

**“ECOSYSTEM SERVICE-BASED URBAN FOREST
PLANNING: A SPATIAL SUITABILITY
ASSESSMENT FOR NARMADAPURAM, M.P.”**

Bachelor of Planning

Prathmesh Deshpande
[Sch. No. 2211002132]



**Department of Architecture and Planning
Maulana Azad National Institute of Technology, Bhopal
462003**

May, 2026

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

*A Thesis Project
submitted in partial fulfillment of the requirements
for the award of the degree of*

Bachelor of Planning

By

Prathmesh Deshpande

Scholar No. 2211002132

Under the Guidance of

Dr. Alka Bharat

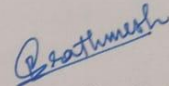


**Department of Architecture and Planning
Maulana Azad National Institute of Technology, Bhopal**

May, 2026

DECLARATION

I **PRATHMESH DESHPANDE**, Scholar No **2211002132** hereby declare that the thesis titled "Ecosystem Service Based Urban Forest Planning: A spatial suitability assessment for Narmadapuram, M.P." submitted by me in partial fulfilment for the award of degree of Bachelor of Planning, at Maulana Azad National Institute of Technology, Bhopal, India, is a record of Bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.



Signature of the Student

Date: 8/05/26

CERTIFICATE

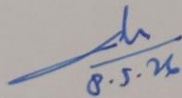
This is to certify that the declaration made by **PRATHMESH DESHPANDE** is true to the best of my knowledge and that the student has worked under my guidance for one semester in preparing this thesis.

RECOMMENDED


08/05/26

Signature of the Guide
(Dr. Alka Bharat)

ACCEPTED

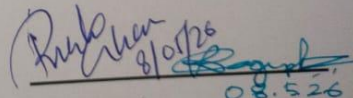

8.5.26

Signature of

Head, Department of
Architecture and Planning
(Dr. Nakul Dhagat)

Date: _____

Place: _____


8/05/26
08.5.26

Signature of

Thesis Coordinators,
Department of Architecture and
Planning
(Dr. Preeti Onkar &
Dr. Premjeet Das Gupta)

Date: 8/05/26

Place: Bhopal

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Acknowledgement

I express my sincere gratitude to my thesis guide, Dr. Alka Bharat, for her invaluable guidance, constant encouragement, and scholarly insights throughout the course of this research. Her constructive suggestions and critical feedback have significantly contributed to the development and completion of this study.

I extend my appreciation to the faculty members of the department for their academic support and for fostering a conducive learning environment. Their guidance at various stages has been instrumental in refining the work.

I also acknowledge the support extended by concerned government agencies and institutions for providing relevant data and information essential for the study.

I am deeply indebted to my family for their unwavering support, encouragement, and understanding, which enabled me to successfully complete this thesis.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Abstract

River-based towns in India are increasingly facing ecological and hydrological stress due to urban expansion, land degradation, and disruption of natural riverine systems. Narmadapuram reflects these challenges through degraded riparian zones, reduced vegetation cover, and weakening hydrological processes. This study explores urban forestry as a planning-led, nature-based solution to restore ecological balance and enhance ecosystem services at the city scale.

A GIS-based multi-criteria approach is adopted to identify suitable locations for intervention through systematic stages of exclusion, suitability assessment, and feasibility evaluation. Parameters related to land use, vegetation, soil, hydrology, and accessibility are analysed to determine areas where green infrastructure can be effectively integrated. The study emphasises interventions such as urban forest patches, green corridors, riparian buffers, and conservatory landscapes to improve infiltration, stabilise soil, and restore ecological continuity.

The proposed framework demonstrates how integrating urban forestry with land-use planning and watershed systems can enhance environmental performance, support public well-being, and strengthen urban resilience. The approach provides a scalable and implementable model for sustainable development in river-influenced urban context.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

सार

भारत के नदी-आधारित नगर तीव्र नगरीय विस्तार, भूमि क्षरण तथा प्राकृतिक नदी तंत्रों के विघटन के कारण बढ़ते हुए पारिस्थितिक और जलवैज्ञानिक दबावों का सामना कर रहे हैं। नर्मदापुरम इन चुनौतियों को प्रदर्शित करता है, जहाँ तटीय क्षेत्रों का क्षरण, वनस्पति आवरण में कमी तथा जलवैज्ञानिक प्रक्रियाओं का कमजोर होना स्पष्ट रूप से देखा जा सकता है। प्रस्तुत अध्ययन शहरी वानिकी को एक नियोजन-आधारित, प्रकृति-आधारित समाधान के रूप में प्रस्तुत करता है, जिसका उद्देश्य नगर स्तर पर पारिस्थितिक संतुलन को पुनर्स्थापित करना तथा पारिस्थितिकी तंत्र सेवाओं को सुदृढ़ करना है।

इस अध्ययन में हस्तक्षेप हेतु उपयुक्त स्थलों की पहचान के लिए जीआईएस-आधारित बहु-मापदंडीय दृष्टिकोण अपनाया गया है, जिसमें बहिष्करण, उपयुक्तता मूल्यांकन तथा व्यवहार्यता परीक्षण जैसे चरण सम्मिलित हैं। भूमि उपयोग, वनस्पति, मृदा, जलविज्ञान तथा अभिगम्यता से संबंधित मापदंडों का विश्लेषण कर उन क्षेत्रों की पहचान की गई है जहाँ हरित अवसंरचना को प्रभावी रूप से एकीकृत किया जा सकता है। अध्ययन में शहरी वन पैच, हरित गलियारे, नदी तटीय बफर तथा संरक्षित हरित परिदृश्य जैसे हस्तक्षेपों पर विशेष बल दिया गया है, जो जल अवशोषण को बढ़ाने, मृदा को स्थिर करने तथा पारिस्थितिक निरंतरता को पुनर्स्थापित करने में सहायक हैं।

प्रस्तावित ढाँचा यह दर्शाता है कि शहरी वानिकी को भूमि उपयोग नियोजन तथा जलग्रहण प्रबंधन के साथ एकीकृत कर पर्यावरणीय प्रदर्शन को बेहतर बनाया जा सकता है, जन स्वास्थ्य को सुदृढ़ किया जा सकता है तथा शहरी लचीलापन बढ़ाया जा सकता है। यह दृष्टिकोण नदी-प्रभावित नगरों के लिए सतत विकास का एक स्केलेबल और कार्यान्वयन योग्य मॉडल प्रस्तुत करता है।

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

This page has been left intentionally

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Table of Contents

Acknowledgement.....	i
Abstract	ii
सार.....	iii
List of Abbreviations	xi
Keywords	xi
CHAPTER – 01.....	1
INTRODUCTION.....	1
1.1 Overview	1
1.2 Background Study	1
1.3 Aim.....	2
1.4 Objective	2
1.5 Planning Problem	3
1.6 Study Area.....	5
1.7 Data Requirements	6
1.8 Methods of Data Collection	7
1.9 Methodology	9
1.10. Scope & Limitations.....	11
1.11 Hypothesis	11
CHAPTER – 02.....	13
LITERATURE REVIEW	13
2.1 Ecohydrological Stress in Urban Areas and Relationship with Vegetation Systems.....	13
2.2 Role of GIS and Remote Sensing in Identifying Urban Forest Patches.....	16
2.3 Vegetation Indices (NDVI, NDWI) and Their Relevance to Urban Forestry.....	18
2.4 Planning Approaches for Urban Forestry	18
2.4.1 Scoping Review;.....	18
2.4.2 Methods and Metrics of Urban Forest Effects.....	19
2.4.3 International Framework & Cases;.....	20

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

2.4.4 National Framework & Cases;	26
2.4.5 The Miyawaki Technique;	34
2.5 Policy and Planning Framework Supporting Urban Forestry	35
Nagar Van Udyan Program.....	35
CHAPTER – 03.....	36
BASE MAP PREPARATION & SITE DATA COLLECTION	36
3.1. Base Map Preparation	36
3.1.1 Municipal Ward Map.....	36
3.1.2 Built – Unbuilt Map	36
3.1.3 Connectivity	37
3.1.4 Slope.....	37
3.1.5 Watershed Delineation.....	38
3.2 Data Collection & Type.....	38
Spatial.....	40
CHAPTER – 04.....	43
DATA ANALYSIS (TECHNICAL & SPATIAL).....	43
4.1. Parameter Extraction Table (for Suitability Analysis Justification)	43
4.2. Parameter identification from cases	46
4.3.1 Land Use Land Cover Map (LULC)	48
4.3.2 Vegetation Layer.....	50
4.3.3 Groundwater Presence.....	50
4.3.4 Road Network Layer, Built up Layer & Watershed & River Layer	51
4.3.5 Soil Texture Layer	52
4.3.6 Slope Layer.....	52
4.4. Correlation between Parameters using Matrices	53
4.4.1 Correlation Check before Suitability Analysis	53
4.4.2. Basis of Correlation Scoring	56
4.5. Matrix based Weighting Method	57

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

4.6. Suitability Evaluation Model.....	61
4.6.1 Reclassification of Parameters for Suitability Analysis	61
4.6.2 Evaluation Criteria	62
4.7. Indicator Description.....	63
4.8. Layers Reclassified & Weighted Overlay	65
4.9 Proposal Outline.....	67
CHAPTER – 05.....	69
PLANNING PROPOSAL	69
Proposal I _ Identification of Suitable Patches based on Size Hierarchy.....	71
Proposal II _ Development of Greenways along Major Roads	74
Proposal III _ Development of Riparian Buffer along River Edge	78
Proposal IV _ Conservatory Landscaping and Eco-Tourism Development.....	82
CHAPTER 06.....	85
CONCLUSION	85
Bibliography.....	87

Table of Maps

Refer to Map No. 1 Study Area Base Map, Location Map & Administrative Limits.....	6
Refer to Map No. 2 Built - Unbuilt Map, Connectivity Map, Slope Map and Watershed Delineation.....	37
Refer to Map No. 3 Land use Land Cover Layer, Vegetation Layer and Groundwater Presence Layer	49
Refer to Map No. 4 Road Network Layer, Built up Layer, Catchment and River layer (drainage) and Soil Texture Layer.....	51
Refer to Map No. 5 Drainage Buffer Layer, Road Buffer Layer & Reclassified Layers.....	65
Refer to Map No. 6 Overlay I, Overlay II & Suitability Map (Overlay)	65
Refer to Map No. 7 (I) Most Suitable Patches, (II) Category based classification of Patches & (III) Selectively proposed sites for intervention.....	72
Refer to Map No. 8 Proposal – 2 Development of Greenways along Major Roads, Proposal – 3 Development of Riparian Buffer along River Edge & Proposal – 4 Conservatory Landscaping and Eco-Tourism Development	74

Table of Figures

Figure 1.1 Past events	3
Figure 1.2 Conceptual Urban Forestry led growth model.....	5
Figure 1.3 Flow Chart of Methodology	10
Figure 2.1 The ecosystem services of urban forests (Escobedo, et al.....	15
Figure 2.2 Sample Quadrant, Kyoto	21
Figure 2.3 Methodology of Syracuse Case	22
Figure 2.4 Methodological framework of Johor, Malaysia.....	24
Figure 2.5 Methodology for analysis of Ranchi, Jharkhand	27
Figure 2.7 (b)Erased layers; (a)cropland agri., (b)forest area, (c)built-up land and (d)waterbodies	28
Figure 2.7 (a)Map of various GIS Based Datasets; (a)LULC, (b)Soil Organic carbon, (c)LST, (d)AA Rainfall, (e)NDVI and (f)DTM (Patiala, Punjab Case)	28
Figure 2.8 Working Framework outlining major	29
Figure 2.9 Zone wise distribution of public.....	30
Figure 2.10 Success Story.....	34
Figure 5.1 Procedure for identification of patches.....	71
Figure 5.2 Layers of trees	72
Figure 5.4 Benefits of trees on greenways.....	76
Figure 5.5 3-30-300 rule	77
Figure 5.6 Buffer sections.....	78
Figure 5.7 Buffer in Three zone.....	79
Figure 5.8 Species of trees	80
Figure 5.9 Infiltration potential.....	80
Figure 5.10 Rejuvenating Pond.....	81
Figure 5.11 Functional Zoning.....	83
Figure 5.12 Trail	84

List of Tables

Table 2.1 Step wise Constanza approach	33
Table 3.1 Spatial Data Extraction	40
Table 4.1 International Cases	44
Table 4.2 Indian Cases	45
Table 4.3 Common parameters identified	46
Table 4.4 Objective parameter linkage.....	48
Table 4.5 LULC Area Distribution	49
Table 4.6 Finalised parameters for analysis	54
Table 4.7 Strength of Relationship between parameters	54
Table 4.8 Parameter Relationship Matrix.....	54
Table 4.9 Matrix 1: Objective and Parameter	57
Table 4.10 Matrix 2: Case Frequency Matrix	58
Table 4.11 Matrix 3: Final Weight	60
Table 4.12 Reclassification of Parameters	62
Table 4.13 Indicator Description.....	64
<i>Table 4.14 Suitability Ranges.....</i>	<i>66</i>
Table 4.15 Proposal Outline.....	68
Table 4.16 Proposal Requiremen	68
Table 5.1 Patch Classification.....	72
Table 5.2 Cost and Carbon Estimation.....	72
Table 5.3 Plantation Strategy	75
Table 5.4 Species Selection.....	75
Table 5.5 Carbon Sequestration Potential	76
Table 5.6 Functional Zonation of Riparian Buffer.....	79
Table 5.7 Conservatory Area Functional Zoning	83
Table 5.8 Plantation Strategy for conservatory area	83
Table 5.9 Water based interventions	84

List of Abbreviations

1. CO₂ – Carbon Dioxide
2. DP – Development Plan
3. GIS – Geographic Information System
4. GSI – Geological Survey of India
5. IRC – Indian Roads Congress
6. LULC – Land Use Land Cover
7. MCDM – Multi-Criteria Decision Making
8. MoRTH – Ministry of Road Transport and Highways
9. TDR – Transferable Development Rights
10. UHI – Urban Heat Island

Keywords

Ecosystem Services, Forest Hydrology, GIS, Land suitability, Patch Identification, Rotation of Plants, Social Forest, Urban Forest.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

CHAPTER – 01

INTRODUCTION

1.1 Overview

This study explores ecological and hydrological regeneration in Narmadapuram through urban forestry and vegetation-based planning, with a focus on classifying land suitable for development and non-development and identifying areas where ecological functions must be prioritised. Located along the River Narmada, the town’s ecological condition is closely linked to its riparian zones, hydrological processes, and existing vegetation systems. The study assesses the eco-hydrological potential of land by examining how green buffers, riverbank vegetation, and native flora can stabilise soil, enhance infiltration, and support watershed functions. It further evaluates urban forestry interventions through a cost–benefit and opportunity cost perspective, linking ecological restoration with human capital, public well-being, and sustainable urbanisation. By integrating spatial analysis, land-use planning, and a priority-based suitability matrix, the study demonstrates how urban forestry can function as ecological infrastructure, enabling informed selection and prioritisation of urban forest patches to support long-term ecosystem services and resilient planning responses for river-influenced towns.

1.2 Background Study

River-based towns in India are increasingly experiencing ecological and hydrological stress due to rapid urbanisation, land degradation, and unsustainable resource extraction. In cities like Narmadapuram, the close interaction between urban development and the River Narmada has resulted in degradation of riparian ecosystems, loss of vegetation cover, and weakening of natural recharge processes. Ecological and hydrological regeneration has therefore emerged as a critical planning concern, requiring approaches that work with natural systems rather than replacing them. Urban forestry and vegetation-based planning offer a viable nature-based solution by enhancing soil stability, restoring ecological functions, and improving urban microclimate. When integrated with land-use planning and watershed considerations, such approaches can strengthen ecosystem services and

urban resilience at the city scale. This study is situated within this context, exploring how planning-led urban forestry can support long-term ecological and hydrological recovery in Narmadapuram.

1.3 Aim

Achieving ecological and hydrological regeneration of a city through urban forestry as a planning tool and its delivering ecosystem services.

1.4 Objective

I. To Identify & Classify Suitable land for Development and Non-Development

The objective is to study urban forests and examine whether they are merely treated as generic green spaces destined for urban development, as often seen under rapid urbanisation pressures, or whether they are given appropriate value in regard to the ecosystem services concept, where urban forests function as ecological infrastructure supporting sustainable urbanisation, environmental regulation, and long-term urban resilience.

II. To find Economic Value of Patches using Cost–Benefit Analysis

This objective aims to determine the economic relevance of potential urban forest patches by assessing the value of ecosystem services they can provide in comparison to alternative land uses. It examines how undeveloped or underutilised land can generate long-term socio-economic and environmental benefits when treated as urban forest rather than being converted for development. The analysis considers opportunity cost, avoided environmental damage, and enhancement of public well-being to justify patch prioritisation within the urban planning framework.

III. To assess Hydrological and Ecological Potential of Identified Patches

This objective evaluates the hydrological characteristics of identified patches by analysing their capacity for infiltration, runoff moderation, groundwater recharge, and soil stability. It assesses how vegetation-based interventions can improve surface–subsurface water interactions and strengthen local water

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

balance conditions. The assessment helps in identifying ecologically responsive locations where urban forestry can support environmental stability and long-term sustainability within Narmadapuram.

IV. Creating hierarchy of identified urban forest patches using priority matrix tool

Initially, to identify suitable planning-based vegetation interventions by tapping and identifying spatial patches for ecological and hydrological regeneration, ensuring that such interventions align with sustainable urbanisation objectives, facilitate green network continuity, and support adaptive planning through ongoing spatial assessment and monitoring.

1.5 Planning Problem

Hoshangabad (now Narmadapuram) is located in the central Narmada Valley, along the southern bank of the River Narmada, and forms a transition zone between the Satpura Plateau and riverine plains. This unique geographical setting makes the city ecologically sensitive and hydrologically significant.

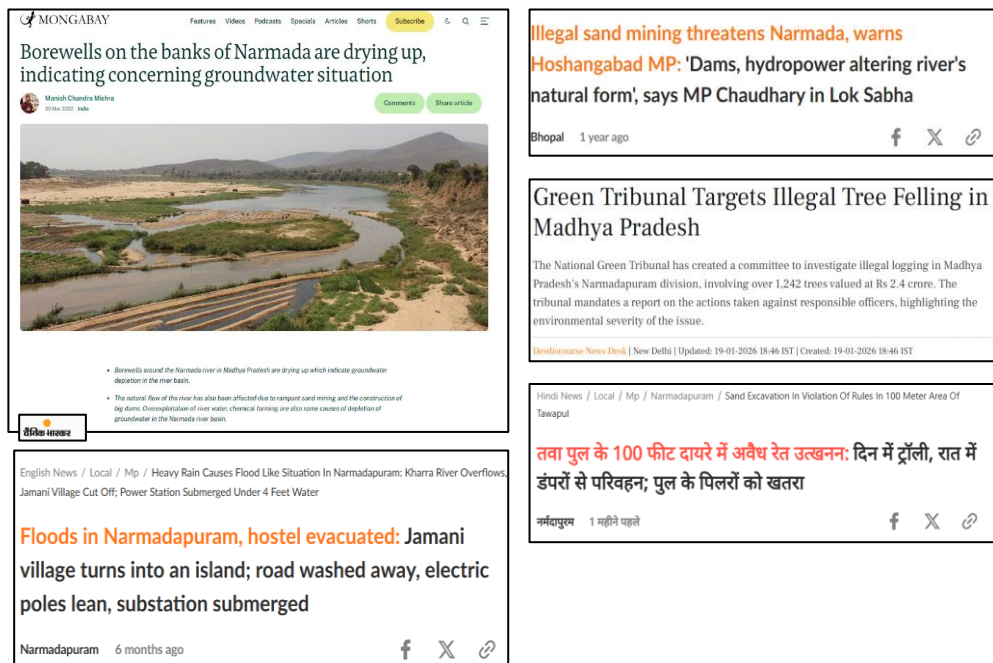


Figure 2.1 Past events

According to the District Environmental Plan, the key challenges arising are mining activity management, particularly sand and soil extraction, water quality

and water resource management, environmental stress on river systems and associated land.

Despite having 36.14% forest cover at the district level, ecological degradation persists along urban and river-adjacent areas, indicating a disconnect between regional forest cover and city-scale ecological health.

The digital newspaper clippings representing issues are also tangibly or intangibly impacting the environmental, social and hydrological aspects and to address them this study is necessary where forests as an ecosystem service within the urban fabric shall act as an hinderance for the illegal activities like sand mining and deforestation leading to soil erosion (causing loosening of soil and flood) where the area shall then be booked under government protection such as NGT and lie under Forest Act. ‘Forestry’ when purposefully revoked into urban areas; will reduce erosion, replenish soil, recharge water table and also improve community wellbeing as a social asset for recreation.

1.5.1 Ecological and Hydrological Regeneration

Ecological regeneration, in its simplest sense, refers to the process of assisting natural systems to heal, recover, and re-establish ecological balance after degradation caused by human activities or natural stressors. It involves restoring soil health, vegetation cover, biodiversity, and ecosystem functions rather than replacing them with artificial systems. In the context of Narmadapuram (Hoshangabad), ecological degradation is closely linked to;

- 1. Disturbance of riverine and riparian ecosystems along the River Narmada*
- 2. Loss of vegetative cover along riverbanks and urban fringes*
- 3. Land degradation associated with mining, erosion, and urban expansion*

Hydrological regeneration refers to the restoration of natural water processes such as infiltration, groundwater recharge, surface–subsurface interaction, and sediment balance within a watershed. In river-based towns like Hoshangabad, hydrological health is inseparable from ecological health, as vegetation, soil, and water systems function as an integrated unit.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

This study positions urban forestry and vegetation-based planning as a strategic planning tool to support both ecological and hydrological regeneration by:

1. Stabilising soil and riverbanks
2. Enhancing infiltration and recharge
3. Restoring riparian ecosystems
4. Delivering ecosystem services at the city scale

This framing aligns with the District Environmental Plan, Hoshangabad, which recognises mining activities, water quality management, and environmental degradation as key concerns requiring district-level planning responses.

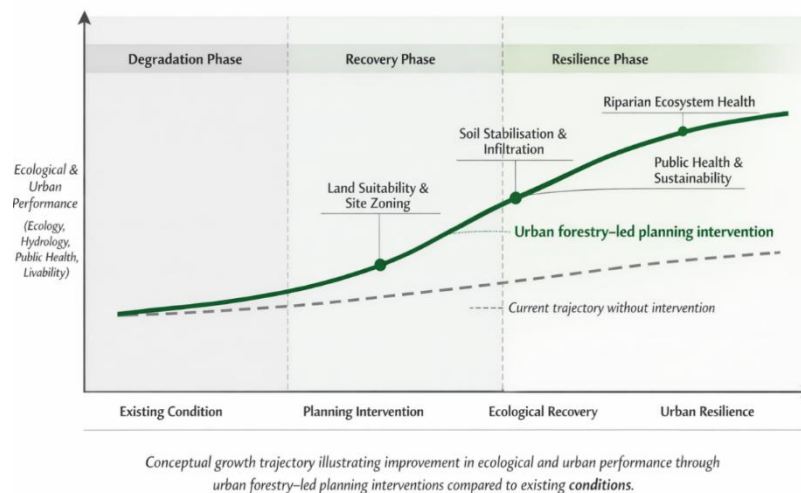


Figure 2.2 Conceptual Urban Forestry led growth model

Planning intervention shall act as a beta stage as shown in above figure for existing condition (which lacked functions of urban forestry with loss and non-interdisciplinary relation with landuse planning) as well as ecological recovery stage where incorporation and introduction of greenness intervention using models, analysis, indicators and techniques shall replenish and recover the losses and gain some benefit in the scope of this study.

1.6 Study Area

Main reason to choose Narmadapuram Town as a study area; Firstly, the city lies entirely within the Narmada River basin. Secondly, the River Narmada forms the

northern boundary of the district and directly influences the town’s ecology and water systems and thirdly the city is characterised by ghats, riverfront activities, and urban expansion along the river edge; where arises the environmental concern due to the prevailing activities eventually making ecological conservation at a standby.

Refer to Map No. 1 Study Area Base Map, Location Map & Administrative Limits

| *The Development Plan 2035 identifies land-use change, infrastructure growth, and environmental considerations as key planning concerns for the town.*

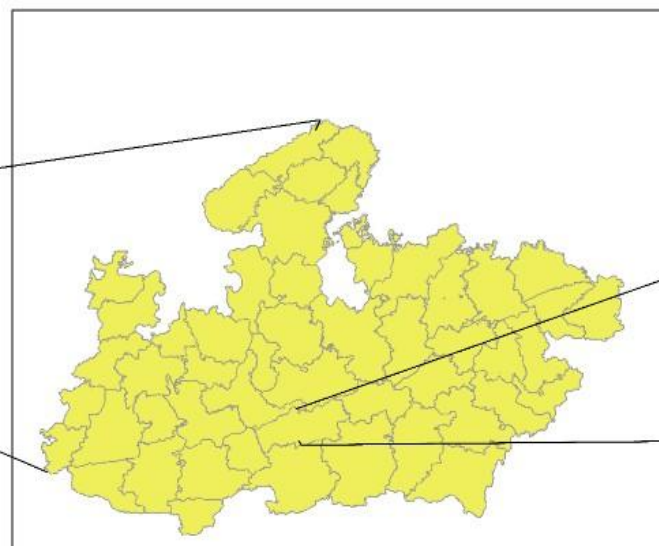
This makes Narmadapuram an appropriate case to study ecological and hydrological regeneration through planning interventions, rather than isolated environmental projects.

1.7 Data Requirements

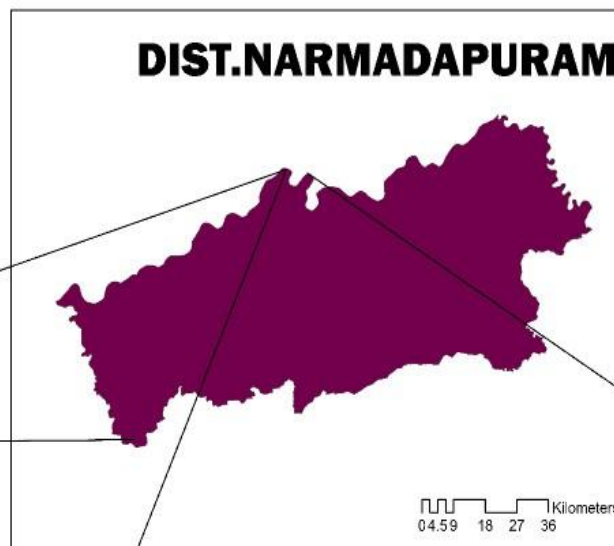
1. Base maps: Administrative boundary (Planning Area Boundary & Municipal Area Boundary), Roads, Water bodies and other features - Development Plan 2035, Hoshangabad (now Narmadapuram)
2. Using ArcGIS 10.8 Version – Topographical Features (Slope, Elevation, Contour); Land use–land cover analysis (using Satellite imagery)
3. Hydrological Interpretation using ArcGIS 10.8 Version - Drainage, River buffer and riparian zone mapping, Proximity Mapping, Recharge zones
4. District Environmental Plan, Hoshangabad – Mapping Forest cover within urban area with peri urban forest on fringes and other green spaces
5. Patch Analysis – Classification of Patch Size (Analysis of Landscape Attributes); GIS
6. Secondary environmental and planning data from district and town-level sources
7. Census of India (Population distribution)
8. Remote Sensing and Spatial Data - Satellite images; DEM / contours; Land cover interpretation using NRSC / Bhuvan, Survey of India (SOI), Open satellite imagery (Landsat / Sentinel)



INDIA



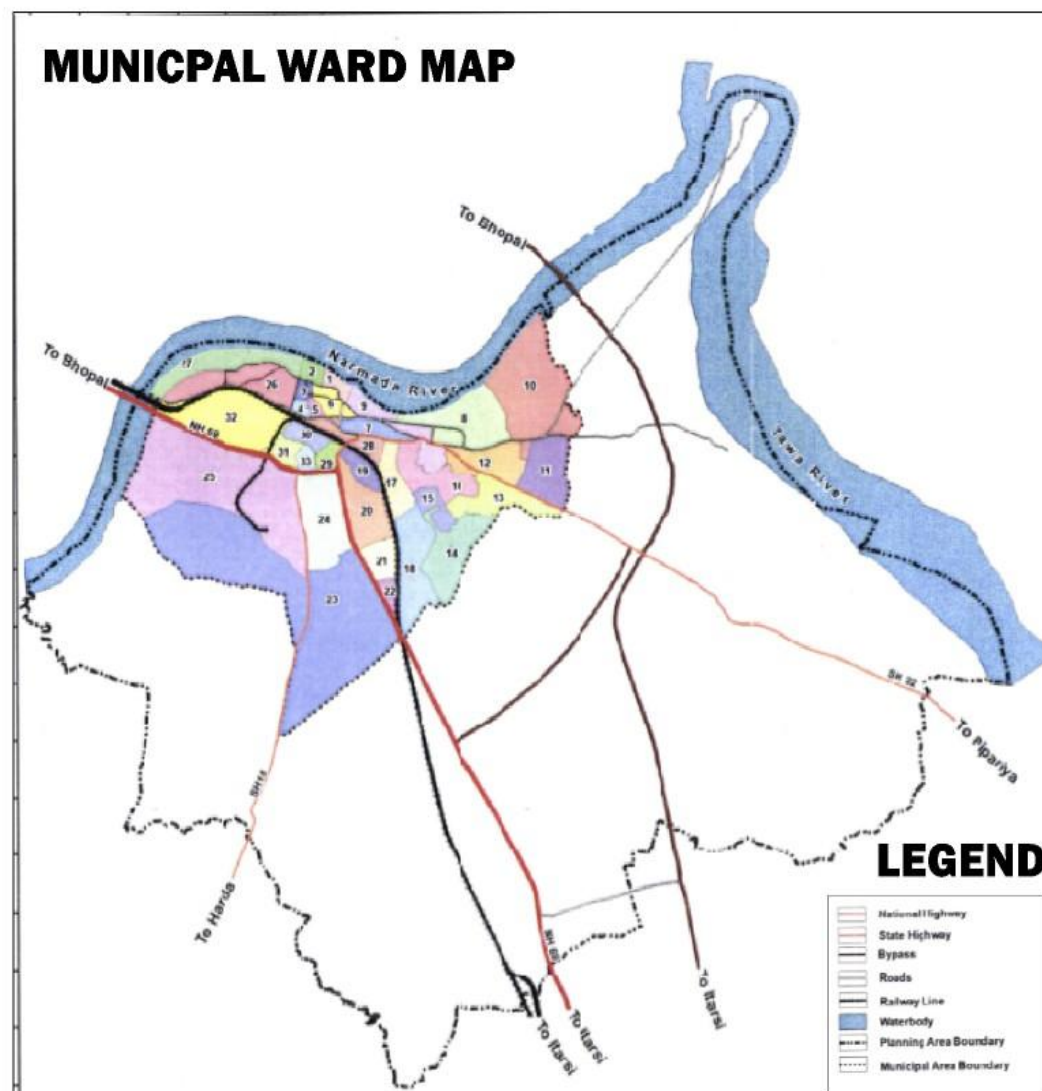
DIST. NARMADAPURAM



NARMADAPURAM TOWN

**AREA
2427 Ha**

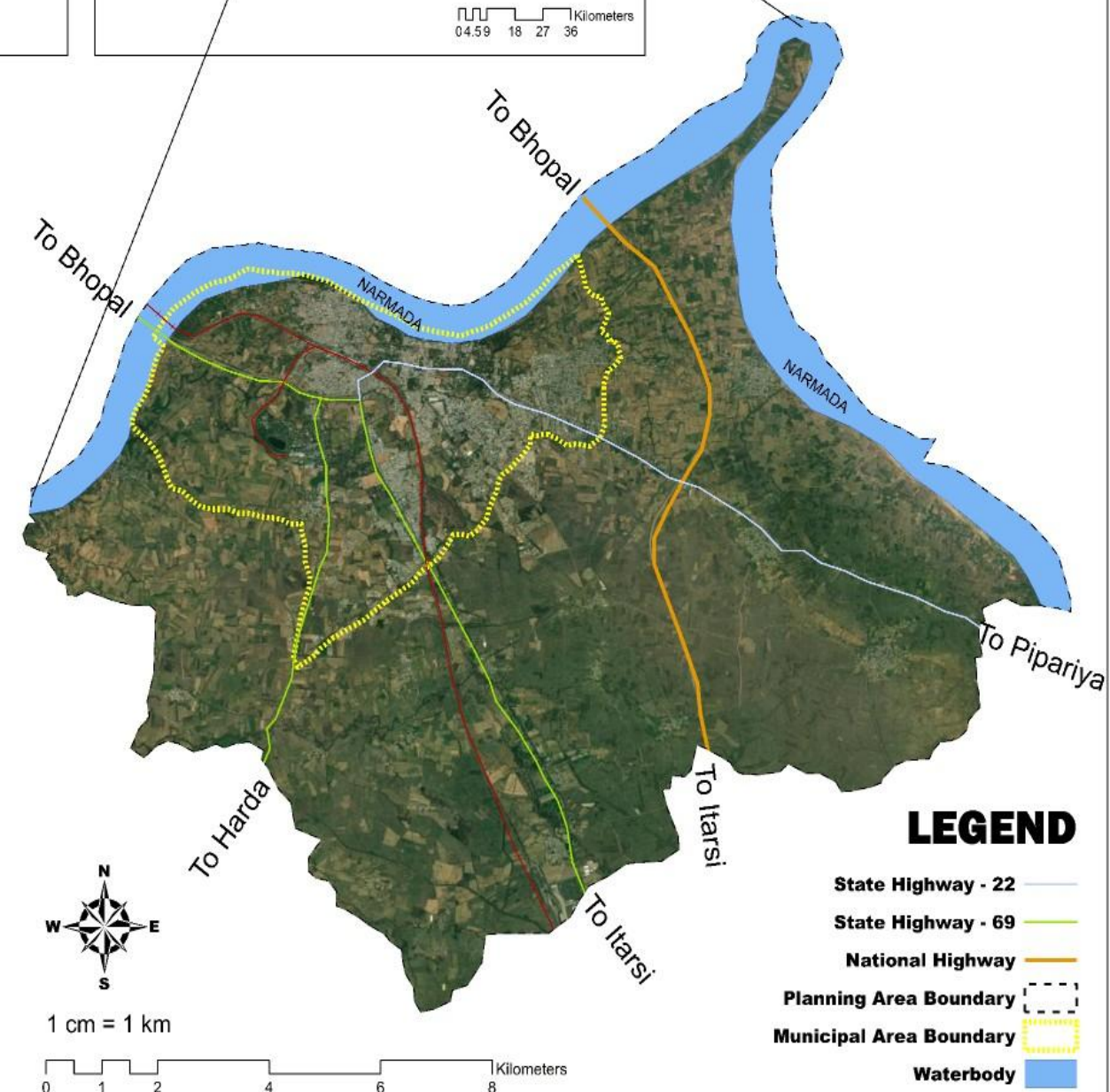
0 4.59 18 27 36 Kilometers



MUNICIPAL WARD MAP

LEGEND

- National Highway
- State Highway
- Bypass
- Roads
- Railway Line
- Waterbody
- Planning Area Boundary
- Municipal Area Boundary



LEGEND

- State Highway - 22
- State Highway - 69
- National Highway
- Planning Area Boundary
- Municipal Area Boundary
- Waterbody
- Railway Line



1 cm = 1 km

0 1 2 4 6 8 Kilometers

“ECOSYSTEM
SERVICE-BASED
URBAN FOREST
PLANNING: A SPATIAL
SUITABILITY
ASSESSMENT FOR
NARMADAPURAM,
M.P.”

**Ward wise
distribution
within Municipal
Limit Area**



Scale *for municipal
ward map

Source
Directorate of Town & Country
Planning, Madhya Pradesh,
Bhopal & Author (2026)

Notes
Municipal area is expected
to grow in future and provide
benefit so, planning
boundary is also considered.



Manit, Bhopal

**MAP NO.
1**

1.8 Data

1. Remote Sensing Data Acquisition

Remote sensing provides spatial information essential for understanding existing vegetation systems, urban green cover, and land-use patterns at the city scale. In this study, satellite imagery is primarily used to identify vegetation cover, degraded lands, riparian zones, and open spaces that can support urban forestry-based ecological and hydrological regeneration. (*mentioned in chapter 3 – part 3.2*)

Land use information derived from satellite data supports planning decisions by indicating where vegetation systems can be strengthened or restored, particularly along the River Narmada and urban–peri-urban transition zones of Narmadapuram.

2. Preprocessing of Satellite Imagery (ArcGIS)

Satellite imagery is pre-processed in ArcGIS to ensure spatial accuracy and compatibility with planning and environmental layers relevant to urban forestry planning.

Preprocessing includes:

- a. Layer stacking of relevant bands to enhance vegetation and surface features
- b. Projection correction for integration with city planning maps
- c. Clipping imagery to the municipal boundary and river influence zones
- d. Basic enhancement to improve visibility of vegetation, open land, and water features

These steps ensure that the spatial data can reliably support vegetation-based planning analysis and urban forestry intervention mapping. Satellite imagery obtained from USGS Earth Explorer. Landsat imagery from Landsat Collection 2 Level-2, Landsat 8–9 OLI/TIRS C2 L2 dataset downloaded with cloud cover less than 10% for the year 2026 to ensure clear surface visibility.

3. Band Selection and Index Calculation

Spectral band combinations and indices are used to identify vegetation condition, water presence, and built-up areas, which together influence ecological and hydrological functioning.

Vegetation Index (NDVI)

NDVI is used to assess vegetation density and health, forming the primary input for identifying existing urban forest cover and potential regeneration zones.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Higher NDVI values indicate healthier vegetation suitable for conservation or enhancement through urban forestry strategies.

Water Index (NDWI)

NDWI supports the identification of surface water and moisture-rich areas, which are critical for planning riparian vegetation systems and hydrological regeneration.

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

Built-up Index (NDBI)

NDBI assists in identifying built-up and impervious surfaces, helping planners understand urban pressure zones where vegetation interventions can improve microclimate and ecosystem services.

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$$

These indices are calculated using raster analysis tools in ArcGIS to support urban forestry-led spatial decision-making.

4. Land Use–Land Cover (LULC) Classification in ArcGIS

Land use–land cover classification is carried out to map the spatial relationship between built-up areas, vegetation systems, water bodies, and degraded land. A supervised classification approach is adopted, where training samples are selected to represent:

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

- a. Urban built-up areas
- b. Tree and grass-based vegetation
- c. Agricultural land
- d. Water bodies
- e. Open or degraded land i.e. undevelopable land

The resulting LULC map serves as a base layer for identifying priority zones for urban forestry, riparian buffers, and ecological restoration, rather than as a standalone land-use exercise.

5. Temporal Comparison and Validation

Temporal comparison of land use and vegetation maps is used to understand changes in urban green cover and ecological condition over time. The change analysis focuses on:

- a. Reduction or improvement in vegetation cover
- b. Expansion of built-up areas into open or riparian land
- c. Changes affecting hydrological and ecological performance

Overlay and comparison tools in ArcGIS are used to evaluate these trends and support urban forestry planning responses.

Validation is carried out through:

- *Visual interpretation of high-resolution imagery*
- *Reference to existing planning and land-use documents*

This ensures that the outputs are reliable for planning-level urban forestry and ecosystem regeneration analysis.

1.9 Methodology

The methodology follows a GIS-based multi-criteria suitability approach for identifying priority urban forest areas. The study begins with literature review and study area analysis, followed by data collection from development plans, satellite imagery, and municipal sources.

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

Based on literature and case studies, key parameters were selected and evaluated through an objective–parameter matrix and case frequency analysis to derive relative importance. Thematic layers were prepared and reclassified into suitability classes, followed by weighted overlay analysis to generate a composite suitability map.

The output was further processed to identify spatially continuous patches suitable for urban forestry. These patches were then categorized based on size hierarchy and integrated into planning proposals such as urban forest patches, greenways, riparian buffers, and conservatory landscapes.

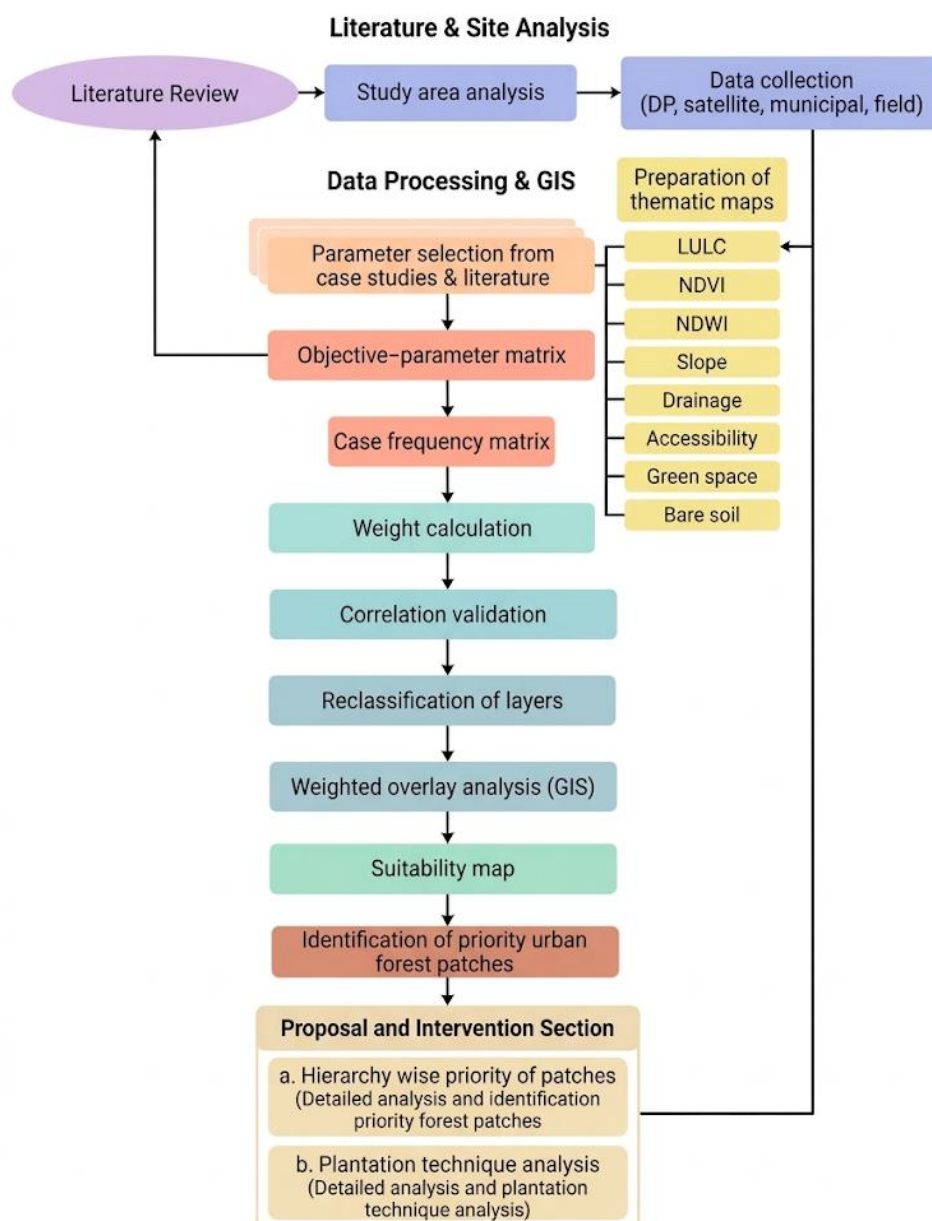


Figure 2.3 Flow Chart of Methodology

The overall approach ensures that urban forestry interventions are guided by ecological suitability, hydrological conditions, and planning feasibility.

1.10. Scope & Limitations

Scope

The study is restricted to Planning Area of Narmadapuram that consists of Peri – Urban Forest and Agricultural Hinterland which shall be a consent in consideration to this report stating for benefits at large scale. Exploring vegetation-based planning strategies for reviving urban ecosystems and strengthening watershed functions in Narmadapuram to be considered (Development Plan, 2035). The study remains within the urban planning and policy framework and involves identification of patches. This research will also function as a revival and rejuvenating approach towards planning.

Limitations

The study is undertaken at a planning and strategic level, and therefore relies primarily on secondary data sources, spatial interpretation, and policy documents to understand ecological and hydrological conditions. While satellite-based analysis provides city-scale insights, certain ecological processes and hydrological interactions are interpreted conceptually rather than measured directly on the ground. To strengthen contextual understanding, a random observational field visit to the town is undertaken to observe on-ground conditions, river-edge activities, land-use transitions, and existing green spaces, which helps in supporting and validating spatial analysis without involving detailed primary surveys which was not done due to time and human resource constraint. The assessment focuses on relative spatial patterns and trends rather than precise quantitative estimation of environmental parameters. Variations in data resolution and temporal availability of spatial datasets may influence the level of detail; it being restricted to selected timeline. Due to data limitation, quantitative estimation was not done, except some general suggestions.

1.11 Hypothesis

The study hypothesizes exhibiting ecological and hydrological stress could be better addressed through planning-led integration of urban forestry and vegetation-

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

based systems, particularly within river-influenced, environmentally sensitive, and non-developable land parcels, thus activating natural ecosystem. It is assumed that when urban forestry is applied as ecological and regulatory infrastructure—rather than as isolated plantation activity—it has the potential to support regulating, provisional and social ecosystem services such as soil stabilisation, infiltration, microclimate moderation, pollution control, hydrological functioning, pollution control and health benefits, while contributing to overall urban livability at the city scale and rejuvenating too.

CHAPTER – 02

LITERATURE REVIEW

2.1 Ecohydrological Stress in Urban Areas and Relationship with Vegetation

Systems

Rapid urbanization has led to severe depletion of forest cover in the last few decades. The depletion of forest cover has in-turn adversely affected the ecological balance and the economic stability of the society. The health of the people has been affected as well. Trees and forests play a significant role in the urban environment and have many important meanings to urban residents. Urban greenery/forestry is one of the ways to bridge this gap between people and nature. Cities across the world are realising the benefits of urban forests. Trees can moderate temperatures in heavily built cities, where heat radiated from concrete on buildings and roads, makes these areas hotter than the surrounding countryside. Urban forestry is the scrupulous care and management of urban forests, i.e. tree populations in urban settings for the purpose of improving the urban environment. The urban forests involve entire cities and their environs and are an environment of trees and related organisms, structures and people. Urban parks, gardens and natural landscapes are better known for their non-market or intangible benefits than market or tangible benefits. Gardening has been popular in India from ancient times. Parks, city forests, biodiversity parks and other green belts contribute to Urban Forestry (Urban Forest through People's Participation).

Despite the increasing awareness of the ecological, social, and economic value conferred by urban forests, several important research gaps still exist. Studies have proven that the potential capital has various patches of forests, mainly the Ridge forests, that act as ecological buffers and sites of reservoirs of biodiversity in the wake of rising anthropogenic pressures.

Urban forests encompass trees and associated vegetation in urban environments, including public parks, street trees, private gardens, and green roofs, managed to provide ecological, social, and economic benefits (Nowak, 2007). These forests consist of diverse components such as; tree species

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

1. Native — forest contain tree species that are naturally originated in the area under consideration.
2. Exotic — forest contain tree species which were introduced through human activity, deliberately or by accident; (Hemant Bherwani¹) shrubs, and understory vegetation, integrated into urban landscapes to enhance ecosystem functionality (Borelli et al., 2023).

The urban forests, in general, can be categorized into various types based on the following aspects.

(a) Cause of existence

Depending on how vegetation happened to exist in an urban area, urban forests could be classified into two types, namely

1. Natural—remnants of natural forest that existed before urbanization and reduced to patches of trees within and around an urban area.
2. Planned—green spaces that have been designed as part of urban planning which later became a full-grown urban forest.
3. Spatial planning

(b) Depending on the spatial arrangement within a city, urban forests are classified as,

1. Sub-urban forests—Forest that surround an urban area and provide goods and services such as forest products and recreation.
2. City parks—large land cover with an area greater than 0.5 ha with facilities for leisure.
3. Gardens—small green spaces with an area less than 0.5 ha with facilities for recreation.
4. Street vegetation—small tree populations on the sides of the streets, parking lots, squares, etc.
5. Other green spaces with trees—agricultural land, open fields, cemeteries, etc.
6. Species diversity

A prior study proved the capacity of mixed-species native plantations to flourish at rates competitive with alien plantings (Montagnini et al., 1998). Trees in metropolitan areas are often appraised at the city or town level by municipalities.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Many cities across the world have their own assessment and monitoring Programme for urban forestry. (Hemant Bherwani1).

Urban forests deliver critical ecosystem services, including air pollution removal, carbon sequestration, temperature regulation, stormwater interception, and biodiversity conservation (S. J. Livesley, 2009). Additionally, urban forests mitigate urban heat islands (UHI), with studies showing temperature reductions of 3.8-7.6°C in urban areas (D. Armsona, 2012). Health benefits include reduced respiratory and cardiovascular diseases due to improved air quality and stress reduction through exposure to green spaces (Richard Mitchell 1, 2008).

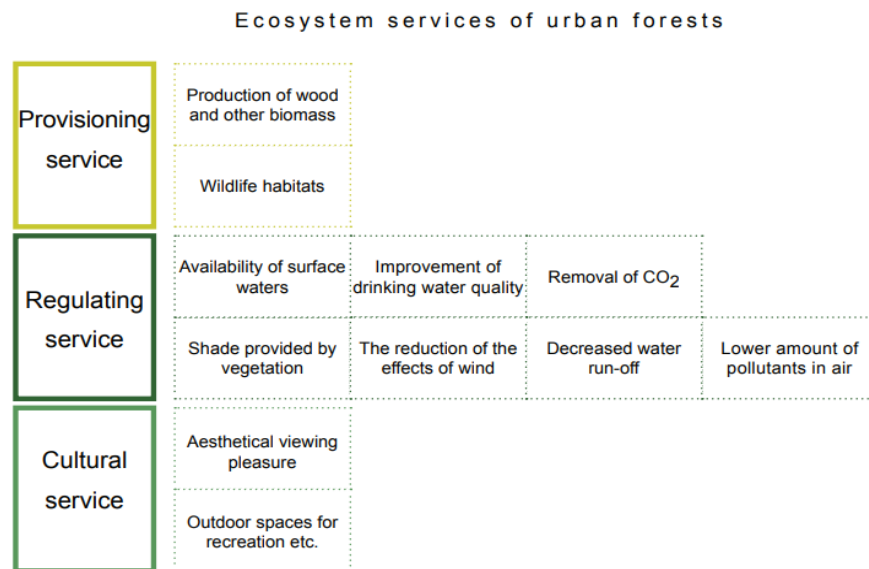


Figure 3.1 The ecosystem services of urban forests (Escobedo, et al. 2011)

Economically, urban forests lower energy costs by reducing air conditioning needs and enhance property values (Akbari et al., 2001; McPherson et al., 2011). However, challenges such as invasive species, urban encroachment, and poor maintenance can diminish these benefits (Esperon-Rodrigue et al., 2025).

Urban forests perform a range of ecosystem services, with regulating services forming a dominant component, including runoff regulation, air quality improvement, temperature moderation, and water quality enhancement. As illustrated in Figure 2, these services function continuously at the urban scale,

thereby positioning urban forests as functional urban infrastructure rather than aesthetic or recreational land uses (Escobedo et al., 2011).

The mechanisms underlying these benefits involve complex ecological processes. Dry depositions, where tree leaves capture pollutants like PM_{2.5}, CO, NO₂, SO₂, and O₃, are a primary mechanism for air quality improvement (Nowak et al., 2006; Hirabayashi et al., 2011). Carbon sequestration occurs through photosynthesis, storing carbon in woody biomass (Nowak & Crane, 2002), while evapotranspiration and shade reduce urban temperatures (Zhou et al., 2011). Stormwater interception by tree canopies minimizes runoff, reducing urban flooding risks (Xiao & McPherson, 2002). Biodiversity conservation is supported by diverse tree species, which provide habitats for wildlife, though invasive species like *Prosopis juliflora* can disrupt ecosystems (Bhalla & Bhattacharya, 2015). Socially, urban forests enhance community well-being by providing recreational spaces and fostering environmental stewardship (Tzoulas et al., 2007)

Urban Green Spaces and their Significance

Urban green space encompasses all the green areas that contribute to greenery in the city such as trees in parks, private lawns, gardens in public spaces, linear green along transport routes, or canals, etc. There are three components of urban green spaces: Patch (urban domestic gardens, public and private parks, gardens, urban forest patches, etc.), corridor (roadside avenues, walkways, and urban green ways, etc.) and network structure (layout of all the patches and corridors connecting the patches (Singh et al, 2010; Sinha, 2013). The Urban Green Space has been defined as public and private open spaces in urban areas, primarily covered by vegetation, which is directly (e.g., active or passive recreation) or indirectly (e.g., positive influence on the urban environment) available for the users. (SINGH, 2019)

2.2 Role of GIS and Remote Sensing in Identifying Urban Forest Patches

Remote sensing methods are valuable in mapping small urban forests. Their small size and the species heterogeneity in these forests, however make it difficult to apply traditional aerial and space borne remote sensing data and analysis methods.

High resolution imagery from drones can be used for the characterization of small urban forests.

Traditional field-based inventories, though detailed at local scales, are often spatially limited, time-consuming, and constrained by sampling boundaries, making them less effective for assessing fragmented vegetation patterns typical of urban environments; therefore, remote sensing and GIS techniques have become essential tools for generating spatially continuous and repeatable observations of urban forest structure and distribution. Satellite imagery, aerial photographs, LiDAR datasets, and hyperspectral data enable quantification of canopy cover, canopy height, vegetation density, and biomass, thereby supporting comprehensive inventories of urban forest resources at city and regional scales. (Dash)

The integration of remote sensing-derived vegetation maps with environmental and planning layers—such as land use, soil characteristics, slope, drainage networks, and urban infrastructure—allows planners to perform spatial overlay analysis and suitability modelling to identify priority areas for urban forest development. (Jusoff, 2004)

Case-based urban forestry planning studies indicate that GIS-supported multi-criteria analysis can evaluate environmental indicators such as land surface temperature, biodiversity potential, ecological connectivity, and environmental stress zones to determine appropriate spatial configurations of urban forest patches, including clustered, linear, and dispersed green networks across urban regions. (Gumilar Adam et al, 2017)

Recent technological developments, including open-access satellite archives and cloud-based geospatial platforms, have significantly improved the accessibility and operational efficiency of GIS-remote sensing workflows, enabling continuous monitoring of vegetation changes and facilitating planning-level decision support for urban forest patch identification, prioritisation, and long-term environmental management. (Dash)

Together, these developments establish GIS and remote sensing as foundational tools for spatially identifying, assessing, and planning urban forest patches within contemporary urban environmental planning frameworks. (Oliver Baines, 2020)

2.3 Vegetation Indices (NDVI, NDWI) and Their Relevance to Urban Forestry

In the context of urban forest planning, remote sensing–based vegetation indices are used primarily as inputs for spatial suitability assessment rather than as indicators of urban expansion. These indices help interpret ecological conditions of land parcels and support identification of areas suitable for urban forestry interventions within planning frameworks.

The Normalized Difference Vegetation Index (NDVI) is widely applied to differentiate non-vegetated land, sparse vegetation, and dense tree cover, enabling planners to recognise degraded or under-utilised areas alongside existing vegetation patches requiring protection or enhancement. Such classification assists in identifying land parcels that may be more suitable for ecological or non-development functions within urban planning. Additional spectral indices improve the understanding of canopy condition and vegetation vitality, providing supporting layers for GIS-based classification and suitability mapping. Therefore, within this study, vegetation indices serve as ecological indicators that contribute to land suitability analysis, eco-hydrological interpretation, and prioritisation of urban forest patches, supporting planning decisions at the city and local plan level. (Jigme Thinley¹, 2026)

2.4 Planning Approaches for Urban Forestry

2.4.1 Scoping Review;

Scoping reviews are useful for identifying the scope, extent, and nature of research conducted on a specific topic and uncovering gaps in knowledge. This study conducted scoping reviews selecting studies that measured the effects and impacts of urban forests, establishing its ecosystem service delivery potential through various Spatial Mapping Techniques. To ensure the comprehensiveness of the results, Web of Science (WOS) and Scopus were used as the primary databases. A topic search was employed for WOS, and a title–abstract– keyword search was utilized for SCOPUS. The search was restricted to peer-reviewed journal articles published in the last twenty-six years (2000–2026), written in English, and indexed in the WOS and Scopus databases.

The first search query was (“urban forest*”) AND (effect OR effects OR impact OR impacts) AND (assess* OR evaluation* OR measure*) This first query sought to identify articles focuses on the effects or impacts of urban forests, including ecological and social aspects.

The second search query was ((“urban forest*” OR “urban vegetation” OR “urban green space*” OR “urban tree*”) AND (effect* OR benefit* OR “ecosystem service*”) AND (landuse* OR mapping* OR patches*) AND (GIS* OR Remote Sensing*) AND (indicator* OR metric* OR criteria*)) This second query addresses (1) urban forest or green space contexts, (2) their effects or benefits to humans, (3) spatial mapping of patches suitable for priority based intervention and (4) efforts to assess or evaluate these effects through indicators or metrics. This ensures that the query captured literature that bridged the evaluation of ecosystem services or benefits and indicators of urban greenery, including urban forests or trees. Because this study focuses on the effects of urban forests or trees rather than facilities or systems, terms such as “urban park”, “green infrastructure”, and “urban greenery” were removed to narrow the search scope.

2.4.2 Methods and Metrics of Urban Forest Effects

(i) For air pollutant reduction and O₂ increase effects of urban forests; *evaluated primarily through a common method, i-Tree Eco (Urban Forest Effects Model). The key metrics includes air quality and air pollutant removal.*

(ii) For temperature reduction; *field measurements and open data, meteorological data, or remote sensing imagery are common methods. A range of tools and metrics employed - including ENVI-met, satellite image analysis (ECOSTRESS, Land Surface Temperature (LST), MODIS, Landsat, Sentinel, and normalized difference vegetation index (NDVI)), and metrics such as LST, Urban Heat Island (UHI) intensity, cooling effect, and air temperature reduction.*

(iii) For carbon sequestration;

field measurements and tools such as i-Tree Eco, i-Tree Canopy, and Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) - predominantly used to measure carbon storage and absorption

(iv) Animal diversity (Avian; birds) (e.g., evenness and richness);
assessed using field observations (Jeong, Joo, Sou, Choi, & Park, 2025)

(v) Economy and Hydrology;

Metrics, Hydro Value = infiltration, recharge, runoff control capability (based on GIS indicators: slope, soil, buffer, NDWI) & Eco Value = economic valuation (ESV from Costanza, carbon, cost saved from floods, water treatment, health benefits)

2.4.3 International Framework & Cases;

Kyoto, Japan —

Urban Forest Ecosystem Services Vary with Land Use and Species

The focus is to understand how urban ecosystem services vary across different land-use types in intra city. The study recognises that traditional urban ecosystem assessments often underestimate the contribution of dispersed green spaces and therefore seeks to develop a more precise understanding of how urban forestry functions differently depending on urban character and land-use context. To achieve this, the study applies a city-centric ecological evaluation model based on land-use heterogeneity, where Kyoto's historical mono-centric urban structure forms the basis of analysis. The methodological model adopted is the i-Tree Eco ecosystem service evaluation framework, integrating field-based vegetation inventory with ecological and economic calculations to estimate ecosystem services such as *carbon storage, carbon sequestration, air pollutant removal, and runoff reduction*. Evaluation techniques include stratified field sampling using quadrats distributed according to land-use classes, species-level tree measurements, and comparison of ecosystem service values at both quadrat and single-tree scales.

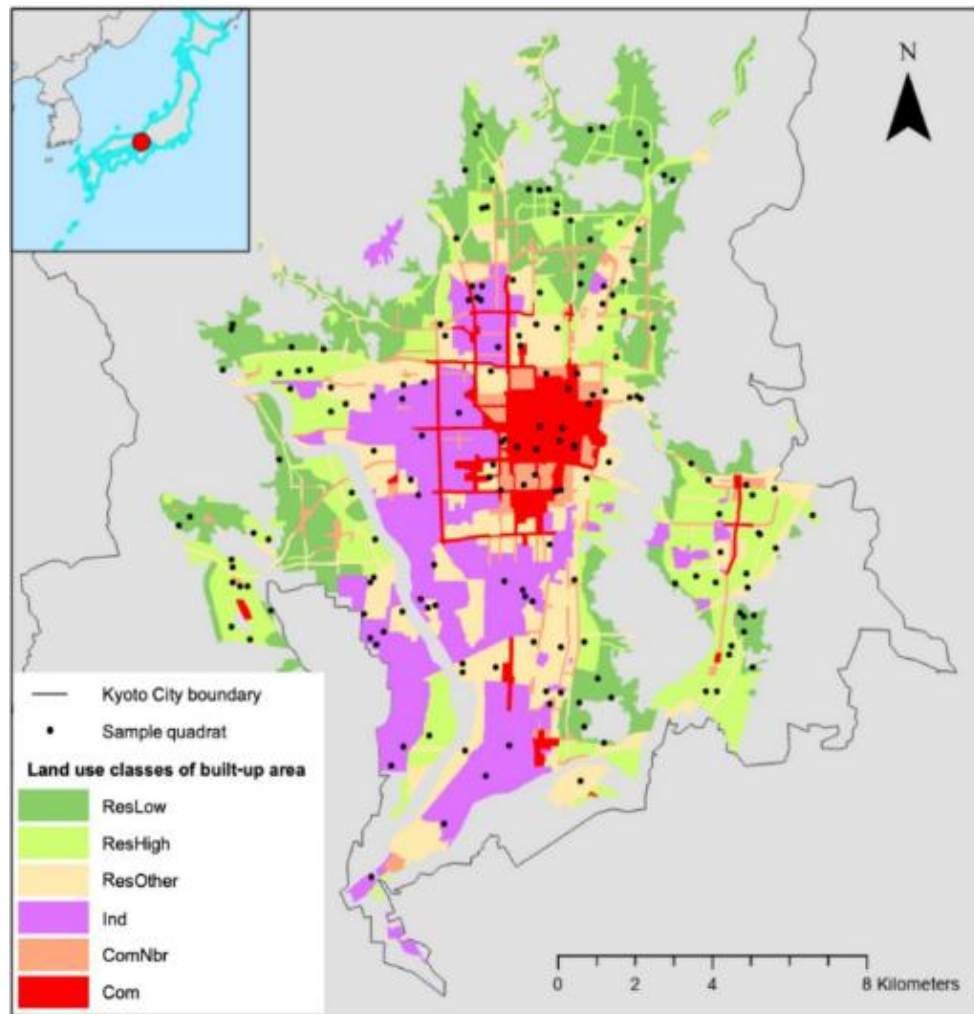


Figure 3.2 Sample Quadrant, Kyoto

The study employs statistical evaluation methods such as non-parametric rank tests to examine variations across land-use classes and species, highlighting how scale influences ecological interpretation.

Calculation three values of each tree: compensatory value, representing compensation for the loss of a tree, monetary value of carbon storage, representing the cumulative result of net carbon sequestration for years; annual ecosystem services, including carbon sequestration, air pollutants removal, and runoff reduction.

A significant contribution is incorporation of monetary ecosystem service valuation, where ecological benefits are translated into economic terms. Monetary valuation methods include social cost of carbon for carbon-related services, health-benefit valuation for pollutant removal using avoided-cost

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

approaches, and stormwater infrastructure cost equivalence for runoff reduction. Compensatory value of trees is also calculated based on replacement cost and structural characteristics, allowing comparison between annual ecosystem services and long-term ecological value. (Kang & Hirabayashi, 2022)

Source: Kang, J., Hirabayashi, S., & Shibata, S. (2022).
Urban Forest Ecosystem Services Vary with Land Use and Species: A Case Study of Kyoto City. Forests, 13(1),
67. <https://doi.org/10.3390/f13010067>

Syracuse, New York —

Urban Forest Patch Origin and Structure

The study aims to understand how different types of urban forest patches—specifically regenerated and remnant forests—differ in composition, structure, disturbance patterns, and ecological functioning within an urban landscape. The primary objective of the study being, evaluating how patch origin influences ecological structure and to demonstrate the ecological importance of both regenerated and remnant urban forest patches for urban ecosystem

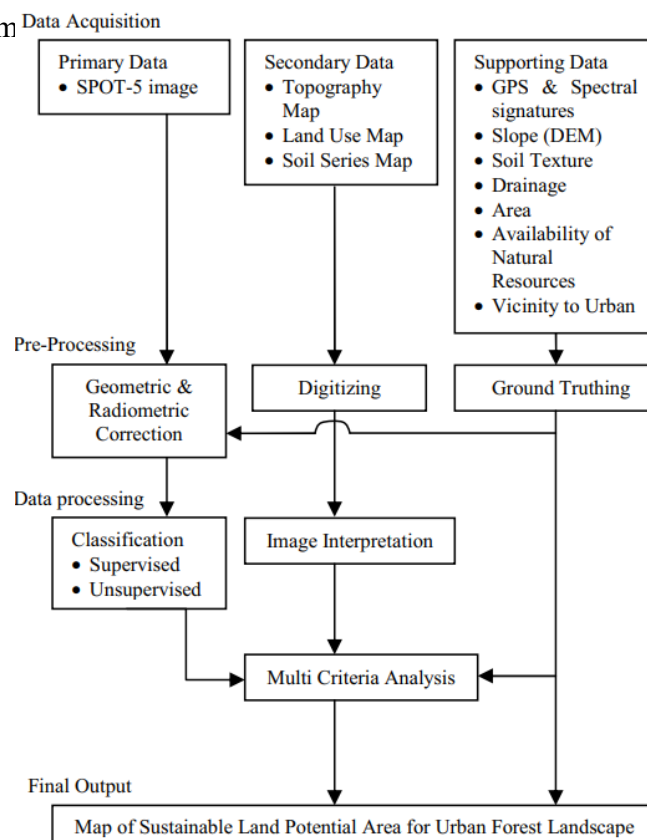


Figure 3.3 Methodology of Syracuse Case

The conceptual model is a patch-origin ecological framework, where urban forests are categorised according to land-use history into regenerated patches (sites previously cleared and later naturally regenerated) and remnant patches (forested areas never fully cleared for urban development). Evaluation techniques are primarily field-based ecological inventories combined with statistical and spatial analysis where forest patches were identified using historical aerial photographs to determine patch origin and Cluster analysis using relative Euclidean distances.

Patch origin, species composition, disturbance regime, and surrounding land-use context were jointly used to classify and evaluate patches. The study shows that regenerated patches are generally smaller, more disturbed, and associated with residential land uses, whereas remnant patches tend to occur in institutional or protected spaces. A key finding indicates that land covers containing remnant and regenerated patches, particularly vacant lots and greenspaces, exhibit the highest net rates of carbon sequestration within the city, highlighting their ecological importance within urban systems. (ZIPPERER, 2003)

Reba, M. N. M., & Zulkifli, A. (2013).

Determination of Sustainable Land Potential Based on Priority Ranking: Multi-Criteria Analysis (MCA)

Technique. 13th International Conference on Computational Science and Its Applications, Johor Bahru, Malaysia.

Johor, Malaysia —

Multi-Criteria GIS Approach for Urban Forest Site Selection

Focuses on identifying suitable areas for urban forest development through a structured decision-making framework, with the primary aim of integrating environmental suitability into urban forestry planning. The study recognises that rapid urban growth frequently leads to unplanned loss of vegetation, and therefore proposes a systematic method where spatial analysis supports planners in selecting locations where urban forests can provide maximum ecological and social benefits while minimising land-use conflict. The research establishes urban forest planning as a spatial decision-support process rather than a plantation-driven activity.

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

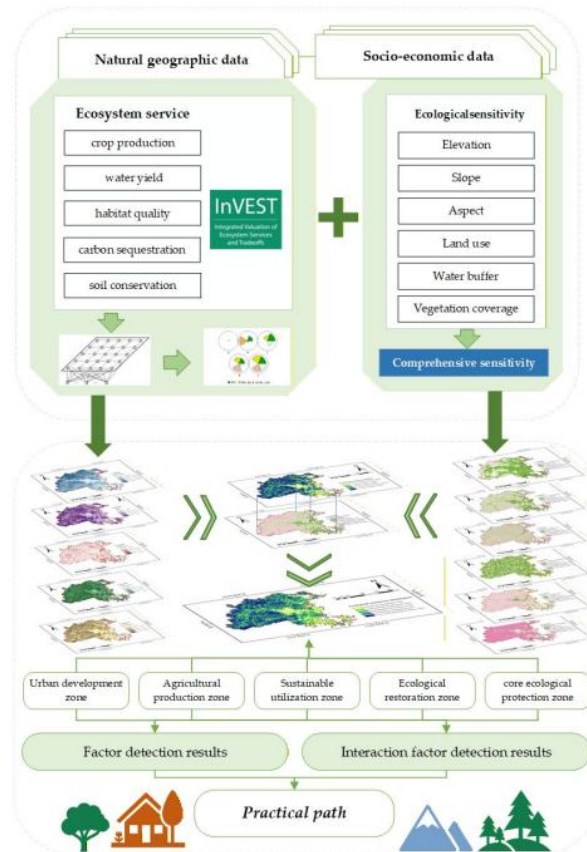


Figure 3.4 Methodological framework of Johor, Malaysia

The model applied is a Multi-Criteria Analysis (MCA) framework integrated within a GIS environment, where multiple environmental and planning parameters are evaluated simultaneously to determine suitability. This approach emphasizes planning decision-making by assigning relative importance (weights) to different criteria influencing urban forestry suitability. Evaluation techniques involve weighted scoring and spatial ranking, where criteria such as slope, existing vegetation cover, land-use compatibility, accessibility, and environmental sensitivity are converted into spatial layers. Each criterion is reclassified into suitability categories and assigned weights based on planning priorities, after which weighted overlay analysis produces a composite suitability map. The method provides a transparent and replicable evaluation process where site selection becomes evidence-based rather than subjective. This evaluation structure demonstrates how GIS can translate complex environmental data into practical planning outputs. Environmental criteria included in the MCA framework indirectly represent regulating ecosystem services such as erosion control, runoff reduction, microclimate improvement, and ecological

buffering. Potential urban forest patches are generated through spatial ranking, where high-scoring areas represent priority sites for intervention. (M. N. M. Reba*, 2013)

Source: Zipperer, W. C. (2003).

Species composition and structure of regenerated and remnant forest patches within an urban landscape. Urban Ecosystems / USDA Forest Service.

Goiânia, Brazil —

Mapping Priority Areas for Urban Afforestation Based on Urban Greening and Social Vulnerability

The Goiânia case study aims to develop a geoenvironmental planning model capable of identifying priority areas for urban afforestation by integrating ecological indicators of urban greening with socio-economic vulnerability factors. The research is grounded in the idea of environmental justice, where access to ecosystem services provided by urban forests and green spaces is considered an essential component of quality of life and equitable urban development. The model used in the study is a geoenvironmental GIS-based integration framework, which combines remote sensing–derived vegetation data with socio-economic variables for urban afforestation planning. The model evaluates ecosystem service distribution through quantification of urban greening and then links this with social vulnerability indicators derived from census data. This integration transforms ecological assessment into a planning-oriented evaluation model that prioritizes intervention zones according to environmental and social needs. Evaluation techniques involve a combination of remote sensing analysis, socio-economic indexing, and spatial overlay methods where ecological component is assessed using NDVI derived from high-resolution CBERS-4A satellite imagery. Social vulnerability is calculated through a composite index incorporating housing quality, sanitation access, income, and education variables. The final evaluation stage applies Boolean integration and weighted classification to combine ecological and social layers, producing a hierarchy of afforestation priority zones thus demonstrates a multi-dimensional evaluation technique. Patch prioritisation is therefore achieved through a planning-based classification approach where areas lacking sufficient vegetation and

showing higher social vulnerability are identified as priority urban forest intervention zones. (Guerrero, et al., 2025).

Source: Guerrero, J. V., Escobar-Silva, E. V., Almeida, C. M., Caiche, D., dos Santos, A. M., & Nunes, F. G. (2025, Mapping Priority Areas for Urban Afforestation Based on the Relationship Between Urban Greening and Social Vulnerability Indicators. Forests, 16, 936.

2.4.4 National Framework & Cases;

Ranchi, Jharkhand —

Geospatial Technology in Urban Forest Suitability Analysis

The study focuses on evaluating the feasibility of geospatial technology for identifying suitable locations for urban forestry development by integrating remote sensing and GIS-based multi-criteria analysis. Urban expansion in Ranchi has significantly reduced green spaces, increased land surface temperature, and intensified environmental stress, making it necessary to identify spatially suitable areas where urban forestry interventions can mitigate urban ecological degradation.

The model used is a GIS-based Multi Criteria Analysis (MCA) suitability framework, where remote sensing data from Landsat OLI imagery forms the base layer, while additional thematic layers such as slope, wetness index, soil organic carbon, drainage proximity, urban buffer distance, and land surface temperature are incorporated into a weighted suitability model with the objective of translating environmental variables into a spatial suitability map.

The workflow diagram illustrates this model clearly, showing how satellite data, DEM analysis, and ancillary datasets converge into weighted suitability mapping. Evaluation techniques combine digital image processing, thematic layer generation, and weighted overlay analysis.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

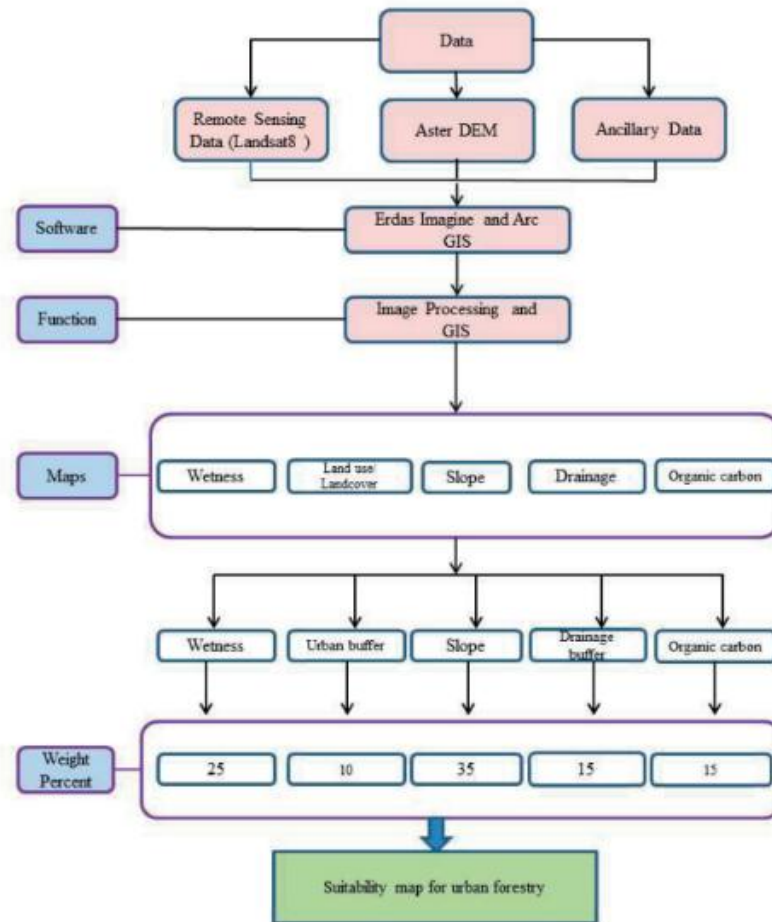


Figure 3.5 Methodology for analysis of Ranchi, Jharkhand

The resulting suitability mapping identifies highly, moderately, and least suitable zones for urban forest development, demonstrating a systematic evaluation method. Spatial analysis through concentric buffers demonstrates that vegetation decreases and temperature increases toward the urban core. Urban forest and patch identification Priority patches are further located along reservoirs, river systems, and areas with gentle slope and higher moisture content. Also, the study introduces indirect socio-economic value through environmental quality improvement and urban livability enhancement.

Source: Dash, S., & Das, S., Remote Sensing and GIS Applications for Monitoring and Managing Urban Forests. Dynamics of Urban Forestry.

Patiala, Punjab —

Geospatial Evaluation of Urban Marginal Lands for Urban Forestry Development

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

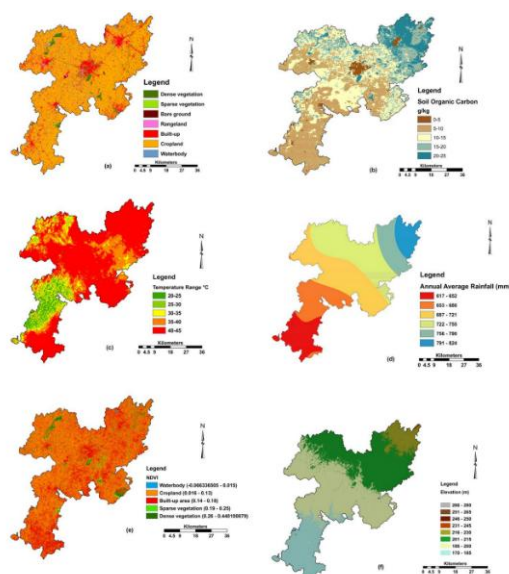


Figure 3.7 (a)Map of various GIS Based Datasets; (a)LULC, (b)Soil Organic carbon, (c)LST, (d)AA Rainfall, (e)NDVI and (f)DTM (Patiala, Punjab Case)

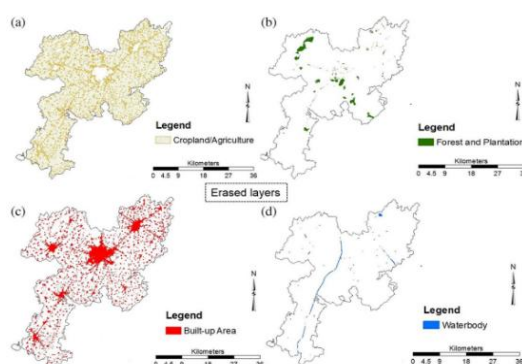


Fig. 4 Erased layers comprising (a) cropland/Agriculture, (b) Forest/plantation areas, (c) built-up land, and (d) waterbodies.

Figure 3.7 (b)Erased layers;
(a)cropland agri., (b)forest area,
(c)built-up land and (d)waterbodies

The case aims to identify and evaluate urban marginal lands (UML) suitable for forestry development using geospatial techniques, with the objective of converting underutilized urban land into ecological assets delivering regulating ecosystem services and bioenergy benefits. UMLs are generally defined as degraded lands, underutilized residential and commercial spaces, and vacant private and public lands.

The naturally occurring biodiverse regions and productive agricultural spaces were not included in the criteria of the recognition approach.

The naturally occurring biodiverse regions and productive agricultural spaces were not included in the criteria of the recognition approach. For

Identifying and estimating the urban marginal lands, concept of planting indigenous bioenergy tree species was executed to assess the potential of cultivating different bioenergy plants in the UML of Patiala. LULC data, climatic variables, vegetation productivity, terrain, and soil factors were the attributes that had the most prominent impact on the feasibility of the UML for cultivating bioenergy crops. This model also establishes multiple input erase layers being plantation areas, croplands, waterbodies, and building spaces. These layers were collated and employed on top of the input layer to omit the regions inappropriate for biomass cultivation due to the present

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

urbanization. Finally, UML, suitable for producing biomass and bioenergy crops, was recognized for its viability.

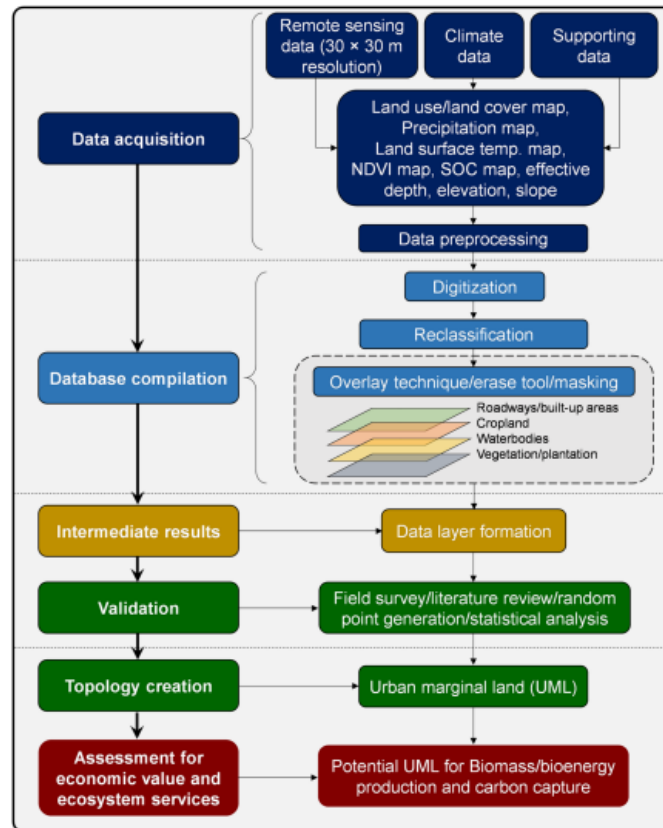


Figure 3.8 Working Framework outlining major
phases in evaluating urban marginal lands,
Patiala, Punjab

Source: Edrisi, S. A., Vashisth, A., et al.

Geospatial Evaluation of Urban Marginal Lands for Forestry Development in Northern India. *Environmental Development and Sustainability*. <https://doi.org/10.1007/s10668-025-06787-z>

The model applied is a GIS-based suitability and screening framework, where multiple environmental and bio-geophysical variables are integrated to delineate potential urban forestry sites. The workflow diagram clearly illustrates this GIS-driven sequence from data acquisition to suitability output.

Evaluation techniques include remote sensing classification, overlay analysis, threshold-based environmental screening, and validation through field surveys and statistical accuracy assessment (kappa coefficient $\kappa = 0.61$). Parameters such as NDVI ranges, soil organic carbon, slope, land surface

temperature, and rainfall thresholds were used to evaluate ecological suitability, indicating a strong multi-criteria GIS approach.

Nagpur —

(Mapping Methodology of Public Urban Green Spaces Using GIS)

The study mainly aims to identify and classify public urban green spaces (UGS) by creating a detailed spatial database that records green space typologies, distribution, and accessibility. The model applied is a GIS thematic mapping framework, where spatial and non-spatial datasets are integrated to produce a high-accuracy inventory of urban green spaces. The evaluation approach rather than suitability, relies on detailed classification of UGS types (parks, playgrounds, lakes, institutional green spaces, corridors, vacant land), supported by field verification and accuracy assessment using confusion matrix and kappa statistics (0.93 accuracy). Green patches are identified through visual interpretation of high-resolution imagery, classification into functional typologies, and attribute integration such as ownership, area, maintenance status, accessibility, and vegetation condition.

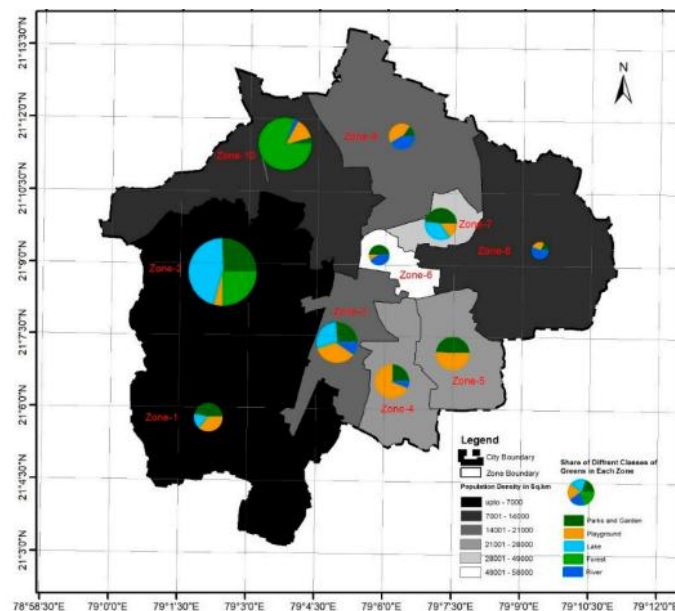


Figure 3.9 Zone wise distribution of public
UGS, Nagpur

Monetary valuation is not included in this study, as the primary goal remains spatial inventory development rather than ecosystem service valuation. ArcGIS is used for georeferencing, thematic classification, data layering,

field validation, spatial distribution analysis, and hierarchical assessment of green spaces.

Considering the importance of direct benefits of recreational facilities of the city, the five main classes are analyzed at finer administrative unit referred at zones. The map shows the share of different classes of green spaces in each zone.

Source: Singh, K. K. (2019).

Probing the Context of Green Spaces in Urban Planning Framework in India.

Burdwan (West Bengal) –

Assessment of Ecosystem Service Value Change Using Land Use Dynamics

The work aims to study the relationship between changes in the ESV and transformations of LULC in Burdwan Planning Area (BPA), a fast-growing secondary town of Eastern India. The study uses a Land Use – Ecosystem Service Value approach, by mapping land use (LULC) followed by ecosystem service value given to each land use type and finally total ESV calculation using $[\text{area} \times \text{value coefficient}]$. This is called the Benefit Transfer Method. After LULC mapping, each land-use type being matched with a global biome category from Costanza et al. (2014) called Costanza adapted values. As shown in table below; lies fixed ecological-economic values taken from global research and steps for assessing ecosystem services as measurable planning indicators that help interpret environmental change within urban areas. Means NOT calculating ecosystem services manually, but using standard value coefficients. Assumption is that each land-use category provides a certain level of ecosystem services and therefore can be assigned a standard ecosystem value coefficient derived from global ecosystem valuation studies.

In their 1997 seminal study, Robert Costanza and his colleagues estimated the value of 17 ecosystem services across 16 biomes (Costanza, 1997).

‘R Constanza’- his approach widely known as the benefit transfer method, allows researchers to estimate ecosystem service value (ESV) using land-use

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

data by multiplying area with corresponding ecosystem value coefficients. Because of its simplicity and applicability in GIS-based studies, the Costanza framework has 17 has become a widely cited reference for evaluating ecological-economic impacts of land-use change and supporting planning decisions related to environmental conservation and ecosystem restoration.

Order	Description																		
Step 1 Classification of satellite images into only 5 land-use categories	i) Open land / sand bars ii) Water bodies iii) Vegetation iv) Agricultural land v) Built-up area																		
Step 2 Assigning Ecosystem Service Values	After LULC mapping, each land-use type being matched with a global biome category from Costanza et al. (2014) called Costanza adapted values. As shown in table below; lies fixed ecological-economic values taken from global research. <table><thead><tr><th>LULC</th><th>Equivalent Biome</th><th>Value coefficient (US\$/ha/year)</th></tr></thead><tbody><tr><td>Water body</td><td>Lake/River</td><td>12,512</td></tr><tr><td>Vegetation</td><td>Tropical forest</td><td>5,382</td></tr><tr><td>Agriculture</td><td>Cropland</td><td>5,567</td></tr><tr><td>Built-up</td><td>Urban</td><td>6,661</td></tr><tr><td>Open land</td><td>Desert</td><td>0</td></tr></tbody></table> Means NOT calculating ecosystem services manually, but using standard value coefficients.	LULC	Equivalent Biome	Value coefficient (US\$/ha/year)	Water body	Lake/River	12,512	Vegetation	Tropical forest	5,382	Agriculture	Cropland	5,567	Built-up	Urban	6,661	Open land	Desert	0
LULC	Equivalent Biome	Value coefficient (US\$/ha/year)																	
Water body	Lake/River	12,512																	
Vegetation	Tropical forest	5,382																	
Agriculture	Cropland	5,567																	
Built-up	Urban	6,661																	
Open land	Desert	0																	
Step 3: Main Formula Used	Ecosystem Service Value: $ESV = Area [Ak] \times Value Coefficient [VCk]$ Where; • Ak = area of land use (ha) • VCk = ecosystem value coefficient (US\$/ha/year)																		
Step 4: Total Ecosystem Service Value	Sum of all land-use ESVs: $Total\ ESV = \sum(Area \times Value)$ So; Water + Vegetation + Agriculture + Built-up = Total ES value of city																		

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

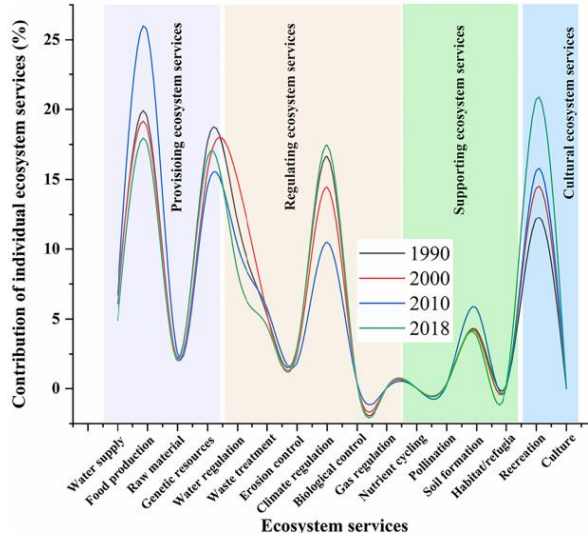
Step 5: Change Over Time	They calculated ESV for:  • 1990 • 2000 • 2010 • 2018 $\%Change = \frac{ESV_{final} - ESV_{initial}}{ESV_{initial}}$ → Where, findings were; ESV declined due to urbanization. Contribution of individual ecosystem services since 1990 to 2018 (provisioning ecosystem services, regulating ecosystem services, supporting ecosystem services, and cultural ecosystem services).
Step 6: Contribution Rate	Calculated which land use contributes MOST to ecosystem services. Formula: $CR = (Value \times Area) / TotalESV$ Result: • Agricultural land → highest contribution • Vegetation & water → next major contributors. This helps identify priority ecological patches.

Table 3.1 Step wise Constanza approach

For priority urban forest patches identify LOW ESV Zones, as they have low ecological value in present and high restoration potential in future. In cost benefit justification, ecosystem service value assessment is used as a planning-support tool to evaluate ecological performance of existing land-use categories. Areas showing lower ecosystem service contribution but high ecological potential are identified as priority zones for urban forest interventions, allowing comparison between existing and proposed scenarios

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Source: (Costanza, 1997), *Environmental Science and Pollution Research* (2023)

2.4.5 The Miyawaki Technique;

One reliable forest restoration method is the “native forests by native trees” based on the vegetation ecological theories proposed by Prof. Akira Miyawaki and applied first in Japan. According to this method, restoring native green environments, multilayer forests and well-developed ecosystems can be quickly established because of the simultaneous use of intermediate and late successional species in plantations through careful ecological engineering and human intervention in an organic and sustainable manner. The Miyawaki technique has been followed in Japan, South American countries, Far East and Malaysia in the environmentally degraded lands as well as urban landscapes. In shorter span of time, more urban forests were developed. The forest has thousands of native tree species grown closely together in a small patch of area in a manner that green receive sunlight only from the top and they grow upwards instead of sideways.

- ✓ Miyawaki Method of tree plantation is 30 times denser and plant growth 10 times faster than usual.
- ✓ After 3 years no maintenance required for the Miyawaki forest. (“No maintenance is the best maintenance” for Miyawaki method of afforestation).

Success Story



Figure 3.10 Success Story

It is also a useful tool in Urban Forestry projects and the development of recreational parks. Expanding forest cover, and use trees as a buffer against natural calamities is a plus. Been applicable to Bengaluru (lakes and parks), Mumbai (Satara region), Kerala (mini forests), Hyderabad (Gachibowli and stadiums), Ahmedabad, Chennai and Coimbatore.

2.5 Policy and Planning Framework Supporting Urban Forestry

Nagar Van Udyan Program

The government has announced implementation of the Nagar Van Scheme on the occasion of the World Environment Day (5th June) in 2020 which envisages developing 400 Nagar Vans and 200 Nagar Vatikas in the country during the period of 2020-21 to 2024-25 with an objective to significantly enhance the tree outside forests and green cover, enhancement of biodiversity and ecological benefits to the urban and peri-urban areas apart from improving quality of life of city dwellers. The Yojana was for the period of 2020-21 to 2024-25 for implementation from the National Funds under Compensatory Afforestation Fund Management and Planning Authority (CAMPA). It has been extended and revised to operate until **2026-27**.

Limitations

Developing an assessment framework also presents limitations because urban forests often overlap conceptually with urban greenery, green spaces, and green infrastructure, making it difficult to isolate their specific effects. Several studies were performed to assess the impact of LULC change on ESV at city scale in India but there is still a lacking long-term assessment of spatial heterogeneity on planning regions in India. (Das & Houqe, R. et al. , 2023)

CHAPTER – 03

BASE MAP PREPARATION & SITE DATA COLLECTION

3.1. Base Map Preparation

After collection of secondary and primary data, the next stage of the study involved preparation of base map and thematic maps for Narmadapuram town, which form the spatial foundation for further analysis. The base map was prepared using the Development Plan and municipal boundary data, and includes ward boundaries, planning area boundary, road network, railway line, water bodies, and major physical features. This map establishes the spatial extent of the study area and helps in understanding the distribution of urban development, transportation corridors, and river influence zone within the municipal limits.

3.1.1 Municipal Ward Map

The introductory base map shows that Narmadapuram town is located along the southern bank of River Narmada, and the urban area is concentrated in the central portion of the planning boundary, while large peripheral areas remain open or sparsely developed.

Refer to Map No. 1 only for Ward wise distribution within Municipal Limit Area

The ward map indicates that the municipal area consists of multiple administrative divisions, but the built-up area is unevenly distributed, with higher density near the central corridor and lower density towards the outer zones. This spatial pattern suggests the presence of unutilised or low-intensity land parcels in peripheral areas, which can be examined further for potential wasteland identification and productivity enhancement.

3.1.2 Built – Unbuilt Map

The built–unbuilt thematic map prepared from the Development Plan data shows the existing built-up areas, transportation network, and open land within the planning boundary. The analysis indicates that significant portions of land within the planning area are not fully developed and are either vacant, agricultural, or under low-intensity use. Such areas are important for the present study, as they may represent potential wasteland or underutilised lan

that can be evaluated for vegetation-based improvement, social forestry, or other productivity enhancement measures.

Refer to Map No. 2 Built - Unbuilt Map, Connectivity Map, Slope Map and Watershed Delineation

3.1.3 Connectivity

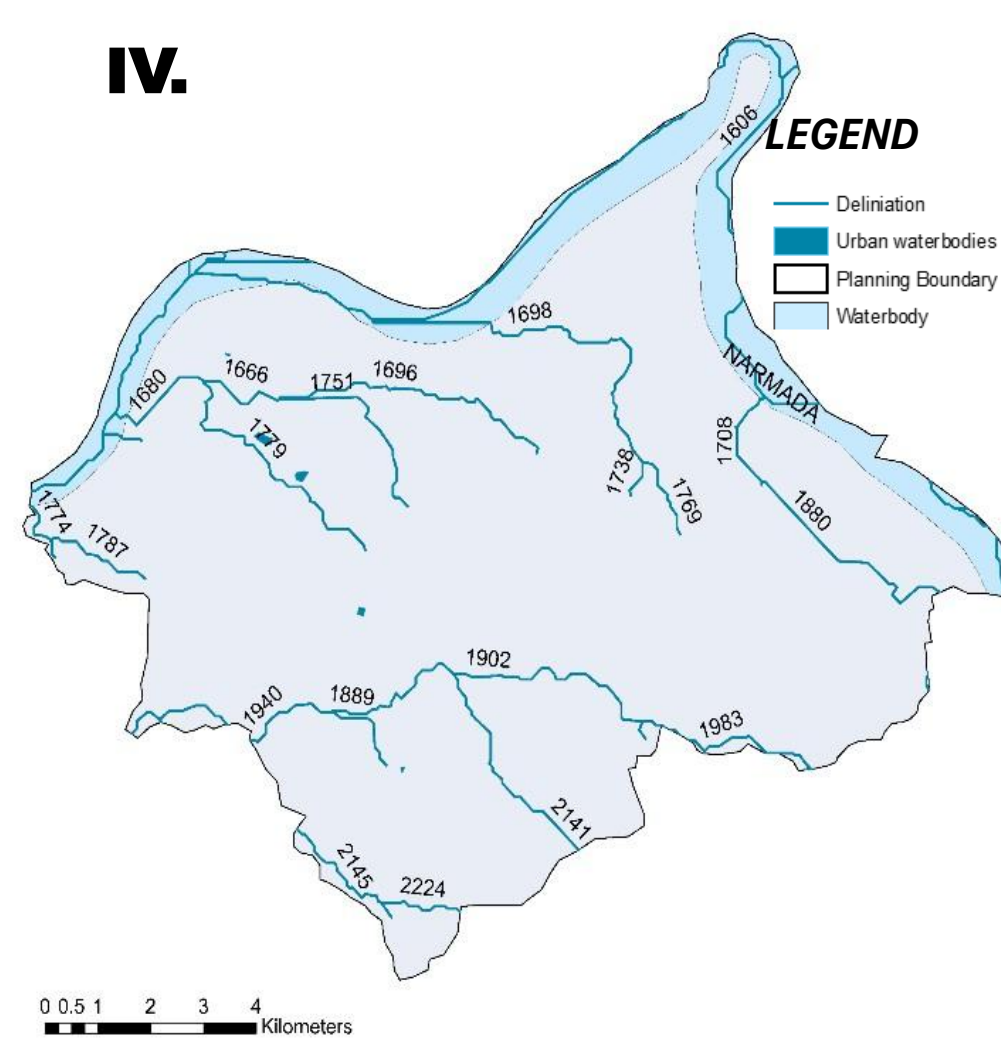
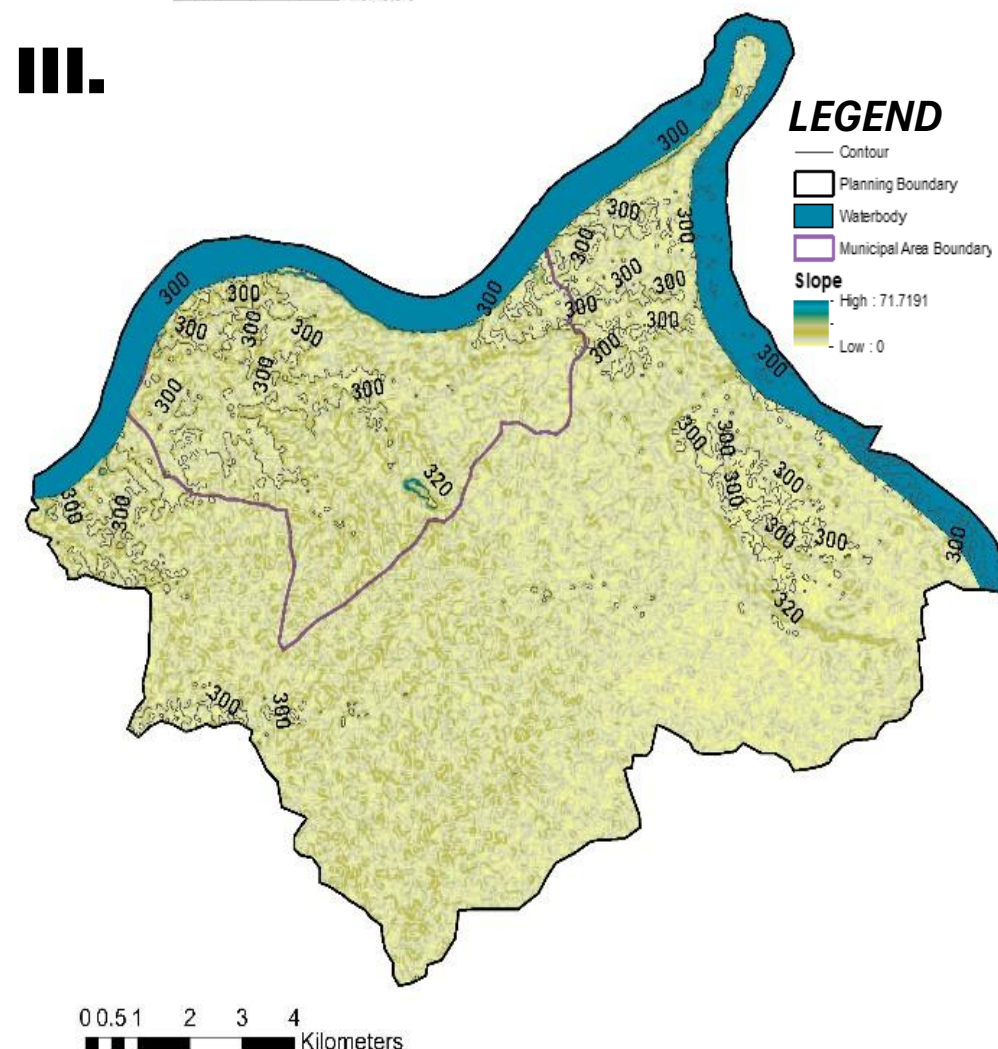
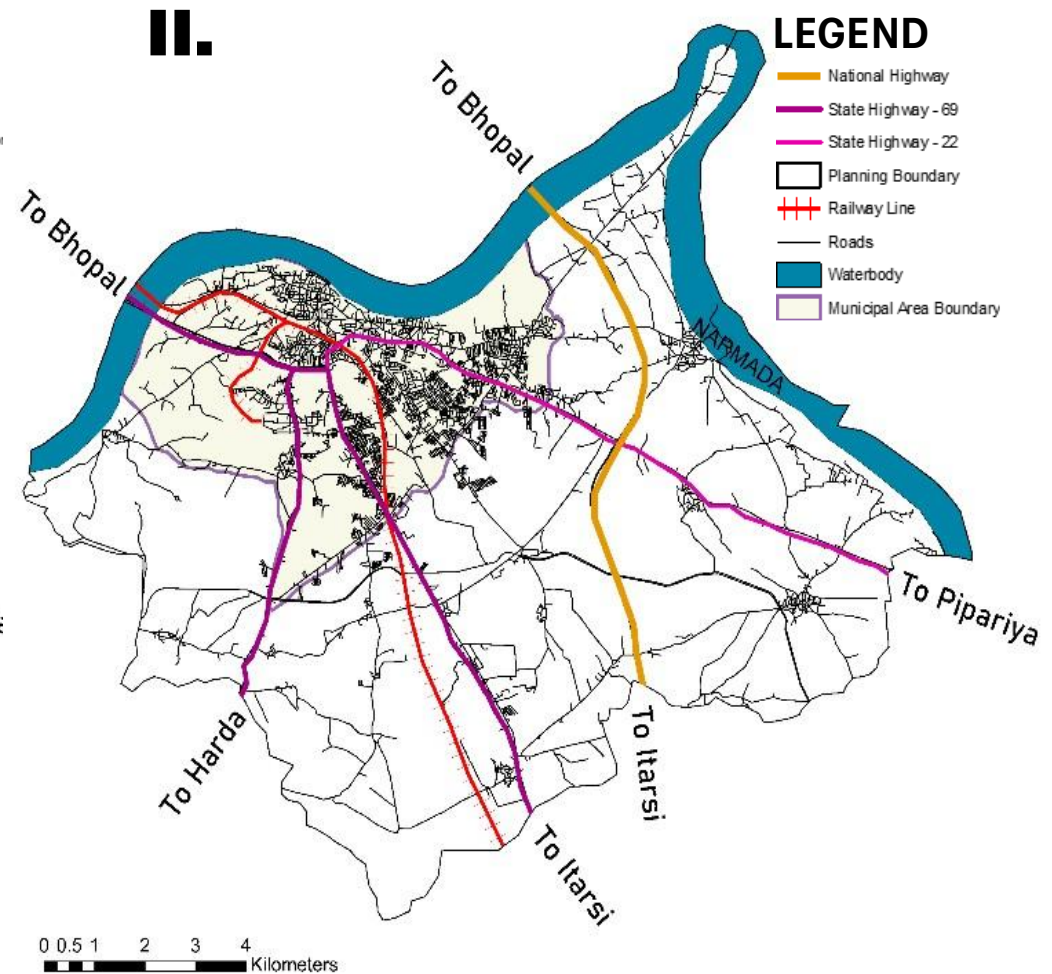
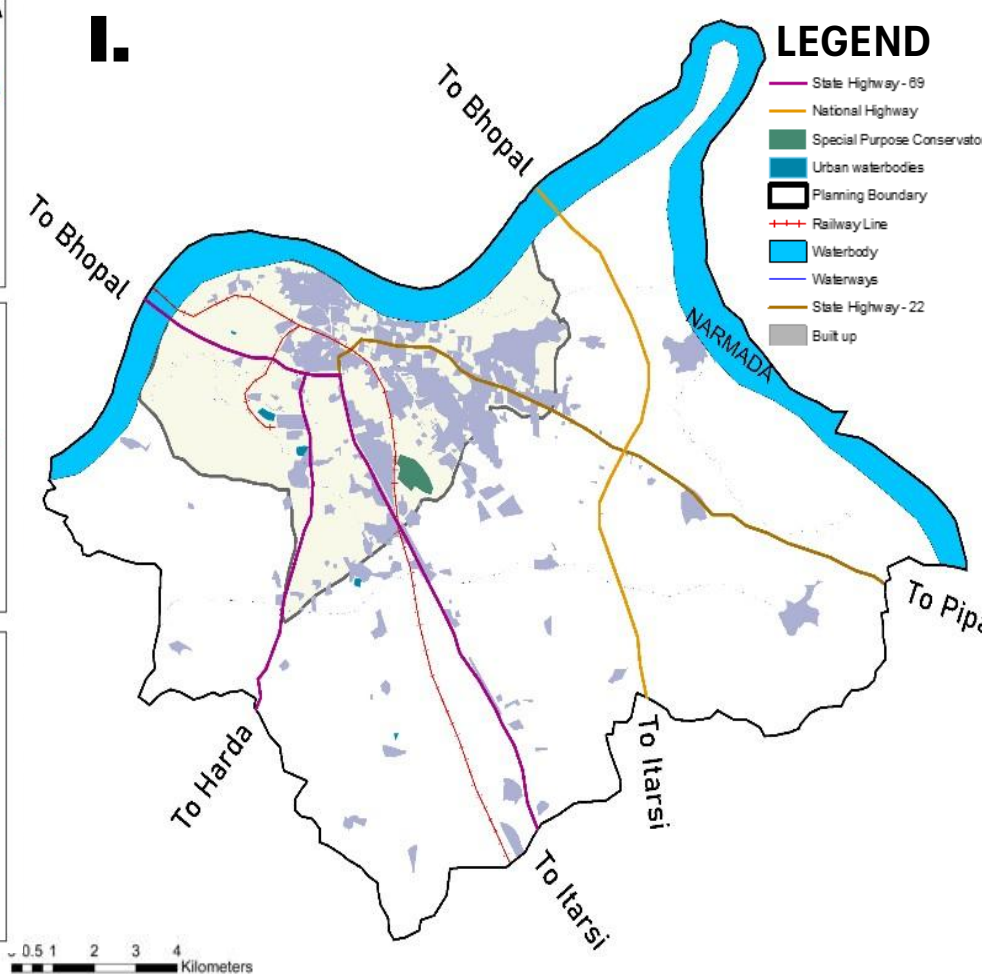
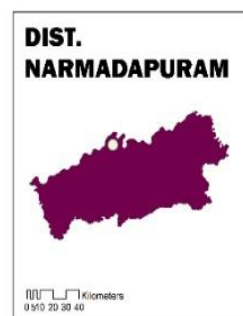
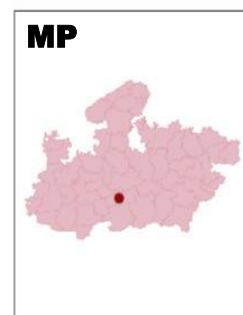
The connectivity map shows the hierarchy of roads including national highway, state highway, and internal road network. The major transportation corridors pass through the central part of the town, while the outer areas have comparatively low connectivity. This variation in accessibility is important in determining the suitability of land for future intervention, because highly connected areas are generally under development pressure, whereas poorly connected areas often remain unused or degraded. Therefore, connectivity becomes an important parameter in identifying wasteland patches that can be improved without conflicting with existing urban use.

Refer to Map No. 2 Built - Unbuilt Map, Connectivity Map, Slope Map and Watershed Delineation

3.1.4 Slope

The slope and contour map prepared from elevation data indicates that most of the study area lies in relatively gentle slope conditions, with gradual variation in elevation from the Satpura side towards the Narmada valley where 320 m above means sea level is highest peak point. The low slope areas are generally suitable for vegetation growth and land improvement activities, whereas areas with higher slope or irregular terrain may require special treatment before being considered for productivity enhancement. The presence of mild terrain in large parts of the planning area suggests that wasteland reclamation through plantation or land development is physically feasible in many locations.

Refer to Map No 2 Built - Unbuilt Map, Connectivity Map, Slope Map and Watershed Delineation



“ECOSYSTEM
SERVICE-BASED
URBAN FOREST
PLANNING: A SPATIAL
SUITABILITY
ASSESSMENT FOR
NARMADAPURAM,
M.P.”

I. Built - Unbuilt Map
II. Connectivity Map
III. Slope Map
**IV. Watershed
Delineation Map**



Scale
Specific to Map

Source
*OpenStreetMap (OSM), Author's
Digitization, Bhuvan/USGS*

Notes
*Municipal area has total of 33
wards
Negligible variation for slope
Consist of Tributaries and
channels.*



Manit, Bhopal

MAP NO.

2

3.1.5 Watershed Delineation

The watershed delineation map shows the drainage pattern and natural flow of water within the planning boundary. The study area is influenced by the River Narmada and its associated drainage channels, which play an important role in soil moisture, groundwater recharge, and land productivity. Areas located near drainage lines or water bodies generally have better moisture conditions and can support vegetation more easily, while areas away from natural water flow may remain dry or unproductive. Therefore, hydrological condition becomes an important parameter in the identification of wasteland patches suitable for improvement.

Refer to Map No. 2 Built - Unbuilt Map, Connectivity Map, Slope Map and Watershed Delineation

From the combined interpretation of base map and thematic maps, it can be observed that the planning area contains a mix of built-up land, open land, river-influenced zones, low-density peripheral areas, and moderately sloping terrain. These spatial characteristics indicate that the town has sufficient land parcels that may be considered for wasteland identification and productivity enhancement, subject to further analysis using vegetation indices, land use classification, and suitability parameters in the next stages of the study.

The prepared base maps and thematic maps are therefore used as the primary spatial input for further GIS-based analysis, including wasteland identification, parameter selection, and suitability mapping for enhancing the productivity of selected land parcels.

3.2 Data Collection & Type

Data Collection

The first stage of the study involved the systematic collection of primary and secondary data required for identifying suitable wasteland patches and assessing their potential for productivity enhancement. Secondary data was collected from statutory planning documents, government reports, and published research studies

in order to understand the physical, environmental, and land use characteristics of Narmadapuram town. The Development Plan and municipal records obtained from Nagar Palika were used to understand existing land use, open land distribution, infrastructure pattern, and available public land parcels within the urban boundary. Information regarding environmental conditions, natural resources, waste management, mining activity, water quality, and plantation status was referred from the District Environmental Plan prepared for Hoshangabad / Narmadapuram, which provides thematic details related to land use, forest cover, water bodies, and environmental management requirements.

To understand the ecological characteristics of the study area, literature related to vegetation and tree diversity in Hoshangabad was reviewed, which indicates the presence of significant native and exotic species along riverbanks, institutional lands, and open spaces, showing the potential of unused land for vegetation-based improvement.

Concepts of social forestry, agroforestry, and reclamation of degraded land were studied from forestry literature to understand how unproductive land can be improved through plantation, community forestry, and vegetation-based land management practices. These studies highlight that wastelands, village commons, degraded lands, and unused urban lands can be converted into productive ecological spaces through planned forestry interventions.

Primary information was collected through a field visit and interaction with the Nagar Palika office, where available records related to parks, open spaces, plantation areas, unused land, and municipal assets were examined. The field visit helped in understanding the actual ground condition of open lands, riverbank areas, unused public lands, and vegetation cover, which supported the secondary data and helped in identifying potential areas for further spatial analysis.

The collected data was used as the base for preparation of thematic maps, spatial analysis, and identification of wasteland patches suitable for productivity enhancement in the later stages of the study.

Data Type

Spatial

In the current study, Data of Landsat images were extracted from USGS Earth Explorer. The cloud coverage of the images is less than 20 %. By employing these data, the study seeks to predict the thematic layers of the region of interest. Details of the data are given in the following table.

Data	Spatial Resolution (m)	Thermal Resolution(m)	Year of Acquisition	Cloud Coverage (%)
Landsat TM	30	120	2020	8
Landsat OLI	30	100	2025, 2026	10

Table 4.1 Spatial Data Extraction

Prior to the process, the Landsat images were first pre-processed to clear the effects caused by illumination and atmosphere attenuation such as pre-processing and image calibration, were applied to all Landsat Images. The study area was clipped out and cloud masking for all Landsat images were performed.

(Municipal Records and Field Verification) —

In order to collect detailed information regarding existing green areas, open lands, plantation activities, and availability of unused land within the municipal boundary, data was obtained from the Nagar Palika office of Narmadapuram. A total of fifteen public parks maintained by the municipality were identified from municipal records, along with information related to plantation work, nursery facilities, and availability of open land under municipal control. The collected records also included details of ward-wise land distribution, road network, and locations where plantation or maintenance work has been carried out by the local authority. During the visit to the municipal office, available documents related to land use, park maintenance, plantation activities, and municipal land ownership were examined. Information regarding the number of open spaces, condition of parks, and presence of vacant land parcels was noted to understand the present level of land utilisation within the town. Records also indicated that plantation work is carried out periodically by the municipality, and a nursery

facility is available for maintaining plant stock, which shows the existing capacity for vegetation development within the urban area. In addition to the municipal records, field observation was conducted to verify the actual condition of selected locations. Several open land parcels, roadside spaces, riverbank areas, and low-use municipal lands were visited to understand the ground situation. The field visit helped in confirming that some parts of the planning area remain unused or under-utilised due to lack of development, poor maintenance, or absence of infrastructure. These areas are important for the present study, as they may represent potential wasteland or low-productivity land that can be considered for further analysis. The data collected from the Nagar Palika was therefore used as supporting information for identifying existing green infrastructure, understanding present land utilisation, and selecting relevant parameters for spatial analysis. The information was not used for direct proposal preparation, but for strengthening the database required for thematic mapping and suitability analysis in later stages of the study.

Information obtained from the municipality also referred to development works and plantation activities carried out under different local programmes and schemes related to urban development and environmental improvement. These programmes mainly focus on park development, roadside plantation, and maintenance of selected public spaces, but do not include systematic identification of unused or low-productivity land. This indicates that although green space development is practiced, there is a lack of spatial analysis for selecting suitable locations for vegetation-based improvement, which justifies the need for the present study.

The municipal data, together with field observation, was therefore interpreted to identify relevant parameters required for further GIS-based analysis. Factors such as availability of open land, distribution of built-up area, proximity to water bodies, terrain condition, accessibility, and existing green space distribution were considered important for evaluating the suitability of land for productivity enhancement. The interpretation of municipal records helped in establishing a logical base for thematic mapping and parameter

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

selection, which is used in the next stage for spatial identification of wasteland and assessment of suitable patches for improving land productivity.

CHAPTER – 04

DATA ANALYSIS (TECHNICAL & SPATIAL)

4.1. Parameter Extraction Table (for Suitability Analysis Justification)

In order to perform suitability analysis for identification of suitable patches, a systematic procedure was followed for selecting parameters and assigning weightage to each layer used in GIS overlay. The parameters were not selected randomly, but were derived through comparative study of national and international case studies, literature review, and objective-based analysis related to vegetation suitability, hydrological condition, land productivity, and planning feasibility.

A tabular comparison method was used to evaluate the relevance of different parameters used in previous studies. Each case study and literature source was examined to identify the indicators commonly used for spatial suitability, ecological assessment, and land evaluation. The selected parameters were then compared with the objectives of the present study, so that only those variables which directly influence land productivity, vegetation growth, moisture availability, and planning suitability were retained for further analysis.

The process involved both quantitative and qualitative evaluation. Quantitative comparison was done by checking the frequency of use of parameters in different case studies, while qualitative analysis was done by examining the logical importance of each parameter in relation to the study objectives. A comparative approach was also used to understand the gap between the conditions observed in the study area and the conditions required for plantation and productivity enhancement.

International Cases

Our Objective	Case / Literature	Name of study	Method used	Parameters used	Proxy variable (math / spatial / standard)
Spatial identification	✓ Case	Johor MCA urban forest study	GIS + MCA suitability	slope, soil, drainage, land use, resources	weight ranking formula

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Our Objective	Case / Literature	Name of study	Method used	Parameters used	Proxy variable (math / spatial / standard)
n of suitable patches	✓ Case	Goiânia afforestation priority mapping	GIS overlay + NDVI	NDVI, land cover, vulnerability	Boolean / overlay
	✓ Case	Syracuse forest patch study	patch inventory + aerial analysis	patch size, disturbance, land use	patch classification
Economic / ecosystem service evaluation	✓ Literature	Kyoto ecosystem service study	i-Tree + land use analysis	carbon, runoff, pollution, tree density	ecosystem service model
	✓ Literature	Costanza ecosystem valuation approach	value transfer	land use × coefficient	standard ESV coefficient
	✓ Case	Kyoto urban forest valuation	ecosystem modelling	species, land use, tree size	iTree calculation
Hydrological potential assessment	✓ Case	Johor MCA	suitability analysis	drainage, slope, soil	weighted ranking
	✓ Literature	Urban ecosystem service studies	eco-hydrology link	vegetation, water, soil	indicator method
Planning suitability for urban forest	✓ Case	Goiânia planning model	GIS + planning units	vegetation %, social data	planning overlay
	✓ Literature	Urban forestry planning research	GIS suitability	land use, open land, buffer	spatial suitability
	✓ Case	Syracuse patch ecology	patch based planning	forest patch, disturbance	patch classification

Table 5.1 International Cases

Based on this analysis, parameters such as land use land cover, vegetation index, moisture index, slope, drainage proximity, bare soil, open land availability, and accessibility were selected as the final input layers for GIS-based suitability analysis. Weightage was assigned to each parameter according to its influence on vegetation growth, hydrological support, land condition, and planning feasibility. Parameters directly affecting land productivity and moisture condition were given

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

higher weight, while supporting parameters such as accessibility and existing green space were given lower weight.

Indian Cases

Our Objective	Case / Literature	Name of study	Method used	Parameters used	Proxy variable (math / spatial / standard)
Spatial identification of suitable patches	✓ Case	Ranchi GIS study	overlay + suitability	LULC, slope, drainage, open land	weighted overlay
	✓ Case	Patiala suitability study	GIS analysis	soil, slope, water, land use	ranking
	✓ Case	Nagpur green planning	planning + GIS	open land, parks, DP map	planning standards
Economic / ecosystem service evaluation	✓ Case	Burdwan ESV study	NDVI + ESV	land use, vegetation	Costanza coefficient
	✓ Literature	Ecosystem service valuation papers	benefit transfer	area × coefficient	ESV method
	✓ Case	Burdwan urban ecosystem	valuation + GIS	NDVI, land cover	standard values
Hydrological potential assessment	✓ Case	Ranchi GIS	drainage + slope	water, slope	suitability ranking
	✓ Case	Patiala GIS	soil + water	hydrology + land	overlay
	✓ Literature	watershed / eco-hydrology studies	terrain analysis	slope, drainage, water	spatial indicators
Planning suitability for urban forest	✓ Case	Nagpur planning	DP + green analysis	land use, open land	planning norms
	✓ Case	Patiala plantation planning	GIS suitability	soil, slope, water	ranking
	✓ Literature	Urban forestry planning papers	suitability modelling	open land, buffer	MCA / overlay

Table 5.2 Indian Cases

This method provided a rational and literature-supported basis for assigning weights and ensured that the suitability analysis is consistent with previous studies and aligned with the objectives of the present research.

Mostly the quantitative approaches are used for determining the index weight in UGS suitability evaluation. This study shall opt for Case-based multi-criteria suitability analysis where, weights for parameters / indices are assigned based on their frequency in cases. Hence, Weightage to each parameter is to be assigned based on frequency of use in literature, ecological importance, and relevance to suitability analysis, following multi-criteria analysis approach used in studies.

Many objective and subjective MCDM methods in the literature can be applied depending on the problem, and new ones are added to the existing methods. The results obtained with MCDM methods vary depending on the parameters used during the analysis phase. These are generally normalization techniques and criterion weighting methods. The focused factor in this study is the normalization techniques used in MCDM methods. When studies in the literature are examined, the generally used normalization techniques are; linear, non-linear, max, max-min, sum, vector and logarithmic normalization technique. (Yağmur ŞAN, 2025)

4.2. Parameter identification from cases

Common parameters identified from International and Indian cases are;

Parameter	LULC	Veg etat ion	Built up Buffer	Slope	Drainage (Buffer Distance)	Soil Textur e	Ground water	Accessibility Buffer (Distance from Road)
-----------	------	--------------------	-----------------------	-------	----------------------------------	---------------------	-----------------	---

Table 5.3 Common parameters identified

Linkage of parameters to objectives (justification)

Objectives already defined:

1. spatial suitability
2. ecosystem value
3. hydrology
4. planning suitability

Each parameter is linked to objective.

After selection of parameters, the next step was to establish a clear linkage between the selected parameters and the objectives of the study. The present study is based on four main objectives, namely spatial identification of suitable patches, evaluation of ecosystem and land productivity potential, assessment of hydrological condition, and planning suitability for plantation and productivity enhancement. In order to achieve these objectives through GIS-based suitability analysis, it was necessary to ensure that each selected parameter contributes to at least one of the objectives.

A systematic comparison was carried out to examine how each parameter influences the different aspects of the study. Parameters such as Land Use Land Cover, vegetation layer, and bare soil were linked with spatial suitability and productivity assessment, as these indicators represent the existing land condition and vegetation potential. Drainage buffer and groundwater availability were linked with hydrological assessment, because moisture availability and proximity to water sources play an important role in vegetation growth and land improvement. Slope was considered only as a reference layer, as variation in terrain is negligible within the study area. Parameters such as accessibility and built-up buffer were linked with planning suitability, as these factors determine the feasibility of implementing plantation or land improvement in practical conditions.

This linkage was necessary to ensure that the suitability analysis is not based on a single factor, but on a combination of spatial, ecological, hydrological, and planning criteria. By connecting each parameter with the objectives, the analysis becomes more logical and consistent, and the assigned weightage can be justified on the basis of its relevance to the study goals.

The linkage of parameters to objectives also helps in reducing unnecessary variables and limiting the analysis to only those layers which directly influence the identification of suitable patches. This approach follows the multi-criteria evaluation method used in previous studies, where different environmental and planning indicators are combined to obtain a final suitability index. Therefore,

the selected parameters (P1–P7) were used as input layers for weighted overlay analysis after confirming their relevance to the four objectives of the study.

Parameter	Objective
Vegetation	Ecosystem
Groundwater	Hydrology
Slope (<i>reference</i>)	Spatial
LULC	Planning
Drainage Buffer	Hydrology
Soil Texture	Ecosystem + Hydrology
Road Buffer	Planning
Built up Buffer	Planning

Table 5.4 Objective parameter linkage

4.3. Preparation of Thematic Maps

In order to carry out spatial identification of wasteland and suitability analysis, a set of thematic maps was prepared using satellite data, secondary data sources, and GIS processing in ArcGIS software. These maps were used to understand land condition, vegetation cover, terrain characteristics, moisture availability, and built-up distribution within the planning boundary. Each thematic layer was generated from reliable data sources and processed in ArcGIS to maintain consistency in projection, resolution, and study area extent.

4.3.1 Land Use Land Cover Map (LULC)

Land Use Land Cover map was prepared using satellite imagery obtained from USGS Earth Explorer. Landsat imagery from Landsat Collection 2 Level-2, Landsat 8–9 OLI/TIRS C2 L2 dataset was downloaded with cloud cover less than 10% for the year 2026 to ensure clear surface visibility. The satellite image was imported into ArcGIS and clipped to the municipal boundary of Narmadapuram. Image classification was carried out using supervised classification to identify major land use classes such as built-up area, vegetation, water body, agriculture, and bare land. The classified LULC map

was used to identify open land, low-use land, and possible wasteland areas required for further suitability analysis.

*Refer to Map No. 3 Land use Land Cover Layer, Vegetation Layer and
Groundwater Presence Layer*

Class Name	Class Area (in sq.km.)	% of Total Area
Built Up	21.1362	15.16
Agriculture	89.7574	64.40
Barren Land	9.31106	6.67
Vegetation	8.738	6.26
Water Body	6.2791	4.50
River Sand	4.204	3.01

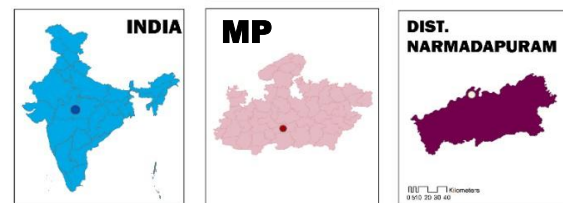
Total Area = 139.42576 sq.km.

Table 5.5 LULC Area Distribution

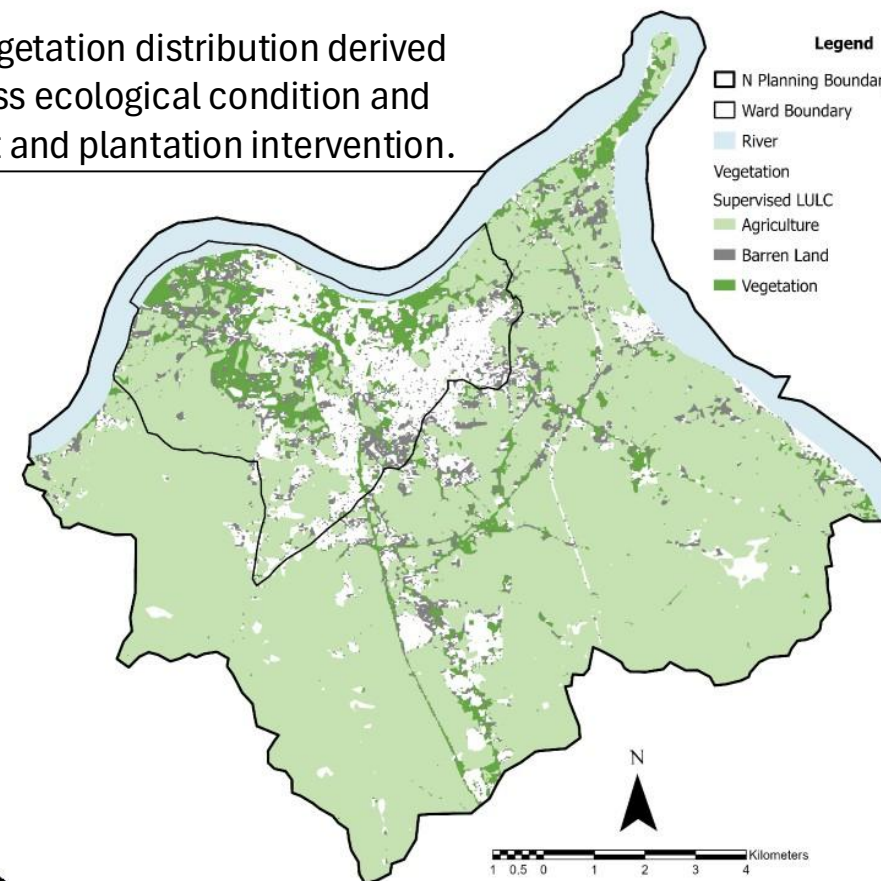
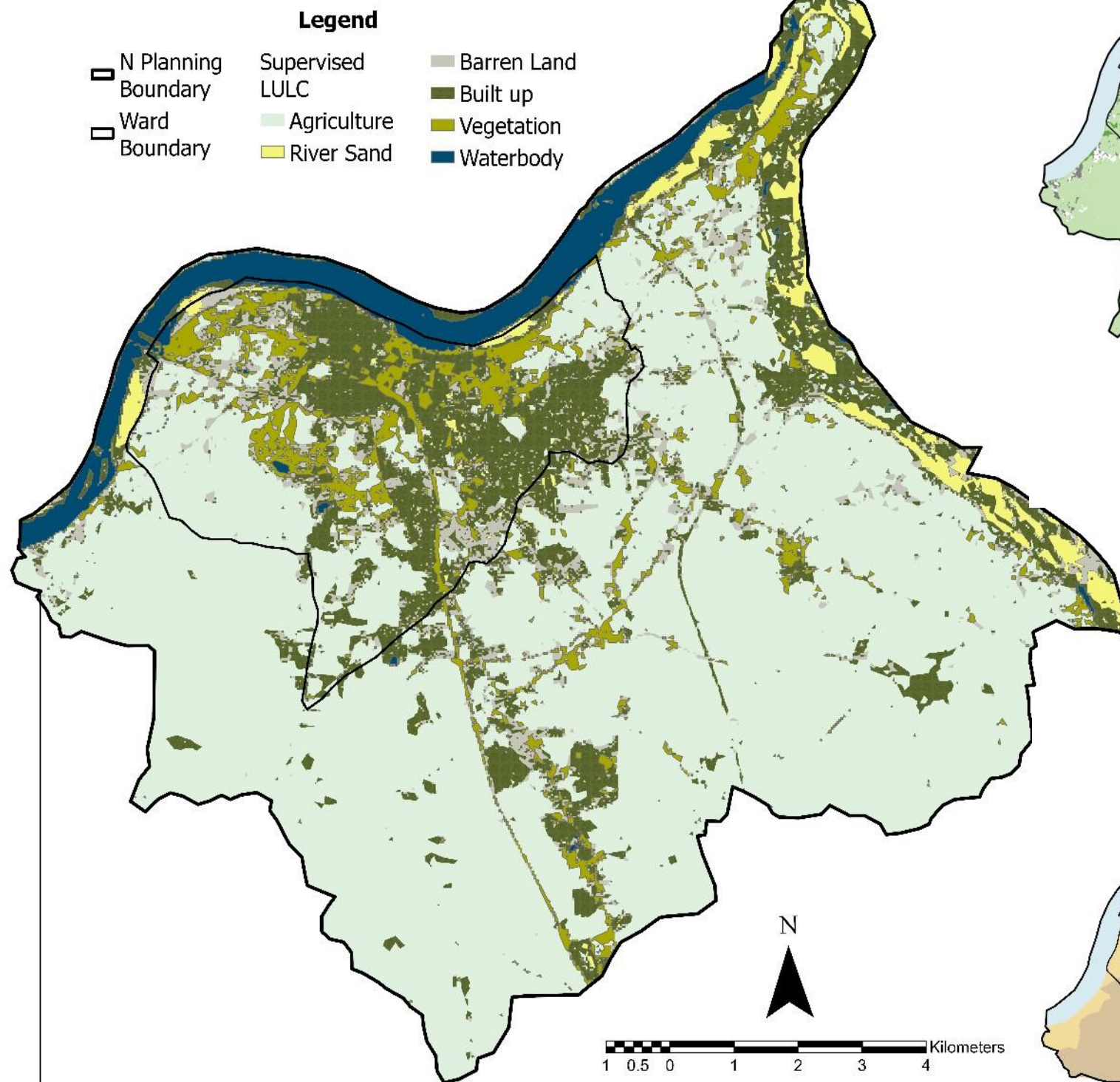
The analysis shows that agriculture land occupies the largest portion of the study area, covering about 89.75 sq.km (64.40%), which indicates that the town is surrounded by extensive agricultural landscape. Built-up area covers 21.13 sq.km (15.16%), mainly concentrated in the central part of the planning boundary, showing that urban development is limited to a smaller portion of the total area. The presence of 9.31 sq.km (6.67%) of barren land indicates availability of unused or low-productivity land, which is important for the present study as such areas can be considered for plantation and productivity enhancement.

Vegetation cover occupies 8.73 sq.km (6.26%), which shows that existing green cover within the planning boundary is relatively limited. Water bodies cover 6.27 sq.km (4.50%), mainly along the Narmada River and drainage channels, indicating strong hydrological influence in the northern part of the study area. In addition, 4.20 sq.km (3.01%) of river sand is observed along the river banks, which represents unstable land surface where development is restricted but ecological restoration or controlled plantation may be possible depending on soil condition.

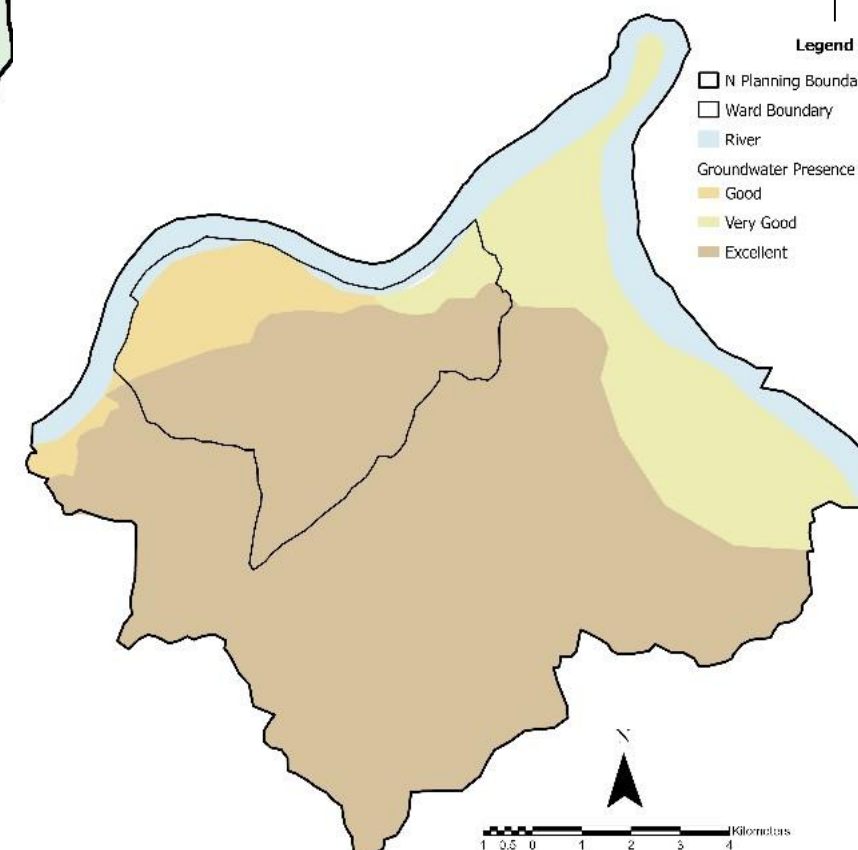
The LULC analysis is important for the present study because it helps in identifying unused land, low vegetation areas, and non-developed zones which



Represents existing green cover and vegetation distribution derived from LULC classification. Used to assess ecological condition and identify areas for canopy enhancement and plantation intervention.



Shows spatial variation of groundwater availability and moisture conditions across the study area



Landsat imagery from Landsat Collection 2 Level-2, Landsat 8-9 OLI/TIRS C2 L2 dataset

Image classification was carried out using supervised classification to identify major land use classes

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

I. Land use Land Cover Layer
II. Vegetation Layer
III. Groundwater Presence Layer



Scale
Specific to Map

Source
Author (2026)

Notes
15.16 area is covered with built up; Here vegetation consist of forest area and agriculture consists of grasslands; groundwater + moisture combined



Manit, Bhopal

MAP NO.

3

can be further examined through suitability analysis. Barren land, low vegetation areas, and open agricultural edges are considered potential zones for productivity enhancement, while built-up areas and water bodies are considered less suitable. Therefore, the LULC map forms a primary input layer for further multi-criteria suitability analysis.

4.3.2 Vegetation Layer

This map represents the spatial distribution of vegetation extracted from the Land Use Land Cover (LULC) classification, identifying areas with existing green cover, agricultural land, and barren land within the planning boundary. Barren and underutilized lands indicate higher potential for urban forest development and plantation interventions, while existing vegetation supports ecological continuity and enhancement.

Refer to Map No. 3 Land use Land Cover Layer, Vegetation Layer and Groundwater Presence Layer

The layer is used as a key input in suitability analysis to assess land condition and identify zones for increasing canopy cover and overall ecosystem productivity.

4.3.3 Groundwater Presence

The groundwater map represents the average groundwater level and moisture availability within the planning boundary, derived from the Narmadapuram Development Plan, 2031. The data reflects the overall groundwater condition by combining information on subsurface water levels and moisture presence across the study area.

For analysis, the groundwater layer was classified into three categories: Good, Very Good, and Excellent. Areas with excellent groundwater presence indicate higher moisture availability and contribute positively to vegetation growth and plantation sustainability. Areas with very good groundwater show moderate suitability, while areas with good groundwater availability indicate comparatively lower moisture support and contribute less to suitability.

*Refer to Map No. 3 Land use Land Cover Layer, Vegetation Layer and
Groundwater Presence Layer*

Thus, regions with higher groundwater presence are considered more suitable for urban forestry and productivity enhancement due to better long-term water availability.

4.3.4 Road Network Layer, Built up Layer & Watershed & River Layer

Road Network map represents the existing road network within the planning boundary, indicating levels of accessibility across the area. Roads act as primary connectors and play a crucial role in determining the feasibility of implementing urban forestry interventions.

This layer is selected to ensure that proposed plantation sites are accessible for development, maintenance, and public use, making it an important parameter for planning suitability.

*Refer to Map No. 4 Road Network Layer, Built up Layer, Catchment and
River layer (drainage) and Soil Texture Layer*

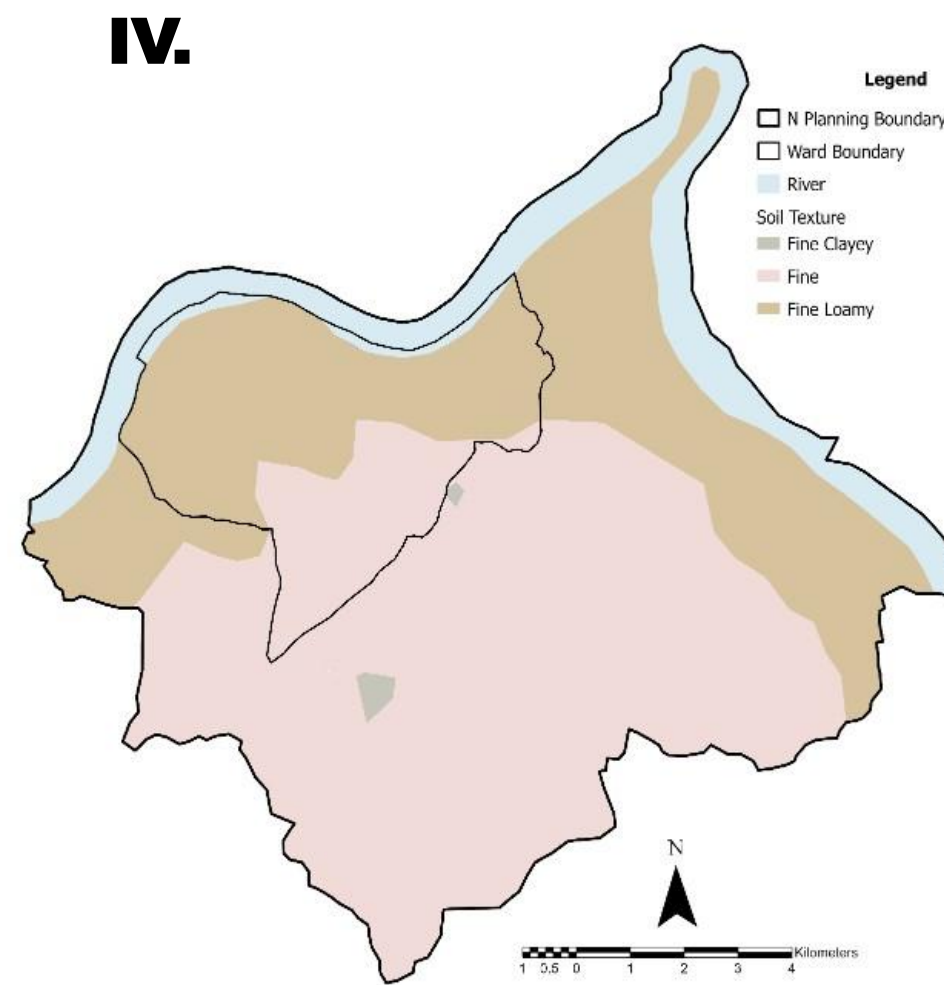
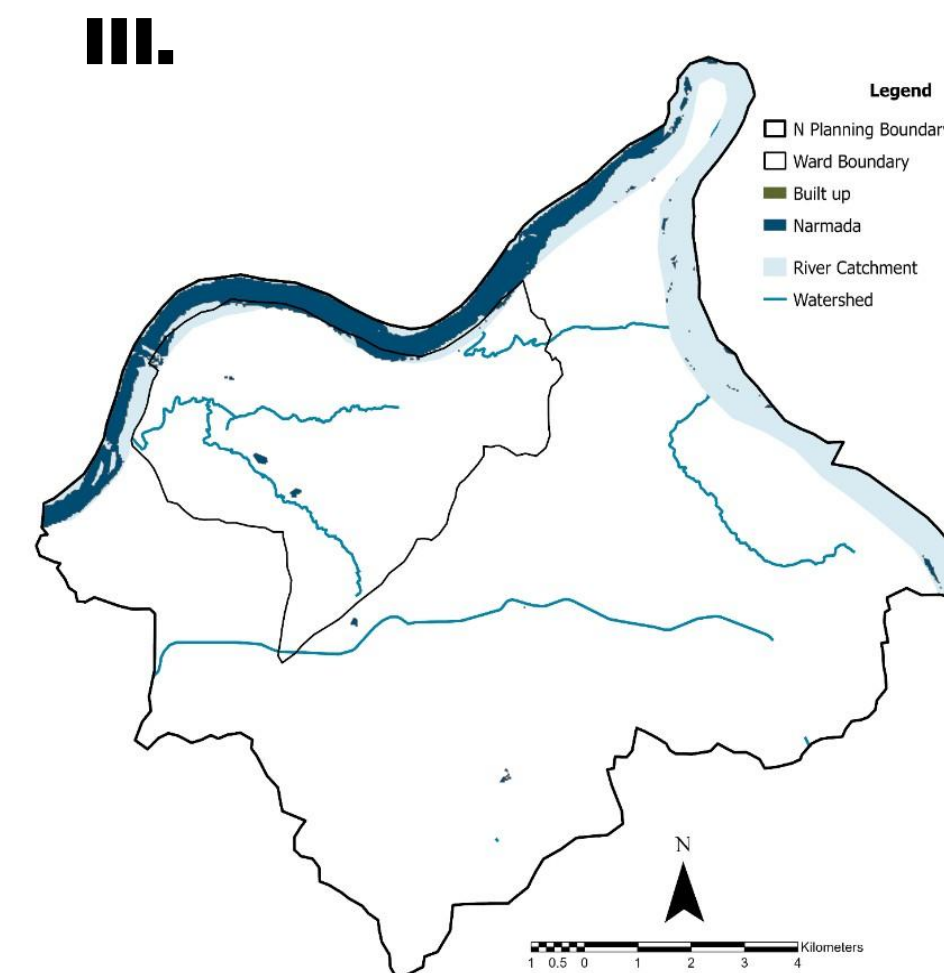
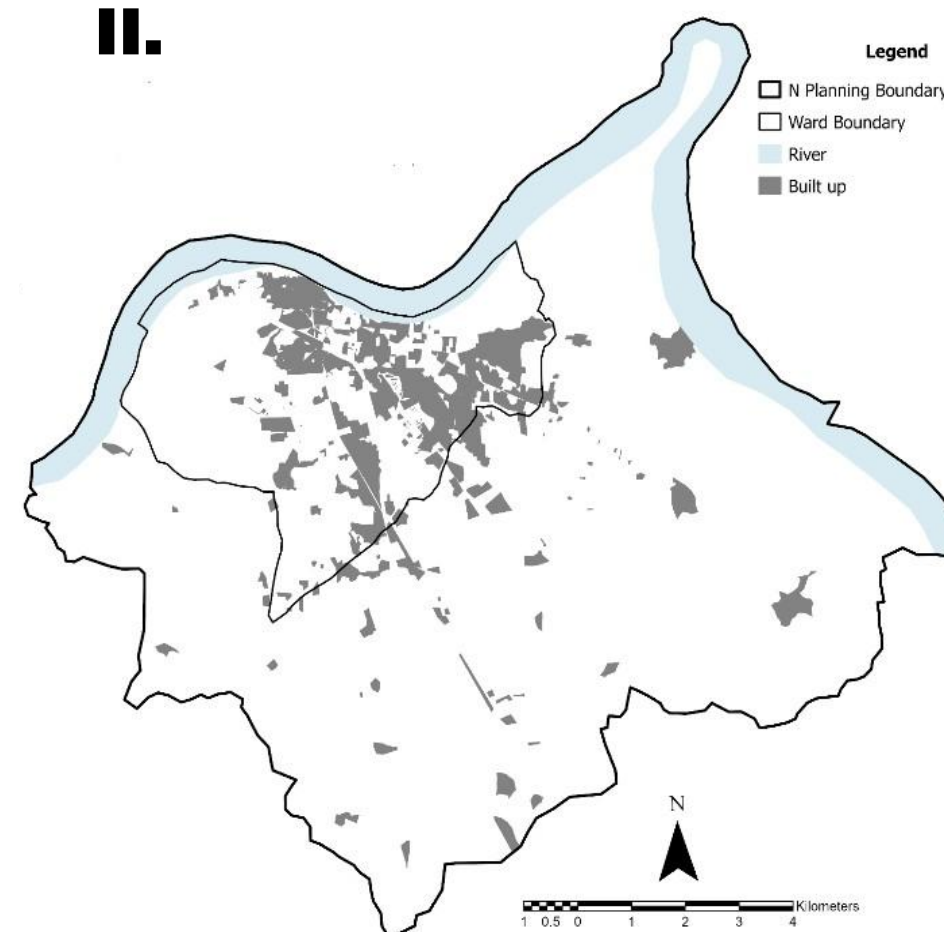
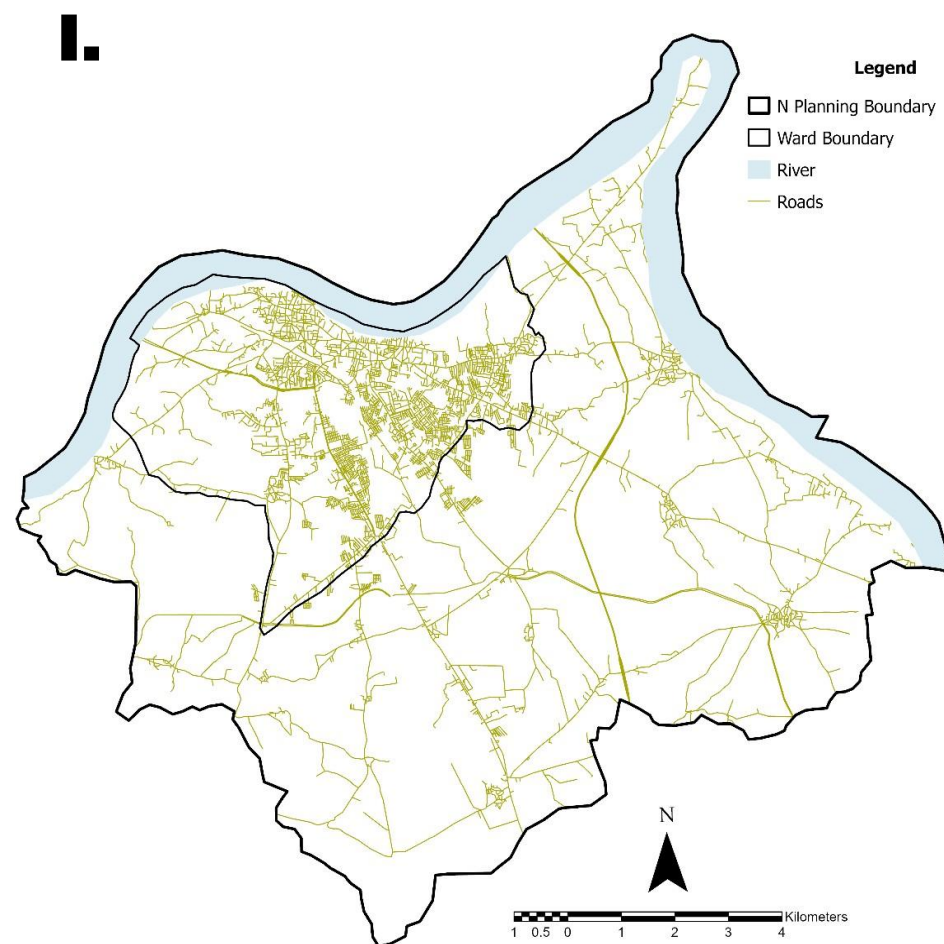
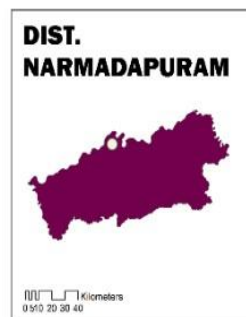
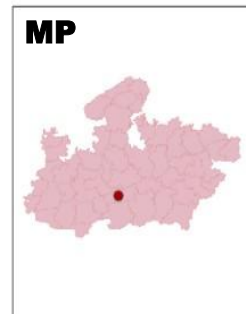
Built up map shows the spatial distribution of built-up areas, identifying developed and densely occupied zones within the study area. Built-up regions act as constraints, limiting the availability of land for plantation and ecological interventions.

This layer is used to exclude unsuitable areas and prioritize underutilized land, ensuring that urban forest development is feasible.

*Refer to Map No. 4 Road Network Layer, Built up Layer, Catchment and
River layer (drainage) and Soil Texture Layer*

Catchment map represents the river system, catchment area, and watershed network, highlighting natural drainage patterns within the planning boundary. It indicates zones of water flow, accumulation, and influence.

This layer is selected to assess hydrological suitability, as areas near drainage networks and within watershed zones have higher moisture availability and



“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

- I. Road Network Layer
- II. Built up Layer
- III. Catchment and River Layer (Drainage)
- IV. Soil Texture Layer



Scale
Specific to Map

Source
OpenStreetMap (OSM);
Development Plan 2035; Bhuvan /
DEM Data; National Bureau of Soil
Survey, Author's Digitization

Notes
Present built up have natural
growth towards fringes
Fine loamy is most suitable for
plantation, as clayey has less
aeration



Manit, Bhopal

MAP NO.

4

groundwater recharge potential, making them more suitable for plantation and ecological restoration.

Refer to Map No. 4 Road Network Layer, Built up Layer, Catchment and River layer (drainage) and Soil Texture Layer

4.3.5 Soil Texture Layer

This map represents the spatial distribution of soil types within the planning area, classified into fine clayey, fine, and fine loamy soils. Fine loamy soils exhibit better infiltration and aeration, making them more suitable for vegetation growth, while fine and clayey soils show comparatively lower permeability and higher water retention.

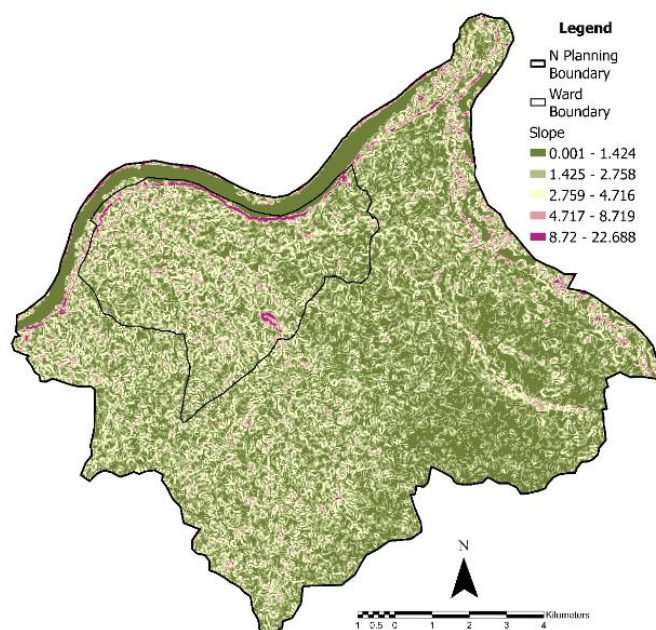
The layer is used to assess soil suitability for plantation, where areas with better infiltration capacity support higher vegetation growth, groundwater recharge, and overall hydrological performance in the suitability analysis.

Refer to Map No. 4 Road Network Layer, Built up Layer, Catchment and River layer (drainage) and Soil Texture Layer

4.3.6 Slope Layer

Slope map was derived from the DEM using the slope tool in ArcGIS. The slope map shows the gradient of land surface within the planning boundary. Areas with low slope are generally more suitable for plantation and land improvement, whereas areas with higher slope may require special treatment.

This map was not considered as one of the parameters in suitability analysis for identifying wasteland patches as, the



slope was negligible and most patches shall lie in relatively gentle slope conditions.

4.4. Correlation between Parameters using Matrices

Before performing multi-criteria suitability analysis, it is necessary to examine the relationship between the selected parameters, because spatial indicators used in ecological and land suitability studies are often inter-dependent. In multi-criteria spatial decision support systems, different environmental, hydrological, and planning variables may influence each other, and therefore their relationships must be analysed prior to assigning weights and performing overlay analysis.

Studies on ecological suitability and spatial decision support emphasize that multi-criteria evaluation requires identification of interrelations among indicators to avoid redundancy and to ensure logical weighting of parameters. The integration of GIS with multi-criteria decision analysis allows the evaluation of different criteria together while considering their mutual influence and dependency.

4.4.1 Correlation Check before Suitability Analysis

Before performing weighted overlay analysis, a correlation matrix was prepared between the selected parameters in order to examine the dependency and interaction among different spatial layers. In multi-criteria suitability studies, environmental and planning variables such as land use, vegetation, moisture condition, slope, drainage, and accessibility are often interrelated, and therefore correlation analysis is used to verify the logical consistency of selected parameters before overlay.

The matrix was prepared for LULC, vegetation, groundwater, drainage buffer, soil texture, built up buffer, and road buffer (accessibility) layers to understand their level of influence on each other. Higher values in the matrix represent strong relation, while lower values indicate weak or no dependency. This step helps in confirming that the selected parameters are compatible for multi-criteria GIS analysis and do not create contradictory results during suitability mapping.

The correlation matrix was used only as a validation step, and the weights assigned to each parameter were not modified, as the weights were already

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

derived from case study comparison, literature support, and objective-based evaluation carried out in the previous section. The matrix was prepared for LULC, vegetation, drainage buffer, groundwater, soil texture, built-up buffer, and road buffer (accessibility) layers to understand their level of influence on each other.

Para meter	LUL C	Vegetatio n	Drainage (Buffer Distance)	Groun dwater	Soil Textur e	Built up Buffer	Accessibility Buffer (Distance from Road)
No.	P1	P2	P3	P4	P5	P6	P7

Table 5.6 Finalised parameters for analysis

A five-level scale was used to represent the strength of relationship between any two parameters. The values were assigned as 0, 0.25, 0.5, 0.75, and 1, corresponding to no relation, low relation, medium relation, high relation, and strong relation, respectively. This scale helps in understanding how much one parameter influences another parameter during suitability evaluation. For example, land use and vegetation index have strong relation, while accessibility and moisture condition have weaker relation. (where, values = relation strength)

Values	0	0.25	0.5	0.75	1
Relation Strength	None	Low	Medium	High	Strong

Table 5.7 Strength of Relationship between parameters

Parameter ↓ / →	LULC	Vegetatio n	Drainag e Buffer	Groun dwater r	Soil Textur e	Built up Buffer	Road Buffer (Accessi bility)
LULC	1	0.75	0.75	0.50	0.75	0.75	0.50
Vegetation	0.75	1	0.75	0.50	0.50	0.75	0.25
Drainage Buffer	0.75	0.75	1	0.75	0.25	0.50	0.25
Groundwater	0.50	0.50	0.75	1	0.25	0.50	0.25
Soil Texture	0.75	0.50	0.25	0.25	1	0.75	0.50
Built up Buffer	0.75	0.75	0.50	0.50	0.75	1	0.50
Road Buffer (Accessibility)	0.50	0.25	0.25	0.25	0.50	0.50	1

5.8 Parameter Relationship Matrix

Before performing the final weighted overlay analysis, a correlation matrix was prepared to examine the relationship between the selected parameters used in the suitability evaluation. The purpose of this matrix was not to calculate the weights of parameters, but to verify the logical dependency among different variables selected from case studies and literature review. Since the present study includes parameters related to land use, vegetation condition, moisture availability, terrain, and planning feasibility, it was necessary to ensure that these parameters are compatible with each other before performing GIS-based overlay analysis.

The correlation values were assigned using a qualitative relation strength scale based on the known relationship between environmental variables, rather than using statistical correlation. This approach is supported in multi-criteria decision-making studies, where correlation or sensitivity analysis is used to examine the interaction among criteria before final suitability evaluation. The normalization and sensitivity analysis method discussed in multi-criteria evaluation research shows that checking the relationship between criteria helps in maintaining consistency in the final decision model and prevents the use of conflicting variables.

Similarly, in urban green space suitability studies, the relationship between criteria is considered during the overlay and weight assignment stage to avoid errors in final suitability mapping. Such studies explain that different spatial indicators such as land use, vegetation, slope (reference), and accessibility may influence each other, and therefore their dependency should be checked before combining them in a single suitability model. This ensures that the final output represents a logical combination of environmental and planning factors.

In the present study, the correlation matrix was therefore used only as a validation table to confirm that the selected parameters (P1–P7) are suitable for combined analysis. The weightage of parameters was not derived from the correlation matrix, as the weights were already assigned based on case study comparison, objective linkage, and parameter frequency analysis. The

matrix was used only to support the suitability model and to ensure that the final overlay is based on logically related spatial, ecological, hydrological, and planning variables.

Understanding it from, logical environmental dependency.

LULC ↔ Vegetation = 0.75

because vegetation depends on land cover

Groundwater ↔ Drainage = 0.75

because moisture depends on water proximity

Slope ↔ Drainage = 0.75

because flow depends on slope, *but here its negligible*

Soil Texture ↔ Vegetation = 0.5

moderate inverse relation

Access ↔ Vegetation = 0.25

weak relation

4.4.2. Basis of Correlation Scoring

The values used in the correlation matrix were assigned on the basis of logical and literature-supported relationships between environmental and planning parameters rather than statistical computation. In GIS-based multi-criteria suitability studies, parameters such as land use, vegetation, moisture index, slope, drainage, and accessibility are known to influence each other through natural and spatial processes. Therefore, correlation values were assigned using qualitative dependency scoring, where strong relationships were given higher values, moderate relationships were given medium values, and weak relationships were given lower values.

This approach is commonly used in multi-criteria decision-making and spatial suitability evaluation to ensure that selected parameters do not contradict each other during overlay analysis and to maintain consistency between environmental indicators and planning variables. The correlation matrix was used only as a validation tool, while final weights were derived

from case study comparison and literature-based parameter frequency analysis.

4.5. Matrix based Weighting Method

This will be a Frequency-based pairwise matrix where the parameters will follow a matrix based weighting method. The Pairwise comparison matrix is prepared based on comparative analysis of national and international case studies. Parameters frequently used in literature and directly related to study objectives were given higher priority.

This involves a 3-stage matrix where,

Matrix 1: Objective and Parameter

Parameter	Spatial	Ecosystem	Hydrology	Planning	Total
LULC	1	1	1	1	4
Vegetation	1	1	0	0	2
Drainage	1	0	1	1	3
Groundwater	0	0	1	0	1
Bare Soil	1	1	0	1	3
Built-up Buffer	1	0	0	1	2
Accessibility	1	0	0	1	2

Table 5.9 Matrix 1: Objective and Parameter

✓ related to objective = 1

✓ not related = 0

In order to ensure that the selected parameters directly support the objectives of the study, a parameter–objective relationship analysis was carried out. The present study is based on four main objectives, namely spatial suitability, ecosystem and productivity evaluation, hydrological assessment, and planning suitability. Since the final suitability analysis depends on multiple parameters, it was necessary to verify that each parameter contributes to one or more objectives of the study.

For this purpose, a tabular comparison was prepared in which the selected parameters were compared with the four objectives. A value of 1 was assigned when the parameter has direct relevance to a particular objective, and 0 was

assigned when the parameter has no significant influence on that objective. This method helps in understanding the functional role of each parameter in the overall suitability analysis and prevents the inclusion of unnecessary variables.

Parameters such as Land Use Land Cover (LULC) were found to be related to all four objectives, as land use controls spatial availability, ecosystem condition, hydrological behaviour, and planning feasibility. Vegetation and Soil Texture were linked mainly with spatial suitability and ecosystem productivity, as they represent vegetation density and exposed land condition. Groundwater and drainage buffer distance were strongly related to hydrological assessment, because moisture availability and proximity to water bodies directly affect vegetation growth and land productivity. Slope was related to both spatial and hydrological objectives, as terrain condition influences runoff, soil stability, and suitability for plantation, but in this case, it has negligible variation. Built up buffer and accessibility buffer were linked with planning suitability, because availability of open land and access to roads determine the feasibility of implementing plantation or land improvement.

The total value obtained for each parameter indicates its overall importance in achieving the objectives of the study. Parameters having higher total score contribute to more objectives and therefore are considered more important in the suitability analysis, while parameters with lower score are given comparatively lower weight. This approach provides a logical basis for assigning weightage and ensures that the final GIS-based suitability model is consistent with the objectives of the study.

Matrix 2: Case Frequency Matrix

Parameters	Intl. (4)	Indian (3)	Literature Support	Total
LULC	4	3	Yes	7
Vegetation	3	2	Yes	5
Drainage	4	3	Yes	7
Groundwater	2	1	Yes	3
Soil Texture	2	1	Yes	3
Built-up Buffer	2	1	Yes	3
Accessibility	2	1	Yes	3

Table 5.10 Matrix 2: Case Frequency Matrix

In order to justify the selection of parameters used in the suitability analysis, a comparative frequency analysis was carried out using international case studies, Indian case studies, and supporting literature. The purpose of this analysis was to identify the parameters that are commonly used in urban forestry, land suitability, and ecological planning studies, so that the present study remains consistent with established methods.

A tabular comparison was prepared in which each selected parameter was checked against the international cases, Indian cases, and relevant literature sources reviewed in the previous chapter. The international cases included studies related to urban forest suitability, ecosystem service evaluation, and GIS-based planning models, while the Indian cases included studies on land suitability, wasteland identification, and urban green space assessment. Literature support was also verified to ensure that the parameter has theoretical or methodological relevance in environmental or planning studies.

For each parameter, the number of cases in which it was used was counted, and a total score was obtained by combining international case frequency, Indian case frequency, and literature support. Parameters such as LULC and drainage show the highest total values, indicating that these variables are widely used in suitability and ecological studies and therefore must be given higher importance in the analysis. Vegetation layer also shows high frequency, confirming its relevance in representing existing land condition and productivity potential. Parameters such as groundwater, soil texture, built-up buffer, and accessibility buffer have comparatively lower frequency, but they were included as they are supported by literature and are important for representing hydrological support, land exposure, and planning feasibility at local level.

This frequency-based comparison provides a rational and literature-supported basis for limiting the analysis to selected parameters and avoids the use of unnecessary variables. The total value obtained for each parameter was further used in assigning relative weightage during the weighted overlay process, ensuring that the final suitability model reflects both case study evidence and study objectives.

Matrix 3: Final Weight Table

Final Score = Objective score + Case frequency

Weight % = Final score / Total score × 100

Taking values from Matrix 1 & 2, then giving final score and converting to weight %.

Here Total Score = 48

Parameter	Final Score	Weight %	Rank	Justification
LULC	11	23%	Very High	core parameter
Drainage buffer	10	21%	Very High	hydrological control
Vegetation	7	15%	High	vegetation suitability
Soil Texture	6	13%	Medium	land exposure
Groundwater	4	8%	Medium	subsurface support
Built-up buffer	5	10%	Medium	constraint
Accessibility	5	10%	Medium	planning feasibility

Table 5.11 Matrix 3: Final Weight

After completing the parameter–objective relationship analysis and case frequency analysis, the final weight of each parameter was calculated to be used in the weighted overlay suitability model. The weight calculation was done by combining the results obtained from the two previous matrices. The first matrix showed the linkage of each parameter with the four objectives of the study, while the second matrix showed the frequency of use of each parameter in international cases, Indian cases, and literature sources.

For each parameter, the values obtained from the objective linkage matrix and the case frequency matrix were added to obtain the final score. This final score represents the overall importance of the parameter based on both study objectives and previous research. Parameters that contribute to more objectives and are used in more case studies received higher final scores, while parameters with limited relevance received lower scores.

After obtaining the final score for all parameters, the values were converted into percentage weight so that they can be used in GIS weighted overlay analysis. The weight percentage was calculated using the formula:

$$\text{Weight (\%)} = \text{Final Score} / \text{Total Score} \times 100$$

The total score obtained from all parameters was 63, and each parameter weight was calculated in proportion to this total. Parameters such as LULC and NDWI received the highest weight because they are related to multiple objectives and are widely used in previous studies. Slope, NDVI, and drainage were given high weight because they directly influence land suitability, vegetation growth, and hydrological condition. Built-up, green space, and accessibility buffer received comparatively lower weight, as they act as supporting or constraint factors rather than primary environmental indicators.

This method ensures that the weight assigned to each layer is not arbitrary, but based on objective relevance, case study evidence, and literature support. The calculated weight percentages were then used in the weighted overlay tool in GIS to generate the final suitability map for identifying suitable patches.

4.6. Suitability Evaluation Model

4.6.1 Reclassification of Parameters for Suitability Analysis

The analysis considers local conditions to reclassify the basic impact factors in line with the attribute characteristics and the degree of influence on the evaluation. The UGS suitability classification consists of 3 levels and these levels have the numerical values 3, 2 or 1, which represent higher-suitability, medium-suitability and low-suitability (unsuitable), respectively in order to perform weighted overlay analysis in GIS. The classification is based on literature review, case study comparison, and environmental logic related to urban forestry and wasteland productivity. Parameters such as land use, vegetation, groundwater, drainage proximity, built up buffer, soil texture, and road buffer (accessibility) were grouped according to their suitability for vegetation development and ecological improvement.

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

This classification aligns with urban forestry requirements, where land is broadly categorized based on its feasibility for plantation.

Criteria	Sub-Criteria	3	2	1
Land surface condition (P1)	LULC	Barren land	Agriculture & Vegetation	Built-up, Waterbody & River Sand
Vegetation condition (P2)	Vegetation (density)	Sparce	Medium	Dense
Moisture condition (P3)	Drainage Buffer	>300 m River influence	150 m Channels	50 m Tributaries
Lithology (P4)	Soil Texture (type)	Fine Loamy	Fine	Fine Clayey
Hydrologic influence (P5)	Groundwater (availability)	High	Medium	Low
Surface exposure (P6)	Built up Buffer	<200 m	-	>200 m
Planning feasibility (P7)	Distance from road	< 100 m	100 - 200 m	>200 m

Table 5.12 Reclassification of Parameters

Higher suitability values were assigned to barren land, moderate vegetation zones, locations near drainage, exposed soil surfaces, open lands, and moderately accessible areas, as these conditions are favourable for plantation and productivity enhancement.

Lower values were assigned to built-up areas, very dry zones, and highly disturbed locations. This reclassification was used as input for weighted overlay analysis to identify suitable patches within the planning boundary.

4.6.2 Evaluation Criteria

The influence at reclassification stage, reflect the natural dynamics of the environmental and territorial systems, where link and interaction pathways

exist between individual elements, which can, positively or negatively, affect each other (Bottero and Ferretti, 2011).

In the next phase, evaluation criteria the parameters have been represented as thematic map layers in a GIS database.

It is worth specifying that factors are compensatory criteria that contribute to a certain degree to the output (suitability). There are two types of factors: (i) benefit criteria and (ii) cost criteria. A benefit criterion contributes positively to the output (the higher are the values, the better it is), while a cost criterion contributes negatively to the output (the lower are the values, the better it is).

The present study does not consider any constraint in the model since the least suitable areas to host ecological corridors, such as urban areas (in layer), are excluded from the analysis.

Maps are computed through basic raster GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.).

4.7. Indicator Description

Indicators	Description
Land Use Land Cover	The criterion considers the existing land use pattern within the planning boundary. The LULC map was prepared using classified satellite imagery to identify built-up area, vegetation, agriculture land, barren land, river sand, and water bodies. The map was further processed in GIS so that each pixel represents the present land surface condition. Areas with barren land, low vegetation, and unused land contribute positively to the suitability for plantation, while built-up areas contribute negatively to the final suitability index.
Vegetation	The criterion considers the distribution and density of vegetation extracted from the LULC map. Instead of using index-based values, vegetation is categorized into dense, medium, and sparse classes. Areas with sparse or low vegetation indicate potential for plantation and contribute positively to suitability, while dense vegetation areas are already ecologically stable and contribute negatively to additional plantation suitability.
Drainage / River Buffer Distance	The criterion considers the proximity to river and drainage network within the planning boundary. Buffer zones were created around rivers and drainage lines using GIS tools to represent the influence of water availability. Areas closer to

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Indicators	Description
	drainage networks have better moisture conditions and support vegetation growth, therefore contributing positively to suitability. Areas farther from drainage contribute less due to lower moisture availability.
Soil Texture	The criterion considers the soil texture within the planning boundary, which influences vegetation growth and plantation suitability. The soil map was classified into Fine clayey, Fine, and Fine loamy soil categories based on their physical characteristics. Fine clayey soils are dense and have poor drainage and aeration, making them less suitable for vegetation. Fine soils show moderate conditions for plantation. Fine loamy soils provide balanced texture with better drainage, aeration, and nutrient availability, making them most suitable for vegetation and productivity enhancement. Therefore, areas with fine loamy soil contribute positively to suitability, while fine clayey soils contribute negatively to the final suitability index.
Groundwater Availability	The criterion considers the availability of groundwater within the planning boundary using data from Geological Survey of India. Areas with higher groundwater availability contribute positively to suitability as they support better vegetation growth and long-term sustainability. Areas with low groundwater availability contribute negatively due to limited moisture support.
Distance from Road (Accessibility)	The criterion considers accessibility of land parcels from the existing road network. Buffer zones were created around roads using GIS to determine the distance of each pixel from roads. Areas located closer to roads are considered more suitable because they are easily accessible for plantation activities, maintenance, and public use. Areas far from roads contribute negatively due to limited accessibility.
Built-up Buffer	The criterion considers the proximity of land to built-up areas. Buffer zones were created around settlements to identify influence zones. Areas located within a defined buffer distance from built-up zones are considered suitable as they can serve a larger population and improve urban environmental conditions. Areas far from built-up zones are less suitable in terms of planning and social benefit.

Table 5.13 Indicator Description

These maps represent different evaluation scenarios in order to analyse land suitability for urban green spaces i.e. urban forests.

Drainage Buffer

River buffer is prepared using the Narmada River, channels and other tributaries layer obtained from base map and satellite reference. Buffer zones were generated in ArcGIS at selected distances of 50m, 150 m and more than it to understand the influence of river proximity on land condition. Areas near the river may have better moisture condition, but some parts may contain sand deposits or unstable soil. Therefore, buffer analysis is used carefully to identify suitable areas for productivity enhancement without including unstable riverbed zones.

Refer to Map No. 5 Drainage Buffer Layer, Road Buffer Layer & Reclassified Layers

Road Buffer

Accessibility buffer map was prepared using the existing road network to understand the distance of different land parcels from transport routes within the planning boundary. Buffer zones of 100 m and 200 m were generated in GIS to evaluate the accessibility condition of each location. The purpose of this analysis is to identify areas that are easily reachable for plantation work, maintenance, and monitoring activities.

Refer to Map No. 5 Drainage Buffer Layer, Road Buffer Layer & Reclassified Layers

Areas located within 100 m from the road network are highly accessible and zones between 100 m and 200 m show moderate accessibility and are considered suitable for plantation as they are reachable but relatively less disturbed. Areas beyond 200 m represent low accessibility zones, where implementation of plantation or land improvement may be difficult due to lack of approach roads.

4.8. Layers Reclassified & Weighted Overlay

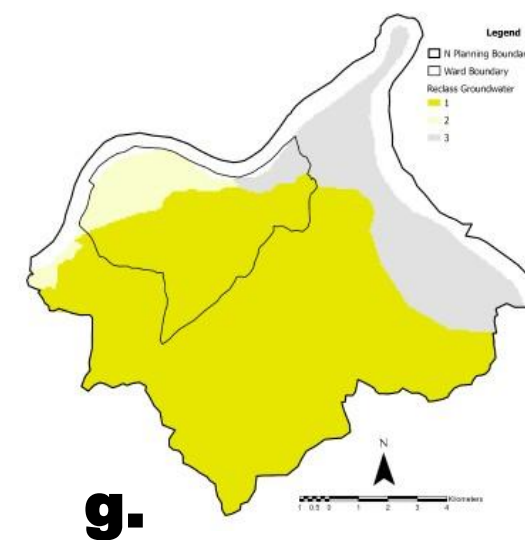
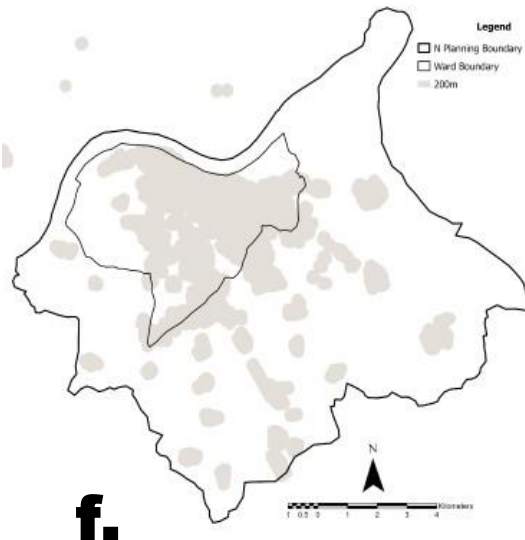
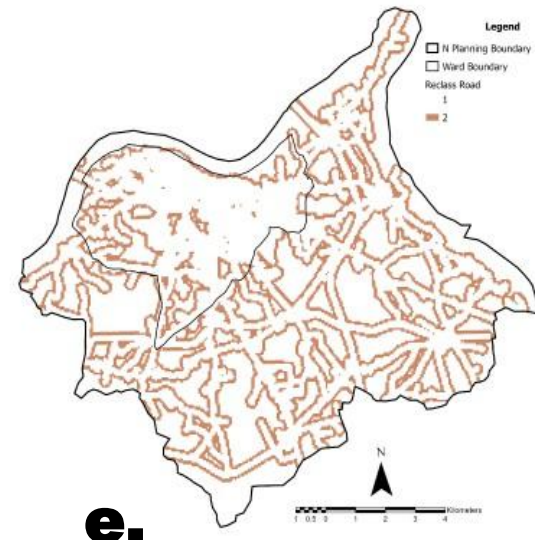
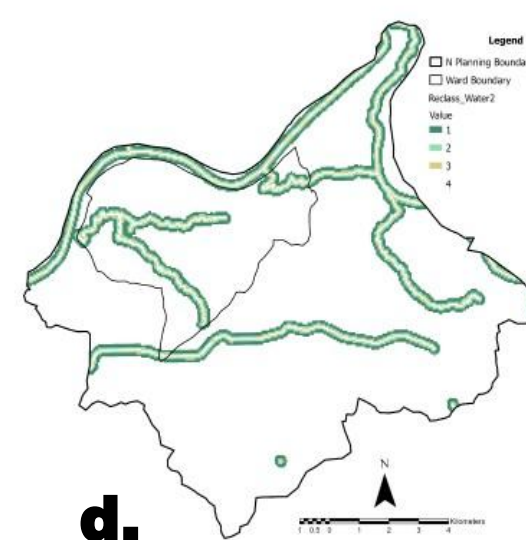
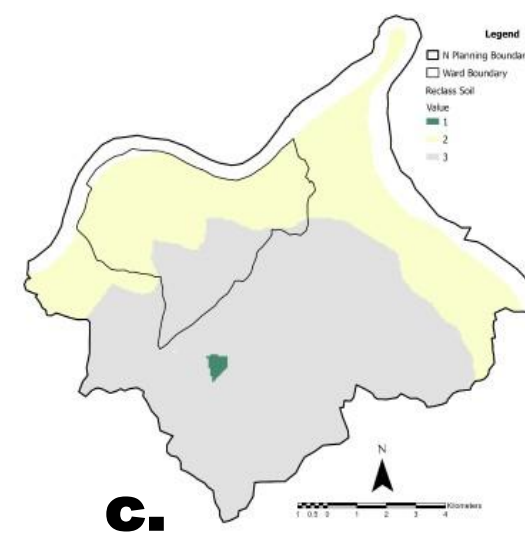
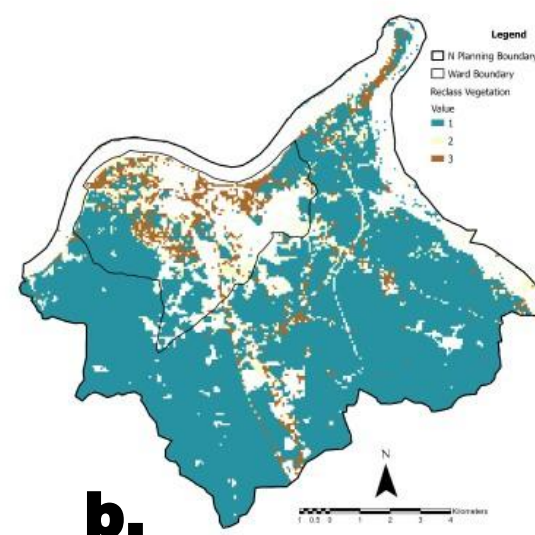
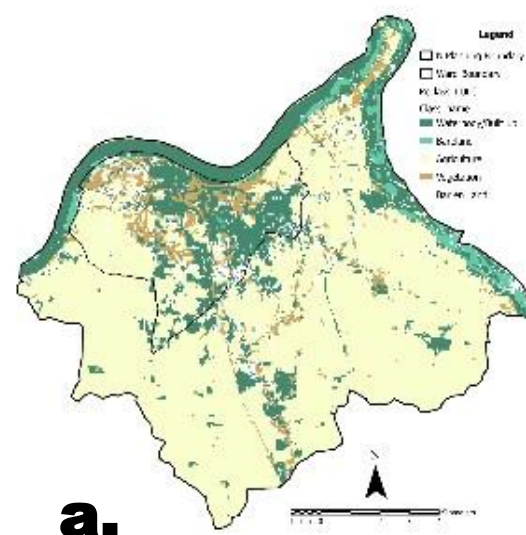
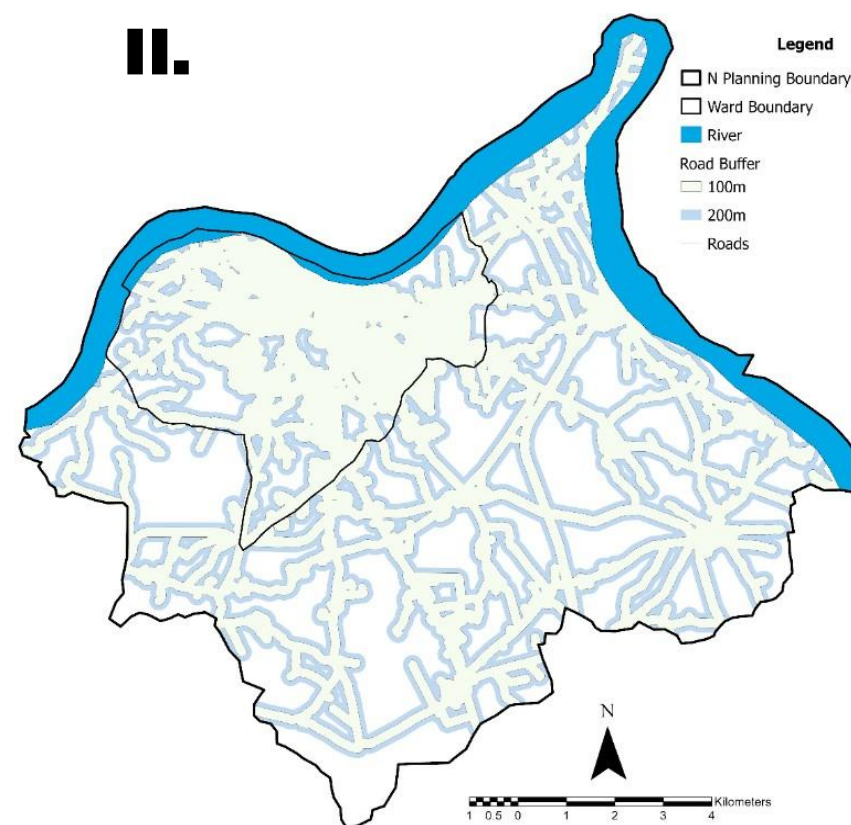
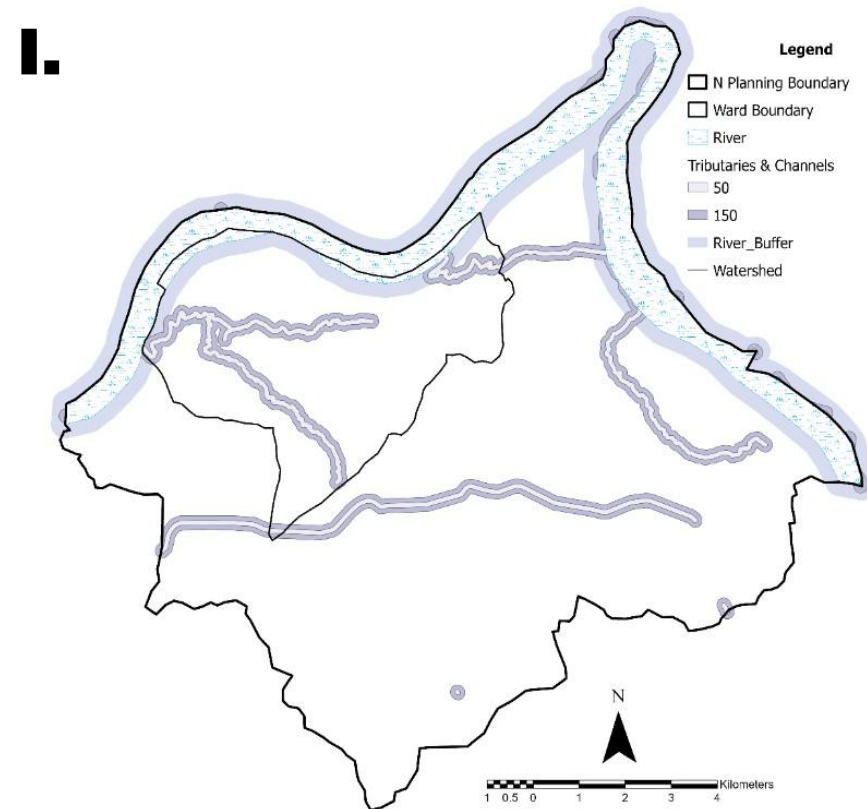
Refer to Map No. 5 Drainage Buffer Layer, Road Buffer Layer & Reclassified Layers

Ecological–Hydrological Layer (First Overlay)

Vegetation + Drainage Buffer + Bare Soil + Groundwater

This layer identifies areas with suitable soil, moisture, and vegetation conditions.

Refer to Map No. 6 Overlay I, Overlay II & Suitability Map (Overlay)



a. Land use land cover
b. Vegetation
c. Soil Texture
d. Drainage Buffer
e. Road Buffer
f. Built up Buffer
g. Groundwater Occurrence

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

I. Drainage Buffer Layer
II. Road Buffer Layer
III. Reclassified Layers



Scale
Specific to Map

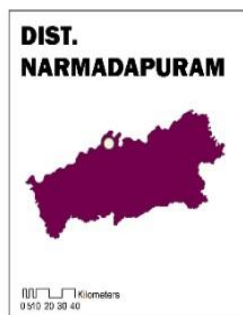
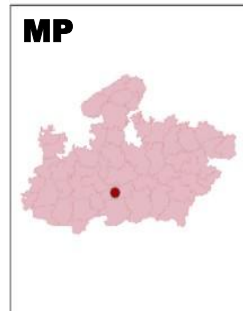
Source
Author (2026)

Notes
m.



Manit, Bhopal

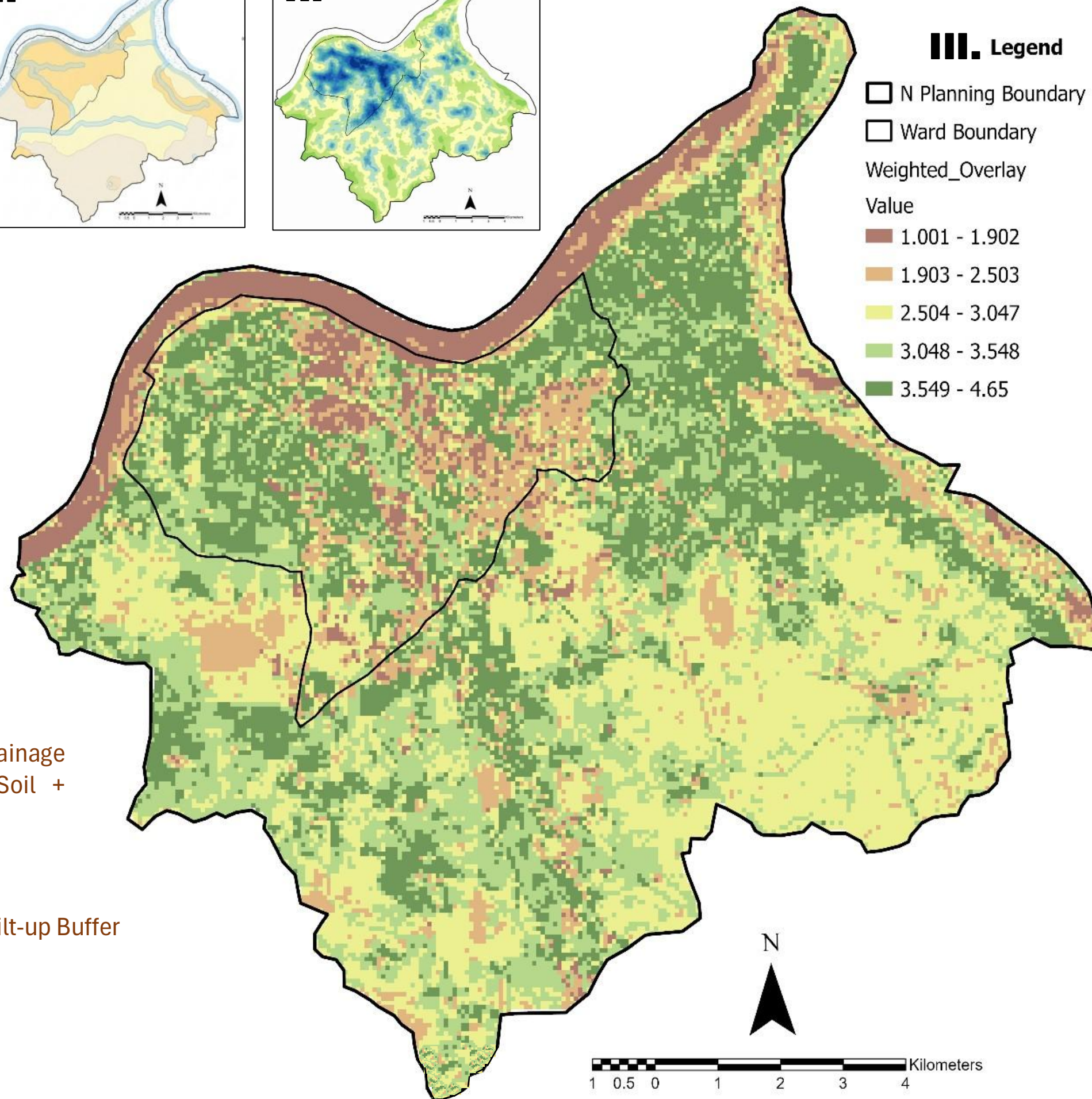
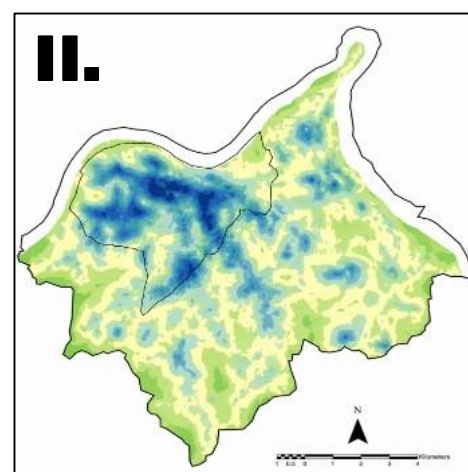
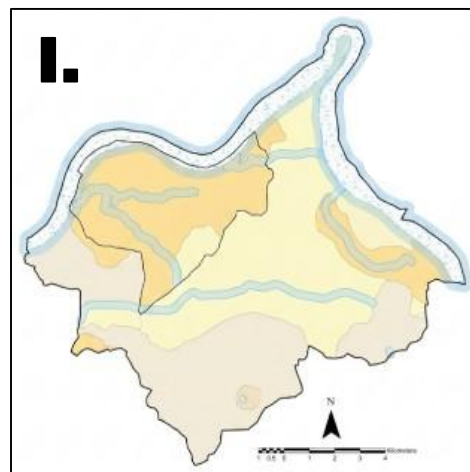
MAP NO.
5



I.
Vegetation + Drainage
Buffer + Bare Soil +
Groundwater

II.
Road Buffer + Built-up Buffer

III.
LULC + I + II



III. Legend

□ N Planning Boundary

□ Ward Boundary

Weighted_Overlay

Value

1.001 - 1.902

1.903 - 2.503

2.504 - 3.047

3.048 - 3.548

3.549 - 4.65

“ECOSYSTEM
SERVICE-BASED
URBAN FOREST
PLANNING: A SPATIAL
SUITABILITY
ASSESSMENT FOR
NARMADAPURAM,
M.P.”

I. Overlay I Layer

**II. Overlay II
Layer**

**III. Suitability
Map (Overlay)**



Scale
Specific to Map

Source
Author (2026)

Notes
m.



Manit, Bhopal

MAP NO.

6

Planning Layer (Second Overlay)

Road Buffer + Built-up Buffer

This layer represents accessibility and feasibility.

*Refer to **Map No. 6 Overlay I, Overlay II & Suitability Map (Overlay)***

Suitability Classification Method

The overlay I and II were overlayed with LULC layer. The final suitability raster obtained from weighted overlay was classified into five categories: Very High, High, Moderate, Low, and Unsuitable. The classification was carried out using Natural Break (Jenks) method in ArcGIS, which groups pixels based on similarity of values. This method is commonly used in spatial suitability analysis because it represents natural grouping of data without forcing equal ranges.

The classification ranges were decided based on the minimum and maximum suitability index values obtained from the overlay result.

*Refer to **Map No. 6 Overlay I, Overlay II & Suitability Map (Overlay)***

Weighted overlay analysis was carried out by combining all the selected parameters including land use land cover, NDVI, NDWI, slope, drainage proximity, bare soil, green land, and accessibility buffer using the assigned weights. The output raster represents the final suitability index for identifying suitable patches within the planning boundary. The resulting values range from 1.001 to 4.65, which were classified into five suitability categories: Very High, High, Moderate, Low, and Unsuitable.

	Range	Class	
–	3.549 – 4.65	Very High	Areas having values between 3.549
	3.048 – 3.548	High	4.65 fall under Very High suitability,
	2.504 – 3.047	Moderate	indicating locations where land
	1.903 – 2.503	Low	condition, moisture availability,
	1.001 – 1.902	Unsuitable	terrain, and accessibility.

Table 5.14 Suitability Ranges

are favourable for plantation and productivity enhancement. These areas are mostly found in peripheral zones, open land patches, and locations having

moderate vegetation and good hydrological support. Such areas are considered most suitable for future plantation and land improvement.

Values between 3.048 – 3.548 represent High suitability areas. These zones have generally favourable land conditions but may have minor limitations such as moderate slope (negligible), partial vegetation cover, or moderate distance from drainage. These areas are also suitable for plantation with minimal intervention.

The range 2.504 – 3.047 falls under Moderate suitability, where some parameters support plantation while others show limitations. These areas may require soil improvement, moisture support, or planning intervention before plantation can be carried out. Moderate suitability zones are mainly observed around mixed land use areas and agricultural edges.

Values between 1.903 – 2.503 represent Low suitability areas. These locations show unfavourable conditions such as poor moisture, higher slope, or unsuitable land use. Plantation in these areas may not be effective without major land treatment or planning changes.

Areas having values between 1.001 – 1.902 fall under Unsuitable category, which mainly includes built-up areas, river sand zones, steep slopes, and locations with very low vegetation or poor accessibility. These areas are not suitable for plantation or productivity enhancement and are therefore excluded from further consideration.

According to the analysis results, the weighted overlay method helped in identifying the most compatible combination of spatial, ecological, hydrological, and planning parameters, and the final suitability map shows the areas where plantation and productivity enhancement can be carried out effectively within the planning boundary.

4.9 Proposal Outline

The proposal shall be prepared using:

- i) Development Plan Land Use
- ii) Hierarchy-wise patch priority classification
- iii) River-centric planning guidelines

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

- iv) NGT buffer and environmental guidelines
- v) Economic feasibility and implementation potential
- vi) Existing and proposed plantation schemes

Component	Basis / Model	Purpose	Proposal Support
Hierarchy wise Priority (size)	Suitability map patch classification size	Identify priority ecological patches	Large → main forest, Medium → plantation, Small → local green
Riparian Buffer	Cases	Eco-conservation & Stabilize floodwater	Dedicated patches along river narmada
MVAK – Nagar Van Yojana	Malakhedi Van-Amrit Kendra	Nutrient recycling, carbon sequestration, urban carbon sink	Large patch urban forest
Green belts along major roads	Linear plantation	Pollution control, buffer, green corridor	Roadside plantation zones
Fort Urban Park (proposed)	Large open land development	Major ecological open space	Priority large patch

Table 5.15 Proposal Outline

- Additional proposal controls derived from the Hoshangabad Development Plan 2035 and Narmada River buffer regulations:

Control Element	Proposal Requirement
Narmada River Buffer	A mandatory 300 m open buffer shall be maintained on both sides of the Narmada River bank.
Permitted Use in Buffer	Only social forestry, landscaping, gardens, plantation, pump house, watchman shelter, parking and ecological restoration shall be permitted.
Prohibited Use in Buffer	No permanent building, residential, commercial or institutional construction shall be allowed within the 300 m buffer zone.
Floodplain Treatment	Floodplain area to be retained as no-development ecological land with native riparian plantation.
Riverfront Edge	Where public use is required, only low-impact recreational space, walking trail, ghat improvement and ecological park may be proposed.
Land Use Priority	Government land, open land, recreational land and vacant public parcels falling within the buffer should be converted into urban forestry and river-edge green belt.
Major Opportunity Area	Malakhedi–Bandrabhan side and other large vacant/open parcels along Narmada edge may be developed as Nagar Van / urban forest blocks.

Table 5.16 Proposal Requirement

CHAPTER – 05

PLANNING PROPOSAL

Tree Cover –

It comprises of tree patches of size less than the minimum mappable 1 ha & more (*upto 0.5 ha*) occurring outside the recorded forest area. Tree cover includes trees in all formations including with patches comprising of;

- a. Block Plantations
- b. Scattered
- c. Linear

The tree cover is assessed following a methodology involving remote sensing based stratification and observations on sample plots laid in the strata as part of the National Forest Inventory.

Trees Outside Forests (TOF) –

TOF refers to all trees growing outside recorded forest areas irrespective of patch size. In India, the definition and standard size of an urban forest patch for mapping and assessment purposes are governed by the Forest Survey of India (FSI), which generally adheres to the following criteria based on the India State of Forest Report (ISFR), 2019.

Proposal Framework and Approach

The proposal framework is developed as an extension of the spatial suitability analysis, translating analytical outcomes into site-specific planning interventions. Based on the identified suitable patches and thematic understanding of ecological, hydrological, and planning parameters, a set of integrated proposals has been formulated to guide urban forestry development within the study area.

The approach focuses on utilizing underdeveloped, environmentally sensitive, and non-developable land for vegetation-based interventions, ensuring that ecological restoration does not conflict with existing land use or urban development patterns. The proposals are structured to address multiple objectives, including enhancement of ecosystem services, improvement of hydrological performance, strengthening of green infrastructure, and provision of accessible public spaces.

A hierarchy-based strategy is adopted, wherein interventions are designed according to the size, location, and functional characteristics of identified patches. Accordingly, the

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

proposals are categorized into urban forest patches, linear greenways, riparian buffers, and conservatory landscapes. Each intervention responds to specific spatial conditions while contributing to an interconnected green network across the city.

The overall framework emphasizes a nature-based, planning-oriented approach, where urban forestry is integrated with land-use planning and watershed systems to achieve long-term environmental sustainability, climate resilience, and improved urban livability.

Proposal I_ Identification of Suitable Patches based on Size Hierarchy

Rationale

The identification of suitable patches for urban forest development is carried out based on a GIS-based weighted overlay analysis, ensuring that selected areas are environmentally suitable, hydrologically viable, and planning-compliant. The approach prioritizes land that can be utilized without violating existing development regulations.

The Development Plan designates a 300 m buffer along the river as a non-construction zone, permitting only ecological and green-based activities. This provides an opportunity to utilize such areas for urban forestry interventions. Additionally, the provision of Green Transferable Development Rights (TDR) can be considered to compensate affected land parcels, enabling their conversion into ecological patches.

Methodology for Patch Identification

The process involves a stepwise spatial analysis to extract suitable patches from the weighted overlay output.

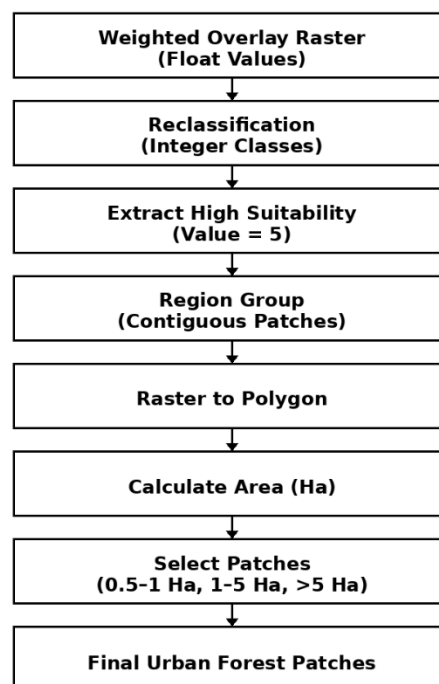


Figure 6.1 Procedure for identification of patches

This method ensures that only spatially continuous and practically implementable patches are selected.

Size Hierarchy of Patches

The identified patches are categorized based on their spatial extent to guide intervention strategies:

Patch Category	Size Range	Intervention Type
Large Patches	> 5 Ha	Nagar Van / Urban Forest
Medium Patches	1–5 Ha	Block Plantation / Green Buffer
Small Patches	0.5–1 Ha	Micro Forest / Community Greens

Table 6.1 Patch Classification

Refer to Map No. 7 (I) Most Suitable Patches, (II) Category based classification of Patches & (III) Selectively proposed sites for intervention

This classification helps in defining the scale, density, and type of plantation suitable for each patch.

Refer to Map No. 7 (I) Most Suitable Patches, (II) Category based classification of Patches & (III) Selectively proposed sites for intervention

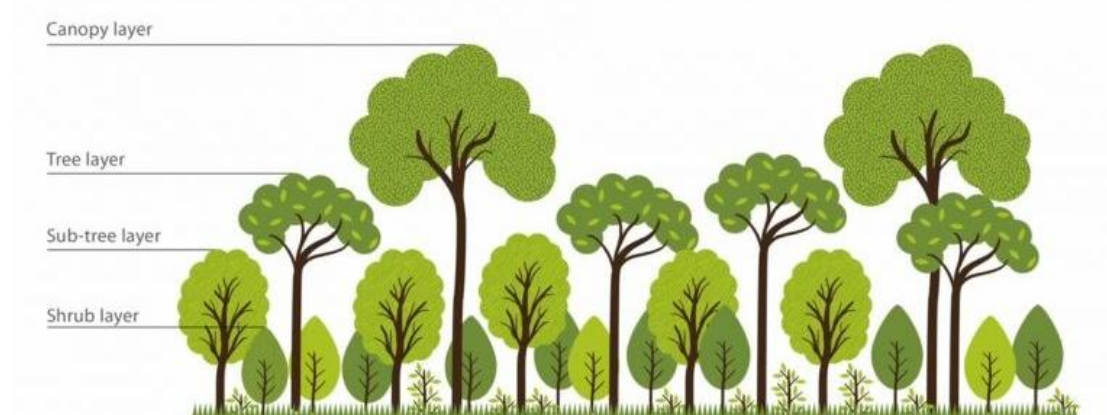
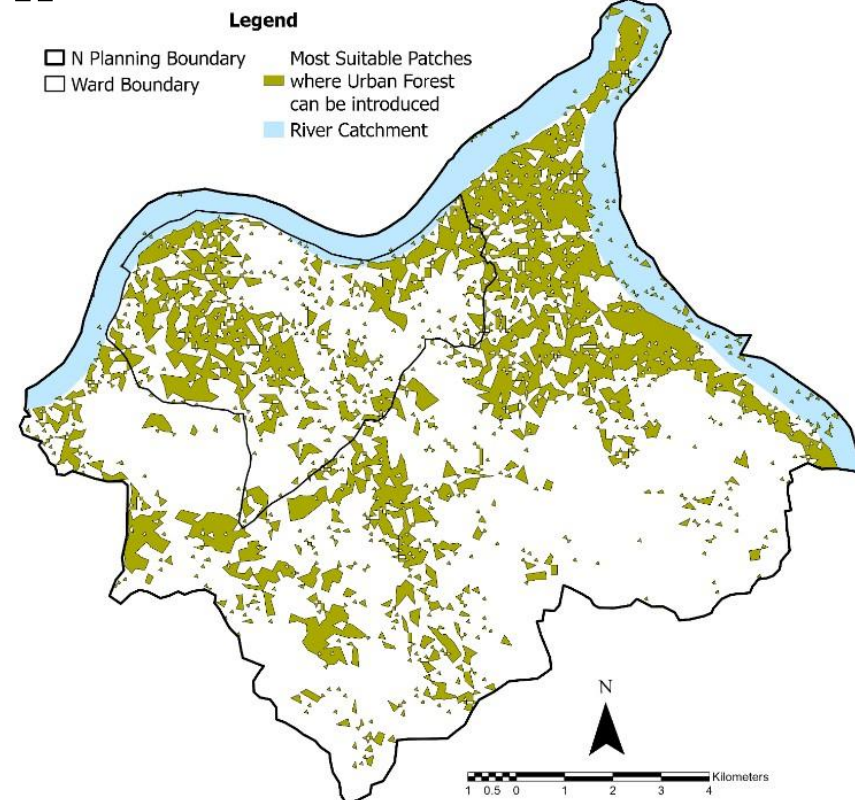
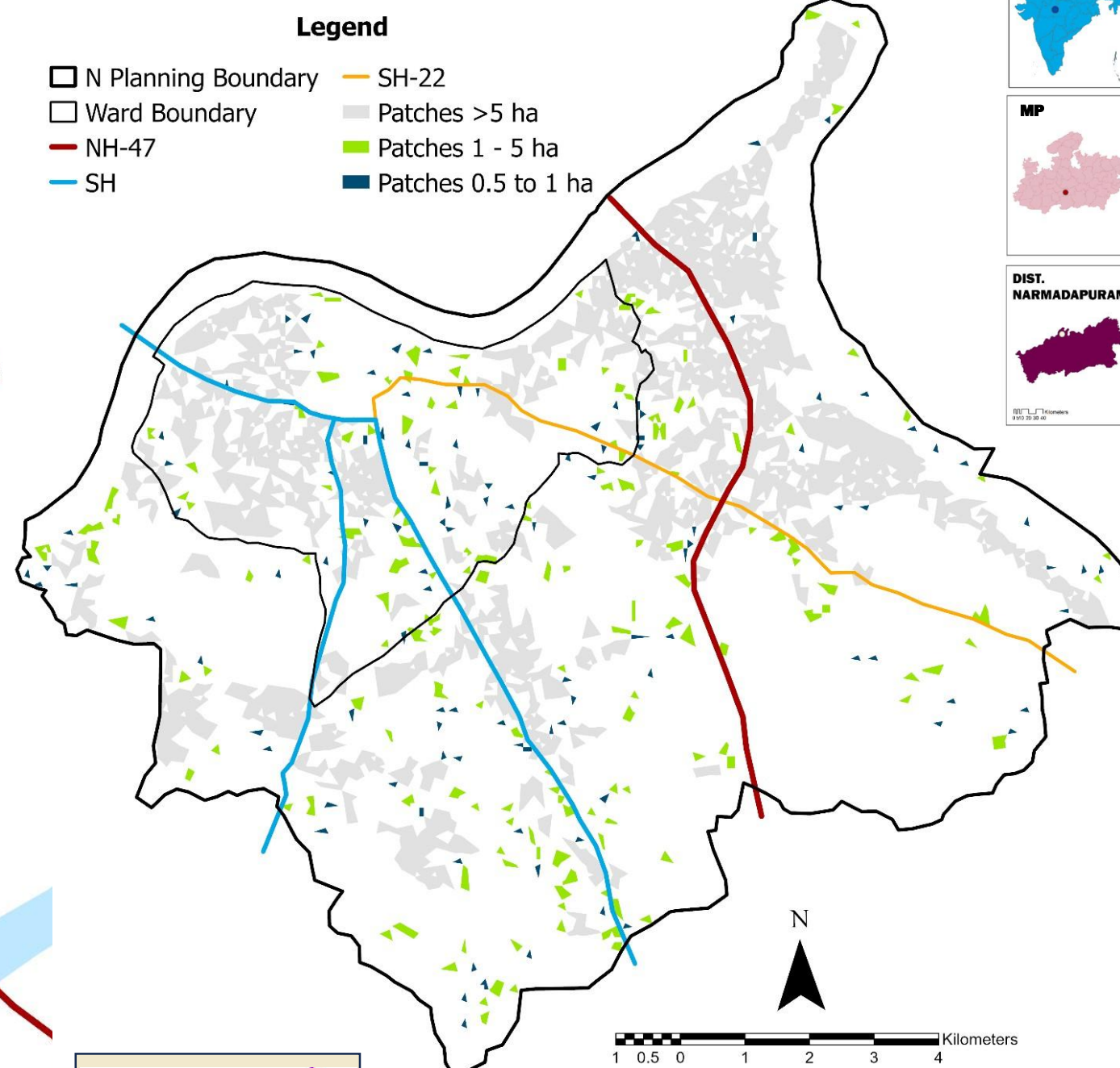


Figure 6.2 Layers of trees

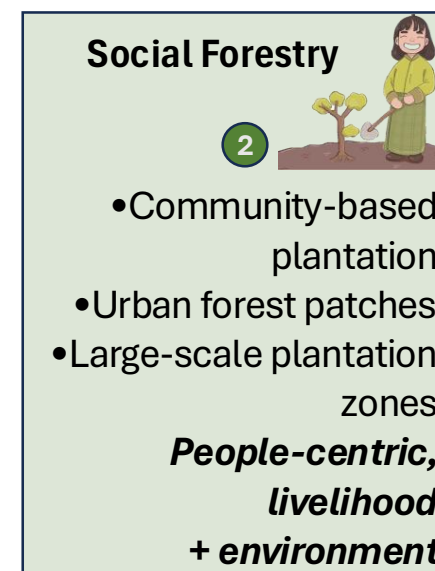
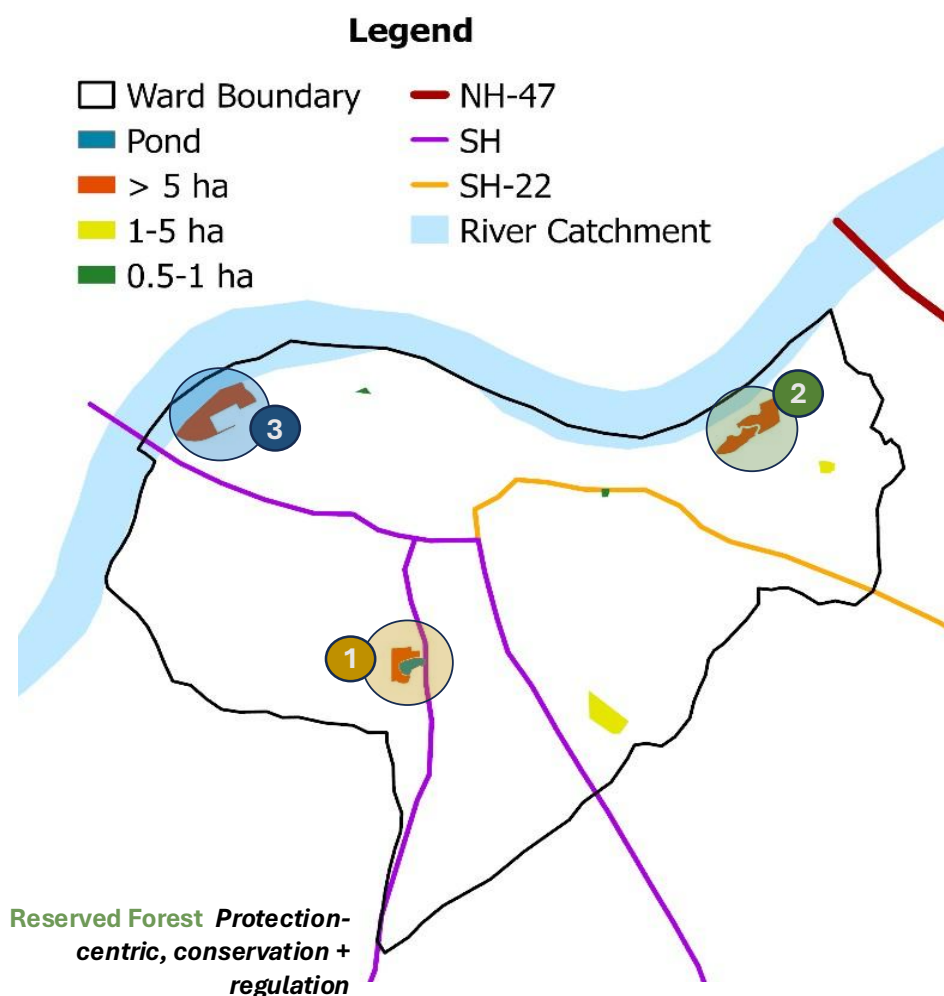
I.



II.



III.



“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Proposal 1
I. Most Suitable Patches
II. Category based classification of Patches
III. Selectively proposed sites for intervention



Scale
Specific to Map

Source
Author (2026)

Notes
This classification helps in defining the scale, density, and type of plantation suitable for each patch.



Manit, Bhopal

MAP NO.

7

Hydrological Considerations

Hydrological suitability plays a critical role in patch selection. The identified patches are evaluated based on:

- I. Proximity to drainage and river systems
- II. Groundwater availability and recharge potential
- III. Soil infiltration characteristics
- IV. Natural rainfall (~1100–1300 mm annually)

Areas with higher hydrological potential support better vegetation growth, leading to increased biomass and carbon sequestration capacity.

Plantation Strategy: Miyawaki Technique

The Miyawaki technique is adopted for plantation due to its rapid growth rate, high survival rate, and dense vegetation structure.

Plantation Characteristics

- i) High density plantation (3–5 saplings per sq.m)
- ii) Multi-layer vegetation (trees, shrubs, ground cover)
- iii) Native species selection

Suggested Species

- I. Neem (*Azadirachta indica*)
- II. Peepal (*Ficus religiosa*)
- III. Banyan (*Ficus benghalensis*)
- IV. Arjun (*Terminalia arjuna*)
- V. Jamun (*Syzygium cumini*)
- VI. Amla (*Phyllanthus emblica*)

Cost and Carbon Estimation

Parameter	Value (Approx.)
Cost per tree	₹80–150
Cost per hectare	₹8–12 lakh
Carbon sequestration	20–25 kg CO ₂ /tree/year
1 Ha plantation	~20–30 tons CO ₂ /year

Table 6.2 Cost and Carbon Estimation

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

This indicates that urban forest patches can act as effective carbon sinks while remaining economically feasible.

Policy and Program Support

The proposal aligns with existing government schemes and policy frameworks:

- *Nagar Van Yojana – supports urban forest development*
- *AMRUT 2.0 – promotes green infrastructure and water management*
- *Urban Forestry Programs – encourage plantation in urban areas*

These frameworks ensure feasibility and institutional support for implementation.

Proposal II _ Development of Greenways along Major Roads

Concept and Rationale

Greenways are defined as linear vegetated corridors that perform multiple ecological, social, and functional roles within urban environments. They act as connectors between larger green spaces while improving environmental quality, enhancing accessibility, and supporting recreational activities.

In the present study, greenways are proposed along major road corridors, particularly in areas intersecting with highly suitable zones identified through spatial analysis. These corridors serve as transitional ecological spaces that connect urban forest patches and river systems, thereby creating a continuous green network.

Planning Approach

The proposed greenways are developed along major transportation routes such as national and state highways, ensuring maximum accessibility and visibility. The design focuses on integrating plantation within available right-of-way (ROW) without interfering with existing infrastructure.

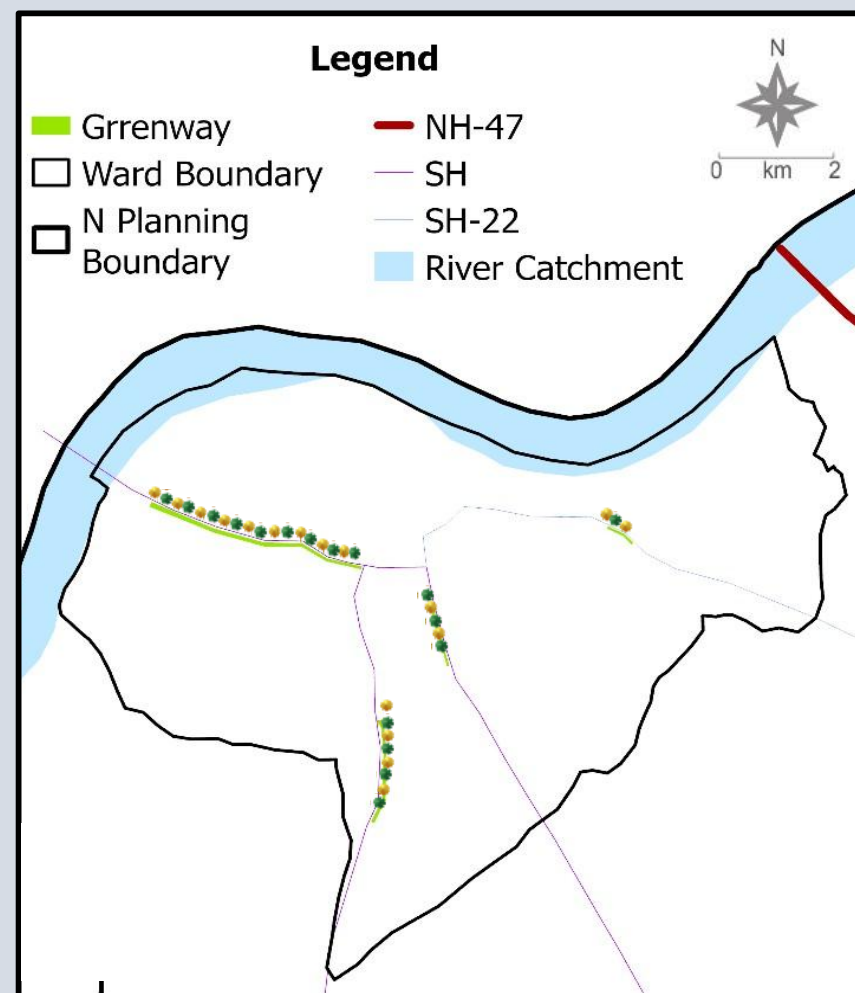
Refer to Map No. 8 Proposal – 2 Development of Greenways along Major Roads, Proposal – 3 Development of Riparian Buffer along River Edge & Proposal – 4 Conservatory Landscaping and Eco-Tourism Development

A plantation strip of approximately 4 meters width is considered along road edges, maintained as a no-construction zone. This strip is designed to function as both an ecological buffer and a movement corridor.

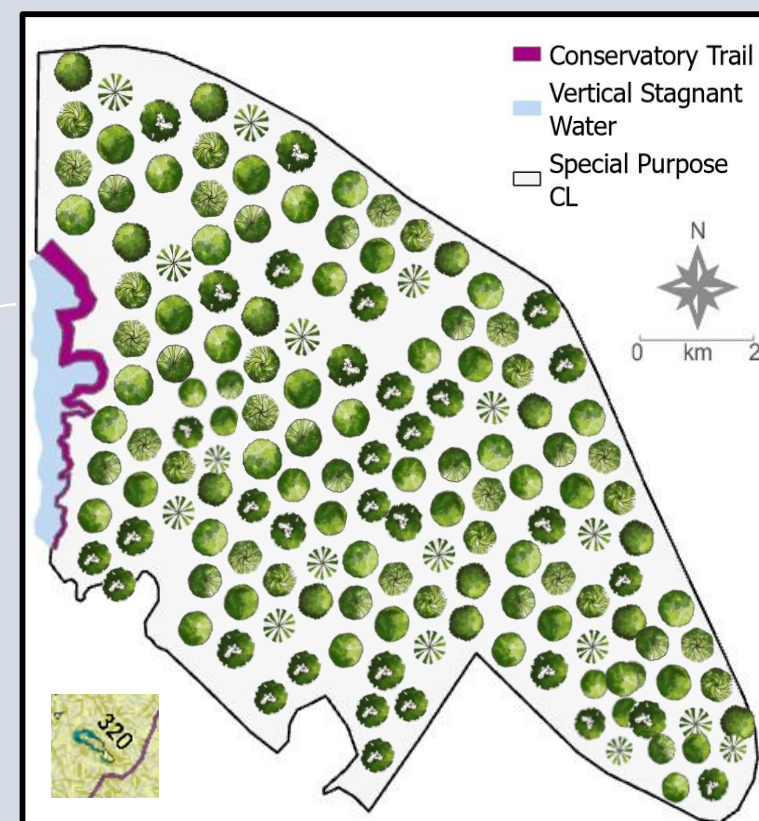
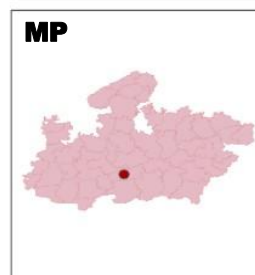
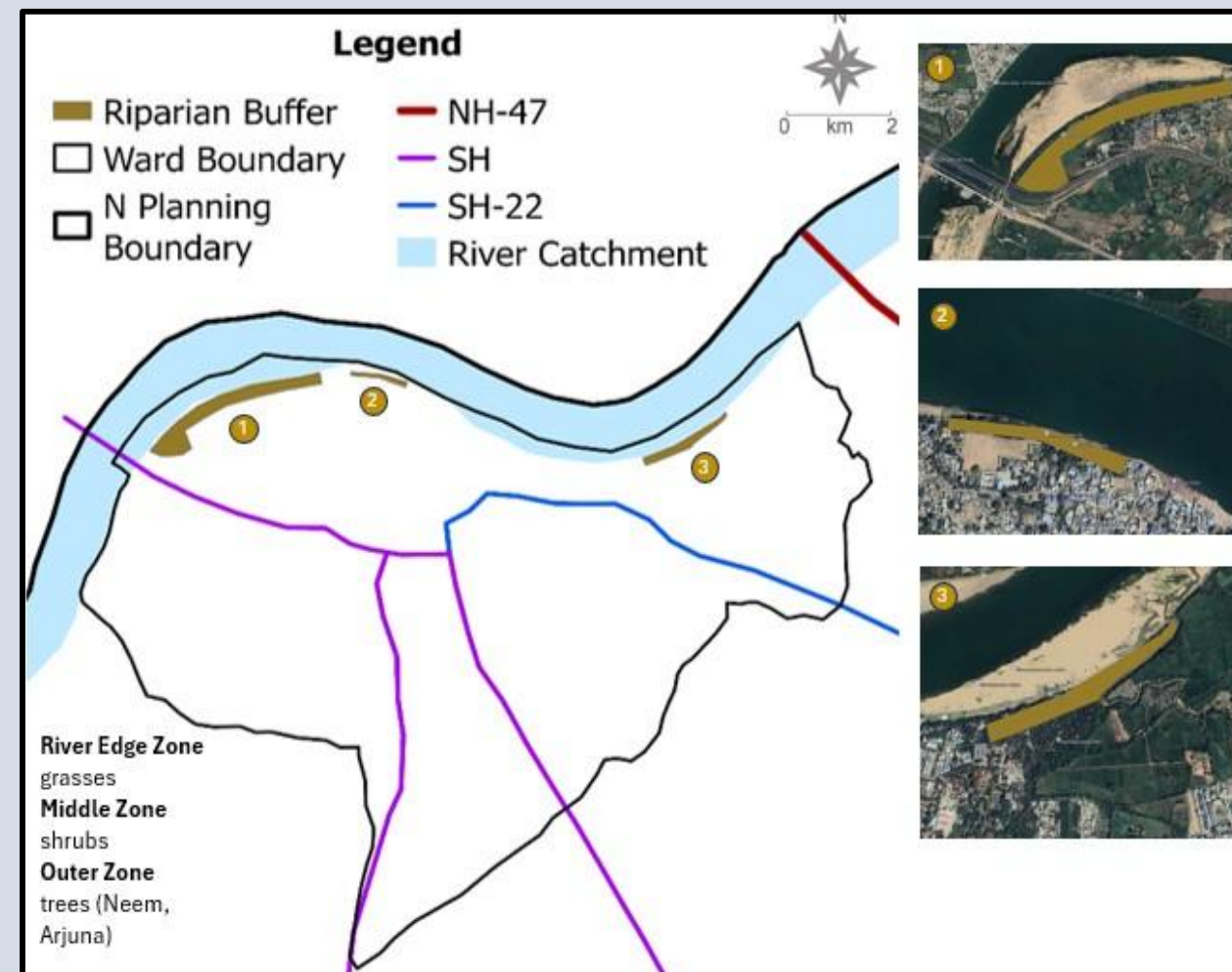
Plantation Design and Structure

The plantation strategy follows a structured yet natural pattern to maximize ecological benefits.

I. Development of Greenways along Major Roads



II. Development of Riparian Buffer along River Edge



III. Conservatory Landscaping and Eco-Tourism Development

- [Edge/Entry]
- ↓
- [Activity Zone – trails, seating]
- ↓
- [Buffer Plantation Zone]
- ↓
- [Core Dense Forest Zone]

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

I. Proposal 2
II. Proposal 3
III. Proposal 4



Scale
Specific to Map

Source
Author (2026)

Notes
m.



Manit, Bhopal

MAP NO.

8

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Parameter	Specification
Plantation type	Linear + staggered
Pattern	Double row / zig-zag
Spacing	3–5 m (trees), 1–2 m (shrubs)
Layers	Trees + shrubs + ground cover

Table 6.3 Plantation Strategy

This multi-layered approach enhances biodiversity, improves microclimate, and strengthens the ecological performance of the corridor.

Species Selection

Species are selected based on functional roles such as shading, pollution tolerance, aesthetics, and river-edge adaptability.

Category	Species
Shade trees	Neem, Peepal
Pollution tolerant	Karanj, Ashoka
Aesthetic	Gulmohar, Cassia
River edge	Arjuna

Table 6.4 Species Selection

Native species are preferred to ensure adaptability, lower maintenance, and higher survival rates.

Environmental and Ecological Benefits

Greenways contribute significantly to urban environmental improvement by:

- I. Reducing air pollution and dust along road corridors
- II. Acting as noise buffers
- III. Lowering ambient temperature by 2–4°C
- IV. Enhancing biodiversity through continuous habitat corridors
- V. Supporting stormwater management and reducing surface runoff

The continuous nature of these corridors also allows them to function as connectors between fragmented green spaces.

Carbon Sequestration Potential

Linear plantation along road networks contributes to carbon sequestration at a cumulative scale.

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

Parameter	Value
Per tree	15–20 kg CO ₂ /year
1 km stretch (~300 trees)	4–6 tons CO ₂ /year
Continuous corridor	Acts as urban carbon sink

Table 6.5 Carbon Sequestration Potential

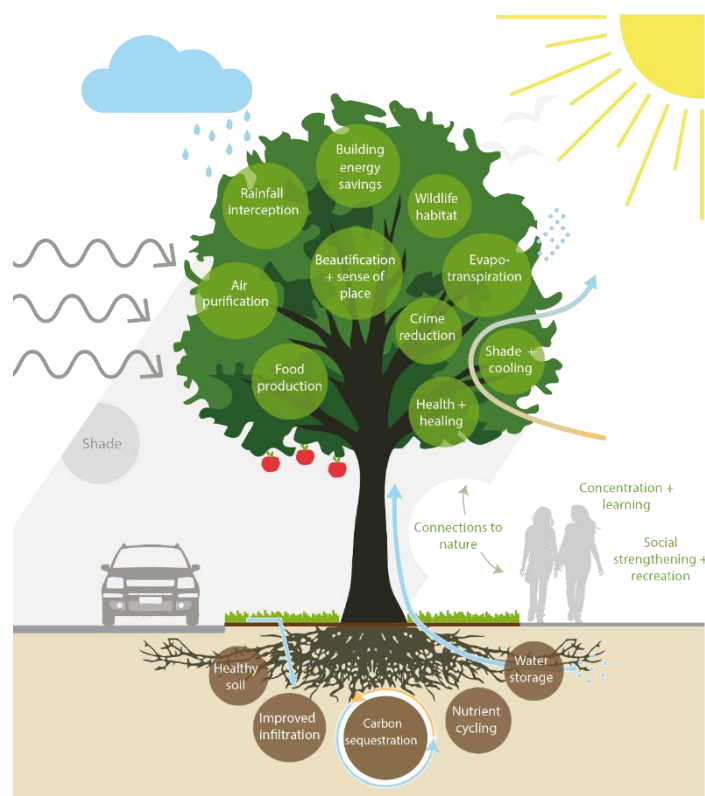


Figure 6.3 Benefits of trees on greenways

Policy and Guideline Support

The proposal aligns with established planning and forestry guidelines, including:

- I. IRC guidelines for roadside plantation
- II. MoRTH norms for avenue plantation
- III. National Urban Forestry Programme

These frameworks support the development of roadside green corridors as part of sustainable urban infrastructure.

Supporting Framework: 3-30-300 Rule

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

The proposed greenway network contributes to achieving broader urban greening targets by:

- I. Increasing visible tree cover within residential areas
- II. Contributing towards achieving approximately 30% canopy cover
- III. Improving accessibility to green spaces within urban areas



Figure 6.4 3-30-300 rule

Thus, the greenway system supports the principles of the 3-30-300 rule by enhancing both ecological and social benefits across the city.

Proposal III _ Development of Riparian Buffer along River Edge

Concept and Rationale

Riparian buffers are vegetated zones along riverbanks that act as transitional interfaces between land and water systems. These areas play a critical role in maintaining ecological balance by stabilizing riverbanks, enhancing biodiversity, and regulating hydrological processes.

In the present study, riparian buffers are proposed along the river edge within the planning boundary, particularly in zones identified as environmentally sensitive and hydrologically significant. These buffers are designed as nature-based solutions to address issues such as soil erosion, flooding, and ecological degradation.

Planning Approach

The proposed riparian buffer is developed along the river corridor, integrating vegetation with natural drainage systems to create a continuous ecological edge.

Refer to Map No. 8 Proposal – 2 Development of Greenways along Major Roads, Proposal – 3 Development of Riparian Buffer along River Edge & Proposal – 4 Conservatory Landscaping and Eco-Tourism Development

(attached after PAGE NO. 82)

The design avoids hard construction and focuses on soft landscape interventions that enhance the natural character of the riverfront while maintaining ecological integrity.

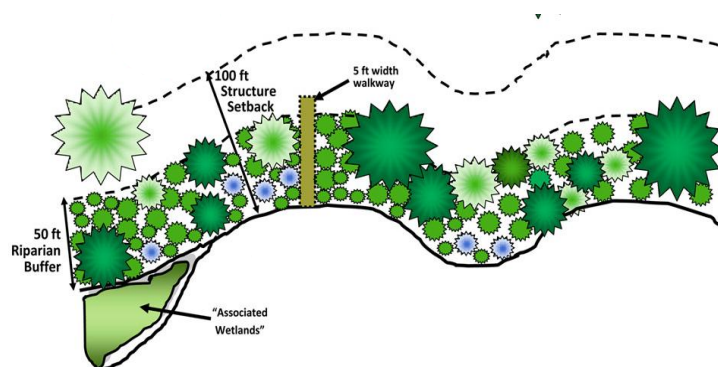


Figure 6.5 Buffer sections

Functional Zonation of Riparian Buffer

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

The buffer is structured into three ecological zones based on proximity to water:

Zone	Function	Vegetation Type
River Edge Zone	Soil stabilization, water interaction	Grasses (Vetiver, Typha)
Middle Zone	Filtration, habitat support	Shrubs
Outer Zone	Canopy cover, shading	Trees (Neem, Arjuna)

Table 6.6 Functional Zonation of Riparian Buffer

This zonation ensures a gradual transition from water to land, improving both ecological and visual quality.

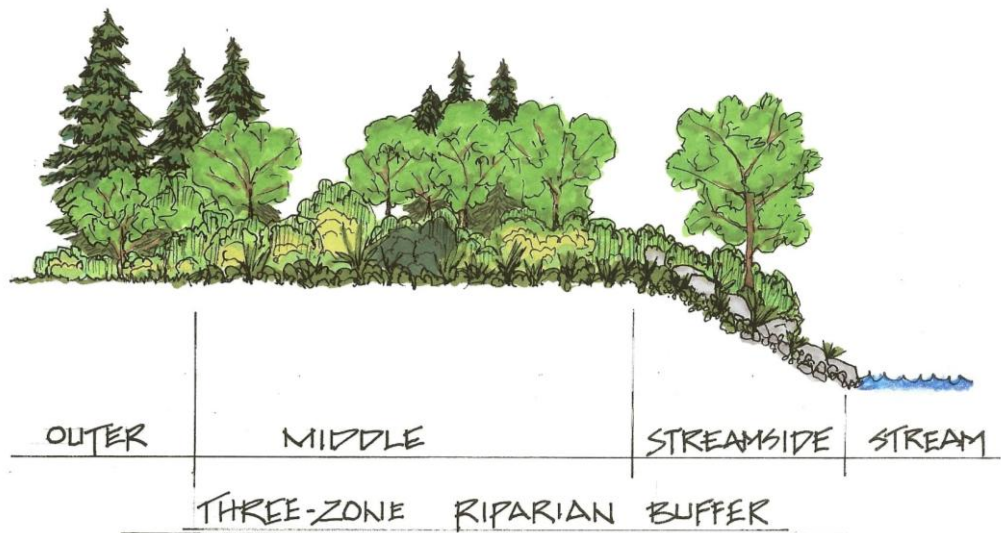


Figure 6.6 Buffer in Three zone

Plantation Strategy and Species Selection

The plantation strategy emphasizes native and moisture-tolerant species to enhance ecological performance.

- Vetiver grass – controls soil erosion and improves water retention
- Typha (cattails) – supports wetland ecology and filtration
- Arjuna (Terminalia arjuna) – suitable for riverbanks and provides shade
- Neem (Azadirachta indica) – drought-tolerant and improves air quality

The combination of grasses, shrubs, and trees creates a multi-layered system that strengthens bank stability and supports biodiversity.



Figure 6.7 Species of trees

Hydrological Functions

Riparian buffers significantly contribute to improving hydrological performance through:

- I. Reduction of surface runoff
- II. Enhancement of infiltration and groundwater recharge
- III. Stabilization of riverbanks and prevention of erosion
- IV. Regulation of flood impacts by slowing water flow

Parameter	Value
Average rainfall	~1200 mm/year
Infiltration increase	20–40%
Runoff reduction	30–50%
Groundwater recharge	Moderate–High

Higher hydrological efficiency leads to improved vegetation growth and increased ecological

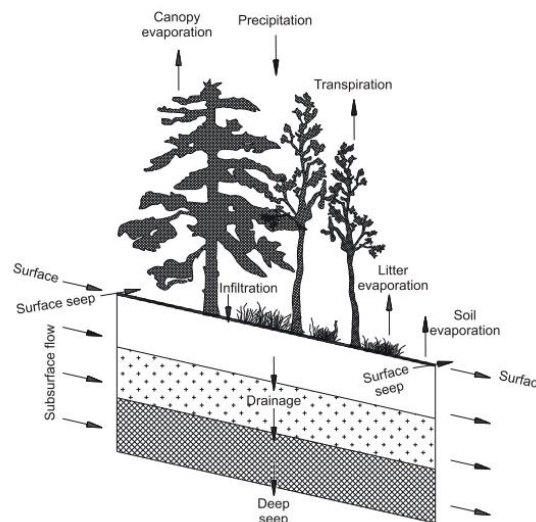


Figure 6.8 Infiltration potential

Rejuvenating Pond Integration

Rejuvenating ponds are introduced as part of the riparian system to enhance water retention and recharge and strengthening the hydrological functioning of the buffer system.



Figure 6.9 Rejuvenating Pond

Environmental and Carbon Benefits

The riparian buffer improves ecological stability by controlling erosion, supporting biodiversity, and regulating microclimate. The dense vegetation also contributes to carbon sequestration, with an estimated potential of ~15–25 tons CO₂/ha/year, enhancing the overall environmental performance of the river corridor.

Proposal IV _ Conservatory Landscaping and Eco-Tourism Development

Concept and Rationale

The conservatory landscape is proposed as a controlled ecological space that prioritizes environmental performance while allowing limited public interaction. Unlike conventional parks, this intervention focuses on biodiversity conservation, hydrological enhancement, and low-impact recreational use.

The site is strategically selected near a water body, making it suitable for integrating plantation, recharge systems, and nature-based tourism activities. The proposal ensures that ecological sensitivity is maintained while enhancing the experiential quality of the landscape.

Planning Approach

The planning approach is based on a zoned structure that balances conservation and accessibility.

The design introduces a trail-based movement system with defined entry points and controlled access to sensitive areas. The slope conditions and natural drainage patterns are utilized to guide plantation and water management strategies

Refer to Map No. 8 Proposal – 2 Development of Greenways along Major Roads, Proposal – 3 Development of Riparian Buffer along River Edge & Proposal – 4 Conservatory Landscaping and Eco-Tourism Development

(attached after PAGE NO. 82)

Functional Zoning

The conservatory is divided into distinct zones to regulate activities and ensure ecological protection:

Zone	Function	Specifications
Core Conservation Zone	Biodiversity protection	No public entry / minimal disturbance
Buffer Plantation Zone	Dense vegetation	Native species, 3–5 m spacing
Water Interaction Zone	Edge experience	Decks, seating (no hard construction)
Trail Zone	Movement	1.5–3 m wide pathways

“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”

Zone	Function	Specifications
Activity Zone	Tourism / learning	Open spaces, interpretation areas

Table 6.7 Conservatory Area Functional Zoning



Figure 6.10 Functional Zoning

Plantation Strategy

The plantation strategy focuses on dense and layered vegetation to enhance ecological performance.



Parameter	Specification
Minimum patch size for specific categories of Landscaping	≥ 1 Ha
Tree spacing	1–1.5 m (dense zones)
Plantation density	3–5 trees/m ² (Miyawaki)
Maintenance	2–3 years intensive care

Table 6.8 Plantation Strategy for conservatory area

The dense plantation improves canopy cover, enhances biodiversity, and strengthens the microclimatic conditions of the site.

**“ECOSYSTEM SERVICE-BASED URBAN FOREST PLANNING: A SPATIAL
SUITABILITY ASSESSMENT FOR NARMADAPURAM, M.P.”**

A 4-meter-wide trail/ corridor have been provided within the limit of conservatory area of zone and rest area will be maintained as no construction area. A walking track along with benches at certain intervals & lighting.

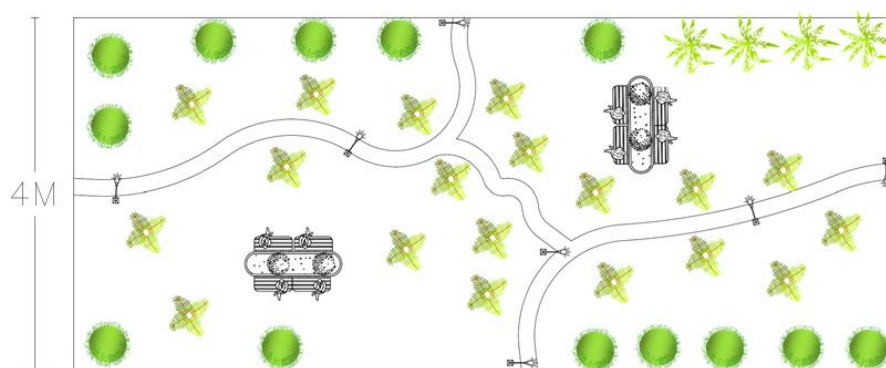


Figure 6.11 Trail

Water-Based Interventions

Water-sensitive design elements are integrated to improve hydrological performance:

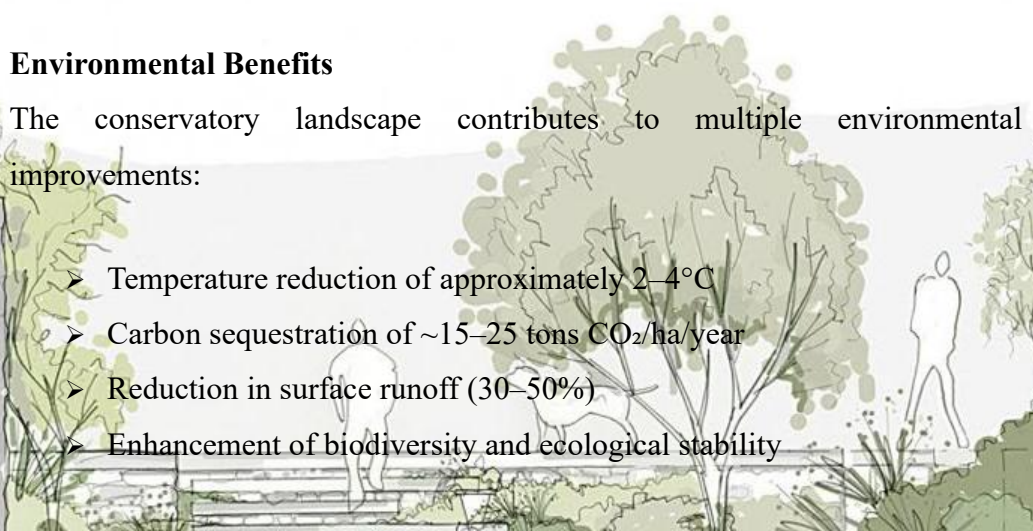
Element	Role	Specification
Rejuvenating pond	Storage + recharge	Depth: 1–2.5 m
Wetland patches	Natural filtration	Typha, reeds
Bioswales	Runoff control	Along trail edges
Percolation pits	Groundwater recharge	Every 20–30 m

Table 6.9 Water based interventions

These interventions collectively enhance water retention, reduce runoff, and support groundwater recharge.

Environmental Benefits

The conservatory landscape contributes to multiple environmental improvements:



- Temperature reduction of approximately 2–4°C
- Carbon sequestration of ~15–25 tons CO₂/ha/year
- Reduction in surface runoff (30–50%)
- Enhancement of biodiversity and ecological stability

CHAPTER 06

CONCLUSION

This study establishes a comprehensive framework for identifying and developing urban forest systems through a combination of spatial analysis, ecological understanding, and planning-based interventions. The research moves beyond conventional plantation approaches by integrating hydrological, environmental, and planning parameters into a structured GIS-based suitability assessment.

The identification of suitable patches using weighted overlay analysis ensured that urban forest development is not arbitrary, but based on scientifically derived criteria such as land use, soil characteristics, groundwater potential, drainage patterns, and accessibility. The introduction of size-based hierarchy further strengthened the approach by aligning different scales of intervention with appropriate plantation strategies, making the proposal both practical and implementable.

The three proposed interventions—urban forest patches, greenways, and riparian buffers—collectively form a connected green infrastructure system. These interventions not only enhance ecological performance but also address critical urban challenges such as heat stress, poor air quality, surface runoff, and lack of accessible green spaces. The inclusion of conservatory landscapes further expands the scope by integrating biodiversity conservation with controlled public interaction and eco-tourism.

A key strength of the study lies in its emphasis on hydrological integration. By linking vegetation planning with groundwater recharge, infiltration potential, and water retention strategies, the research demonstrates how urban forestry can function as a nature-based solution for water-sensitive urban development. The incorporation of rejuvenating ponds and buffer systems highlights the potential of landscape interventions in improving long-term environmental resilience.

The study also aligns with existing policy frameworks and development regulations, ensuring that the proposed interventions are feasible within the

planning context. The use of concepts such as Green TDR, buffer zone utilization, and national urban forestry schemes strengthens the implementation potential of the proposals.

Overall, the research demonstrates that urban forestry, when approached through a multidisciplinary and data-driven framework, can significantly contribute to sustainable urban development. It not only enhances ecological and hydrological performance but also improves livability, supports climate resilience, and creates opportunities for community engagement and environmental awareness.

The proposed framework can be replicated and adapted in similar urban contexts, providing a scalable model for integrating green infrastructure into urban planning.

Bibliography

1. al, G. A. (2017 IOP). *Use of Geographical Information System (GIS) and remote sensing in development of urban forest types and shapes in Tangerang Selatan City. Conf. Ser.: Earth Environ. Sci.* 54 012051.
2. Costanza, R. d.–2. (1997).
3. D. Armsona, *. P. (2012). *Urban Forestry & Urban Greening*.
4. Das, A. D., & Houqe, R. et al. , D. D. (2023). *Mapping ecosystem services for ecological planning and management: a case from a tropical planning region, Eastern India. Environ Sci Pollut Res* 30, 7543–7560 (2023). <https://doi.org/10.1007/s11356-022-22732-3>.
5. Dash, S. D. (n.d.). *Remote sensing and GIS applications for monitoring and managing urban forests. Dynamics of Urban Forestry*.
6. Edrisi S.A., V. V. (n.d.). *Geospatial evaluation of urban marginal lands for the forestry development in Northern India. Environ Dev Sustain*. <https://doi.org/10.1007/s10668-025-06787-z>.
7. Edrisi, S. V.-0.-0.-z. (n.d.).
8. Guerrero, J., EscobarSilva, E., Almeida, C., Caiche, D., dos Santos, A., & Nunes, F. (2025). Guerrero, J.V.; Escobar-Silva, E.V.; Almeida, C.M.d.; Caiche, D.; dos Santos, A.M.; Nunes, F.G. *Mapping Priority Areas for Urban Afforestation Based on the Relationship Between Urban Greening and Social Vulnerability Indicators. Forests* 2025, 16, 936. .
9. Gumilar Adam et al. (2017). *Use of Geographical Information System (GIS) and remote sensing in development of urban forest types and shapes in Tangerang Selatan City. IOP Conf. Ser.: Earth Environ. Sci.* 54 012051.
10. Hemant BherwaniI, 2. . (n.d.). *Role and value of urban forests in carbon sequestration: review and assessment in Indian context. Environ Dev Sustain* 26, 603–626 (2024). <https://doi.org/10.1007/s10668-022-02725-5>.
11. INDIA STATE OF FOREST REPORT, 2. V.-I. (n.d.). *India State of Forest Report 2023 (Volume II). Forest Survey of India, Ministry of Environment, Forest and Climate Change*.
12. Jeong, J., Joo, H.-R., Sou, H.-D., Choi, S., & Park, C.-R. (2025). Jeong, J.; Joo, H.-R.; Sou, H.-D.; Choi, S.; Park, C.-R. *Development of an Indicator*

Assessment Framework for Urban Forest Effects Through a Scoping Review.
Forests 2025, 16, 1870. . <https://doi.org/10.3390/f16121870>.

13. Jigme Thinley¹, 2. . (2026). *Mapping Tree Cover Patterns in an Urban Arboretum from Multispectral Drone Imagery Using Pixel-Based Classification and Object-based Image Analysis.* *Remote Sens Earth Syst Sci* 9, 3 (2026). <https://doi.org/10.1007/s41976-025-00257-w>.
14. Jusoff, M. H. (2004). *Urban Forestry Planning Using Remote Sensing/GIS Technique.* *Pertanika J. Sci. & Techno!*. 12(1): 21 - 32 (2004).
15. Kang, J., & Hirabayashi, S. (2022). Kang, J.; Hirabayashi, S.; Shibata, S. *Urban Forest Ecosystem Services Vary with Land Use and Species: A Case Study of Kyoto City.* *Forests* 2022, 13, 67. <https://doi.org/10.3390/f13010067>.
16. M. N. M. Reba*, A. Z. (2013). *DETERMINATION OF SUSTAINABLE LAND POTENTIAL BASED ON PRIORITY RANKING: MULTI-CRITERIA ANALYSIS (MCA) TECHNIQUE.* *13th International Conference on Computational Science and Its Applications. Johor Bahru, Johor, MALAYSIA .*
17. Nowak, D. a. (2007). *Understanding the Benefits and Costs of Urban Forest Ecosystems.*
18. Oliver Baines, P. W. (2020). *Quantifying urban forest structure with open-access remote sensing data sets.* *Urban Forestry & Urban Greening*, 10.1016/j.ufug.2020.126653.
19. Richard Mitchell 1, F. P. (2008). *Effect of exposure to natural environment on health inequalities: an observational population study.*
20. S. J. Livesley, *. E. (2009). *The Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale .*
21. SINGH, K. K. (2019). *Probing the Context of Green Spaces in Urban Planning Framework in India.*
22. *Urban Forest through People's Participation.* (n.d.).
23. Yağmur ŞAN, E. Ş. (2025). *Correlation based sensitivity analysis and suitability evaluation of multi criteria decision-making methods according to different normalization techniques.* *Sigma J Eng Nat Sci*, Vol. 43, No. 4, pp. 1321–1338, August, 2025.

24. ZIPPERER, W. C. (2003). *Species composition and structure of regenerated and remnant forest patches within an urban landscape*. USDA Forest Service, c/o SUNY-ESF, 5 Moon Library, Syracuse, NY 13210, USA.
25. *Urban Forestry & Planning*
26. Konijnendijk, C. C., Nilsson, K., Randrup, T. B., & Schipperijn, J. (2005). *Urban Forests and Trees: A Reference Book*. Springer.
27. Tyrväinen, L., Pauleit, S., Seeland, K., & de Vries, S. (2005). *Benefits and uses of urban forests and trees*. *Urban Forestry & Urban Greening*, 4(3–4), 81–114.
28. FAO (2016). *Guidelines on Urban and Peri-urban Forestry*. Food and Agriculture Organization.
29. Fletcher, T. D., Shuster, W., Hunt, W. F., et al. (2015). *SUDS, LID, BMPs, WSUD and more – The evolution of terminology surrounding urban drainage*. *Urban Water Journal*, 12(7), 525–542.
30. Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). *Adapting cities for climate change: The role of the green infrastructure*. *Built Environment*, 33(1), 115–133.
31. Bolund, P., & Hunhammar, S. (1999). *Ecosystem services in urban areas*. *Ecological Economics*, 29(2), 293–301.
32. Tzoulas, K., Korpela, K., Venn, S., et al. (2007). *Promoting ecosystem and human health in urban areas using green infrastructure*. *Landscape and Urban Planning*, 81(3), 167–178.
33. Malczewski, J. (2004). *GIS-based land-use suitability analysis: A critical overview*. *Progress in Planning*, 62(1), 3–65.
34. Eastman, J. R. (2012). *IDRISI Selva Manual: GIS and Image Processing Software*. Clark Labs.
35. Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). *Urban greening to cool towns and cities: A systematic review*. *Landscape and Urban Planning*, 97(3), 147–155.

36. *alder, I. R. (2007).*
Forests and water—Ensuring forest benefits outweigh water costs. Forest Ecology and Management, 251(1–2), 110–120.
37. *Ministry of Housing and Urban Affairs (MoHUA). (2019).*
Urban Green Guidelines, 2019.
38. *National Institute of Urban Affairs (NIUA). (2021).*
Urban Green Space Planning Toolkit.
39. *Central Public Health and Environmental Engineering Organisation (CPHEEO). (2019).*
Manual on Storm Water Drainage Systems.
40. *River & Riparian Ecology*
41. *Naiman, R. J., & Décamps, H. (1997).*
The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics, 28, 621–658.
Pauleit, S., & Duhme, F. (2000). GIS Assessment of Munich’s Urban Forest Structure for Urban Planning. Journal of Arboriculture.
42. *Dwivedi, P., Rathore, C.S., & Dubey, Y. (2008). Ecological Benefits of Urban Forestry: The Case of Kerwa Forest Area (KFA), Bhopal, India. Urban Forestry & Urban Greening.*
43. *American Forests. (2013). Urban Forest Assessments Resource Guide. U.S. Forest Service.*
44. *UNECE. (2021). Sustainable Urban and Peri-Urban Forestry Policy Brief. United Nations Economic Commission for Europe.*
45. *Baines, O., Wilkes, P., & Disney, M. (2020). Quantifying Urban Forest Structure with Open-Access Remote Sensing Data Sets. Urban Forestry & Urban Greening.*
46. *Gul, A., Gezer, A., & Kane, B. (2006). Multi-Criteria Analysis for Locating New Urban Forests. Urban Forestry & Urban Greening.*
47. *Borgogno-Mondino, E., Fabietti, G., & Ajmone-Marsan, F. (2015). Soil Quality and Landscape Metrics as Driving Factors in a Multi-Criteria GIS Procedure. Urban Forestry & Urban Greening.*

48. Thinley, J., et al. (2026). *Mapping Tree Cover Patterns in an Urban Arboretum from Multispectral Drone Imagery. Remote Sensing in Earth Systems Sciences.*
49. Song, I.J., Hong, S.K., Kim, H.O., Byun, B., & Gin, Y. (2005). *Landscape Patches and Invasion of Naturalized Plants in Urban Seoul. Landscape and Urban Planning.*
50. Duinker, P., Messier, C., Esperon-Rodriguez, M., et al. (2024). *Limitations of Quantified Rules in Urban Forestry. Urban Forestry & Urban Greening.*
51. Antoine, J., Lin, M., El-Kulak, A.M., & Van Stan II, J.T. (2025). *Integrating Tree Canopy Runoff into Blue-Green Infrastructure. Urban Forestry & Urban Greening.*
52. Qi, H., Dempsey, N., & Cameron, R. (2025). *Miyawaki Mini-Forests and Urban Ecology. Urban Forestry & Urban Greening.*
53. Nazer, N., Bimal, P., & Chithra, K. (2025). *GIS-Based Methodology to Identify Priority Areas for Land Use Regulations. Environmental Planning Journal.*
54. Town and Country Planning Organisation (TCPO). (2014). *Urban Greening Guidelines. Government of India.*