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Urban Street Trees and Tropical Microclimate Regulation: A Review of Ecosystem Services and Research Gaps

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Abstract

Globally, street trees have become essential in improving environmental sustainability in rapidly urbanizing areas. This review investigates the contribution of street trees to urban microclimate in tropical regions, based on both empirical and simulation studies. With the guidance of the PRISMA framework, a systematic review of 48 peer-reviewed studies published between 2000 and 2025 was carried out using both Scopus and Google Scholar databases. Findings show that Street trees support urban thermal regulation by lowering ambient air temperature by 1–3 °C, and up to about 8 °C under dense canopy conditions, while achieving even greater reductions in mean radiant temperature through shading of people and urban surfaces. This improves outdoor thermal comfort in tropical cities, enhances air quality by removing pollutants, and reduces the cooling energy demand of buildings. There remain gaps in the literature with specific regard to long-term field measurements, species-specific performance data, and the incorporation of street trees into frameworks for climate-resilient urban planning in the tropics. The review concludes that street trees in urban areas are important, and suggests improved design, research, and policy approaches to maximize their environmental advantages.

Keywords: Street Trees, Microclimate, Ecosystem Services, Urbanization, Climate Resilience.

Introduction

Globally, the increasing urban population, coupled with persistent conflict between expanding socio-economic activities and biodiversity conservation, continues to affect tropical regions (Akbari et al, 2015). The resultant demand for land, infrastructure, and

resources continues to intensify as cities grow. These challenges are of particular significance given that more than 42% of the global population lives in tropical zones (Aghamohammadi et al, 2021). Tropical cities experience elevated energy consumption, a rise in heat-related health problems, deteriorating outdoor thermal conditions, increased heat stress, and air quality deterioration, largely because of their locational attributes (Coccolo et al, 2016; Burkart et al, 2011; Gamero-Salinas et al, 2021; Macedo et al, 2022).

Construction activity continues to be on the rise in parallel with urban population growth. Annually, studies indicate that tropical regions, especially in Africa and Asia, are projected to sustain urban growth rates of about 1.5% and 1.1%, respectively (Song et al, 2018; Nagendra et al, 2018). Further projection by the UN suggests that by 2025, the global urban population will have risen by approximately 68% (Yu et al, 2020). Additionally, nearly one-third of the world's population lives in tropical regions, which highlights the significant demographic pressures shaping urban development in these areas (Priya and Senthil, 2021).

Numerous studies have emphasized the importance of urban street trees, a component of green infrastructure, at various spatial scales (Ali and Patnaik, 2019; Koyata et al, 2022; Adegun et al, 2021; Lian et al, 2024). Street trees support biodiversity (Blasi et al. 2008), have therapeutic properties in their herbs, and lower temperatures (Bowler et al. 2010). In a comparative manner, various disadvantages of street trees have also been noted in places where they are improperly managed and/or placed. These include infrastructure damage from root outcrops, leaf litter from tree shedding, view obstruction, the spread of pests and diseases, invasive species from poor species selection, and maintenance expenses.

In order to fill the knowledge gap, this paper examines research on how urban street trees contribute to the tropical microclimate through a review of the literature. Through the prism of experimental and survey research, it focuses on the ecosystem services offered based on temperature regulation, energy conservation, air quality, noise control, pollution, and biodiversity contribution. Studies from tropical regions are included in the review. This review is organized into five sections. Section 1 explored the subject of street trees and their traits. An outline of the research methodology used in this study is given in Section 2. The contributions of street trees to ecosystem services are covered in detail in Section 3. Section 4 synthesizes the discussions related to street trees, while Section 5 offers recommendations and concludes the review.

Study Method

Search Strategy

To ensure an open and repeatable selection of relevant studies, a systematic review methodology based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework was utilized. The Scopus and Google Scholar databases were used to search the literature for articles published between 2000 and 2025. The search employed keyword combinations such as "street trees", "urban trees", "urban greenery", "microclimate", "urban microclimate", "mean radiant temperature", "air temperature, "energy demand", "ecosystem services", and "tropical microclimate". A total of 512 records were

initially retrieved. 118 full-text articles were assessed for eligibility based on inclusion and exclusion criteria after duplicates were eliminated and titles and abstracts were screened. After this procedure, the final qualitative synthesis contained 48 peer-reviewed studies.
The PRISMA flow diagram (Figure 1) and summary table (Table 2) illustrate the stages of identification, screening, eligibility assessment, and inclusion applied in this review.

Table 1: Summary of Literature Selection Process Based on PRISMA Guidelines

Phase	Description	Detail/Outcome
Identification	Databases Searched	Scopus and Google Scholar
	Timeframe Covered	2000-2025
	Keywords Used	*"urban street trees"*, *"roadside trees"*, *"urban tree canopy"*, *"tropical climate"*, *"urban microclimate"*, *"ecosystem services"*, *"air quality"*, *"temperature regulation"*, *"stormwater runoff"*, *"energy saving"*, *"walkability"*, and *"urban noise"*
	Total records identified	512 articles retrieved
	Additional records identified through other sources	8 (manual reference screening)
Screening	Total records after duplicates removed	490
	Titles and abstracts screened	490
	Records excluded (irrelevant scope, temperate/subtropical focus, or not peer-reviewed)	372
Eligibility	Full-text articles assessed for eligibility	118
	Full-text articles excluded, with reason	70 (conceptual only=24; Rural forestry focus = 18; Incomplete data or unclear methods = 28
Included	Studies included in qualitative synthesis (review)	48 peer–reviewed journal articles
	Studies included in quantitative synthesis	
Inclusion Criteria	- Conducted in a tropical climate zone - Empirical studies (Field, simulation, or survey) - Focus on microclimate or ecosystem services - Peer-reviewed journal articles (2000-2025)	

Phase	Description	Detail/Outcome
Exclusion Criteria	- Studies from temperate/subtropical zones - Conceptual/theoretical papers without data - Rural forestry or non-street green spaces - Grey literature, dissertations, or conference papers	

Results and Discussion

What are street trees?

Depending on the particular context and field of study, street trees are characterized differently, highlighting the fact that their significance extends beyond simple landscaping. Street trees are recognized for their significant contributions to enhancing the urban environment and fostering biodiversity (Ettinger et al., 2024; Egerer et al., 2024; Zheng et al., 2016). Street trees are crucial to the formation of the urban landscape because they define street boundaries, promote a pedestrian- friendly atmosphere, ease traffic, provide shade, enhance visual aesthetics, soften the urban environment, and bring in the beauty of nature (Zhang and Ludwig, 2025; Zhu et al, 2024; Dover and Massengale, 2013; Smart et al, 2020).
Municipal authorities regularly plant trees within the public right-of-way because they are generally regarded as public assets (City Plants, 2019). The main function of street trees has changed over time, moving from being mainly concerned with aesthetics and beautification to incorporating a variety of ecosystem services they offer (Anujan et al, 2024; Seamans, 2013).

Street Trees and Ecosystem Services

a. Temperature regulation

According to Zheng et al. (2024), street trees significantly affect urban temperatures and enhance thermal comfort. By providing shade, street trees help lower direct solar radiation in the surrounding area by cooling the streets and sidewalks (Armson, Rahman, & Ennos, 2013; Li et al, 2018; Takacs et al, 2016). Similarly, regions with more trees are typically colder than those without. For instance, there is proof that planting street trees enhances thermal performance in Malaysia (Zaki et al, 2020).
Additionally, at midday in a subtropical park, the air temperature beneath tree canopies was found to be 0.64 – 2.52 °C lower than the open (Lin and Lin, 2010). Abreu-Harbich et al., (2015) found that street trees can lower the summertime ambient air temperature by 1.10 °C and 2.80 °C. The averages of streets with trees (19.2 °C) and without trees (20.9 ^{o}C) differ significantly, according to an experimental study conducted in Brazil (Martini et al, 2020). Similarly, ambient air temperatures in Bangalore, India, varied between 23.1 and 34.2 °C on roads with trees and between 23.4 and 38.3 ^{o}C on road segments without trees.

Similar findings regarding street trees' ability to lower temperatures are found in studies conducted in African cities. Anacarduim, Mangifera indica, Catalpa Bungei, and Azadirachta indica were among the street trees in Nigeria that, according to experimental analysis, reduced ambient temperature from 8 to 5 ^{o}C during the rainy and dry seasons, respectively (Enete et al, 2012). Further proof of the beneficial impact of trees on improving thermal comfort was provided by a simulation study conducted by Morakinyo et al, (2016) using ENVI-met. Similarly, the Generalized Linear Mixed Model (GLMM) revealed a decrease in air temperature in Benin that ranged from -0.6 °C to -1.4 °C (Djikpo et al, 2023).

b. Air quality improvement

By efficiently eliminating pollutants and reducing ground-level ozone, which is more common in warmer weather, street trees significantly improve air quality (Yang et al, 2025; Kaveh et al, 2024; Uka et al, 2019). According to the findings of a study conducted in India by Vailshery et al, (2013), trees have a major impact on lowering Suspended Particulate Matter (SPM).

Vehicular traffic contributes to pollution by releasing significant amount of exhaust emissions, including carbon monoxide (CO), Sulphur dioxide (SO_2), nitrogen oxide (NO_x), volatile organic compounds (VOC_s), and particulate matter, which account for 60 -70% of the air pollution in urban areas (Ren et al, 2023; Dwivedi and Tripathi, 2007). Similarly, other sources of pollution in cities include domestic activities and industries (Essel, 2017). Peper et al, (2007) conclude that street trees improve air quality by absorbing gaseous pollutants through their leaf surfaces, intercepting particulate matter, lowering emissions from power generation, releasing oxygen through photosynthesis, transpiring water, and providing shade, which lowers air temperatures.

Street trees have also shown promise in enhancing general health, despite the paucity of research. Asthma is less common in kids who live in neighborhoods with more street trees (Lovasi et al, 2008).

c. Energy savings

In tropical climates, street trees significantly contribute to increased energy efficiency. The overall effect is still favourable though the precise mechanism may be slightly different from those in temperate regions. To combat the high temperatures in tropical cities, more active interior cooling techniques are required, which raises electricity consumption. By creating shade and lowering air temperatures, street trees lower the energy required for building cooling (Jayasinghe et al, 2024; Choothong et al, 2016; Hesler and Brazel, 2010; Palme et al, 2020). Results from an additional study conducted in Cairo suggest that street trees can lower annual electricity costs by 280 euros and consumption by 12kWh (Aboelata and Sodoudi 2020).

Lower temperatures in shaded areas reduce the need for cooling systems in surrounding buildings (Rahman et al, 2019). According to Rahman et al. (2017), transpiration has a direct effect on lowering air temperatures within or beneath the tree canopy between 1^{o}C to 8^{o}C. Results from the simulation study by Aboelata and Sodoudi (2020) using the ENVI-met reveal that trees are ineffective in low-density built-up areas but effective in reducing energy

consumption in very high-density built-up areas. Further modelling study (Balogun et al, 2014) revealed that when buildings are adequately shaded by trees, monthly energy cost can be reduced by up to 34, 500 NGN (US$ 218).

d. Sound attenuation

Trees have an impact on the features of the urban environment, which in turn affect the characteristics of the sound field. The dispersion of sound energy by trees can alter acoustic parameters such as reverberation time (RT) and sound attenuation, particularly in these reverberant areas. Several studies have examined how trees affect urban noise in tropical cities and how they contribute to sound reduction (Kusweanto et al, 2025; Pudjowati and Naryono, 2024; Rawat and Singh, 2024). Numerous variables, including species and size, are anticipated to affect a single tree's acoustic impact (Zhao et al, 2025). Tree size can have a major impact on reverberation time, according to field measurement studies (Portaccio et al, 2025; Alencar et al, 2025; Yang et al, 2013). According to Murugadoss (2024) and Deshmukh et al. (2019), trees can serve as natural barriers by absorbing and deflecting sound waves, creating a more peaceful and comfortable atmosphere. As screes, trees disperse sound in all directions. Also based on a simulation study using the RAYNOISE model, sound reductions on streets with trees and absorbent building façades are usually less than 1.5 dB (Haron et al, 2009).

e. Enhanced walkability

Since streets are a community's lifelines, street trees significantly improve walkability in tropical cities (Anuntavachakorn et al, 2025; Alharbi et al, 2024). Urban planning techniques known as "Transit-Oriented Development" (TOD) are strategies that structure urban development so that it is within walking distance of major public transportation hubs. Reducing the need for cars is essential, especially in small cities.

Different techniques, such as physical surveys, on-site interviews, simulations, online reviews, and GIS tools, have since been used in different studies to evaluate walkability (Aisyah and Rahmah, 2020; Zayed, 2016; Shaaban, 2019). Pedestrian activity and street trees are significantly correlated when compared to sidewalks with few or no trees (Castro-Mendoza and Vazquez-Perez, 2025; Erna et al, 2015). A study carried out in the Philippines found that street trees help regulate temperature and offer shade, thereby making walking more comfortable, particularly in hot climates (Galingan et al, 2009). Another similar study in Egypt discovered that trees can be utilized to create shaded sections along a path and are regarded as sources of fresh air (Zayed, 2016). Street trees also improve pedestrian walking, regulate wind flow, and cut solar radiation by about 80% (Erna et al, 2015).

f. Storm water retention

Urban stormwater management is crucial for preventing flooding, lowering runoff, and improving water quality. In tropical areas, where heavy and frequent rainfall is typical, this is especially crucial. Street trees play an essential role in urban stormwater management because they improve infiltration, intercept rainfall, and lower runoff (Woon et al, 2024; Alves et al,

2024). The high volume and intensity of rainfall in tropical areas make their role even more significant. Street trees can lessen the hydrologic effects of urbanization and stormwater runoff in a variety of ways (Kuehler et al, 2017). Similarly, street trees have an impact on water quality by influencing the concentration of pollutants in water as well as water volume and consequently, pollutant transport (Coville et al, 2020).

Table 2: Identified Research Gaps on Contribution of Urban Street Trees to Tropical Urban Microclimate

Ecosystem Services	Existing Findings (from literature)	Identified Research Gaps	Type of Gap	Suggested Future Research Direction
Temperature Regulation	In tropical and subtropical cities, studies reveal a 1 to 8 °C drop in temperature beneath tree canopies. The majority of conclusions are derived from isolated case studies (Brazil, India, Malaysia, Nigeria.	Limited cross-seasonal and long-term research in tropical Africa; absence of uniform metrics for evaluating the impact of microclimate; few studies compare different species and canopy forms.	Methodological / Contextual	Perform multi-site, multi-season empirical research; Create consistent metrics to evaluate tree-based thermal regulation; Compare how well native and exotic tree species perform.
Air Quality Improvement	Research demonstrates that street trees reduce CO, SO2, NOx, and particulate matter. primarily based on research using models or simulations	Limited field measurements in real tropical urban corridors; Inadequate understanding of pollutant absorption efficiency by specific tropical tree species; Little integration of traffic intensity and wind dynamics.	Methodological / Conceptual	Put in place real-time, sensor-based air quality monitoring; Study pollutant capture efficiency per species; and integrate tree placement and traffic patterns in urban air quality models.
Energy Savings	Trees reduce building cooling demand via shading and evapotranspiration (12kWh to 34,500 NGN savings per month)	Few empirical validations from tropical cities; Lack of studies linking tree spacing, canopy density, and orientation with energy savings; restricted socioeconomic analysis of the cost-benefit of energy.	Methodological / Conceptual	Quantify energy savings using on-site monitoring; Model energy–tree relationships using ENVI-met or iTree; Evaluate economic feasibility of large-scale street tree planting for energy conservation.
Sound Attenuation	Some models (RAYNOISE) show minor noise reduction (<1.5 Db) by trees; evidence largely from non-tropical or suburban settings	Scarce studies in dense tropical cities; Insufficient experimental validation of species-specific acoustic performance; Lack of integration between tree morphology and urban canyon geometry.	Contextual / Methodological	Conduct in-situ acoustic studies in tropical city streets; Examine acoustic absorption by different tropical species; Model combined effects of vegetation and building façades.

Ecosystem Services	Existing Findings (from literature)	Identified Research Gaps	Type of Gap	Suggested Future Research Direction
Walkability and Human Comfort	Studies in Egypt, Indonesia, and the Philippines show that trees enhance walkability, shade, and comfort.	Limited quantitative linkage between tree density, shade quality, and pedestrian comfort in tropical microclimates; Absence of gender or age-sensitive comfort studies.	Methodological / Conceptual	Use microclimate and pedestrian perception surveys; Develop walkability indices integrating thermal and psychological comfort; Explore social inclusivity in tree–walkability research.
Storm Water Management	Street trees reduce runoff, enhance infiltration, and improve water quality through interception	Few hydrological studies quantify the exact interception capacity of street trees in tropical rainfall conditions; Limited integration with Sustainable Urban Drainage Systems (SUDS).	Methodological / Contextual	Measure interception and infiltration under varying rainfall intensities; Model synergy between street trees and SUDS; Evaluate species-based water management efficiency.
Biodiversity and Ecosystem Services	Street trees support urban biodiversity and aesthetic value	Limited evaluations of biodiversity that were especially concerned with street corridors; There are few studies that connect species diversity in tropical cities to ecosystem resilience.	Conceptual / Contextual	Examine urban street biodiversity indices; contrast how native and exotic trees contribute to ecosystem resilience; and develop biodiversity-aware street tree management frameworks.
Integrated Urban Planning	Trees are recognized as vital urban assets for microclimate and livability improvement	In tropical regions, there is a weak connection between research and urban design practice; street tree management is not integrated with urban climate adaptation policies.	Policy / Institutional	Develop policy frameworks that integrate tree planning with urban design regulations; Promote interdisciplinary collaboration in research (planning, architecture, ecology).
Research Coverage and Data Accessibility	Most studies concentrated in Asia (India, Malaysia, Indonesia); few in Africa.	Geographic imbalance: Lack of open databases for tropical urban tree research; insufficient data from cities in Sub-Saharan Africa	Contextual / Data	Establish regional databases for urban green infrastructure research; Encourage locally funded tropical microclimate monitoring projects.

Conclusion

This review offers a comprehensive summary of the evidence underpinning the importance of urban street trees for EGS delivery in tropical cities. The literature agrees on the potentially numerous benefits of street trees, including climate regulation, air quality enhancement, energy saving, stormwater treatment, noise protection, improving walking conditions, and

biodiversity. Together, these functions attenuate environmental stresses in relation to urbanisation and climate change in the tropics.

However, there are substantial gaps in the research. Empirical, species-specific, and long-term studies are especially scarce in Africa and other tropical regions. Street trees are still in most planning models treated as decorative elements rather than climate-resilient city infrastructure. To further maximise their environmental performance, better integrating the modelling framework and social perception studies with in-situ field capabilities is needed.

Future studies should focus on cross-seasonal monitoring, inter-species comparisons, and the generation of standardised indices to assess microclimatic benefits. In addition, the integration of remote sensing technologies and citizen science approaches such as community-based temperature logging and tree inventory reporting could expand spatial and temporal data coverage significantly, particularly in data-scarce tropical cities. Furthermore, scientific outputs need to become more relevant for policymakers, and scientific expertise needs to be better integrated in the practice of urban planning, for street trees to be mainstreamed in climate change adaptation policies.

By acknowledging street trees as working urban infrastructure rather than ornament, tropical cities can improve resilience, environmental quality, and provide healthier and more sustainable living conditions.

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