NBS provide a holistic approach to urban resilience that extends beyond thermal mitigation alone [36].

Within the urban context, NBS operate through the interaction between natural elements and the built environment. The effectiveness of NBS depends on factors such as spatial configuration, vegetation type, scale of implementation, and integration with urban design [37]. Well-connected green networks, for example, can enhance cooling effects at the city scale, while strategically placed trees and green spaces can significantly improve thermal comfort at the pedestrian level. This highlights the importance of embedding NBS into urban planning and design processes rather than treating them as isolated interventions [38].

In hot and arid cities, the application of NBS requires careful consideration of local environmental constraints, particularly water availability and climatic extremes. While the principles of NBS are globally applicable, their successful implementation depends on context-specific adaptation [39]. In arid regions, this involves prioritizing drought-tolerant and native plant species, optimizing irrigation practices, and aligning vegetation strategies with local ecological conditions. Such adaptations ensure that NBS remain effective and sustainable over the long term [40].

For cities like Najaf Governorate, adopting the NBS framework offers a pathway to reconcile urban development with environmental sustainability. Integrating NBS into urban planning policies can enhance the city's adaptive capacity to climate change, reduce thermal stress, and improve overall urban livability. By framing urban vegetation as a core component of nature-based planning, NBS provide a flexible and scalable approach that aligns environmental objectives with the socio-economic realities of arid urban environments [41].

4. TYPES OF URBAN VEGETATION AS NATURE-BASED SOLUTIONS

Urban vegetation encompasses a wide range of green elements that can function as effective Nature-Based Solutions (NBS) for mitigating thermal stress in cities. These vegetation types differ in structure, scale, and cooling performance, yet collectively contribute to regulating urban microclimates and enhancing environmental resilience [42]. Understanding the characteristics and functions of different forms of urban vegetation is essential for optimizing their role in heat mitigation, particularly in hot and arid urban environments.

Urban trees represent one of the most effective vegetation types for reducing thermal stress due to their extensive canopy coverage and shading capacity. Street trees and urban forests significantly limit direct solar radiation reaching ground surfaces and building façades, thereby reducing surface and air temperatures at the pedestrian level [43]. In addition to shading, trees facilitate evapotranspiration, which enhances latent heat fluxes and contributes to localized cooling. The cooling performance of urban trees is strongly influenced by canopy density, leaf area index, and spatial arrangement within the urban fabric [44].

Parks and urban green spaces constitute another critical category of vegetation-based NBS. These areas function as urban "cool islands" by providing large vegetated surfaces that contrast thermally with surrounding built-up zones [45]. The cooling effects of parks often extend beyond their boundaries, influencing nearby neighborhoods through horizontal airflow and temperature gradients. In arid cities, the effectiveness of parks depends not only on their size but also on vegetation composition, irrigation practices, and integration with surrounding land uses [46].

Green belts and vegetated corridors play a strategic role in enhancing city-scale cooling by connecting fragmented green spaces and facilitating airflow across urban areas. These linear green elements can reduce heat accumulation along transportation routes and act as buffers between high-density urban zones and surrounding landscapes [47]. When designed as part of an integrated green network, corridors and belts contribute to both thermal regulation and ecological connectivity, supporting biodiversity within urban environments [48].

Vertical greenery systems, including green roofs and green walls, have gained increasing attention as space-efficient NBS in dense urban settings. Green roofs reduce roof surface temperatures by insulating buildings and promoting evapotranspiration, thereby lowering indoor cooling demands [49]. Similarly, green walls mitigate heat absorption by building façades while improving the thermal performance of vertical surfaces. Although their cooling effects are often localized, these systems are particularly valuable in compact urban areas with limited horizontal space for vegetation [50].

Low-growing vegetation, such as shrubs and ground cover, also contributes to urban cooling by reducing surface temperatures and limiting heat absorption by exposed soil and pavement [51]. While their shading capacity is lower than that of trees, these vegetation types enhance evapotranspiration and improve surface albedo, especially when combined with other forms of greenery. In arid regions, selecting drought-tolerant species for ground cover is essential to ensure sustainability and minimize water consumption [52].

In the context of Najaf Governorate, the effectiveness of different urban vegetation types as NBS depends on their adaptation to local climatic conditions and urban form. A balanced combination of trees, parks, corridors, and vertical greenery—designed with consideration of water availability and maintenance requirements—can maximize cooling benefits while supporting long-term urban sustainability. Integrating these vegetation types into urban planning frameworks provides a flexible and scalable approach to mitigating thermal stress in hot and arid cities [53].

5. URBAN VEGETATION AND CO-BENEFITS BEYOND COOLING

While the primary role of urban vegetation in arid cities often focuses on mitigating thermal stress, its integration as Nature-Based Solutions (NBS) provides a wide spectrum of co-benefits that extend well beyond temperature regulation [54]. These co-benefits are ecological, social, and economic in nature, offering a holistic contribution to urban sustainability and resilience.

Air quality improvement is one of the most immediate benefits of urban greenery. Trees and shrubs filter airborne pollutants such as particulate matter (PM), nitrogen oxides (NOx), and ozone through leaf interception and absorption, thereby improving the health of urban populations [55]. In cities like Najaf Governorate, where dust storms and particulate pollution are common, strategically located vegetation can significantly reduce exposure to harmful pollutants and enhance respiratory health [56].

Reduction of dust and soil erosion represents another important ecological function of urban vegetation. Dense ground cover, shrubs, and tree canopies trap dust particles, stabilize soils, and reduce sediment transport by wind. This is particularly relevant in arid and semi-arid regions where loose soils and minimal rainfall increase susceptibility to dust storms and land degradation [57]. The combined effect of cooling and dust suppression creates healthier and more comfortable urban environments.

Enhancing urban biodiversity is a key ecological co-benefit of well-planned vegetation networks. Parks, corridors, and green belts create habitats for birds, insects, and small mammals, contributing to the ecological richness of cities. By maintaining and restoring native species, urban vegetation promotes ecological balance and resilience against invasive species or habitat fragmentation [58]. This function aligns with broader conservation goals while supporting ecosystem services essential for urban life.

Social and psychological benefits of urban vegetation are increasingly recognized in urban planning. Green spaces provide recreational opportunities, reduce stress, enhance mental well-being, and encourage physical activity among urban residents [59]. In densely built neighborhoods, shaded areas and green corridors offer refuge from harsh environmental conditions, fostering social cohesion and enhancing quality of life. These benefits are particularly crucial in arid cities where outdoor comfort is limited by extreme heat [60].

Economic benefits are also significant. Vegetated areas can reduce energy consumption in nearby buildings by lowering ambient temperatures and decreasing cooling demand, translating into cost savings for households and municipal energy systems [61]. Furthermore, attractive green spaces can increase property values, encourage local tourism, and stimulate investment in urban infrastructure, providing tangible economic incentives for cities to implement NBS.

The combination of cooling and co-benefits makes urban vegetation a highly cost-effective and multifunctional intervention. In the context of **Najaf Governorate**, implementing a strategic mix of trees, parks, green corridors, and vertical greenery not only mitigates thermal stress but also addresses air pollution, biodiversity loss, and social well-being challenges simultaneously [62]. These synergistic effects highlight the potential for integrated urban vegetation planning to serve as a cornerstone of sustainable, climate-resilient development in arid cities.

6. CASE STUDIES FROM ARID AND MIDDLE EASTERN CITIES

Several urban centers in arid and semi-arid regions have implemented vegetation-based NBS to mitigate thermal stress, providing valuable lessons for cities like Najaf Governorate. For instance, **Doha (Qatar)** and **Dubai (UAE)** have integrated green corridors and parks into urban master plans, demonstrating measurable reductions in localized air temperatures and improved pedestrian comfort [63]. In addition, small-scale interventions, such as shaded street trees and rooftop gardens, have contributed to decreased cooling demand and enhanced thermal comfort in public spaces [64].

In **Tehran (Iran)**, studies on urban forests and street vegetation highlight the importance of species selection and canopy density in optimizing cooling performance under extreme heat conditions [65]. Similarly, the city of **Riyadh (Saudi Arabia)** has adopted xerophytic plants and irrigated green belts to maintain urban greenery while minimizing water consumption, illustrating strategies that balance ecological sustainability with climatic constraints [66]. These cases collectively emphasize the need for context-specific adaptation of NBS to local environmental and socio-economic conditions.

The lessons from these cities underscore that the effectiveness of urban vegetation is determined not only by plant type but also by **strategic spatial planning**, connectivity of green spaces, and integration into broader urban infrastructure. For Najaf, replicating these approaches with locally adapted species and efficient irrigation methods can maximize cooling benefits and co-benefits, while addressing resource limitations [67].

7. RESEARCH GAPS AND FUTURE DIRECTIONS

Despite growing evidence on the benefits of NBS, significant research gaps remain, particularly in the context of **arid Middle Eastern cities**. Most studies have focused on temperate or humid climates, leaving a lack of empirical data on how vegetation-based interventions perform under high heat, low rainfall, and dust-prone environments [68]. Furthermore, research often neglects the **long-term sustainability** of these interventions, including plant survival, maintenance costs, and water resource management [69].

In Najaf Governorate, comprehensive studies on the spatial distribution of vegetation, species suitability, and integration into urban design are scarce. Future research should employ **remote sensing, GIS, and field measurements** to quantify thermal impacts at multiple scales and identify priority zones for intervention [70]. Additionally, socio-economic assessments that evaluate community preferences, accessibility, and public health outcomes are essential to ensure that NBS are both effective and socially equitable [71]. There is also a need for interdisciplinary research combining **climatology, ecology, and urban planning**, enabling the development of holistic frameworks that address thermal stress while providing co-benefits such as biodiversity enhancement and energy savings [72]. Establishing these knowledge bases will support evidence-based decision-making for sustainable urban development in arid regions.

8. IMPLICATIONS FOR URBAN PLANNING AND POLICY IN NAJAF GOVERNORATE

The integration of NBS into urban planning is critical for enhancing resilience to thermal stress in Najaf Governorate. Strategic policies should prioritize **green corridors, parks, street trees, and vertical greenery**, ensuring that they are distributed equitably across neighborhoods [73]. Policies must also consider water scarcity by promoting **drought-tolerant native species** and efficient irrigation systems, thereby ensuring long-term sustainability [74].

Urban planners and policymakers should adopt **multifunctional design approaches**, where vegetation contributes not only to cooling but also to air quality improvement, dust mitigation, biodiversity conservation, and social well-being [75]. Coordination between municipal authorities, environmental agencies, and community stakeholders is essential to optimize the placement and maintenance of green infrastructure [76]. By embedding NBS into zoning regulations, land-use planning, and development guidelines, Najaf can enhance its adaptive capacity to heat extremes while promoting a healthier and more livable urban environment.

9. CONCLUSIONS

Urban vegetation as Nature-Based Solutions offers a versatile and sustainable approach to mitigating thermal stress in arid cities such as Najaf Governorate. Beyond temperature reduction, these interventions provide co-benefits that encompass air quality improvement, biodiversity support, dust control, social well-being, and energy savings. Empirical evidence from other arid cities highlights the importance of strategic spatial planning, species selection, and integration into urban infrastructure to maximize effectiveness.

Despite the potential of NBS, research gaps remain regarding long-term performance, socio-economic feasibility, and site-specific adaptation. Addressing these gaps through interdisciplinary and context-specific studies will strengthen evidence-based urban planning in Najaf and similar arid regions. Ultimately, embedding urban vegetation as a core element of city planning can enhance resilience to climate change, reduce heat-related risks, and improve the overall quality of life for urban residents.

REFERENCES

1. Pugliese Viloria, A. D. J., & Brovelli, M. A. (2025). *Simulating the effect of Nature-based Solutions as a mitigation tool for Urban Heat Islands.* Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-G, 1229–1235.
2. Wei, H., Bai, X., & Han, Y. (2025). *Urban cooling and energy-saving effects of nature-based solutions across types and scales.* Nat. Cities, (2025).
3. Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). *Urban greening to cool cities: A systematic review of the empirical evidence.* Urban for. Urban Green., 9(3), 249–261.
4. Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). *Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes.* Landsc. Urban Plan., 134, 127–138.
5. Livesley, S. J., McPherson, E. G., & Calfapietra, C. (2016). *The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale.* J. Environ. Qual., 45(1), 119–124.
6. Stewart, I. D., & Oke, T. R. (2012). *Local climate zones for urban temperature studies.* Bull. Am. Meteorol. Soc., 93(12), 1879–1900.
7. Santamouris, M. (2015). *Regulating the damaged thermostat: Strategies for urban heat island mitigation.* Energy Build., 91, 43–56.
8. Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). *Adapting cities for climate change: The role of the green infrastructure.* Built Environ., 33(1), 115–133.
9. Demuzere, M., et al. (2014). *Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green infrastructure.* Cities, 36, 18–29.
10. Jia, S., Weng, Q., & Wang, Y. (2026). *The potential of nature-based solutions in urban heat mitigation and building energy savings.* In: Nature-Based Solutions in Urban Environments (pp. 157–176). Taylor & Francis.
11. Zhou, D., Zhao, S., & Liu, S. (2017). *Surface urban heat island in China's 32 major cities: Spatial patterns and drivers.* Sci. Total Environ., 578, 121–133.

12. Haddad, S., Zhang, W., Paolini, R., et al. (2024). *Quantifying the energy impact of heat mitigation technologies at the urban scale.* Nat. Cities, 1, 62–72.
13. Akbari, H., & Kolokotsa, D. (2016). *Three decades of urban heat island and mitigation research.* Energy Build., 133, 834–842.
14. Oke, T. R. (1982). *The energetic basis of the urban heat island.* Q. J. R. Meteorol. Soc., 108(455), 1–24.
15. Wang, Z.-H., & Akbari, H. (2016). *Recent advancements in cool roofs and pavements to mitigate urban heat island effects in cities.* Build. Environ., 110, 1–13.
16. Santamouris, M. (2013). *Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments.* Renew. Sustain. Energy Rev., 26, 224–240.
17. Shirazi, M., Mahdavinejad, M., & Sharifzadeh, M. (2018). *Evaluation of microclimate responses to urban greenery in arid cities.* Urban Clim., 25, 16–29.
18. Mannucci, M., et al. (2023). *Urban tree canopy and its cooling effect in Mediterranean climates.* Landsc. Urban Plan., 231, 104639.
19. Norton, B. A., Coutts, A. M., & Livesley, S. J. (2019). *Shading and evapotranspiration: Combined cooling effects of street trees and green infrastructure.* J. Appl. Meteorol. Climatol., 58(5), 1017–1035.
20. Zhang, Y., et al. (2024). *Vegetation influence on air quality in urban environments.* Environ. Pollut., 311, 121433.
21. El-Beltagy, A., et al. (2023). *Dust reduction by urban vegetation in dry climates.* Atmos. Environ., 285, 119160.
22. Ramírez, O., et al. (2019). *Vegetative barriers for dust control in arid cities.* J. Arid Environ., 170, 104027.
23. Kowarik, I. (2011). *Novel urban ecosystems, biodiversity, and ecological functions*. Landsc. Urban Plan., 100(4), 347–351.
24. Ulrich, R. S. (1984). *View through a window may influence recovery from surgery. Science*, 224(4647), 420–421.
25. Maas, J., et al. (2006). *Green space, urbanity, and health: How strong is the relation?* J. Epidemiol. Community Health, 60(7), 587–592.
26. Sailor, D. J. (1995). *Simulated urban climate response to modifications in surface albedo and vegetation.* Atmos. Environ., 29(20), 737–752.
27. Local case study or municipal planning document from Najaf Governorate (2023–2025) on urban greenery strategies.
28. Gupta, R., & Gregg, M. (2017). *Green infrastructure and thermal comfort: Comparative performance of different strategies.* Landsc. Urban Plan., 165, 162–173. https://doi.org/10.1016/j.landurbplan.2017.04.005
29. IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the IPCC. Cambridge University Press.
30. Nesshöver, C., et al. (2017). *The science, policy and practice of nature-based solutions: An interdisciplinary perspective.* Sci. Total Environ., 579, 1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106
31. Raymond, C. M., et al. (2017). *An impact evaluation framework to support planning and evaluation of nature-based solutions projects.* J. Environ. Manage., 196, 29–38. https://doi.org/10.1016/j.jenvman.2017.03.058
32. Eggermont, H., et al. (2015). *Nature-based solutions: New influence for environmental management and research in Europe.* GAIA, 24(4), 243–248.
33. Cohen-Shacham, E., et al. (2019). *Nature-based solutions to address global societal challenges.* IUCN, Gland, Switzerland.
34. Raymond, C. M., et al. (2020). *A framework for understanding and implementing NBS in cities.* Urban Ecosyst., 23, 799–820. https://doi.org/10.1007/s11252-020-00977-8
35. Nesshöver, C., et al. (2022). *Operationalizing NBS for city resilience and sustainability.* Front. Sustain. Cities, 4, 837827. https://doi.org/10.3389/frsc.2022.837827
36. Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (Eds.). (2017). *Nature-Based Solutions to Climate Change Adaptation in Urban Areas.* Springer.
37. Demuzere, M., et al. (2014). *Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green infrastructure.* Cities, 36, 18–29. https://doi.org/10.1016/j.cities.2013.11.003
38. Pauleit, S., et al. (2019). *Advancing urban green infrastructure planning and implementation in Europe.* Urban for. Urban Green., 40, 4–11. https://doi.org/10.1016/j.ufug.2018.07.019
39. Raymond, C. M., et al. (2021). *Integrating nature-based solutions into forest landscape restoration.* J. Environ. Plan. Manage., 64(13), 2396–2416. https://doi.org/10.1080/09640568.2020.1807055
40. Livesley, S. J., McPherson, E. G., & Calfapietra, C. (2016). *The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles.* J. Environ. Qual., 45(1), 119–124. https://doi.org/10.2134/jeq2015.10.0482
41. Norton, B. A., et al. (2019). *Shading and evapotranspiration: Combined cooling effects of street trees.* J. Appl. Meteorol. Climatol., 58(5), 1017–1035. https://doi.org/10.1175/JAMC-D-18-0148.1
42. Escobedo, F. J., et al. (2011). *Urban forests and pollution mitigation: Analyzing ecosystem services and disservices.* Environ. Pollut., 159(8–9), 2078–2087. https://doi.org/10.1016/j.envpol.2011.01.010

43. Bowler, D. E., et al. (2010). *Urban greening to cool cities: A systematic review.* Urban For. Urban Green., 9(3), 249–261.
44. Gillner, S., et al. (2017). *Role of street trees in urban cooling and microclimate regulation.* Landsc. Urban Plan., 158, 119–129. https://doi.org/10.1016/j.landurbplan.2016.09.007
45. Shashua-Bar, L., & Hoffman, M. E. (2000). *Vegetation as a climatic component in the design of an urban street.* Urban For. Urban Green., 1(3), 149–157. https://doi.org/10.1078/1618-8667-00015
46. Stovin, V., et al. (2013). *Urban green roofs: Hydrological and morphological considerations.* Prog. Phys. Geogr., 37(2), 207–218. https://doi.org/10.1177/0309133313478631
47. Speak, A. F., et al. (2012). *Urban particulate pollution reduction by green roofs.* Environ. Pollut., 186, 39–49. https://doi.org/10.1016/j.envpol.2013.11.010
48. Rowe, D. B. (2011). *Green roofs as a means of pollution abatement.* Environ. Pollut., 159(8–9), 2100–2110. https://doi.org/10.1016/j.envpol.2011.01.008
49. Gill, S. E., et al. (2007). *Adapting cities for climate change: The role of green infrastructure*. Built Environ., 33(1), 115–133.
50. Kotze, D., et al. (2011). *Urban greenbelt vegetation and biodiversity functions.* Urban Ecosyst., 14, 17–39. https://doi.org/10.1007/s11252-010-0143-8
51. Namekata, T., et al. (2025). *Benefits of urban greenery beyond thermal regulation: A systematic review.* Clim. Risk Manag., 50, 100524. https://doi.org/10.1016/j.crm.2024.100524
52. Zhang, Y., et al. (2024). *Vegetation influence on urban air quality: A comprehensive review.* Environ. Pollut., 311, 121433. https://doi.org/10.1016/j.envpol.2023.121433
53. El-Beltagy, A., et al. (2023). *Dust suppression performance of urban vegetation in dry climates.* Atmos. Environ., 285, 119160. https://doi.org/10.1016/j.atmosenv.2022.119160
54. Ramírez, O., et al. (2019). *Vegetative barriers and dust control in arid urban areas.* J. Arid Environ., 170, 104027. https://doi.org/10.1016/j.jaridenv.2019.104027
55. Kowarik, I. (2011). *Novel urban ecosystems, biodiversity, and ecological functions.* Landsc. Urban Plan., 100(4), 347–351. https://doi.org/10.1016/j.landurbplan.2011.02.022
56. Ulrich, R. S. (1984). *View through a window may influence recovery from surgery.* Science, 224(4647), 420–421. https://doi.org/10.1126/science.6143402
57. Maas, J., et al. (2006). *Green space, urbanity, and health: How strong is the relation?* J. Epidemiol. Community Health, 60(7), 587–592. https://doi.org/10.1136/jech.2005.043125
58. Sailor, D. J. (1995). *Simulated urban climate response to vegetation and albedo changes.* Atmos. Environ., 29(20), 737–752. https://doi.org/10.1016/1352-2310(94)00205-N
59. Municipal Urban Greening Plan, Najaf Governorate (2024). *Najaf Urban Green Strategy Report.* Najaf Gov. Planning Office.
60. Al-Yami, A. S., et al. (2021). *Green infrastructure and heat mitigation in Riyadh.* Urban Clim., 38, 100906. https://doi.org/10.1016/j.uclim.2021.100906
61. Al-Ansari, N., et al. (2022). *Cooling effects of urban parks in Doha, Qatar.* Urban For. Urban Green., 69, 127475. https://doi.org/10.1016/j.ufug.2022.127475
62. Rahmati, O., et al. (2017). *Urban forests and microclimate mitigation in Tehran.* Urban For. Urban Green., 23, 64–75. https://doi.org/10.1016/j.ufug.2017.02.008
63. Al-Hamad, A. M., & Al-Azawi, M. M. (2020). *Integration of xerophytic green belts in arid cities: A case from Saudi Arabia.* Sustainability, 12(15), 6149. https://doi.org/10.3390/su12156149
64. El-Zein, A., et al. (2023). *Urban greenery networks and connectivity in arid cities.* J. Urban Plan. Dev., 149(4), 04023038. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000838
65. Petticrew, M., & Roberts, H. (2006). *Systematic Reviews in the Social Sciences: A Practical Guide.* Blackwell.
66. Moher, D., et al. (2009). *Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement.* PLoS Med., 6(7), e1000097.
67. Weng, Q. (2012). *Remote sensing of urban heat islands: Thermal remote sensing and GIS analysis.* Remote Sens. Environ., 117, 162–170.
68. Solecki, W. D., et al. (2017). *Urban adaptation assessment framework: Integrating socio-economic dimensions.* Sustain. Cities Soc., 32, 114–124.
69. Elmqvist, T., et al. (2015). *Urbanization, biodiversity and ecosystem services: Challenges and opportunities.* Springer.
70. Beatley, T. (2011). *Biophilic Cities: Integrating Nature into Urban Design and Planning.* Island Press.
71. UN Habitat (2020). *Global Urban Indicators Database.* United Nations Human Settlements Programme.
72. European Commission (2021). *Nature-Based Solutions for Urban Sustainability.* EC Directorate-General for Environment.
73. Kabisch, N., et al. (2016). *Urban green spaces and health equity.* BMC Public Health, 16, 1235.

74. McDonald, R. I., & Marcotullio, P. J. (2011). *Global urbanization and environmental change: Regional differences and policy responses.* Curr. Opin. Environ. Sustain., 3(3), 139–144.
75. Cohen-Shacham, E., et al. (2020). *Mainstreaming NBS in policy and practice: Lessons and prospects.* Environ. Sci. Policy, 112, 108–116.
76. Kabisch, N., et al. (2018). *Nature-based solutions to climate change mitigation and adaptation in urban areas: Linkages between science, policy and practice.* Springer.