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## **STRENGTHENING URBAN CLIMATE RESILIENCE THROUGH GREEN INFRASTRUCTURE: CHALLENGES AND PROSPECTS**

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### **Abstract:**

Urban air quality in India has reached alarming levels in early 2026, with many cities recording Air Quality Index (AQI) values in the ‘very poor’ to ‘severe’ range, and several monitoring stations exceeding hazardous thresholds, posing serious risks to public health and urban liveability. In the National Capital Region, AQI levels above 400 have triggered emergency response measures, while other metropolitan regions continue to experience persistent pollution despite short-term meteorological variations. This reflects a broader global trend of deteriorating urban environments driven by rapid urbanisation, rising energy demand, vehicular emissions and industrial activity, compounded by climate-induced stressors such as extreme heat, intense rainfall and flooding.

This paper examines green infrastructure including urban forests, wetlands, green belts, permeable surfaces, green roofs and nature-based stormwater systems as an integrative strategy for strengthening climate resilience in cities. Drawing on district disaster management plans, municipal climate reports, national urban mission documents and sectoral data from relevant ministries, the study evaluates the capacity of green infrastructure to mitigate urban heat island effects, enhance stormwater management, improve air filtration and support ecosystem services.

The analysis demonstrates that green infrastructure can simultaneously reduce air pollution, urban heat stress, surface flooding and the loss of urban green cover. However, large-scale implementation remains constrained by fragmented institutional frameworks, limited availability of urban land, financial and maintenance challenges, and weak integration of nature-based solutions within city master plans and development regulations. Evidence from selected municipal initiatives suggests that coordinated planning, stable financing mechanisms and community participation significantly enhance project effectiveness and long-term sustainability. The paper concludes that systematic mainstreaming of green infrastructure into urban planning, infrastructure investment and regulatory systems is essential for strengthening climate resilience and safeguarding urban populations in rapidly urbanising Indian cities.

**Keywords:** Green Infrastructure; Climate Resilience; Urban Sustainability; Air Quality Management; Nature-Based Solutions; Indian Cities.



## 1. Introduction

Indian cities are experiencing escalating environmental stress driven by rapid urbanisation, population growth, and expanding infrastructure demand. These pressures intensify climate-related risks such as air pollution, heat stress, flooding, water scarcity, and ecological degradation, directly affecting public health, economic productivity, and urban liveability. National monitoring systems consistently report exceedances of air quality standards, rising frequency of heatwaves, and increasing incidence of urban flooding, highlighting the growing vulnerability of urban systems.

Climate variability compounds these challenges by amplifying extreme temperature events and short-duration, high-intensity rainfall that overwhelms conventional drainage infrastructure. Simultaneously, the degradation of urban green and blue spaces—such as trees, wetlands, and lakes—reduces natural buffering capacity against climate extremes, increasing reliance on costly engineered solutions.

In response, national urban policy frameworks increasingly emphasise sustainable and climate-resilient development. Within this context, green infrastructure—comprising urban forests, wetlands, permeable surfaces, green roofs, and restored water bodies—has emerged as a multifunctional strategy that integrates ecological systems into the urban fabric. Green infrastructure supports microclimate regulation, stormwater management, air quality improvement, and ecosystem services while contributing to long-term urban resilience. However, despite policy recognition, systematic integration of green infrastructure into statutory planning, infrastructure investment, and governance processes remains limited.

This paper examines the role of green infrastructure in strengthening climate resilience in Indian cities, focusing on its environmental benefits, institutional challenges, and policy pathways for effective mainstreaming within urban development frameworks.

## 2. Problem Statement

Indian cities face a set of interconnected environmental and climate-related challenges that increasingly undermine urban resilience. Rapid urban expansion, population growth, and infrastructure intensification have placed severe pressure on air quality, thermal comfort, water systems, and ecological assets, with direct implications for public health, economic productivity, and urban liveability.

Air pollution remains a persistent concern, with monitoring data indicating that particulate matter levels in many cities regularly exceed prescribed standards, particularly during winter months. Emissions from transport, construction activity, and biomass burning, combined with unfavourable meteorological conditions, continue to drive elevated exposure and health risks despite ongoing mitigation efforts.

Urban heat stress has intensified due to climate change and dense built environments. Increasing frequency of heatwaves, extensive paved surfaces, and declining tree cover limit



natural cooling, raising energy demand and disproportionately affecting vulnerable populations. At the same time, urban flooding has become more frequent as encroachment on natural drains, inadequate stormwater infrastructure, and expansion of impervious surfaces reduce infiltration and increase runoff during rainfall events.

The degradation of urban green and blue spaces further exacerbates climate vulnerability. Loss of trees, wetlands, and lakes reduces ecosystem services such as cooling, air filtration, and stormwater regulation, increasing reliance on engineered infrastructure solutions. Urban water security is also under stress due to groundwater depletion, limited recharge, and degradation of recharge zones, leading to greater dependence on energy-intensive water transfers.

Despite national missions promoting climate-resilient urban development, responses remain fragmented at the city level. Institutional responsibilities for land use planning, drainage, forestry, water supply, and environmental protection are distributed across multiple agencies with limited coordination. Urban planning frameworks often treat green spaces as residual land uses rather than functional infrastructure systems, constraining integrated responses to interconnected urban climate risks.

### 3. Literature Review and Policy Framework:

Green infrastructure has gained increasing recognition in Indian urban policy as a means of addressing climate risks while improving environmental quality and urban liveability. Government missions, planning guidelines, and project evaluations acknowledge the role of natural systems in mitigating heat stress, managing stormwater, improving air quality, and supporting ecological stability. However, practice remains uneven and largely project-based.

At the policy level, the National Mission for Sustainable Habitat promotes integrated planning approaches that emphasise compact urban form, enhanced green cover, sustainable transport, and improved water management as pathways for climate-resilient urban development. AMRUT 2.0 operationalises these objectives by prioritising urban water supply, sewerage, stormwater drainage, and rejuvenation of water bodies, thereby strengthening green–blue infrastructure systems. Spatial planning guidance under the URDPFI Guidelines further supports integration of green spaces, buffers, and ecological protection zones within statutory plans. Environmental regulations such as the Wetlands (Conservation and Management) Rules and urban forestry programmes provide a legal and institutional basis for ecosystem conservation, while disaster management guidelines recognise ecosystem-based measures as complementary flood risk reduction strategies.

Evidence from government-supported initiatives demonstrates the practical application of green infrastructure across Indian cities. Lake rejuvenation projects under AMRUT, particularly in Bengaluru, have improved water storage capacity, groundwater recharge potential, and local flood moderation. The East Kolkata Wetlands illustrate large-



scale ecosystem-based wastewater treatment and flood regulation while sustaining livelihoods. Urban forestry initiatives in cities such as Indore, Hyderabad, and Ghaziabad show localised cooling and air quality benefits, while riverfront developments such as the Sabarmati Riverfront integrate public green spaces with flood management infrastructure, albeit with contested ecological outcomes.

Despite these initiatives, government evaluations consistently identify limitations in large-scale mainstreaming of green infrastructure. Fragmented institutional responsibilities, emphasis on asset creation over long-term maintenance, weak performance monitoring, and limited data integration constrain effectiveness. Land scarcity, development pressures, and uneven community participation further restrict sustained implementation. These gaps indicate that while policy intent exists, stronger institutional coordination, financing mechanisms, technical capacity, and outcome-based monitoring are necessary to fully realise the climate resilience potential of green infrastructure.

#### 4. Data Sources and Methodology

This study adopts a qualitative, descriptive research approach to examine the role of green infrastructure in strengthening urban climate resilience in Indian cities. The methodology is exploratory and policy-oriented, appropriate for analysing institutional arrangements, implementation practices, and governance challenges associated with nature-based solutions in urban contexts.

The analysis relies exclusively on secondary data drawn from authoritative government sources to ensure policy relevance and reliability. These include national air quality datasets, disaster management guidelines, urban planning frameworks, environmental regulations, and official reports from central ministries, state governments, and municipal corporations. Project documentation related to lake rejuvenation, urban forestry, wetland conservation, and riverfront development was reviewed to identify recurring patterns of implementation and outcomes.

A resilience-based analytical framework was applied to interpret how green infrastructure interventions contribute to multiple urban risk dimensions, including heat mitigation, stormwater management, environmental health, ecological stability, and water security. Interventions were assessed qualitatively using reported outcomes such as reduction in waterlogging incidents, improvements in local environmental conditions, and integration of green assets into urban service delivery systems.

Case illustrations were selected based on availability of verified government documentation, geographic diversity, and relevance to key climate risks. The study does not employ quantitative modelling or comparative statistical analysis; instead, it focuses on interpretive synthesis to examine policy alignment, institutional coordination, and implementation constraints. This approach enables identification of systemic gaps and policy-



relevant pathways for mainstreaming green infrastructure within urban development frameworks.

## 5. Findings and Results

The findings indicate that green infrastructure contributes measurable co-benefits across multiple urban climate risk dimensions in Indian cities, particularly when integrated with broader policy and infrastructure programmes. Evidence from government assessments suggests that benefits are most pronounced where interventions are planned at appropriate spatial scales and supported by institutional coordination.

With respect to air quality, national assessments under the National Clean Air Programme report measurable reductions in particulate matter concentrations in selected cities, coinciding with implementation of urban forestry, roadside plantations, and green buffer development. While emission control remains the primary driver of long-term air quality improvement, vegetation-based interventions contribute localised particulate capture, dust suppression, and microclimate moderation. However, persistent poor air quality in major metropolitan regions demonstrates that green infrastructure functions as a complementary rather than standalone solution.

In the context of stormwater management and urban flooding, government programme reviews highlight that rejuvenation of lakes, wetlands, and drainage-linked green infrastructure has reduced chronic waterlogging in several cities. Restored water bodies act as temporary retention zones during peak rainfall, lowering pressure on engineered drainage systems. District disaster management reports corroborate reductions in flood-prone locations where such interventions are implemented systematically.

Urban heat mitigation outcomes are less uniformly quantified, yet qualitative evidence from municipal and state forestry programmes indicates improved thermal comfort in areas with increased canopy cover. Tree plantations and park development contribute to shading and evapotranspiration, reducing surface temperatures at micro-scales. The absence of standardised national metrics, however, limits precise measurement of heat reduction impacts.

Findings related to ecological restoration indicate that protection and rejuvenation of green and blue assets deliver long-term ecosystem services, including biodiversity support, recreational value, and enhanced urban environmental quality. Wetland conservation initiatives demonstrate significant flood buffering and livelihood benefits, though post-restoration ecological performance monitoring remains limited.

Urban water security outcomes suggest that lake rejuvenation and protection of recharge zones support groundwater replenishment and surface water storage. While systematic quantification of recharge impacts is limited, policy frameworks explicitly link healthy water bodies with long-term urban water resilience. Overall, the findings confirm that



green infrastructure is most effective when embedded within integrated planning, financing, and governance systems rather than implemented as isolated projects.

## 6. Discussion and Interpretation

The findings reinforce the understanding that green infrastructure functions as a multi-dimensional strategy for enhancing urban climate resilience rather than as a single-purpose environmental intervention. Its capacity to address air pollution, flooding, heat stress, ecological degradation, and water insecurity simultaneously distinguishes it from conventional sector-specific infrastructure responses.

Evidence from Indian cities suggests that green infrastructure delivers the strongest outcomes when planned as interconnected systems rather than isolated projects. Lake rejuvenation, urban forestry, and wetland conservation initiatives demonstrate cumulative benefits only when supported by appropriate spatial scale, institutional coordination, and long-term maintenance. Fragmented or aesthetic-focused interventions, by contrast, yield limited resilience gains.

The discussion also highlights that green infrastructure complements, rather than replaces, engineered solutions. In the case of air quality management, vegetation-based interventions provide localised mitigation and microclimate benefits but cannot offset high emission loads without parallel pollution control measures. Similarly, flood mitigation outcomes depend on integration with drainage planning and protection of natural flow pathways.

Institutional factors emerge as a critical determinant of effectiveness. Fragmented governance structures, short-term funding cycles, and limited technical capacity constrain sustained performance of green assets. Cities that demonstrate better outcomes tend to align green infrastructure with statutory planning frameworks, capital investment programmes, and community stewardship mechanisms.

Overall, the discussion underscores the need to shift from project-based implementation toward network-based and performance-oriented governance of green infrastructure. Such a transition is essential for translating documented co-benefits into durable climate resilience outcomes in rapidly urbanising Indian cities.

## 7. Challenges and Implementation Barriers

Despite growing recognition of green infrastructure within national urban policy frameworks, large-scale and sustained implementation in Indian cities remains constrained by structural and governance-related barriers. Institutional fragmentation is a primary challenge, as responsibilities for land use planning, drainage, forestry, water supply, transport, and environmental regulation are distributed across multiple agencies with limited coordination. This fragmentation weakens integrated planning and accountability for long-term outcomes.



Spatial constraints further limit implementation. High urban densities, competing land-use priorities, and continued encroachment on wetlands, floodplains, and natural drains restrict the availability of land for green infrastructure expansion, despite regulatory protections. In many cases, green spaces are treated as residual land uses rather than essential infrastructure assets.

Financial and operational challenges also undermine effectiveness. Capital funding mechanisms tend to prioritise asset creation, while long-term operation and maintenance of green assets receive inadequate attention. Limited municipal revenue capacity and absence of lifecycle costing contribute to rapid deterioration of restored lakes, parks, and plantations once initial project funding ends.

Monitoring and evaluation systems remain weak. Current frameworks focus largely on physical outputs rather than ecosystem performance indicators such as temperature reduction, runoff retention, or pollutant absorption. Limited technical capacity and poor data integration across agencies further constrain evidence-based scaling of green infrastructure initiatives.

Finally, community engagement and stewardship remain uneven. While policy documents encourage citizen participation, lack of sustained institutional support and clarity of responsibility often results in poor maintenance, encroachment, and misuse of green spaces. These barriers collectively indicate that overcoming implementation challenges requires coordinated institutional reform, stable financing mechanisms, technical capacity building, and stronger governance frameworks.

## 8. Policy Recommendations and Strategic Pathways

To unlock the full climate resilience potential of green infrastructure in Indian cities, policy interventions must move beyond isolated pilot projects toward systematic mainstreaming across planning, finance, governance, and monitoring systems. International experience demonstrates that nature-based solutions achieve durable outcomes when embedded within statutory frameworks, lifecycle financing models, and performance-oriented governance structures.

A primary policy priority is the integration of green infrastructure into statutory urban planning instruments. Master plans and development control regulations should treat green spaces, wetlands, floodplains, and permeable surfaces as essential infrastructure assets rather than residual land uses. Establishing minimum green cover standards, protection of ecological corridors, and mandatory use of permeable surfaces can strengthen climate resilience outcomes.

Citywide blue–green network planning is critical for maximising resilience benefits. Connecting lakes, wetlands, parks, drainage corridors, and street-level greenery as integrated systems enhances flood buffering, thermal regulation, and ecological connectivity. Such



spatial integration enables cities to address multiple climate risks simultaneously rather than through fragmented interventions.

Financing mechanisms must also evolve to support long-term performance of green infrastructure. Dedicated maintenance funds, lifecycle costing, and convergence of existing urban and environmental funding streams can improve fiscal sustainability. Innovative instruments such as municipal green bonds and climate adaptation funds offer additional pathways for scaling investment.

Strengthening performance monitoring and technical capacity is equally important. Shifting from output-based reporting to outcome-oriented indicators—such as temperature reduction, runoff retention, and ecosystem health—can enable evidence-based planning and adaptive management. Capacity-building programmes for urban local bodies and mechanisms for community stewardship can further enhance implementation and asset longevity.

## 9. Conclusion

Indian cities are entering a period of heightened climate vulnerability marked by deteriorating air quality, rising heat exposure, recurrent urban flooding, degradation of ecological assets, and growing water stress. These interconnected risks increasingly threaten public health, infrastructure reliability, and urban liveability, underscoring the limitations of fragmented and sector-specific urban responses.

This study demonstrates that green infrastructure offers a practical and scalable pathway for strengthening urban climate resilience when integrated into formal planning, investment, and governance systems. Evidence from government programmes and city-level initiatives indicates that green infrastructure delivers measurable co-benefits in flood mitigation, microclimate regulation, ecological restoration, and localized air quality improvement, particularly when implemented as interconnected systems rather than isolated projects.

However, the analysis also highlights persistent constraints, including fragmented institutional arrangements, insufficient maintenance financing, weak performance monitoring, and limited technical capacity. Without systematic integration into statutory planning frameworks and municipal budgeting processes, green infrastructure risks remaining confined to pilot initiatives rather than becoming a core component of urban infrastructure systems.

The paper concludes that transitioning from project-based implementation toward network-based and performance-oriented governance of green infrastructure is essential for achieving durable climate resilience outcomes. Embedding green infrastructure within urban development strategies can enable Indian cities to address multiple climate risks simultaneously while advancing more sustainable, resilient, and liveable urban futures..



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