सत्यमेव जयते

# Natural Infrastructure

## & Resilient Cities

### Role of Green Infrastructure in Urban Planning for Adaptation to Climate Change in India

nidm

Resilient India : Disaster free India

National Institute of Disaster Management

(Ministry of Home Affairs, Govt. of India)

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**2025**

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*(Ministry of Home Affairs, Govt. of India)*

Plot No. 15, Block B, Pocket 3, Sector 29, Rohini, Delhi 110042

Website: https://nidm.gov.in

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**Authors:**
Dr Pallavi Saxena
Dr Saurabh Sonwani
Prof Anil K Gupta
Shri Rajendra Ratnoo, IAS
Ms Pritha Acharya

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**Dr. Akhilesh Gupta**
Secretary, SERB and Senior Advisor

**Department of Science and Technology (DST)**
Government of India
Technology Bhavan, New Mehrauli Road,
New Delhi-110016

# MESSAGE

With home to more than 1.4 billion people, cities are the harbinger of growth and development. Nonetheless, cities and communities today are struggling with the impacts of natural disasters and human health challenges. On one hand cities are trying hard to improve the quality of live for people due to environmental degradation, economic shocks, migration and demographic shocks. While on the other natural disasters like floods, droughts etc have already affected almost 220 million people causing a damage of USD 100 billion per year.

Resilient cities are much better placed to handle any form of disasters. This concept has been acknowledged by a number of national and international policies and developmental goals are relying on the potentials of Green Infrastructure as a tool to improve the city resilience. The Prime Ministers' 10 point agenda on Disaster Risk Mitigation also mentions the need to imbibe the principles of disaster risk reduction across all developmental sectors.

This policy paper is a genuine attempt by the authors to bring out the Green Infrastructure potentials in urban planning as effective strategy for climate adaptation. I congratulate all the authors for bringing out this important and timely report.

**(Akhilesh Gupta)**

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राजेन्द्र रत्नू, भा. प्र. से.
कार्यकारी निदेशक
**Rajendra Ratnoo,** IAS
**Executive Director**

सत्यमेव जयते

राष्ट्रीय आपदा प्रबंधन संस्थान
National Institute of Disaster Management
(गृह मंत्रालय, भारत सरकार)
Ministry of Home Affairs, Govt. of India
प्लॉट नं. 15, ब्लॉक बी, पॉकेट 3,
सेक्टर 29, रोहिणी, दिल्ली – 110042
Plot No. 15, Block B, Pocket 3,
Sector 29, Rohini, Delhi-110042

# FOREWORD

Cities are the engines of development and are also main source of pollution. In Indian cities, rapid urbanization is causing the challenges of pollution and over exploitation of natural resources. One of the main cause of urbanization is the "Urban Heat Island" (UHI) effect, where, cities tends to be more warmer than the surrounding rural area. It has been determined that climate change will elevate the intensity of UHI, particularly in hot areas characterized by dry days during summer season.

Green Infrastructures are considered as the most effective and efficient ways to improve the microclimate and impacts of climate change and UHI effect. GIs consists of green roofs, vertical gardens, urban forests, urban agriculture, river parks, green buildings, areas of constructed wetlands, nature conservation zones and alternative energy farms. Green Infrastructures strengthen the process of carbon sequestration and mitigate the climate change impacts and in doing so it enhances the resilience of the built environment.

This policy paper tries to establish the role of green infrastructure in promoting climate resilience in cities and urban areas. It focuses on Green Infrastructure methodologies and models as an effective tools for climate adaptations in cities. I am sure that this policy paper will add value to the existing knowledge of climate adaptation and city resilience.

**(Rajendra Ratnoo)**

फोन / Ph: +91-11-20873401, • ई मेल / E-mail: ed.nidm@nic.in, ratnoor@ias.nic.in, • वेब साईट / Website: www.nidm.gov.in

nidm
Resilient India - Disaster Free India

**Dr. Anil Kumar Gupta**
Project Director: CAP-RES (DST)
Professor and Head - Environment,
Climate and Disaster Risk
Management Division

सत्यमेव जयते

राष्ट्रीय आपदा प्रबंधन संस्थान
(गृह मंत्रालय, भारत सरकार)
National Institute of Disaster Management
(Ministry of Home Affairs, Govt. of India)
Plot No. 15, Pocket-3, Block-B, Sector-29,
Rohini, Delhi-110042

# PREFACE

Green Infrastructures (GIs) are cost-effective tools to mitigate climate change, maintain aesthetic and recreational centres for urban communities and improve the well-being of local residents in cities. Climate-related challenges like urban heat islands, urban floods, dust storms etc are exponentially rising. Disturbances in the rainfall patterns and sea level rise, are increasing the vulnerability of urban centres located in low coastal regions, most likely leading to extreme events such as floods, tsunamis, and cyclones that cause high economic, social and physical damage to the environment. For urban development planning, Green Infrastructures (GIs) play an important role in combating climate change challenges and promoting environmental sustainability in Indian cities

This policy paper on "Natural Infrastructure and Resilient Cities: Role of Green Infrastructure in Urban Planning for Adaptation to Climate Change in India" is taken up under the Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment (CAP-RES) project at NIDM-funded by DST-GoI. It is an attempt to understand the role of green infrastructures (GIs) as a cost-effective measure for climate adaptation and recommends best practices in green space planning to satisfy various environmental, social and economic needs of urban areas and enhancement of ecosystem services in Indian cities. This article also proposes the need for a coherent approach to developing effective guidelines by urban planners and green infrastructure planners to meet the socio-ecological needs of cities. I hope that this publication will serve as a good knowledge kit for students, researchers, academicians, professors, officials and practitioners.

**(Anil K Gupta)**

# ACKNOWLEDGEMENT

The policy paper on "Natural Infrastructure and Resilient Cities Role of Green Infrastructure in Urban Planning for Adaptation to Climate Change in India" is carried out under the Project Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment (CAP-RES) supported by the Department of Science & Technology (DST), Government of India. A special note of thanks to Dr Akhilesh Gupta, Senior Advisor and Secretary, Science and Engineering Research Board (SERB) for entrusting NIDM with the opportunity to take up and work on the CAP-RES project. The project team is thankful to Shri Rajendra Ratnoo, Executive Director, NIDM, Dr (Mrs) Anita Gupta, Head of Climate Change and clean energy Division, Dr Nisha Mendiratta, Advisor and Head of WISE-KIRAN Division at the Department of Science and Technology, Dr Susheela Negi, Principal Scientist, and Dr Rabindra Panigrahi, Senior Scientist of Department of Science and Technology, Government of India for their support to this policy paper.

Contributions of the authors including Dr. Pallavi Saxena, Assistant Professor, Department of Environmental Sciences, Hindu College, University of Delhi, Dr. Saurabh Sonwani, Assistant Professor, Department of Environmental Studies, Zakir Husain Delhi College, University of Delhi and Ms Pritha Acharya (Research Associate, CAP-RES, NIDM) are acknowledged for joining hands with us in undertaking this policy paper which takes into account both technical understanding and policy interventions at the same time.

A special thanks to Ms Pritha Acharya for designing the report and coordinating the policy paper. The project team also extend thanks to Shri Surendra Thakur Ji (Consultant & I/C, Admin & HR), Dr. Kundan for review and useful inputs, Shri S.K. Tiwari (Librarian, NIDM) and the entire publication cell of NIDM including Ms Karanpreet Kaur Sodhi, Jr Consultant (Publication) for helping in printing and publication of this report.

**Prof Anil K Gupta**
Project Director
CAP-RES, NIDM

# Table of Contents

# Abbreviations

AMRUT: Atal Mission for Rejuvenation and Urban Transport
BGI: Blue-Green Infrastructure
CAP-RES: Climate Adaptive Planning for Resilience and Sustainable Development in Multi-hazard Environment
CBA: Cost Benefit Analysis
CBD: Convention on Biological Diversity
CBI: City Biodiversity Index
CC: Climate Change
CCA: Climate Change Adaptation
DBH: Diameter Breast Height
DDA: Delhi Developmental Authority
DM Cycle: Disaster Management Cycle
DRM: Disaster Risk Management
DRR: Disaster Risk Reduction
DST: Department of Science and Technology
EbA: Ecosystem-based Approaches
Eco-DRR: Ecosystem-based Disaster Risk Reduction
EEA: European Environment Agency
EIA: Environmental Impact Assessment
EPA: Environment Protection Act
EU: European Union
GIs: Green Infrastructures
GIS: Geographical Information System
GHGs: Green House Gases
GoI: Government of India
IIHS: Indian Institute of Human Settlements
IPCC: Intergovernmental Panel on Climate Change
IUCN: International Union for Conservation of Nature
LCA: Life Cycle Assessment
LULC: land-use and Land-cover

MSPA: Morphological Spatial Pattern Analysis
NbS: Nature-based Solutions
NAPCC: National Action Plan for Climate Change
NDMA: National Disaster Management Authority
NDMP: National Disaster Management Plan
NIDM: National Institute of Disaster Management
SAPCC: State Action Plan for Climate Change
SDG: Sustainable Development Goals
SMCE: Social-Green model using Social Multi-Criteria Evaluation
TCPO: Town and Country Planning Organization
UFORE: Urban Forest Effects Model
UHI: Urban Heat Island
ULBs: Urban Local Bodies
UN: United Nations
USD: United States Dollars
USDA: United States Department of Agriculture
VOC: Volatile Organic Compounds
WHO: World Health Organization

# Abstract

Cities are identified as the main source of pollution. Most of the problems of energy consumption and water resources (wastewater and drinking water) are related to cities, which need extensive efforts to manage resources sustainably under the social, environmental and economic aspects and to improve the quality of life of people residing in the cities. In developing countries like India, urban socio-ecological systems are recognized by population growth, extensive change in land use and over-exploitation of natural resources. Moreover, urbanization and industrialization processes are rapidly increasing in India and have a major impact on human health and environmental quality, like the “Urban Heat Island” (UHI) effect and degradation of air quality. The adaptation of cities in India is emerging as one of the largest challenges that urban planners will face in this century. Therefore, the enhancement of Green Infrastructures (GIs) by increasing urban and peri-urban forests and roadside trees and vertical gardens, natural wetland restoration or the creation of artificial wetlands for wastewater treatment could help cities adapt to climate change and could play an important role in the sustainability and resilience of cities and communities. Hence, this article highlights the role of Green Infrastructures (GIs) as a cost-effective measure for climate adaptation and recommends best practices in green space planning to satisfy various environmental, social and economic needs of urban areas and enhancement of ecosystem services in Indian cities. This article also proposes that there should be proper guidelines for urban planners and green infrastructure planners by using a coherent approach that meets the socio-ecological needs of cities.

# Introduction

More than half of the world's population resides in urban areas and suffers from air pollution-related health disorders due to the failure of World Health Organization (WHO) air quality guidelines for healthy well-being. As per the prediction made by the United Nations (2018), the percentage of people residing in urban areas will rise from 50% in 2010 to almost 70% by 2050. Cities are identified as the main source of pollution. High energy consumption is related to cities and stringent efforts are needed to promote sustainability of natural resources which can improve the social, economic and ethical lifestyle of people. Heat waves in most of the cities are a matter of big concern which causes serious inconveniences to most of the residents, particularly children and old-aged people. Most of the cities are under the threat of high population density, loss of land cover and overexploitation of natural resources.

In developing countries like India, urbanization processes are exponentially rising up which causes the problem of pollution and climate change. One of the main causes of urbanization is the "Urban Heat Island" (UHI) effect, where, cities tend to be more warmer than the surrounding rural area. It has been determined that climate change will elevate the intensity of UHI, particularly in hot areas characterized by dry days during the summer season. Urban and sub-urban rapid development also affects the health of native ecosystems and consequently results in the deterioration of air and water quality (Schiermeier, 2015). Disturbances in the rainfall patterns and sea level rise are increasing the vulnerability of urban centres located in low coastal regions, most likely leading to extreme events such as floods, tsunamis, and cyclones that cause high economic, social and physical damage to the environment (Nowak et al. 2013).

Between 1970 and 2019, more than 11000 disasters were reported causing 2 million deaths and an economic loss of USD 3.64 trillion (UN, 2021). The assessment also showed that the top 10 extreme events that resulted in this heavy share of loss were (a) storms (USD 521 billion) and (b) floods (USD 115 billion). Studying the past trends one can see that cities and urban areas are affected by disasters including Urban

Heat Islands, Storms and Floods. Cities are accountable for 80% of the economic growth (World Bank, 2023), these massive loss figures suffer a devastating blow to the economy and overall development. Water is central to any form of development, be it in cities/urban centres or rural areas. Understanding the dynamic of water and changing climate and thin manifestation is very crucial for cities as they are currently the harbingers of growth. Among most of the important ecosystems, wetlands are not recognized for their role in increasing the resilience of Indian cities. In India, wetlands cover 4.63% (Tandon, 2021) of the total geographical area, however, reckless encroachment of wetlands due to overexploitation, agricultural expansion and pollution are some of the overarching threats faced by these important ecosystems today.

In most of the Indian cities, ambient temperatures have increased over decades due to UHI, overpopulation growth, GHG emissions and climate change. For example, three Indian cities Kolkata, Mumbai and Bangalore have shown a significant increase in temperatures; while Ramachandra and Kumar (2010) observed a sharp temperature rise of ~2ºC in Bangalore city due to UHI effect. In 2005, Mumbai also faced high precipitation and flooding problem, where, water levels rose to 0.5-1.5 m in low-lying areas, causing heavy damage to life and property (Ranger et al. 2011). Therefore, India and other such countries strictly need to create smart and sustainable cities. Climate resilience, and mainstreaming climate adaptation in urban development planning emergency management are some important steps that should be taken to improve the status of cities and foster the healthy well-being of people living in such urban areas (Sharma and Tomar, 2010).

In India around 4.63% of the total geographical area is under wetlands. A total of 757060 wetlands have been mapped in the country with a surface area of 15.26 million hectares. Of these, 80 of the most important Ramsar Conservation Sites find their home in India.

*(Source: Tandon, 2021)*

To urban development planning, green infrastructures (GIs) play an important role in combating climate change challenges and promoting environmental sustainability in Indian cities. The maintenance of GIs is also an important approach suggested by the Intergovernmental Panel on Climate Change (Pachauri et al. 2014). For combating climate change risk through adaptation, especially by reduction of vulnerability and exposure through development, planning and practices. The Prime Minister's 10-point agenda on DRR also talks about imbibing the principles of DRM into developmental planning (Gupta, Chopde, Singh, Wajih & Katyal, 2016) and GI holds immense potential as an effective adaptation tool to combat the local climate change impacts. Urban GIs is also the motto of SDG 11 (Sustainable Cities and Communities) of the UN Agenda for 2030 (United Nations, 2015). In recent times, GIs have been a reliable, cost-effective and ecosystem-based approach for climate adaptation in many metropolitan cities particularly, Indian cities; and recommend a constructive method for GI planning which sets a goal for best practices for climate adaptation, air pollution mitigation, healthy living and environmental and social sustainability.

Hence, this article highlights the role of Green Infrastructures (GIs) in climate adaptation and promotes green space planning to satisfy various environmental, social and economic needs of urban areas and enhancement of ecosystem services in Indian cities. This article also proposes that there should be proper guidelines for urban planners and Green Infrastructure Planners by using coherent approaches that meet the socio-ecological needs of cities.

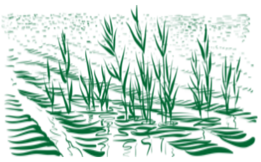
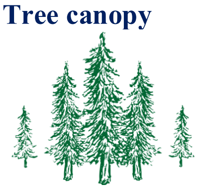
| Green Infrastructure | Description | Adaptation Benefit |
|---|---|---|
| **Green Roofs**  | Rooftop vegetation reduces surface runoff and enhancing building performance. | Reduce storm water runoff<br>Reduce heat island effect (energy efficiency) |
| **Green walls**  | Vertical vegetated structure absorbs air pollution, provides sound proofing and also acts as beautification feature. | Energy saving |
| **Detention basins, Swales, Green swales and constructed wetlands**  | Vegetated channel that reduces and filters runoff. Dry swales consist of a filter bed. | Reduce storm water runoff<br>Filter /reduce water pollutant |
| **Bioretention- Rain gardens, retention ponds**  | Depressed areas, planted or ornamental rock-filled designed to manage surface runoff by collecting, infiltrating and filtering it. | Reduce storm water runoff,<br>Filter /reduce water pollutant<br>Store storm water<br>Absorb greenhouse gases |
| **Permeable pavement systems- Porous paving, Interlocking block pavers, Grassed surfaces**  | Hard Surfaces for pedestrian or vehicular traffic enabling rainwater to infiltrate into the ground. | Reduce storm water runoff<br>Filter /reduce water pollutants |
| **Tree canopy**  | Tree plantation, protection and maintenance increases the total amount of tree canopy, which helps in providing ecosystem services such as clean air, filter water and shade. | Mitigate urban heat island effect<br>Absorb greenhouse gases |
| **Soakaways, Infiltration basins/ trenches and chambers**  | Control surface runoff through infiltration and promoting groundwater recharge. | Store storm water |

*Figure 1: GI and Adaptation Benefits. Source: (Bhardwaj, Gupta , Dhyani, & Thummarukudy , 2020)*

# Green Infrastructures and Climate Change Adaptation

Green Infrastructures (GIs) are cost-effective tools to mitigate climate change, maintain aesthetic and recreational centres for urban communities and improve the well-being of residents in cities (Sturiale and Scuderi, 2018). As per the European Union, the term GIs first came into existence in the 2009 Commission white paper, “Adapting to Climate Change” (Commission of European Communities, 2009). In all acts of the EU, GIs are used concerning landscape resources, with special attention to ecological systems. The European Environment Agency (EEA) and other international programs, prefer to use the terms “green infrastructures”, “green spaces” or “green systems” in urban areas or related to urban systems. GIs are generally used i) to restore and conserve biodiversity by establishing relationships between natural and semi-natural areas and enhancing landscape planning and mitigating fragmentation ii) to maintain and restore the proper functioning of ecosystems to maintain ecosystem and cultural services iii) to promote economic value of ecosystem services by consolidating their functionality iv) to create incentives for local stakeholders and communities by maintaining ecosystem services v) to reduce urban sprawl and their harmful impacts on biodiversity, ecosystem services and human well-being conditions vi) to mitigate and adapt climate change by increasing resilience and reducing vulnerability to natural disaster risks vii) to frame and execute better landuse policies and viii) to contribute to healthy living, the right to live in better areas with recreation facilities, healthy urban-rural relationships, encourage the use of sustainable transportation systems and promote community participation (Anguluri and Narayanan, 2017).

GIs are considered the most effective and efficient ways to improve the microclimate and impacts of climate change and the UHI effect. GIs consist of green roofs, vertical gardens, urban forests, urban agriculture, river parks, green buildings, areas of constructed wetlands, nature conservation zones and alternative energy farms (Foster et al. 2011). Green Infrastructures strengthen the process of carbon sequestration and mitigate the climate change impacts (Mass et al. 2006). They also help in improving the water quality by preventing runoff and contributing to groundwater recharge. GIs can also act as buffers in case of extreme events like floods and act as natural storm water drains, therefore, minimizing climate-related disaster risks for cities and climate adaptation. They also act as "soft engineering" technology for climate adaptation which is a perfect method for low and middle-income countries like India. Green Infrastructures also provide ecosystem services, which mostly contribute to climate change adaptation and disaster risk reduction (Niemelä et al. 2010 and Andrade et al. 2011).

When cities become more resilient, their ability to prevent hazards also increases. Ecosystems like wetlands are among one of the most underestimated and undervalued GI for enhancing the adaptive capacities of cities. Wetlands are in themselves a unique ecosystem exhibiting mixed characteristics of both green and blue resources. An estimate suggests that the total economic valuation of wetland services turns out to be USD 3.4 billion per year with a maximum value of USD 1.8 billion per year, found to be in Asia (Brander & Schuyt, 2010). Unfortunately, since the 1900s the world has lost almost 64% (Davidson, 2014) of its total wetlands. Under the major four types of ecosystem services, wetlands offer a plethora of services which fit fairly well as a GI instrument for water management providing healthy water ecosystems with multiple benefits of water provisioning; water flow regulation; water retention for future use; water purification and drinking water; species protection; air and water

## Ecosystem Services of Wetlands

### Flood Reduction

Wetlands act as natural sponges and absorb and store excess rain and storm-water and thus reduce the surface runoff by 5-10% by volume

### Replenish Drinking Water

Wetlands help in replenishing water aquifers by slowly seeping groundwater in them

### Waste Water Filtration and Water Quality Improvement

The diversity of plans and silt rich characteristics found in wetlands act as natural kidneys and filter out nutrient pollution by absorbing toxins agricultural pesticides and industrial waste

### Urban Air Quality

The interplay of plant and water and functions of seepage and evaporation cause a cleansing effect and reduce the local temperature and maintain the local climate

### Promote Well-Being

Nature therapy helps in improving the physical, spiritual and emotional health. Further wetlands promote opportunity and scope for recreational activities quality improvement; microclimate regulation; habitat protection; shoreline erosion control; recreation and aesthetics; disaster preparedness and climate adaptation; disaster prevention and mitigation.

GIs directly or indirectly improve ecosystem services and this would in return adapt cities for climate change via air quality improvement, temperature regulation, global climate regulation, noise pollution mitigation and agricultural runoff reduction (CBD, 2015). GIs also help in cooling the air which reduces UHI effect, increases forest cover and integration of vegetation in the fronts and on the terrace of buildings helps to balance the temperature inside as well as to protect the structures (Hunt and Watkiss, 2011; Escobedo et al. 2011; Gómez-Baggethun and Barton, 2013; Brink et al. 2016). Climate change needs the use of innovative solutions and sustainable tools for urban management and planning. Green urban structures, cost-effective energy consumption buildings, green infrastructures and the adoption of advanced methods and techniques to mitigate global emissions and local pollution, enhance climate change adaptation. For sustainable and resilient cities, green infrastructures have higher importance and help in maintaining the well-being of the residents.

The benefits of GIs are: i) increased life expectancy and improved physical and mental health of residents ii) reduced UHI, flood risk and improved water quality, iii) promotes sustainable transport and improved air quality iv) promotes proper landuse planning with improved quality of surrounding and increased aesthetics and well-being v) increased habitat areas, restored vulnerable and endangered species and reduced migration of species vi) increased economic values through effective land, biodiversity and ecosystem services and vii) enhanced social interaction, community participation, education and awareness about nature (Sturiale and Scuderi, 2018).

*Box 1: Implementational Challenges for BG Infrastructure.*

**Challenges for Implementing Blue-Green Infrastructure**

***Planning paucities:***

- > Overlapping jurisdiction among different agencies
- > Cost benefits
- > Rigid Regulatory and funding policies

***Implementational barriers:***

- > High density of build areas in Urban agglomerates
- > Mix patterns of land-use
- > Skewered development pattern
- > Technical difficulties
- > Limited space for Blue-Green installations
- > Resource Constraint

***Behavioural barriers:***

- > Socio-political will
- > Lack of awareness about the solutions
- > Inadequate leaderships

*Source: (Acharya, Gupta, Dhyani , & Karki , 2020)*

# Green Infrastructure Methodologies

Globally, GIs play a significant role in providing social and environmental benefits and also act as a sustainable tool for combating climate change in urban areas. In developed countries like USA, several cities (Chicago, New York, Washington D.C.) have formulated the implementation of GIs plans or reported their findings in climate mitigation plans like in San Diego and Philadelphia which is known as the “Greenest City of America” (Nowak et al. 2006; Economides, 2014). In northern Europe and the Mediterranean region, climate mitigation and adaptation plans have been executed for the establishment of sustainable methods like GIs, in urban and sub-urban areas that play a significant role in regulating urbanization and land-use planning. Some successful examples are reported in this regard, like, British Green Belts in the UK, Anella Verda of Barcelona, Spain, the vertical forest in Milan, Italy, the Green Belt in Turin, and urban gardens in Catania (Sturiale et al. 2019). Successful projects are also there in some Asian countries like Hong Kong (Jim, 2002), Beijing and Nanjing in China (Yang et al. 2005) and Delhi and Bangalore in India (Singh, 2012).

As per the detailed analysis of urban planning and socio-economic and environmental aspects of cities, different methodologies are used for GIs implementation. Like, the application of the i-Tree model is a very popular approach for GIs where the output from the interaction of energy exchange and surface temperature and runoff are evaluated in present and future climate scenarios (Gill et al. 2007), or to quantify the biological, physical and economical benefits in terms of ecosystem services that contribute in air quality improvement, global climate regulation and monitoring and analyzing biogenic emissions which contribute in climate change (Baro et al. 2014). Several studies have also been focused on other methodologies used in GIs like Morphological Spatial Pattern Analysis (MSPA) method used in Nanjing, China (Kabisch, 2015); the Eco-Social-Green model using Social Multi Criteria Evaluation (SMCE) used in Catania, Italy (Sturiale and Scuderi, 2018) and Ecosystem-based approach (EBA) used in Bangalore and Delhi, India (Andrade et al. 2011).
The details and applications of the model and methods are as follows:

## i-Tree Eco Model

This model uses tree measurements and other physiological data to evaluate ecosystem services and structural characteristics of urban or rural forests which will help policy planners design policies and execute planning for GIs and further help in climate change adaptation (USDA, 2016). This model involves:

i. Sampling and data collection method and design: Total population and standard error estimates are calculated based on sampling methodologies. For inventory planning, this model calculates values for each tree.
ii. Easy data collection plans: Using mobile data collection systems with well-equipped smartphones, tablets or data logbooks.
iii. Efficient and automated processing: A central computing device that makes estimates of the forest effects based on previously collected scientific equations from literature review and predicts eco-environmental benefits.
iv. Reports: Compile the reports which consist of tables, charts, descriptions, and figures.

**A. i-Tree Eco Model works in the following way:**

Tree measurement observations and field data are entered into Eco application either online or on a manual basis and they are further combined with local meteorological hourly observations and air pollution concentration data. These observations allow the model to calculate structural and functional information by using scientific equations and algorithms. Moreover, forecasted benefits have also been derived from this model by running the new forecast model after Eco results are obtained. Such forecast methods use structural estimates, environmental variables, and species characteristics which include growth and mortality rates to predict tree diameter breast height (DBH) and crown size. So, forecasted benefits are achieved like pollution removal, carbon storage and carbon sequestration based on projected tree growth and leaf area (USDA, 2017).

**B. i-Tree Eco model provides the following benefits:**

a. Urban Forest Structure: Species composition, quantity of trees, forest health etc.
b. Pollution Mitigation: Hourly amount of pollution removed by urban forest, and related per cent air quality improvement in the whole year. Pollution removal is estimated for ozone, nitrogen dioxide, carbon monoxide, sulphur dioxide and particulate matter. These will further help in climate change mitigation and adaptation.
c. Public Health Benefits: Health effects are reduced and economic benefits arise based on air quality improvement capacity.
d. Carbon: Net carbon stored and sequestered by the urban forest.
e. Energy Effects: GIs can reduce $CO_2$ emissions from power plants and buildings.
f. Reducing runoff: Runoff can be reduced or avoided with the use of GIs.
g. Forecasting and Predictability: Forecast models can provide carbon and pollution benefits by analyzing tree planting inputs, pathogen impacts and storm effects.
h. Biogenic emissions: Real-time biogenic Volatile Organic Compounds (VOCs) from different tree species can be evaluated as well as the impact of tree species on total ozone and aerosol formation all over the year.

## Morphological Spatial Pattern Analysis (MSPA) method

This method is based on the application of binary graphs in the identification process and can perfectly recognize ecological sources particularly based only on land-cover data (Vogt et al. 2009). This method is generally used by landscape planners by considering ecological resources and accordingly trees have been planted to combat pollution and climate change problems. This method is used to identify the spatial pattern needed to sustain landscape connectivity which will further enhance the ability to select ecological sources and can improve the efficiency of ecological planning (Peng et al. 2017).

MSPA is used to analyze the landscape types like branches, edges, perforations, islets, cores, bridges, and loops in the forest area which is used to calculate patch density, largest patch index, landscape shape index, interspersion and juxtaposition index, patch cohesion index and aggregation index. These parameters are very useful in the development of the design of GIs which are used in urban cities to combat pollution and climate change problems.

### Social Multi Criteria Evaluation (SMCE) method

SMCE defines the concept of evaluation which represents the combination of representation, assessment and quality check related to a given policy problem (e.g. GIs implementation or urban planning in cities) (Munda, 2008). It also aims to foster transparency, reflection and learning decision processes, together integrating political, socio-economic as well as ecological, cultural and technological characteristics of the problem.

For the motive of determining evaluation criteria, SMCE examines stakeholder's objectives and expectations, trying to ignore a specific technological approach. As various parameters are taken into consideration, the main objective is to establish a balance between them and aim at 'compromise solutions' (Munda, 1995). Mathematical algorithms, social factor analysis and conflict analysis are used to frame a policy or urban development. SMCE can provide a methodology which is:

a. Multidisciplinary in nature by using results of economic, environmental, energy and other simulation models.
b. A participatory approach reflects fairness in the policy process both ethically and socially.
c. Transparent in nature, all criteria should be represented in their original form without any modifications in money, energy etc.

### Ecosystem-based approach (EBA) Method

This method is used as a cost-effective tool in climate adaptation by using GIs which provide ecosystem services and help in climate change adaptation and disaster risk reduction (Munang et al. 2013). In this method, Li et al. (2005) suggested a 3-layered system, consisting of an integrated ecological network for urban sustainable management of cities. This method has shown its successful results in Beijing, China and Hanoi, Vietnam. Based on the successful stories of this method, urban planners have started adopting in Indian cities too for climate adaptation.

There are various steps involved in this method:

a. **Site selection:** McHarg (1969) was the first person to introduce the concept of design for green infrastructure planning in urban areas. The technique involves a robust Geographical Information System (GIS) analysis of several layers. This method applies overlaying layers of landuse, slope, hydrological features, and agricultural, visual and historical resources which are suitable for the development of buildings and infrastructure and areas which are having dense green cover. GIS-based land suitability analysis is a very efficient technique for strong and effective green space planning (Miller et al. 1998). This method also involves graph theory and gravity model which helps in guiding urban planning for biodiversity conservation.

b. **Landscape Ecological Approach:** Landscape-ecology principles are efficient tools for urban planning and GIs development (Dramstad et al. 1996). This approach is based on 3 main structural components: Patches, Corridors and Matrix. The planning includes the listing of spatial elements like major corridors, large patched areas and landscape functions like water protection and reducing human-wildlife conflict (Richard TT, 1995). It is also vital to connect green spaces like patches, gardens etc using corridors (riverine buffers, green ways etc.) to maintain ecological interrelationships. Corridors are useful in green infrastructure planning and ecological corridors can be used to minimize the effect of landscape fragmentation.

c. **Green Infrastructure Planning:** Certain models are used like the Urban Forest Effects Model (UFORE) can be used to quantify important values of urban green spaces like carbon storage and sequestration and also in the selection of specific trees which help in air pollution and climate change mitigation (Nowak et al. 2006). This model can explain and quantify the structure of urban forests and also helps planners identify the existing GIs and provides technical support in urban forestry improvement.

d. **Green Infrastructure Planning for Meeting Social Needs:** For improving the quality of life in urban areas/cities, GIs planning is required. In this context, it is vital to provide attractive GIs in residential areas so that interaction between social-human-environment relationships can flourish. According to the principle of GIs, the green area per capita must be >20 sq.m or maintain a minimum of 1.25 ha of open space per 1000 residents and this open space is needed at each level, such as in children's parks near schools and residential areas, small parks for routine activities and large parks can act as place for weekend destinations (Herzele and Weidmann, 2003).

# Urbanization and Green Infrastructures in India

India has been experiencing rapid urbanization and industrialization since 1970, with its population rising from 19% to 31% over four decades (Census of India, 2011). The vehicular traffic in Indian cities has also been rising from 5.4 million in 1981 to 156 million in 2018, which is a high exponential growth. The vehicular sector in Indian cities contributes approximately 7% of GHG emissions in India and has raised air pollution problems to a larger extent (Saxena et al. 2021). By 2030, India is predicted to have 6 cities with a population above 10 million, and more than 100 million-plus cities (IIHS, 2012). Due to serious environmental degradation and loss of green spaces climate change problems will aggravate and Indian cities will face serious threats soon. Therefore, to solve such problems, models can be used in GIs that will integrate the ecological, aesthetic and social needs of people. GIS has emerged as an important planning tool based on the overlay method proposed by McHarg (1969). Moreover, models like UFORE can help in estimating the patch quality and planning for efficient usage of GIs for climate adaptation and mitigation. Teng et al. (2011) proposed an integrated approach to GIs planning, which aims to manage human recreation, water protection and air pollution mitigation objectives. Such models need to be used in India for GI planning.

Indian cities are now focusing on harnessing the benefits of ecosystem services by including GI in their master plans (Udas-Mankikar & Driver, 2021). Cities like Delhi, Bhopal, Madurai and Bengaluru have tried to utilize the interplay of Blue-Green infrastructure in their urban developmental planning. The capital city of Delhi has a policy focus on Blue-Green Infrastructure in their master plan for 2042 (DDA, 2013). The master plans are synchronously planning the green and blue spaces in an interdependent fashion. In this case, both cities are taking up landscape-based approaches to plan and integrate their greens and blues. Following a separate approach Bhopal city's "Green Master Plan", promotes a people-centric development within the city. The idea is to ensure both environmental and social sustainability by increasing and maintaining a higher green cover in the city (Directorate of Town and Country Planning, 2009).

# Policy Frameworks

## Entry Points for Mainstreaming Green Infrastructure in Urban Planning

The policy regimes in India provide a fair scope and opportunity for integrating, mainstreaming and qualified upscaling the GIs in disaster risk reduction and management. By fostering effective preparedness and mitigation measures to respond to disasters of all kinds, these provisions ensure a resilient and sustainable future (NDMA, 2019).

The Disaster Management Act of 2005 aims to make India resilient against disasters and reduce the damages caused during and after disasters. It ensures that disaster risk reduction is a legal requirement and is integrated at all levels of development and development planning. The Prime Minister's Agenda 10 on Disaster Risk Reduction, 2016 mandates imbibing the principles of DRM in development sectors. Thus, the upcoming development projects will be inclusive of disaster safety and build upon appropriate standards contributing towards community resilience (Gupta, Chopde, Singh, Wajih & Katyal, 2016). . National Disaster Management Plan (NDMP, 2019) covers the disaster management cycle for all types of hazards. It focuses on i) understanding risks; ii) inert-agency coordination; iii) investing in DRR-structural measures; iv) investing in DRR- non-structural measures; v) capacity development; and vi) climate change risk management. The plan highlights the role of central ministries in promoting appropriate combinations of blue and green infrastructure approaches for climate change adaptation for multiple hazards within the country.

The National Action Plan for Climate Change (NAPCC) was introduced in 2008 with two core principles; a) "to achieve national growth and poverty alleviation while ensuring ecological sustainability" and b) "to promote the extensive and accelerated deployment of appropriate technologies for adaptation and mitigation" (PIB-GoI, 2021). Amongst the 12 missions under this, 3 missions including the National Mission on Sustainable Habitat, National Water Mission and National Mission for a Green India open up the scope to integrate and optimize the use of GI in developmental planning and realise the benefits of ecosystem services.

As a top-down effect of the NAPCC, the State Action Plan for Climate Change (SAPCC) was taken up by all states to mainstream climate action at a local level. The SAPCCs provide an open window to understand localized vulnerabilities, prioritize specific adaptation measures and direct towards climate-resilient developmental planning (Googoi, 2017).

The Smart Cities Mission launched in 2015, focuses on the smart and inclusive development of cities through the application of smart solutions to promote core infrastructure, and a clean and sustainable environment while giving a decent quality of life to its citizens (GoI, 2021). The SAPCCs outline the state's strategies for multi-sectors important for the economy, local livelihood and resilient development. The ability to generate greater outcomes using fewer resources and innovative methods, integrated and sustainable solutions as one of the core concepts of the Smart Cities Mission, can thus align with the greater benefits offered by implementing appropriate GI solutions for the urban areas. The mission also provides financial assistance from both the centre and the state or Urban Local Bodies to achieve the mission's goals and may act as drivers to take up successful GI models and further upscale them.

Atal Mission for Rejuvenation and Urban Transport (AMRUT) focuses on the commissioning and provisioning of basic amenities and services including sewage, water supply and urban transport to households in cities to improve the quality of and lifestyle for all (GoI, 2022). The components covered under this mission include water supply, sewage management, storm water drainage, development of green spaces and parks etc. Thus GI can be seen as a potent tool for the direct implementation of ecosystem-based approaches in cities/urban planning. In addition, AMRUT also gives the Urban Local Bodies (ULBs) the freedom to include smart features in physical infrastructure components within the city plans. However, in such a case where the ULBs are involved, continuous capacity building and reform implementation should be given more priority for effective and smart utilization of technological interventions and suitable applications of GI.

City Master Plans are said to be the blueprints for the future and are the most potent document for local implementation of inclusive, resilient and holistic development. It is interesting to note that often neglected, yet, Master plans serve the dual role of: i) a powerful policy toolkit for taking up city development in a coordinated and controlled way-ensuring a proper balance between economic, environmental and social dynamics;  and ii) important guidance tool to learn, understand and document the failures and successes, dos and don’ts. The features under the masterplans may take up the use of GI models for good sanitation, water supply, open-air spaces and green spaces, transport and road networks with green belts etc.

## Tools for Mainstreaming Green Infrastructure in Urban Planning

Cost Benefit Analysis (CBA) is an important process that supports the implementation of any decision. The process compares the benefits (opportunities and gains) versus the costs (threats and losses) associated with any developmental projects at the planning stage (Stobierski, 2019). Before implementing any GI solution, it is essential to run it through a CBA exercise. While CBA may seem a burdensome task at the beginning, it helps to outline the benefits and costs associated with any GI. In doing so the tangible benefits and the intangible costs can be easily understood and the process of planning gets rather easy (Bindal, Acharya, Gupta, & Kishore, 2020).

Environmental Impact Assessment (EIA) was notified under the Environment Protection Act (1986), which mandates environmental clearance for any developmental projects. For urban areas projects like airports, thermal power, roads and highways, ports and harbours, cement plants etc. need to undergo the four stages of EIA process to get clearance from the government.

Life Cycle Assessment (LCA) follows a cradle-to-grave approach for assessing the environmental impacts of any developmental project across all the stages of the product, services and processes (Bindal, Acharya, Gupta & Kishore, 2020). It also includes the evaluation of the entire organizational structure across the entire value chain along with the third-party elements. Planning GIs with LCA may further increase resilience and reduce the externalities and intangible losses.

City Biodiversity Index (CBI) is a self-evaluation toolkit for assessing, monitoring and evaluating the city's progress in its efforts on biodiversity conservation. The CBI guidelines provide 28 indicators against which the native biological and ecological diversity of cities can be scored (CBI, 2013).

The Town and Country Planning Organization (TCPO) has formulated a set of guidelines for city planning. These guidelines just like the CBI rather have a focused perspective to increase the urban green cover. Even though they emphasize on enhancing biodiversity and are aesthetically appealing, however, they fail to inculcate the resilience perspective in urban planning.

## *Landscape-based City Planning*

Landscape-based City Planning leverages the principles of the landscape approach, as it provides a framework to balance the productive, social and environmental demands on land. In doing so, it turns out to be an effective alternative to basic land use planning. Based on the philosophy of integrated land sharing, the landscape approach considers land as an "Unit of Action" and incorporates all aspects of physical, social, economic and ecological needs for futuristic planning of natural resources and risk management (Agrawal, Gupta, & Acharya, 2022). The uniqueness of this approach is as follows:

| | |
|---|---|
| **Addressing the underlying causes of vulnerabilities** | The approach keeps the community at the core and primarily the most disadvantaged ones. |
| | Considering the ground water hydrology is an essential part of this approach (50% of the disasters are water based). |
| **Informed Choices** | All actors and factors involved in and/or contributing to disaster risks are considered. |
| **Holistic Perspective** | It covers the entire landscapes where the risks emerge and can manifest themselves. |
| **Leveraging on GI potentials** | Ecosystems and Ecosystem Services are at the core of the approach. |
| **Futuristic Planning Tool** | Provides scope for long term planning and imbeds the flexibility of future changes in disaster risk landscape. |
| **Reduces Externalities** | It manages the trade-offs and develops synergies between building resilient system, development and livelihoods. |

## *Watershed-based City Planning*

A watershed/ catchment/ drainage basin can be understood as a geographic area where water, sediments and dissolved minerals from the higher areas are collected into common low-lying outline outlets like rivers, creeks, streams, ponds etc and eventually drains to outflow points like underlying aquifers and surface water outlets like bays, reservoirs and oceans. Often city planners ignore this useful tool for planning urban developmental projects, but this tool may have answers to the water challenges of urban and peri-urban areas. This approach is an effective alternative to river basin management as it manages all the water bodies as a whole rather than as single entities, this helps address water quality and ecosystem problems in an integrated manner. It brings in solutions for the priority problems through a combination of science and technology, effective governance models and large involvement of stakeholders. When considering this approach, goes beyond a river basin, thus the challenges upstream and downstream can be addressed easily in an integrated and sustainable manner.

# Conclusion

Several studies and reports have given significant evidence that GIs can be used as a cost-effective measure to combat climate change. Some studies have also shown that GIs are found to be effective in offsetting urban carbon emissions; heat stress can reduced due to the cooling effect of green roofs in different types of buildings. Nevertheless, the GIs can also provide social and psychological benefits to residents. The introduction of GIs has been broadly identified as playing a significant role in meeting the challenge of climate change mitigation. GIs are one of the best tools for climate adaptation strategies, however, these strategic tools must be considered through particular integrated territorial and urban planning, long-term investments, planning and sustainability in decision-making, evaluating economic, social and environmental benefits and motivating public participation in planning of GIs for climate adaptation.

In the current scenario of India, urban planning has limited consideration of climate adaptation strategies. Moreover, the possible role of GIs in social and environmental urban sustainability and their important role in cost-effective climate adaptation and mitigation is not fully recognized. Conversion of open spaces to commercial places for economic benefits is one of the limitations pertinent to urban planning in India. In addition, the cost of maintaining open spaces is often high, thus the involvement of the state or any governing body becomes necessary to conserve, maintain and use these urban green spaces or climate change mitigation and environmental conservation. Currently, many urban development authorities in India are considering the incorporation of more green spaces in future urban/suburban development plans and promoting such GIs can be an important step towards climate-adaptive cities.

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# About the Authors

| | | | |
|---|---|---|---|
|  | **Dr. Pallavi Saxena**<br>Assistant Professor, Department of Environmental Science, Hindu College, University of Delhi, Delhi |  | **Prof. Anil K Gupta**<br>Professor and Head, ECDRM Division, National Institute of Disaster Management (NIDM), Delhi |
|  | **Dr. Saurabh Sonwani**<br>Assistant Professor, Department of Environmental Studies, Zakir Husain Delhi College, University of Delhi, New Delhi |  | **Ms. Pritha Acharya**<br>Research Associate, CAP-RES, National Institute of Disaster Management (NIDM), Delhi |

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## About Climate Adaptive Planning for Resilience and Sustainable Development in Multi-Hazard Environment (CAP-RES) Project:

"Climate Adaptive Planning for Resilience and Sustainable Development in Multi-Hazard Environment (CAP-RES)" aims at developing and implementing capacity building including knowledge and training support system for wider use by related institutions and training centres across sectors and regions. The CAP-RES focuses across three specific regional contexts, i.e. Indian Himalaya Region (special reference to North East), Coastal region and Central-western region. Region specific climate related hazard complex, including flood, drought, water scarcity, forest fire, cyclone/storm surge, coastal erosion, slope erosion/landslide, windstorms, heat wave, disease epidemics, industrial/chemical risks, etc.

CAP-RES added value to the programme sub-areas of the NKMCC by engaging with the institutions/research centres and network of experts, researchers and practitioners, across the following 5 key sub-sets of the project focus:

- Green Growth and Disaster Risk Reduction
- Resilient Agriculture Systems
- Public Health Resilience
- Climate Proofing Disaster Relief and Recovery
- Environmental Policy Instrument in Disaster Risk Reduction

## Some Publications under CAP-RES:






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Resilient India : Disaster free India

**National Institute of Disaster Management**

(Ministry of Home Affairs, Government of India)
Plot No. 15, Block B, Pocket 3, Sector 29, Rohini, Delhi 110042
Website: https://nidm.gov.in