CITY RENEWAL THROUGH URBAN FORESTATION

A THESIS

Submitted in partial fulfillment of the

requirements for the award of the degree

of

Master of Planning in Urban Planning

In

Department of Architecture and Planning

Submitted by:

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MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY

BHOPAL (MP)-462003

JULY 2026

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I hereby certify that the work which is being presented in the thesis entitled "**CITY RENEWAL THROUGH URBAN FORESTATION**" in partial fulfillment of the requirements for the award of the Master of Planning in Urban Planning and submitted in the Department Of Architecture And Planning of the Maulana Azad National Institute of Technology, Bhopal is an authentic record of my own work carried out during the period from July 2025 to JUNE 2026 under the supervision of Dr. Vinay Mohan Das, Professor, Department of Architecture And Planning, Maulana Azad National Institute of Technology, Bhopal.

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ABSTRACT

Urban areas and cities face the rapid degradation of urban green cover, increasing land surface temperature, declining environmental quality, ecological stress, and reduced carbon sequestration capacity. Rapid urbanization and industrial expansion have intensified air pollution, urban heat island effects, biodiversity loss, and environmental imbalance, creating serious challenges for sustainable urban living. Existing urban planning approaches often address infrastructure growth while giving limited attention to ecological restoration and climate resilience. This thesis proposes an integrated framework, "City Renewal," focused on urban forestation and ecological regeneration to improve environmental quality and urban livability. The research aims to quantify existing environmental stress conditions, assess the carbon sequestration potential of urban forestation, identify suitable ecological restoration zones, and develop a sustainable urban greening model for climate-responsive city development. The primary contribution of this study is a novel integrated framework for urban ecological renewal that strengthens green infrastructure, enhances biodiversity, reduces urban heat stress, and supports sustainable and healthy urban environments through nature-based solutions.

Keywords: Urban Forestation, Carbon Sequestration, Urban Ecology, Green Infrastructure, Carbon Sequestration, Climate Resilience, Ecological Restoration, Sustainable Urban Development.

सारांश

शहरी क्षेत्रों और शहरों में शहरी हरित आवरण (Urban Green Cover) का तीव्र ह्रास, भूमि सतह तापमान (Land Surface Temperature) में वृद्धि, पर्यावरणीय गुणवत्ता में गिरावट, पारिस्थितिकीय तनाव तथा कार्बन अवशोषण क्षमता में कमी जैसी गंभीर समस्याएँ तेजी से बढ़ रही हैं। तीव्र शहरीकरण और औद्योगिक विस्तार ने वायु प्रदूषण, शहरी ऊष्मा द्वीप प्रभाव (Urban Heat Island Effect), जैव विविधता के ह्रास तथा पर्यावरणीय असंतुलन को बढ़ा दिया है, जिससे सतत एवं स्वस्थ शहरी जीवन के समक्ष गंभीर चुनौतियाँ उत्पन्न हो रही हैं। वर्तमान शहरी नियोजन पद्धतियाँ मुख्यतः आधारभूत संरचना विकास पर केंद्रित हैं, जबकि पारिस्थितिकीय पुनर्स्थापन और जलवायु सहनशीलता (Climate Resilience) को सीमित महत्व दिया जाता है। यह शोध "सिटी रिन्यूअल" (City Renewal) नामक एक समेकित रूपरेखा प्रस्तुत करता है, जो शहरी वनीकरण (Urban Forestation) और पारिस्थितिकीय पुनर्जीवन के माध्यम से पर्यावरणीय गुणवत्ता एवं शहरी जीवन-योग्यता में सुधार पर केंद्रित है। इस अध्ययन का उद्देश्य वर्तमान पर्यावरणीय तनाव की स्थिति का आकलन करना, शहरी वनीकरण की कार्बन अवशोषण क्षमता का विश्लेषण करना, उपयुक्त पारिस्थितिकीय पुनर्स्थापन क्षेत्रों की पहचान करना तथा जलवायु-संवेदनशील शहरी विकास हेतु एक सतत शहरी हरित मॉडल विकसित करना है। इस शोध का प्रमुख योगदान एक नवीन समेकित शहरी पारिस्थितिकीय पुनर्जीवन ढाँचा विकसित करना है, जो हरित अवसंरचना को सुदृढ़ करता है, जैव विविधता को बढ़ावा देता है, शहरी ऊष्मा तनाव को कम करता है तथा प्रकृति-आधारित समाधानों के माध्यम से सतत एवं स्वस्थ शहरी पर्यावरण को समर्थन प्रदान करता है।

मुख्य शब्द: शहरी वनीकरण, कार्बन अवशोषण, शहरी पारिस्थितिकी, हरित अवसंरचना, जलवायु सहनशीलता, पारिस्थितिकीय पुनर्स्थापन, सतत शहरी विकास।

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CERTIFICATE OF PLAGIARISM

This is to certify that the Thesis entitled "CITY RENEWAL THROUGH URBAN FORESTATION" is a piece of research work carried out by Rishi Kumar Sinha, Scholar No. 24209011118 under my guidance and supervision for the degree of Master of Planning from the Department of Architecture and Planning of Maulana Azad National Institute of Technology, Bhopal (M.P.) India.

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ACKNOWLEDGMENT

The completion of this synopsis report has been one of the most significant parts of our synopsis study. We would like to acknowledge everyone who has helped us throughout in the completion of this Synopsis Report, directly or indirectly.

At this moment of accomplishment, first of all we would like to thank our Thesis Coordinator ***Dr. Seemi Ahmed*** *and our Synopsis Guide* ***Dr. Vinay Mohan Das****. This work would not have been possible without their guidance, support and encouragement. Their insightful leadership and knowledge benefited us to successfully overcome many difficulties through the process and taught us a lot. Their valuable suggestions helped us make our work better. Thank you so much for your continuous support and presence whenever needed.*

We would like to thank our teachers and supervisors for their unending assistance, generosity, and tolerance throughout the project's term and to express our gratitude and debt of gratitude to them.

Additionally, we want to thank our seniors and fellow classmates. Our synopsis work has benefited from their assistance and support. Last but not least, we would want to express our gratitude to the Great Almighty for his blessings as well as to all of our friends, family, and relatives who helped us in any way they could.

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ABBREVIATIONS

Abbreviation	Full Form
AI	Artificial Intelligence
BHEL	Bharat Heavy Electricals Limited
BMC	Bhopal Municipal Corporation
CDM	Clean Development Mechanism
CE	Circular Economy
CER	Certified Emission Reduction
CH_4	Methane
C&D	Construction and Demolition Waste
CFI	Crop-Forest Integration system
CO_2 / CO_2e	Carbon Dioxide / Equivalent
CPCB	Central Pollution Control Board
GIS	Geographic Information System
GHG	Greenhouse Gas
GPS	Global Positioning System
GGI	Green Governance Initiative
HDPE	High-Density Polyethylene
ICESat-2	Ice, Cloud and land Elevation Satellite–2
IPCC	Intergovernmental Panel on Climate Change
LDPE	Low-Density Polyethylene
LiDAR	Light Detection and Ranging
MFA	Material Flow Analysis
MoEFCC	Ministry of Environment, Forest and Climate Change
MRF	Material Recovery Facility
MWh	Megawatt-hour
MSW	Municipal Solid Waste
N/A	Not Available / Applicable
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
OTC	Over-the-Counter
PET	Polyethylene Terephthalate
PPPs	Public–Private Partnerships
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SBM	Swachh Bharat Mission

SDGs	Sustainable Development Goals
TLS	Terrestrial Laser Scanning
TDVI	Transformed Difference Vegetation Index
UGI	Urban Green Infrastructure
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UHI	Urban Heat Island
UF	Urban Forestation
VERRA (VCS)	Verified Carbon Standard
W2R	Waste-to-Resource
WTE / WtE	Waste-to-Energy

UNITS

Unit	Meaning / Context
avg	Average
C&D	Construction & Demolition
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CH_4	Methane
cm	Centimeter (tree/biomass context, implied)
%	Percentage (waste %, cover %, processing %, segregation %)
g	Grams (implied in scientific references)
ha	Hectare (forest literature references)
HDPE	High-density polyethylene
kg	Kilogram
kg/year	Kilograms per year
km^2 / sq. km	Square kilometer
LDPE	Low-density polyethylene
m	Meter (implied in remote-sensing formulas)
m^2	Square meter (urban forestry plot sizes)
m^3	Cubic meter (biomass/soil context)
MWh	Megawatt-hour
MWh/year	Megawatt-hour per year
mm	Millimeters (rainfall/moisture context implied)
ton / tonne	Waste quantity & CO_2 calculations
ton/day	Waste generated per day
ton/year	Annual emissions/sequestration
yrs	Years (tree maturity age)
0.5 ton	CO_2 savings per household
1 credit = 1 ton CO_2	Carbon credit definition

CHAPTER 1: INTRODDUCTION

Rapid urbanization and industrial development have significantly transformed cities worldwide, contributing to economic growth while simultaneously creating environmental challenges such as loss of green spaces, rising temperatures, increasing pollution levels, ecological degradation, and declining urban livability. The continuous expansion of built-up areas often disrupts the natural balance between urban development and environmental sustainability, leading to long-term ecological and public health concerns. In this context, urban forestation has emerged as an effective nature-based solution for restoring ecological balance, enhancing climate resilience, improving air and water quality, reducing urban heat island effects, and promoting human well-being. Therefore, this study, "City Renewal Through Urban Forestation," explores urban forestry as a strategic planning approach for ecological regeneration and sustainable urban development, aiming to create healthier, greener, and more resilient cities for future generations.

1. Introduction: Green Infrastructure for Urban Restoration

India's accelerated urbanization has precipitated a critical environmental challenge, defined by systematic degradation of urban ecosystems and the rapid decline of urban green cover. Expanding built-up areas, industrialization, and infrastructure growth have intensified environmental stress, increased land surface temperatures, reduced biodiversity, and weakened the ecological balance necessary for sustainable urban living. This unsustainable trajectory is largely driven by conventional urban development practices that prioritize physical expansion over ecological resilience, a challenge increasingly observed across rapidly developing nations (Iqbal et al., 2023).

This synopsis proposes a paradigm shift toward sustainable and climate-responsive urban development through work cantered on urban green infrastructure and urban forestation (Yang et al., 2023). The research aims to develop a replicable model that strengthens urban ecological systems through the expansion of urban forests, green corridors, biodiversity parks, and ecological restoration zones. By integrating nature-based solutions within the urban fabric, the framework seeks to enhance environmental quality, improve microclimatic conditions, reduce urban heat island effects, and restore ecological balance (Yu et al., 2020).

The proposed result emphasizes the ecological and environmental benefits of urban forestation by quantifying the carbon sequestration potential of urban green infrastructure and assessing its role in mitigating climate change impacts (Calfapietra et al., 2015; Lorenzo-Sáez et al., 2021; Suhardono et al., 2024). Urban forests and green infrastructure not only improve air quality and urban biodiversity but also contribute significantly to climate resilience and sustainable urban ecosystems. The study ultimately aims to present a holistic and sustainable blueprint for transforming Indian cities into resilient, environmentally balanced, and regenerative urban ecosystems through integrated ecological planning and urban forestation strategies, recognizing that nature-based urban development approaches are essential for future sustainable cities (Su et al., 2024).

2. Background: The Global Urban Challenge and the Indian Imperative

2.1. The Global Predicament: A World of Cities

The 21st century is fundamentally the urban century. For the first time in history, more than half of the world's population resides in cities, a figure projected to rise to nearly 70% by 2050. This global wave of urbanization, while a powerful engine of economic growth, has been largely powered by a linear 'take-make-dispose' economic model (Iqbal et al., 2023).

This model has precipitated a dual environmental crisis now confronting cities worldwide. First, it has led to an unprecedented challenge in waste management. Cities globally are grappling with overflowing landfills, which are significant sources of methane, a potent greenhouse gas, and other pollutants that contaminate soil and water (Iqbal et al., 2023; Pandey et al., 2023). Second, the relentless physical expansion of urban areas has systematically eroded green infrastructure (Koh et al., 2023). The replacement of natural ecosystems with concrete and asphalt has intensified the urban heat island effect, diminished biodiversity (Siikamäki & Newbold, 2012), and weakened the resilience of cities to the impacts of climate change (Dye et al., 2024).

In response, the urban development has to be **nature-based solutions to restore urban ecosystems (Buma et al., 2024; Calfapietra et al., 2015)** or try the min damage to ecosystem.

2.2. The Indian Imperative: A Magnified Challenge

Nowhere is this global urban predicament more acute and concentrated than in India. The nation is in the midst of one of the most rapid and large-scale urban transformations in history, making it a critical proving ground for sustainable urban solutions. India's challenges are a magnified reflection of the worlds, but with unique characteristics that demand a tailored approach.

1. Accelerated Ecological Decline: The pace of urban expansion in India often outstrips planning and regulation (Koh et al., 2023), leading to a rapid and often irreversible loss of green cover. This not only contributes to severe air and water pollution but also makes its densely populated cities highly vulnerable to extreme heat and flooding (Agrawal et al., 2021), hazards exacerbated by climate change (Dye et al., 2024).
2. A Conducive Policy Environment: Recognizing these threats, India has established a policy framework that creates an impetus for action. The Solid Waste Management (SWM) Rules, 2016, mandate waste processing, while the nation's Nationally Determined Contributions (NDCs) under the Paris Agreement commit it to reducing emissions intensity and increasing its carbon sink capacity through measures like afforestation (Hou & Yin, 2023; Su et al., 2024), reflecting broader global forest policy approaches for carbon dioxide removal (von Hedemann et al., 2020).

3. This confluence of a massive, organic-rich waste stream (Iqbal et al., 2023; Yu et al., 2020), a critical need for ecological restoration (Calfapietra et al., 2015), and a supportive policy landscape (von Hedemann et al., 2020) makes India the ideal context for pioneering an integrated solution. A successful framework that transforms urban waste into a resource for green infrastructure in India would not just solve a domestic crisis but also serve as a globally relevant blueprint for other rapidly urbanizing nations facing similar pressures of waste management and land-use change (Iqbal et al., 2023; Koh et al., 2023; Schroth & da Mota, 2013).



Figure 1: Sustainable Cities and Communities *Source: https://ggiindia.in/*

3. Need for the Study

The need for this study is driven by the urgent problems faced by Indian cities, framed by critical gaps in the existing literature:

The Integration Gap: The literature often examines the circular economy (waste) and urban greening (carbon) as separate, siloed fields. His study addresses the need for an integrated framework that creates synergistic links between them—such as valorizing organic waste into soil amendments (Yu et al., 2020) at the urban scale.

The Scale Gap: Most forest carbon research focuses on large, rural landscapes, such as national-scale strategies (Hou & Yin, 2023; Gauthier et al., 2024) or commercial timber concessions (Ndjondo et al., 2014). While some studies address urban/peri-urban forests (Calfapietra et al., 2015; Martes & Köhl, 2022), there is a distinct lack of actionable models designed for integration within the statutory planning and governance framework of a city at the local (ward) level (Gauthier et al., 2024; Koh et al., 2023; Sears et al., 2021).

The Integrity Gap: Widespread critiques of carbon offset integrityhighlight the need for a more transparent, verifiable, and locally-grounded framework. This research addresses critiques of additionality (i.e., proving the climate benefits are new) (Macintosh et al., 2024; Stapp et al., 2023) and permanence (i.e., ensuring the carbon stays stored) in the face of climate risks like fire and drought (Chu et al., 2023; Wu et al., 2023; Mummery, 2024). this study aims to develop a model that can ensure genuine environmental and social benefits for an Indian city.

The need for this study is critical and immediate, driven by several interconnected factors:

Waste Crisis: Landfill saturation, frequent fires, and poor waste segregation are acute problems in most Indian cities, demanding a shift from disposal to resource recovery (Iqbal et al., 2023; Yang et al., 2023).



Figure 2 A sustainable city Model *Source: https://co2mmunity.eu/roadmap /*

Environmental Degradation: The unchecked loss of urban forests and green belts due to urban sprawl threatens ecological resilience and resident well-being (Koh et al., 2023; Agrawal et al., 2021).

Integrating Siloed Efforts: Current urban management approaches often address urban forestry, ecological restoration, and urban planning in isolation. An integrated framework is required to create synergistic environmental benefits through the coordinated development of urban green infrastructure, ecological corridors, biodiversity parks, and urban forestation strategies (Yu et al., 2020; Souza et al., 2024).

Economic & Environmental Opportunity: There is a significant, largely untapped, opportunity to create economic value from waste (e.g., waste-to-energy, recycling) (Nowak et al., 2024; Bhati & Mallick, 2016) and environmental value from greening

(e.g., carbon sequestration, improved air quality) (Suhardono et al., 2024; van der Gaast et al., 2018).

4. Research Need and Design

Finalized Title of the Topic: City Renewal Through Urban Forestation

4.1. Aim: This research aims to create an integrated framework for cities. This framework will use circular economy principles to turn urban waste into valuable resources, such as compost or biochar (Nowak et al., 2024; Yu et al., 2020), that support urban greening and afforestation (Calfapietra et al., 2015).

4.2. Research Questions:

1. What are the major environmental, planning, and institutional challenges affecting the development and expansion of urban green infrastructure and urban forestation in rapidly urbanizing and industrial cities (Iqbal et al., 2023; Yang et al., 2023)?
2. What specific urban planning interventions and ecological restoration strategies are required to enhance urban green cover, improve environmental quality, reduce urban heat island effects, and strengthen carbon sequestration potential through urban forestation and green infrastructure development (Yu et al., 2020; Calfapietra et al., 2015)?
3. How can an integrated and sustainable urban ecological framework be incorporated within city-level planning policies, master plans, and governance structures to improve climate resilience, public health, environmental quality, and long-term urban livability through nature-based solutions (Khatun et al., 2015; Sears et al., 2021)?

4.3. Objectives:

1. To calculate the reduction in carbon footprint when MANDIDEEP shifts from satellite town to industrial city.
2. To estimate how much carbon new **urban green spaces** (trees, parks, etc.) can absorb (sequester).
3. To identify and propose suitable urban forestation and green infrastructure strategies that can transform environmentally stressed urban areas into healthier, climate-responsive, and ecologically balanced urban environments.

5. Research Methodology

This research will employ a mixed-methods approach, combining quantitative analysis and qualitative insights within a structured, two-phase study design focused on city data. The methodology is designed to first establish an empirical baseline and then use that data to build and validate an innovative planning framework.

5.1. Methodology Flowchart:

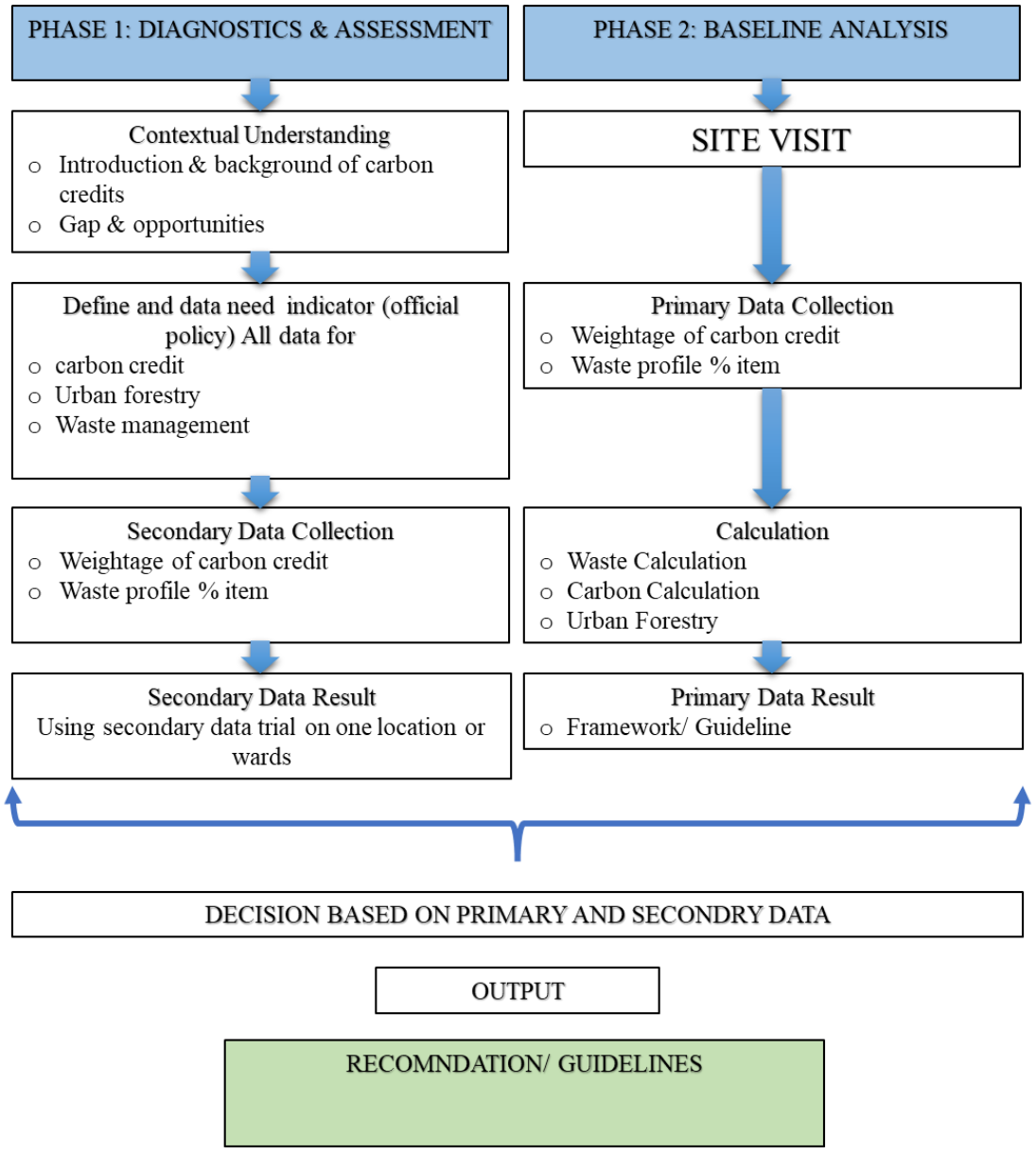


Figure 3: Methodology Flowchart *Source: Author*

5.2 PHASE I: Diagnostic & Baseline Assessment (Objectives 1 & 2)

1.Contextual Understanding (Any City Thumb Rule)

- Review Any city Development Plan & Environmental Policies.
- Analyze waste management Rules, 2016 implementation.
- Identify Gaps & Opportunities

2.Defining Data Needs & Indicators

- Indicators for GHG emissions (waste volume, composition, transport distance).
- Indicators for carbon sequestration (green cover %, species, age).
- Develop Assessment Framework

3. Data Collection

3.1 Secondary Data:

- Municipal waste reports
- Census data
- Satellite Imagery (Landsat, Sentinel-2)
- GIS base layers

3.2 Primary Data:

- Field surveys & waste characterization
- GPS mapping of green spaces

- Semi-structured interviews with BMC officials, waste workers, etc.

3.3 Compile Geospatial & Statistical Database

4.Baseline Analysis

3.1 Waste Sector: Material Flow Analysis (MFA) & GHG emissions calculation.

Outcome: Carbon Footprint Baseline (Objective 1)

3.2 Greening Sector: Geospatial (GIS) analysis & carbon stock modeling.

Outcome: Carbon Sequestration Baseline (Objective 2)

5.3. PHASE II: Framework Development & Validation (Objectives 3 & 4)

1. **Scenario Modeling**
    - Model waste valorization scenarios (e.g., 100% composting).
    - Model urban afforestation scenarios using recovered resources.
    - Quantify Net Carbon Impact (Avoided Emissions + New Sequestration)
2. **Developing the proposal** (Objective 3)
    - Synthesize findings into a planning framework linking waste streams to greening sites.
    - Recommendations and demonstration of Actionable Policy
3. **Planning proposal for Phase I & Phase II**

6. Analytical Techniques

A quantitative analysis will be performed to assess metrics like waste segregation rates, green cover percentage, and potential **carbon sequestration** for each ward. This data will be used to create a baseline for the proposed framework.

Table 1: Different Carbon Calculation with Emission Factor

	EMISSION FACTOR	**CARBON CREDIT CALCULATION**
AFFORESTATION	1 TREE ≅ 22 KG CO_2 (ABSORBED/YEAR)	45 YOUNG TREE = 1 CARBON CREDIT/ YEAR
WASTE TO ENERGY	1 TON WASTE ≅ 25 KG CO_2 (EQUIVALENT)	1 TON CH_4 AVOIDED = 25 CREDIT
ENERGY EFFICIENCY	0.5 TON CO_2 SAVED PER HOUSEHOLD/YEAR	200 HOUSEHOLDS = 100 CREDIT/YEAR

Source: Author

***1 CREDIT = 1 TON CO_2 AVOIDED/ REMOVED**

Table 2: Weightage of Carbon Credit

	DESCRIPTION	FORMULA/ DATA	EXAMPLE
DEFINE PROJECT	Identify the Activity that Reduces GHS Emission	SOLAR, WIND, Waste to Energy Afforestation	Solar Power Plant 1000(MWh/Year)
BASELINE EMISSIONS	Emission If Projected was not Implemented	{Baseline Emissions = (Activity Output * Emission Factor)}	Coal Emits ≅ (1 Ton CO_2/MWh) {1MWh *1 = 1000-ton CO_2}
PROJECT EMISSIONS	Emission with the Project	Project Emission = Actual Emission from Project	Solar Plant = 0 CO_2/MWh
NET REDUCTION	Difference Between Baseline and Projected Emission	Net Reduction = (Baseline – Project)	1000-0 = 1000 CO_2 Avoided
CARBON CREDITS	1 CREDIT = 1 TON CO_2 AVOIDED/ REMOVED	Credits = Net Reduction	1000 Carbon Credit Earned
VERIFICATION	Certification by Agencies {CDM, MoEFcc, VERRA(VCS), GOLD STANDERD}	Verified through International/ National Standards	Registered under UNFCCC-CDM

Source: Author

Feature	Ward No. 29 (Old City / Chowk)	Ward No. 51 (New Market / T.T. Nagar)	Ward No. 32 (Arera Colony)	Ward No. 74 (Kolar Road)	Ward No. 1 (BHEL Township)	Government Guideline /Baseline
Ward Profile	Dense commercial & residential	Commercial & administrative	Planned, affluent residential	Rapidly developing residential	Planned industrial township	N/A
Area (Approx. sq. km)	2	3.5	4.5	5	6	N/A
Green Cover (%)	5%	12%	25%	10%	30%	15-20%
Number of Trees	300 (Old, stressed)	1,000 (Mixed)	3,000 (Mature, planned)	1,200 (Young, roadside)	5,000 (Well-maintained)	Varies by area
Est. Annual Carbon Sequestration (Tonnes CO_2e)	6	18	60	15	100	Higher is better
Waste Generation (Tonnes/day)	20	30	25	40	35	N/A
Waste Segregation (%)	30%	60%	80%	40%	75%	100% (Target)
Waste Processing (%)	20%	50%	70%	30%	65%	80-100% (Target)
Waste to Landfill (%)	80%	50%	30%	70%	35%	< 20% (Target)

Table 3 A demonstration of Carbon credit in Bhopal Ward An Example

Est. Annual Emission Reduction from Waste (Tonnes CO_2 e)	35	135	160	110	210	Higher is better
Total Carbon Credit Potential (Tonnes CO_2e/year)	41	153	220	125	310	N/A
Assessment	High scope for improvement.	Good progress, needs better processing.	High performer.	Urgent need for greening & wastes infra.	Excellent performer, model ward.	N/A

Source: Author

CHAPTER 02: LITERATURE REVIEW

2.1. SYSTEMATIC LITERATURE REVIEW

1. Principles of Reuse or Recycle in Urban Systems

2. Urban Forestry & Carbon Sequestration Models

This synopsis is situated at the confluence of two transformative paradigms in sustainable urban development: the circular economy and nature-based climate solutions. A comprehensive review of the literature reveals both the significant potential of these fields and the critical challenges that necessitate an integrated approach.

1. Principles of Reuse or Recycle in Urban Systems

The transition from a linear 'take-make-dispose' model to a recycle is increasingly recognized as a fundamental necessity for sustainable urban development. The literature defines this shift not merely as improved waste management, but as a systemic redesign of urban resource flows.

- **Systemic Frameworks and Models:** Research by Iqbal et al. (2023) highlights the need for integrated environmental frameworks that connect urban ecological systems with sustainable planning approaches, the study emphasizes the importance of strengthening recycling practices and environmental restoration to reduce ecological degradation. Similarly, Cheong (2022) utilized dynamic material flow modeling to analyze environmental impacts associated with urban development, demonstrating that sustainable and circular planning principles must be incorporated at the planning stage to mitigate long-term environmental impacts such as global warming and ecological stress.

- **Measuring Circularity:** A critical gap identified in the literature is the inadequacy of traditional metrics. Yang, Ma, & Yuan (2023) critique standard "recycling rates" as insufficient for capturing true circularity. They propose dynamic indicators such as "recycling circularity" and "real circularity

performance" to provide a more accurate assessment of how materials are retained and regenerated within the urban economy.

- **Policy and Governance:** The success of these principles relies heavily on the policy landscape. Koh et al. (2023) and Gauthier et al. (2024) emphasize that while high-level policies often exist (e.g., national pledges), there is an "implementation gap" at the local level due to economic pressures and lack of institutional coordination, necessitating stronger local governance frameworks.

2. Urban Forestry & Carbon Sequestration Models

Accurate quantification of carbon storage is the cornerstone of integrating urban greening into climate strategies. The literature reveals a rapid evolution in measurement technologies and modeling approaches.

- **Urban Forest Potential:** provide a foundational review asserting that urban and peri-urban forests are significant, yet often neglected, carbon sinks. They argue that sustainable management combined with the expansion of urban greening is crucial for maximizing this mitigation potential Calfapietra et al. (2015).

- **Advanced Measurement Technologies:** The shift from manual inventory to advanced remote sensing is evident. Illarionova et al. (2022) surveyed computer vision techniques, finding them highly applicable for forest characterization tasks like species classification, though limited by training data availability. Ruza et al. (2021) validated the use of Terrestrial Laser Scanning (TLS) in eucalyptus plantations, proving it provides data accuracy comparable to manual methods but with greater efficiency. Similarly, Zaki et al. (2018) successfully integrated field data with high-resolution satellite imagery to create accurate biomass estimation models for tropical forests.

- **Spatial and Temporal Modeling:** Introduced a novel method using "Google Plus Codes" to map forest carbon storage with high granular precision over time Wen et al. (2024). This approach allows for the detailed tracking of carbon dynamics at a cell level, which is essential for verifying the additionality of

urban forestry projects. Liang & Zhou (2014) further emphasize that data fusion—combining LiDAR, satellite, and field data—is essential for reducing uncertainty in large-scale carbon mapping.

2.2. Recycling and Sustainable Urban Environmental Management

A growing body of academic literature establishes recycling and sustainable resource utilization as effective responses to increasing urban environmental challenges. The core principle involves shifting from conventional disposal practices toward recycling-based systems that promote environmental restoration and resource conservation. Research confirms the technical viability of recycling diverse urban materials—including municipal residues, construction materials, and organic resources—for environmentally beneficial applications such as soil improvement, ecological restoration, and sustainable urban development (Iqbal et al., 2023; You & Cheong, 2022; Bhati & Mallick, 2016). This transition requires moving beyond conventional management approaches and adopting more integrated and holistic indicators of environmental sustainability and urban resilience to accurately measure long-term ecological performance (Yang et al., 2023).

2.3. Urban Greening, Nature-Based Solutions

Concurrently, urban green infrastructure has been recognized as a potent nature-based solution for climate change mitigation. Urban forests and green spaces act as crucial carbon sinks, and their climate benefits can be significantly enhanced through active management and the strategic use of harvested biomass to replace carbon-intensive materials like steel and concrete (Calfapietra et al., 2015; Martes & Köhl, 2022).

2.4. The Research Gap: Impact

The literature consistently emphasizes that effective urban ecological transformation depends on strong governance systems, participatory planning, and long-term environmental management strategies (Hodgdon et al., 2013; Khatun et al., 2015; Alves et al., 2024). Existing studies primarily examine urban forestry, green infrastructure, and environmental planning independently, with limited focus on their combined role

in improving overall urban ecological health. A major research gap therefore exists in developing an integrated approach that connects urban forestation, ecological restoration, biodiversity enhancement, and climate-responsive planning within a single urban framework. This synopsis seeks to bridge that gap by proposing a comprehensive urban ecological model focused on expanding green infrastructure, restoring degraded urban landscapes, improving environmental quality, and creating healthier, more resilient, and sustainable urban environments in the Indian context.

2.5. Temporal Analysis of Research Evolution (2010–2024)

The literature reveals a distinct shift from foundational policy debates (2010–2014) to market maturation and critique (2015–2019), and finally to integrated systemic solutions and integrity crises (2020–2024).

Table 4: Temporal Research Evolution (2010-2024)

Time Period	Key Research Themes & Paradigm Shifts	Specific Work Done & Key Contributions (Citations)
Phase 1: 2010–2014(Foundational Policy & Early Barriers)	Focus: Limitations of the Kyoto Protocol (CDM); Early potential of Community Forestry; Initial REDD+ pilots. Paradigm Shift: Recognition that top-down international mechanisms were failing to capture local potential, leading to calls for more flexible land-use rules.	1. Critique of International Policy: Identified that the Clean Development Mechanism (CDM) rules restricted community forestry potential in Africa, arguing for a moral reconsideration of biocarbon sinks (Purdon, 2010). 2. Community Enterprise Models: Demonstrated that community forest concessions in Guatemala could successfully combine timber revenue with conservation, serving as a pre-platform for REDD+ (Hodgdon et al., 2013). 3. Mapping Foundations: Established early methodologies for large-scale geospatial mapping of forest carbon to support emerging REDD+ verification needs (Liang & Zhou, 2014).

Phase 2: 2015–2018(Market Growth, Co-benefits & Measurement Critique)	Focus: Rise of Voluntary Carbon Markets; Economic valuation of "Co-benefits"; Initial critiques of measurement bias; Bio-valorisation experiments. Paradigm Shift: A move from purely carbon-centric valuation to valuing social/biodiversity "co-benefits," alongside growing scrutiny of credit integrity.	1. Safeguards & Governance: Highlighted that despite social safeguards, REDD+ projects often failed locally due to unclear tenure and benefit-sharing mechanisms (Harada et al., 2015; Khatun et al., 2015). 2. Measurement Bias Discovery: Simulated how "Carbon Cowboys" could inflate payments through biased tree sampling, calling for stricter verification (Rifai et al., 2015). 3. Market Dynamics: Analysed transaction data to prove that voluntary market credits with verifiable co-benefits (biodiversity/social) commanded higher prices (Lee et al., 2018; van der Gaast et al., 2018).• Early Circularity: Lab-scale proof of converting poultry waste into biopolymers, linking waste treatment to product creation (Bhati & Mallick, 2016).

Phase 3: 2019–2021(Technological Precision & Circular Integration)	Focus: Advanced Remote Sensing (LiDAR/AI); Integrated Agroforestry Systems; Social Vulnerability Mapping; Policy Instruments. Paradigm Shift: Integration of disparate fields (Agri-Silvi-Culture) and the adoption of high-precision technology (AI, Computer Vision) to reduce estimation uncertainty.	1. Advanced Monitoring: validated Terrestrial Laser Scanning (TLS) as a highly accurate alternative to manual inventory for carbon accounting (Ruza et al., 2021) and reviewed Computer Vision applications for forestry (Illarionova et al., 2022). 2. Integrated Systems: Proved the economic feasibility of integrated livestock-forest systems in Brazil, moving beyond monocultures (Ansolin et al., 2020). 3. Vulnerability Mapping: Developed statistical indices to map urban social vulnerability, a method transferable to climate risk assessment (Agrawal et al., 2021). 4. Policy Portfolios: Synthesized Forest CDR policies, arguing no single approach works; success depends on socio-political context (von Hedemann et al., 2020).

Phase 4: 2022–2024(The "Integrity Crisis," Climate Risk & Systemic Circularity)	Focus: Additionality & Permanence Crisis; Climate Risks (Fire/Drought); Regenerative Circular Economy; High-Resolution Spatial Analysis. Paradigm Shift: A critical "reality check" on carbon markets (questioning if credits are real) combined with urgent calls for regenerative circular models that actively restore ecosystems rather than just managing waste.	1. The Integrity Crisis: Major empirical studies found limited evidence that offset projects actually changed forest management or reduced deforestation, questioning the "additionality" of millions of credits (Stapp et al., 2023; Macintosh et al., 2024). 2. Climate Risk & Permanence: Quantified that climate risks (fire, drought) are threatening the permanence of forest carbon, often reversing gains, and are not priced into current credits (Wu et al., 2023; Chu et al., 2023; Dye et al., 2024). 3. Systemic Circular Models: Proposed comprehensive regenerative circular economy models for developing nations to integrate informal waste sectors (Iqbal et al., 2023) and advanced bio-economy analyses (Nowak et al., 2024). 4. High-Precision Tracking: Introduced "Google Plus Codes" for granular, cell-level tracking of carbon storage over time to improve verification accuracy (Wen et al., 2024). *Source: Author*

2.6. Thematic Analysis of Literature

1. Waste Management & Circular Economy

Core Synthesis: The literature confirms a decisive shift from linear disposal models to regenerative circular systems, though measurement remains a challenge.

- **Systemic Transition:** Iqbal et al. (2023) and Cheong (2022) argue that waste management must evolve into resource management. They present evidence that integrating the informal sector and modeling material flows (e.g., construction waste) can turn waste streams into economic assets.
- **Valorization Pathways:** There is high consensus on the technical viability of converting specific waste streams. Bhati & Mallick (2016) demonstrated the production of biopolymers from organic waste, while Nowak et al. (2024) proved the profitability of processing biogas digestate into pellets. Yu et al. (2020) link this directly to the thesis by showing how **biochar** from waste can serve as a soil amendment, closing the loop between waste and land use.

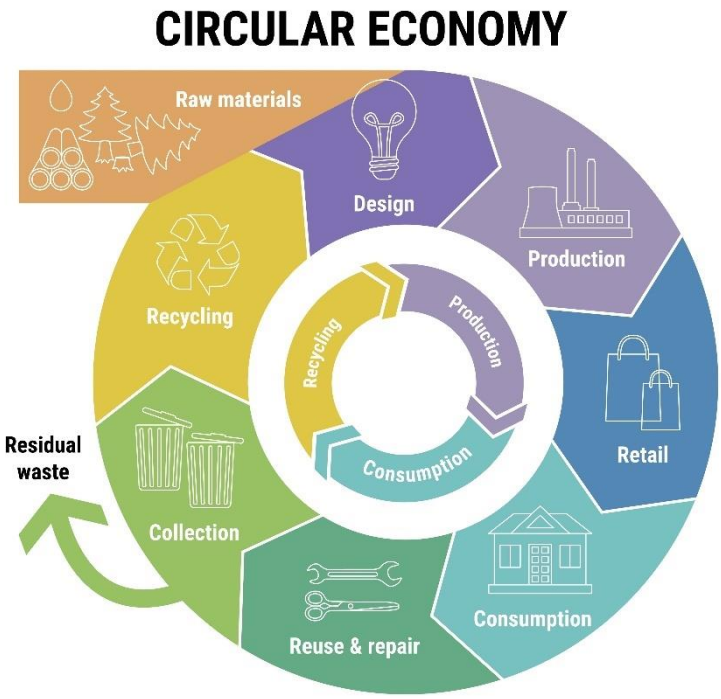


Figure 4: Circular Economy *Source: Shutterstock*

- **Measurement Gap:** A critical finding by Yang et al. (2023) is that traditional "recycling rates" are insufficient. They propose "circularity performance" indicators to measure the quality and regenerative capacity of the system, not just the volume processed.

2. Forest Carbon Accounting & Measurement

Core Synthesis: A technological revolution is replacing manual estimation with high-precision digital monitoring to ensure credibility.

- **Technological Shift:** The literature shows a move away from rough manual estimates. Ruza et al. (2021) validated **Terrestrial Laser Scanning (TLS)** as a highly accurate alternative to manual inventory, essential for verified carbon accounting. Illarionova et al. (2022) and Liu et al. (2022) demonstrate the efficacy of **Computer Vision** and satellite data fusion (Sentinel-2/ICESat-2) for large-scale biomass estimation.
- **Spatial-Temporal Tracking:** Introduced a novel methodology using **Google Plus Codes** to track carbon storage changes at a granular cell level over time Wen et al. (2024). This offers a specific methodological solution for the thesis to verify "additionality" in urban settings.

3. Forest Management for Climate Mitigation

Core Synthesis: Active management often outperforms passive conservation due to the "substitution effect."

- **Substitution vs. Sequestration:** Martes & Köhl (2022) and Butarbutar et al. (2016) argue that the greatest climate benefit often comes from "substitution"—using harvested wood to replace carbon-intensive materials like steel and concrete—rather than just storing carbon in standing trees.

- **Management Intensity:** Blanc et al. (2019) and Pukkala (2020) demonstrate that "Improved Forest Management" (IFM) can generate additional carbon

credits compared to business-as-usual baselines. This is relevant for urban forestry where active management is required.

5. Climate Change Risks & Forest Carbon Permanence

Core Synthesis: Long-term carbon storage is threatened by climate risks, which are currently undervalued.

- **The Risk Premium:** Chu et al. (2023) and Wu et al. (2023) argue that current carbon markets fail to price in the risk of reversal. Fire, drought, and pests (exacerbated by climate change) threaten to release stored carbon.

- **Policy Gaps:** Mummery (2024) and Dye et al. (2024) critique existing policies for relying on historical data rather than future climate projections, putting the "permanence" of carbon credits at risk.

6. Governance, Social Equity & Livelihoods

Core Synthesis: Technical solutions fail without social legitimacy and strong local governance.

- **Local Empowerment:** Hodgdon et al. (2013) and Khatun et al. (2015) present evidence that successful projects (like REDD+) depend on equitable benefit-sharing and clear tenure. Sears et al. (2021) emphasize that local governance is often the missing link in national policies.

- **Political Ecology:** Carton & Andersson (2017) offer a critical perspective, warning that carbon offsetting can lead to the "subsumption of nature," where ecological functions are commodified in ways that may obscure local community needs.

7. Biodiversity & Co-Benefits & Urban Greening & Sustainability

Core Synthesis: Urban greening is a multi-functional asset; integrating biodiversity enhances value but requires specific planning.

- **Urban Potential:** Calfapietra et al. (2015) and Suhardono et al. (2024) highlight that urban and peri-urban forests are significant, underutilized carbon sinks.

- **Biodiversity Alignment:** Siikamäki & Newbold (2012) note that carbon-dense areas do not always overlap with high-biodiversity areas, suggesting that urban planning must intentionally design for both to maximize **co-benefits**.

- **Educational Value:** Oliveira et al. (2024) highlight the educational and biotechnological potential of specific species (like *Inga edulis*) in urban settings, adding a layer of social sustainability.

8. Methodology & Technology (General)

Core Synthesis: Advanced analytical tools are allowing for more complex, multi-variable assessments of urban systems.

- **Vulnerability Mapping:** Agrawal et al. (2021) utilize Factor Analysis to create social vulnerability indices. This methodology is transferable to the thesis for identifying which urban wards are most vulnerable to climate risks.

- **Bibliometric & Expert Analysis:** Su & Wang (2022) and Buma et al. (2024) use large-scale bibliometrics and expert elicitation to validate the scientific certainty of different nature-based solutions, providing a high-level justification for choosing specific interventions (like afforestation) over others.

CHAPTER 3: CASE STUDY

The five selected case studies **Barcelona (Spain), Montreal (Canada), Dar es Salaam (Tanzania), Indore (India), and Bengaluru (India)** demonstrate diverse pathways through which cities transition from linear, landfill-dependent waste systems to circular, resource-generating models with measurable climate benefits.

1. **Barcelona** represents a mature European circular-economy model, characterized by high-quality waste segregation, extensive recycling and composting, and integration of waste-to-energy systems. The city's landscape-scale NDVI (Normalized Difference Vegetation Index) assessment reports an average NDVI value of approximately 0.20 within 100-m urban grid cells, highlighting the structural contribution of both urban green spaces and peri-urban forests. Institutional coherence and EU policy mandates serve as strong enablers, while capital intensity, governance complexity, and public resistance to incineration act as constraints.
2. **Montreal** demonstrates a robust integration of city-wide greenhouse gas (GHG) accounting with NDVI-based green-cover mapping. The island-wide vegetation assessments are used to evaluate environmental equity and guide urban greening. Montreal's waste system remains reliant on landfills, but it benefits from strong provincial climate policies and well-developed GHG inventories. Barriers include high infrastructure costs and coordination challenges among multiple municipalities.
3. **Dar es Salaam** provides a contrasting perspective as a Global South example centered on a Clean Development Mechanism (CDM) landfill-gas project. The Mtoni dumpsite project illustrates how methane capture and electricity generation can offer carbon-credit revenue streams. Despite technical capability, the project faced institutional delays, financing hurdles, and governance complexities. While NDVI and urban forestry integration are limited in the documented project, capped landfills hold substantial potential for future greening and carbon sequestration.
4. **Indore**, consistently ranked among India's cleanest cities, showcases a city-wide operational model of source segregation, composting of organic waste,

mechanized material recovery, and green-waste palletization. Organic content forms over 40% of its municipal solid waste (MSW), enabling significant methane avoidance through composting. NDVI studies reveal expanding peripheral green cover and decreasing vegetation in the urban core, providing spatial justification for compost-supported plantations. Indore's major enablers include strong political leadership, rigorous enforcement, and effective public–private partnerships, while initial barriers involved contractor inefficiencies and unsegregated waste streams.

5. **Bengaluru** offers a nuanced circular model centered on decentralized segregation, market-scale zero-waste systems, and a strong environmental NGO ecosystem. Waste composition in major markets is overwhelmingly organic, with daily wet waste ranging between 7–22 tonnes. NDVI studies consistently show a negative correlation between vegetation and land-surface temperature, guiding urban greening initiatives across biodiversity heritage sites, campuses, and lake precincts. Key enablers include community engagement and decentralized governance, while barriers stem from rapid urbanization and initial resistance to behavioral change.

Collectively, these five cases highlight that effective circular systems require

1. Robust segregation and waste-processing infrastructure,
2. Planning mechanisms linking recovered resources (e.g., compost) to urban greening,
3. Institutional frameworks that incorporate GHG accounting and carbon-credit finance into official city planning documents.

3.1 Comparative Analysis of Case Studies

Table 5: Comparative Analysis of International & Indian Case Studies

Parameter	Barcelona (Spain)	Montreal (Canada)	Dar es Salaam (Tanzania)	Indore (India)	Bengaluru (India)
Type of Case	Integrated circular city + NDVI study	City-scale GHG & NDVI mapping	Landfill-gas CDM project	High-performing MSW & green-waste valorization	Circular market (zero-waste) + NDVI + urban forestry
NDVI / Green-Cover Findings	Mean NDVI ≈ **0.20** (100m buffers); strongest correlation with urban & natural green zones	Full island NDVI/TDVI maps; used in climate equity studies	No formal NDVI study; potential for post-landfill NDVI gains through afforestation	NDVI increasing on periphery; decline in core; linked to UHI patterns	NDVI varies by zones; strong NDVI–temperature correlation; higher NDVI in forest patches
Waste Composition	Organics ~40–45%; paper/plastic ~35–40%; rest inserts	Organics ~30–40%; recyclables ~35–45%	High-organic MSW (>50%) typical of African cities	Compostable **40.28%**, paper 8.2%, plastics 5.8%, inserts 20.19%	Market waste mostly **organic** (7–22 T/day), dry 200–500 kg/day
Waste Techniques Used	Door-to-door segregation; recycling; composting; WtE incineration	Landfill + methane accounting; recycling; organics diversion	Landfill gas capture + electricity (CDM)	Segregation, composting, bio methanation, MRFs, green-waste palletization	Segregation, food redistribution, animal feed, composting, recycling
Urban Forest / Green Types	Street trees, urban parks, peri-urban forests	Parks, riparian green, street trees, peri-urban woodlands	Potential urban forest on capped landfill	Parks, lakeside green belts, roadside plantations	Biodiversity heritage sites, lakeside forests, street trees
Barriers	High costs; public opposition to WtE; multi-level governance difficulty	Legacy landfills; high infrastructure costs; inter-municipal coordination issues	Complex institutional approvals; financing delays	Earlier lack of segregation; informal dumping; poor contractor performance	Behavior change resistance; informal waste-handling; high urbanization pressure

Enablers	Strong EU regulations; high-quality segregation; institutional coordination	Robust GHG inventory; strong provincial climate policies	CDM methodology + technical partners	Political leadership; GPS tracking; strict enforcement; PPP model for green waste	NGO partnerships; community involvement; zone-level waste systems
Use of Waste for Urban Greening	Compost in parks; soil enhancement	Compost for parks; landfill-to-park conversions	After capping landfill, potential afforestation	Compost for parks; pellets reduce fossil-fuel use	Compost feeds urban forest & heritage sites
Carbon Credit Potential	WtE energy & organic diversion	Avoided landfill methane	CDM-certified CER generation	Avoided CH_4 + green-waste pellets reduce CO_2	Avoided food waste methane + compost sequestration
Relevance to Your RQs	Strong integration of planning + waste + green spaces	GHG accounting + NDVI integration	Pure carbon-finance + institutional lessons	Best Indian circular system + data-rich	Circular economy + NDVI + community governance

Source: Author

3.2 Limitations:

The in-depth findings will be specific to the selected location in map and may require contextual adaptation for application elsewhere.

1. Spatial Generalizability: The in-depth primary surveys and micro-level analysis are restricted to **selected representative wards** within the area due to time and resource constraints. While these wards are chosen to reflect diverse urban typologies (historic, administrative, residential, developing), the findings may not fully capture the heterogeneity of the entire city, particularly in peri-urban or unauthorized settlements not included in the sample.

2. Data Reliability and Availability: The study relies partially on **secondary data** for historical waste generation trends and baseline carbon emissions (from sources like CPCB and municipal records). As noted in similar contexts (Iqbal et al., 2023), official waste data in developing nations can sometimes lack granularity or accuracy regarding informal sector contributions. The study attempts to triangulate this with primary surveys, but some margin of error in baseline data remains.

3. Estimation vs. Direct Measurement: The quantification of carbon sequestration in urban green spaces will rely on **non-destructive methods**, such as allometric equations and remote sensing indices (NDVI/biomass estimation models) (Zaki et al., 2018; Wen et al., 2024). It will not involve destructive sampling or long-term laboratory analysis of soil carbon dynamics, which means the calculated "Carbon Credit Potential" will be an **estimation** rather than a verified laboratory measurement.

4. Temporal Limitations: The primary data collection represents a **cross-sectional snapshot** in time. It may not fully account for seasonal variations in waste composition (e.g., increased moisture in monsoons) or the seasonal phenology of urban vegetation, which can influence both waste processing efficiency and carbon sequestration rates.

3.3 Expected Outcomes:

The primary outcome will be a **replicable framework for integrating circular economy principles into the master planning process of cities**. This will include actionable **policy recommendations** for strengthening the local circular economy ecosystem, creating a practical tool for urban planners and policymakers.

10.1. Summary of Evolution:

1. **Methodological Evolution:** Research has moved from simple **manual inventories** (2010s) to **simulation modeling** (mid-2010s) to **advanced AI, LiDAR, and Big Data analytics** (2020s).

2. **Scope of Solution:** The scope has widened from **siloed approaches** (forests *or* waste) to **integrated systems** (Circular Bio-economy), where waste becomes an input for regeneration.

3.4 Site Selection

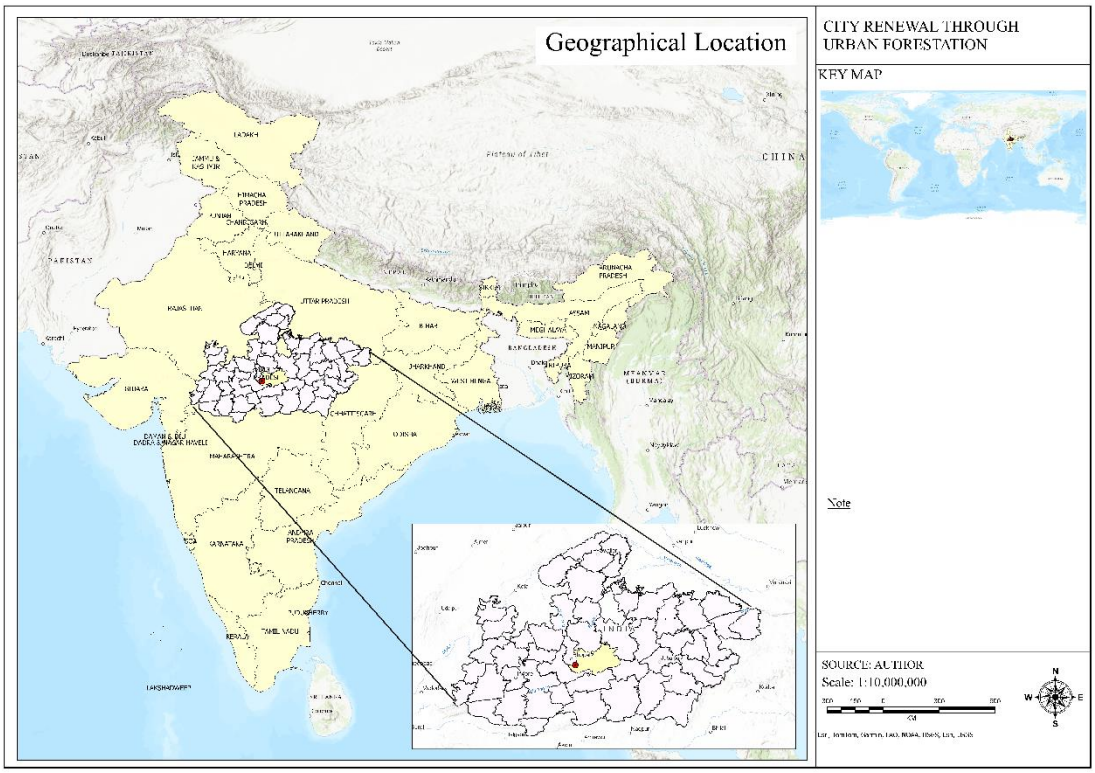
Sub District	**CP, Delhi**	**Parliament street, Delhi**	**Bhel, Bhopal**	**Mandideep, bhopal**	**Source**
Type	Commercial	Administrative	Industrial	Industrial	ISRO Bhuvan
Area (sqkm)	7.2	7.5	7	3	author
Peri-Urban Area	No	No	No	Yes	author
Open space inside	No	No	Yes	No	author
Forest Cover (Vegetation)	~13	~15	~8	~5	FSI Report
LULC	Urban	Urban	Industrial	Industrial	ISRO Bhuvan

Air Quality Montier	**mg/m3**				
PM2.5	~90	~90	~70	~65	CPCB
PM10	~180	~180	~140	~130	CPCB
NO2	~40	~40	~30	~28	CPCB
SO2	~15	~15	~12	~10	CPCB
CO	~1.5	~1.6	~1.2	~1.1	CPCB
Base Line Emission	High	High	Medium	Medium	IPCC / Inventory

Indicator	2005	2025	Change
Green Cover (%)	~25	~18	-28%
Built-up Area (%)	~28	~48	+71%
Industrial Footprint (%)	~10	~18	+80%
Average Surface Temperature	31–33°C	38–44°C	+6 to 10°C
Ecological Stress Index	Moderate	Very High	↑
Carbon Emissions	Baseline	~2–3× higher	↑↑
Groundwater Recharge Potential	High	Moderate-Low	↓
Air Quality	Moderate	Poor in industrial pockets	↓

CHAPTER 4: SELECTED SITE: MANDIDEEP, RAISEN

Mandideep is an industrial town located in Raisen District, situated to the south-east of Bhopal along the railway line and National Highway No. 12. The town lies approximately at 23°06' North latitude and 77°31' East longitude with an elevation of about 474.5 meters above sea level. Due to its strategic connectivity through road and rail networks, Mandideep has developed as an important industrial and transportation hub in the region. Over the last 15–20 years, the establishment of major industrial units has accelerated the town's growth, transforming a significant portion of the surrounding



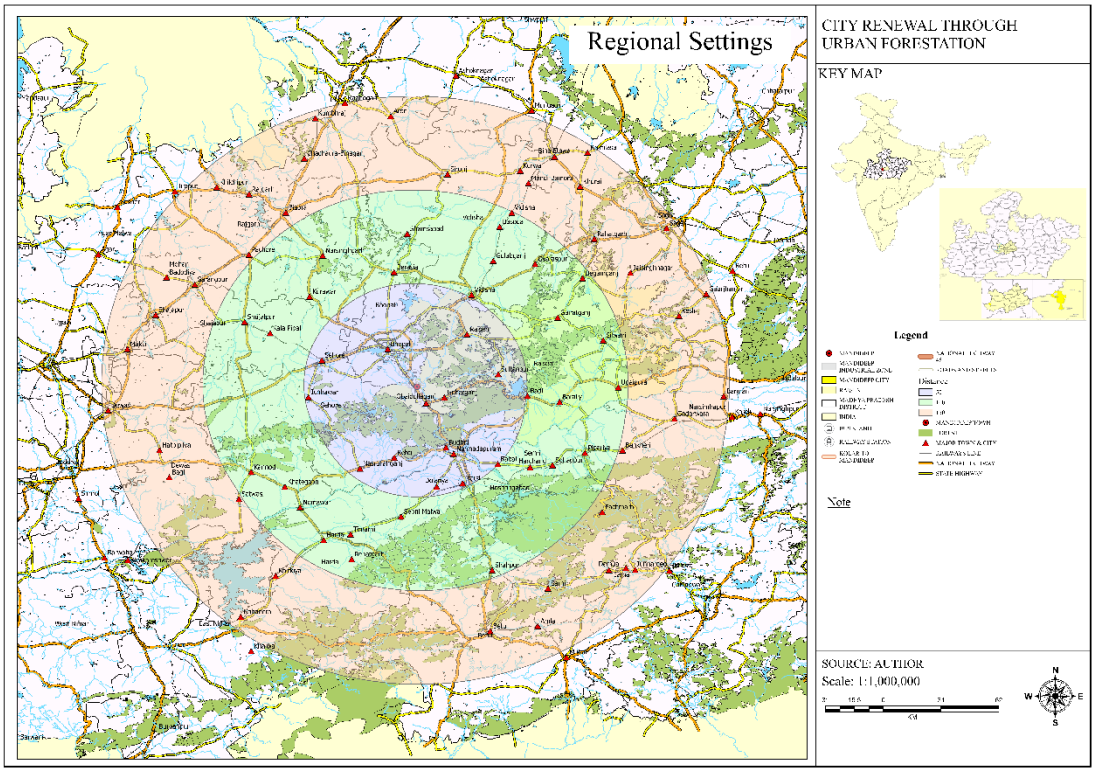
Map 1 Geographic location *Source: Author*

rural population into urban residents. Additionally, the proximity of the state capital, Bhopal, has increased residential and developmental pressure on the town. In such circumstances, controlling unplanned expansion and promoting planned urban development has become essential to ensure sustainable and organized growth of the urban area.

4.1 Regional Importance and Historical Background

Mandideep has gained regional importance due to the passage of National Highway No. 12 through the town and the movement of railway lines connecting major cities such as New Delhi, Mumbai, and Chennai. The industrial expansion and increasing population pressure of the nearby capital city, Bhopal, have also contributed significantly to the rapid growth of Mandideep over the past 15 years. The establishment of both large-scale and small-scale industrial units has accelerated the town's urban and economic development.

The town is located near important cultural and tourism sites such as Bhojpur Temple and Bhimbetka Rock Shelters, which enhance its historical and tourism significance. In addition, the rocky nature of the land in Mandideep makes it suitable for industrial use and infrastructure development.



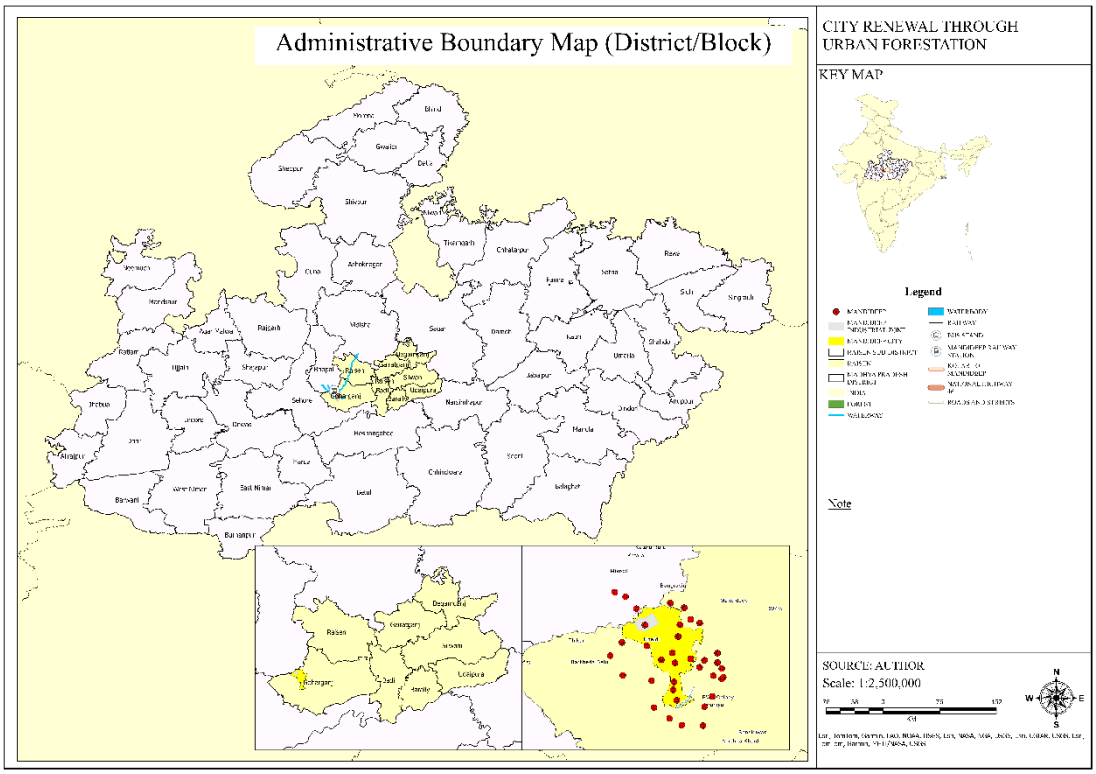
Map 2 Regional Settings

Source: Author

4.2 Physical Setting

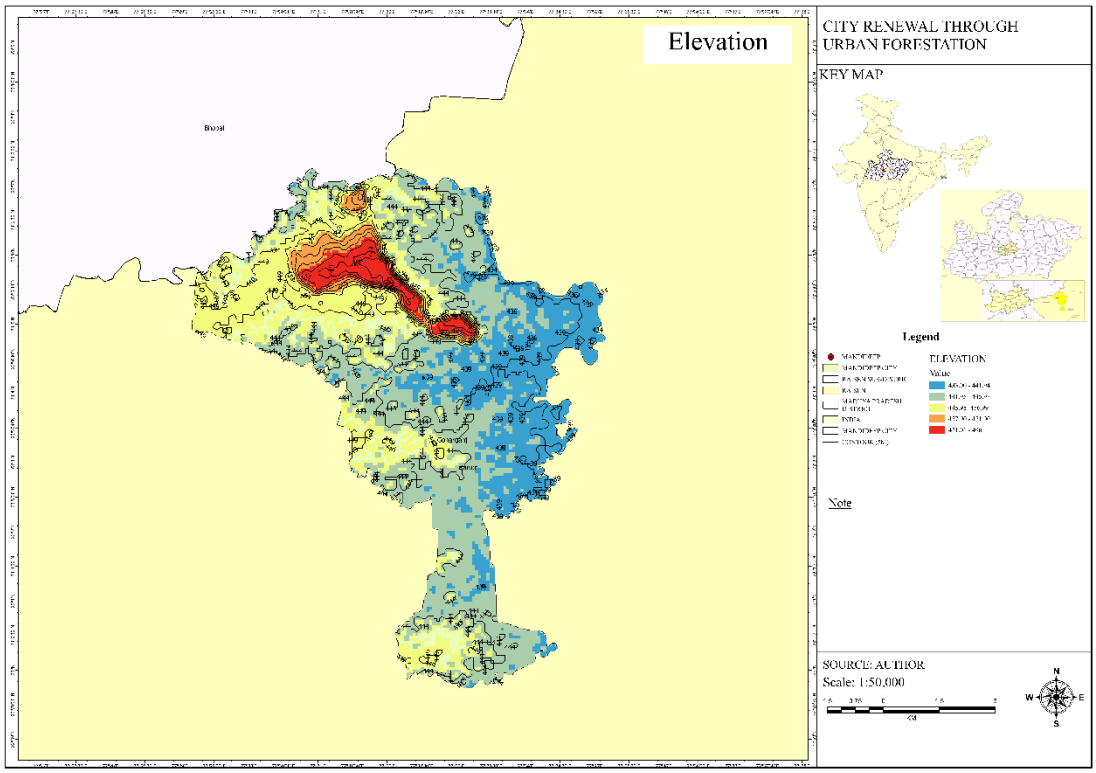
Mandideep is situated on a sandstone ridge. The town has mainly developed between the National Highway and the railway line, and its expansion continues largely within this corridor. The direction of urban growth has primarily been towards Bhopal, where considerable development has already taken place. To the south lies Obedullaganj, while the older settlement of Mandideep village is located towards the west.

The general slope of the town is towards the east. Mandideep is spread across three different elevation levels: the eastern side consists of higher elevated land near Satlapur, the central portion contains the present urban expansion, and the western side includes the lower-level old Mandideep settlement. Therefore, the natural topography of the town is uneven.

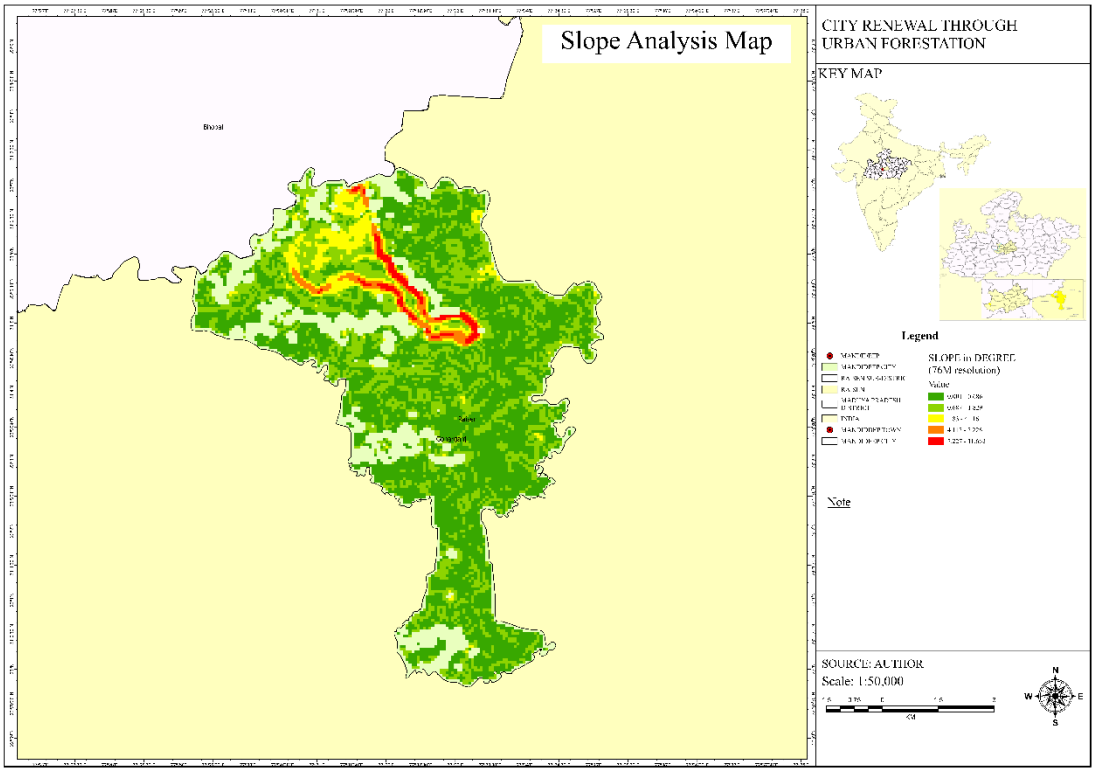


Map 3 Adminstrative Boundry *Source: Author*

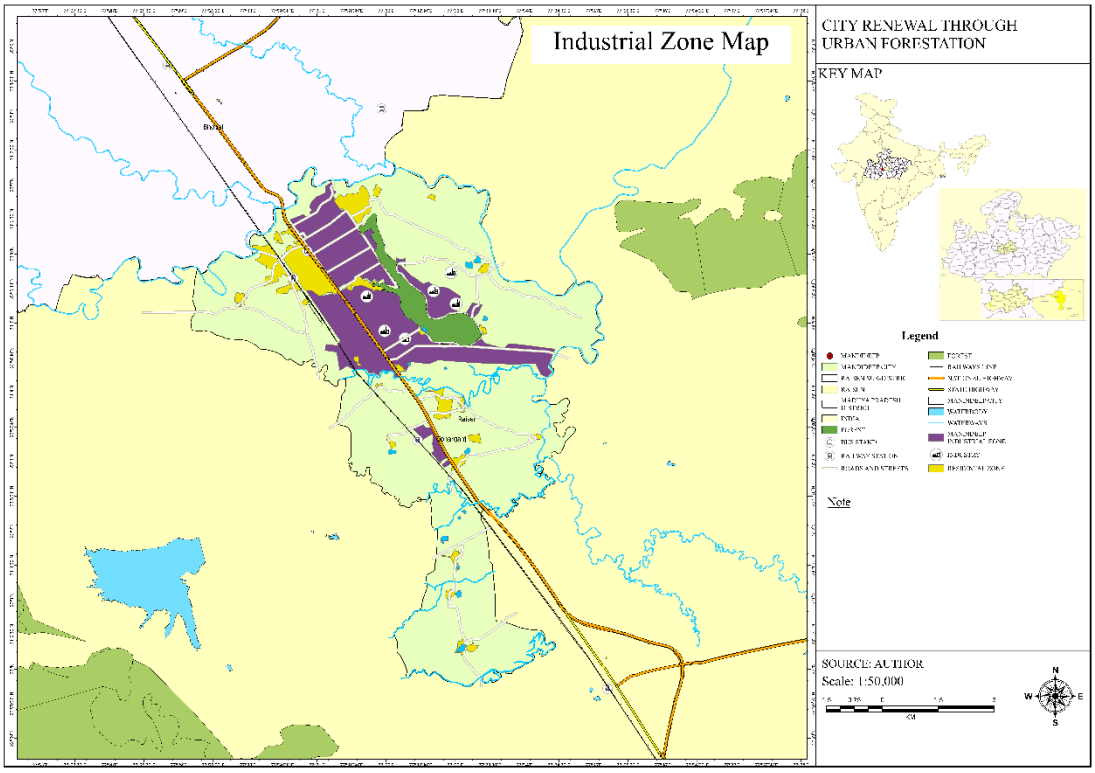
The natural drainage system of the town is connected with the Betwa River and Kaliasot River, along with several small streams and drains flowing through the area. It is believed that the original settlement of Mandideep began around Patel Baba Mohalla, Khidiya Mohalla, and Badwala Kuwa. With the continuous increase in population, the physical form and structure of the town gradually transformed into its present urban character.



Map 4 Elevation *Source: Author*



Map 6 Slope Analysis Map *Source: Author*



Map 5 Current Land Use *Source: Author*

4.3 Geological Formation and Vegetation

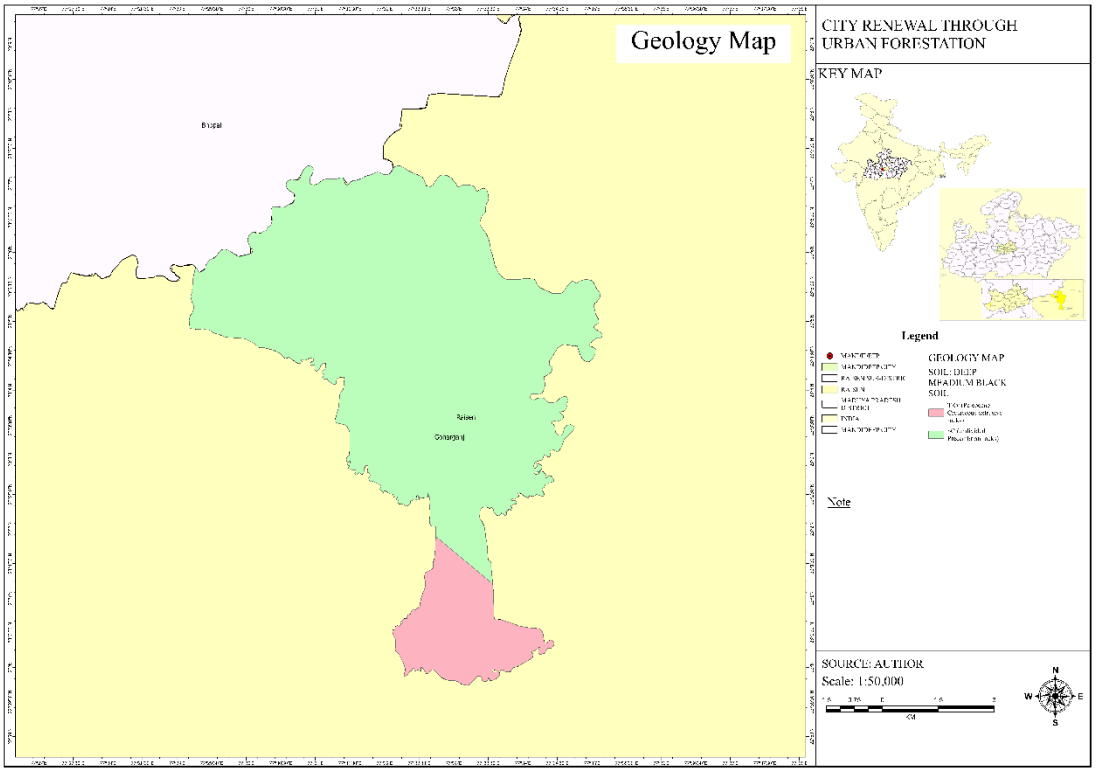
The major geological formations and vegetation found in Raisen District are described as follows:

Geological Formation

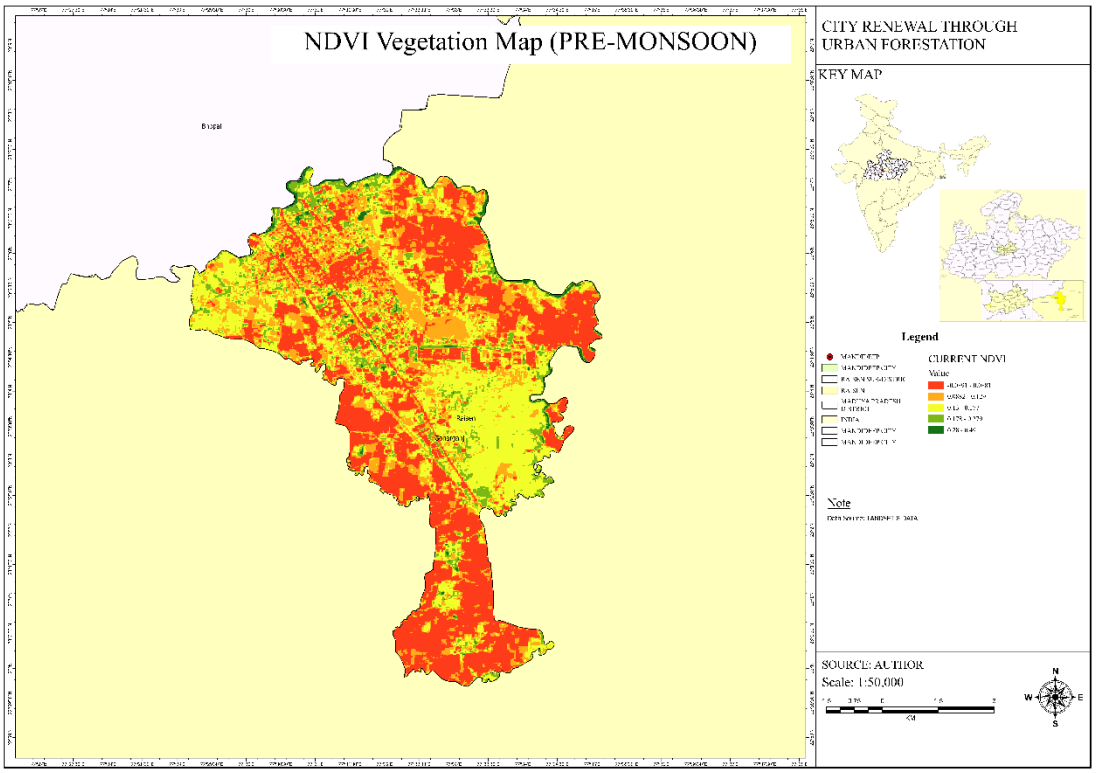
1. **Alluvial Deposits**
   These are mainly found along river valleys and large drainage channels. The soil generally consists of gravel mixed with light-colored clay and sandy deposits. Beneath these layers, compact sandy sediments and coarse-textured formations are found, often extending up to a thickness of about 6 meters. The soil is mainly yellowish to light brown in color and contains a comparatively higher proportion of clay. Fertile flat lands are also found in the valleys of the Varna and Chamarsil rivers within the Goharganj tehsil area.
2. **Laterite Formation**
   Laterite soil and rock formations are found in some elevated plateau and hill regions. These formations generally occur as limestone-rich rocky layers covering the low-elevation hills and upland areas of the southern plateau region.

Vegetation

Raisen District is one of the extensively forested districts of the state. Under the Obedullaganj forest range, the area of reserved forests extends over approximately 621.60 square kilometers, while protected forests cover around 303.028 square kilometers. Mixed forest vegetation is mainly found in the Nagri block of the Goharganj range and the Varosot block of the Obedullaganj range. Important tree species found in these forests include teak, saja, dhawda, and salai.



Map 8 Soil and Rock Map *Source: Author*

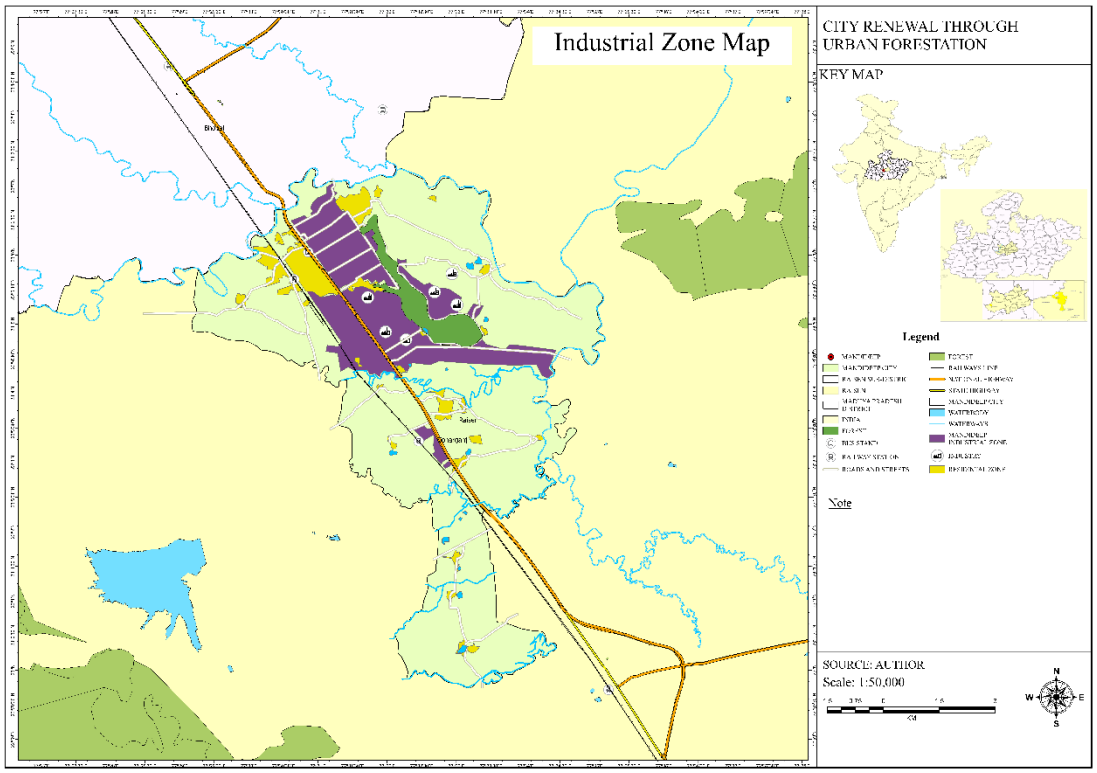


Map 7 NDVI Vegetation Map *Source: Author*

4.4 Existing Land Use Pattern

The size and development of any town largely depend upon its physical structure and spatial growth pattern. In Mandideep, the present urban development has been significantly influenced by National Highway No. 12 and the railway corridor. Due to the physical barriers created by the railway line on the western side and the Kaliasot River towards the north-east, the town has mainly expanded towards the southern direction. Development has also taken place parallel to both sides of the National Highway.

Mandideep has emerged as an important third-order industrial town. As a result, transportation facilities, road connectivity, commercial activities, and trade-related functions have increased rapidly. The major concentration of population is located on the western side of National Highway No. 12. After the establishment of industrial areas along the Bhopal Road corridor, urban development expanded further on both sides of the route in a linear pattern parallel to the highway.

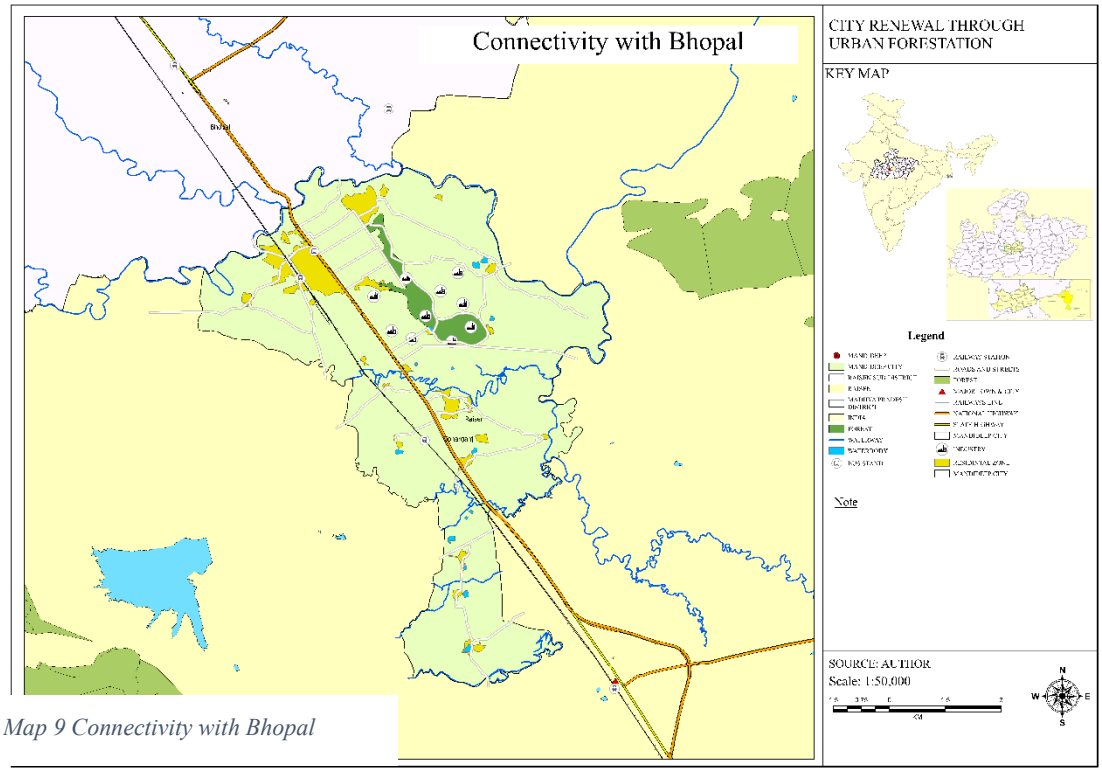


4.5 Transportation and Connectivity

Due to the increasing size and expansion of Mandideep, there is a growing need for an efficient transportation and traffic management system. The circulation structure of the town largely depends upon its major activity centers and land-use pattern. Thus, transportation and land use are closely interconnected and influence each other significantly. The circulation network, traffic pattern, traffic volume, and road capacity determine the travel time, distance, and movement of people and goods from one place to another within the town.

Regional Connectivity Structure

Mandideep is strategically located on the major railway routes connecting New Delhi–Mumbai and Chennai–New Delhi. The town is also situated along National Highway No. 12 on the Bhopal–Hoshangabad corridor. Because of this advantageous location, Mandideep is well connected with major cities such as Mumbai, Chennai, Hyderabad, Itarsi, Bhopal, Indore, and Bina. As a result, a high volume of regional traffic passes through the town.

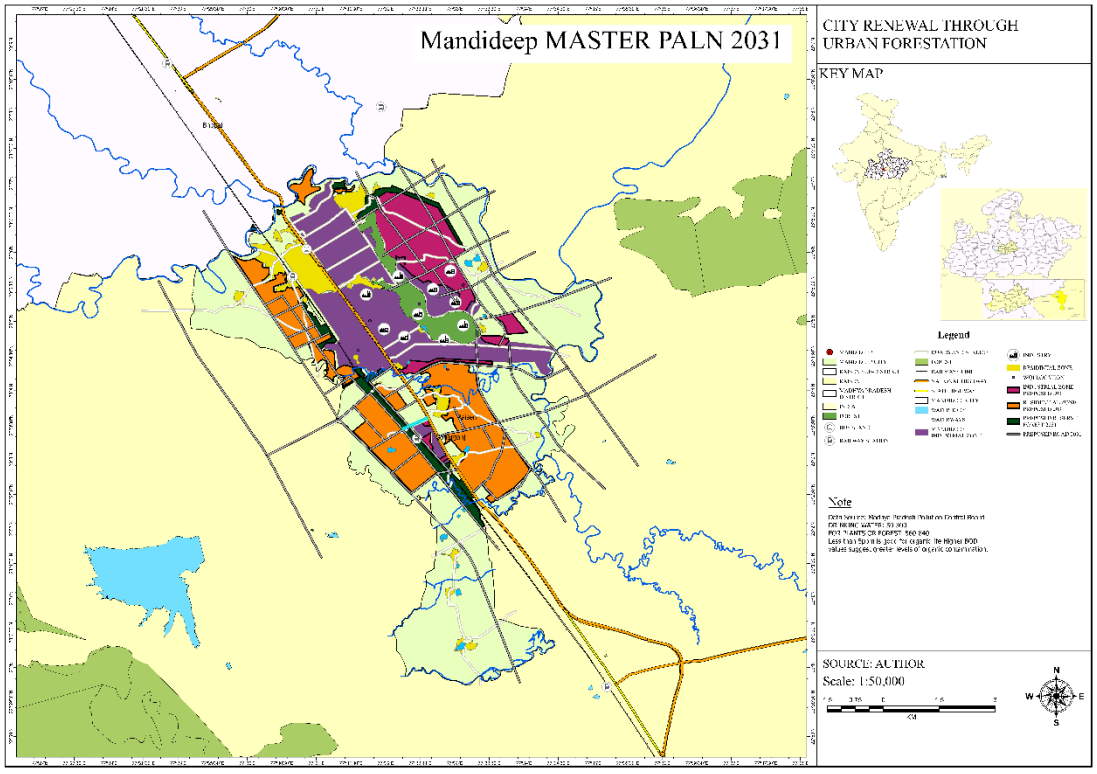


Map 9 Connectivity with Bhopal

4.6 Master-Plan 2031: Industrial Land Use Proposal

In the proposed development plan of Mandideep, a total of 1,588.30 hectares of land has been allocated for industrial use, which constitutes approximately 54.73% of the total proposed development area. The town possesses strong potential for the establishment of both small-scale and large-scale industries.

Keeping future industrial requirements in view, land has been proposed for industrial development in areas such as Satlapur, Tilakhedi, Pipliya Lodra, Mojpura, Khanpura, and Mandidehri. These industrial areas are intended for the establishment of various general industrial units, including agriculture-based and forest-based industries. The proposal also includes provisions for warehouses and cold storage facilities within the industrial zone.



Map 10 Master Plan 2031

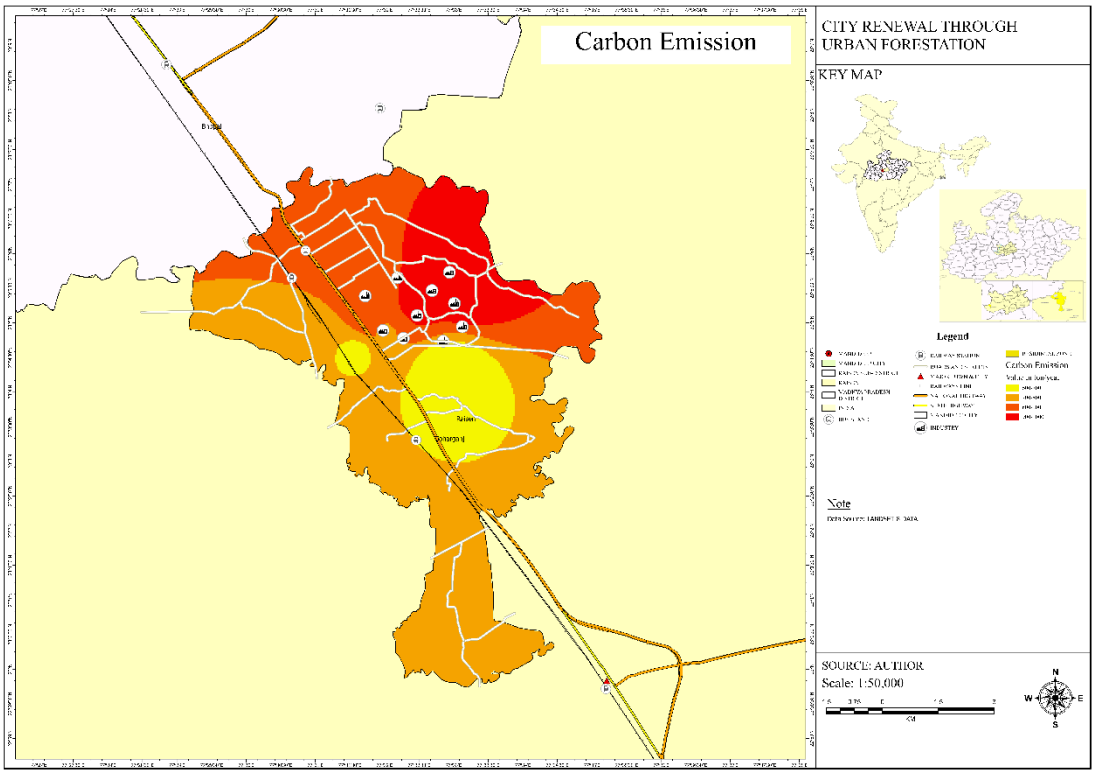
4.7 Problem because of Rapid Industrial Development

Based on the industrial growth pattern, pollution maps, emission zones, hydrology, vegetation, land surface temperature, and water quality indicators, the following major problems have emerged due to rapid industrialization:

4.7.1 Environmental Problems

Increase in Air Pollution

Rapid expansion of industrial units has increased emissions of particulate matter, smoke, industrial gases, and vehicular pollutants, especially near major industrial corridors and highway zones.



Map 11 Carbon Emission Map

a. High Carbon Emission Zones

Industrial clusters and transportation corridors have become major carbon emission hotspots, contributing significantly to greenhouse gas accumulation and climate stress.

iii. Urban Heat Island Effect
The Land Surface Temperature (LST) map indicates higher temperatures in built-up and industrial areas due to concrete surfaces, machinery heat, and reduced vegetation cover.

iv. Decline in Vegetation Cover
NDVI analysis shows reduced green cover around industrial and urbanized zones because of land conversion, construction activity, and deforestation.

v. Ecological Stress and Habitat Disturbance
Industrial expansion has disturbed natural ecosystems, fragmented green spaces, and increased ecological stress in sensitive zones.

4.7.2 Water and Soil Related Problems

i. Water Pollution Risk
WQI maps for pH, TDS, and Biological Oxygen Demand (BOD) indicate deterioration in water quality in some industrial influence zones due to untreated or partially treated industrial discharge.

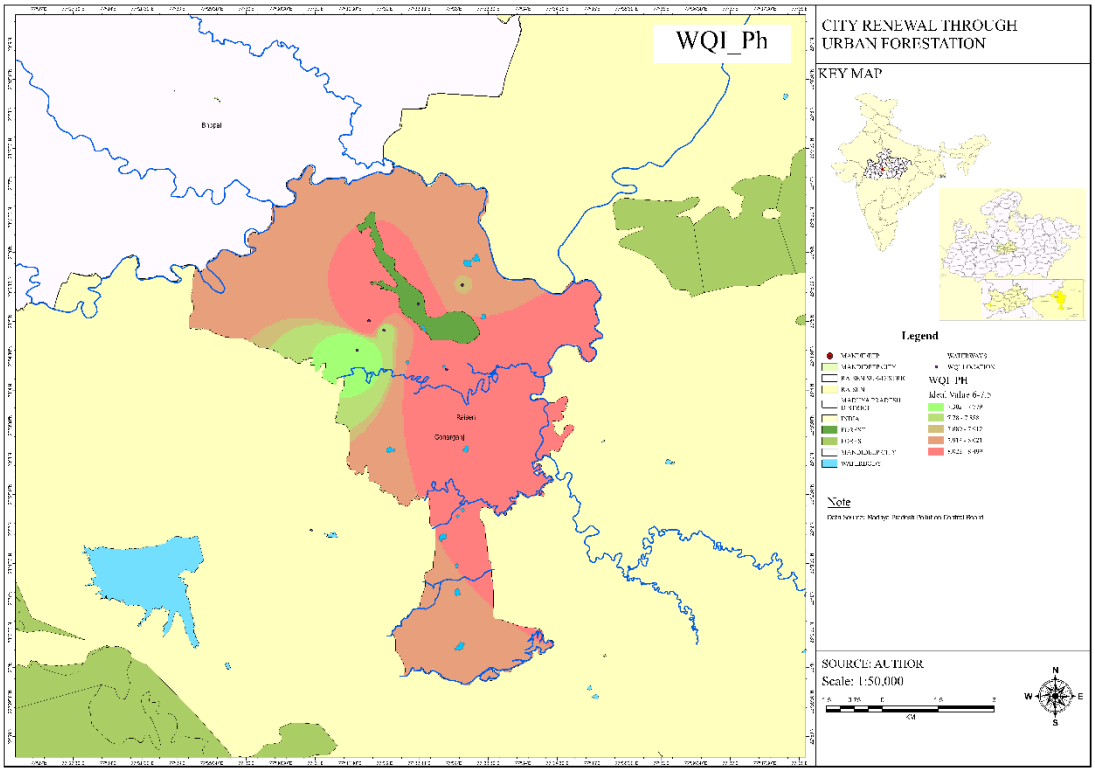
ii. Increase in Total Dissolved Solids (TDS)
Industrial effluents and waste disposal activities have increased dissolved contaminants in nearby water bodies and groundwater sources.

iii. Higher Biological Oxygen Demand (BOD)
Elevated BOD levels indicate organic and chemical pollution in water systems, reducing dissolved oxygen availability and affecting aquatic life.

iv. Pressure on Drainage Systems
Natural drainage channels and hydrological networks are being encroached upon by industrial and urban development, increasing flood and waterlogging risks.

v. Soil Degradation

Continuous industrial activity, waste dumping, and land alteration have reduced soil quality and increased land degradation in surrounding areas.



Map 12 water quality index _Ph

4.7.3 Urban and Infrastructure Problems

i. Unplanned Urban Expansion

Rapid industrial growth has accelerated informal and scattered urban development without adequate planning controls.

ii. Traffic Congestion and Transport Pressure

Increased movement of heavy vehicles and industrial transport on National Highway corridors has created congestion, road deterioration, and higher accident risk.

iii. Pressure on Public Infrastructure

Water supply, sanitation, housing, electricity, and waste management systems

are under stress because of increasing population and industrial workforce concentration.

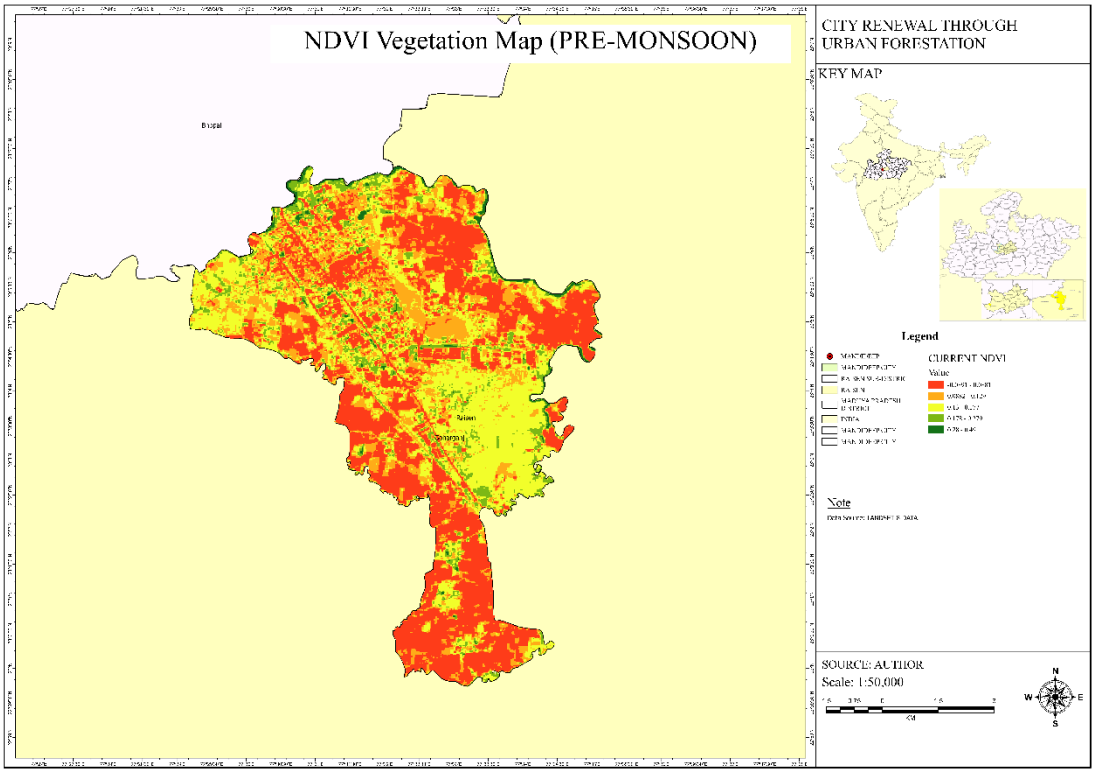
iv. Conversion of Agricultural Land
Productive agricultural land is gradually being converted into industrial and residential uses, affecting local livelihoods and food security.

4.7.4 Climate and Sustainability Concerns

i. Reduction in Carbon Sequestration Capacity
Loss of vegetation and open land has reduced the area's natural ability to absorb carbon dioxide.

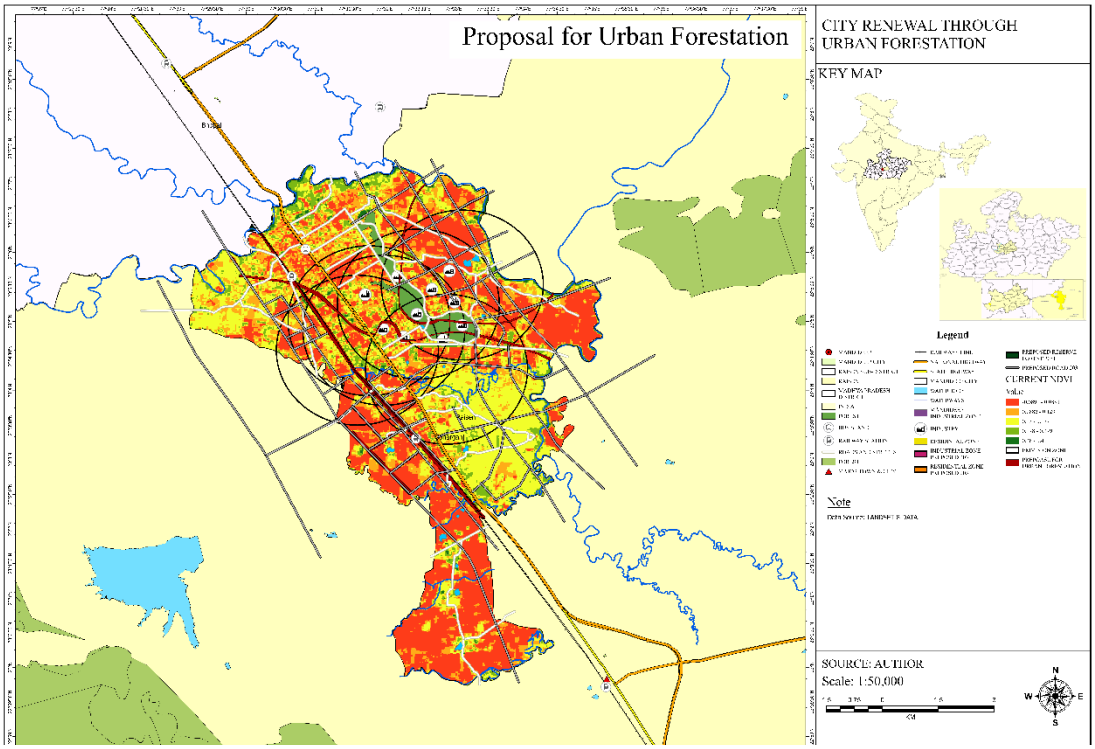
ii. Increased Climate Vulnerability
Rising temperatures, declining green cover, and pollution exposure increase long-term environmental and public health risks.

iii. Risk of Industrial Pollution Spread
Wind direction and regional atmospheric circulation can spread industrial pollutants toward nearby residential and ecological zones.



Map 13 NDVI pre Monsoon

CHAPTER 5: PROPOSAL FOR MANDIDEEP ECOLOGICAL PROBLEMS



Map 14 Proposal Map

5.1 Urban Forestation Calculation for Mandideep

1. Existing Green Cover Estimation (NDVI Map)

From the NDVI vegetation map and industrial land dominance:

Land Category	Estimated Area (%)	Approx Area (sq.km)
Dense Vegetation	8%	4.8
Moderate Vegetation	12%	7.2
Sparse Vegetation/Open Land	25%	15

Built-up + Industrial Area	55%	33

Total Existing Effective Green Cover

4.8+7.2=12 sq.km

2. Healthy Urban Green Cover Requirement

WHO and sustainable industrial city standards recommend:

30%−35% green cover

Assuming total urban planning area ≈ 60 sq.km

Required Green Cover

60×0.35=21 sq.km

A required=60×0.35=21

Existing Green Cover

12 sq.km

Additional Green Cover Needed

21−12=9 sq.km

Additional=21−12=9 sq.km

3. Tree Plantation Requirement

Standard Urban Forestry Density

Forest Type	**Trees/Hectare**
Normal Urban Plantation	1000

Convert Required Area

9 sq.km=900 hectares

Normal Plantation Requirement

900×1000=900,000 trees

Carbon Sequestration Calculation

Average mature urban tree absorbs:

20 kg CO_2/year

Total Carbon Capture

Using 9 lakh trees:

$900000 \times 20 = 18{,}000{,}000$ kg CO_2/year

5. Heat Island Reduction Calculation (LST Map)

From Land Surface Temperature map:

Zone	Existing Temp
Industrial Core	40–44°C
Vegetated Areas	30–34°C

Expected Cooling After Forestation

Average reduction:

$3^\circ C - 5^\circ C$

Estimated New Temperature

$44 - 5 = 39^\circ C$

6. Industrial Green Buffer Requirement

As per CPCB industrial planning norms:

Pollution Level	Recommended Buffer
High Pollution Industry	100–300 m
Medium Pollution	50–100 m

Approximate Industrial Edge Length

Estimated industrial perimeter:

25 km

Using 200 m average buffer:

25×0.2=5 sq.km

Green Belt Area Needed

5 sq.km

7. Runoff Reduction & Groundwater Recharge

Urban forests increase infiltration by:

Surface Type	Infiltration Rate
Concrete	10–15%
Forest Soil	50–70%

Expected recharge improvement:

25%−40%

Especially near:

- Drainage corridors
- Slope zones
- Low elevation pockets

Parameter	Calculated Value
Total Planning Area	60 sq.km
Existing Green Cover	12 sq.km
Required Green Cover	21 sq.km
Additional Forestation Needed	9 sq.km
Estimated Trees Required	9–10 lakh
Carbon Sequestration Potential	18,000 tons CO_2/year
Expected Temperature Reduction	3–5°C
Industrial Green Buffer Needed	5 sq.km
Per Capita Green Space Requirement	1.8 sq.km

Groundwater Recharge Improvement	25–40%
Pollution Reduction Potential	20–40% PM reduction

Parameter	**Existing Condition in Mandideep**	**Ideal Healthy Urban Standard**	**Urban Forestation Requirement**	**Suggested Action**
Industrial Pollution	Very High industrial emissions and ecological stress zones	Low emission urban environment	35–45% green cover around industrial belt	Develop industrial green buffer plantations
NDVI Vegetation Cover	Sparse to moderate vegetation in core industrial zones	Minimum 30% urban vegetation	Additional 15–20 sq.km plantation required	Dense Miyawaki + roadside plantation
Land Surface Temperature	High heat zones near industries and highways	Reduce surface temp by 3–5°C	1 tree per 25–30 sq.m in heat zones	Urban cooling forest corridors
Carbon Emission	High carbon emission hotspots	Net carbon-neutral growth	Approx. 5–8 lakh trees needed	Carbon sink forest blocks
Water Quality (TDS/BOD)	Water stress and pollution in drainage areas	Healthy water recharge ecosystem	Riparian forest strips along drainage	Wetland forestry + biofiltration

Slope & Drainage	Moderate runoff and soil erosion areas	Stable soil with groundwater recharge	Green slope stabilization plantation	Native grass + deep root species
Industrial Buffer Zones	Limited green separation	100–300 m green buffer	Continuous green belt required	Multi-layer vegetation barriers
Road Connectivity Corridors	Heat and dust along highways	Shaded mobility corridors	Avenue plantation on major roads	Native canopy tree plantation
Population Health Exposure	Air pollution exposure high	WHO healthy air quality	Increase per capita green space to 12–15 m^2/person	Urban parks + micro forests
Ecological Stress Zones	Highly stressed industrial pockets	Balanced urban ecology	Convert vacant land to ecological forests	Urban biodiversity parks

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study demonstrates that rapid industrialization and urban expansion in Mandideep have significantly altered the environmental balance of the city, resulting in declining vegetation cover, increasing land surface temperatures, rising pollution levels, ecological degradation, and reduced carbon sequestration capacity. The analysis of land use, NDVI, water quality indicators, and industrial growth patterns reveals that existing development trends are placing considerable pressure on natural ecosystems and urban infrastructure.

The research confirms that urban forestation can serve as an effective nature-based solution for addressing these challenges. The proposed framework highlights the potential of increasing urban green cover, establishing industrial green buffers, restoring degraded landscapes, and integrating ecological planning within the urban development process. The assessment indicates that Mandideep requires substantial expansion of green infrastructure to achieve a healthier and more climate-resilient urban environment.

The proposed urban forestation strategy has the potential to enhance carbon sequestration, improve air quality, reduce urban heat island effects, strengthen groundwater recharge, and increase biodiversity. Furthermore, the study demonstrates that ecological restoration should be considered a core component of urban planning rather than a supplementary environmental measure. The developed framework provides a replicable model that can assist planners and policymakers in promoting sustainable urban growth while maintaining environmental quality and long-term urban resilience.

Overall, the study concludes that city renewal through urban forestation offers a practical and sustainable pathway for transforming environmentally stressed industrial cities into healthier, greener, and climate-responsive urban environments.

6.2 Recommendation

i. Increase Urban Green Cover Achieve a minimum of 30–35% urban green cover through large-scale plantation drives, urban forests, biodiversity parks, and green corridors.

ii. Establish Industrial Green Buffers: Develop continuous green belts of appropriate width around industrial zones to reduce pollution dispersion, noise levels, and ecological stress.

iii. Protect Existing Natural Assets: Conserve existing forests, drainage corridors, water bodies, and environmentally sensitive areas through strict land-use regulations and ecological zoning.

iv. Integrate Urban Forestation into Master Planning: Incorporate urban forestry targets, green infrastructure networks, and ecological restoration zones within future development plans and planning regulations.

v. Promote Native and Climate-Resilient Species: Prioritize indigenous tree species adapted to local climatic conditions to improve survival rates, biodiversity, and ecological performance.

vi. Develop Green Corridors and Roadside Plantations: Strengthen connectivity between fragmented green spaces through avenue plantations, green corridors, and linear parks along transportation routes.

vii. Restore Degraded and Vacant Lands: Convert abandoned, degraded, and underutilized lands into urban forests, community parks, and ecological restoration sites.

viii. Improve Environmental Monitoring: Establish periodic monitoring of NDVI, land surface temperature, air quality, and carbon sequestration using GIS and remote sensing technologies.

ix. Strengthen Community Participation: Encourage participation of industries, local communities, educational institutions, and environmental organizations in urban greening initiatives.

x. Develop a Long-Term Green Infrastructure Policy: Formulate a dedicated urban green infrastructure policy that links environmental conservation, climate resilience, public health, and sustainable urban development goals.

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ANNEXURE

1 Urban Forestry Inputs

Table 6: Urban Forestry Inputs

Species	Indian name	CO_2 (kg/year)	Full rate age (yrs)
Moringa	सहजन (Sahjan)	480	8
Albizia lebbeck	सिरिस (Siris)	287	10
Neem	नीम (Neem)	135	7
Acacia nilotica	बबूल (Babul)	123	7
Dalbergia sissoo	शीशम (Sheesham)	122	12
Arjun	अर्जुन (Arjun)	63	10
Karanj	करंज (Karanj)	50	8
Gmelina	गम्हार (Gamhar)	26	10
Peepal/Banyan	पीपल (Peepal)/ बरगद (Bargad)	250 (avg for urban)	20

Source: NCERT

2 Combined Waste-Composition Table

Table 7: Waste-Composition Table

Waste Category	Definition	India % (Urban MSW)	Global % (World Avg.)	Sources
Organic / Biodegradable	Food, vegetable, fruit, garden waste	**52%**	**44%**	CPCB (2020–22); World Bank (2018) "What a Waste 2.0"
Paper & Cardboard	Newspaper, cartons, mixed paper	**10%**	**17%**	CPCB; World Bank
Plastics (Rigid + Soft)	PET, HDPE, LDPE bags, packaging	**9%**	**12%**	CPCB; UNEP Global Waste Review
Glass	Bottles, broken glass	**2%**	**4%**	CPCB; World Bank
Metals	Aluminium cans, ferrous scraps	**1%**	**4%**	CPCB; UNEP
Textiles & Leather	Clothing, fabrics, leather pieces	**4%**	**2%**	CPCB; World Bank
Rubber	Footwear, miscellaneous rubber	**1%**	**1%**	CPCB; UNEP
Wood Waste	Furniture scraps, small wood pieces	**1%**	**3%**	CPCB; World Bank
E-Waste	Phones, small electronics, chargers	**0.50%**	**1%**	CPCB E-waste Assessment; UNEP
Sanitary Waste	Diapers, sanitary pads, medical-type waste	**3%**	**1%**	Swachh Bharat Mission (SBM) Waste Audit 2021
Inserts / Others	Soil, stones, silt, C&D residues	**16%**	**11%**	CPCB; World Bank
Total		100%	100%	

Source: Given