Mitigating Urban Heat Island Effect in Megacities: The Case of Delhi and Bangalore, India

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Abstract: Urban Heat Island (UHI) is a rising environmental concern that has gathered increasing attention due to its profound impact on quality of life in megacities worldwide. This paper delves into the Urban Heat Island phenomenon in megacities like Bangalore and New Delhi, its root causes, resulting consequences as well as potential remedies. Furthermore, this study emphasizes the urgency of addressing UHIs in megacities through strategic urban planning. The paper aims to comprehend the adverse impacts of UHIs and investigate planning strategies to mitigate them, with a primary focus on urban characteristics such as urbanization, land use patterns, and green spaces as the main drivers of UHIs. Rapid urbanization transforms natural landscapes into areas dominated by heat-retaining materials such as concrete and asphalt, leading to higher temperatures that intensify the effect of Urban Heat Islands (UHIs). Densely built-up areas with towering buildings trap heat, while diminishing green spaces such as parks, gardens, and trees etc., lose their ability to provide cooling shade and evapotranspiration (the process by which plants release water vapor). This paper highlights the necessity of adaptive urban planning strategies tailored to the unique challenges of each megacity, aiming to create more sustainable and resilient urban environments. Additionally, the inclusion of green infrastructure, water bodies and sustainable urban development practices can also lead to an increase in the resilience and liveability of cities alongside the mitigation approach towards UHI effect.
Keywords: urban heat island, megacities, urban planning, mitigation strategies, sustainability, India

1. Introduction

Urban Heat Island (UHI) is a phenomenon characterized by higher temperatures in urban areas compared to their rural surroundings. The UHI effect is primarily attributed to human activities, such as industrialization, transportation, and urbanization, which lead to the modification of land surfaces and the emission of heat (Yang, 2016). The UHI effect poses significant challenges to urban areas, including adverse impacts on public health, energy consumption, and the environment due to increase in temperature of urban areas (Wong et al., 2005). Therefore, it is imperative to develop effective urban planning strategies to mitigate the UHI effect and enhance the sustainability and liveability of mega cities. The Urban Heat Island (UHI) effect is a rising environmental issue that has gathered escalating awareness because of its significant influence on major cities globally. The rise in temperatures within urban areas compared to their rural counterparts has raised significant alarm, particularly due to the detrimental effects on public health and overall quality of life. The UHI phenomenon is intricately linked to human activities, such as urbanization, industrialization, and transportation, which have led to the transformation of land surfaces and the release of heat. (Jain et al., 2022). As a result, urban planners are focusing on developing long-term solutions to mitigate the negative effects of UHIs.

Understanding the complexity of the UHI effect is critical for developing effective measures to mitigate its effects. The modification of land surfaces and the emission of heat due to human activities have significantly altered the thermal characteristics of urban areas, leading to increased temperatures. This has far-reaching implications, including heightened energy consumption, compromised air quality, and adverse health outcomes. Consequently, there is a growing consent on the necessity of developing comprehensive urban planning strategies to address the UHI effect and foster the creation of more sustainable and resilient urban environments (Jain et al., 2025).

2. Research Methodology

The research methodology is based n a qualitative approach The study involves a literature review to understand the concept of UHI and its causes. The literature review has been explored through internet and secondary data from books, research papers and journals articles and conclusions will be drawn based on the findings of literature review. The article review related to the subject matter acted as a source of the empirical data for this paper. This paper explores the adverse impacts of urban heat islands (UHI) on mega cities and potential mitigation measures. The paper also investigates the potential planning strategies to mitigate the adverse impacts of UHI in mega cities.

3. Urban Heat Island Effect: Background Study

According to Jenerette et al. (2019), Urban heat refers to the increase in temperature that occurs in urban areas compared to surrounding rural areas. This phenomenon is also known as the urban heat island (UHI) effect. The UHI effect is caused by several factors, including the absorption of heat by buildings and pavement, the lack of vegetation, and the release of heat by vehicles and industry. The UHI effect can lead to several negative impacts, including increased energy consumption, air pollution, and heat-related illnesses.

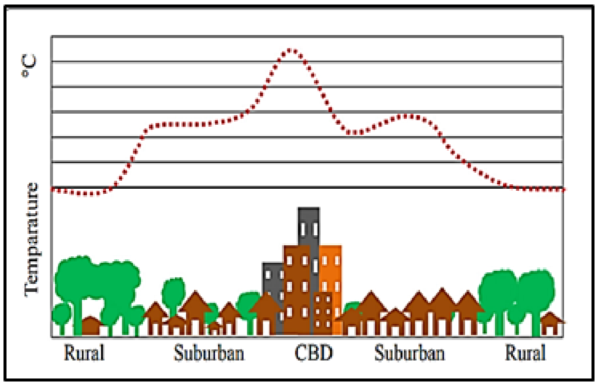


Figure 1. Urban Heat Island Effect Profile.

3.1 Causes of Urban Heat Island Effect

According to Santamouris et al. (2007); Akbari et al. (2001) and Oke (1987) the principle factors are:

- Reduced evapotranspiration due to fewer plants.
- Low albedo and absorption of solar radiation
- Blockage to the airway due to increased rugosity
- High anthropogenic heat release.

3.2 Impacts of Urban Heat Island Effect

The negative effects of UHI can include human health problems, high energy consumption, and environmental issues.

Human Health: Urban heat can also threaten people's health. If temperatures rise, residents, especially the elderly and young children, may be at greater risk of heat-related ailments, including heat stroke (Kjellstrom et al., 2018). The UHI effect can also lead to increased levels of air pollution, which can have negative impacts on respiratory health. (Chen et al., 2019). Additionally, the increased demand for energy for cooling buildings can lead to higher energy costs, which can be a burden for low-income households. (Clarke et al., 2020).

Energy Consumption: The UHI effect can increase the demand for energy for cooling buildings. This can lead to higher energy costs and greenhouse gas emissions. (Wang et al., 2020). The increased demand for energy can also put a strain on the electricity grid, particularly during heat waves when there is high demand for electricity (Naeem et al., 2019).

Environment: The UHI effect can have negative impacts on the environment. The increased demand for energy can lead to higher greenhouse gas emissions, which contribute to climate change. (Wang et al., 2020). The lack of vegetation in urban areas can also lead to reduced biodiversity and lower carbon sequestration. Additionally, the UHI effect can exacerbate the urban heat stress, which can lead to changes in weather patterns and alter the hydrological cycle. (Kjellstrom et al., 2018)

Urban Planning Aspects of UHI: Urban planning aspects play a pivotal role in shaping the Urban Heat Island (UHI) effect, influencing factors such as urbanization, land use patterns, anthropogenic heat emissions, population density, infrastructure design, green spaces, and urban geometry (Bokhad et al., 2024).

Urbanization and Land Use Pattern: Urbanization replaces vegetation with structures like buildings and roads, reducing overall vegetation cover in cities (Wong & Yu, 2005). Rural areas, with more vegetation, contribute to evaporation, cooling the atmosphere, unlike urban areas where ad-hoc development inhibits evaporation. Impervious surfaces in developed urban areas lead to high runoff and low infiltration rates, reducing moisture available for cooling through evapotranspiration. Each 10% increase in vegetative cover can lower temperatures by 0.6 K, highlighting the significant cooling impact of trees and vegetation in mitigating urban heat. (Rovers, 2016)

Green Cover: Shading and evapotranspiration the process of a tree releasing water to the air will lower the temperature (Farooq & Kamal, 2020). As there is less green cover around us, there is lesser shading, as a result exposed surface tend to take more heat and release it in the air. Because of the lesser evaporation, however, the humidity that cools the air is not there and the air temperature stays high (Figure 2). Urban paved surfaces consist of up to 75% impervious surfaces, whereas natural ground cover is about 10% impervious, hence natural ground surface can provide sufficient moisture for cooling the air near the surface. (Rovers, 2016).

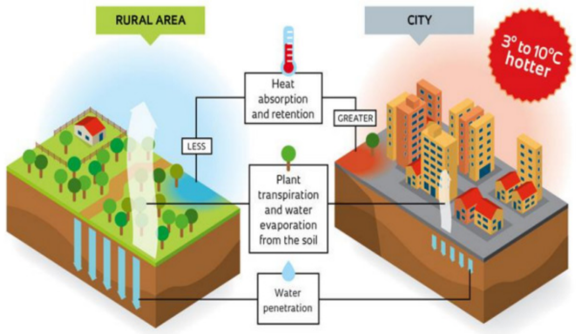


Figure 2. Green cover impacts Urban Heat Island.

Urban Geometry: Urban geometry in cities affects wind movement, shading patterns, heat absorption, and long-wave radiation emission. Urban canyons, formed by narrow streets and tall buildings, are hotspots for the Urban Heat Island (UHI) effect (Figure 3). Tall buildings in urban canyons can provide shade, reducing surface temperatures during the day. Yet these skyscrapers also reflect and trap the heat, raising the air temperature in the canyon.

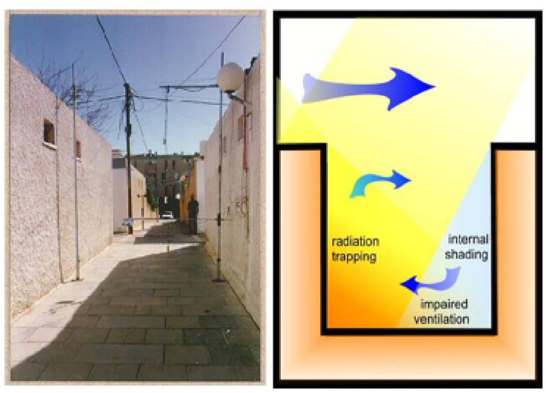
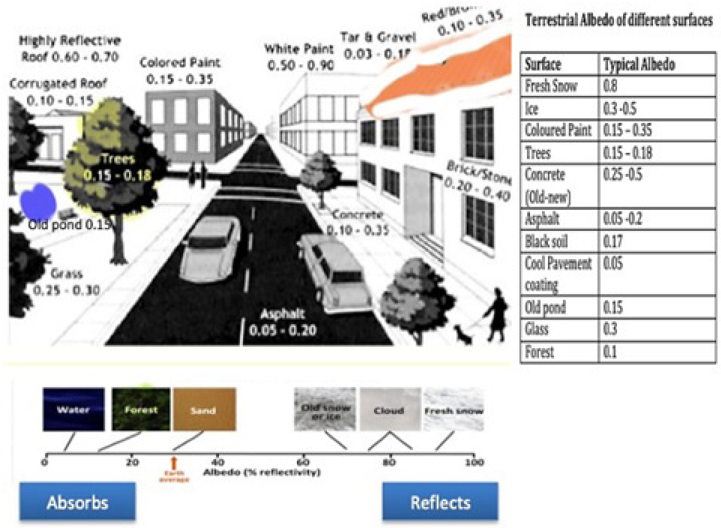


Figure 3. Urban Canyons based on different heights and widths of urban masses impacts UHI.

Urban Surface Characteristics: Urban surfaces' characteristics, including thermal capacity, emittance, absorbance, and reflectance, play a significant role in Urban Heat Island (UHI) formation by influencing solar energy absorption and reflection.

Albedo= Reflected energy /Albedo Incident energy

Low-albedo surfaces like roads, rooftops, and pavements in urban areas absorb more solar heat than rural areas, contributing to increased surface temperatures and UHI formation (Figure 4). Building materials such as steel, cement, etc, that are used in urban surfaces have considerably more thermal capacity than those used in rural surfaces like soil, sand, etc, and this higher heat capacity in combination with the heat retention by buildings and pavement are the major causes of the UHI. This further contributes to temperature in urban heat islands not condensing as much (Kamal, 2024). Property of urban materials Influence on albedo estimation. Albedo is simply defined as the ratio of incident solar radiation to reflected solar radiation. Resistance to heat, or high albedo, is a helpful quality to have. Albedo is a function of surfaces layout, material, pavements and colours (Bhargava et. al., 2017)



Surface	Typical Albedo
Fresh Snow	0.8
Ice	0.3-0.5
Coloured Paint	0.15 - 0.35
Trees	0.15 - 0.18
Concrete (Old-new)	0.25 -0.5
Asphalt	0.05 -0.2
Black soil	0.17
Cool Pavement coating	0.05
Old pond	0.15
Glass	0.3
Forest	0.1

Figure 4. Urban surface Albedo characteristics of different materials.

4. Mitigating Measures to Restrict Urban Heat Island Effect

There are various mitigating measures to restrict urban heat island effect (Figure 5). They are summarized as below:

4.1 Green Infrastructure

Green Roof: Implement green roofs with vegetation to absorb sunlight, reduce heat absorption, and provide insulation.

Green Wall: Install vertical gardens on building facades to enhance cooling and air quality.

Green Parking and Pavement: Use permeable surfaces or vegetation in parking lots and sidewalks to reduce heat build-up.

Shaded Street: Plant trees along streets to provide shade and reduce direct sunlight exposure.

4.2 Sustainable Building Materials

Reflective Street Pavement: Use reflective material, such as light-colored surfaces for roads or pavements, to help reduce the uptake of heat.

Cool Roof Coatings: Apply reflective coatings to a rooftop system to decrease thermal heat gain from the sun.

Colour Changing Paint: Employ thermo-chromatic paints for temperature-controlled reflections.

Bright materials: Use materials with high albedo.

Energy-efficient Appliances: Support energy-efficient appliances that save on total energy consumption.

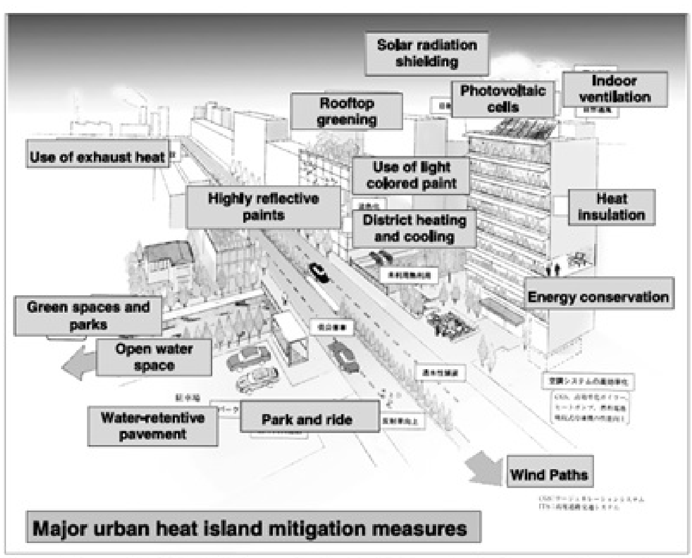


Figure 5. Major Urban Heat Island mitigation measures.

4.3 Urban Planning and Land Use

- Smart Growth Practice: Design compact, mixed-use neighbourhoods and limit sprawl to minimize the impact of heat islands.
- Vegetative Cover: Plant more trees and shrubbery to create shade and decrease heat.
- Mixed land use: Promote mixed residential, commercial, and recreational activities to decrease the generation of localized heat.
- Building Massing and Form: To make designs with natural ventilation and heat dissipation.
- public mental health Microclimate: Consideration of local, place specific climate and design (e.g., prevailing winds, solar exposure.
- Heat-Tolerant Landscaping: Pick the local flora that is well suited to the climate and doesn't need a lot of water.
- Cooling Centers: Identify areas of the community (i.e., parks, public buildings) that could serve as cooling centers during extreme heat.

4.4 Policy and Education

- Government Legislation: Enforce regulations promoting sustainable practices and UHI mitigation.
- Public Awareness: Educate residents, builders, and policymakers about UHIs and their impact.

5. Case Studies

Urban Heat Island (UHI) effects are spatially heterogeneous, shaped profoundly by microclimatic conditions, urban geometry, land use typologies, and the degree of vegetative integration. To comprehend these spatial dynamics in Indian megacities, this study undertakes a comparative analysis of New Delhi and Bangalore—two urban centres with differing climate profiles, development trajectories, and land transformation patterns.

5.1 Case Study 1: New Delhi, India

Geographical and Climatic Context: Situated at 28.61°N and 77.23°E, New Delhi lies within a semi-arid climatic zone characterized by a pronounced diurnal temperature range. The region endures extreme summer temperatures (up to 45°C), cold winters (as low as 5°C), and an annual average precipitation ranging between 600–800 mm.

Study Sites: Three representative residential neighbourhoods - Vasant Kunj (R1), Belvedere (R2), and Chhatarpur (R3)—were selected based on contrasting morphological and environmental variables, including proximity to water bodies, green cover density, and urban geometry (Figure 6).

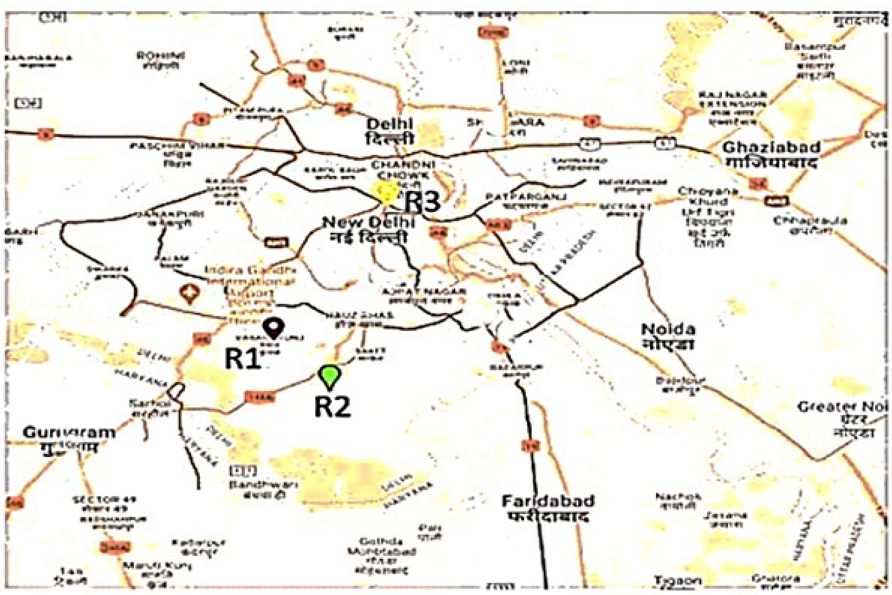


Figure 6. Satellite image of Delhi showing different locations selected for the study.

Table 1. Comparative Analysis of Urban Heat Island (UHI) Impacts Based on Green Cover, Water Proximity, and Urban Geometry in New Delhi Residential Areas

Location	Green Cover	Proximity to Water	H/W Ratio	Observed UHI Impact
Vasant Kunj	Medium	High	Low	Moderated temperatures due to evapotranspiration
Belvedere	Low	Absent	Medium	Elevated temperatures and heat retention
Chhatarpur	High	Moderate	High	Lowest recorded temperatures

Key Observations: Belvedere showed the highest degree of UHI intensity, being also energetically charged with high globe temperature and thermal discomfort, with the smallest vegetative fraction and the largest impervious surface fraction. Although, Vasant Kunj had lesser H/W, it held cooler microclimatic conditions as it was close to a major water body and vegetative passes. Chhatarpur, having the maximum H/W ratio, showed the minimum thermal moderation, due to its canyon shaped urban form, providing reduced direct radiation and increased shading.

Analytical Inference: The geometry of urban canyon especially the H/W ratio was a major factor controlling diurnal thermal fluctuation. Higher urban canyons ($H/W \geq 2.2$) delayed heat release and improved pedestrian thermal comfort while lower canyons ($H/W \leq 0.75$) were into the solar exposure and the radiative heat evacuation from vertical faces.

5.2 Case Study 2: Bangalore, India

Geographical and Climatic Context: Bangalore, located at 12.98°N and 77.57°E, enjoys a moderate climate due to its elevation (approximately 900 m above MSL). However, rapid urbanization has altered the city's thermal landscape significantly. Summers register temperatures up to 39°C with low relative humidity (20–40%), and annual precipitation averages 900 mm.

Urbanization Trends: Studies by Ramachandra & Kumar (2010) and Gopalakrishnan (2002) highlighted a 52.5% increase in built-up area from 1973 to 2009, concomitant with a 78% reduction in vegetation and 79% decline in surface water bodies, establishing a direct link between land cover transformation and thermal amplification.

Study Locations: Location 1 - Lalbagh (Jayanagar IV Block): High vegetative index and compact form, Location 2 - Basweshwar Nagar: Intermediate morphology and green cover, Location 3 - Bellandur: Rapid urban expansion with sparse green spaces (9%).

Figure 7. Satellite image of Bangalore showing different locations selected for the study.

Thermal and Microclimatic Observations: Lalbagh had the lowest air and globe temperatures throughout the site, suggesting a large effect of canopy-level shading and latent heat exchange (evapotranspiration). Bellandur with its large proportions of built up surfaces and few vegetation was found to have high thermal load and low diurnal cooling rates. Basweshwar Nagar (moderate in nature) confirmed that the nature of gradient effect influenced UHI intensity.

5.3 Comparative Synthesis

The comparisons between empirical results show that urban form (e.g., block spacing, street aspect) and landscape features (e.g., vegetative buffers, water presence) are strong determinants of UHI magnitude. The surface effects on the heat storage and release fluxes were supported by the averages of air temperature, wet-bulb temperature, and relative humidity at hourly intervals. The comparative summary of UHI mitigation performance and dominant contributing factors in New Delhi and Bangalore is shown in the Table 2.

Table 2. Comparative Summary of UHI Mitigation Performance and Dominant Contributing Factors in New Delhi and Bangalore.

Variables	New Delhi	Bangalore
UHI Mitigation Best Performer	Chhatarpur (high H/W, green)	Lalbagh (dense canopy)
UHI Mitigation Least Performer	Belvedere (impervious, sparse vegetation)	Bellandur (low green cover)
Dominant Factor	Urban Geometry and Water Bodies	Vegetation and Land Use Change

The comparative case study shows that UHI mitigation varies locally, but there are shared driving factors: green infrastructure, spatial morphology, and surface materials. Although rapid land cover change in Bangalore has increased heat exposure over the past three decades, the variety of urban morphologies observed in the megacity of New Delhi points to opportunities for adaptive cooling via planned geometry and landscape connectivity.

6. Conclusions

The empirical case studies of New Delhi and Bangalore clearly establish the strong influence of urban planning parameters on the formation and intensity of the Urban Heat Island effect. The findings reveal that urban planning elements such as land use, green cover, urban geometry, and proximity to water bodies significantly influence the magnitude of UHI effects. In both cities, areas with higher green cover, better urban canyon geometry (H/W ratio), and thoughtful integration of open spaces demonstrated lower air and globe temperatures, thereby validating the critical role of urban form and vegetation in climate resilience. The comparative effectiveness of UHI mitigation strategies in New Delhi and Bangalore is summarized in Table 3.

Table 3. Comparative Effectiveness of UHI Mitigation Strategies in New Delhi and Bangalore

City	Location	Green Cover (%)	H/W Ratio	Proximity to Water Body	UHI Mitigation Effectiveness	Remarks
New Delhi	Belvedere	Very Low	1.2	No	Poor	Worst performer; high surface temperatures
New Delhi	Vasant Kunj	Moderate	Low	Yes	Moderate	Proximity to water body helped lower RH
New Delhi	Chhatarpur	High	High	No	High	Best performer in Delhi case
Bangalore	Lalbagh (Jayanagar)	High	Moderate	Yes	High	Effective due to large park and water body
Bangalore	Basweshwar Nagar	Moderate	Low	No	Moderate	Moderate due to average vegetation and layout
Bangalore	Bellandur	Low	Low	No	Poor	Similar challenges to Belvedere

The vegetative presence is the single most effective cooling mechanism in both spatial and temporal terms. The urban geometry, particularly the height-to-width (H/W) ratio of built forms, plays a pivotal role in modulating microclimatic conditions through shading and airflow dynamics. The impervious surfaces and low-albedo materials contribute significantly to surface heat retention, emphasizing the need for reflective and permeable surfaces in design codes. The context-specific interventions, including the integration of water-sensitive design, preservation of natural vegetation, and optimization of built form geometry, must be institutionalized in urban policy frameworks. As the effects of urban heat islands (UHI) continue to escalate, planners need to incorporate UHI mitigation strategies into urban design, which requires:

- A minimum of 30–40% green cover in urban layouts
- The use of high-albedo and highly pervious surface materials
- Preservation and restoration of natural water bodies
- Optimal street canyon design to enhance wind flow and provide effective shading

A thermal-sensitive integrated approach to urban planning, in which land use decisions are analysed in terms of their contribution to the thermal performance of cities, should be a key focus of future urban planning to build urban resilience against increasing urban temperatures and climate stressors in Indian cities.

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