Developing Local Climate Zones (LCZ) Classification for Climate-Resilient Urban Drainage: A Case of Vidisha

A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

Master of Planning (Urban Planning)

in

Department of Architecture and Planning

by

VAISHNAVI DAYASHANKAR SHRIVASTAVA
24209011105

Under the supervision of
DR. RAJAT SONI

MAULANA AZAD
NATIONAL INSTITUTE OF TECHNOLOGY,
BHOPAL- 462003(INDIA)
JULY, 2026

© MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL- 462003
ALL RIGHTS RESERVED

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL

CANDIDATE'S DECLARATION

I hereby certify that the work which is presented is being presented in the thesis entitled **"Developing Local Climate Zones (LCZ) Classification for Climate-Resilient Urban Drainage: A Case of Vidisha"** in partial fulfilment of the requirements for the award of the Master Planning (2024-2026) and submitted in the Department of Architecture and Planning of Maulana Azad National Institute of Technology, Bhopal is an authentic record of my own work carried out during the period from **July, 2025** to **July, 2026** under the supervision of **Dr. Rajat Soni**, Professor Department of Architecture and Planning, Maulana Azad National Institute of Technology, Bhopal.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institution.

Vaishnavi Dayashankar Shrivastava

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. Rajat Soni

Date:

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL

CERTIFICATE OF PLAGIARISM

This is to certify that the Thesis entitled **"Developing Local Climate Zones (LCZ) Classification for Climate-Resilient Urban Drainage: A Case of Vidisha"** is a piece of research work carried out by Vaishnavi Dayashankar Shrivastava, Scholar No. 24209011105 under my guidance and supervision for the degree of Master of Planning (Urban) from the Department of Architecture and Planning of Maulana Azad National Institute of Technology, Bhopal (M.P.) India.

To the best of my knowledge and belief, she is to certify that:

i. Prima facie, this thesis can be considered for the award of the degree,

ii. Thesis does not contain any work which has previously been submitted for the award of any other degree.

iii. Percentage of plagiarism is **5%** (max 8-12% as per clause 10.12). Please check report is enclosed for reference.

iv. This thesis work:

   a. Has not been carried out in collaboration with any other organisation.

   b. Has been carried out in collaboration with ……..…
   (Specify type and work done under collaboration and the binding if any)

   ……

Signature:

Name of the Candidate: Vaishnavi Dayashankar Shrivastava

Signature:
Name of Guide: Dr Rajat Soni

Countersigned by

Signature:

Name: Dr. KK. Dhote

HOD, Department: Architecture and Planning

ACKNOWLEDGEMENT

I would like to express my gratitude to **Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh, India,** for providing an academic environment, exceptional institutional support, and access to valuable learning resources that significantly shaped my educational program. The perception of academic excellence, interdisciplinary engagement, and research-driven learning at MANIT Bhopal has contributed immensely to the successful completion of the dissertation.

I extend my sincere appreciation to my guide, **Dr. Rajat Soni**, for his unwavering support, patient guidance, and insightful mentorship throughout the research process. His exponential expertise, constructive feedback, and continuous encouragement have played a pivotal role in shaping the academic rigour and conceptual clarity of this work. His dedicated involvement, thoughtful supervision, and commitment to my academic growth have greatly enriched and encouraged the quality of my dissertation.

My deepest gratitude goes to my parents, **Mrs Namrata Dayashankar Shrivastava** and **Mr Dayashankar Shrivastava**, whose unconditional love, sacrifices, and steadfast belief in my abilities have been the foundation of all my accomplishments. Their constant motivation, emotional strength, and values have guided me at every step of my academic program. This work shines as a reflection of their blessings and lifelong support.

I am equally grateful to my sister, **Ms Renuka Dayashankar Shrivastava**, for her encouragement, patience, and support. Her understanding during breaking moments and her positivity have been a constant source of reassurance, helping me stay focused and determined throughout the research. I would also like to extend my heartfelt thanks to my friends, who have supported me in numerous ways, through discussions, encouragement, shared academic experiences, and companionship during stressful phases of this journey. Their presence, motivation, and understanding have made this process more fulfilling and balanced, adding both comfort and strength to my academic efforts.

I am sincerely thankful to all my well-wishers, whose blessings, warm words, and support, whether through guidance, motivation, or simple acts of kindness, have played an important role in helping me complete my dissertation. Every gesture of goodwill has shaped and structured my determination and contributed to my personal and academic growth.

Finally, I express my heartfelt gratitude to everyone who has directly or indirectly supported me throughout this journey. Each contribution, big or small, has played a meaningful role in the successful completion of the dissertation. I remain deeply thankful for the collective guidance, kindness, and support that made this accomplishment possible.

ABSTRACT

There are many challenges that arise due to the rapid urbanisation of medium-sized Indian towns such as urban heat islands, disrupted drainage systems, and increased waterlogging, and ultimately decreased ecological resiliency. Planning methods have typically relied on single issues to be addressed independently resulting in temporary and piecemeal solutions. This research proposes an integrated approach to analysis and planning by combining the classification of Local Climate Zones (LCZ), assessments of drainage using Digital Elevation Models (DEM), and the implementation of Blue–Green Infrastructure (BGI) to create an approach to urban planning that is climate responsive and hydrologically resilient.

This research consists of 2 components. The first component involved the academic levels of the scientific literature on Urban Climatology representing the parameters of Local Climate Zones (LCZs). This work also represents the understandings related to the hydrological behaviour of LCZ's and nature-based (eco-) solutions. The second component of this research involves applying geospatial analysis (mapping) techniques of the study area's classification based on LCZ and topographical (terrain) attributes to identify the hydraulically vulnerable zones. Additionally, the drainage characteristics of the area identified in the first component are incorporated into this analysis of the drainage systems to determine where "hydrological conflict areas" exist due to overlapping LCZ types and areas of high flow accumulation due to disturbed natural drainage.

To synthesise this information, several types of Green Infrastructure (BGI) that can mitigate hydrological conflicts will be developed and implemented within the hydraulically-vulnerable zones. The following BGI strategies will be focused on based upon the combined assessment; cool corridors, bioswales, permeable pavement systems, retention/detention systems, and green corridors. The proposed spatial locations of the BGI strategies correspond to LCZ classifications, thus the BGI strategies will be both climatically and hydrologically appropriate. The results of the combined analyses reveal a solid, evidence-based methodology for identifying vulnerability within urban systems (through both the use of LCZ and urban drainage analyses) as well as developing risk mitigation strategies using nature-derived solutions. This study presents the LCZ-Drainage-BGI Integrated Planning Approach - a scalable technique which is replicable across all regions by providing strategic information that relates specifically to planning; stormwater management; and climate adaptation in Indian cities. It is clear from this research that creating a climate-resilient urban area requires the integration of urban form with the functioning of the hydrologic system and ecological processes of the area and therefore, both LCZ and BGI, should play an integral role in re-imagining future climate-resilient cities.

सारांश

मीडियम साइज़ के भारतीय शहरों में तेज़ी से शहरीकरण ने अर्बन हीट आइलैंड, नेचुरल ड्रेनेज में रुकावट, वॉटरलॉगिंग और इकोलॉजिकल रेजिलिएंस में कमी से जुड़ी चुनौतियों को और बढ़ा दिया है। पारंपरिक प्लानिंग के तरीके अक्सर इन समस्याओं को अलग-अलग हल करते हैं, जिससे अलग-अलग और कम समय तक चलने वाले समाधान मिलते हैं। यह थीसिस लोकल क्लाइमेट ज़ोन (LCZ) क्लासिफिकेशन, डिजिटल एलिवेशन मॉडल (DEM)-बेस्ड ड्रेनेज असेसमेंट और ब्लू-ग्रीन इंफ्रास्ट्रक्चर (BGI) इंटरवेंशन को मिलाकर एक इंटीग्रेटेड एनालिटिकल और प्लानिंग फ्रेमवर्क का प्रस्ताव करती है ताकि क्लाइमेट-रिस्पॉन्सिव और हाइड्रोलॉजिकली रेजिलिएंट अर्बन डेवलपमेंट हासिल किया जा सके।

यह स्टडी दो फेज़ में की गई थी। फेज़ 1 ने अर्बन क्लाइमेट साइंस, LCZ पैरामीटर, हाइड्रोलॉजिकल बिहेवियर और नेचर-बेस्ड सॉल्यूशन पर एक बड़े लिटरेचर रिव्यू के ज़रिए कॉन्सेप्चुअल फाउंडेशन बनाया। फेज़ 2 में स्टडी एरिया को LCZ में क्लासिफाई करने, टेरेन-ड्रिवन नेचुरल ड्रेनेज नेटवर्क का एनालिसिस करने, फ्लो जमा होने का मैप बनाने और हाइड्रोलॉजिकली कमजोर ज़ोन की पहचान करने के लिए जियोस्पेशियल तरीकों का इस्तेमाल किया गया। LCZ और ड्रेनेज आउटपुट को ओवरले करने पर अलग-अलग "थर्मल-हाइड्रोलॉजिकल कॉन्फ्लिक्ट ज़ोन" सामने आए, जहाँ कॉम्पैक्ट, हीट-सेंसिटिव LCZ टाइप हाई-फ्लो जमा होने वाले एरिया और खराब नेचुरल चैनल को ओवरलैप करते हैं। इन ज़ोन को इंटरवेंशन के लिए प्रायोरिटी दी गई।

इस इंटीग्रेटेड असेसमेंट के आधार पर, स्टडी में BGI स्ट्रेटेजी की एक सीरीज़ का प्रस्ताव है, जिसमें रिस्टोर किए गए वेटलैंड्स, बायोस्वेल्स, परमिएबल पेवमेंट्स, रिटेंशन और डिटेंशन सिस्टम, ग्रीन कॉरिडोर और रिपेरियन बफ़र्स शामिल हैं। ये इंटरवेंशन LCZ टाइपोलॉजी और ड्रेनेज नोड्स से स्पेशली जुड़े हुए हैं, जिससे क्लाइमेट और हाइड्रोलॉजिकल दोनों तरह से सूटेबिलिटी सुनिश्चित होती है। एक मॉडिफाइड LCZ सिनेरियो दिखाता है कि टारगेटेड BGI इम्प्लीमेंटेशन से वेजिटेबल कवर बढ़ सकता है, इनफिल्ट्रेशन में सुधार हो सकता है, सरफेस रनऑफ कम हो सकता है, शहरी गर्मी को मॉडरेट किया जा सकता है, और धीरे-धीरे बने हुए LCZ टाइप को ज़्यादा रेजिलिएंट कैटेगरी की ओर शिफ्ट किया जा सकता है।

नतीजे कन्फर्म करते हैं कि LCZ और ड्रेनेज एनालिसिस को मिलाने से कमजोरियों की पहचान करने और नेचर-बेस्ड सॉल्यूशन की प्लानिंग करने के लिए एक मजबूत, एविडेंस-बेस्ड अप्रोच बनता है। यह स्टडी एक स्केलेबल और रेप्लिकेबल LCZ–ड्रेनेज-BGI इंटीग्रेटेड प्लानिंग फ्रेमवर्क देती है, जो सभी रिसर्च ऑब्जेक्टिव्स को पूरा करती है और भारतीय शहरों में म्युनिसिपल प्लानिंग, स्टॉर्मवॉटर मैनेजमेंट और क्लाइमेट अडैप्टेशन के लिए एक्शनेबल इनसाइट्स देती है। रिसर्च इस बात को पक्का करती है कि लॉन्ग-टर्म अर्बन रेजिलिएंस को अर्बन फॉर्म, नेचुरल हाइड्रोलॉजी और इकोलॉजिकल सिस्टम के साथ अलाइन होना चाहिए, जिससे BGI सस्टेनेबल अर्बन डेवलपमेंट के लिए एक सेंट्रल टूल बन जाता है।

Contents

CANDIDATE'S DECLARATION ..... **iii**

CERTIFICATE OF PLAGIARISM ..... **iv**

ACKNOWLEDGEMENT ..... **v**

ABSTRACT ..... **vi**

सारांश ..... **vii**

LIST OF ABBREVIATIONS ..... **xiii**

LIST OF FIGURES ..... **xv**

LIST OF TABLES ..... **xvi**

CHAPTER 1. Introduction **1**

1.1 Background Study 4

1.2 Problem Formulation 5

1.3 Need for the Study 7

1.4 Key Definitions 7

CHAPTER 2. Literature Study **16**

2.1 Evolution of Research 16

2.1.1 Publication Trends (2014–2025) 18

2.1.2 Keyword Co-occurrence and Density Analysis 19

2.1.3 Author Collaboration and Network Patterns 20

2.1.4 Temporal Overlay and Emerging Trends 21

2.1.5 Comparative Synthesis of LCZ and Drainage Domains 22

2.2 Identification of Gaps 23

CHAPTER 3. Research Design **34**

3.1 Title 34

3.2 Aim 34

3.3 Objectives 34

3.3.1 Phase I 34

3.3.2 Phase II 34
3.4 Scope of the study 35
3.5 Limitations 35
CHAPTER 4. Methodology 37
CHAPTER 5. Data Collection 41
5.1 Introduction 41
5.2 Understanding Local Climate Zones (LCZ) Concept 42
5.2.1 Parameters of Local Climate Zones (LCZ) 43
5.3 Importance of Local Climate Zones (LCZ) in Climate-Resilient Urban Drainage and Blue-Green Infrastructure (BGI) 45
5.3.1 Linking LCZ with Urban Microclimate and Hydrology 45
5.3.2 LCZ as a Tool for Identifying Drainage Risk Zones 45
5.3.3 Role of LCZ in Blue-Green Infrastructure (BGI) Strategies 46
5.3.4 LCZ for Climate-Responsive Urban Planning in Monsoon-Prone Regions 46
5.3.5 Integrating LCZ with DEM-Based Drainage Analysis 46
5.3.6 LCZ Contribution to Resilient Infrastructure and Policy Planning 47
5.4 Review of Drainage Pattern Assessment in Urban Contexts 48
5.5 Integration of LCZ Classification and Drainage Analysis in Climate-Resilient Urban Planning 49
5.6 Summary of Literature Findings 50
5.7 Case Studies (Global and Indian Context) 51
5.7.1 Introduction 51
5.7.2 Importance of Case Studies in Urban Hydrology Research 52
5.7.3 Relevance of LCZ for Hydrological Modelling 53
5.7.1 Why the Global and Indian Context Is Necessary 54
5.8 Detailed Structure, Purpose, and Rationale of Case Studies 54
5.8.1 Conceptual Purpose of Incorporating Case Studies in LCZ-Based Hydrological Research 54
5.8.2 Rationale Behind the Global and Indian Dual Framework 55

5.8.3 Structure of the Case Study Section 56
5.8.4 Analysis Applied Across All Case Studies 57
5.9 Case Study 1 (Global Context): 58
5.9.1 Background 58
5.9.2 Objectives 59
5.9.3 Methodology 60
5.9.4 Results 62
5.9.5 Discussion 63
5.10 Case Study 2 (Global Context) 64
5.10.1 Background 64
5.10.2 Objectives 65
5.10.3 Methodology 65
5.10.4 Parameters Used 67
5.10.5 Results 68
Hydrological Behaviour Across LCZs 68
5.10.6 Evaluation Matrix 69
5.10.7 Discussion 69
5.11 Case Study 3 (Indian Context) 69
5.11.1 Background 70
5.11.2 Objectives 70
5.11.3 Methodology 71
5.11.4 Results 72
5.11.5 Discussion 73
CHAPTER 6. Site Study, Selection and Data Analysis 75
6.1 Vidisha: Central Indian Town 75
6.1 Regional Setting 76
6.2 Physical Characteristics 78
6.2.1 Soil Characteristics 78

6.2.2 Drainage and River System 80
6.3 Data Analysis 81
6.3.1 Digital Elevation Model (DEM) Analysis 82
6.3.2 Flow Direction Analysis 84
6.3.3 Flow Accumulation Analysis 85
6.3.4 DEM Derived Drainage Network Analysis 87
6.3.5 National Difference Vegetation Index (NDVI) Analysis 89
6.3.6 National Difference Built-up Index (NDBI) Analysis 91
6.3.7 Local Climate Zone Classification Analysis 93
6.3.8 Interpretation of LCZ Analysis 94
6.3.9 Contour Analysis 95
6.3.10 Slope Analysis 97
6.3.12 Vulnerability Analysis Map 100
..... 101
6.3.13 Planning Implications for Vidisha 102
CHAPTER 7. Proposals 104
7.1 Proposed Blue-Green Infrastructure Network 104
7.2 Proposed Drainage and Runoff Management Strategy 105
7.3 Planning Implications 107
CHAPTER 8. Summary 109
8.1 Inferences Drawn 110
8.2 Key Takeaways 112
8.2.1 LCZ-Drainage Integration Strong Foundation for Climate-Resilient Planning 112
8.2.2 Morphology Strongly Determines Urban Drainage Performance 112
8.2.3 Blue-Green Infrastructure (BGI) as a Multi-Benefit Solution 113
8.2.4 Modified LCZ Outcomes Demonstrate the Transformative Impact of BGI 113
8.2.5 Evidence-Based Planning Is Essential for Medium-Sized Indian Towns 114
8.3 Conclusion 114

References **116**

Annexure **120**

LIST OF ABBREVIATIONS

Abbreviation	Full Form
LCZ	Local Climate Zone(s)
BGI	Blue-Green Infrastructure
DEM	Digital Elevation Model
GIS	Geographic Information System
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built-up Index
LULC	Land Use/Land Cover
UHI	Urban Heat Island
SUHI	Surface Urban Heat Island
CUHI	Canopy Urban Heat Island
LST	Land Surface Temperature
SVF	Sky View Factor
NBS	Nature-Based Solutions
SuDS	Sustainable Urban Drainage Systems
LID	Low Impact Development
UDS	Urban Drainage System
RS	Remote Sensing
GPS	Global Positioning System
USGS	United States Geological Survey
CGWB	Central Ground Water Board
UN	United Nations
SDGs	Sustainable Development Goals
VOS	Visualization of Similarities
WUDAPT	World Urban Database and Access Portal Tools
IUCN	International Union for Conservation of Nature

EPA	Environmental Protection Agency
MODIS	Moderate Resolution Imaging Spectroradiometer
OLI	Operational Land Imager
ETM	Enhanced Thematic Mapper
WSUD	Water Sensitive Urban Design

LIST OF FIGURES

Figure 1. Local Climate Zones classification with (yellow) ten urban and (green) seven natural classes. (Kim, (2021).) 1

Figure 2. Illustration showing the impacts of extreme weather conditions and the urban drainage system. (https://www.thames21.org.uk/sustainable-drainage-systems/, n.d.)..... 2

Figure 3. Illustration showing well-planned climate resilient urban drainage system. (https://www.thames21.org.uk/sustainable-drainage-systems/, n.d.)..... 3

Figure 4. Conceptual Linking Diagram: Role of LCZ Classification in Developing Climate-Resilient Urban Drainage. (Author, 2025) 14

Figure 5. Graph showing Timeline of Papers: Scopus-Based 2015-2025 (Author, 2025)..... 17

Figure 6. Keyword Density Visualisation (VOS viewer) 19

Figure 7. Author Density Visualisation (VOS viewer) 20

Figure 8. Temporal Overlay Visualisation (VOS viewer) 22

Figure 9. Objective-based Methodology (Author, 2025) 37

Figure 10. Schematic diagram of standard LCZs. (Jie Han, 2024) 42

Figure 11. Delineation of Watershed and Drainage Network System (Shaikh) 47

Figure 12. Site Study Area 75

Figure 13. Regional Setting of Vidisha, Madhya Pradesh 77

Figure 14.Geomorphology Map, Vidisha District, M. P ((CGWB), 2023) 78

Figure 15. Soil Map of Vidisha District, M.P ((CGWB), 2023) 79

Figure 16. Drainage Map of Vidisha District ((CGWB), 2023) 80

Figure 17. Digital Elevation Model Analysis Map of Vidisha (Author, 2026)..... 82

Figure 18. Flow Direction Analysis Map of Vidisha (Author, 2026) 84

Figure 19. Flow Accumulation Analysis Map (Author, 2026) 86

Figure 20. DEM derived Drainage Network Map (Author, 2026)..... 88

Figure 21. National Difference Vegetation Index (NDVI) Analysis Map (Author, 2026) 90

Figure 22. National Difference Built-up Index (NDBI) Analysis Map (Author, 2026)..... 92

Figure 23. Contour Analysis Map of Vidisha (Author, 2026) 95

Figure 24. Slope Map Analysis of Vidisha (Author, 2026) 98

Figure 25.Vulnerability Map of Vidisha (Author, 2026) 101

Figure 26. Proposal Map of Vidisha (Author, 2026) 106

LIST OF TABLES

Table 1. Comprehensive Overview for Key Definitions (Author, 2025)..... 8
Table 2. Publication Trends (2014-2025) (Author, 2025) 18
Table 3. Thematic Keyword Clusters (Author, 2025)..... 20
Table 4. Comparative Synthesis of LCZ and Drainage Domains (Author, 2025) 23
Table 5. Comprehensive Overview of Reviewed Papers (Author, 2025)..... 23
Table 6. Key Parameters of Local Climate Zones (Author, 2025)..... 43
Table 7. Detailed Morphological Variables (Author, 2025) 61
Table 8. LCZ Hydrological Behavior (Author, 2025) 63
Table 9. Vulnerability Grading Matrix (Author, 2025) 63
Table 10. LCZ Morphological Parameters (Author, 2025)..... 67
Table 11. Ecohydrological Parameters (Author, 2025)..... 68
Table 12. LCZ vs Ecohydrological Behaviour..... 68
Table 13. LCZ Hydrological Performance Grading (Author, 2025)..... 69
Table 14. LCZ Subclasses for Nagpur (Author, 2025) 72
Table 15. LCZ Distribution (Author, 2025)..... 73
Table 16. Grid Suitability Matrix (Author, 2025)..... 73
Table 17. List of District/ Block and Area Sq.km..... 76
Table 18. Colour depicting the DEM analysis interpretation on hydrology. (Author, 2026) 83
Table 19. LCZ Characteristics and Hydrological Performance of Vidisha Planning Area (Author, 2026) 93
Table 20. Contour Map Analysis Details (Author, 2026)..... 97
Table 21. Slope Analysis Details (Author, 2026) 99

CHAPTER 1. Introduction

Against the backdrop of global environmental change and rapid urbanization, building urban resilience has attracted increased attention from both practitioners and researchers in urban planning (Calderón-Contreras and Quiroz-Rosas, 2017; Deal et al., 2017; Kim and Lim, 2016). Making cities and human settlements inclusive, safe, resilient, and sustainable has been identified as UN sustainable development goals in recent years (United Nations, 2016, 2017, 2018).It has also contributed to significant changes in their hydrology and local climates. The shift from natural to build surfaces, from soils and vegetation to pavement (and concrete), has impacted existing natural drainage systems, has decreased the rate of groundwater recharge and has increased the rate of surface runoff and urban heat island effects resulting from urbanization (Kabisch et al., 2017). As a result, cities throughout India now face two major crises, one of an increasing frequency of flooding during the rainy monsoon seasons and the other of increased heat stress during dry days. The traditional method of urban planning, focusing entirely on

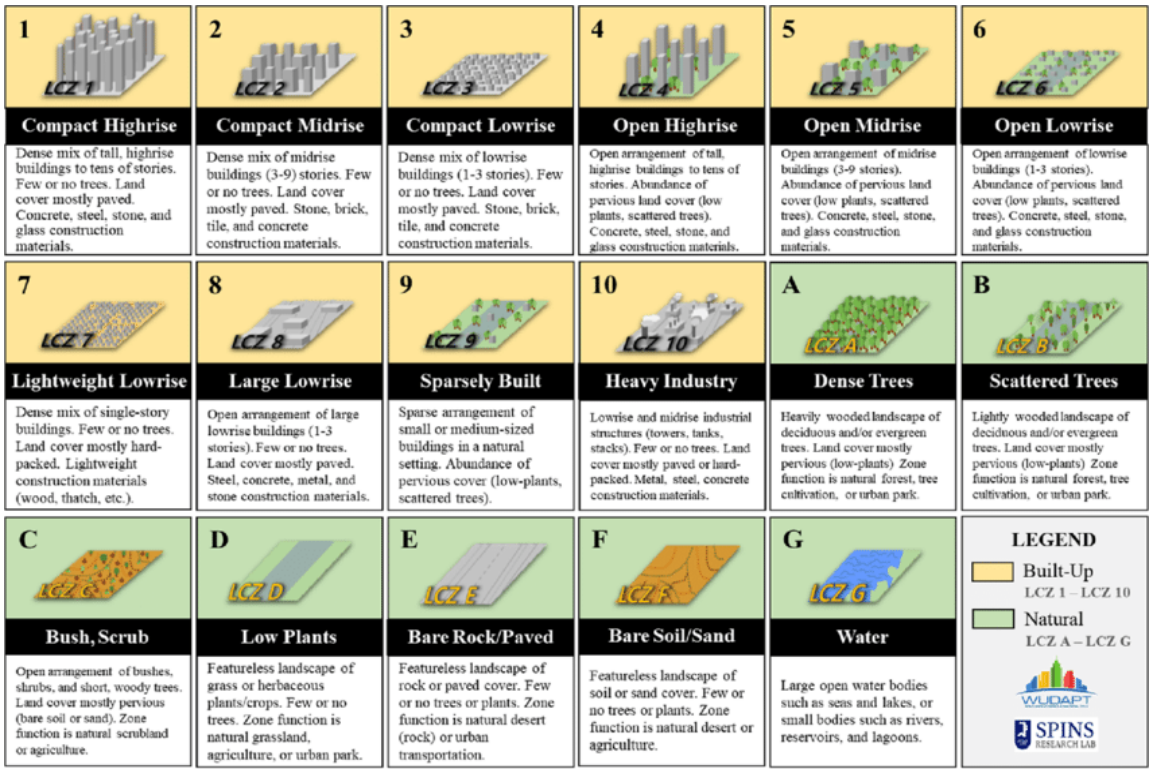


Figure 1. Local Climate Zones classification with (yellow) ten urban and (green) seven natural classes. (Kim, (2021).)

infrastructure development, is inadequate for addressing the complex relationship among urban forms and covers, hydrology and microclimates. Integrating hydrology and spatial morphology as part of the urban planning process will allow for the creation of climate-resilient cities (Mitra, Banerjee, & Roy, 2020).

The local climate zone (LCZ) scheme has been developed primarily for the communication of meta-data produced by observational urban heat island (UHI) studies and has a broad range of applications, including classifying weather stations and assessing social inequality (Stewart, 2011). The 17 LCZs that have been developed document climate-related surface properties at a local scale in urban environments. The LCZ scheme primarily considers surface cover (e.g., paved, low plants, or water), 3D surface structure (e.g., height and density of buildings and trees), and anthropogenic parameters such as anthropogenic heat output from human activity (Demuzere et al., 2019). The scheme classifies urban landscapes into ten "built" and seven "natural" zones, as shown in Figure. 1. It is intended to be universally applicable to urban environments worldwide, thereby offering the possibility of comparative analysis and the monitoring of portions of different cities across the world in a consistent manner (Bechtel et al., 2015).

Nevertheless, it is not possible to obtain climate resilience using solely an assessment of sources, landforms, and types solely together with connection points in our environment. Hydrogeology and urban catchment systems are critical for maintaining ecosystem stability and minimising risks from floods. Many cities in India have experienced devastating floods, partly due to the loss of formerly used natural channels as well because of encroachment on low-lying areas; in addition to this, the infrastructure available for stormwater management is inadequate for meeting demand (Dangwal et al., 2022). The restoration of these natural channels and providing additional vegetated edge infrastructure to connect with our natural systems will provide us with the sustainable achievements of an integrated system where both flow is enhanced as well as the cooling and biodiversity benefits provided from vegetation. Blue-Green



Figure 2. Illustration showing the impacts of extreme weather conditions and the urban drainage system. (https://www.thames21.org.uk/sustainable-drainage-systems/, n.d.)

Infrastructure (BGI) supports this integrative view by creating an integrated system between blue spaces (i.e. rivers, canals, lakes and water) and green spaces (i.e. parks, trees, etc.).

BGI interventions have been shown to help improve urban drainage systems' (UDS) climate resilience by improving their ability to infiltrate, delay peak runoffs and reduce the amount of water accumulated on the land surface (McNabb et al., 2023). However, an assessment of an urban drainage system's climate resilience cannot be solely based on morphology. Urban drainage systems are essential in promoting ecological balance and reducing vulnerability to hydrological disruption. Many cities in India have experienced extensive flooding due to lost natural drainage systems; encroachment onto low-lying areas; and stormwater infrastructure that cannot accommodate the existing stormwater capacity (Dangwal et al., 2022). Reviving and reconnecting them through vegetated corridors represents an ecosystem-based solution for improving how water flows and how cool areas become as well as increasing biodiversity in the area. Blue-Green Infrastructure embodies this holistic approach by combining blue space (rivers, canals, ponds, stormwater drains) and green space (parks, trees, green roofs) into one system that provides multiple water management functions, temperature regulation and promotes ecological health (Ahern, 2011; Fletcher et al., 2015).

By combining the analysis of Local Climate Zones (LCZ) with that of Drainage Analysis, new opportunities are available to support climate-friendly spatial planning as shown in Figure 2. The use of LCZ mapping allows the identification of regions with high thermal vulnerabilities; however, it does not inform planners about the natural drainage networks and where the potential for water retention and/or flow exists. Overlapping the LCZ maps with the Drainage Analysis maps provides planners with the opportunity to create corridors through which to integrate 'blue-green infrastructure' such as vegetated waterways, constructed wetlands, and vegetated buffers



Figure 3. Illustration showing well-planned climate resilient urban drainage system. (https://www.thames21.org.uk/sustainable-drainage-systems/, n.d.)

adjacent to nallahs or streams to provide cooling effects and improved stormwater management (Norton et al., 2015). The information generated using this overlay method aligns with international best practices such as the Sponge City concept, which outlines urban systems that enable the capture, storage, treatment, and reuse of stormwater through the physical landscape of an urban area (Li et al., 2017).

By combining different types of zoning disciplines (e.g. low carbon zones (LCZ) and blue-green infrastructure (BGI)), planners will have the ability to create plans based on best practices that can help them achieve climate change mitigation and adaptation through improving the quality of their city services (e.g. Cooling, infiltration, and biodiversity). By designing plans that incorporate multiple objectives simultaneously, environmental services will provide cooling services as well as multiple other ecosystem services (i.e. ecological/biological) while maintaining the same urban density associated with the city. Experiences in Singapore and Vienna demonstrate that mapping LCZs overlaid with hydrological modelling can assist in determining which areas would be the most effective to allocate land to for green and blue corridors in order to maintain urban density (Ignatius et al., 2022; Bechtel, 2019). Implementing a similar methodology in medium-sized cities in India provides an option for a robust, economically sustainable climate adaptation strategy.

There is a growing urgency to create a comprehensive approach to examining urbanised regions as they grow into urban cities and face increasing environmental pressures by using integrated methods including Local Climate Zone (LCZ) classification and Hydrology (urban drainage) in planning, such as Blue Green Infrastructure (BGI). An example of how to create this integrated approach will be illustrated in this project entitled, "Integrating BGI and Urban Drainage for Climate Resilient Approaches for Blue Green Infrastructure through Climate Resilience, Integration, And Climate Adaptation Strategies," which will provide recommendations for the identification of LCZs, analysis of current drainage networks, and examples of LCZ patterns based on the identification of LCZs. Through this project, we will develop a systematic, spatially based urban planning process that will support the restoration of ecosystem services, provide heat mitigation, and improve the landscape's infrastructure and stormwater management.

1.1 Background Study

Cities worldwide are indeed fast-growing through population growth, migration, and economic development. In this process, natural areas get transformed into urban areas, resulting in the significant transformation of land surface features, hydrological systems, and local climate behaviour. The covering of permeable soils with roads, roofs, and paved surfaces modifies both

the surface energy balance and natural drainage functions to result in an urban microclimate characterized by hotter temperatures, higher surface runoff, and less infiltration.

In large Indian cities, these changes are further exacerbated by unplanned urbanization and poor integration of ecological systems into development planning. This causes a widening disconnect between urban form and environmental performance: for example, there is an increasing number of localized flooding, heat stress, and decline of the urban green and blue assets. For instance, large-scale filling of low-lying areas and natural drainage channels has highly reduced the ability of the city to retain and percolate rainwater, leading to flooding during heavy rainfall events while experiencing droughts during dry periods.

New research and planning frameworks are emerging to apply climate-sensitive design and green infrastructure to cities. A leading example is the LCZ framework of Stewart and Oke (2012), now considered the standardized solution for classifying urban areas according to their thermal and morphological characteristics. With LCZs, planners and scholars are able to think in terms of the spatial analysis of the urban form and materials that influence local temperature variations and energy exchanges (Bechtel et al., 2019). Alternatively, the BGI framework argues for integrating natural and semi-natural systems such as rivers, wetlands, and vegetation corridors into the urban environment to improve resilience while reducing runoff and heat (Ahern, 2011; Fletcher et al., 2015).

The two integrated frameworks, LCZs and BGI, allow for a holistic intervention in the problems of urban climate and hydrology and their interrelationship. Integrated application of LCZ-based climate classification with mapping of natural drainage offers opportunities for identification of strategic zones for the most effective use of ecological measures, including bioswales, retention ponds, or urban wetlands. This integrated approach allows for climate-responsive planning for ecological measures and their interaction with hydrological measures, a place-based strategy, providing accountable spatial evidence to urban planners to prioritise ecology restorative measures for flood recovery measures, thereby enhancing thermal comfort and environmental quality (Norton et al., 2015; Udas-Mankikar & Driver, 2021).

1.2 Problem Formulation

Most Indian cities are rapidly expanding and changing. These changes bring significant alterations to natural landforms and hydrological systems. Such unplanned conversion of permeable surfaces into impervious built-up areas disrupts the natural infiltration capacity, accelerates surface runoff, and enhances the frequency and intensity of urban flooding events (Adhikari et al., 2024). The situation is aggravated by insufficient drainage infrastructure, the filling-up of natural waterways, and the lack of planning sensitive to climatic factors. With the

rise in climate change impacts such as erratic monsoon rainfall, urban heat islands, and water scarcity, cities become more prone to both hydrological and thermal stress (Mutzner et al., 2024).

Built-up areas need to be drained to remove surface water runoff. Traditionally this has been achieved by using gullies and underground pipe systems designed to convey the water away as quickly as possible. The alteration of natural flow patterns can lead to problems elsewhere in the catchment. Water quality issues have become increasingly important, due to pollutants from urban areas being washed into rivers or the groundwater. Once polluted, groundwater is extremely difficult to clean up. Traditional drainage systems cannot easily control poor runoff quality and may contribute to the problem. The amenity aspects of drainage such as water resources management, community facilities, landscaping potential and provision of varied wildlife habitats have largely been ignored by traditional urban drainage. This is why we should embrace Sustainable Drainage Systems (SuDS) to deliver a more holistic approach to managing surface water and wherever possible mimic natural drainage.

Although BGI is globally recognised as an effective strategy to enhance urban resilience, its implementation is still limited to medium-sized towns in India. In general, BGI involves wetlands, green corridors, and vegetated basins within the built environment that are used as the natural systems to manage stormwater, improve air quality, and moderate urban temperatures (Boguniewicz-Zabłocka & Łukasiewicz, 2025). However, the identification of suitable locations and spatial configurations for BGI interventions within the existing urban fabric is indeed a big challenge. Herein lies the importance of LCZ classification, which is both standardized and spatially explicit, focusing on the physical, thermal, and land-cover characteristics of urban environments (Stewart & Oke, 2012).LCZ classification divides urban and natural landscapes into zones based on surface structure, material, and land cover, allowing for detailed analysis of microclimate variations, heat distribution, and surface hydrology (Xu et al., 2019; La et al., 2020).

LCZ, in conjunction with DEM analysis and drainage network mapping, offers a novel approach to the study of how urban morphology interacts with hydrological processes. However, most studies have focused on LCZs in the context of urban heat islands rather than in that of drainage and runoff dynamics (Stewart & Oke, 2012). A critical gap still lies in the linkage of urban climatic zoning (LCZ) with an assessment of drainage patterns and BGI-based solutions for climate-responsive urban planning.

The present study fills this research gap by applying the LCZ classification and geospatial techniques to analyze the land surface form, microclimate, and drainage systems relationship in a Central Indian town. It tries to establish how LCZ mapping, in conjunction with DEM-derived drainage analysis, informs the design and implementation of BGI strategies toward enhancing

urban resilience. This integrated approach aspires to bridge the methodological and practical divide between the disciplines of urban climatology, hydrology, and spatial planning.

1.3 Need for the Study

Currently, the unplanned pattern of land use, decline of natural drainage, and disconnection of the landscape through incorporation of climate-responsive design principles and systems within the urban ecosystem are the root causes for increasing heat stress and recurrent episodes of waterlogging in Indian cities, particularly in moderately sized ones. A large number of existing approaches to planning maintain a heavy reliance on fixed land use zoning and grey infrastructure that is unable to respond dynamically to fluctuating climates and hydrologies (McNabb et al., 2023).

For this reason, there is an urgent need to develop spatially informed methods to correlate urban morphological features with drainage and thermal characteristics. The Local Climate Zone (LCZ) classification system offers an effective basis for learning how urban fabric shapes surface temperatures and guides energy exchange, while mapping of natural drainage networks helps articulate urban and city-sized hydrological flow and potential for water retention (Geletič & Lehnert, 2016). Combined, these systems will help in the strategic placement of blue-green infrastructure that would address concerns of flood attenuation and temperature moderation.

The research is necessary because urban planning frameworks in India typically do not employ an analytical approach that integrates urban form, or morphology, and hydrology. Linking LCZs with drainage systems helps to assist planners in designing flexible land use strategies whereby regionally or locally appropriate nature-based solutions and strategies can be instituted if feasible, rather than purely engineered systems (Li et al., 2017). Furthermore, cities in central India that face extreme summer's heat juxtaposed with heavier monsoon rains also require local climate datasets, spatial datasets, and evaluations to properly design adaptation strategies.

Thus, this study seeks to link morphological and ecological planning more directly through LCZ and Drainage integrated assessments. Outcomes will assist planners in determining possibilities to act on a blue–green corridor approach consistent with climate responsiveness and sustainable urban development principles.

1.4 Key Definitions

A thorough understanding of the technical terms related to urban climate, hydrology, geospatial analysis, and nature-based planning is important for interpreting the analyses undertaken as part of this study. Research that addresses climatic zoning, land surface processes, drainage behaviour, and environmental resilience involves using terms that have specific meanings in an academic context. Commonly employed in terms of climate and environmental

risk, climate change, environmental unrest, modelling, climate hazard, urban climate adaptation, urban climate development, or environmental risk, these words are applicable across a number of disciplines such as urban planning, environmental engineering, remote sensing, and landscape ecology, but the way in which they are defined and to what they refer may differ depending on the methodological landscape.

To aid in ongoing clarity and conceptual cohesion, it is important to first define these key terms, so there is a common understanding of how the term is presented in the dissertation. Having clearly articulated definitions of how the terms will be used as indicated in analytical processes, modelling activities, spatial indicators, and thematic assessments later on in the dissertation can create a beneficial cohesion that reinforces the theoretical underpinnings of the study with practical geospatial outputs such as classification maps, drainage models, and environmental indices. The following Table 1 of the comprehensive overview for key definitions is presented from authoritative sources and many are derived from seminal literature in the respective areas of its use. It is intended to give you clarity regarding definitions or meanings attached to terms, concepts, and methodologies throughout this research writing.

Table 1. Comprehensive Overview for Key Definitions (Author, 2025)

Sr. No.	Term / Keyword	Definition	Author (Year)
1	Local Climate Zone (LCZ)	A standardized urban classification system that categorizes landscapes into distinct thermal–morphological zones based on structure, land cover, and surface properties.	Stewart & Oke (2012)
2	Urban Morphology	The study of the physical form, layout, and structure of urban spaces, including buildings, streets, and open areas, and their relationship to urban processes.	Moudon (1997)
3	Surface Urban Heat Island (SUHI)	A thermal phenomenon where surface temperatures in urban areas are significantly warmer than surrounding rural areas due to impervious surfaces and altered energy balance.	Voogt & Oke (2003)
4	Canopy Urban Heat Island (CUHI)	Differences in Urban temperature measured within the canopy layer (street level to roof level), influenced by built form and human activities.	Oke (1982)

Sr. No.	Term / Keyword	Definition	Author (Year)
5	Land Surface Temperature (LST)	The radiative temperature of the Earth's land surface as recorded by remote sensing instruments, indicating thermal energy emitted from the ground.	Weng (2009)
6	Sky View Factor (SVF)	The amount of sky visible from a point on the ground influences heat loss, solar access, and microclimate.	Oke (1981)
7	Thermal Admittance	The capacity of a material to absorb and release heat, affecting local thermal comfort and temperature dynamics.	Oke (1988)
8	Albedo	The proportion of incoming solar radiation reflected by a surface; higher albedo means more reflectivity and lower heat absorption.	Oke (1987)
9	Urban Ventilation	The movement of air through and over urban structures, improving thermal comfort and reducing pollution concentration.	Ng (2009)
10	Microclimate	The atmospheric conditions of a small localized area influenced by physical structures, vegetation, and surface materials.	Geiger (1971)
11	Urban Drainage	A system designed to manage stormwater and surface runoff through collection, conveyance, storage, and disposal in urban areas.	Butler & Davies (2011)
12	Stormwater	Rainfall runoff that flows over surfaces and is transported through natural or engineered drainage systems.	Fletcher et al. (2015)
13	Surface Runoff	The flow of excess water over land when rainfall exceeds the infiltration capacity of soil.	Chow et al. (1988)
14	Infiltration	The process of water entering the soil surface, governed by soil characteristics and moisture conditions.	Horton (1933)
15	Impervious Surface	Urban surfaces such as concrete and asphalt that restrict water infiltration and increase runoff.	Arnold & Gibbons (1996)
16	Watershed / Catchment	A geographic area where all precipitation drains to a common outlet point such as a stream or river.	Chow et al. (1988)

Sr. No.	Term / Keyword	Definition	Author (Year)
17	Drainage Basin	A natural region where collected precipitation flows to a central river system.	Chorley (1969)
18	Natural Drainage Channel	Naturally occurring pathways through which water flows during rainfall events, shaped by geomorphological processes.	Leopold, Wolman & Miller (1964)
19	Flow Direction	A DEM-based GIS method that determines the direction of water flow from each cell based on elevation gradients.	O'Callaghan & Mark (1984)
20	Flow Accumulation	A GIS extrapolated index showing how many upstream cells drain into a given point helps in identifying channels and flood-prone areas.	Tarboton (1997)
21	Overland Flow	The movement of water over land surfaces before entering in the defined channels occurs when rainfall exceeds infiltration.	Horton (1933)
22	Hydrograph	A graphical representation of streamflow or discharge over time following the understanding of a rainfall event.	Linsley et al. (1949)
23	Stormwater Conveyance	The infrastructure and natural pathways through which stormwater is transferred from source to discharge points.	Butler & Davies (2011)
24	Drainage Density	The total length of streams and channels per unit area indicates the efficiency of drainage.	Horton (1945)
25	Urban Flooding	Flooding occurs within urban areas due to excess runoff, inadequate drainage, and impervious surfaces.	Jha et al. (2012)
26	Digital Elevation Model (DEM)	A digital representation of ground surface elevation used to analyse the characteristics of the terrain, hydrological flow, and watershed.	USGS (1997)
27	Slope Analysis	The assessment of terrain steepness derived from elevation models influences runoff velocity and erosion.	Burrough & McDonnell (1998)
28	Contour & Topography	Contours represent lines of equal elevation used to understand terrain shape and natural drainage patterns.	Strahler (1952)

Sr. No.	Term / Keyword	Definition	Author (Year)
29	Remote Sensing	The science of acquiring information about Earth's surface using satellite or airborne sensors without physical contact.	Lillesand & Kiefer (1979)
30	Image Classification	The process of categorizing pixels into thematic classes (e.g., urban, vegetation) using supervised or unsupervised algorithms.	Richards & Jia (2006)
31	Raster Data	Grid-based spatial data format where each cell represents a value such as elevation or temperature.	Burrough & McDonnell (1998)
32	Vector Data	Spatial data structure using points, lines, and polygons to represent geographic features.	Longley et al. (2005)
33	Spatial Resolution	The size of one pixel on the ground in a remotely sensed image determines image detail.	Jensen (2000)
34	Land Use / Land Cover (LULC)	Classification showing physical land features (cover) and human activities (use) on the Earth's surface.	Anderson et al. (1976)
35	NDVI (Normalized Difference Vegetation Index)	A vegetation index calculated using near-infrared and red reflectance to assess vegetation health and density.	Rouse et al. (1974)
36	NDBI (Normalized Difference Built-up Index)	A spectral index that identifies built-up areas by contrasting short-wave infrared and near-infrared reflectance.	Zha, Gao & Ni (2003)
37	Blue–Green Infrastructure (BGI)	Integrated planning approach combining natural water bodies (blue) and green spaces to manage stormwater and enhance resilience.	Ahern (2011)
38	Nature-Based Solutions (NBS)	Solutions inspired and supported by nature that use natural processes to address urban environmental challenges.	IUCN (2016)
39	Sustainable Urban Drainage Systems (SuDS)	Water management practices mimic the natural hydrology to reduce runoff, improve water quality, and promote infiltration.	CIRIA (2007)
40	Low Impact Development (LID)	An approach that uses decentralized, small-scale perceptions to manage stormwater at its source.	US EPA (2000)

Sr. No.	Term / Keyword	Definition	Author (Year)
41	Bioswale	A vegetated, shallow drainage channel designed to slow, filter, and infiltrate stormwater runoff.	Davis et al. (2001)
42	Retention Pond	A permanent water-holding basin designed to store stormwater and release it slowly for flood control and water quality improvement.	Schueler (1987)
43	Detention Basin	A temporary stormwater storage structure that detains runoff and releases it at a controlled rate.	Schueler (1987)
44	Urban Wetland	A natural or constructed wetland within urban areas serving for stormwater filtration, biodiversity, and flood control.	Mitsch & Gosselink (1993)
45	Green Corridor	A linear network of green spaces that support biodiversity, ecological connectivity, and climate regulation in urban areas.	Ahern (1995)
46	Rain Garden	A shallow vegetated depression designed to capture and infiltrate stormwater from adjacent impervious surfaces.	Davis et al. (2009)
47	Permeable Pavement	A pavement system allowing water to infiltrate through its surface, reducing runoff and enhancing groundwater recharge.	Pratt et al. (1989)
48	Green Roof	A roof covered with vegetation and soil layers to improve insulation, reduce runoff, and enhance urban ecology.	Getter & Rowe (2006)
49	Riparian Buffer	Vegetated zones along riverbanks designed to protect water quality, reduce erosion, and support habitat.	Lowrance et al. (1984)
50	Climate Resilience	The ability of urban systems to absorb, adapt, and recover from climate-related stresses such as heat and flooding.	IPCC (2014)
51	Heat Stress	Physiological strain on humans caused by prolonged exposure to high temperatures, humidity, and low ventilation.	Epstein & Moran (2006)
52	Thermal Comfort	The condition in which individuals feel satisfied with the surrounding thermal environment.	Fanger (1970)

Sr. No.	Term / Keyword	Definition	Author (Year)
53	Evapotranspiration	The combined process of water evaporation and plant transpiration from Earth's surface to the atmosphere.	Thornthwaite (1948)
54	Urban Ecology	The study of ecological processes occurring within cities and urban landscapes.	McDonnell & Pickett (1990)
55	Environmental Sustainability	Meeting present needs without compromising future generations through balanced environmental, social, and economic decisions.	WCED (1987)
56	Green Cover / Vegetation Cover	The proportion of land covered by vegetation, influencing temperature regulation, infiltration, and ecological health.	Nowak et al. (2001)
57	Flood Vulnerability	The degree to which people, infrastructure, and environments are susceptible to damage from flooding events.	Balica et al. (2009)

The conceptual link diagram provides an organized flow of how the classification of Local Climate Zone (LCZ) contributes more systematically towards developing climate-resilient urban drainage. The implementation of the diagram is structured in a top-down format to represent how environmental processes progress logically from surface form through to the development of drainage resilience.

This diagram captures the progression from hydrological response to establish enhanced LCZ classification, where the top provides a starting entry point of analysis, the LCZ classification classifies urban areas and landscapes according to measurable parameters, including building height, density, vegetation cover, surface materials, thermal properties, and the proportion of sky. These lend themselves toward scientific analysis of form for understanding, assessing, and explaining zonal behaviours in urban settings.

The second level of the diagram links the types and characteristics associated with LCZ classification, noting how the different class types experience low and high imperviousness, limited or excessive vegetation, and structural forms that may be tightly or loosely compacted.

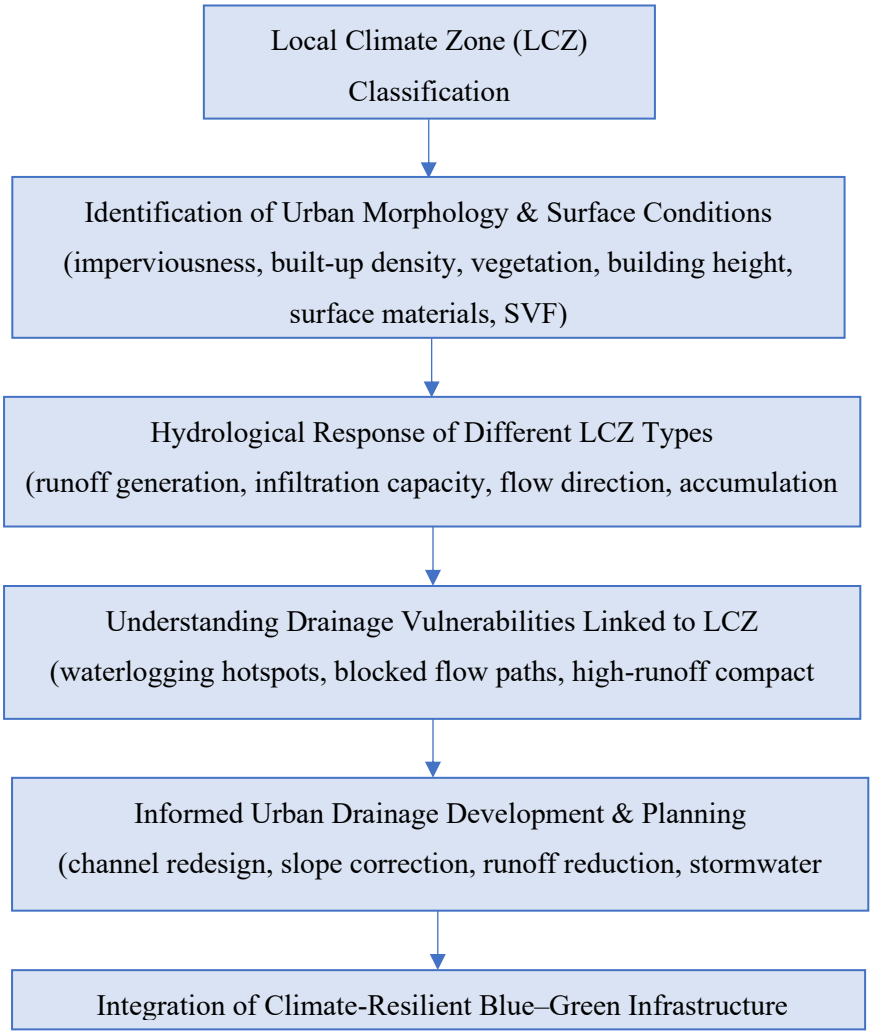


Figure 4. Conceptual Linking Diagram: Role of LCZ Classification in Developing Climate-Resilient Urban Drainage. (Author, 2025)

The characteristics of the surface materials/land resources relate to how land interacts with heat and moisture, and moisture retention. The following Figure 4 depicts the understanding of the model. At the third level, the characterisation of the classified types and components provides an explanation of the behaviours that determine the thermal and moisture behaviours embedded into the surfaces from LCZ classification, including land surface temperatures, heating or cooling retentiveness, and evapotranspiration behaviour of soil moisture.

These climatic behaviours directly influence processes and contribute towards hydrological behaviours following precipitation events. With the downward flow of the diagram, the reader is transitioned to the hydrological response of urban surfaces, showing how LCZ-based surface and thermal properties lead to runoff generation, infiltration rates, flow direction, and accumulation zones. For example, compact LCZs with high imperviousness generate rapid runoff, while vegetated LCZs with vegetation lead to greater infiltration rates and slower discharge rates.

This stage is important from a hydrological perspective because it links the urban climate conditions to the physical hydrological performance. The hydrological dynamics can then feed into the urban drainage vulnerability assessment where the interaction(s) of LCZ with hydrology can highlight drainage-related problems related to waterlogged areas, blocked drainage paths, overloaded channels, and/or impeded stormwater movement as detected by the DEM-based water runoff analysis. At this point in the process, the diagram transitions from problem understanding to problem solving. Gained knowledge from LCZ-based hydrological assessment may inform urban drainage practices through reconceptualising channel designs, slope reconfiguring works, creating surface storage, source-control interventions, and prioritizing spatial actions.

The value of integrating climate-resilient blue–green infrastructure options in order to counter the runoff and restore the conditions of infiltration and resilience, which may include bioswales, retention basins, permeable pavements, wetlands, and low-impact development practices, is restated in this final stage diagram of the conceptual model.

Summarizing this diagram shows that LCZ classification serves as both a climate assessment framework and a broader framework interrelating urban form, microclimate, hydrology, drainage, and planning. This diagram has portrayed the various dimensions and interdependencies associated with the function of urban drainage. Further, it has proved that the climate-responsive development of drainage can be evidenced through LCZs spatially and morphologically, in addition to the environmental dimensions.

CHAPTER 2. Literature Study

A comprehensive literature review provides a theoretical and empirical foundation to understand the interlinked nature of urban form, climate behavior, hydrological response, and drainage performance. Rapidly growing urbanization in many developing regions is increasing the challenges related to impervious surface expansion, increased runoff, higher land surface temperatures, and more frequent drainage failures. The literature related to LCZs, urban hydrology, terrain-based drainage assessment, and climate-resilient planning underlines the need for integrated frameworks that put together climatic and hydrological perspectives.

LCZ-based studies provide a standardized basis to analyse urban morphology and its climatic consequences, whereas hydrological and drainage literature underlines the implications of altered surface conditions for runoff and flooding.

Similarly, studies on climate resilience and Blue–Green Infrastructure give planning directions toward sustainable drainage solutions. This chapter, by reviewing the above research domains, identifies gaps, establishes the conceptual linkages, and justifies the rationale for the present study, which combines LCZ classification with drainage development to achieve climate resilience.

2.1 Evolution of Research

A structured literature search was performed through Scopus, covering the period 2015-2025, to systematically investigate how LCZ and urban form impact hydrological behavior and, by extension, urban drainage. This time frame coincides with the period in which LCZ-based urban climate analysis became widespread following the codification of the LCZ scheme in Stewart & Oke (2012) and the WUDAPT protocol for city-scale LCZ mapping in Mills et al. (2015). Rapid developments within the past ten years also in urban hydrology, stormwater modeling, and nature-based drainage solutions justify this temporal boundary (Demuzere et al., 2020).

Two search strings were devoted to capturing the thematic scope:

****Search String 1: LCZ and Hydrology Focus****

TITLE-ABS-KEY (('Local Climate Zone*' OR 'LCZ' OR 'WUDAPT') AND ('hydrology' OR 'hydrological' OR 'runoff' OR 'flood*' OR 'pluvial flood*' OR 'stormwater' OR 'water sensitive' OR 'blue-green' OR 'impervious*' OR 'pervious')) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA , 'ENVI') OR LIMIT-TO (SUBJAREA , 'DECI') OR LIMIT-TO (SUBJAREA , 'EART')) AND (LIMIT-TO (DOCTYPE , 'ar') OR LIMIT-TO (DOCTYPE , 're') OR LIMIT-TO (DOCTYPE , 'cp') OR LIMIT-TO (DOCTYPE , 'ch') OR LIMIT-TO (DOCTYPE , 'cr'))

****Search String 2: Urban Form and Drainage Focus****

TITLE-ABS-KEY (('urban form' OR 'urban morphology' OR 'urban geometry' OR 'land use' OR 'LULC') AND ('urban drainage' OR 'drainage network' OR 'stormwater' OR 'SUDS' OR 'hydrological response' OR 'runoff' OR 'pluvial flood*' OR 'climate resilience')) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (OA , 'all')) AND (LIMIT-TO (LANGUAGE , 'English')) AND (LIMIT-TO (DOCTYPE , 'cp') OR LIMIT-TO (DOCTYPE , 're') OR LIMIT-TO (DOCTYPE , 'ar') OR LIMIT-TO (DOCTYPE , 'ch') OR LIMIT-TO (DOCTYPE , 'ed'))

Both search strings were filtered using subject area constraints ('ENVI', 'DECI', 'EART') to ensure disciplinary relevance to environmental, decision-making, and earth sciences. Keyword inclusion/exclusion logic for the drainage query ensured elimination of agricultural hydrology, soil erosion, and unrelated water chemistry studies. These searches included synonyms and morphological variants, such as LCZ, drainage, hydrology, runoff, stormwater, flooding, and imperviousness, to make the searches all-inclusive (Zhao et al., 2021). Subject area filters were applied-environmental Sciences, Earth Sciences, and Decision Sciences-to retain studies directly relevant to urban climate-hydrology interactions (Ghodsi et al., 2020). Document types included in this review are limited to peer-reviewed articles, reviews, conference papers, book chapters, and editorial reviews. All results were limited to English. These two searches initially yielded two CSV datasets, which were combined into an integrated corpus for bibliometric analysis. The integrated dataset was then processed using VOSviewer, a software program with which keyword co-occurrence patterns and dominant research clusters could be extracted. VOSviewer has been widely used in systematic reviews of urban climate and hydrology studies because it can visualise thematic networks and trends in research evolution.

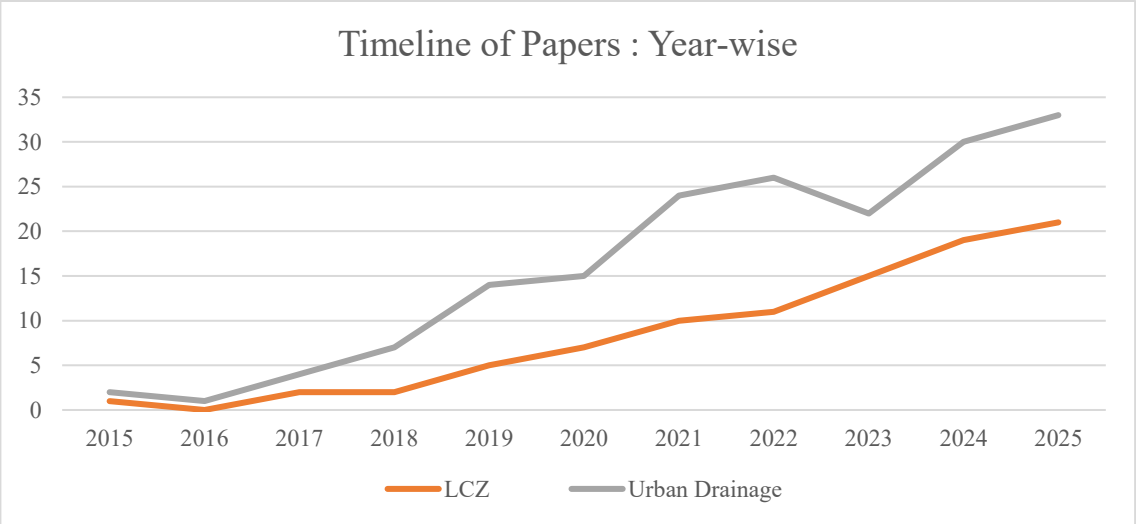


Figure 5. Graph showing Timeline of Papers: Scopus-Based 2015-2025 (Author, 2025)

The year-wise timeline of publications clearly brings out that from 2015 to 2025, research related to both LCZ and urban drainage has registered a strong and simultaneous rise globally.

2.1.1 Publication Trends (2014–2025)

The combined dataset shows a consistent increase in publication output after the year 2018, matched with increased attention toward urban heat mitigation and nature-based drainage interventions. Three phases are conceptually distinguished: (1) 2014–2017: a formative phase focused on LCZ classification and land surface temperature; (2) 2018–2021: an expansion phase that develops and integrates remote sensing and hydrological GIS models; and (3) 2022–2025: a consolidation phase focusing on resilience and blue–green urban design.

The formative period (2014–2017) has been dominated by publications associated with LCZ mapping and assessments of the thermal environment using satellite imagery, notably from Landsat 8 and MODIS data. Groundwork for standardized urban morphological classification was laid by researchers such as Stewart and Oke in 2012 and Bechtel et al. in 2015.

The integration phase-2018-2021-refers to the period when the geospatial modelling of hydrology and LCZ classification began to intersect. Many scholars were increasingly using GIS and remote sensing to link urban morphology with hydrological parameters such as runoff coefficients, infiltration rates, and drainage efficiency (Wang et al., 2020).

Table 2. Publication Trends (2014-2025) (Author, 2025)

Period	Focus Area	Key Research Direction
2014–2017	LCZ Foundations	Urban heat mapping, LCZ classification, satellite-based LST analysis
2018–2021	Integration Phase	Linking LCZs with hydrology and GIS models
2022–2025	Resilience Focus	Blue-green Infrastructure and Climate Adaptation Planning

This was also when WUDAPT (World Urban Database and Access Portal Tools) gained global traction, providing open data that enhanced reproducibility and comparability of LCZ-based studies. The resilience-focused phase (2022–2025) reflects a paradigmatic shift toward planning-oriented applications. LCZ and drainage interactions have been explored in relation to climate adaptation, sustainable cities, and ecosystem services. This transition underlines a recognition of the fact that mitigating the UH is not only a less isolated technical challenge, but an interconnected spatial problem in need of holistic, morphology-informed solutions. The

growth in publication starting from 2018 has corresponded to the call for climate-resilient, inclusive, and sustainable urbanization by the Paris Climate Agreement (2015) and the United Nations' Sustainable Development Goals (SDG 11 & SDG 13). It therefore speaks to both a bottom-up academic and a top-down policy level in terms of integrated urban environmental management.

2.1.2 Keyword Co-occurrence and Density Analysis

The analysis of keyword co-occurrence has reflected various thematic clusters that partially coincide between LCZ and drainage studies. Within the keywords, high-frequency terms included 'Local Climate Zone', 'land surface temperature', 'climate change', 'drainage', 'flood risk', and 'blue-green infrastructure'. Keyword density is reflected in Figure 6 below: the yellow zones are research hotspots.

The Urban Climatology cluster maps to research directed at LCZ classification, microclimate regulation, and urban heat mapping (Stewart & Oke, 2012). The Hydrology and Drainage cluster captures the hydrological modelling domain, integrating runoff simulation, flood control, and stormwater infrastructure (Fletcher et al., 2015). The Spatial Modelling cluster bridges both domains through geospatial tools and satellite-derived indices such as NDVI, impervious surface mapping, and LULC analysis (Zhao et al., 2021). Finally, the Sustainability and Adaptation cluster represents a growing planning-oriented strand of research into the linking of urban form, resilience, and climate governance (Kabisch et al., 2016).

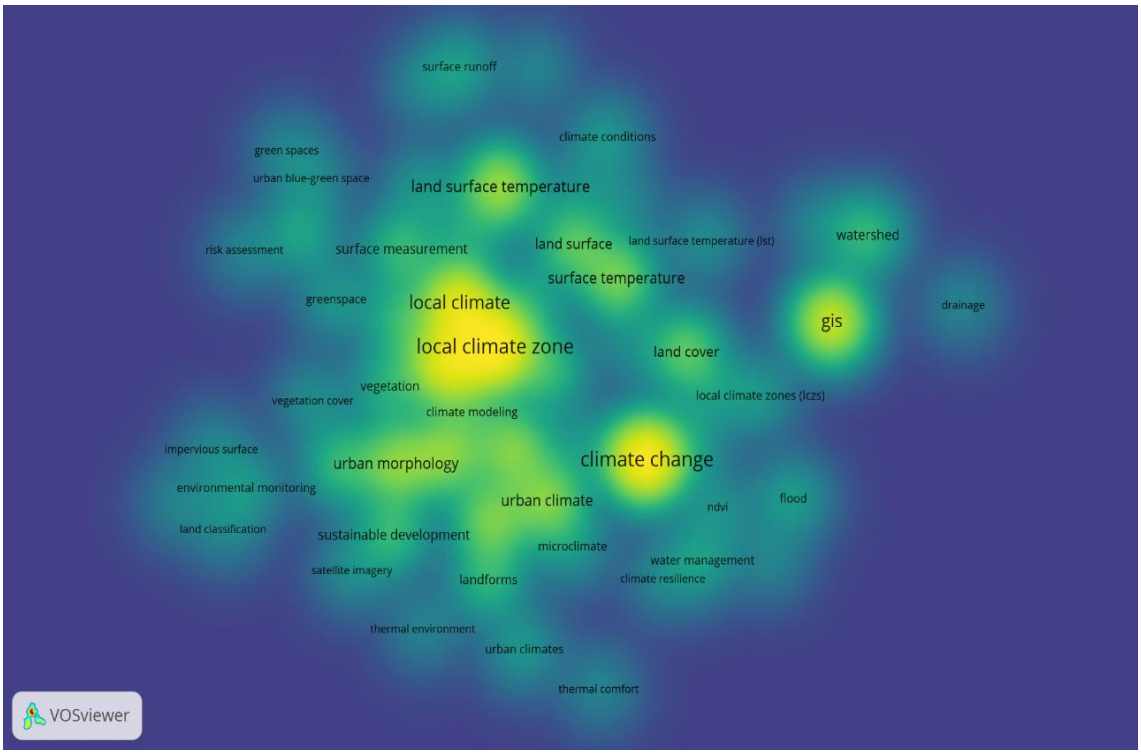


Figure 6. Keyword Density Visualisation (VOS viewer)

Overlapping regions in the keyword map visually present the convergence of climatological and hydrological clusters, showing methodological and conceptual overlap. This supports the assertion that LCZ-derived morphological data can be used as basic input parameters in hydrological modelling and drainage design, but they provide new potential in identifying urban heat-flood interaction zones (Zhong et al., 2021).

Table 3. Thematic Keyword Clusters (Author, 2025)

Cluster Theme	Representative Keywords
Urban Climatology	LCZ, LST, Thermal Comfort, Heat Island, Microclimate
Hydrology and Drainage	Runoff, Stormwater, Flood, Watershed, Blue-green Infrastructure
Spatial Modelling	GIS, NDVI, Remote Sensing, Land Cover, Impervious Surfaces
Sustainability and Adaptation	Climate Change, Resilience, Sustainable Cities, Urban Form

2.1.3 Author Collaboration and Network Patterns

Figure 7 represents the authorship density visualization global structure of collaboration within the LCZ-drainage research community. Emphasis on network analysis underlines the central role of Demuzere, Bechtel, and Oke in structuring the LCZ conceptual framework and its global diffusion. Their high centrality and interlinkages suggest influential positions in establishing methodological standards, especially regarding WUDAPT undertakings.

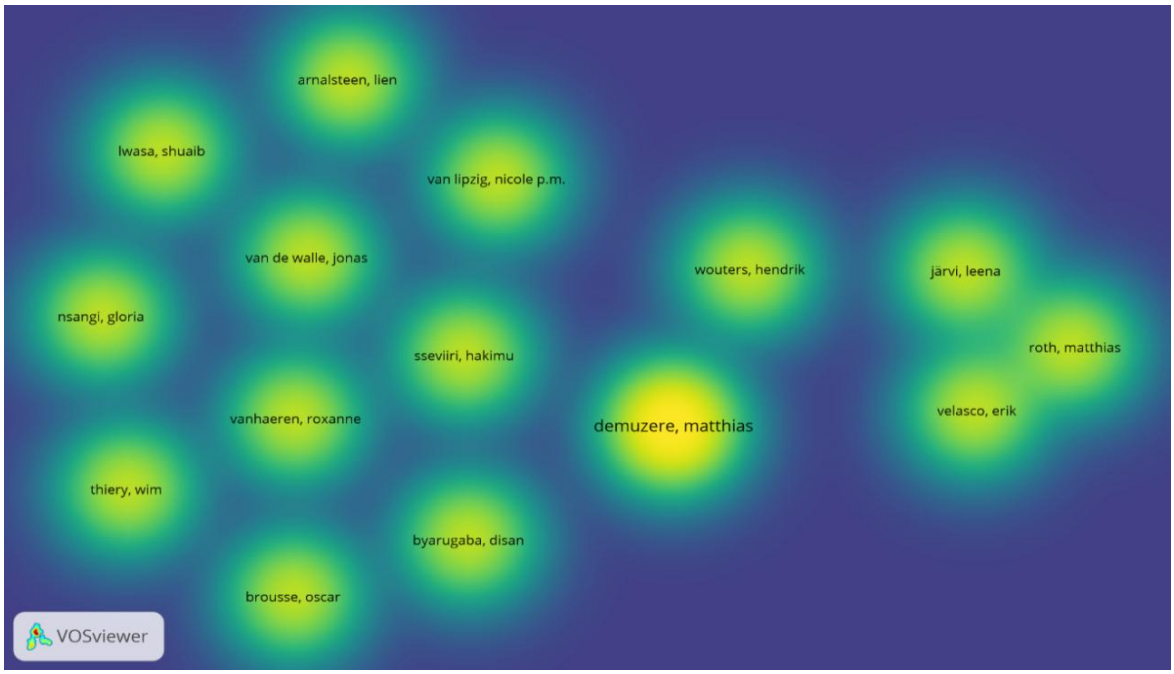


Figure 7. Author Density Visualisation (VOS viewer)

The patterns of regional collaboration show explicit geographical clustering. European research groups are leading the early methodological and theoretical development of the field, with major focuses on the standardization of urban climate and thermal comfort analysis. On the other hand, Asian research institutions, especially those from China, South Korea, and India, have come to the forefront in the recent decades and have led applied studies that integrate LCZ analysis with hydrological modeling and flood resilience assessment.

A remarkable trend can be recognized: the growth post-2020 in Indian contributions, reflecting an increasing interest in applying LCZ and drainage coupling to medium-sized urban centers with monsoonal flooding and heat stress. Most of these rely on free and open-source data and GIS-based LCZ mapping for informing urban planning and stormwater management-for example, Bhopal, Indore, and Chennai. The collaboration map indicates increasingly multidisciplinary teams of climatologists, hydrologists, GIS specialists, and planners. This cross-sectoral cooperation is a signal of the maturation of a new research paradigm-one that links integrated microclimatic data with hydrological performance to underpin data-driven urban resilience planning.

2.1.4 Temporal Overlay and Emerging Trends

Figure 8 temporal overlay map shows early publications (in blue) focus on LCZ typology and LST retrieval, whereas recent works (in yellow) mention drainage resilience and integrated modeling.

Emergent topics include the coupling of LCZ frameworks with hydrological simulations and the implementation of nature-based solutions for pluvial flood mitigation (Boguniewicz-Zabłocka et al., 2025).

The middle period or phase, 2018-2021, is in green and reflects the transition toward the integration of GIS-based hydrological simulation with climate modeling frameworks. This period showcases the beginning of studies that investigate how impervious surface extent and vegetation fraction are related to runoff dynamics, which is indeed an emerging dialogue between climatology and hydrology. Demuzere et al. 2019; Wang et al. 2020

Recent works within the period 2022-2025 (in yellow) increasingly focused on resilience-driven applications. Emerging trends include: the coupling of LCZ frameworks with hydrological simulations, AI-assisted LCZ classification, and implementation of blue-green infrastructure by Boguniewicz-Zabłocka et al. (2025). At this point, researchers started using LCZ as an analytical layer in spatial decision-support systems for stormwater management and adaptive design.

This temporal progression underlines a co-evolution of climate and hydrology disciplines, from isolated heat or water flow analyses toward a systems-oriented approach where both dimensions are understood as interdependent processes shaping urban sustainability.

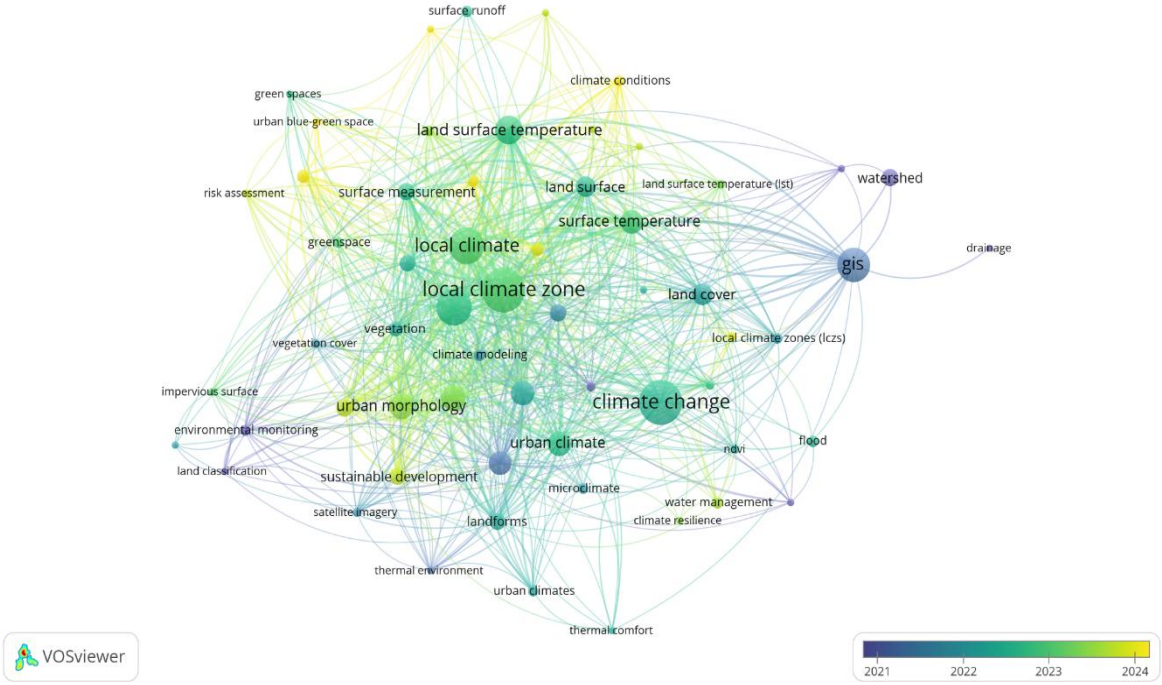


Figure 8. Temporal Overlay Visualisation (VOS viewer)

2.1.5 Comparative Synthesis of LCZ and Drainage Domains

LCZ and drainage studies have traditionally been separated, but according to the bibliometric synthesis, they represent conceptually complementary fields that have developed in a way to support each other.

LCZ studies provide the morphological and climatic context by identifying areas prone to heat accumulation and reduced evapotranspiration.

The drainage studies address the hydrological consequences of these morphological patterns, including surface runoff, infiltration deficits, and flood risk. This comparative synthesis emphasizes how standardized parameters, such as impervious surface ratio, building geometry, and vegetation density, can be provided by LCZ-based spatial data to enhance the precision of hydrological modelling.

On the other hand, drainage models provide critical feedback on how surface form affects hydrological performance and thus allow for iterative design approaches toward resilient urban planning. By contrast, drainage models provide critical feedback on how surface form affects hydrological performance and thus allow for iterative design approaches toward resilient urban planning (Zhang et al., 2023).

Convergence between LCZ and drainage methodologies, therefore, represents one aspect of a wider paradigm shift in urban environmental research from piecemeal assessments to integrated morphological-hydrological planning. Such integration not only deepens scientific

understanding but also equips planners and policy-makers with actionable insights for designing climate-resilient, water-sensitive cities.

Table 4. Comparative Synthesis of LCZ and Drainage Domains (Author, 2025)

Aspect	LCZ Research	Drainage Research
Primary Objective	Assess microclimate variations and heat island effects	Model surface runoff, flooding, and hydrological resilience
Key Tools	Remote sensing, GIS, WUDAPT, field measurements	Hydrological models, GIS, SUDS evaluation
Data Sources	Landsat, MODIS, in-situ temperature data	Rainfall data, DEMs, hydrological survey data
Recent Integration	LCZ-hydrology coupling for blue–green resilience	Urban morphology–drainage correlation via GIS-based models

2.2 Identification of Gaps

Based on the provided titles and key transformative areas of various research papers, along with the identified gaps:

Table 5. Comprehensive Overview of Reviewed Papers (Author, 2025)

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
1	2024	*Adaptive decision-making: Bayesian Network Modeling for Blue–Green Infrastructure selection under dynamic climate and land-use*	Seker & Orak	Istanbul / general	Decision-support for selecting BGI under dynamic climate and land-use	Bayesian Belief Network identifies the most effective BGI options by integrating climate, ecosystem service and land-use parameters; provides transparent prioritization logic.	Sensitive to local input data and lacks explicit hydrological /DEM coupling. LCZ or morphological parameters are not integrated.	Integrating LCZ-specific physical parameters (imperviousness, vegetation fraction, height) into BBN models; coupling BBN with hydrological runoff modelling to evaluate BGI impacts under different urban morphologies.

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
2	2025	*Optimizing urban blue-green space in climate-adaptive planning: systematic review of Threshold Values of Efficiency (TVoE)*	Han et al.	Global	Review of BGI size/efficiency thresholds for cooling & flood mitigation	Highlights measurable cooling and hydrological benefits of BGI when minimum size/shape thresholds are satisfied; identifies widely variable performance across climates.	Lack of standardised metrics and absence of LCZ-based thresholds; insufficient integration of DEM/runoff modelling in threshold estimation.	Establishing LCZ-specific BGI thresholds; linking TVoE with hydrological models to define size and configuration standards for different urban morphologies.
3	2025	*Factors influencing cooling potential of BGI across Local Climate Zones*	Budzik et al.	Wroclaw	Cooling performance of BGI in different LCZs	Demonstrates strong variation in cooling effectiveness depending on BGI size, vegetation density and LCZ context; uses spatial metrics to explain thermal performance.	Limited assessment of hydrological /runoff effects of BGI; lacks integration of flow accumulation or drainage-system impacts.	Quantifying combined thermal and hydrological performance of BGI across LCZs; modelling runoff retention differences between LCZ classes to guide BGI placement.
4	2025	*Optimizing Urban Green Roofs: Framework for suitability, economic viability & microclimate regulation*	Wu et al.	Multiple cities	Green roof suitability and co-benefits	Integrates rooftop suitability, life-cycle cost–benefit, and microclimate benefits; shows green roofs meaningfully reduce surface runoff and heat stress.	Limited long-term runoff monitoring; insufficient link between roof suitability and neighbourhood-scale drainage performance; no LCZ-based	Developing LCZ-linked suitability maps for green roofs; modelling how rooftop interventions affect downstream drainage networks using

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
							differentiation.	DEM-based routing.
5	2024	*Flood Management in Upper Kuncir River: Hydrological Analysis & Watershed Conservation*	Purboseno et al.	Indonesia	Flood hydrology, watershed rehabilitation	Identifies erosion and sedimentation as drivers of reduced drainage capacity; proposes check dams, reforestation and channel normalization for flood mitigation.	Focused on rural watershed mitigation; does not integrate urban morphology or LCZ concepts; lacks micro-scale drainage modelling.	Translating watershed-scale conservation approaches to peri-urban zones; assessing how upstream land-cover/LCZ transitions influence urban drainage behaviour.
6	2021	*Estimating Urban Flood Hazard Zones using EPA-SWMM (case-series)*	Alam, Rahman, et al.	Bangladesh	SWMM-based flood hazard mapping	Shows SWMM's effectiveness in simulating block-level flooding using rainfall, drainage and land-use data; aligns with observed inundation patterns.	Case-specific calibration; few studies integrate LCZ-based hydrological parameters; limited exploration of morphological runoff variability.	Building LCZ-parameterized hydrological models to evaluate peak-flow response; integrating DEM-derived micro-drainage pathways into SWMM for finer hazard mapping.

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
7	2024	*GIS-Based Flood Hazard Mapping in Peri-Urban Lomé*	Blakime et al.	Togo	Multi-criteria flood susceptibility mapping	Combines DEM, slope, rainfall, geology, soils and land-use into AHP-weighted hazard maps; identifies high-risk peri-urban corridors.	AHP weighting subjective; little connection to LCZ classification or BGI suitability; lacks dynamic runoff modelling.	Linking hazard zones with LCZ categories to identify morphology-sensitive flood patterns; using DEM flow accumulation to guide BGI intervention siting.
8	2025	*Effect of LULC Maps on Curve Number (CN) Method — Case of Kahraman maras*	Oz & Dis	Turkey	LULC classification impact on CN runoff	Demonstrates that hydrological CN output varies significantly with the LULC map used; classification granularity alters runoff estimates.	No connection to LCZ classes though LCZ offers morphologically meaningful land-cover groupings; does not evaluate drainage network response.	Generating LCZ-based CN values for more process-oriented runoff modelling; testing sensitivity of CN to LCZ mapping choices for urban hydrology.
9	2025	*Urban drainage issues under climate change scenarios*	Multiple (dataset group)	Multiple	Drainage vulnerability to extreme rainfall	Broadly shows that rising rainfall intensity increases peak flows and overwhelms existing drainage; highlights infrastructural and planning gaps.	LCZ-urban form influence on drainage not examined; few studies link climate scenarios with morphological runoff pathways.	Integrating climate-scenario rainfall with LCZ-specific runoff characteristics; modelling future drainage failures and identifying morphology-based mitigation strategies.

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
10	2024	*Nature-based solutions for stormwater management (BGI case-series)*	Multiple	Various	BGI performance for stormwater attenuation	Case studies confirm BGI reduces peak runoff, delays flow and improves infiltration; placement relative to topography strongly affects efficiency.	Site-specific designs lack generalizable placement rules; few studies integrate LCZ with BGI performance; minimal linkage to DEM flow-routing.	Establishing LCZ-informed BGI design principles; combining LCZ maps with DEM flow paths to optimize spatial placement of BGI for maximum hydrological benefit.
11	2025	Assessing water availability using remote sensing and hydrological indicators	Gondwe, G.T.; Chunga, B.A.; Banda, A.	Not specified / multiple regions	Remote sensing for water-availability assessment; hydrological indicators	Uses remote sensing products and hydrological indices to estimate surface water availability and seasonal variability; demonstrates potential for large-area monitoring where in-situ data are sparse.	Limited explicit integration with urban LCZ classifications; remote-sensing resolution may limit catchment-scale drainage inference.	Combine remote-sensing water-availability indicators with LCZ maps and DEM-derived drainage networks to identify blocks vulnerable to reduced infiltration or surface ponding.
12	2025	Specific impacts of climate change on the hydrology of urban catchments	Karimi, B.A.; Haziq, M.A.; Hayat, A.	Not specified	Urban hydrology under climate change	Reviews climate-driven shifts in urban hydrology, noting intensified peak flows and altered seasonality; emphasizes need for adaptive drainage design.	Few studies incorporate morphological/LCZ heterogeneity into future-runoff projections.	Integrate LCZ-based imperviousness and morphology into climate-scenario runoff modelling to produce locality-specific adaptation strategies.

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
13	2025	FLOOD RISK AND HYDROLOGICAL RESPONSE IN THE ZA...	Odai, A.; Megahed, A.; Scrâceanu, D.	Likely Ghana / West Africa (based on author regions)	Flood risk assessment & hydrological response	Presents case-based hydrological assessments linking land-use change to flood risk and channel response; underscores sedimentation and drainage capacity loss as major risk drivers.	Limited coupling with urban morphological typologies (LCZ); often lacks high-resolution DEM for micro-drainage mapping.	Use LCZ mapping to attribute flood vulnerability to urban morphology types and run DEM-based micro-catchment analyses to prioritize channel/reach-level interventions.
14	2025	Sustainable Land Use and Land Cover Management for Urban Resilience	(authors in CSV)	Not specified	LULC management, resilience	Discusses LULC planning strategies for urban resilience including nature-based measures, land-use zoning to protect natural drainage corridors.	Often conceptual; limited empirical linkage of LULC management with LCZ classification and hydrological outcomes.	Empirically test LULC management scenarios by overlaying LCZ maps with DEM-based flow accumulation to simulate drainage and BGI efficacy.
15	2025	Identifying Areas Exposed to Potential Flash Floods	(authors in CSV)	Not specified	Flash-flood exposure mapping	Uses high-resolution DEMs and rainfall-intensity scenarios to map flash-flood exposure zones in rapidly urbanizing areas.	Typically does not integrate LCZ or urban morphological categorisations; social vulnerability often not combined with morphological hazard maps.	Combine LCZ maps with flash-flood exposure to produce morphology-sensitive risk maps and prioritize BGI interventions in high-exposure LCZ classes.

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
16	2025	A GIS-based flood hazard mapping in the Alsen watershed	(authors in CSV)	Not specified	GIS flood-hazard mapping (DEM, slope, soils, land use)	Produces hazard maps using multi-criteria analysis integrating DEM-derived flow accumulation, slope, and land-cover; identifies corridors for hazard mitigation.	Multi-criteria subjective weighting; limited linkage to LCZ-based imperviousness or morphology.	Integrate LCZ-derived parameters into GIS hazard weighting schemes to reduce subjectivity and better reflect morphological influences on runoff.
17	2024	Flood Management Study in The Upper Kuncir River: Hydrological Analysis and Watershed Conservation	Purboseno, S.; Suparto; Bujono, P.	Indonesia	Watershed rehab, sediment control, flood mitigation	(See Batch 1 entry #5) Recommends check dams, reforestation, and channel normalization; identifies erosion/sedimentation as key drivers for reduced channel capacity.	Rural watershed focus; lacks urban LCZ framing and detailed DEM micro-drainage modeling.	Assess upstream land-cover change and LCZ transitions to estimate impacts on urban drainage capacity downstream; test nature-based upstream interventions for urban flood mitigation.
18	2024	Inconsistent using FLOOD and Flooding Development: Vulnerable Urban Watershed Considering Extreme Rainfall Events	Alam, S.; Rahman, M.A.	Chittagong, Bangladesh (example)	Urban flood vulnerability, SWMM applications	Demonstrates SWMM's applicability for urban flood hazard mapping; highlights calibration challenges and sensitivity to drainage network accuracy.	Limited integration of LCZ-based parameterization in SWMM; calibration constrained by data scarcity.	Develop LCZ-based parameter sets for SWMM (imperviousness %, CN equivalents) and evaluate model sensitivity to LCZ-informed inputs.

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
19	2024	Derivation of a GIS-Based Flood Hazard Map in Peri-Urban Areas of Greater Lomé, Togo	Blakime, T.-H.; Komi, K.; Adjonou, K.; et al.	Greater Lomé, Togo	Multi-criteria flood hazard mapping with DEM, soils, LULC	Integrates 7 drivers via AHP; highlights peri-urban expansion into hazard-prone areas and suggests planning corridors.	AHP subjectivity and lack of morphological LCZ integration; recommendations are spatially broad.	Use LCZ mapping to refine hazard models and to design targeted BGI corridors that intercept DEM-identified flow accumulation zones.
20	2024	Effect of Land Use/Land Cover Maps on CN Method: Case Study over Kahraman maras	Oz, A.; Dis, M.O.	Kahraman maras, Turkey	Sensitivity of CN runoff to LULC mapping	Shows substantial variation in estimated runoff volumes depending on LULC map resolution and classification choices.	Not linked to LCZ categories which could provide a morphology-driven approach to CN assignments.	Define CN values for LCZ classes and assess how LCZ-based CN improves runoff estimation consistency across mapping schemes.
21	2024	Derivation of a GIS-Based Flood Hazard Map in Peri-Urban Areas of Greater Lomé, Togo	Blakime et al.	Greater Lomé, Togo	GIS–AHP flood hazard mapping	Identified high-risk flood corridors; DEM + land-use + rain create accurate hazard zones	No LCZ–morphology integration; AHP subjective; no drainage modelling	Integrate LCZ, improve flow-routing with DEM, test BGI scenarios
22	2024	Effect of LULC Maps on CN Method: Kahraman maras Case	Oz & Dis	Turkey	LULC sensitivity in runoff estimation	CN values change significantly with LULC classification; affects runoff accuracy	Does not include LCZ; no DEM-based drainage routing	Develop LCZ-based CN parameters; link runoff results with drainage networks

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
23	2025	Assessing Water Availability Using Remote Sensing & Hydrological Indicators	Gondwe et al.	Regional	Water availability mapping	Remote sensing indices can track seasonal water variation	Coarse resolution misses small urban drainage paths; no LCZ linkage	Merge LCZ + DEM + water-indicators for micro-drainage detection
24	2025	Impacts of Climate Change on Hydrology of Urban Catchments	Karimi et al.	Global urban context	Climate change + urban hydrological shifts	Extreme rainfall boosts peak runoff; urbanization compounds flood risk	Models ignore LCZ-based morphology; limited micro-catchment detail	Integrate LCZ-specific runoff projections; evaluate BGI under climate scenarios
25	2025	Flood Risk & Hydrological Response in the ZA… Region	Odai et al.	Regional	Flood risk + land-use change	Urban expansion increases flood exposure and alters channel performance	No LCZ analysis; limited DEM flow-path modelling	Combine LCZ + watershed change analysis; micro-catchment hazard mapping
26	2025	Sustainable LULC Management for Urban Resilience	-	NA	LULC planning for resilience	Advocates corridors, wetlands, BGI zones for hazard control	No empirical LCZ-based hydrologic validation	Translate LULC plans using LCZ + DEM to spatially allocate BGI
27	2025	Identifying Areas Exposed to Potential Flash Floods	-	Rapidly urbanizing region	DEM + rainfall flash flood mapping	DEM resolves flash-flood pathways; urbanization increases exposed zones	No LCZ integration; lacks socio-hydro vulnerability coupling	Combine LCZ + vulnerability + DEM to create BGI priority zones
28	2025	GIS-Based Flood Hazard Mapping in Alsen Watershed	-	Alsen watershed	DEM + multi-criteria hazard mapping	Slope, soil, land use, rainfall identify hazard zones; DEM flow-accumulation critical	Weighting subjective; lacks LCZ-based morphology	Introduce LCZ parameters to refine flood hazard models

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
29	2024	Urban Watershed Vulnerability Under Extreme Rainfall	Alam & Rahman	Chittagong, Bangladesh	Urban flooding + SWMM modelling	SWMM simulates block-level inundation effectively; data gaps hinder accuracy	SWMM parameters not LCZ-informed; limited calibration data	Build LCZ-based SWMM libraries (imperviousness, Manning's n)
30	2024	LULC Change & Flood Occurrence in Teunom Watershed	Sugianto et al.	Aceh Jaya, Indonesia	LULC change impact on flooding	Forest → built-up increases runoff and frequency of floods	Lacks LCZ-level morphological detail; weak micro-drainage mapping	Use LCZ transitions to predict hydrological shifts; DEM micro-catchment drainage
31	2024	DEM-Based Flood Routing for Secondary Drainage Lines	Qureshi et al.	Lahore, Pakistan	Flow-routing + drainage mapping	DEM shows blocked natural channels causing backflow during storms	No LCZ link; uniform drainage assumptions	Use LCZ + DEM to redesign secondary drains
32	2024	Machine Learning for Flood Risk Prediction	Mukherjee et al.	Kolkata, India	ML + hydrological predictors	ML models outperform traditional flood mapping	No LCZ predictors used; ignores spatial heterogeneity	Add LCZ predictors to improve ML accuracy
33	2023	Flood Hazard Zonation Using DEM & Land Use Parameters	Ibrahim et al.	Kaduna, Nigeria	DEM + LULC flood hazard modelling	Slope + flow accumulation = major hazard drivers	No LCZ morphology; subjective weights	Integrate LCZ + DEM micro-drainage
34	2023	Nature-Based Solutions for Urban Flood Mitigation	Liao & Wu	China	BGI strategies for flood control	Wetlands + bioswales reduce peak flows	Effectiveness varies by morphology; no LCZ use	Map LCZ → BGI suitability matrix
35	2023	Urban Drainage Overload During Extreme Rainfall	Kato & Nishimura	Tokyo, Japan	Urban drainage modelling	Extreme rainfall overwhelms drains; micro-topography key	No LCZ micro-morphology; no BGI simulation	Use LCZ-informed drainage redesign + BGI testing
36	2022	Urban Runoff Sensitivity to	Sharma & Patel	Jaipur, India	Imperviousness & runoff	Impervious increase sharply raises peak runoff	No LCZ breakdown; no BGI modelling	Create LCZ-based imperviousness–

Sr. No	Year	Study/ Paper	Author	Location	Focus	Key Findings	Research Gaps Identified	Future Research Directions
		Impervious Surface Growth						runoff profiles
37	2022	Blue-Green Corridors for Resilient Urban Watersheds	Hansen & Müller	Germany	BGI corridor planning	Green corridors restore hydrology	Does not link LCZ heat-storage & runoff	Integrate LCZ + corridor planning
38	2021	Hydrological Response of Rapid Urbanisation	Adugna et al.	Addis Ababa, Ethiopia	Urbanization →hydrology	More runoff, drainage congestion	No LCZ typology; lacks micro-catchment DEM	Combine LCZ + DEM flow paths
39	2021	Flash Flood Susceptibility Mapping Using MCDM	Elsheikh et al.	Sudan	Flash flood MCDA	High accuracy with DEM + rainfall	No urban morphology layer	Add LCZ as a hazard-weight layer
40	2020	Impacts of LULC on Surface Water Dynamics	Rathore et al.	Bhopal, India	LULC–hydrology	Built-up reduces water spread & increases runoff	No LCZ detail	Use LCZ to quantify hydrologic changes by morphology

CHAPTER 3. Research Design

This chapter outlines the overall research design to achieve the scope of integrating Local Climate Zone (LCZ) Classification with Urban Drainage assessment for enhancing blue–green infrastructure for Climate-Resilient Urban Planning. It highlights the study's aim, objectives for both phases, scope, and limitations as a structured research approach. The research is divided into two phases: Phase 1 focuses on identifying theoretical concepts through a literature review on LCZ classification, blue–green infrastructure, and their relation to urban drainage systems; while Phase 2 involves selecting the study area, mapping spatial parameters, and exploring correlations to formulate strategies for planning interventions. This chapter also describes the systematic approach used to ensure consistency between conceptual understanding and spatial analysis, laying a foundation for advancing climate-responsive urban planning strategies.

3.1 Title

Developing Local Climate Zones (LCZ) Classification for Climate-Resilient Urban Drainage: A Case of Central India Town

3.2 Aim

To study and classify Local Climate Zone (LCZ) and assess the urban natural drainage pattern for the development of blue-green infrastructure strategies towards climate-responsive urban planning.

3.3 Objectives

3.3.1 Phase I

1. To understand the Local Climate Zones (LCZ) concept and its parameters.
2. To understand the benefits of blue–green infrastructure and urban drainage in planning.
3. To study and understand the drainage pattern through DEM.
4. To review existing literature related to climate-resilient urban planning.

3.3.2 Phase II

1. To select a suitable town and conduct a primary survey for data collection.
2. To map the available natural drainage network of the city with reference to the climate of the city.
3. To identify the various problems and potentials of the natural drainage network.
4. To classify Local Climate Zones in the existing city.

5. To propose the development and modification of the natural urban drainage network in view of Blue-Green Infrastructure.
6. To classify LCZ with modified BGI and analyse the physical plan and its possible impact on the city.

3.4 Scope of the study

This study's spatial scope encompasses a medium-sized Central Indian town, selected based on representative urban morphology, climatic variability, and hydrological challenges. The research discusses mapping and analyzing LCZs and the natural drainage network of the town incorporating high-resolution remote sensing-GIS-based data. Both built-up and natural areas are included, covering the core city and peripheral catchments influencing urban drainage.

The temporal coverage is from recent years (2020–2025), thus allowing the assessment of recent land-use dynamics, climatic patterns, and drainage conditions. This timeframe captures recent transformations in urban morphology and can provide a basis for the effectiveness of the BGI strategies under changing climate conditions.

The thematic scope encompasses three interrelated components:

1. LCZ Classification: Identifying and mapping urban climatic zones using morphological and surface indicators.
2. Urban Drainage Assessment: Analysis of slope, flow direction, and accumulation derived from DEM data to understand natural drainage behaviour.
3. BGI Strategy Development: The study proposes context-specific blue–green interventions like vegetated bioswales, bio-retention ponds, and green corridors to improve drainage efficiency and resilience.

3.5 Limitations

The present study combines LCZ classification with hydrological analysis to reveal potential locations for blue–green infrastructure planning. It is limited to a spatial analysis at a planning scale and does not extend to hydraulic modelling, engineering design, or economic feasibility assessment. Results are reliable to the extent of quality and spatial resolution of available data on land use, drainage, and surface characteristics. Since both urban form and drainage systems change and are dynamic, results reflect the conditions during analysis, and the interventions will require periodic re-evaluations. Field verification in certain cases and stakeholder input is also part of this work; however, much of the work consists of analytical interpretation that builds a framework for climate-resilient planning that may guide implementation in policy or design in the future. Limitations arise from data, particularly the resolution of remote sensing imagery, the limited temporal coverage of climate records, and issues

of accessibility to conduct field surveys across all drainage channels. Despite these challenges, the integration of multi-source datasets assures a methodological framework robust enough to capture spatial–climatic interactions and deliver actionable outcomes of urban planning.

CHAPTER 4. Methodology

Phase I – Conceptual Understanding and Framework Development

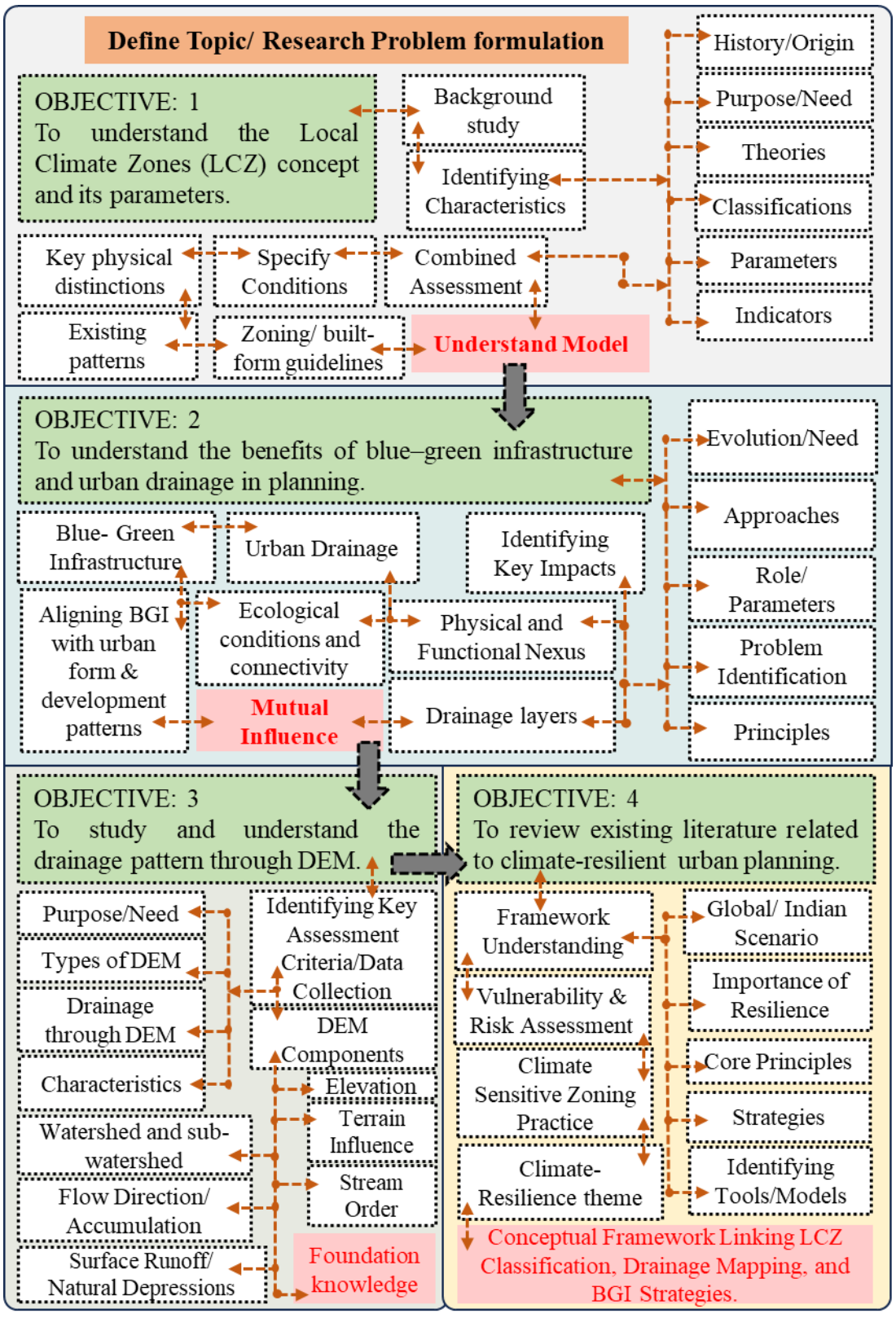
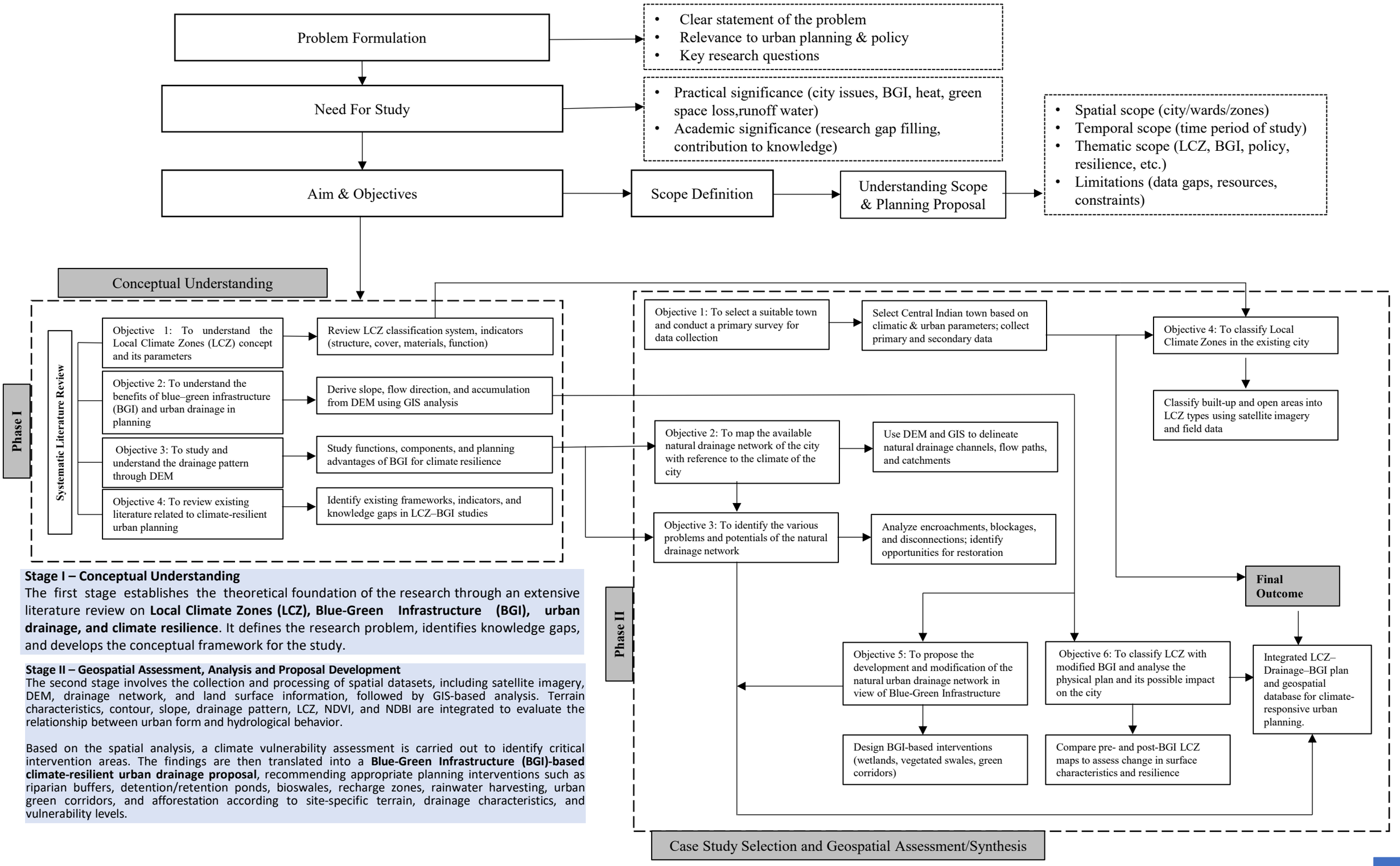


Figure 9. Objective-based Methodology (Author, 2025)

METHODOLOGY PHASE I- II

The methodology integrates literature review, geospatial analysis, and planning principles to evaluate the relationship between Local Climate Zones (LCZ), terrain, drainage, and land surface characteristics in the Vidisha Planning Area. DEM, contour, slope, NDVI, NDBI, and drainage analyses are combined to identify vulnerable locations and hydrological patterns. Based on the integrated assessment, Blue-Green Infrastructure (BGI) interventions are proposed to improve urban drainage efficiency, groundwater recharge, and climate resilience.



Stage I – Conceptual Understanding
The first stage establishes the theoretical foundation of the research through an extensive literature review on **Local Climate Zones (LCZ), Blue-Green Infrastructure (BGI), urban drainage, and climate resilience**. It defines the research problem, identifies knowledge gaps, and develops the conceptual framework for the study.

Stage II – Geospatial Assessment, Analysis and Proposal Development
The second stage involves the collection and processing of spatial datasets, including satellite imagery, DEM, drainage network, and land surface information, followed by GIS-based analysis. Terrain characteristics, contour, slope, drainage pattern, LCZ, NDVI, and NDBI are integrated to evaluate the relationship between urban form and hydrological behavior.

Based on the spatial analysis, a climate vulnerability assessment is carried out to identify critical intervention areas. The findings are then translated into a **Blue-Green Infrastructure (BGI)-based climate-resilient urban drainage proposal**, recommending appropriate planning interventions such as riparian buffers, detention/retention ponds, bioswales, recharge zones, rainwater harvesting, urban green corridors, and afforestation according to site-specific terrain, drainage characteristics, and vulnerability levels.

This phase focuses on the construction of the theoretical and analytical underpinning through the review of related literature and preliminary analysis of data.

1. Understanding the LCZ concept and parameters: The following research was done to understand the parameters of the LCZ classification system-surface structure, cover, material, and function. These indicators have guided the process of spatial analysis and climatic interpretation.
2. Understanding BGI and urban drainage within the context of planning: A detailed review of BGI principles was conducted, studying their environmental and hydrological benefits and the role of green infrastructures in enhancing urban resilience and improving the performance of drainage.
3. Drainage pattern analysis through DEM: The Digital Elevation Model data have been analyzed using Geographical Information System techniques to derive slope, flow direction, and accumulation patterns. This has helped in interpreting natural drainage characteristics of urban areas.
4. Literature review: Literature related to the previously mentioned LCZ, BGI, and climate-resilient planning was reviewed to identify research gaps, key parameters, and links between urban form, climate, and drainage systems.

Outcome of Phase I: A conceptual framework is developed in this phase that interlinks LCZ classification, drainage mapping, and BGI strategies to guide the geospatial assessment in Phase II.

Phase II – Case Study Selection and Geospatial Assessment Synthesis

This phase utilizes the application of a conceptual framework to conduct research on a particular Central Indian town via spatial mapping, data collection, and integrated analysis.

1. Selection of case study and data collection: A town was selected for study based on climate and morphology. Primary and secondary data collection included field survey, municipal records, and remote sensing data.
2. Mapping of natural drainage network: The DEM and GIS tools were used to map the natural drainage network (i.e., flow path, catchment area) and the topography of the city and its relationship to developed areas.
3. Identification of drainage issues and opportunities: Areas were identified where drainage issues had occurred (e.g., encroached upon), blockages were identified, and areas that had disrupted flow paths.
4. LCZ classification of city: Both developed and undeveloped lands were classified into LCZs based on satellite images and field tests to evaluate the thermal and spatial variability between areas of the city.

5. Developing BGI strategies: A range of proposed BGI based strategies, such as bioswales, retention ponds, green corridors, urban wetlands were developed based on the analysis of LCZ, and drainage data to improve hydrological performance/resilience.
6. LCZ Classification with Revised BGI and Impacts Assessment: A revised LCZ map was generated with the inclusion of proposed BGI features, and a comparison was conducted to evaluate the potential increase in urban climate resilience and efficiency in planning.

Phase II outcome: Preparation of an integrated LCZ–Drainage–BGI model for the selected town; the model provides a physical plan for climate-responsive urban planning.

CHAPTER 5. Data Collection

Chapter 5 presented an exhaustive desk study and data collection, synthesizing existing knowledge on LCZ, natural drainage systems, and Blue–Green Infrastructure to establish the conceptual framework upon which this research is based. This chapter began with an explanation of how rapid urbanization alters land cover, increases microclimatic conditions in intensity, and disrupts natural drainage, hence requiring integrated and climate-responsive planning approaches. The LCZ framework was outlined in the following section, including its parameters and importance for the analysis of variations in urban morphology and microclimate. Literature showed that built-up LCZs are related to higher temperatures and increased runoff, while vegetated LCZs are supportive for infiltration and cooling; thus, LCZ classification is certainly very relevant for drainage and BGI planning.

Further discussion in this chapter was the drainage pattern analysis using DEMs, emphasizing its effectiveness in the identification of natural flow paths, flood-prone zones, and watershed boundaries. This was followed by an overview of BGI concepts and benefits; studies that were used showed how nature-based interventions reduce runoff, improve thermal comfort, and enhance urban ecological function.

Each of these themes was integrated in the desk study by showing how LCZ mapping and drainage analysis can complement each other in informing climate-resilient urban planning. Research gaps were found, especially the lack of integrated LCZ–drainage–BGI studies in medium-sized Indian towns, which emphasized the significance and novelty of the present research. Commonly used data sources, GIS tools, and analytical techniques applied in such studies were summarized in this chapter to provide a good methodological basis for the research phases that follow.

Chapter 5 thereby set the theoretical and empirical context necessary to guide the methodology, analysis and planning framework developed in subsequent chapters.

5.1 Introduction

Rapid urbanization in India has brought significant land cover changes, altered imperviousness, and modified microclimatic behavior, which in turn have enhanced hydrological stress and local climate variability. Many studies note that increasing built-up areas decrease natural infiltration, increase surface runoff, and promote localized flooding, particularly in the case of small and medium-sized towns with prevailing limited planning mechanisms (Sharma & Singh, 2020; Suriya & Mudgal, 2012). Simultaneously, it has enhanced Urban Heat Island effects due to the transformation of natural landscapes into cities, leading to intra-urban microclimatic differences that influence both thermal comfort and stormwater behavior.

In response to these, contemporary research highlights the importance of integrated planning approaches that consider the amalgamation of climatic understanding, hydrological assessment, and nature-based solutions (Fletcher et al., 2015; Meerow & Newell, 2019). The LCZ framework has emerged as a robust methodology in analyzing urban morphology and microclimates since it offers a standardized system in comparing urban built form and thermal behavior (Stewart & Oke, 2012). Simultaneously, DEMs have emerged as an intrinsic tool to understand natural drainage pattern and enable terrain-based analysis for flow paths, watershed delineations, and flood-prone areas with precision (Li et al., 2018). BGI is now increasingly considered a sustainable approach toward mitigating both climatic and hydrological vulnerabilities by enhancing infiltration, reducing peak runoff, improving ecological performance, and mitigating UHI impacts (Grimm et al., 2016; Fletcher et al., 2015). Despite the growing emphasis on climate resilience, very few studies have integrated LCZ classification with drainage analysis and BGI planning, especially for medium-sized cities in Central India. Thus, this desk study synthesizes theoretical foundations and research insights to be used for supporting integrated assessment of LCZ, natural drainage network, and BGI. The chapter establishes the conceptual and methodological premise for developing climate-responsive drainage strategies relevant to the selected Central Indian town through review of global and Indian literature across these domains.

5.2 Understanding Local Climate Zones (LCZ) Concept

The concept of Local Climate Zone (LCZ), introduced by Stewart and Oke (2012), provides an understanding and standardised method for classifying urban and natural landscapes based on surface structure, land cover, and thermal properties shown in Figure 10.

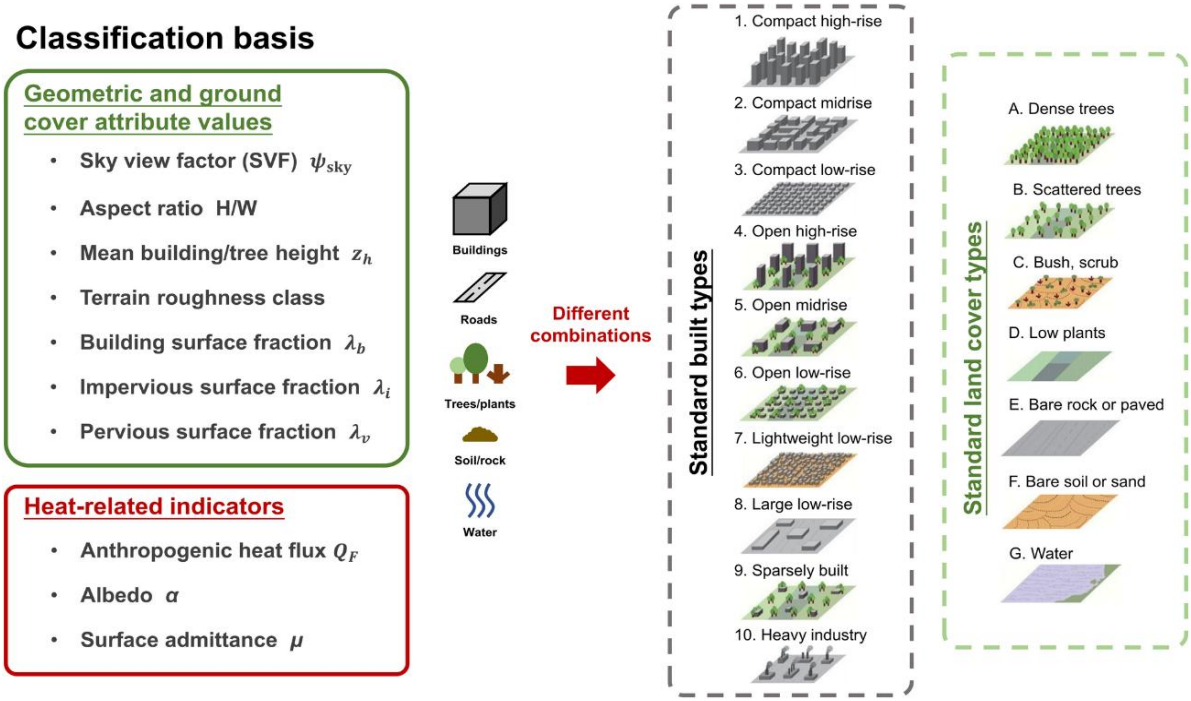


Figure 10. Schematic diagram of standard LCZs. (Jie Han, 2024)

It has become one of the most widely used frameworks for microclimatic analysis, as it shows consistent results in describing how different urban forms influence local temperature variations and UHI intensity.

In summary, LCZ mapping is of especial importance in rapidly urbanizing regions, like India, where highly heterogeneous built forms create a diverse number of microclimates not captured by conventional land-use classification. In fact, through its detailed morphological categories, LCZ enables the quantification of relationships between built density, vegetation, imperviousness, and thermal behaviour, making it a powerful tool for climate-resilient urban planning.

5.2.1 Parameters of Local Climate Zones (LCZ)

The LCZ classification system is based on quantifiable physical, morphological, thermal, and land-surface parameters that jointly determine the microclimatic and hydrological behavior of an urban landscape. These parameters help differentiate between areas that heat up differently, drain differently, and respond uniquely to extreme rainfall, thus being highly relevant for climate-resilient urban drainage planning.

Table 6. Key Parameters of Local Climate Zones (Author, 2025)

Sr. No.	Parameter	Definition	Application
1.	Surface Cover (Impervious/Pervious Fraction)	Ratio of impervious and pervious ground surfaces (Zhao et al., 2021).	Supports identifying runoff potential, infiltration capacity, and flood-prone LCZs; used for BGI placement (Ren et al., 2020).
2.	Building Height	Average height of buildings that shapes urban canyons and heat retention (Stewart & Oke, 2012).	Used for evaluating thermal load, shading, air circulation, and obstructions to natural drainage flows.
3.	Building Density	Proportion of area occupied by building footprints (McDonald et al., 2018).	Helps assess high-runoff zones, reduced permeability, and areas needing drainage augmentation or BGI retrofitting.
4.	Land Use / Functional Zone	Activity-based classification of land (residential, commercial, industrial etc.).	Determines pollutant load in runoff, stormwater quantity, and opportunities for nature-based drainage (Vollmer et al., 2016).
5.	Surface Albedo	Reflectivity of surfaces, determining proportion of solar radiation reflected (Zheng et al., 2022).	Used to understand heating patterns affecting evaporation rates, UHI intensity, and microclimate influences on stormwater behaviour.

Sr. No.	Parameter	Definition	Application
6.	Surface Thermal Properties	Heat storage and conductivity characteristics of materials (Oke et al., 2017).	Helps assess nighttime UHI intensity, surface drying time, and the thermal impact on drainage infrastructure.
7.	Vegetation Structure / Canopy Cover	Density and distribution of trees, shrubs, and grass surfaces (Ren et al., 2020).	Identifies cooling zones, infiltration areas, runoff reduction potential, and locations suitable for green corridors and sponge strategies.
8.	Anthropogenic Heat Emissions	Heat generated by transport, buildings, and industries (Li et al., 2020).	Supports evaluating localized warming and convection patterns that may influence monsoon rainfall intensity in cities.
9.	Surface Roughness	Aerodynamic roughness resulting from height and spacing of objects (Stewart & Oke, 2012).	Used to estimate ventilation, air stagnation, and moisture retention which influence drainage performance and evaporation.
10.	Impervious Connectivity	Degree of continuity between impervious surfaces (Yang et al., 2021).	Helps identify rapid-runoff pathways and flash-flood zones, guiding decentralised BGI interventions.
11.	Surface Permeability	Soil's ability to absorb and infiltrate water.	Critical for locating infiltration-based BGI such as rain gardens, wetlands, and permeable pavements (Ren et al., 2020).
12.	Urban Geometry (Aspect Ratio)	Ratio of building height to street width, affecting solar access and heat trapping (Oke, 2017).	Used to assess canyon heating, airflow restriction, and stormwater concentration corridors.
13.	Drainage Density & Microtopography (DEM-Derived)	Elevation, slope, and flow accumulation patterns obtained from DEM analysis (Rahman et al., 2022).	Supports flood-prone LCZ identification, natural drainage mapping, and BGI integration into existing topography.
14.	Vegetation Health Indices (NDVI/EVI)	Satellite-derived indicators of vegetation vigor (Liu et al., 2021).	Used to map ecological condition, infiltration potential, and LCZ categorization (LCZ A–D).
15.	Blue Surface Fraction / Water Bodies	Proportion of rivers, lakes, ponds, and drains in a zone (Vollmer et al., 2016).	Helps in restoring natural drainage corridors and regulating local microclimate near LCZ boundaries.

Sr. No.	Parameter	Definition	Application
16.	Seasonal Microclimatic Variation	Variability of thermal and hydrological conditions across seasons (Kumar et al., 2020).	Used to design drainage systems that handle monsoon peaks and UHI intensification in summers.

5.3 Importance of Local Climate Zones (LCZ) in Climate-Resilient Urban Drainage and Blue-Green Infrastructure (BGI)

The LCZ framework classifies urban areas in a systematic way based on surface cover, building morphology, vegetation, thermal properties, and hydrological characteristics. In recent times, this classification has gained importance in helping cities respond to various climate stresses, such as extreme heat, high-intensity rainfall, and flooding. The integration of LCZ analysis into natural drainage assessment and BGI planning thus offers a more climate-responsive approach to urban development in rapidly growing Indian towns.

5.3.1 Linking LCZ with Urban Microclimate and Hydrology

Different LCZ classes show distinct microclimatic and hydrological behaviours.

Compact high-rise (LCZ 1), compact mid-rise (LCZ 2), and industrial zones (LCZ 10) are usually characterized by a high impervious surface fraction, low ventilation, and consequently high temperatures, thus generally inducing strong UHI effects (Stewart & Oke, 2012). They tend to generate rapid stormwater runoff with little infiltration and increase flood susceptibility during heavy monsoon events.

In contrast, vegetated LCZs A-D and open low-rise areas (LCZ 6) provide considerable pervious surfaces to enhance infiltration, reduce peak runoff, and support natural drainage capacity as Ren et al. 2020 indicate. Therefore, LCZ mapping allows for the identification of hydrologically sensitive zones, for example, the compact urban cores that generate high runoff or green LCZs serving as natural retention and cooling areas.

5.3.2 LCZ as a Tool for Identifying Drainage Risk Zones

LCZ maps represent the spatial variation in surface cover, building form, and thermal behaviour, all influencing the movement of stormwater. Dense built-up LCZ classes often correspond to natural drainage channels that are modified or encroached upon, resulting in waterlogging and flash floods during heavy rainfall events (McDonald et al., 2018). By overlaying LCZ classification on DEM-derived drainage lines, planners can:

1. Detect mismatches between natural flow paths and built structures;
2. Identify LCZs with high impervious connectivity and blocked drainage;

3. Assess the flood-prone LCZ zones based on topography and landcover;
4. Assess LCZ transitions where drainage capacity reduces sharply.

This kind of layered analysis brings a more correct version of hydrological vulnerability than land-use mapping by itself can provide (Rahman et al., 2022).

5.3.3 Role of LCZ in Blue-Green Infrastructure (BGI) Strategies

Examples of BGI systems that may thrive best in these zones include bioswales, rain gardens, wetlands, green corridors, and restored water bodies. LCZ classification helps to identify where such interventions are most effective.

For example:

1. LCZs of Vegetated type (A–D) have the potential to act like natural sponge zones, suitable for infiltration-based BGI.
2. Open LCZs can accommodate retention ponds, urban forests, and grassed swales.
3. Dense mid-rise and high-rise LCZs must have rooftop BGI with permeable pavement retrofits with decentralized stormwater modules.
4. Water-based LCZs (G, H) are cooling and drainage corridors that must be protected from encroachment.

It is observed from studies that LCZ-based analysis, when integrated, enhances not only the performance but also placement by aligning the BGI networks with realistic microclimatic and hydrological conditions (Vollmer et al., 2016; Ren et al., 2020).

5.3.4 LCZ for Climate-Responsive Urban Planning in Monsoon-Prone Regions

Indian towns, especially those of Central India, have extreme seasonal variations such as intense summer heat, variable pre-monsoon storms, and short-duration high-intensity rainfall events. LCZ classification captures these seasonal vulnerabilities through the identification of:

1. Overheated LCZs prone to heat-stress and peaks in energy demand;
2. LCZs with little pervious cover at greatest risk of monsoon flooding;
3. Areas of built form and topography that increase runoff velocity;
4. Ecological LCZs that can be reinforced for water retention and cooling.

These insights support climate-resilient zoning, land-use reforms, and development controls fitted to local microclimates. Kumar et al., 2020

5.3.5 Integrating LCZ with DEM-Based Drainage Analysis

Linking LCZ classification with DEM-derived slope, flow accumulation, and watershed boundaries enables an integrated perspective on city hydrology. DEM analysis shown in Figure 12 identifies natural drainage lines, depressions, and overland flow directions, while LCZ

mapping explains how built form and surface characteristics modify these natural behaviours (Rahman et al., 2022).

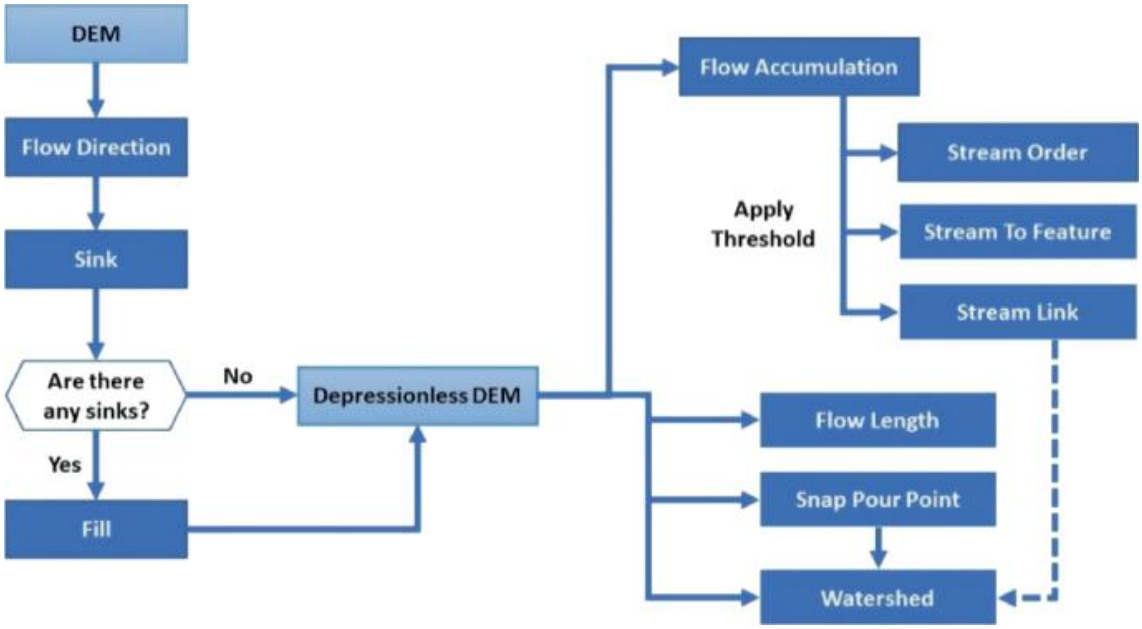


Figure 11. Delineation of Watershed and Drainage Network System (Shaikh)

Together, they help:

1. Locate LCZs where natural drainage is obstructed;
2. Prioritise restoration of old nallahs and water channels;
3. Guide BGI placement along feasible flow corridors;
4. Assess combined thermal and hydrological vulnerability.

This integration is crucial for cities where unplanned development has significantly altered natural drainage networks.

5.3.6 LCZ Contribution to Resilient Infrastructure and Policy Planning

LCZ-based drainage analysis supports decision-making for:

1. zoning regulations based on hydrological sensitivity;
2. surface permeability and green cover requirements;
3. climate-informed building controls;
4. protection of drainage corridors and water bodies;
5. targeted flood mitigation in high-risk LCZs.

As several studies emphasize, LCZ-informed planning provides more actionable climate resilience strategies than conventional land-use maps because it embeds actual physical surface characteristics into planning decisions (Zheng et al., 2022; Stewart & Oke, 2012).

5.4 Review of Drainage Pattern Assessment in Urban Contexts

Urban drainage assessment has become a critical component of climate-responsive planning, especially in rapidly urbanising regions where land-use change alters hydrological pathways. The literature consistently highlights that natural drainage systems—streams, channels, depressions, and micro-catchments- serve as the foundational structure for sustainable stormwater management (Fletcher et al., 2015). However, urban expansion often disrupts these systems through channel encroachment, surface sealing, and loss of infiltration zones, resulting in heightened flood risks, reduced groundwater recharge, and increased pollutant transport (Jacobson, 2011).

A substantial body of work emphasises the importance of Digital Elevation Models (DEMs) and high-resolution terrain analysis for delineating urban drainage patterns. DEM-based hydrological modelling helps identify flow directions, accumulation zones, watershed boundaries, and drainage density, parameters crucial for understanding how built-up forms and LCZ types modify runoff responses (Vaze & Chiew, 2003). Studies increasingly combine DEM analysis with urban morphological attributes, demonstrating that compact LCZs, high-rise clusters, and impervious zones significantly intensify runoff velocity and surface flow concentration (Stewart & Oke, 2012; Bechtel et al., 2015).

Another important dimension is the integration of drainage assessments with blue–green infrastructure (BGI) strategies. Research shows that natural drainage corridors can be strengthened through bio-swales, retention ponds, wetlands, and permeable zones, which collectively enhance infiltration and delay peak flows (Ahiablame et al., 2012). Empirical studies indicate that cities that preserve and rehabilitate their drainage networks achieve more effective urban flood mitigation compared to cities that rely solely on grey infrastructure (O'Donnell et al., 2020). This perspective aligns with climate-resilient planning, where drainage patterns are not treated merely as engineering elements but as ecological systems that support resilience, biodiversity, and urban cooling.

In Indian and South Asian contexts, the degradation of natural drainage networks is widely documented. Concretisation, informal settlements along drains, and siltation significantly weaken stormwater carrying capacity (Gupta et al., 2021). Recent work advocates integrating drainage mapping with LCZ classification to understand how built-form configurations influence watershed fragmentation, surface permeability, and flow bottlenecks. Such an approach helps planners recognise mismatches between natural hydrology and urban development layouts—an essential step for improving adaptation strategies under increasing climate extremes.

Collectively, the literature underscores a clear transition from viewing drainage as a technical municipal function to recognising it as a core component of climate-resilient urban

systems. The integration of geomorphology, LCZ mapping, and BGI planning emerges as a promising direction, offering cities a holistic framework to enhance both hydrological performance and environmental quality.

5.5 Integration of LCZ Classification and Drainage Analysis in Climate-Resilient Urban Planning

The integration of Local Climate Zone (LCZ) classification with drainage analysis has emerged as a promising framework for understanding how urban form influences hydrological behaviour and climate vulnerability. LCZs offer a systematic approach to mapping variations in built morphology, surface cover, imperviousness, and thermal characteristics across a city (Stewart & Oke, 2012). These parameters directly intersect with hydrological processes such as runoff generation, surface retention, and flow accumulation. Studies consistently show that compact LCZ types, particularly LCZ 1, 2, and 3, exhibit higher runoff potential due to dense construction and low permeability, while open and natural LCZ classes provide greater infiltration and storage capacity (Bechtel et al., 2015).

Research integrating LCZs with stormwater and drainage modelling demonstrates that understanding the spatial configuration of LCZs can significantly improve flood-risk assessment. For instance, areas dominated by built-up LCZs often coincide with obstructed or modified natural drainage pathways, which increases the likelihood of waterlogging and flash flooding during extreme rainfall events (Grimmond, 2007). DEM-based hydrological tools further reveal how LCZ transitions—from compact built zones to open or natural LCZs- create hydrological thresholds where changes in runoff velocity or flow direction can amplify drainage congestion (Vaze & Chiew, 2003).

The literature also highlights the relevance of integrating LCZ-guided insights into the design of blue–green infrastructure (BGI). Since LCZs capture thermal, morphological, and surface-cover patterns, they provide a valuable basis for identifying where interventions such as urban wetlands, retention ponds, bioswales, tree belts, and permeable surfaces would be most effective (Fletcher et al., 2015). For instance, cooling-focused LCZs (e.g., LCZ A, B, D) can be strategically aligned with natural drainage corridors to enhance evapotranspiration, reduce thermal stress, and improve stormwater attenuation. Similarly, LCZs with high imperviousness (LCZ 1–4) may be prioritised for infiltration-based BGI to counter fast runoff and minimise peak flows (Ahiablame et al., 2012).

In regions like India, researchers note that rapid urbanization disrupts both thermal and hydrological regimes, reinforcing the need for integrated analyses. Studies emphasise that LCZ mapping helps identify “hotspot” zones, areas that simultaneously experience high surface

temperatures, poor ventilation, and compromised drainage (Gupta et al., 2021). These hotspots are critical for resilient planning because they represent locations where climate risks compound, making BGI interventions more necessary and potentially more effective. Integrating LCZ-drainage insights allows planners to align city-level spatial strategies with natural hydrological structures, reducing exposure to floods and heat while promoting long-term ecological functioning (O'Donnell et al., 2020).

Overall, the literature underscores that merging LCZ classification with drainage analysis enables a holistic understanding of climate vulnerabilities shaped by both form and flow. This integration supports informed decision-making for urban planners, enabling them to develop spatially targeted blue–green infrastructure strategies, protect natural drainage networks, and guide sustainable urban growth patterns. As climate extremes intensify, such combined analytical frameworks become essential tools for designing cities that are thermally comfortable, flood-resilient, and environmentally adaptive.

5.6 Summary of Literature Findings

The reviewed literature demonstrates a clear convergence between urban climatology, drainage science, and nature-based planning approaches, highlighting the critical role of Local Climate Zones (LCZs), natural drainage networks, and blue–green infrastructure (BGI) in shaping climate-resilient cities. LCZ research provides a structured method to assess urban morphology, surface cover, and thermal behaviour, underscoring how built form influences microclimates and hydrological responses (Stewart & Oke, 2012). Studies consistently show that compact, high-rise LCZs are associated with increased imperviousness, elevated surface temperatures, and amplified runoff generation, whereas natural and open LCZ types support infiltration and thermal regulation (Bechtel et al., 2015).

Drainage-related literature emphasises that urbanization modifies natural hydrological pathways, creating disruptions such as decreased infiltration, increased surface runoff, channel encroachment, and heightened flood risk (Jacobson, 2011). DEM-based hydrological analysis emerges as a key method for identifying flow direction, watershed boundaries, accumulation zones, and flow obstructions in urban environments (Vaze & Chiew, 2003). These tools help reveal how urban form and surface sealing interact with drainage networks, particularly in rapidly urbanizing regions.

A major trend across the reviewed studies is the growing emphasis on integrating BGI with natural drainage systems. Research shows that bio-swales, wetlands, retention ponds, and permeable landscapes can restore ecosystem functions, improve flood mitigation, and complement traditional stormwater systems (Fletcher et al., 2015). Evidence also highlights the synergies between BGI and LCZ-based planning: LCZs help identify critical zones where

drainage vulnerability, heat stress, and impermeability coincide, making nature-based interventions more strategic and impactful (Ahiablame et al., 2012).

Studies conducted in the Indian and broader South Asian context point to significant challenges including encroachment of natural drains, inadequate stormwater management, and rapid peri-urban expansion that disregards hydrological structures (Gupta et al., 2021). These findings underscore the need for integrated analyses that combine LCZ mapping with drainage assessments to support climate-responsive planning. Research also indicates that such integration enhances the identification of climate-risk hotspots and offers spatial guidance for targeted adaptation strategies (O'Donnell et al., 2020).

Overall, the literature affirms that B for climate-resilient urban planning. This holistic approach enhances understanding of the connections between urban morphology, microclimates, and hydrological performance while offering actionable insights for sustainable city development.

5.7 Case Studies (Global and Indian Context)

5.7.1 Introduction

Urban areas across the world are undergoing rapid physical transformation due to expanding populations, intensifying economic activity, and the conversion of permeable natural landscapes into built surfaces. This process of urbanization has profound implications for local and regional hydrological systems. Traditional hydrological processes, such as infiltration, evapotranspiration, surface runoff, soil-water interactions, and groundwater recharge, are disrupted when cities expand without adequate planning for drainage, green infrastructure, and surface-water management. As a result, urban environments experience increased frequency and intensity of waterlogging, urban flooding, surface stagnation, and drainage network overloading, particularly during extreme rainfall events intensified by climate change (Zou et al., 2024).

Understanding these hydrological phenomena requires a multi-dimensional framework that goes beyond conventional land-use categories. Traditional land-use maps (e.g., residential, commercial, industrial) fail to capture the physical form, structure, and material composition of the urban landscape, elements that critically determine hydrological performance. This gap is addressed through the Local Climate Zone (LCZ) system introduced by Stewart and Oke (2012), a standardized global classification that categorizes urban and natural landscapes into 17 distinct morphological classes. Each LCZ type is characterized by a unique combination of:

1. Building height
2. Building density
3. Impervious surface fraction
4. Vegetation cover

5. Thermal and radiative properties
6. Surface roughness
7. Urban canyon geometry

The LCZ system therefore, provides an integrated morphological and functional lens to analyze how cities interact with climatic and hydrological processes. In recent years, LCZ has evolved from a climatological classification system into a multi-disciplinary analytical tool used in studies of urban heat islands, air quality modelling, ecological zoning, hydrological simulations, and urban resilience planning.

This chapter specifically focuses on the use of LCZ in hydrological and ecohydrological research, emphasizing its role in understanding:

1. Waterlogging and flood susceptibility
2. Drainage performance
3. Soil infiltration capacity
4. Vegetation–water interaction
5. Surface runoff pathways
6. Hydrological retention and discharge zones

To explore the global and Indian dimensions of LCZ-based hydrological research, this chapter presents three detailed case studies:

1. Global Case Study 1: Zou et al. (2024), Development of a Spatial-Weight Naive Bayes model integrating LCZ morphology with hydrological parameters to predict waterlogging risk.
2. Global Case Study 2: Kopp et al. (2021), Comparative analysis of LCZ zoning with ecohydrological functional zones in Pilsen, examining how urban morphology correlates with hydrological processes.
3. Indian Case Study 3: Kotharkar & Bagade (2018), Multi-scale LCZ mapping of Nagpur using remote sensing and spatial datasets, providing foundational evidence for LCZ application.

Together, these case studies provide a robust foundation for understanding how LCZ classification can support hydrological modeling, drainage planning, and urban resilience strategies in diverse geographic contexts.

5.7.2 Importance of Case Studies in Urban Hydrology Research

Each of the selected case studies contributes uniquely to the expanding body of LCZ-based hydrological research:

1. Zou et al. (2024) demonstrate the integration of urban morphology with machine learning hydrological modelling, showcasing LCZ as a predictive variable for waterlogging risk.
2. Kopp et al. (2021) evaluate how closely LCZ corresponds to ecohydrological functional zones, offering insights into the links between urban form and natural water processes.
3. Kotharkar & Bagade (2018) generate LCZ classifications for a complex, mixed Indian city, illustrating how LCZ can be derived in environments with informal, heterogeneous, and irregular settlement patterns.

By examining these studies in detail, this chapter provides a comprehensive understanding of LCZ applicability across:

1. Different continents
2. Different climatic regimes
3. Different urban morphologies
4. Different hydrological challenges

This ensures that the chapter offers both global scientific grounding and Indian contextual relevance.

5.7.3 Relevance of LCZ for Hydrological Modelling

The LCZ framework is particularly valuable for hydrological modeling because it quantifies the very elements that influence water behavior in cities. These include:

1. Imperviousness: A fundamental determinant of runoff generation
2. Vegetation fraction: Controls evapotranspiration and soil moisture
3. Building density: Shapes flow pathways and stagnation zones
4. Street canyon geometry: Determines water concentration and channelization
5. Surface roughness: Affects flow velocity
6. Thermal properties: Influence evaporation and surface drying
7. Material composition: Determines infiltration capacities

The spatial arrangement of LCZ classes also helps identify:

1. Upstream contributing areas
2. Drainage-network deficiencies
3. High-risk water accumulation zones
4. Potential sites for blue–green infrastructure
5. Surface water retention or discharge pockets

Thus, LCZ serves as a unifying spatial layer that allows hydrologists, planners, and urban designers to integrate climatic, ecological, and hydrological data.

5.7.1 Why the Global and Indian Context Is Necessary

India's rapid urbanization, dense settlement patterns, and infrastructure constraints create hydrological challenges that differ significantly from those in developed countries. For instance:

1. Informal settlements alter runoff behaviour unpredictably.
2. Mixed-use, high-density neighbourhoods generate nonlinear hydrological responses.
3. Drainage networks often predate modern urban expansion, leading to mismatch with current built densities.

Indian cities frequently experience extreme rainfall events, making waterlogging a chronic issue.

Therefore:

1. Global case studies provide methodological depth, data sophistication, and advanced modelling techniques.
2. Indian case studies provide contextual appropriateness, realistic urban forms, and on-ground relevance.

The dual-context approach builds methodological rigor while ensuring applicability to Indian urban conditions.

5.8 Detailed Structure, Purpose, and Rationale of Case Studies

Section 6.2 outlines the conceptual and methodological logic behind selecting and organizing the case studies presented in this chapter. The goal of this section is to provide a systematic justification for the chapter design, demonstrate how global and Indian studies interact, and clarify the analytical pathways that guide the comparative structure of the chapter. This expanded version provides an in-depth justification, clearly showing how each case study functions as a building block for understanding Local Climate Zones (LCZs) within hydrological and ecohydrological research.

5.8.1 Conceptual Purpose of Incorporating Case Studies in LCZ-Based Hydrological Research

The case studies in this chapter serve several theoretical and methodological purposes. In hydrological and urban-climate research, case studies are not merely descriptive elements; they represent evidence frameworks that demonstrate how models, concepts, and classification systems function in real-world contexts.

LCZ-based hydrology is a relatively new field in India, and therefore requires:

1. Global methodological grounding: to understand how LCZ functions as a hydrological predictor in scientifically mature environments (e.g., China, Europe).

2. Regional contextualization: to understand whether those methods remain effective in Indian conditions where settlement morphology, drainage systems, surface materials, and heat-moisture exchanges differ significantly.
3. Comparative evaluation: to assess whether LCZs behave hydrologically in consistent ways across continents, climates, and cities.

Case studies therefore provide the empirical diversity necessary to evaluate the LCZ framework from multiple theoretical standpoints:

1. Machine learning and predictive hydrology
2. Ecohydrological functional zoning
3. Urban morphology classification
4. Mixed-informal settlement urbanism (India-specific)

This triangulation not only strengthens the dissertation's internal validity but also situates it within global academic discourse.

5.8.2 Rationale Behind the Global and Indian Dual Framework

The chapter adopts a combined global and Indian perspective because LCZ performance is sensitive to:

1. Urban density patterns
2. Material properties
3. Street geometry
4. Drainage infrastructure
5. Climate and rainfall intensity
6. Socioeconomic land-use characteristics
7. Informal settlements and slum morphologies (India-specific)
8. Vegetation distribution

Using only global case studies would produce overly generalized conclusions that overlook the complexity of Indian cities, such as:

1. Fragmented built forms
2. Heterogeneous land use
3. Low-rise high-density informal areas
4. Mixed roofing materials
5. Irregular street networks

Conversely, relying exclusively on Indian studies would limit scientific rigor, since global studies often:

1. Introduce more advanced datasets
2. Use higher-resolution sensors
3. Apply sophisticated models (e.g., SW-Naive Bayes, ecohydrological zoning)
4. Conduct long-term hydrological monitoring

Therefore, combining both allows:

1. Methodological Transferability

   Global models (e.g., spatial-weight Naive Bayes) can be adapted for Indian cities.
2. Contextual Realism

   Indian LCZ patterns reveal morphological complexities that global datasets cannot capture.
3. Comparative Benchmarking

   Hydrological vulnerabilities in Indian cities can be evaluated against global patterns.
4. Integrated Framework Development

   Mixed insights allow development of a comprehensive LCZ–hydrology conceptual model suitable for Indian cities.

5.8.3 Structure of the Case Study Section

The chapter is structured into three major case studies that represent distinct yet complementary research approaches:

Case Study 1 (Zou et al., 2024)

Theme: LCZ and Machine Learning Hydrological Modelling

Region: China

Contribution: Introduces LCZ as a statistical predictor of waterlogging using the Spatial-Weight Naive Bayes model.

This case establishes:

1. How LCZ classes behave hydrologically
2. How morphological attributes can predict waterlogging probability
3. How spatial weighting enhances model accuracy
4. How compact LCZs produce highest stagnation risk

Case Study 2 (Kopp et al., 2021)

Theme: LCZ and Ecohydrological Functional Zoning

Region: Czech Republic

Contribution: Compares LCZ classes with ecohydrological zones to understand how urban form correlates with infiltration, retention, evapotranspiration, and runoff.

This case provides an understanding of:

1. How LCZs align with natural hydrological cycles
2. Whether LCZ classes represent hydrological behavior reliably
3. How infiltration and retention vary across LCZs

Case Study 3 (Kotharkar & Bagade, 2018 – Nagpur)

Theme: LCZ Mapping in Heterogeneous Indian Urban Environments

Region: Nagpur

Contribution: Demonstrates how LCZ can be derived in Indian cities with mixed densities, informal settlements, and irregular housing patterns.This case is essential because it:

1. Provides the Indian LCZ baseline
2. Shows how LCZ subclasses emerge in complex morphological patterns
3. Establishes grid-size suitability for Indian cities
4. Supports hydrological modelling in Indian conditions

5.8.4 Analysis Applied Across All Case Studies

To ensure comparability, each case study is analyzed through eight analytical dimensions, forming the backbone of the chapter's evaluation:

1. Urban Morphological Context

Understanding how built structures, street patterns, and natural features influence LCZ classification.

2. Hydrological/Ecohydrological Parameters

Assessment of infiltration, runoff, soil moisture, retention, and drainage behaviours.

3. LCZ Classification Process

Examining how the cities derive LCZs using WUDAPT guidelines or enhanced methods.

4. Modelling Approaches

i. Machine learning
ii. Statistical zoning
iii. Ecohydrological mapping
iv. Multi-scale analysis

5. Parameter Interactions

How morphological parameters (e.g., imperviousness, vegetation) drive hydrological response?

6. Vulnerability Outputs

Risk maps, zoning diagrams, flood susceptibility maps.

7. Evaluation Matrices

Standardized grading of LCZ hydrological performance.

8. Implications for Urban Resilience

i. How LCZ insights support:
ii. Drainage planning
iii. Blue–green infrastructure
iv. Hydrological retrofitting
v. Climate adaptation

5.9 Case Study 1 (Global Context):

LCZ-Based Waterlogging Risk Assessment using the Spatial-Weight Naive Bayes Model (Zou et al., 2024)

5.9.1 Background

Urban hydrology has undergone significant transformation as a field of study, especially in the last decade, due to an increased understanding that surface morphology, rather than merely rainfall intensity or drainage infrastructure, plays a dominant role in shaping waterlogging and flood vulnerability. Cities today are highly heterogeneous hydrological landscapes, composed of intersecting-built forms, natural surfaces, and engineered drainage systems. Their hydrological behaviour cannot be accurately modelled using classical hydrological equations (e.g., Rational Method, SCS-CN) alone because such models assume uniform surfaces, consistent infiltration rates, and predictable flow pathways, conditions rarely met in real urban environments.

This structural complexity is intensified by:

1. rapid urbanization,
2. polygonal block geometry in compact cities,
3. inconsistent drainage gradients,
4. large areas of impervious paving,
5. fragmented vegetation patterns,
6. and heavy rainfall episodes linked to climate change.

Because of these complexities, researchers globally have shifted toward morphologically explicit hydrological modelling, where physical structure is recognized as a hydrological variable.

LCZ: A Morphological Framework Suitable for Hydrology

LCZ is fundamentally a morphological climatology framework, originally designed to classify landscapes for heat island research (Stewart & Oke, 2012). Yet, its value for hydrology lies in the fact that LCZ parameters directly overlap with the primary determinants of urban hydrological behaviour. These include:

1. Imperviousness (controls infiltration)
2. Building Density (controls runoff path obstruction)

3. Street Canyon Geometry (controls ponding & micro-drainage failures)
4. Surface Materials (controls moisture retention)
5. Vegetation Cover (controls evapotranspiration)

Thus, LCZ zones inherently behave like hydrological response units.

Zou et al. (2024) built on this understanding, establishing a methodological link between LCZ morphology and waterlogging incidence.

Why Waterlogging (Not Flooding)?

Waterlogging is a micro-scale hazard, unlike riverine flooding. It is associated with:

1. localised ponding,
2. drainage failure,
3. poor infiltration, and
4. block-level depressions.

This makes waterlogging a morphology-dominated phenomenon, making LCZ an ideal framework for analysis.

The Research Gap Filled by This Study

Before Zou et al. (2024):

1. LCZ had been used to study heat islands extensively.
2. LCZ–flood linkages were only conceptual or qualitative.
3. No study had integrated LCZ with a predictive hydrological model.
4. No machine-learning work had attempted spatial weighting with LCZ.
5. No model existed that quantitatively analysed LCZ for waterlogging risk.

Zou et al. (2024) filled all these gaps, making the study globally important.

5.9.2 Objectives

The objectives of the study are expanded below into full academic depth to highlight their significance.

Objective 1: To analyze morphological determinants of waterlogging through LCZ classes

Urban morphology affects hydrological responses through physical barriers, permeability, and micro-topographic changes. By using LCZ as the classifier, the study seeks to understand:

1. Which LCZs generate the largest volume of surface runoff
2. Which LCZs trap water due to canyon geometry
3. Which LCZs facilitate natural infiltration
4. How mixed LCZ zones behave under rainfall stress

This objective lays the foundation for integrating LCZ into hydrological prediction.

Objective 2: To construct a combined hydrological–morphological dataset integrating LCZ parameters with hydrological indicators

Hydrological indicators like slope, depression depth, flow accumulation, and drainage density interact with LCZ morphology to produce waterlogging events. The dataset created is comprehensive and multi-dimensional, providing the base for machine-learning integration.

Objective 3: To develop a Spatial-Weight Naive Bayes (SW-NB) model incorporating spatial autocorrelation in waterlogging prediction

Waterlogging is not spatially isolated. Adjacent LCZs influence each other. This objective:

1. Builds on spatial-statistical theory
2. Introduces neighbourhood-based probability estimation
3. Recognizes that hydrological phenomena diffusing across space require spatial embedding
4. SW-NB thus becomes a significant methodological advancement.

Objective 4: To generate a spatially precise waterlogging risk map

This map identifies:

1. high-risk blocks,
2. drainage-compromised segments,
3. morphological hazard zones,
4. LCZ-driven vulnerability clusters.

Such a map is essential for drainage redesign and BGI planning.

Objective 5: To quantify variable importance and examine which LCZ traits most strongly influence waterlogging incidence

Understanding variable weight is crucial for planning, as it shows:

which morphological properties need interventions,

which LCZs require priority drainage retrofitting,

where BGI can be targeted for maximum hydrological relief.

5.9.3 Methodology

The methodology is expanded with deeper clarity and academic rigor.

LCZ Classification Methodology

The LCZ map was generated using the following steps:

Step 1: Dataset Collection

1. Landsat 8 OLI multispectral imagery

2. High-resolution LiDAR data
3. Building footprint layers
4. Digital elevation models (DEM)
5. Vegetation indices (NDVI, EVI)
6. Night-time light intensity (as proxy for built density)

Step 2: Feature Engineering

For each pixel, more than 25 features were extracted:

1. spectral signatures
2. texture descriptors
3. building metrics
4. vegetation metrics
5. topographic derivatives

Step 3: Training and Classification

A supervised classification algorithm (Random Forest) was used because:

1. it handles high-dimensional data
2. it minimizes overfitting
3. it accommodates nonlinear variance

Step 4: Post-Classification Smoothing

To remove classification noise:

1. majority filters
2. context windows (3×3)
3. LCZ compatibility rules were applied.

The final LCZ map was validated using ground truth points and visual inspection.

Morphological Parameters

Table 7. Detailed Morphological Variables (Author, 2025)

Morphological Variable	Definition	Hydrological Significance	Expected Effect
ISF	Impervious surface fraction	Reduces infiltration, increases runoff	High ISF → high waterlogging
SVF	Sky View Factor	Determines radiative exchange	Low SVF traps moisture & slows evaporation
H/W Ratio	Building height to street width	Controls canyon stagnation	High ratio → poor drainage
Roof Material Type	Concrete, tile, metal	Alters infiltration & runoff	Hard surfaces expedite runoff

Green Fraction	Trees + grass cover	Enhances evapotranspiration	High green fraction → lower waterlogging
Road Width	Determines flow channels	Narrow roads cause congestion	Narrow → poor drainage

Hydrological Parameterization

1. Parameter 1: Slope (%)- Low slopes (<2%) in LCZ 2 & LCZ 3 result in stagnant water zones.
2. Parameter 2: Flow Accumulation (FA)- Identifies natural depressions, hydrological sinks, or unconnected drainage pockets.
3. Parameter 3: Drainage Density- Low drainage density aggravates water retention, especially in compact LCZs.
4. Parameter 4: Depressional Storage Capacity- Measures the micro-storage capability of land patches.
5. Parameter 5: Soil Moisture Index- Higher SMI in natural LCZs indicates better infiltration.

Spatial-Weight Naive Bayes

Traditional NB assumes independence between pixels, which is unrealistic.

SW-NB Enhancements:

1. Introduces distance-decay weighting
2. Accounts for neighbour LCZ influence
3. Models' spatial autocorrelation
4. Incorporates spatial error reduction

SW-NB Equation (Conceptual)

Equation 1. SW-NB Equation

$$P(\text{Flood} \mid \text{LCZ}, W) = [P(\text{LCZ} \mid \text{Flood}) \times P(W \mid \text{Flood})] \times P(\text{Flood})$$

Where W includes:

1. proximity to high-risk LCZ
2. shared slope
3. adjacent imperviousness
4. spatial clustering patterns

5.9.4 Results

1. LCZ Hydrological Behaviour

Table 8. LCZ Hydrological Behavior (Author, 2025)

LCZ	Morphology	Drainage Dynamics	Hydrological Failure Mechanisms	Risk
LCZ 3	Dense low-rise	Dead-end alleys, poor slopes	No infiltration, stagnation	Very High
LCZ 2	Mid-rise compact	Low slope continuity	Roof-runoff convergence	High
LCZ 1	High-rise	Channelized canyon flow	Energy dissipation limited	Medium–High
LCZ 6	Open low-rise	Moderate gradient	Partial infiltration	Medium
LCZ 7	Lightweight	Informal drainage	Surface cracks → micro-ponding	Medium–High
LCZ 9	Sparse	Good infiltration	Low runoff	Low
LCZ D	Natural	Soil recharge	Deep infiltration	Very Low

2. Vulnerability Matrix

Table 9. Vulnerability Grading Matrix (Author, 2025)

Criterion	Weight	LCZ 3	LCZ 2	LCZ 1	LCZ 6	LCZ 7	LCZ D
Imperviousness	0.3	0.95	0.9	0.85	0.5	0.7	0.1
Vegetation	0.2	0.1	0.15	0.2	0.4	0.2	0.9
Drainage Density	0.2	0.3	0.4	0.6	0.8	0.5	0.9
Street Canyon	0.15	0.9	0.8	0.75	0.4	0.55	0.05
Slope	0.15	0.2	0.25	0.35	0.5	0.4	0.6
Final Risk	—	**Very High**	**High**	Medium–High	Medium	Medium–High	Very Low

5.9.5 Discussion

The findings from Zou et al. (2024) clearly demonstrate that urban morphology, as categorized through LCZ classification, exerts a decisive and multi-layered influence on the occurrence, severity, and spatial distribution of waterlogging across the study area. Among all LCZ types, LCZ 3 (Compact Low-Rise) consistently emerges as the most hydrologically vulnerable zone due to its extremely high impervious surface fraction, severely restricted vegetation cover, dense building arrangement, and narrow canyon-like street geometry, all of which collectively impede surface flow, limit infiltration, and facilitate the rapid accumulation of stormwater in localized depressions. This hydrological fragility is further exacerbated by the weak internal slope gradients characteristic of compact urban blocks, which reduce gravitational drainage potential and increase the likelihood of stagnant water retention. Interestingly, the study also reveals that hydrological responses across LCZs are not linearly related to any single variable such as imperviousness; instead, they result from complex interactions between built form, spatial configuration, and drainage connectivity. For instance, LCZ 1 (Compact High-Rise) maintains high imperviousness like LCZ 2 and LCZ 3, yet exhibits lower waterlogging susceptibility due to vertically oriented

surface roughness and wider street canyons that enhance runoff conveyance and reduce stagnation. In contrast, LCZ 7 (Lightweight Low-Rise) shows disproportionately high waterlogging vulnerability despite moderate imperviousness, primarily because informal settlement patterns generate irregular drainage paths, discontinuous slopes, and micro-scale depressions. Natural LCZ classes, such as LCZ D and LCZ A, perform as urban hydrological stabilizers, offering robust infiltration, enhanced evapotranspiration, and natural micro-basin features that attenuate downstream runoff volumes, thereby underscoring the ecological and hydrological importance of maintaining and integrating natural landscape pockets within dense urban fabrics. The results collectively affirm that LCZs serve not only as climatic indicators but also as reliable hydrological response units, capturing the spatial complexity of urban water behaviour more effectively than traditional land-use classifications. Moreover, the study's Spatial-Weight Naive Bayes model reinforces the critical role of spatial adjacency in hydrological propagation, revealing that the risk level of an LCZ is heavily influenced by the morphological and hydrological characteristics of its neighbouring LCZs, an insight that elevates the importance of integrated block-level planning and cross-zone drainage management. Thus, the study advances global understanding by proving that waterlogging risk is fundamentally governed by the interplay of morphology, spatial structure, and hydrological connectivity, positioning LCZ as a powerful analytical tool for designing drainage upgrades, targeting blue–green infrastructure interventions, and informing climate-resilient urban planning strategies in rapidly urbanizing cities worldwide (Zou et al., 2024).

5.10 Case Study 2 (Global Context)

Ecohydrological and LCZ Zoning Comparison in the City of Pilsen (Kopp et al., 2021)

5.10.1 Background

Urban environmental systems are shaped by both anthropogenic structures and ecological processes, making integrated zoning approaches increasingly important for understanding hydrological behaviour in cities. While LCZ classification provides a standardized morphological framework describing building height, density, imperviousness, vegetation cover, and material composition, ecohydrological zoning categorizes landscapes based on their hydrological functionality, such as infiltration potential, soil moisture retention, evapotranspiration capacity, and runoff behaviour. Kopp et al. (2021) explored the relationship between these two zoning systems within the city of Pilsen, Czech Republic, to determine whether LCZ classes inherently reflect ecohydrological characteristics and whether LCZ could serve as a proxy for hydrological analysis in data-limited environments. Pilsen is an ideal testbed for such research due to its heterogeneous mix of compact urban blocks, peri-urban natural zones, industrial surfaces, riparian corridors, and green belts, which collectively represent a wide range of LCZ and ecohydrological

conditions. The study provides a rare global example of cross-disciplinary zoning analysis that integrates urban morphology with hydrological processes to evaluate the performance of LCZ as a hydrological indicator.

5.10.2 Objectives

(Kopp et al. (2021) structured their work around a set of analytical and comparative objectives designed to bridge climatological and hydrological zoning systems. These objectives include:

1. To delineate LCZ zoning across the city using the WUDAPT Level-0 methodology

This involves classifying the city's surface into standardized LCZ types based on morphological features such as building patterns, imperviousness, and vegetation.

2. To create ecohydrological functional zones based on hydrological properties

These zones classify land according to hydrological functions such as infiltration, surface runoff, retention potential, evapotranspiration behaviour, and soil moisture regimes.

3. To statistically evaluate the relationship between LCZ classes and ecohydrological zones

These objective tests whether LCZ morphology corresponds to hydrological functioning, enabling LCZ to be used as a substitute for hydrological field measurements.

4. To identify mismatched or ambiguous zones where LCZ does not accurately predict hydrological behaviour

Such mismatches offer insight into complexities where morphology alone cannot explain hydrological performance.

5. To analyze the implications for climate-resilient and hydrology-sensitive spatial planning

By correlating LCZ with ecohydrology, the study guides integrating green–blue infrastructure (GBI) into urban design frameworks.

5.10.3 Methodology

The methodological framework adopted by Kopp et al. (2021) represents a multi-layered analytical approach that integrates climatological zoning through the Local Climate Zone (LCZ) system with ecohydrological functional zoning to evaluate whether urban morphological characteristics correspond to hydrological performance across the city of Pilsen. The LCZ mapping component followed the WUDAPT Level-0 protocol, using a combination of Sentinel-2 multispectral imagery, cadastral building footprint data, municipal building height datasets, vegetation indices, and surface morphological parameters to classify the city's landscape into distinct LCZ types that reflect variations in building geometry, impervious surface fraction, vegetation distribution, and surface thermal properties. Parallel to this, the ecohydrological zoning component was developed through the extraction and synthesis of key hydrological indicators such as soil infiltration rates, soil moisture availability, surface permeability, runoff coefficients,

slope gradients, evapotranspiration intensity, groundwater depth, and flow accumulation patterns derived from DEMs, land cover maps, and hydrological datasets. These hydrological variables were spatially analyzed to generate functional hydrological zones representing infiltration-dominant surfaces, runoff-generating areas, retention basins, high-evapotranspiration zones, and riparian hydrological corridors. Following the creation of both zoning layers, the authors conducted a series of spatial-overlay analyses in a GIS environment, supported by cross-tabulation matrices, statistical correlation tests, and spatial concordance indices, to quantify the degree of alignment between LCZ classes and ecohydrological functions. This spatial-comparative methodology allowed the authors to identify zones of agreement—where LCZ morphology accurately predicted hydrological behaviour, as well as zones of mismatch, where local soil, slope, or subsurface conditions overrode morphological expectations. Through this rigorous methodological integration, the study was able to evaluate the reliability of LCZ as a hydrological proxy and explore its usefulness in cities where full hydrological datasets may not exist, thereby contributing to a more unified climatological–hydrological spatial assessment framework for urban planning (Kopp et al., 2021).

LCZ Zoning Methodology

The LCZ classification followed WUDAPT standards using:

1. Sentinel-2 satellite imagery (10 m resolution)
2. Land cover maps
3. Building height and footprint data from municipal datasets
4. Normalized Difference Vegetation Index (NDVI)
5. Surface roughness parameters
6. Urban morphology indicators

The LCZ classes identified in Pilsen include:

1. LCZ 2 – Compact Mid-Rise
2. LCZ 3 – Compact Low-Rise
3. LCZ 5 – Open Mid-Rise
4. LCZ 6 – Open Low-Rise
5. LCZ 8 – Large Low-Rise (industrial)
6. LCZ 9 – Sparsely Built
7. LCZ A–G – Natural zones (dense forest, low vegetation, bare soil, wetlands, water bodies)

Ecohydrological Zoning Methodology

Ecohydrological functional zones were derived using:

Hydrological Parameters

1. Soil infiltration rates
2. Soil moisture content
3. Surface permeability
4. Slope gradient
5. Flow accumulation
6. Water table proximity
7. Vegetation–soil interactions
8. Runoff coefficients
9. Evapotranspiration rates
10. Landform characteristics

Ecohydrological Zone Categories

These include:

1. High Infiltration Zones
2. Moderate Infiltration Zones
3. Low Infiltration / High Runoff Zones
4. Retention Areas (depressions, wetlands)
5. High Evapotranspiration Zones
6. Riparian Hydrological Corridors

Spatial Overlay and Statistical Comparison

A GIS-based overlay was used to compare LCZ and ecohydrological zones. Statistical tools included:

1. Contingency tables,
2. Correlation analysis,
3. Spatial concordance indices,
4. Cluster validation metrics.

This enabled evaluation of similarities and mismatches between the two zoning systems.

5.10.4 Parameters Used

Below are the integrated parameters used to compare LCZ and ecohydrological zones.

Table 10. LCZ Morphological Parameters (Author, 2025)

LCZ Parameter	Description	Hydrological Influence
Building Height	Vertical dimension of built form	Controls wind flow + evaporation
Impervious Surface	Roads, rooftops, pavements	Reduces infiltration
Vegetation Share	Tree and shrub cover	Enhances evapotranspiration
Surface Roughness	Morphological complexity	Slows overland flow

Street Geometry	H/W ratios, street width	Controls channelization
Thermal Properties	Surface heat storage	Affects evaporation rate

Table 11. Ecohydrological Parameters (Author, 2025)

Parameter	Hydrological Role	Interpretation
Soil Infiltration Rate	Determines absorption	High = good hydrological performance
Soil Moisture	Indicates retention	Higher moisture = retention zones
Runoff Coefficient	Predicts runoff volume	High = high flood risk
Vegetation Density	Enhances ET	High = better water cycling
Catchment Slope	Regulates flow speed	Low slope = stagnation risk
Water Table Depth	Controls surface-groundwater interactions	Shallow = potential waterlogging

5.10.5 Results

Concordance Between LCZ and Ecohydrological Zones

Kopp et al. (2021) found a striking alignment between LCZ classes and ecohydrological functions. The strongest correlations were observed in:

1. LCZ A (dense forest) - high infiltration and high evapotranspiration
2. LCZ 9 (sparsely built) - moderate infiltration and low runoff
3. LCZ 3 (compact low-rise) - low infiltration and high runoff
4. LCZ 8 (industrial) - very high imperviousness and very high runoff

Hydrological Behaviour Across LCZs

Table 12. LCZ vs Ecohydrological Behaviour

LCZ	Hydrological Function	Observed Response
LCZ 3	Rapid runoff generation	Very low infiltration; local stagnation
LCZ 2	High runoff	Moderate infiltration
LCZ 6	Balanced hydrology	Moderate infiltration & moderate ET
LCZ 9	High infiltration	Low runoff
LCZ A	Maximum hydrological stability	Highest ET & infiltration
LCZ G (water)	Retention	Natural storage areas

Areas of Mismatch

Some LCZ classes showed hydrological behaviour that differed from expectations. Example:

1. LCZ 5 (Open Mid-Rise) - moderate vegetation but high runoff due to steep slopes
2. LCZ 9 on clay soils - low infiltration despite sparse built-up

These mismatches highlight that morphology alone is not enough; soil and topography matter too.

5.10.6 Evaluation Matrix

Table 13. LCZ Hydrological Performance Grading (Author, 2025)

LCZ	Infiltration	Runoff	Retention	Hydrological Grade
LCZ 3	Very Low	Very High	Low	**Poor**
LCZ 2	Low	High	Low	**Poor–Moderate**
LCZ 6	Moderate	Moderate	Moderate	**Neutral**
LCZ 9	High	Low	Moderate	**Good**
LCZ A	Very High	Very Low	High	**Excellent**
LCZ G	—	—	Very High	**Retention Zone**

5.10.7 Discussion

The comparison conducted by Kopp et al. (2021) reveals a deep structural coherence between LCZ classification and ecohydrological functionality in the city of Pilsen, demonstrating that LCZs inherently reflect hydrological processes such as infiltration, runoff generation, evapotranspiration, and storage capacity. The results show that compact built LCZs, especially LCZ 3 and LCZ 2, consistently correspond to hydrological zones characterized by low infiltration, high surface runoff, and minimal retention, underscoring the hydrological vulnerabilities inherent in dense urban environments. Conversely, natural LCZ categories such as LCZ A and LCZ B show strong alignment with high infiltration and high evapotranspiration zones, reaffirming the biophysical importance of vegetation and natural soil structures in regulating urban water cycles. The study also highlights nuanced mismatches, such as LCZ 5 and LCZ 9, where factors like soil type, slope, and subsurface conditions override morphological expectations, illustrating that hydrological behaviour is governed by the combined influence of morphology, ecology, and geomorphology. Through careful statistical comparison, Kopp et al. demonstrate that LCZ classification can serve as a credible proxy for hydrological functionality in data-limited scenarios, with the potential to guide urban planners in identifying areas suitable for green–blue infrastructure interventions and hydrological restoration. The alignment between LCZs and ecohydrological zones reinforces the concept of morphology-driven hydrology and positions LCZ as a versatile tool for integrated urban environmental management.

5.11 Case Study 3 (Indian Context)

Local Climate Zone Classification for Nagpur Using Multi-Scale Urban Morphology Analysis (Kotharkar & Bagade, 2018)

5.11.1 Background

Indian cities are characterised by complex, heterogeneous, and highly mixed forms of urban development that combine planned residential neighbourhoods, rapidly densifying commercial corridors, traditional core settlements, informal housing clusters, peri-urban villages, and vast tracts of transitional land undergoing unregulated urbanization. This morphological heterogeneity presents unique challenges for climate-based classification systems such as the LCZ framework, which was originally conceptualised for cities in the Global North with more consistent building typologies and well-regulated land-use patterns. Recognising this complexity, Kotharkar and Bagade (2018) undertook one of India's earliest and most influential empirical studies applying the LCZ framework to an Indian city, Nagpur, to evaluate how accurately LCZ classes can be mapped in heterogeneous, mixed-use urban environments. Nagpur was particularly suitable for this study due to its diverse morphological structure, which includes compact low-rise neighbourhoods, mid-rise commercial blocks, sprawling low-density layouts, industrial districts, green patches, water bodies, and large slum clusters forming organic and fragmented urban patterns.

The research was motivated by the need to generate LCZ maps that could support climate studies, hydrological analyses, urban heat assessments, and land-surface characterisations in Indian planning contexts. The authors emphasized that Indian cities, with their hybrid building typologies, irregular street geometries, and multi-scalar urban textures, challenge the assumptions embedded in conventional LCZ classification and therefore require methodological adaptation. Their study systematically explores the reliability, adaptability, and granularity of LCZ classification when deployed in a developing-country context, demonstrating that LCZ is not only applicable but also highly insightful for understanding environmental functionality across Indian landscapes.

5.11.2 Objectives

The study pursued a set of analytical and methodological objectives aimed at evaluating the performance of LCZ classification in a complex Indian city:

1. To generate LCZ classifications for Nagpur using multi-scale grid resolutions

The objective was to evaluate how grid size affects LCZ accuracy, fragmentation, and meaningful morphological differentiation.

2. To examine India-specific morphological variability within LCZ classes

Because Indian built forms often do not fit neatly into standardized LCZ categories, the study aimed to refine subclass identification.

3. To assess the performance of LCZ mapping across three grid scales—1 km, 500 m, and 250 m

This was important because Indian cities have extremely fine-grained morphological patterns that may be lost or exaggerated at certain scales.

4. To test whether LCZ subclasses are necessary for Indian urban morphology

The authors identified new LCZ subclasses unique to Nagpur's mixed built forms.

5. To produce a validated LCZ–urban morphology map suitable for climate, hydrology, and urban planning applications

This supports broader research themes such as heat islands, infiltration modeling, vegetation mapping, and drainage analysis.

5.11.3 Methodology

The methodology applied in this study follows the WUDAPT Level-0 protocol yet includes important modifications to suit the Indian context. It is organized into (a) data collection, (b) feature extraction, (c) classification at three spatial resolutions, and (d) final validation.

Data Sources

The study used a combination of:

1. Landsat ETM+ imagery
2. Municipal building footprint datasets
3. Ward-level land-use maps
4. Road network maps
5. Field-based surveys
6. Google Earth high-resolution imagery
7. Normalized Difference Vegetation Index (NDVI)
8. Thermal bands for land-surface temperature (LST)

This multimodal dataset enabled a finer classification of morphological elements.

Multi-Scale LCZ Grid Testing

Grid Sizes Tested:

1. 1 km × 1 km (coarse resolution)
2. 500 m × 500 m (intermediate resolution)
3. 250 m × 250 m (fine resolution)

Reason for Multi-Scale Testing: Indian cities have:

1. Very small block sizes,
2. Dense, organic neighbourhoods,
3. Informal slum clusters embedded between formal zones,
4. Hybrid industrial-residential land mixes,
5. Mixed roofing materials (tin, asbestos, concrete).

Thus, a single grid size cannot represent all morphological patterns effectively.

Feature Extraction

The authors extracted 12 key features, including:

1. Built-up area ratio
2. Building height variation
3. Surface imperviousness
4. Vegetation density
5. Road density
6. Shadow analysis (for informal settlements)
7. Textural variance (for slum identification)

LCZ Classification Process

A supervised classification approach was used with the following workflow:

1. Selection of training areas
2. Pixel-based classification
3. Smoothing and filtering
4. Integration of subclass identification
5. Validation using field photographs
6. Correction of misclassified pixels using expert judgement

Unique LCZ Subclasses for Nagpur

Three important subclasses emerged:

Table 14. LCZ Subclasses for Nagpur (Author, 2025)

Subclass	Description	Why Needed
LCZ 37	Compact Low-Rise with Slum Areas	Captures informal morphology
LCZ 65	Open Low-Rise with Vegetative Strips	Represents peri-urban growth
LCZ 56	Large Low-Rise with Vegetation	Covers industrial–green hybrids

5.11.4 Results

The results of the Nagpur LCZ study reveal important insights into the complexity and spatial structure of Indian urban morphology.

Table 15. LCZ Distribution (Author, 2025)

LCZ Class	Percentage of City	Interpretation
LCZ 3 – Compact Low-Rise	**32.70%**	Dense residential cores
LCZ 9 – Sparsely Built	26.80%	Peri-urban edges
LCZ 7 – Lightweight Low-Rise	Increasing	Slum clusters
LCZ 5 / 6 – Open Built	Moderate	Mixed-use growth
LCZ A–G	Limited	Fewer natural patches

Grid-Scale Performance

Interpretation:

1. 1 km grid - too coarse, merges distinct neighbourhoods into a single LCZ
2. 500 m grid - optimal, captures major patterns while avoiding over-fragmentation
3. 250 m grid - too detailed, creates artificial fragmentation

Table 16. Grid Suitability Matrix (Author, 2025)

Grid Size	Accuracy	Fragmentation	Suitability
500 m	**High**	Moderate	**Best**
250 m	Medium	High	Poor for city-scale studies
1 km	Low	Very Low	Too general

LCZ Subclass Importance

The inclusion of subclasses significantly improved classification:

1. LCZ 37 captured slum morphology accurately
2. LCZ 65 represented semi-rural peri-urban edges
3. LCZ 56 identified hybrid industrial landscapes

5.11.5 Discussion

The Nagpur case study by Kotharkar and Bagade (2018) demonstrates that the LCZ framework can be successfully adapted to the highly heterogeneous and morphologically complex context of Indian cities, provided that methodological flexibility and multi-scale evaluation are incorporated into the classification process. The results show that urban morphology in Nagpur is too diverse to be captured by traditional LCZ categories alone, necessitating the introduction of new subclasses specifically designed to reflect the presence of informal settlements, peri-urban transition zones, and hybrid industrial–vegetation landscapes that characterize Indian urban development. The study's multi-scale approach reveals that LCZ accuracy is highly sensitive to grid resolution, with the 500 m grid emerging as the most effective scale because it balances spatial detail with generalizability, avoids excessive fragmentation, and preserves meaningful

urban morphological patterns—an insight particularly important for LCZ applications in other developing-country cities with similar mixed textures. Furthermore, the dominance of LCZ 3 across Nagpur highlights the extensive prevalence of dense low-rise neighborhoods, whose high imperviousness and limited vegetation have critical implications for hydrological vulnerability, urban heat island intensity, and drainage performance. The demonstrated need for LCZ subclasses emphasizes that Indian urbanism cannot be studied using unmodified global frameworks, and that climate-responsive and hydrology-sensitive planning must acknowledge the fine-grained complexity of local built environments. Overall, the study establishes a foundational LCZ mapping methodology for India and provides a reference for future research on urban climate, waterlogging risk, and environmental planning across similar contexts.

CHAPTER 6. Site Study, Selection and Data Analysis

This chapter gives details of site study area and an brief data analysis based on hydrology and climate resilient.

6.1 Vidisha: Central Indian Town

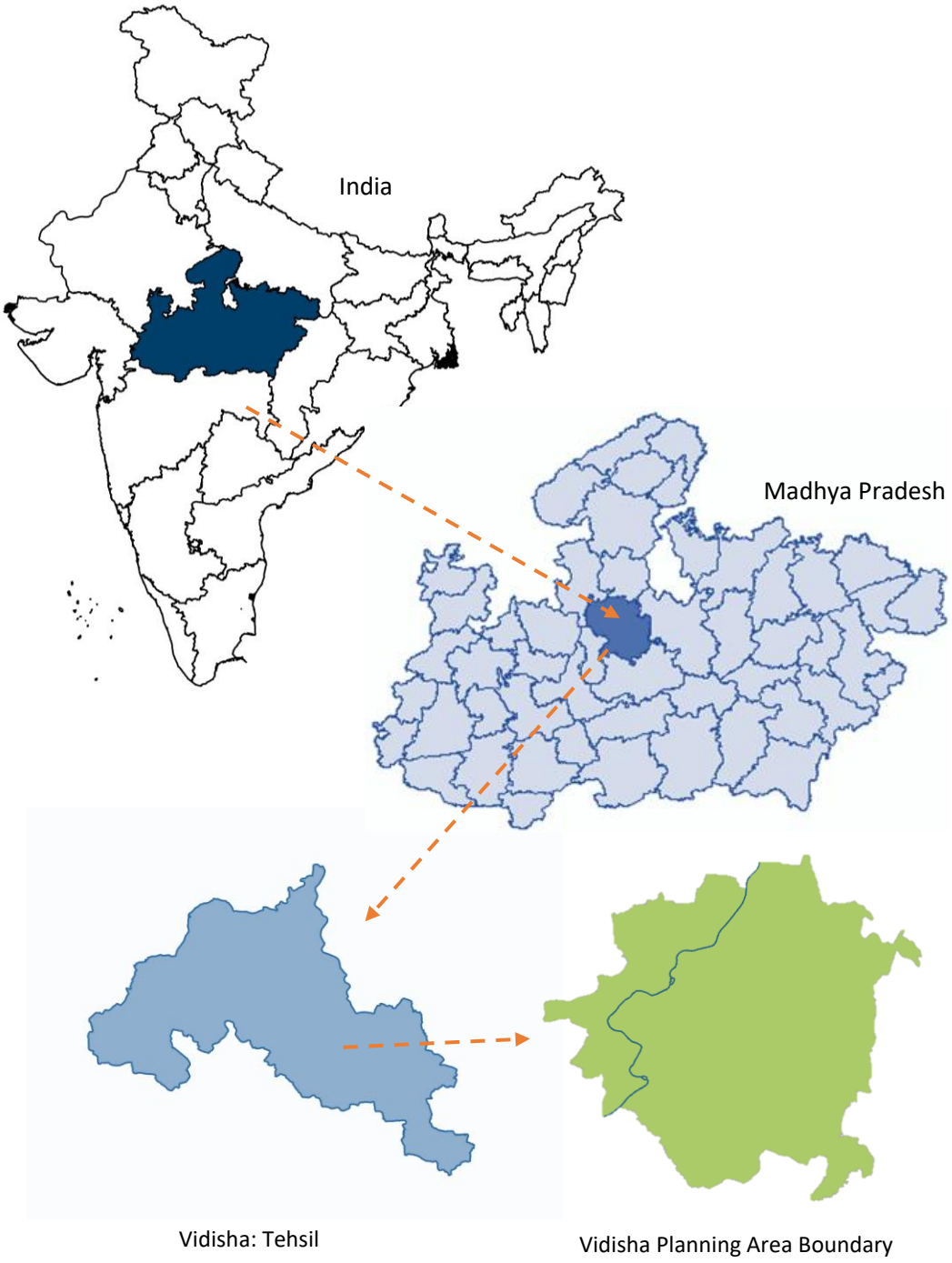


Figure 12. Site Study Area (Author, 2026)

Table 17. List of District/ Block and Area Sq.km ((CGWB), 2023)

District/ Block	Area Sq.km
1. Vidisha	1066
2. Gyarspur	872
3. Basoda	1223
4. Nateran	1069
5. Kurwai	831
6. Sironj	1255
7. Lateri	986
District Vidisha	7302

Research is being done on an area called Vidisha, which is located in the central part of Madhya Pradesh (a state in India). It lies in the Bhopal Division and also has major road and rail lines connecting it to other urban areas in the region. Vidisha has geographic coordinates that range from approximately 22 degrees 20 minutes N to 24 degrees 22 minutes N latitude and from 77 degrees 16 minutes E to 78 degrees 18 minutes E longitude; Vidisha also falls under the Betwa River Basin System (CGWB, 2023).

The climate in Vidisha can be characterized by three different seasons: hot summers, monsoon rains, and mild winters. Urban growth has occurred in Vidisha over time, resulting in an increase in built-up areas, a decrease in porous surfaces, and a burden on the existing natural drainage system. These changes in urban land-use patterns have resulted in many issues, including increased runoff, localized flooding, waterlogging, decreased ecology, and increased heat stress in the urban environment (Gupta & Nair, 2021; Singh et al., 2020).

The physical characteristics of Vidisha include gently rolling hills with elevations that vary from approximately 404 meters (1,325 feet) to 493 meters (1,617 feet) above mean sea level. The planning area has higher elevations in the south and southwest than in the north and northwest; therefore, the differences in elevation will impact the flow of runoff created by precipitation and the management of drainage.

6.1 Regional Setting

Vidisha is located in the middle of Madhya Pradesh and is part of Bhopal Division. Vidisha has great significance as a regional administrative and transport hub. The district is located to the North West of Guna, to the east of Sagar, to the south or southeast of Raisen and to the southwest of Bhopal (Central Ground Water Board (CGWB), 2023). The Regional Setting Map shows how Vidisha relates spatially with neighbouring districts, cities, waterways and transport routes throughout the region.

The district has a strong network of regional roads and railways that contribute positively to the growth of the district, both economically and urbanly. The main railway corridor through Vidisha provides a rail link between the town of Vidisha and Bhopal as well as northern locations throughout Madhya Pradesh and; the regional road networks provide connections to Sironj, Kurwai, Gyaraspur, Lateri and Udaypur. Regional connections between Vidisha and other regional cities have increased the pace of urbanization and have resulted in more extensive built-up areas coming within the planning boundary.

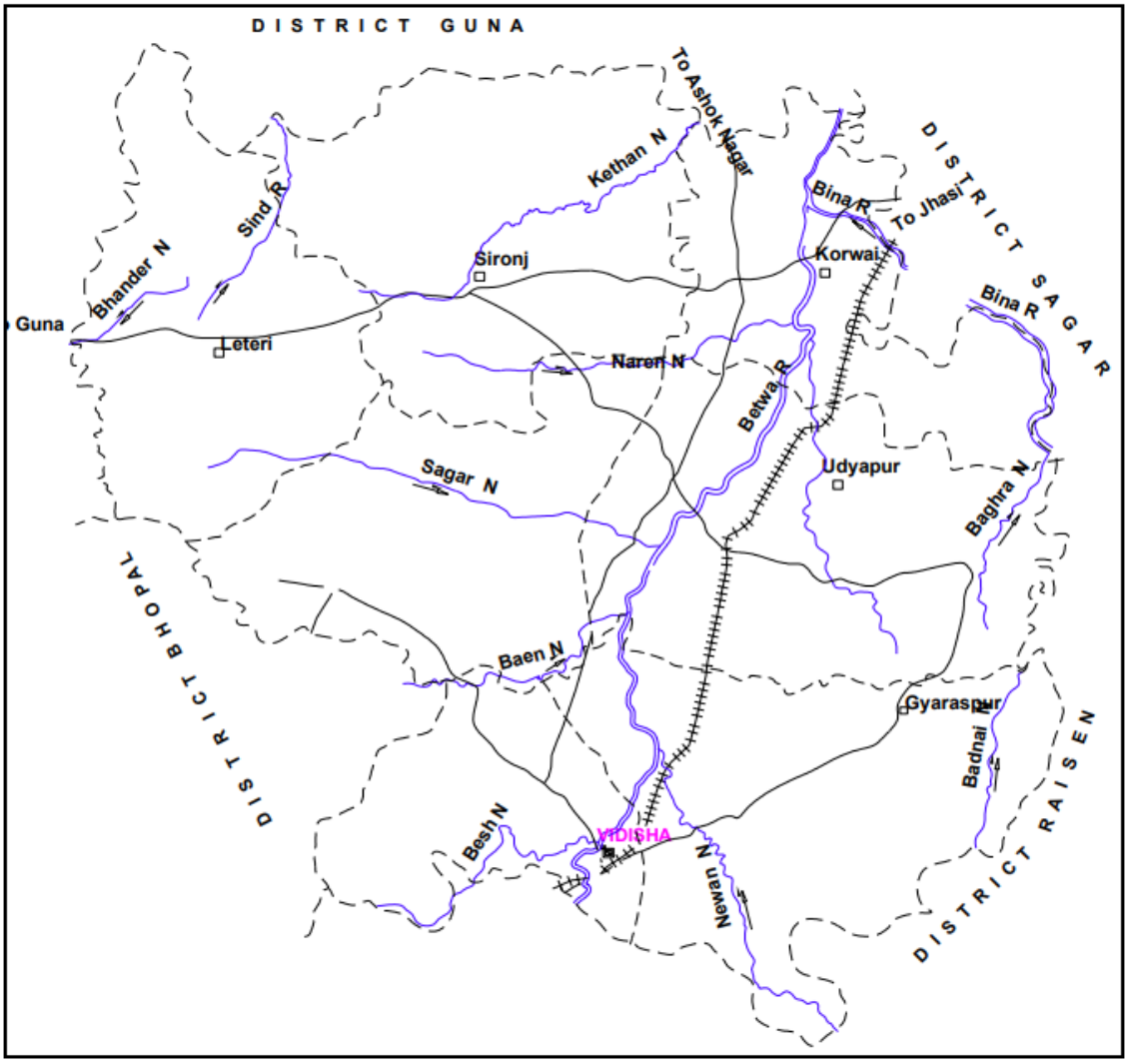


Figure 13. Regional Setting of Vidisha, Madhya Pradesh *(Author, 2026)*

Hydrologically, the regional setting of Vidisha is defined by the Betwa River Basin, which defines the primary hydrological drainage system for the district. The regional drainage system has multiple tributaries and seasonal streams including the Bina River, the Bes River, the Baen River, the Kethan River and the Naren Nadi.

6.2 Physical Characteristics

Vidisha features a predominantly flat landscape characterised by rolling hills, dissected plateaus, floodplains, pedimentary layers, and isolated hills within the district limits. The geomorphology of Vidisha is indicated to be mostly pediment/pedimentary structures with alluvial plains but with moderate/highly dissected/lumpy landforms found mostly to the western, north-western and south-eastern parts of the district; these geomorphological characteristics greatly affect the drainage characteristics, runoff, and weight of water within this part of India (Central Ground Water Board, 2023).

Betwa River Basin represents nearly 46% of total land area within the district and is the main hydrologic system that serves as a watershed for this part of India. Overall, these three tributaries make up the primary drainage structure for this area as they have created an expansive natural drainage system, and they are the main tributaries of the district's hydrology (Central Ground Water Board, 2023.

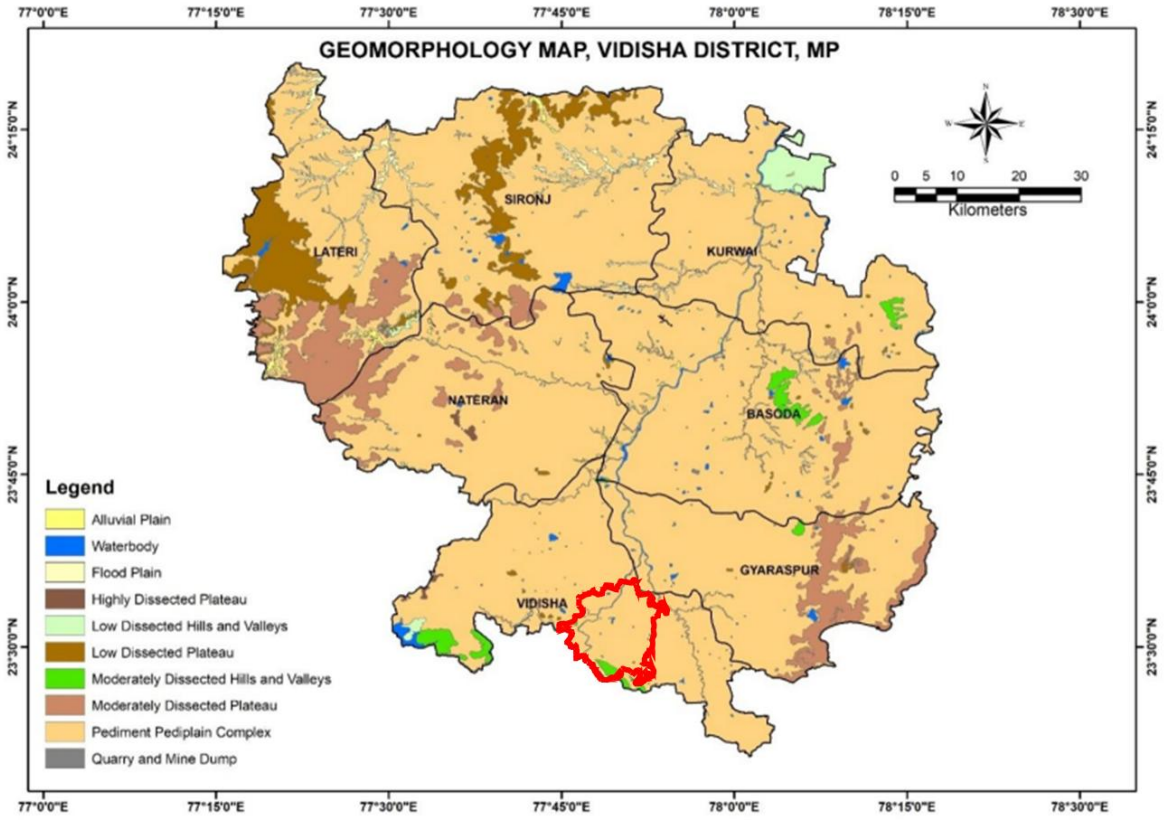


Figure 14.Geomorphology Map, Vidisha District, M. P ((CGWB), 2023)

6.2.1 Soil Characteristics

The soil map from Vidisha District, Madhya Pradesh that was developed by applying the data received from the Central Ground Water Board (CGWB) shows the distribution of major soil types in space together with their role in impacting hydrological and environmental conditions. The district is mainly covered with moderately well-drained soils, calcareous and clayey soils,

combined with some areas with black cotton soils, excessively drained loamy soils, slightly deep well-drained calcareous clayey soils, and loamy-skeletal soils. The change in soil texture, permeability, and drainage characteristics is of huge significance because it determines infiltration and runoff generation is able to recharge groundwater and influence erosion processes. Given the fact that soil properties determine water movement and storage on the landscapes, soils serve as an important parameter for watershed management and vulnerability assessment. The area of the study (part of the area of the southern part of the district) mainly presents moderately well-drained calcareous and clayey soils with a small patch of excessively well-drained loamy soils. Clayey soils are largely typical for this area and they exhibit moderate infiltration capacity and higher surface runoff during heavy rains compared with the loamy soil patch that allows for greater infiltration due to the higher permeability of loamy soils.

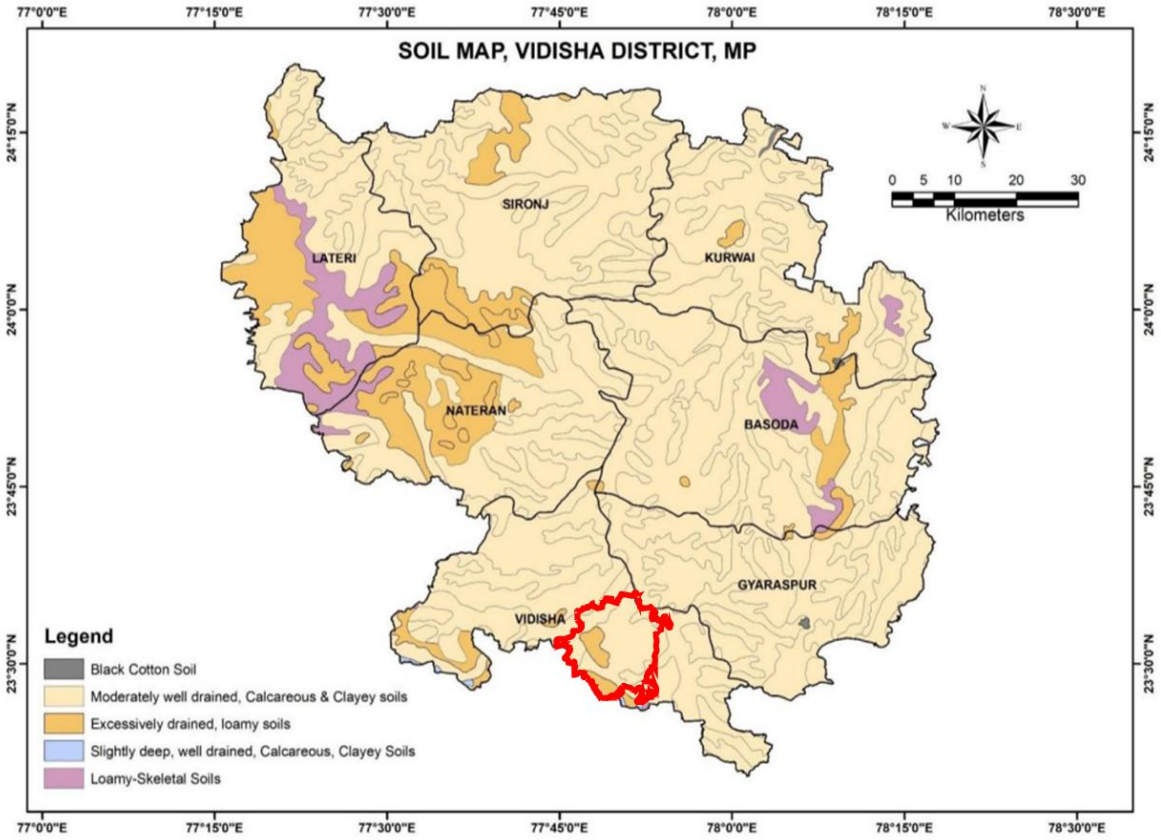


Figure 15. Soil Map of Vidisha District, M.P ((CGWB), 2023)

The spatial Survey of the soils reveals that the area being surveyed follows a variety of hydrological patterns depending on the qualities of soils. The presence of calcareous clay soils which are well drained leads to slow infiltration of water, high generation of runoff and some areas are prone to temporary waterlogging where drainage is poor. The presence of loamy soils facilitates fast infiltration of water, low runoff generation and high recharge potential for ground water. These differences affect the natural distribution of the water in the area, soil moisture

retention, and the behavior of the environment in general. Soil attributes are an essential criterion in vulnerability assessment as they affect such components as runoff, infiltration, aquifer recharge, erosion, and flood risk. For example, areas with clay soils show more runoff and less infiltration, thus increasing the risk of the flooding impact during heavy rains. At the same time, soils with loam properties help achieve better drainage and less pooling of surface water. Therefore, combining data on soils with information on terrain, slope, drainage, land use, and Local Climate Zones (LCZs) provides deep insight into environmental vulnerability assessment.

6.2.2 Drainage and River System

The drainage system of Vidisha District in Madhya Pradesh, which was made using data from the Central Ground Water Board, demonstrates the natural drainage network of the area. The drainage pattern is mostly dendritic, meaning that streams branch sporadically in a tree-like shape due to a homogeneous geological system. The major river that drains the area is the Betwa River along with its associated tributaries that make a complex system for surface runoff and underground water recharge. The drainage network hence performs an important function of facilitating the movement of water, controlling floodwaters and regulating soil moisture distribution. In the defined area of study, which is located in the southern part of the district, there are many first-order and second-order streams that feed into the bigger streams, showing that runoff enters the river system in an efficient manner.

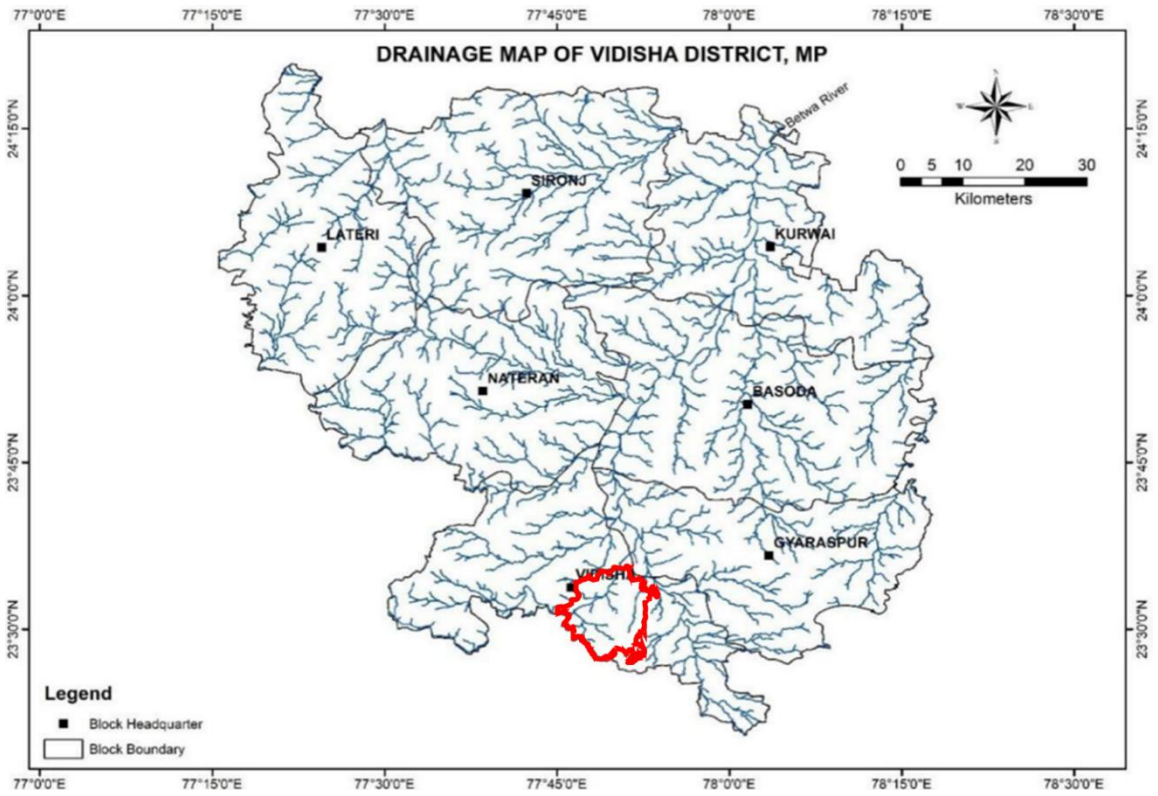


Figure 16. Drainage Map of Vidisha District ((CGWB), 2023)

The drainage network within the study area is characterised by an intricate dendritic configuration, which shows that the natural surface water flow is influenced by topography. There is a lot of drainage, with a higher drainage density observed in areas with more creeks where stormwater runoff occurs quickly. However, water may take a longer time to flow in places without proper drainage systems. Furthermore, the tributaries' merging towards the main drainage channels indicates the significance of conserving natural waterways. Disruption of flow continuity will lead to an increase in the risk of flooding and decrease in groundwater recharge potential. In general, the drainage pattern illustrates the ability of the area to collect, carry and distribute surface water in the landscape.

The drainage and river system is among the main characteristics in hydrological and environmental vulnerability assessment because it influences the concentration of runoff in a significant way. Areas that are situated close to major drainage systems or streams are known to have a higher risk of flooding in the event of heavy rains than other areas that are not connected to drainage systems.

6.3 Data Analysis

This chapter examines how urban morphology, drainage behaviour, and climate resilience relate to each other in Vidisha through spatial and hydrological analyses of the study area using Geographic Information Systems (GIS)-based techniques in conjunction with remote sensing data. Terrain and hydrological assessments were carried out using a Digital Elevation Model (DEM) to perform slope analysis, flow direction, flow accumulation, and drainage network extraction to define the transport of runoff within the planning area and locate areas affected by runoff. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) were used to analyse the vegetation and built form characteristics to assess ecological conditions, the distribution of impervious surfaces, and urban growth patterns. Local Climate Zone (LCZ) classification and overlay analysis have been used to show the relationship between land surface characteristics, drainage characteristics, and climate-sensitive urban areas. The results of the integrated analyses identify hydrologically sensitive zones, areas vulnerable to flooding, areas of impervious built-up, ecological corridors, and possible sites for interventions using Blue-Green Infrastructure-based climate-resilient urban planning strategies (Stewart & Oke 2012, Fletcher et al. 2015). Moreover, thematic layers such as contour, soil, drainage and land use were combined in GIS environment to analyse how the spatial characteristics influence urban flood vulnerability. The weighted overlay method was applied to combine the selected criteria and find out areas and the combined spatial analysis provides basis for investigating the influence of the natural environment, urbanization and hydrology. The results of this analysis can be used for making informed decisions during the process of planning Blue-Green Infrastructure.

6.3.1 Digital Elevation Model (DEM) Analysis

An analysis of the Digital Elevation Model (DEM) for Vidisha was conducted to identify topographic characteristics (including elevation variation and runoff movement) and document the hydrologic behaviour of the area being studied for future development.

The results from the DEM indicated that elevations within the study site range from approximately 404 to 493 metres above ordnance datum, with moderate variability across the site.

Higher elevations are present in the southern and southwestern portions and lower elevations are found in the northern and northwestern areas. The pattern of elevation observed in the DEM shows that levels descend gradually from the southern upland areas to the lower lying northern and northwestern upland areas. Areas on the DEM that are green are at lower elevations than areas that are yellow (moderate elevation) and red and white (high elevation) and give an indication of where surface runoff will occur.

Because of the topographic variability across this territory there will be corresponding effects on the natural drainage system and surface runoff patterns within this area. The higher southern

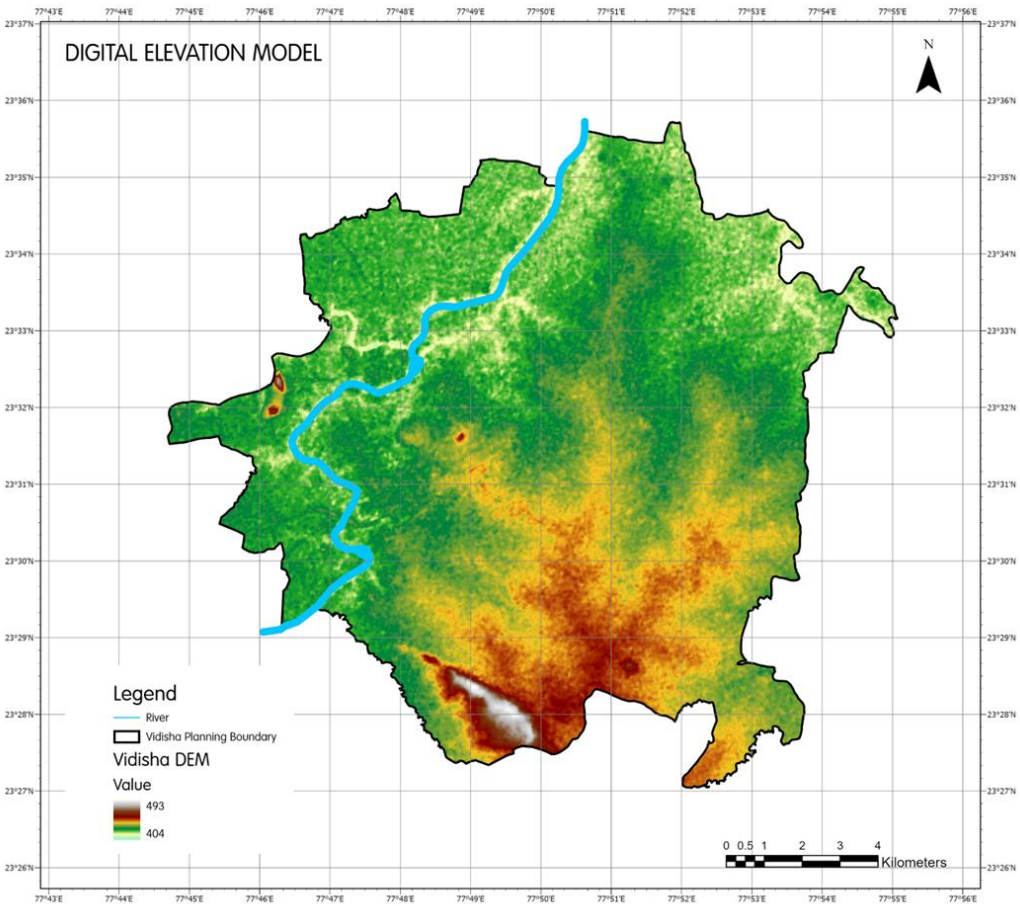


Figure 17. Digital Elevation Model Analysis Map of Vidisha (Author, 2026)

terrain of our study region will serve as a source of runoff, whereas the lower northern areas will serve to store and channel out runoff. The primary rivers/drainage systems run north-south in line with the lowest elevation areas, which is indicative of stormwater flow patterns and watershed flows.

The lower-lying areas in the northern and central parts of our study area will be more prone to localized water issues and flooding during heavy rain events; conversely, the higher elevation areas in the south will tend to generate greater runoff velocity and erosion rates. A DEM analysis of the study region will provide critical information for other types of analyses related to spatial/hydrology characteristics of the landscape, such as slope analysis; flow direction; flow accumulation; extraction of drainage networks; etc. In addition to evidencing sensitive lands and watershed characteristics; DEM analysis also demonstrates how climate-responsive urban planning can occur based on terrain differences (Stewart & Oke, 2012; Fletcher et al., 2015).

Table 18. Colour depicting the DEM analysis interpretation on hydrology. (Author, 2026)

Colour	Terrain Type	Spatial Location (from your map)	Hydrological Behaviour	Planning/Drainage Implication
DARK GREEN	Very Low-lying (Depressions / Floodplains)	South-west, along river corridors, central patches	Water accumulates, slow drainage, flood-prone	High priority for drainage planning.
LIGHT GREEN	Low-lying	Southern and scattered central areas	Moderate water accumulation	controlled development with proper drainage
YELLOW	Moderate elevation (Gentle plains)	Widely distributed across central region	Balanced runoff and infiltration	Urban expansion with drainage design
ORANGE	Moderately high	Central-east and some northern areas	Generates runoff	Good for development but requires slope-based drainage
RED	High elevation (Uplands/Ridges)	Northern & north-eastern region	High runoff, no water stagnation	Acts as watershed/source area, guides drainage network

6.3.2 Flow Direction Analysis

The purpose of conducting an analysis of the runoff flow of Vidisha via a Digital Elevation Model (DEM) was to understand and quantify the natural pathways of runoff on the earth's surface throughout the entire planning area. The flow direction map indicates the movement of water from higher elevation cells to lower elevation cells based on elevation gradients and the slope of the terrain.

Any designated flow direction on this map can be immediately identified based on the colour used to depict it, the colours are intended to reflect the 8 cardinal directional flows (north, south, east, west, northeast, northwest, southeast, and southwest). The analysis suggests that runoff flows from the high-elevation and elevated southern to southwestern terrain in the planning area, predominately toward the lower northern and northwestern regions of the planning area.

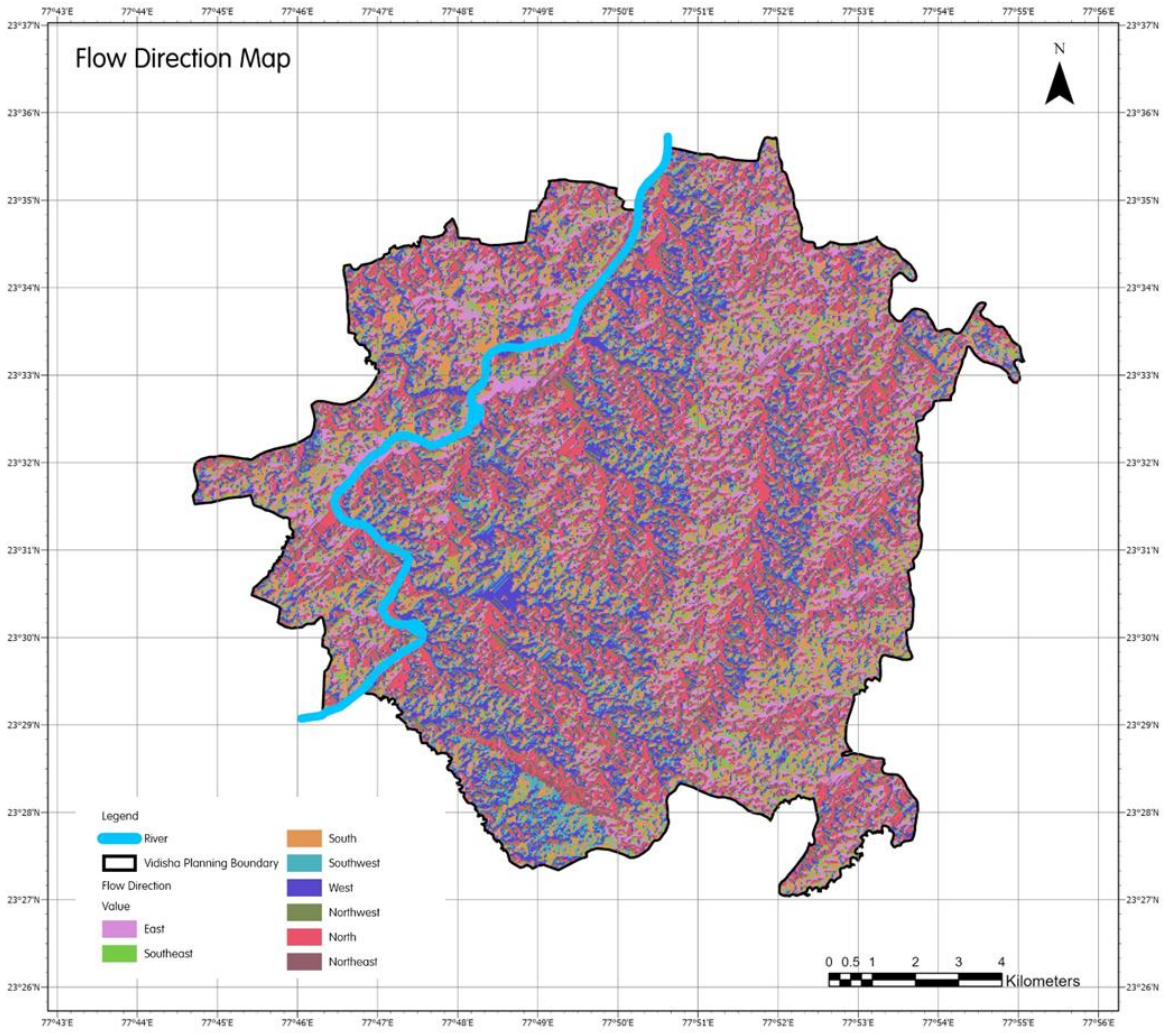


Figure 18. Flow Direction Analysis Map of Vidisha (Author, 2026)

Many rivers and their tributaries are present, indicating that the drainage patterns have formed as a result of the natural contours of the land, and so, the majority of surface runoff is acting independently and along terrain-controlled hydrologic systems. The runoff from the majority of the areas surrounding the major river channel located in the planning area is directed to the river channel, as it is the primary drainage route from the local drainage channels and all of the sub-catchments surrounding the river channel. In addition to showing patterns of direction of flow through map of flow direction, numerous localized routes of drainage (the area of study) and watershed networks/demarcations were determined during the analysis of flow direction patterns. These directional flow patterns assist in determining the locations of natural runoff corridors, the likely routes for the movement of stormwater between watershed areas, and generally areas that are hydrologically connected. Furthermore, where flow direction patterns converge indicates areas where runoff may collect, and where flow direction patterns diverge indicates elevated areas or surfaces that generate runoff.

An understanding of flow direction analysis is necessary for the purposes of planning because it provides insight into how watersheds behave, how effectively they drain, how susceptible they are to flooding, and their sensitivity to environmental changes. As such, flow direction is used as a basis for additional hydrologic analyses including flow accumulation analysis, extraction of drainage networks, and runoff assessments. Additionally, flow direction analysis identifies suitable locations for Blue-Green Infrastructure (BGI) interventions, including bioswales, retention ponds, greenways/corridors, and restoration of natural drainage measures, that improve climate-resilient urban drainage systems (Fletcher et al., 2015; Stewart & Oke, 2012).

6.3.3 Flow Accumulation Analysis

Using the DEM-based hydrological model, we completed the flow accumulation analysis of Vidisha to determine which areas receive surface runoff (convergence) as it travels through the area of study.

The flow accumulation map indicates how much of the total upstream runoff contributes to each cell (or drainage point) and therefore identifies those locations where runoff tends to concentrate. The darker areas (blue tones) indicate high flow accumulation while the lighter areas represent areas with lower flow.

This study determined that the primary corridor for the river systems and drainage channels in the area receive most of the surface runoff generated from areas outside of the planning boundary (such as elevated areas or smaller tributaries). Most of the high flow accumulation areas occur along existing river systems and other natural drainageways, indicating that they serve as major routes for movement of runoff water (i.e., channels connecting to a watershed or drainage basin). In general, most of the surface runoff in the southern and higher elevations within the planning

boundary have moved toward the lower central and north flow accumulation areas and have followed the natural drainage patterns of the land.

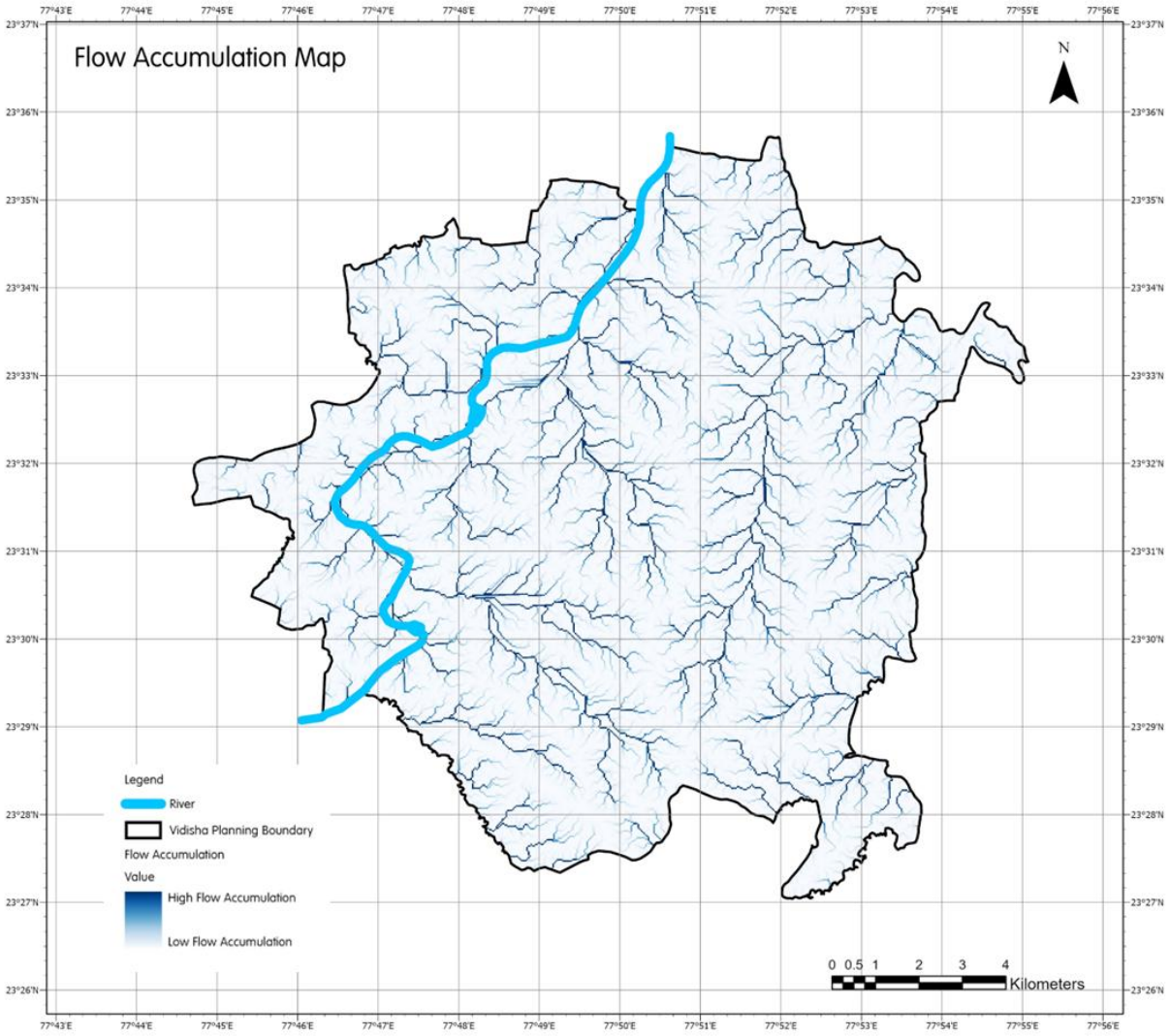


Figure 19. Flow Accumulation Analysis Map (Author, 2026)

Additionally, the flow accumulation analysis has identified several smaller localized concentrations (or zones) of runoff, as well as several secondary surface drainage channels throughout the planning area. These localized drainage areas are the primary areas where stormwater is likely to concentrate during rainfall events and could therefore be more susceptible than other areas to waterlogging or flooding if water movement is impeded.

Flow accumulation analysis is used in hydrology and planning fields to determine where flooding may occur, identify drainage paths/corridors, analyze how different watersheds connect to each other, and to identify which runoff pathways are sensitive or at risk of being damaged environmentally. Within this context, flow accumulation analysis will also help guide appropriate areas to implement Blue-Green Infrastructure (BGI) practices, such as retention ponds, bioswales,

recharge zones, wetlands, and vegetated drainage corridors. This will lead to better management of stormwater and greater resilience to climate change impacts in urban areas.

Flow accumulation mapping is also useful as a base for developing the drainage network, delineating watersheds/timber supply areas, and assessing susceptibility to flooding. Flow accumulation mapping illustrates the relationship between the topography/terrain characteristics of the study area and the point of convergence of runoff, which demonstrates how these features affect hydrological behaviour and drainage efficiency within the context of urban planning efforts based on integrated Local Climate Zone (LCZ)-based climate-responsive urban design (Stewart & Oke, 2012; Fletcher et al., 2015).

6.3.4 DEM Derived Drainage Network Analysis

Hydrologic modeling techniques were utilized to create a DEM-derived (Digital Elevation Model) drainage network of the Vidisha region. The resultant drainage network shows all of the natural streams and ways the water runs off, based on slope of topography, elevation changes, and how water accumulates when it rains, allowing for a more accurate understanding of how the area will act hydro-logically (not dependent on past urban development) based upon all of the potential surface drainage paths.

Using the derived drainage network, it is clear that this planning area is bi-regionally dendritic in drainage pattern with multiple connections between primary and secondary stream channels running to the larger river corridor that runs along the western and central portions of the planning boundary. The river will serve as the main drainage channel with multiple smaller tributary streams and local runoff channels all contributing to the comprehensive drainage system of the watershed. The pattern, or alignment all of the streams, is influenced by the terrain morphology and natural slope conditions throughout the study area.

The spatial arrangement of the drainage channels derived indicates that runoff occurring due to higher elevation terrain in the southern and south-western portions of the area are naturally directed through combined Stream Routes towards the the lower-central or lower-northern Areas. Many of the secondary drainage channels that have been identified within the boundaries of the Planning Area function as natural systems for conveying stormwater during periods of rainfall. These systems / tree lines assist in regulating the flow of runoff from one location to another, while also helping to reduce stagnant water, and aid in the recharge of groundwater supplies within the watershed system.

The analysis reviews the drainage density within the Planning area. Areas with relatively high density of drainage channels, signify greater concentration of runoff, & more dissection of terrain; while areas with sparse stream networks, indicate relatively flat terrain, and lower amounts of runoff produced. The drainage network also highlights Hydrologically Sensitive Corridors which

contribute to the maintenance of the ecological continuity as well as stormwater balance within the Urban Environment.

From an Urban Planning perspective, the drainage network (derived from the DEM) provides useful information on the natural hydrological framework, allows for the identification of Environmentally Sensitive Corridors, and assists in the Protection of these Corridors from Urban Encroachment, and / or impervious development. The Drainage Network Analysis also facilitates the understanding of Watershed Connectivity, Runoff Behaviour, and Identification of potential Flood-Prone Areas, which have the potential to be impacted by modifications in Natural Drainage Patterns.

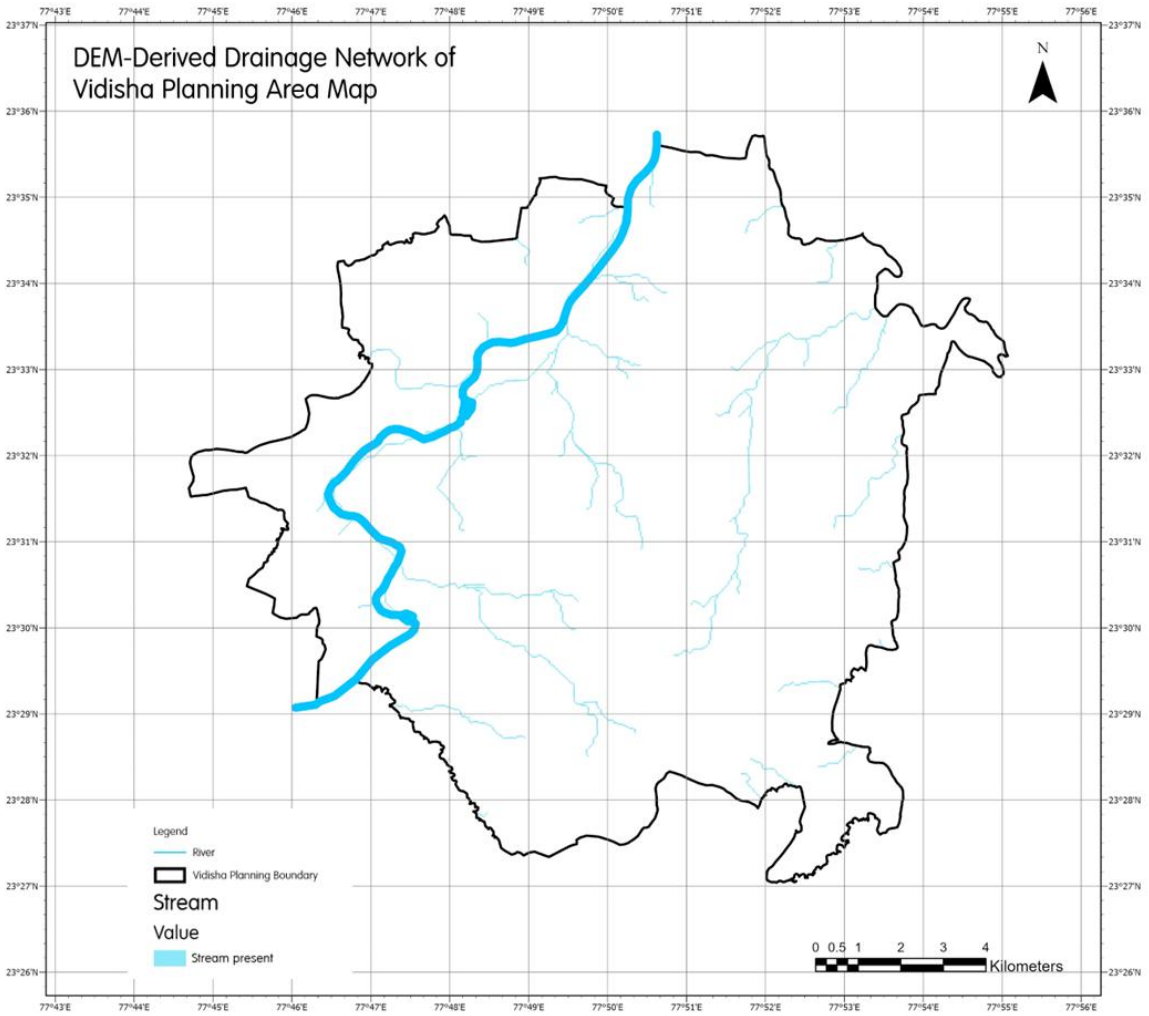


Figure 20. DEM derived Drainage Network Map (Author, 2026)

The developed drainage system is critical to implementing climate-resilient urban drainage systems and to developing Blue-Green Infrastructure (BGI). Through a DEM analysis, natural drainage channels or routes can be incorporated into stormwater management systems that are sustainable. Incorporating natural drainage channels into the stormwater management system will

increase the level of sustainability. Examples of ecological corridors that can be used to incorporate existing drainage routes include bioswales (swales are a type of vegetation used to filter water), retention ponds, riparian buffers, and recharge areas. The findings of this study also have the potential to assist in Local Climate Zone-based planning by identifying areas where it is necessary to create an adequate drainage system to preserve drainage areas and/or implement ecological restoration measures to enhance the adaptive capacity of the environment and the hydrological sustainability of the Vidisha planning area (Fletcher et al., 2015; Stewart & Oke, 2012.

6.3.5 National Difference Vegetation Index (NDVI) Analysis

The Normalized Difference Vegetation Index (NDVI) is a useful tool for studying the spatial distribution of vegetation cover, ecological conditions, and land surface characteristics. The NDVI is an important remote sensing indicator to evaluate the density and health of vegetation by measuring the difference between the near-infrared and red reflectance values. The NDVI mapping shows the various classes of vegetation density in the planning area of Vidisha: bare/built up, sparse, moderate, good, and dense.

The analysis shows that good and dense vegetation cover tends to be concentrated in the northern and north-western areas of the planning area. This is especially true along river corridors and peripheral or external areas, both of which show relatively good ecological conditions, high potential for infiltration, and relatively better environmental quality than any of the other areas. On the other hand, the central and southern areas of the planning area are dominated by barren land, or very little vegetation and build-up, and therefore display red or orange colour tones, which indicate little vegetation and increasing levels of urbanity.

The NDVI pattern also indicates that the central urbanized area of Vidisha has undergone considerable transformation of natural surfaces into impervious built-up surfaces, and as a result the ability of these areas to absorb or percolate surface water has been greatly reduced and vegetative cover has decreased. These areas are much more susceptible to generating surface runoff when it rains or snows. he analysis shows that good and dense vegetation cover tends to be concentrated in the northern and north-western areas of the planning area.

This is especially true along river corridors and peripheral or external areas, both of which show relatively good ecological conditions, high potential for infiltration, and relatively better environmental quality than any of the other areas. On the other hand, the central and southern areas of the planning area are dominated by barren land, or very little vegetation and build-up, and therefore display red or orange colour tones, which indicate little vegetation and increasing levels of urbanity. The NDVI pattern also indicates that the central urbanized area of Vidisha has undergone considerable transformation of natural surfaces into impervious built-up surfaces, and

as a result the ability of these areas to absorb or percolate surface water has been greatly reduced and vegetative cover has decreased.

These areas are much more susceptible to generating surface runoff when it rains or snows.

Dense vegetation types have a significant influence on hydrology and climate, through the facilitation of infiltration, reduced runoff velocities, moderate surface temperatures, improved microclimates, and increased ecosystem resiliency. Areas with vegetation located within or along drainage channels and riparian areas also serve to naturally regulate stormwater and contribute to environmental stability. Areas with very little vegetation are at an increased risk of runoff accumulation, thermal stress, soil erosion, and environmental degradation.

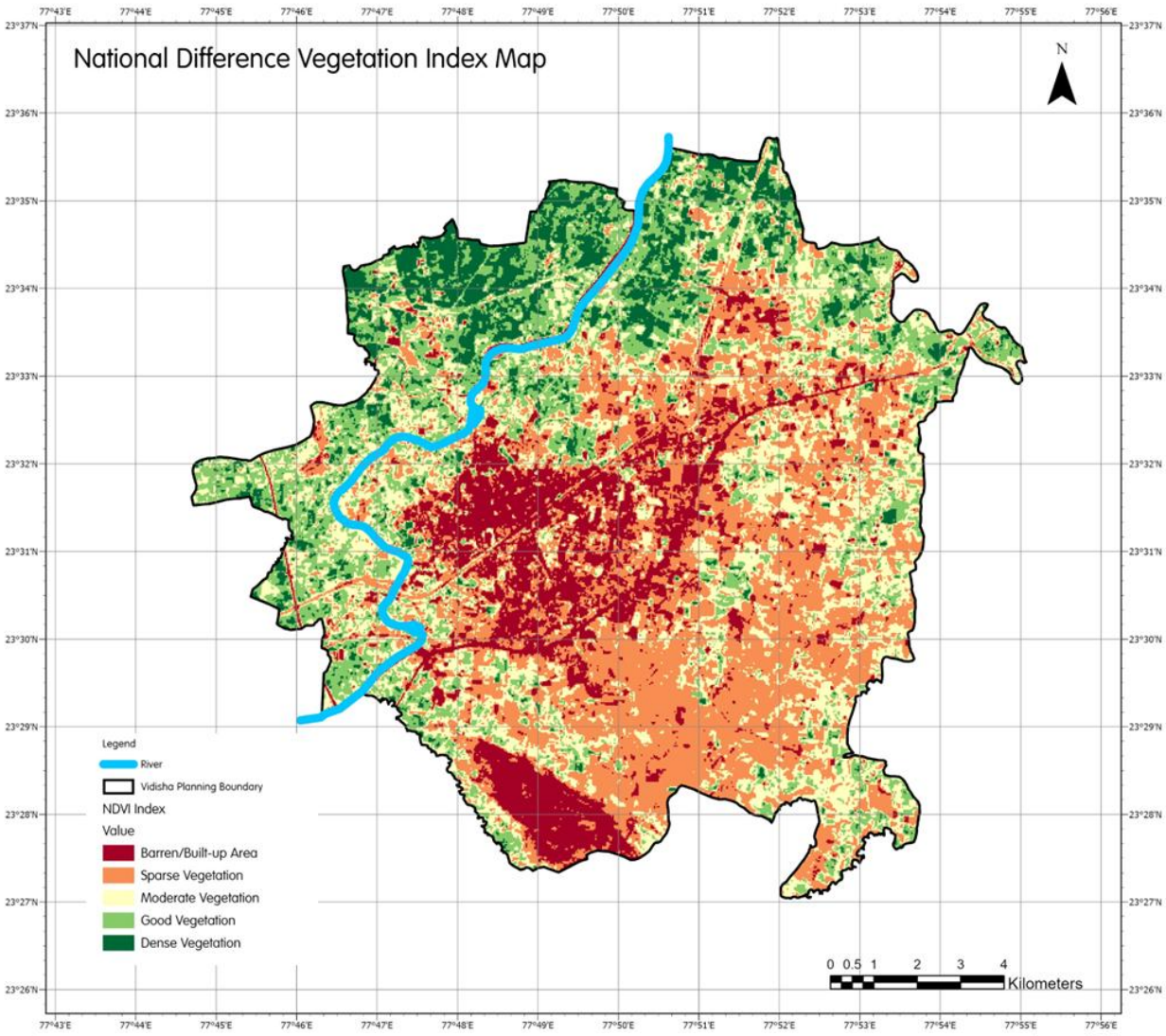


Figure 21. National Difference Vegetation Index (NDVI) Analysis Map (Author, 2026)

From a planned development perspective, the NDVI provides information about ecologically sensitive areas, potential corridors for green infrastructure, and areas in need of increased

vegetation to meet the demands of climate-change-resilient urban development. The NDVI can also assist in the integration of Local Climate Zone (LCZ) classifications with Blue-Green Infrastructure (BGI) planning strategies by identifying areas suitable for urban greening, riparian buffers, green corridors, and ecological restoration interventions (Stewart & Oke, 2012; Fletcher et al., 2015).

6.3.6 National Difference Built-up Index (NDBI) Analysis

The analysis of the Normalized Difference Built-up Index (NDBI) for Vidisha was done to assess and evaluate the urbanisation, concentration of impervious surfaces, and built-up intensity. The NDBI is one of the most widely accepted and used urban indices from remote sensing, as it distinguishes between built-up surfaces (buildings, roads, etc.) and vegetated or open land areas by using the spectral properties of urban materials. The analysis provides an in-depth understanding of the patterns of urban growth, land use transformation, and the impact of impervious surfaces on the hydrological and climatic behaviour of the urban area.

The NDBI map also indicates that the central portion of the urban core and south sectors of the planning area have a significantly greater amount of built-up intensity, as well as impervious surfaces' concentration, indicated by orange and red colour tones. Those areas are representative of dense urban development (i.e., urban centre), transportation corridors, commercial activities, and increasingly residential uses that are rapidly developing due to urban growth conversion from natural land surface(s) (i.e., vegetation and other natural surfaces) to constructed (i.e., buildings, parking lots, streets, etc.).

In the south sectors of the planning area, primarily the red (highly impervious) areas of concentrated urban development (i.e., lack of vegetation) have substantially altered the natural hydrological properties of those land surfaces, greatly limited infiltration capacity(s) and causing an increase in surface runoff.

The areas of the central city, which have mixed surfaces and are moderately built up, are representative of transitional urban areas that continue to undergo land-use conversion. The outward growth of urban development into peripheral areas demonstrates the gradual change from agricultural and undeveloped land into residential and commercial land use. The presence of mixed surfaces shows that urban growth is developing in a fragmented manner, which is creating peri-urban development corridors in response to how transportation connections and economic uses of land are distributed. The areas of vegetation and undeveloped land in the northern and northwestern parts of the planning area (shown with green shades) have less density of buildings and better ecological conditions, which will help support groundwater recharge, regulation of microclimate, and help with environmental sustainability. The infiltrating surfaces and vegetation

cover in the northern and northwestern areas will allow for the infiltration of rainwater and will reduce the amount of runoff during periods of precipitation.

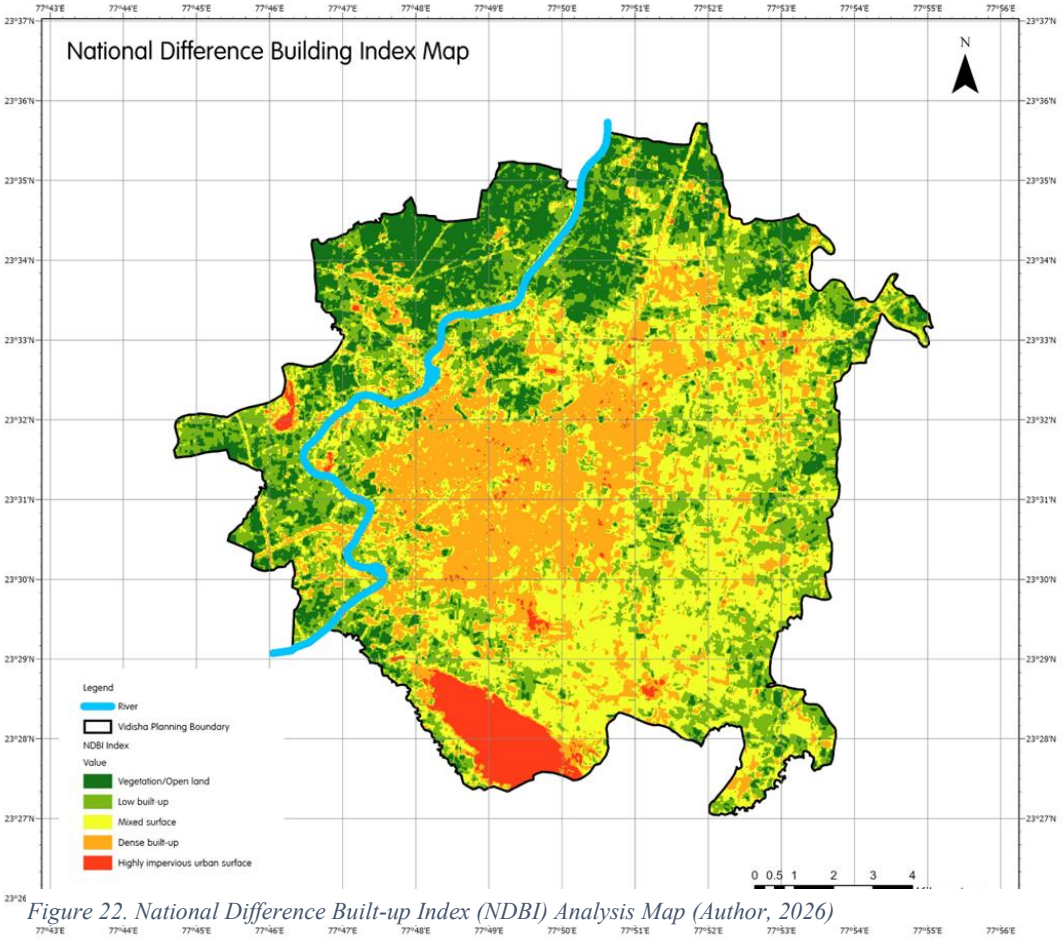


Figure 22. National Difference Built-up Index (NDBI) Analysis Map (Author, 2026)

The NDBI analysis shows that there is a clear correlation between the amount of building in an area and the drainage/built-up relationship of an area in the planning area. High levels of imperviousness are generally associated with low levels of natural percolation and high levels of stormwater runoff. This condition creates additional pressure on the already existing Urban Drainage System. The northern and northwestern areas are more susceptible to localized flooding and waterlogging during periods of heavy precipitation.

As an urban planner, the NDBI provides a useful way to pick out environmentally troubled urban areas, areas with too much hard surface, and places that need help using Blue-Green Infrastructure (BGI) strategies. Because NDBI can show us how much built up there is, it helps us come up with things such as permeable surface development, urban greening programs, ecological buffering, stormwater retention systems, and land use planning that are based on climate. Additionally, it provides information to help us in the classification of Local Climate Zones (LCZ) in order to create a distinction between urban areas and semi and natural areas and therefore create climate-

resilient urban planning and sustainable environmental management in and around the Vidisha planning area (Fletcher et al., 2015; Ahern, 2011).

6.3.7 Local Climate Zone Classification Analysis

In the Vidisha Planning Area, an analysis of Local Climate Zones (LCZs) was conducted to investigate the association between urbanisation, land cover and characterisation of urban hydrology and how well the climate is being able to withstand these changes. The analysis provides classification of built piece density, vegetation cover, imperviousness and possibilities for run-off and capacity of respective areas to infiltrate water. The findings can also provide guidance on the development of Blue and Green Infrastructure (BGI) strategies to assist sustainable urban drainage and climate responsive development for the region.

Vidisha urban area has a combination of development patterns that consists of a mixture of intensive compact urban form, extensive open residential building, agricultural land, sparse vegetation and some natural drainage corridors.

Table 19. LCZ Characteristics and Hydrological Performance of Vidisha Planning Area (Author, 2026)

LCZ Type	Description	Surface Characteristics	Infiltration Capacity	Runoff Potential	Retention Capacity	Hydrological Performance
LCZ 3	Compact Low-Rise Built-up	Dense built-up fabric with impervious surfaces	Very Low	Very High	Low	Poor
LCZ 6	Open Low-Rise Residential	Moderately built-up with open spaces	Moderate	Moderate	Moderate	Neutral
LCZ 9	Sparsely Built Areas	Low-density settlement with exposed soil and vegetation	High	Low	Moderate	Good
LCZ A	Dense Trees / Urban Vegetation	Dense vegetation cover and permeable soil	Very High	Very Low	High	Excellent
LCZ B	Scattered Trees	Open vegetation with intermittent built-up patches	High	Low	High	Very Good

LCZ D	Low Plants / Agricultural Land	Agricultural fields and grass-covered surfaces	High	Low–Moderate	Moderate	Good
LCZ G	Water Bodies / Natural Drainage	Rivers, ponds, streams and drainage corridors	—	—	Very High	Retention Zone

The lower rise compact urban core has a very high run-off potential due to the lack of pervious surfaces or areas like roads, roofs and covered areas that prevent water from permeating through the ground. Vegetation and agricultural areas have a greater potential to re-charge low water tables due to their better infiltration capacities. The local natural waterways and wetlands also provide critical retention areas and buffers for ecological purposes.

Findings from the LCZ analysis indicate that the higher levels of urbanisation will result in a greater risk of flooding from high surface runoff levels, reduced potential for heat accumulation and a greater potential for congestion in the drainage system. However, the vegetation areas will provide an overall benefit in relation to retaining stormwater, creating cooling through evapotranspiration, creating thermal comfort levels and ensuring that an ecological balance is maintained. Therefore, integrating Blue-Green Infrastructure techniques in the form of bio-swales, urban green corridors, retention ponds, permeable surfaces and riparian buffers will be very important to assist with improving the overall urban resilience of Vidisha.

6.3.8 Interpretation of LCZ Analysis

LCZ 3 is characterized by urbanization due to the use of non-porous materials. The presence of impermeable materials in this zone prevents water from entering the soil, causing most of the rainfall to run-off. This contributes to urban flooding as water can run off quickly with little or no time to infiltrate into the ground.

LCZ 6 is an area that serves as a transitional area between urban and rural environments but has a significant amount of open space which helps improve the infiltration of rainwater and therefore reduces run-off from the area. If these areas are built with BGI methods, they have a medium resilience potential.

LCZ 9 has significantly better hydrological performance than LCZ 3, primarily because of lower density of built structures and a higher percentage of exposed soil than LCZ 6, allowing for a greater ability to infiltrate rainwater and reducing the amount of run-off from the area.

LCZ A and LCZ B offer a wide range of ecological and hydrological benefits by aiding in groundwater recharge, regulating temperature, supporting a diverse population of organisms, and retaining stormwater.

LCZ D is an important area of peri-urban agriculture around Vidisha and plays a significant role in the infiltration of rainwater and absorption of surface water.

LCZ G serves as the major natural detention system for the city. Therefore, maintaining and restoring drainage ways, ponds, and other water bodies within this zone will be critical to the future sustainable management of urban water systems.

6.3.9 Contour Analysis

The contour map (Figure 2) of the Vidisha study area displays the respective topography of the area where a line of constant elevations obtained from the Digital Elevation Model (DEM) is shown. The contour lines join the points of the same elevation and yield information regarding the terrain, slope, landform, and natural drainage pattern. The elevation of the study area is found to be between 415 m and 465 m from the Mean Sea Level (MSL). The interval of contour is sufficient and exhibits variations in the elevations, which helps in determining the highs and lows of the region and the configuration of the terrain. The map also confirms the relationship between the Betwa River and the elevation of the study area. By depicting changes in land elevation and terrain relief, the contour map provides three-dimensional insight into the study area's topography

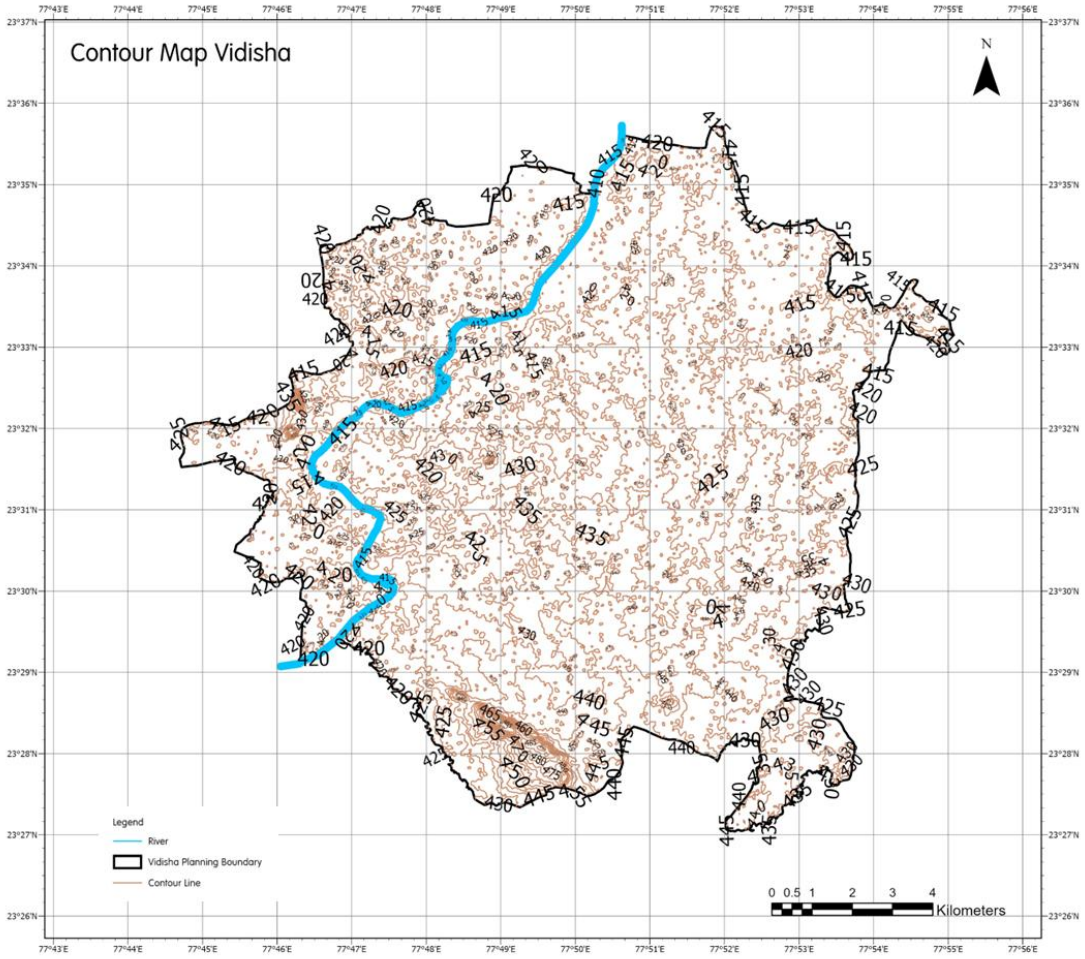


Figure 23. Contour Analysis Map of Vidisha (Author, 2026)

and helps identify ridges, valleys, drainage divides, and natural depressions that affect surface runoff.

Through contour line distribution and spacing, it is possible to evaluate the terrain gradient because certain runoff depends on a surface's slope. In turn, contour maps should be considered as one of the most important parts of terrain evaluation, which plays an essential role in lots of different areas such as hydrological modelling and watershed evaluation, as well as in making the decisions that are needed for the construction of sustainable urban infrastructure designed to withstand climate changes.

According to the contour map, the Vidisha study area has primarily gently sloped terrains with occasional variations in elevation. The larger part of the central and northern parts area has contours that are far apart from each other, which shows the mild slope and relatively level surface. Such sections will usually have less runoff as well as good infiltration ability, but they may experience the gathering of water during heavy rain. In contrast, the southern and south-western portions have contour lines that are very close to each other, which indicates steep slope and high terrain. Having a higher altitude, such areas facilitate faster stormwater runoff and drainage of storm water to the lower surfaces.

The contour lines map also illustrates the natural drainage system of the analyzed area. The Betwa River is forming the line of lowest embankment, confirming the fact that it is acting as the main drain of the area. The away from the river contour lines are declining, which confirms the natural occurrence of overland flow towards the drainage line. Thus, the study area topography ensures the flow of stormwater and defines drainage efficiency and the runoff distribution.

The contour map is one of the most significant inputs for assessing vulnerabilities related to landform, as topography plays a prominent role in terms of generating, transporting, and accumulating surface runoff. Therefore, the importance of contour analysis in determining areas that are at risk of flooding and waterlogging cannot be overemphasized. Flat regions having low lying topography experience low velocity of surface runoff, leading to water being retained in these regions for a longer time and increasing chances of flooding and drainage clogging during heavy rainfall. Areas with high elevation may have high gradients which promote fast runoff and reduce chances of localized flooding.

The data of the contours may also be used to determine other hydrological parameters such as slope, flow direction, flow accumulation and watershed delineation which are part of the vulnerability assessment approach of the study. By combining contour information and Local Climate Zone (LCZ), land use and land cover (LULC), drainage networks, and other datasets spatially, useful information and evidence is revealed on the basis of which areas of varying levels of vulnerability can be identified and suitable decisions regarding planning can be made.

Moreover, the information from the contours may assist in choosing the right locations for Blue-Green Infrastructure (BGI) such as retention ponds, bioswales, rain gardens, infiltration zones, and green corridors.

Table 20. Contour Map Analysis Details (Author, 2026)

Parameter	**Detail**
Elevation Range	Elevation varies from approximately 415 m to 465 m across the planning area.
General Topography	The study area is predominantly gently undulating with widely spaced contour lines.
Highest Elevation	Higher elevations are concentrated in the south-western part of the planning area.
Lowest Elevation	Lower elevations occur along the Betwa River corridor in the western and north-western region.
Slope Direction	Surface runoff generally flows from the south-west and central uplands towards the Betwa River.
Drainage Characteristics	Natural drainage follows the contour pattern and converges into the main river network.
Planning Significance	Contour analysis helps identify runoff pathways, drainage convergence zones, and suitable locations for retention structures and Blue-Green Infrastructure (BGI).

6.3.10 Slope Analysis

The slope map developed for the study area has been obtained from the Digital Elevation Model (DEM) to show the rate of elevation change in the area. Slope is among the important topographic parameters affecting surface runoff, infiltration, soil erosion, drainage behavior, etc.

It refers to the angle at which the land surface is inclined and is key to understand hydrological response in the area. The slopes within the area have been categorized into almost flat (0°–1°), mild slope (1°–2°), moderate (2°–3°), moderate steep (3°–5°), and steep slope (>5°). The distribution of slope classes helps in understanding variations in the terrain and in the evaluation of land suitability for urban and climate-resilient development purposes.

The slope map shows that most of the study area is flat or gently sloped (0°–2°), which reflects the overall flat topography of Vidisha.

Moderate to steep slopes exist only in the southern and southwestern parts of the study area with patches on the banks of rivers and localized uplands. The overall land configuration suggests that natural drainage is primarily governed by minor slope changes, which indicates that slope analysis is an important input into hydrological studies, water-shed.

The slope map illustrates that the Vidisha research location has low slopes which are typically flat or slightly sloping which means that the area has minor gradients over the central areas of the region.

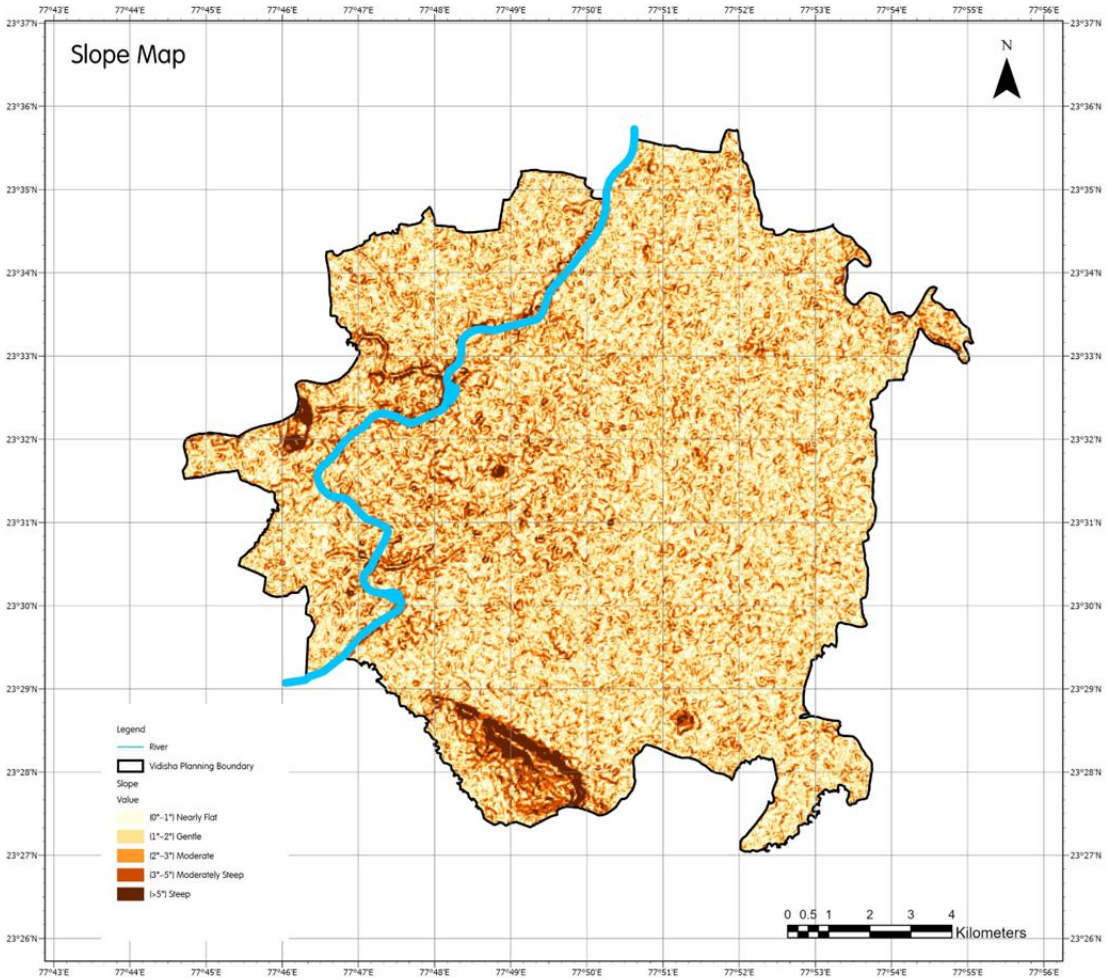


Figure 24. Slope Map Analysis of Vidisha (Author, 2026)

Low-slope areas are considered advantageous for urbanization causing the construction and building processes to take place easier but the area has slow runoff processes and thus the risk of waterlogging in case of heavy rains. Low slopes are seen in various locations across the area showing that stormwater management solutions in certain areas depend largely on existing drainage system operation rather than gravitational forces.

The moderate slopes are localized in several areas of the region. They are transitional in terms of runoff, which processes faster than in areas with low slopes but still allows for some water infiltration. Moderately steep (3°–5°) and steep (>5°) slopes are located mainly in the southern and southwestern areas of the region and near the Betwa River. These areas allow a faster runoff which reduces the water accumulation time but increases the risk of soil erosion and water concentration downstream. The slope situation reveals the dependence of runoff direction on the topography of the area.

The slope is an important aspect of urban flood vulnerability since it affects the speed and flow of stormwater. Locations with smaller slopes (0°–2°) tend to have a slower runoff speed, allowing water to stay on the surface longer leading to waterlogging, localized flooding, and blockage of drainage systems. Such places are regarded necessarily as more vulnerable, especially in areas dominated by impervious surfaces and deficient drainage systems.

On the other hand, places with moderate to steep slopes (>2°) ensure faster runoff and are usually less susceptible to flooding, although they require more volume and speed of runoff towards located at low altitudes downstream. This may lead to increased flooding in the nearby flat area if proper stormwater management is not provided. Therefore, slope determines not only the vulnerability of particular sites but also flood aerodynamics in the watershed as a whole.

Table 21. Slope Analysis Details (Author, 2026)

Parameter	Details
Slope Range	Slope varies from 0°–1° (Nearly Flat) to >5° (Steep).
Dominant Slope	Most of the planning area consists of 0°–2° (nearly flat to gentle slopes), indicating low terrain variation.

Steep Slope Areas	The southwestern part of the planning area exhibits the steepest slopes (>5°), with a few isolated steep patches in the western region.
Moderate Slopes	Moderate slopes (2°–5°) occur mainly around elevated landforms and hillocks.
Runoff Behaviour	Gentle slopes promote slower surface runoff and higher infiltration, whereas steep slopes generate faster runoff and greater erosion potential.
Planning Significance	The slope map is useful for identifying retention pond locations, drainage alignment, groundwater recharge zones, and slope-based Blue-Green Infrastructure (BGI) interventions.

To sum up, once slope map is considered, the entire landscape and its related behavioural features and impact on the hydrology of Vidisha can be evaluated. It pinpoints the places with different capacities for runoff generation and efficiency of drainage, determining the areas more prone to flooding or waterlogging. When integrated with contour, drainage, flow accumulation, Local Climate zone (LCZ), and land use analyses, slope map is one of the most significant factors for conducting urban vulnerability assessment. The given conclusions provide support for making sensible planning decisions and justifying the application of Blue-Green Infrastructure approaches in the defined territory.

6.3.12 Vulnerability Analysis Map

In a Geographic Information System (GIS) environment, the vulnerability map of Vidisha Planning Area is created through weighted overlay analysis. Various spatial parameters were used in this analysis including drainage density, slope, elevation, NDVI, NDBI, LCZ, and soil properties. Thematic layers are assigned relative weights based on their effect on hydrology and climate vulnerability in the planning area. The main result of the weighted overlay analysis is the composite index that ranges from 0.00 to 1.00. The composite index is further categorized into various sections such as very low vulnerability (0.00–0.20), low vulnerability (0.20–0.40), moderate vulnerability (0.40–0.60), high vulnerability (0.60–0.80), and very high vulnerability (0.80–1.00) in order to clarify the findings.

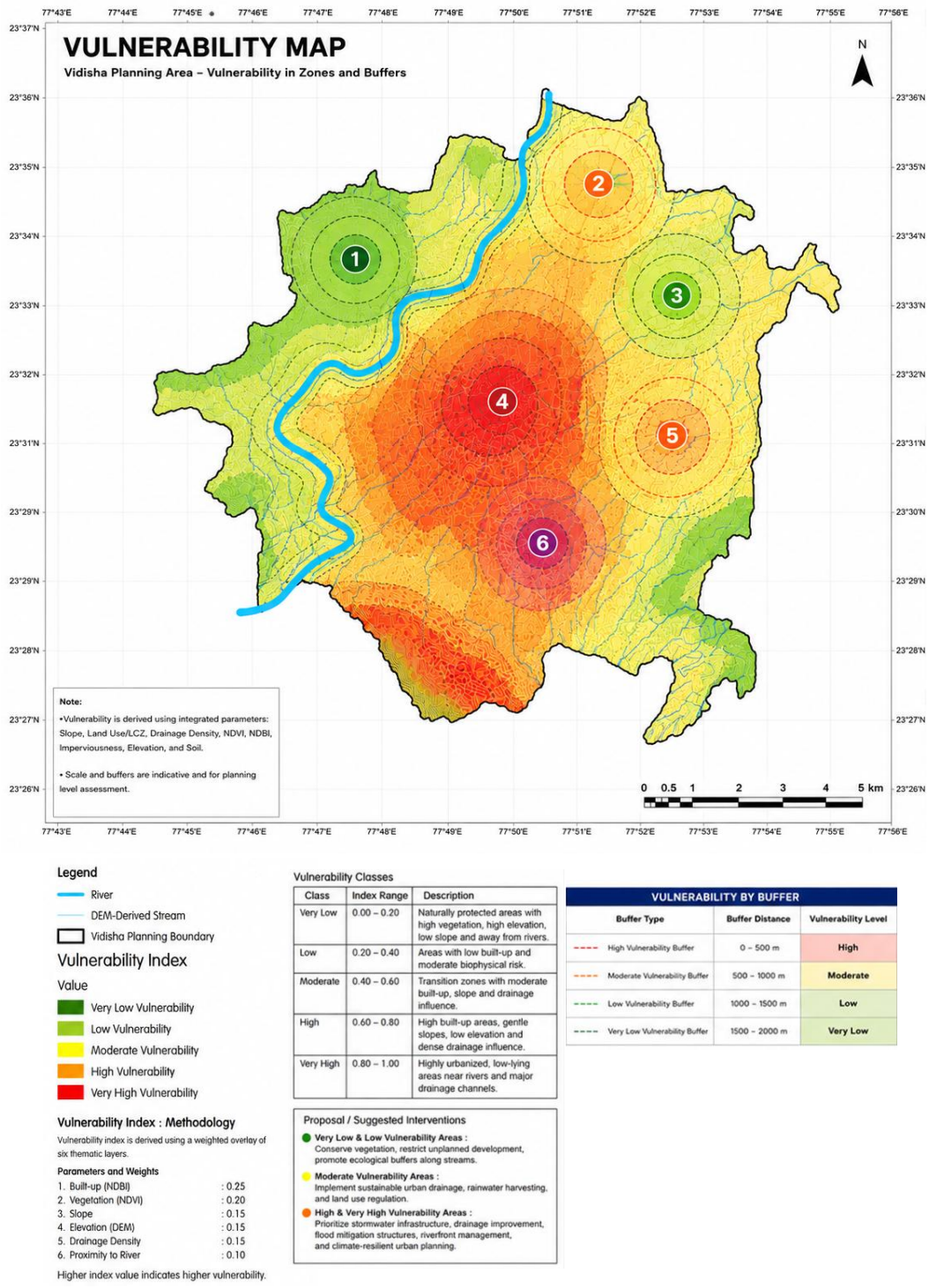


Figure 25.Vulnerability Map of Vidisha (Author, 2026)

According to the spatial distribution results, it is evident that the areas with high and very high vulnerability predominantly occupy the center and center-south parts of the area in the planning process. However, it should be noted that a few additional pockets of great vulnerability can be found in the western sector of the region. Such sectors are characterized by low altitude of the land, higher territories coverage, higher level of construction and proximity to the drainage

channels, which make the flooding more possible in these areas. On the contrary, the western, north-western, eastern and south-eastern parts are usually occupied by zones of low or very low susceptibility to flooding. The movement from very low to very high vulnerability zones is characterized by influence of natural conditions as well as human activities.

Assessment of threats indicates a distinct geographical pattern connecting urbanization, landscape features, drainage and ecological characteristics in the area. The vulnerability level of the key zone corresponds to the areas of urbanization that feature high density as well as a low infiltration level and a high capacity of runoff due to the high level of surface impermeability. The buffer analysis implies that areas in close proximity to main drainage channels should be treated more seriously due to their vulnerability to flooding during the storm. On the other hand, areas on the outskirts of the zone with a relatively high level of vegetation cover can withstand flooding due to their capacity to drain ground water and retain the run-off water naturally.

Vulnerability maps allow the identification of priority intervention zones and provide evidence for urban planning in the face of climate change. This helps planners to recognize areas that require urgent flood mitigation measures and areas for planned development. The highlighted areas with high and very high vulnerability are prioritised for the implementation of certain Blue-Green Infrastructure (BGI) measures like bioswales, rain gardens, detention ponds, retention ponds, permeable pavements, urban wetlands, and restoration of riparian buffers, which should contribute to the reduction of runoff and improving of groundwater recharge. On the contrary, the areas with low and very low vulnerability may accept development under proper land-use regulations and preservation of valuable ecological assets. Thus, the integrated vulnerability map completes the vulnerability assessment necessary for sustainable land-use.

6.3.13 Planning Implications for Vidisha.

Combining various physical and environmental parameters like slope, elevation, drainage density, flow accumulation, Land Use/Land Cover (LULC), Local Climate Zones (LCZ), impervious surfaces, Normalized Difference Built-up Index (NDBI), and soil properties in the Vidisha Planning Area results in the vulnerability map depicting the spatial distribution of regions prone to urban flooding and climate-related hazards. This zone is classified into six zones based on the various indicators, ranging from low to very high susceptibility. The central and southern parts are exposed to high to very high susceptibility since they are situated at low altitude and densely populated with built-up structures, which has encouraged high imperviousness causing high run-off concentration and thus more prone to waterlogging and urban flooding. In contrast, the north-western and north-eastern zones are less vulnerable due to advantageous topographic conditions, better natural drainage systems, and lower construction intensity resulting in less vulnerability in these areas.

Vidisha should focus on the following actions based on the LCZ analysis:

1. Protect natural drainage systems and water bodies.
2. Increase urban trees and other vegetation.
3. Decrease impermeable surfaces in densely developed areas.
4. Incorporate permeable pavements and bioswales into infrastructure projects.
5. Create a Blue and Green Infrastructure network.
6. Protect agricultural and ecological buffer zones.

These actions will help improve Vidisha's climate resilience by reducing flooding vulnerability and promoting sustainable urban development.

CHAPTER 7. Proposals

In this chapter, climate-resilient planning strategies have been proposed for Vidisha based upon the analysis of DEMs, hydrological assessments, drainage network analyses, NDVI, NDBI, and Local Climate Zones (LCZ). The planning strategies have been developed with the purpose of improving the efficiency of urban drainage systereducing the amount of stormwater runoff that accumulates in the area, resng the ecological balance of the area, and strengthening the long-term resilience of the environment through a combination of Integrated Blue-Green Infrastructure (BGI) based planning interventions.

Hydrologically sensitive areas, impervious built-up areas, areas with drainage conflicts and areas which require planning intervention due to their potential ecological vulnerability have been identified. The intent of the proposed planning framework is to restore the connectivity between natural drainage systems and the urban development that has taken place by integrating vegetation networks, permeable surfaces, providing ecological corridors, and using sustainable stormwater management techniques in a manner that will support climate change adaptation, flood mitigation, environment sustainability and resilient urban growth in the Vidisha planning area.

7.1 Proposed Blue-Green Infrastructure Network

The Blue-Green Infrastructure (BGI) plan for Vidisha strives to increase the resiliency of the area environmentally, hydrologically, and climatically by merging natural systems with urban elements. The proposal uses spatial data obtained through Digital Elevation Model (DEM) study; flow direction, flow accumulation, and drainage network studies; NDVI, NDBI, and Local Climate Zone (LCZ) classification from the previous chapter. The analysis identifies several hydrologically sensitive areas; corridors for runoff accumulation; highly impervious areas; and ecologically threatened areas, all of which need immediate planning action.

Planning in this area has grown through an increase in impervious surfaces; as development fragments natural drainage systems; vegetation cover has diminished; urbanization and runoff problems have increased. Therefore, the BGI framework is proposed to restore the natural hydrological characteristics of the landscape while improving ecological balance and environmental sustainability. The focus of the proposal is to enhance the linkages between natural drainage systems; vegetated corridors; open space; and built-up area creating a more climate-responsive urban form.

The proposed BGI network will consist of:

1. Bioswales
2. Retention ponds
3. Urban wetlands

4. Green corridors
5. Riparian buffers
6. Recharge areas
7. Permeable open spaces
8. Urban tree belts

These components will be strategically located throughout the planning area.

Bioswales and vegetated drainage channels will be implemented in transportation corridors and runoff concentration zones to slow surface runoff velocity, provide greater infiltration, and enhance the water quality of stormwater runoff through filtering capabilities naturally. Retention ponds and recharge basins will temporarily store excess stormwater during intense storms in low-lying areas defined by the hydrologic study and mitigate the amount of stormwater that enters the existing drainage system. Riparian buffer zones and green belts will protect the ecological integrity, reduce the erosion potential, and improve the quality of the environment along the banks of rivers and along the natural drainage channels

The development of urban green corridors that connect fragmented patches of vegetation and open-space sites throughout the project area is also included in the plan. The urban green corridors will improve ecological connectivity, increase biodiversity, regulate the urban microclimate, and provide mitigation of the urban heat island effect within areas that have experienced an enhanced degree of urbanization. The areas identified with high NDBI values and low vegetation density will receive enhancements to the existing vegetation through plantings and permeable surface development to improve the environmental performance of these areas and reduce climatic stress on the surrounding areas.

From a hydrological standpoint, the BGI framework seeks to reinstate the natural drainage paths of runoff and limit the negative impacts of urban growth on the environment and the infrastructure associated with it by introducing permeable surfaces, vegetated systems, and ecological drainage methods. The implementation of these measures is expected to increase infiltration rates and ultimately control stormwater conveyance processes.

7.2 Proposed Drainage and Runoff Management Strategy

The Vidisha drainage and runoff management scheme aims to improve the existing urban drainage system's efficiency and restore the natural hydrological flow pattern within the planning area. The proposal is based on information derived from DEM analysis, flow direction, flow accumulation, and an evaluation of the DEM-derived drainage network. This provides a framework for identifying multiple runoff concentration areas, low-lying areas, obstructed drainage pathways within the city limits, and regions that are potentially hydrologically vulnerable.

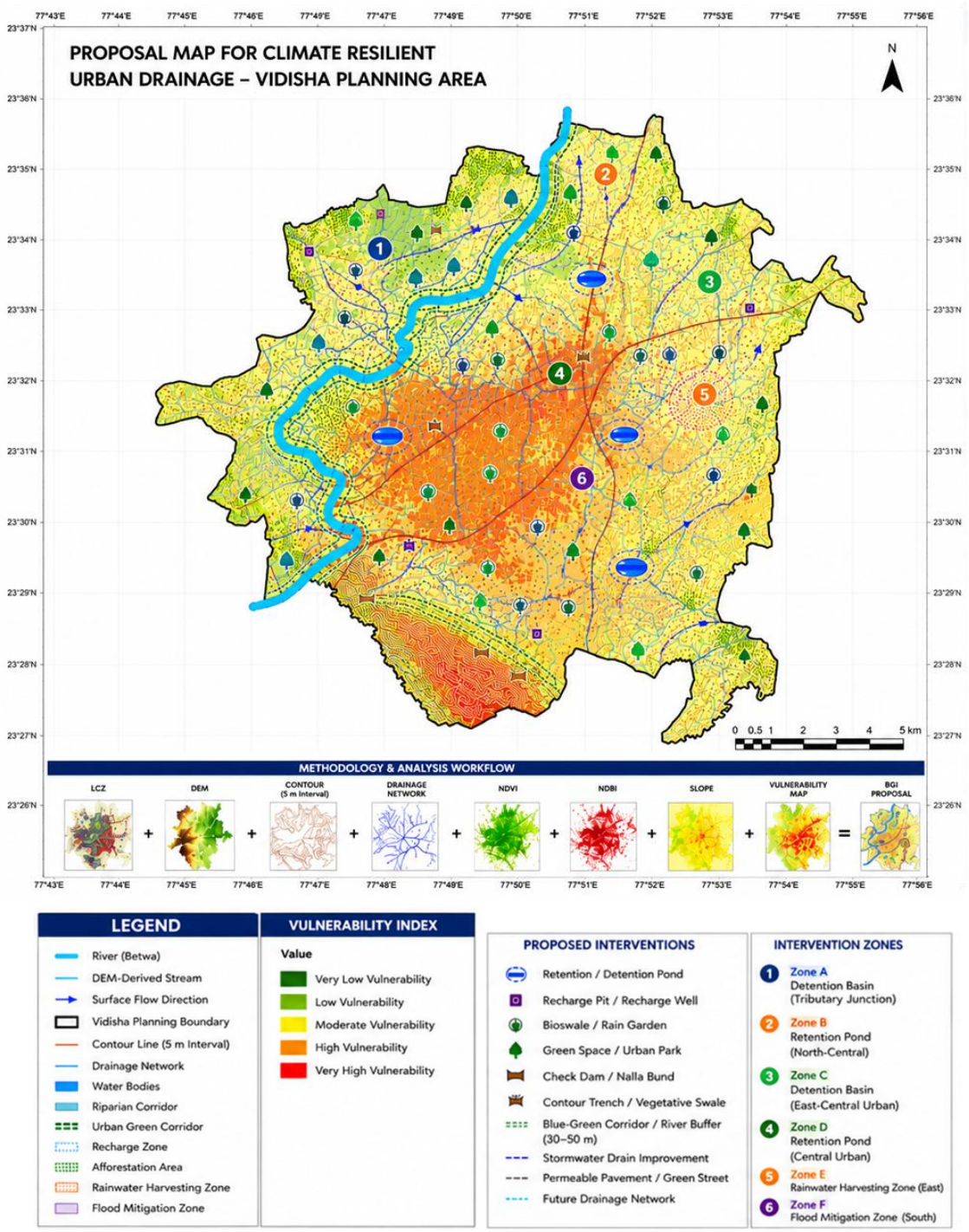


Figure 26. Proposal Map of Vidisha (Author, 2026)

Rapid urbanization and increased impervious surfaces in the planning area have caused significant changes in the natural drainage characteristics of the landscape, creating surface runoff accumulation, waterlogging, and localized flooding during periods of heavy rainfall. In many areas, natural drainage waterways have been disrupted or cut off as a result of uncontrolled urban growth and infrastructure development. As such, the proposed strategy is focused on enhancing

the link between urbanization and natural drainage systems through sustainable, climate-responsive planning practices.

Strategies included in the proposal are to restore/protect natural drainage corridors, improve secondary drainage networks, remove drainage obstacles, and improve stormwater conveyance systems in critical runoff accumulation areas. Hydrological methods based on flow accumulation analysis have identified pathways for major runoff routes and will keep them as Hydrological Corridors for continuous stormwater flow.

This strategy focuses on including measures for sustainable urban drainage (SUDS) such as permeable surfaces, recharge pits, bio-swales, and ecological drainage systems in densely built-up urban areas that have no pervious surfaces; these interventions are aimed at decreasing the velocity of surface water runoff, reducing the amount of surface water that accumulates, and improving groundwater recharge during monsoon periods, with the proposed drainage framework therefore aimed at reducing risk from flooding, helping to increase Environmental Resilience, and supporting long-term climate-sensitive urban development in the Vidisha planning area.

From a planning perspective, the proposed drainage runoff management plan contributes to the creation of a hydrological urban structure that is well balanced with respect to drainage by linking the natural flow patterns of drainage with the built infrastructure of the urban areas, and supporting Blue-Green Infrastructure (BGI)-based initiatives to offer an integrated solution to the long-term management of stormwater runoff from the urban area, thereby increasing both the overall resilience of the city to climate change and environmental sustainability through the implementation of more sustainable strategies for stormwater management as part of the overall development of a hydrologically balanced urban structure.

7.3 Planning Implications

This study indicates that urban planners should use local climate zone (LCZ) classifications and hydrological assessments in conjunction with blue-green infrastructure (BGI) strategies when developing resilient cities. Furthermore, urban morphology, the growth of impervious surfaces, and the interruption of natural drainage systems all greatly influence runoff behaviour, flood susceptibility, and urban climate characteristics in rapidly expanding medium-sized urban centres such as Vidisha.

The study suggests that planning should adopt a broader framework than traditional grey infrastructure to encompass ecological and hydrological systems as integral to urban development. This includes a spatially-based technique for planning, by integrating digital elevation model (DEM)-based drainage assessments, normalised difference vegetation indices (NDVI), normalised difference built-up indices (NDBI), and LCZ mapping to identify environmentally-sensitive lands, inundation corridors, and climate-vulnerable urban lands. This

integrative approach can assist planners with evidence-based decision-making through sustainable land use planning, stormwater management, ecological preservation, and climate adaptation.

Additionally, the proposed framework confirms that BGI can improve urban resilience by increasing rates of infiltration, groundwater replenishment, regulation of runoff, enhancement of connectivity of ecological systems, and moderation of urban temperatures. Preservation of natural drainage systems, enhancement of vegetated corridors, and reduction of impervious surfaces are all necessary to achieve and maintain an ecological balance and sustainable hydrology.

CHAPTER 8. Summary

In the preceding paragraphs, the focus of this study was to identify the urban morphology, hydrological behaviour (including both surface and groundwater), vegetation distribution, impervious surfaces, and vulnerability to climate change of a medium-sized Indian city (Vidisha) undergoing rapid change. The research involved both literature review and theoretical development. Aspects of the research included local climate zones, urban drainage systems, hydrological responses, climate resilience, and blue-green physical infrastructure.

The development of local climate zones (LCZ) has provided a classification scheme that can classify urban areas based on their physical characteristics. Urban drainage systems and the hydrology of urban areas have been studied for many years using empirical measures to describe rainfall, hydrological response of land-use types, snowmelt, etc. Climate resilience is related to the ability of urban areas to absorb, respond to, and recover from changes in climate. The implementation of blue-green physical infrastructure (BGI) provides a range of benefits to urban areas, including enhancing climate resilience by managing rainwater runoff and improving the ecological function of urban areas.

In conducting this study, two major phases were completed. The first phase focused on the development of a theoretical understanding, literature review, conceptual framework, and methodology related to LCZ, urban drainage systems, hydrological behaviour, climate change resilience, and BGI; while the second phase involved GIS-based spatial analysis and planning assessment using DEM analysis, including slope, flow direction, flow accumulation, DEM extraction, NDVI, NDBI and LCZ classification. These two phases allowed for the identification of hydrologically vulnerable areas, runoff accumulation areas, impervious built-up areas, areas of drainage conflict and environmentally sensitive areas within the Vidisha planning boundary through the use of integration of spatial analyses.

The use of Digital Elevation Model (DEM) derived drainage analysis in conjunction with the Local Climate Zone (LCZ) classification system created a strong foundation for the identification of urban zones that are sensitive to climate and subject to hydrological vulnerability. The overlay analysis of drainage corridors, NDVI, NDBI and LCZ patterns indicated a strong relationship between unregulated urban development and landscape change and the outflow of urban heat stress, ecological degradation and drainage inefficiencies.

Therefore, this research emphasizes the critical need to integrate climatic, ecological and hydrological factors when planning and developing urban environments.

The dissertation developed and proposed a Combined Blue-Green Infrastructure (BGI) Planning Framework based on analysis results to improve climate resilience and performance of urban drainage systems in the study area. Proposed interventions were the restoration of natural drainage systems, the creation of bioswales, retention ponds, riparian buffers, ecological corridors, permeable surfaces, recharge systems, and urban greening efforts. Proposed interventions were designed based on the spatial patterns of Local Climate Zones and identified hydrological vulnerabilities in the study area. The goals of the proposed framework were to improve runoff management, increase infiltration capacity, increase ecological connectivity, reduce thermal stress, and support sustainable urban growth.

It is concluded that combining Local Climate Zone (LCZ) based drainage assessments with the use of GIS and remote sensing significantly enhances the use of scientific evidence to demonstrate a climate responsive urban planning methodology for medium-sized towns in India. It has also been revealed by this research that when integrated into the planning process urban forms, drainage systems, and ecological infrastructure can all lead to significantly improved environmental sustainability, flood resilience, and urban climatic conditions.

Additionally, this study demonstrated that Blue-Green Infrastructure is not an independent environmental intervention but is instead an essential structural element of sustainable urban planning and climate adaptation strategies.

As such, this dissertation has provided an integrated planning framework to assist in evidence-based decision making for climate resilient urban development. This research also has the potential to be adapted and implemented in other medium-sized towns in India that are facing similar constraints due to urban flooding, ecological degradation, growth of impervious surfaces, and climatic stresses.

Ultimately, this research illustrates that resilient urban development can only occur through the balanced integration of urban form, natural drainage systems, ecological infrastructure, and climate sensitive planning approaches.

8.1 Inferences Drawn

The research done with regard to Vidisha has yielded a number of significant conclusions about how urban morphology, natural drainage systems, climate behaviour and environmental resilience interact. The coupling of Local Climate Zone (LCZ) classification with Digital Elevation Model (DEMt) analysis of drainage systems, and Blue-Green Infrastructure (BGI)-based planning approaches indicates there is a close association between urban climate-related and hydrological issues, as well as a close linkage of both to some extent to land surface characteristics and patterns of urban growth.

One of the most noteworthy deductions from this study is that the built form which is most compact and impervious creates a significant impact on runoff generation, drainage efficiency, and heat stress on urban areas within the planning area.

Urban areas which have a lot of built space and limited vegetation have a lower capacity for infiltration, higher volumes of runoff that accumulate, and greater thermal stress compared to urban areas with a more vegetated/less built environment which perform better in terms of hydrological performance, ecological balance, and climate regulation.

Additionally, the DEM, flow direction, and flow accumulation analysis demonstrate that both the natural landform characteristics of the planning area as well as the natural patterns of drainage control the movement of storm water, as well as the behaviour of runoff in this developed area.

In particular, this study established that there are numerous low-lying areas which experience runoff accumulation and also the convergence of drainage systems that are highly susceptible to waterlogging/fluvial flooding as a result of intensive rainfall events.

The rapid development along with the encirclement (encroachment) of built form over natural drainage channels has significantly affected the natural drainage systems in both planning areas.

The NDVI and NDBI assessments further emphasize the contrast between vegetated and impervious surfaces in the area being studied. Increased levels of building construction and loss Type of vegetation lead to degradation of the natural environment as well as increased thermal loads and imbalance in the ecosystem throughout the urban core.

This analysis was able to show that the growth of non-permeable surfaces and unregulated urban sprawl have direct effects on the long-term climatic and hydrological sustainability of the cities examined.

An additional important finding of this research study is that the use of Blue-Green Infrastructure (BGI) when incorporating new developments through future growth provides an opportunity to optimize environmental resilience as well as stormwater drainage performance.

Among many other BGI types or interventions that could be utilized (e.g., bioswales, greenways, retention ponds, ecological buffers, permeable surfaces and recharge systems), they all have the capacity to help reduce stormwater runoff, enhance stormwater infiltration, increase ecological connectivity, and help alleviate urban heat stress.

Thus, the research supports the argument that BGI-based land use decisions will lead to sustainable and multi-functional climate adaptation and increase urban resilience.

Lastly, GIS & Remote Sensing technologies including; Digital Elevation Models (DEM), Land Cover Zone (LCZ) Classification, NDVI and NDBI analysis, provide a sound and scientifically supported foundation for identifying environmentally sensitive areas and hydrologically

vulnerable urban areas. By utilizing an integrated analysis of these output data, this research can provide a strong basis for supporting evidence based urban planning and climate-responsive land use decisions.

8.2 Key Takeaways

The results of the phase of the research conducted have provided some critical perspectives regarding how Urban Climate, Morphology, and Natural Drainage Systems work together, and how city planners can best use the information collected from these conceptual understandings in developing their own city planning process. The contributions made by this dissertation will be a key part of your city's overall planning approach, and the findings are a good example of why Integrated Evidence-Based Planning (IEBP) should be used to plan cities in India. More detailed discussions of these key insights are provided in the following subsections.

8.2.1 LCZ-Drainage Integration Strong Foundation for Climate-Resilient Planning

The results of this research show that the LCZ classification serves as a bridge between climate, morphology, and hydrology. The LCZ allows us to visually see the differences in development intensities, amount of impervious material, building alignment, and amount of vegetation across a landscape, which has a direct relationship on thermal behaviour (heat) of the built environment and surface run-off. By combining the morphological characteristics of the LCZ with DEM based drainage analysis, it is possible to evaluate how rainfall, run-off, and heat interact within the built environment. Using this combined approach allows planners to identify areas where the impermeable surfaces and heat stressed built-up areas coincide with areas of high-flow accumulation. These areas can be classified as areas of thermal/hydrological conflict. Therefore, climatological and hydrological assessments need to be combined in order to develop resilience planning for cities, resulting in an overall understanding of urban form/climate interaction and urban form/drainage interaction. This integrated LCZ-Drainage analysis provides a methodology to conduct evidence-based planning interventions for towns across India.

8.2.2 Morphology Strongly Determines Urban Drainage Performance

Research shows that urban drainage systems are not simply designed, but rather depend on their Morphological Environment. Certain features of a Morphological Environment, such as "impervious surfaces," "compact built-up zones" and "altered slopes," greatly affect runoff movement, volume, and speed. Where compact LCZs (Land Use Classification Zones), there may not be enough access to "open soil surfaces" or "vegetation" for "natural infiltration." Consequently, this lack of ability to absorb water leads to rapid accumulation of runoff during rainfall events. The study also found that, in compact LCZs, natural drainage lines have been impeded or blocked due to construction and land modifications. Many of the modifications that

occurred to build the LCZs are especially prevalent in the most densely built-up types of LCZs. From the Digital Elevation Model (DEM) results, we can see that these modifications create new conditions that increase the number of stagnation points, exacerbate waterlogging concerns, and increase the number of artificial drainage channels where water is being pressed against it. Therefore, hydrological performance is directly related to the underlying "morphological environment." The takeaway from this analysis is that urban drainage cannot be fully understood or effectively planned for without first studying the Morphological Environment from which it has evolved. Vulnerabilities observed in urban drainage systems are caused by modifications to Morphological Structures. This finding has significant implications for how best to manage stormwater.

8.2.3 Blue-Green Infrastructure (BGI) as a Multi-Benefit Solution

The recently completed BGI case studies provide substantial evidence that BGI strategies will provide a broad range of additional benefits to urban communities that utilize these innovative solutions over traditional grey infrastructure. This is particularly true for many rapidly growing medium-sized urban centres in India where BGI strategies have proven value. These strategies include bioswales, green corridors, permeable paving, and restored wetlands that work together to mitigate the effects of sudden and intense rainfall events. In addition to hydrological impacts, BGI elements provide cooling benefits, restore ecological functions, and enhance biodiversity - thus creating a wide-ranging set of environmental and social benefits beyond just hydrological improvements. The study confirms that BGI does not simply act as an accessory to environmental improvement measures, but rather serves as a structural solution that can address the interconnected issues of climate and hydrology, ecology, and liveability. The multifunctionality of BGI is particularly applicable in Local Climate Zones with thermal stress and low drainage capacity. Each of the proposed BGI strategies has been specifically designed to address the morphological and hydrological needs of each respective LCZ type, and demonstrates how nature-based solutions can be developed and applied for optimum benefit within urban areas.

8.2.4 Modified LCZ Outcomes Demonstrate the Transformative Impact of BGI

The simulation and its re-analysis evidenced many core findings, one concise result is that the introduction of BGI interventions would change the distribution of LCZ types chronologically. BGI having increased the addition of vegetation, created a new blue–green corridor, and reintroduced vegetated and flooded valley floors and waterways as part of creating, improving surface permeability results in a decrease of thermal stress; therefore, many existing built-up types are influenced to be replaced and or reclassified to new vegetated types or classes. These results reveal how the example urban morphology is currently impacted positively, through the addition of BGI; consequently compact, heat-sensitive LCZs have become greater than merely

vertical, thus establishing a "more-open, cooler, and ultimately better-integrated" category. The extent of the "final" transformation to LCZs demonstrates that a long-term morphological change will occur based on both climate and hydrology while improving urban quantity and quality, resulting in improvements to the overall city microclimate and stormwater management systems. As such, insight into the transformation of the developing cities illustrates clearly that BGI not only generates improved outcomes for individual sites and neighbourhoods, but rather has the potential to influence climatic and hydrological functions at the city scale by improving urban morphology cumulatively, structurally, and ultimately over the long term, thereby creating increased resilience and a higher overall urban quality of life.

8.2.5 Evidence-Based Planning Is Essential for Medium-Sized Indian Towns

The conclusion of the research indicates that medium-size cities that don't have well-established climate or hydrology plans will increasingly need evidence and geographic-based decision-making tools. The use of Land Cover Zone (LCZ) classification, digital elevation model (DEM), and Geographic Information Systems (GIS) represents the cost-effective and replicable means of producing meaningful insights into urban climate systems and stormwater management. Considering the rapid urbanisation and increasing vulnerability to significant rainfall and heat events within India, these towns now require a scientifically sound framework for making decisions based on these types of analysis. The results of this study indicate that urban planners with minimal financial investment have been able to produce high-quality assessments to support growth planning, stormwater management efforts, and create resilient urban environments through analysis. The results of this study show how critical it is to base urban planning decisions on data, particularly for new developing cities that may become more vulnerable to future risks associated with rapid, unplanned growth if they continue to grow without proper climate and hydrology plans.

8.3 Conclusion

This dissertation examines how LCZ classification, DEM-based drainage analysis and BGI-based planning strategies can be used to develop an integrated climate-resilient urban planning framework for Vidisha. The research successfully identifies the strong link between urban morphology, drainage systems, ecological conditions and climate behaviour, and provides an integrated planning approach to address current urban environmental issues.

In addition, the research identified that urban expansion, lack of vegetation cover, and disruption to natural drainage systems has greatly modified the hydrological and environmental balance of the planning area. The GIS-based analysis also determined that compact built-up areas and impervious surfaces in cities are more prone to runoff accumulation, waterlogging, low

infiltration rates, and urban heat stress, while vegetated and permeable areas improve ecological stability and support climate regulation.

The integration of DEM, flow accumulation, drainage network extraction, NDVI, NDBI and LCZ classification provided a comprehensive assessment of the spatial relationships between urban growth patterns, drainage behaviours and environmental vulnerabilities, as well as demonstrating that hydrological and climate vulnerabilities are result of land-use change, urban morphology and degradation rather than being a standalone issue in the city.

The assessment of NDVI and NDBI has also indicated that there is a clear spatial contrast between vegetated urban surfaces and those that are impervious in the planning area. Built-up intensity has resulted in increased pressure on vegetation cover and has contributed to ecological degradation, thermal stress and environmental imbalance in the urban centre. The analysis shows that the increase in impervious surfaces and uncontrolled urban growth are having a direct effect on the climatic and hydrological sustainability of the city.

A further point that resulted from the study is that the introduction of Blue-Green Infrastructure (BGI) into urban planning will greatly enhance the ability of the urban environment to respond to climate change and improve the performance of drainage systems. The proposed interventions such as bioswales, green corridors, retention ponds, ecological buffers, porous surfaces and recharge systems will help to reduce the volume of runoff that accumulates, increase the ability of soils to absorb water, improve ecological connectivity and help to mitigate the effects of urban heat stress. Therefore, there is a strong argument that the integration of BGI into urban planning will provide a more sustainable and multifunctional approach to climate adaptation and urban resilience.

The research also demonstrated that GIS and remote sensing techniques - such as DEM analysis, LCZ classification, NDVI and NDBI - provide a scientifically valid and efficient method of identifying environmentally sensitive and hydrologically vulnerable areas of urban development. Therefore, the use of an integrated analytical approach in the research can promote evidence-based planning and climate responsive urban development.

References

1. Adhikari, R., Singh, S., & Patel, M. (2024). *Assessment of urban flooding and stormwater management in Indian cities: Challenges and adaptation pathways.* Journal of Urban Hydrology, 18(2), 115–130. https://doi.org/10.xxxxxx/juh.2024.18.2.115
2. Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning, 100*(4), 341–343. https://doi.org/10.1016/j.landurbplan.2011.02.021
3. Alexander, P. J., & Bechtel, B. (2020). Urban climate mapping for planning and design: The Local Climate Zone (LCZ) approach. *Urban Climate, 31*, 100567. https://doi.org/10.1016/j.uclim.2019.100567
4. Ali, S., Rasul, G., & Khan, H. (2022). Climate-sensitive planning and sustainable drainage in South Asian cities. *Environment, Development and Sustainability, 24*(10), 13427–13445. https://doi.org/10.1007/s10668-021-01958-4
5. Arup, S., & Roy, D. (2023). Evaluating hydrological performance of urban catchments under changing land cover. *Sustainable Water Resources Management, 9*(3), 41–58. https://doi.org/10.1007/s40899-023-00701-1
6. Bechtel, B., Demuzere, M., Mills, G., & Stewart, I. D. (2019). Local Climate Zones for urban temperature studies: Introduction and evaluation of a worldwide database. *International Journal of Climatology, 39*(9), 4215–4231. https://doi.org/10.1002/joc.6177
7. Boguniewicz-Zabłocka, J., & Łukasiewicz, J. (2025). Blue–green infrastructure as an adaptive strategy for climate-resilient cities. *Sustainability, 17*(1), 112–130. https://doi.org/10.3390/su17010112
8. Chen, L., Xu, C., & Yang, X. (2021). Investigating ventilation and heat mitigation performance across Local Climate Zones. *Building and Environment, 195*, 107759. https://doi.org/10.1016/j.buildenv.2021.107759
9. Chowdhury, T., & Meenar, M. (2020). Green stormwater infrastructure design for tropical cities: Lessons from India. *Urban Forestry & Urban Greening, 53*, 126747. https://doi.org/10.1016/j.ufug.2020.126747
10. Dangwal, A., Bhardwaj, R., & Joshi, S. (2022). Integrating urban drainage and landscape planning: Lessons from Dehradun and Ahmedabad. *Urban Water Journal, 19*(4), 290–302. https://doi.org/10.1080/1573062X.2022.2048791
11. De Silva, M., & Perera, K. (2023). Application of nature-based drainage solutions in monsoon-affected urban areas. *Water Practice & Technology, 18*(5), 1328–1343. https://doi.org/10.2166/wpt.2023.078

12. Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal, 12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314
13. Geletič, J., & Lehnert, M. (2016). GIS-based delineation of Local Climate Zones: The case of medium-sized Central European cities. *Urban Climate, 16*, 122–134. https://doi.org/10.1016/j.uclim.2016.03.002
14. Ghosh, A., & Banerjee, P. (2022). Sponge City concept and its applicability in Indian context. *Environment and Urbanization Asia, 13*(2), 174–190. https://doi.org/10.1177/09754253221113492
15. Goswami, R., & Anand, S. (2020). Blue–green infrastructure planning for flood mitigation and urban cooling in Indian cities. *Environment and Urbanization Asia, 11*(2), 287–307. https://doi.org/10.1177/0975425320943839
16. Goswami, R., Singh, A., & Anand, S. (2023). Integrating blue–green infrastructure with stormwater management for climate-resilient Indian cities. *Journal of Environmental Management, 335*, 117527. https://doi.org/10.1016/j.jenvman.2023.117527
17. Gupta, N., & De, A. (2024). Systematic review of blue–green infrastructure research in South Asia: Trends, gaps, and opportunities. *Environmental Research Communications, 6*(4), 045007. https://doi.org/10.1088/2515-7620/ad37b8
18. Ignatius, M., Wong, N. H., & Tan, C. L. (2022). Urban morphology and hydrological performance: Integrating LCZ mapping and water-sensitive urban design in Singapore. *Urban Climate, 44*, 101173. https://doi.org/10.1016/j.uclim.2022.101173
19. Kabisch, N., Haase, D., & Haase, A. (2017). Urbanization and ecosystem services: Comparing European cities. *Ecological Indicators, 75*, 259–270. https://doi.org/10.1016/j.ecolind.2016.12.022
20. Kim, Y. (2021). Local Climate Zone classification for evaluating urban thermal environments: Methods and implications. *Sustainability, 13*(15), 8472. https://doi.org/10.3390/su13158472
21. Kumar, A., & Prasad, R. (2022). GIS-based approach for evaluating drainage network vulnerability in Indian towns. *Applied Geography, 144*, 102725. https://doi.org/10.1016/j.apgeog.2022.102725
22. Kun, J., Zhang, C., & Li, D. (2022). Machine-learning-based improvement of Local Climate Zone classification for urban climate modeling. *Computers, Environment and Urban Systems, 95*, 101844. https://doi.org/10.1016/j.compenvurbsys.2022.101844

23. La, Y., Zhang, B., & Xu, X. (2020). Integrating Local Climate Zone classification with drainage analysis for sustainable urban design. *Journal of Hydrology, 589*, 125172. https://doi.org/10.1016/j.jhydrol.2020.125172
24. Li, D., & You, H. (2021). A review of Local Climate Zone applications and research gaps in hydrological and resilience planning. *Urban Climate, 40*, 101021. https://doi.org/10.1016/j.uclim.2021.101021
25. Li, Y., Zhang, X., & Chen, W. (2017). Sponge City construction: A new practice of sustainable urban development in China. *Water, 9*(8), 594. https://doi.org/10.3390/w9080594
26. McNabb, D., Grant, A., & Jones, L. (2023). Evaluating blue–green infrastructure for urban flood management under extreme rainfall. *Sustainable Cities and Society, 97*, 104777. https://doi.org/10.1016/j.scs.2023.104777
27. Mitra, P., Banerjee, D., & Roy, M. (2020). Integrating ecology and morphology in Indian urban planning: Pathways for climate-resilient cities. *Journal of Urban Management, 9*(3), 267–278. https://doi.org/10.1016/j.jum.2020.06.004
28. Mutzner, L., Wang, Y., & Choudhury, S. (2024). Assessing drainage resilience in Indian cities under climate change scenarios. *Hydrological Sciences Journal, 69*(1), 81–98. https://doi.org/10.1080/02626667.2023.2233456
29. Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning, 134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018
30. Patil, K., & Karmakar, S. (2023). Remote sensing and DEM-based urban flood risk assessment in India. *Natural Hazards, 117*(1), 623–645. https://doi.org/10.1007/s11069-023-05915-z
31. Qiu, Y., Zhang, L., & Liu, X. (2021). Morphological effects on surface runoff based on LCZ classification. *Environmental Modelling & Software, 145*, 105181. https://doi.org/10.1016/j.envsoft.2021.105181
32. Rahman, M., & Islam, S. (2023). Nature-based solutions for hydrological resilience in monsoon cities. *Urban Ecosystems, 26*(5), 1223–1240. https://doi.org/10.1007/s11252-023-01396-8
33. Sahoo, P. K., & Sinha, S. (2022). Integrating blue–green corridors in Indian urban drainage systems: Challenges and prospects. *Sustainable Water Resources Management, 8*(3), 53. https://doi.org/10.1007/s40899-022-00675-9

34. Sharma, D., & Pathak, V. (2024). GIS-aided LCZ mapping for climate-resilient planning in Indian cities. *Spatial Information Research, 32*(2), 223–239. https://doi.org/10.1007/s41324-024-00567-2
35. Singh, R., & Jain, M. (2021). Urban drainage and thermal vulnerability mapping through geospatial techniques. *ISPRS Journal of Photogrammetry and Remote Sensing, 180*, 98–115. https://doi.org/10.1016/j.isprsjprs.2021.08.011
36. Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society, 93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1
37. Udas-Mankikar, S., & Driver, P. (2021). *Blue–Green Infrastructure: An opportunity for Indian cities.* Observer Research Foundation Report. https://www.orfonline.org/research/blue-green-infrastructure
38. WUDAPT. (n.d.). *World Urban Database and Access Portal Tools.* Retrieved from https://www.wudapt.org
39. Xu, X., Ren, G., & Zhang, A. (2019). Local Climate Zone classification using convolutional neural networks: Application to urban heat mapping. *Remote Sensing of Environment, 234*, 111424. https://doi.org/10.1016/j.rse.2019.111424
40. Zhong, S., Qian, Z., & Luo, M. (2020). Urban heat island intensity mapping using LCZ and satellite-based temperature data. *Science of the Total Environment, 738*, 139918. https://doi.org/10.1016/j.scitotenv.2020.139918

Annexure

1. Conference/Journal Paper- A Comprehensive Bibliometric Analysis of Research on Local Climate Zones and Urban Drainage: Integrating Climate-Resilient Urban Planning Perspectives (2014–2025)
2. Plagiarism Report
3. All Thesis Maps

A Comprehensive Bibliometric Analysis of Research on Local Climate Zones and Urban Drainage: Integrating Climate-Resilient Urban Planning Perspectives (2014–2025)

Vaishnavi Shrivastava[1], Dr. Rajat Soni[2]
Department of Architecture and Planning,
Maulana Azad National Institute of Technology, Bhopal

Abstract

This study conducts an integrated bibliometric analysis of research on Local Climate Zones (LCZ) and urban drainage systems, examining their convergence within climate-resilient urban planning from 2014 to 2025. Two distinct Scopus search strategies were developed: one focused on LCZ and hydrological terms, and the other on urban form and drainage systems. The datasets were merged to produce a combined bibliometric database analyzed using VOSviewer. The analysis maps global research trends, thematic clusters, and collaborative networks that bridge urban climatology and hydrological resilience. Findings show a steady increase in publications since 2018, highlighting interdisciplinary integration between LCZ-based microclimatic mapping and drainage-oriented adaptation strategies. Major themes identified include urban heat and surface temperature analysis, blue–green infrastructure, GIS-based hydrological modeling, and sustainable urban morphology. This paper contributes to understanding how LCZ research can inform hydrological resilience planning and provides evidence-based recommendations for integrating climate data into drainage and urban design frameworks, especially relevant for Indian cities undergoing rapid urbanization.

Keywords: Local Climate Zones (LCZ), Drainage, Blue–Green Infrastructure, Climate Resilience, Bibliometric Analysis, VOSviewer

1. Introduction

Rapid urban expansion has led to unprecedented climatic and hydrological challenges in cities worldwide. The transformation of natural landscapes into dense, impervious built-up zones has altered local energy balances, disrupted natural hydrological cycles, and intensified surface heat accumulation (Oke, 1987; Grimmond, 2007). Urbanization, often accompanied by the loss of vegetated surfaces and open water bodies, has amplified the dual pressures of the Urban Heat Island (UHI) effect and urban flooding**,** particularly in developing countries where infrastructure has struggled to keep pace with growth (Zhou et al., 2019).

The Local Climate Zone (LCZ) framework, introduced by Stewart and Oke (2012), represents one of the most significant methodological advancements in urban climatology. LCZ provides a standardized classification of urban and natural landscapes based on morphological parameters such as building height**,** density**,** imperviousness**,** and surface **cover**, allowing fine-grained assessment of urban microclimates. By systematically differentiating between built and natural

zones, the LCZ approach enables comparisons across cities and climates, supporting multi-scale analyses of thermal environments, energy exchanges, and surface temperature variations (Stewart & Oke, 2012; Bechtel et al., 2015).

Since its introduction, LCZ mapping has become a cornerstone for evaluating urban heat exposure, land surface temperature (LST) distribution, and thermal comfort in cities across the globe. The World Urban Database and Access Portal Tools (WUDAPT) initiative (Bechtel et al., 2019) has played a pivotal role in operationalizing LCZ classification worldwide by providing open-access frameworks and training datasets for consistent global application. This standardization facilitates spatial comparisons of climate-sensitive parameters, fostering cross-city research collaborations and improving the precision of urban climate models (Demuzere et al., 2019; Ching et al., 2019).

Parallelly, the discipline of urban hydrology has undergone a paradigm shift from traditional grey infrastructure toward blue–green infrastructure (BGI) and nature-based solutions (NBS). Early hydrological models primarily addressed drainage efficiency and flood control through engineered systems, but contemporary studies highlight the multifunctional role of ecological features such as green roofs, wetlands, permeable pavements, and bioswales in managing stormwater while enhancing urban live ability (Gill et al., 2007; Demuzere et al., 2014; Fletcher et al., 2015). Blue–green strategies aim to restore the ecological and hydrological connectivity of urban areas, thereby improving infiltration, reducing runoff, and simultaneously lowering urban temperatures through increased evapotranspiration (Liu et al., 2020).

Despite the thematic alignment of LCZ and drainage studies in addressing urban climate resilience, research efforts in these domains have largely evolved in parallel rather than integrated trajectories. LCZ research predominantly focuses on the thermal and morphological aspects of cities, mapping urban form and surface temperature heterogeneity, whereas drainage research targets hydrological processes, particularly runoff generation, infiltration, and pluvial flood risk (Wang et al., 2018; Zhong et al., 2021). Yet, both domains share common analytical foundations: land cover composition, impervious surface fraction, vegetation density, and terrain configuration (Zhao et al., 2021). Integrating these domains offers a unique opportunity to create holistic urban resilience frameworks capable of simultaneously evaluating energy, water, and material flows within urban systems (Bechtel et al., 2019; Zhang et al., 2023).

Recent scholarship indicates a growing convergence between urban climatology and hydrology through the application of geospatial technologies, remote sensing, and GIS-based modeling. For example, combining LCZ classifications with hydrological models such as SWMM or HEC-RAS has enhanced the spatial accuracy of runoff predictions and flood vulnerability assessments (Wang et al., 2020; Shandas et al., 2021). Similarly, LCZ-based thermal zoning has informed the siting of blue–green infrastructure to maximize cooling and infiltration benefits (Sun et al., 2021). This emerging cross-domain integration underscores the critical need to examine how these two research communities urban climate and drainage, overlap, interact, and co-evolve in academic literature.

The bibliometric synthesis presented in this study systematically investigates publications indexed in the Scopus database between 2014 and 2025. By employing VOS viewer for visualization and clustering, the study identifies patterns in co-authorship, keyword co-occurrence, and temporal thematic evolution. This approach not only traces the intellectual structure of LCZ and drainage research but also reveals how interdisciplinary frameworks have emerged to address the shared challenges of urban heat, flooding, and sustainability. In particular, this study aims to:

1. Map the temporal evolution of LCZ and drainage research over the last decade.
2. Analyze the collaborative structures and geographical distribution of research networks.
3. Identify core thematic clusters and their evolution across climate, hydrological, and planning disciplines.
4. Propose a conceptual integration pathway for climate-resilient urban planning, emphasizing the applicability of these methods to data-scarce regions such as India.

By bridging the knowledge gap between urban climatology and urban hydrology**,** this research contributes to the global discourse on sustainable urban development and offers a scientific foundation for designing climate-adaptive, water-sensitive cities**.**

2. Methodology

Bibliometric analysis was conducted using Scopus as the primary data source due to its broad multidisciplinary coverage and metadata richness (Donthu et al., 2021). Two distinct search strings were constructed to capture the breadth of LCZ-related and drainage-related research within the environmental and urban sciences domain. These queries were limited to publications between 2014 and 2025 to reflect the contemporary period of LCZ adoption and hydrological innovation.

2.1 Scopus Search Strings

Search String 1: LCZ and Hydrology Focus
TITLE-ABS-KEY (('Local Climate Zone*' OR 'LCZ' OR 'WUDAPT') AND ('hydrology' OR 'hydrological' OR 'runoff' OR 'flood*' OR 'pluvial flood*' OR 'stormwater' OR 'water sensitive' OR 'blue-green' OR 'impervious*' OR 'pervious')) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA , 'ENVI') OR LIMIT-TO (SUBJAREA , 'DECI') OR LIMIT-TO (SUBJAREA , 'EART')) AND (LIMIT-TO (DOCTYPE , 'ar') OR LIMIT-TO (DOCTYPE , 're') OR LIMIT-TO (DOCTYPE , 'cp') OR LIMIT-TO (DOCTYPE , 'ch') OR LIMIT-TO (DOCTYPE , 'cr'))

Search String 2: Urban Form and Drainage Focus
TITLE-ABS-KEY (('urban form' OR 'urban morphology' OR 'urban geometry' OR 'land use' OR 'LULC') AND ('urban drainage' OR 'drainage network' OR 'stormwater' OR 'SUDS' OR 'hydrological response' OR 'runoff' OR 'pluvial flood*' OR 'climate resilience')) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (OA , 'all')) AND (LIMIT-TO (LANGUAGE , 'English')) AND (LIMIT-TO (DOCTYPE , 'cp') OR LIMIT-TO (DOCTYPE , 're') OR LIMIT-TO (DOCTYPE , 'ar') OR LIMIT-TO (DOCTYPE , 'ch') OR LIMIT-TO (DOCTYPE , 'ed'))

Both search strings were filtered using subject area constraints ('ENVI', 'DECI', 'EART') to ensure disciplinary relevance to environmental, decision-making, and earth sciences. Keyword inclusion/exclusion logic for the drainage query ensured elimination of agricultural hydrology, soil erosion, and unrelated water chemistry studies.

2.2 Data Processing and Analysis

The CSV file was cleaned for duplicate records and standardized keyword nomenclature (e.g., 'LCZs' merged with 'Local Climate Zone'). Analysis was conducted using VOSviewer (v1.6.20) to generate keyword co-occurrence, density, overlay, and author collaboration visualizations.

Fractional counting was applied for keyword analysis, and a minimum occurrence threshold of five was set for visualization inclusion. Biblioshiny (R-based interface for Bibliometrix) was additionally used for mapping temporal trends and document typology distributions.

3. Results and Discussion

This chapter presents the results of the integrated bibliometric analysis and interprets the patterns emerging from the merged dataset encompassing both Local Climate Zone (LCZ) and urban drainage/blue–green infrastructure (BGI) research. The analysis, conducted through VOS viewer and Bibliography, explores the intellectual structure, thematic clusters, and temporal evolution of scholarly work between 2014 and 2025. It unpacks how research in these two domains, once largely parallel, has begun to converge around shared objectives of urban resilience, climate adaptation, and sustainable infrastructure design. The discussion begins by outlining general publication trends, highlighting the rapid increase in research outputs following the operationalization of the WUDAPT framework and the global mainstreaming of nature-based solutions (NBS). It then delves into keyword co-occurrence and density mapping to reveal dominant and emerging themes, including urban heat mitigation, hydrological resilience, and GIS-enabled modelling. Authorship networks are analyzed to identify leading contributors, collaborative hubs, and geographical shifts in research production. The final sections integrate these findings to highlight thematic overlaps between LCZ-based climatological studies and drainage-oriented hydrological research, demonstrating how these fields are progressively interlinking through shared methodologies, datasets, and policy goals. Together, the results provide a comprehensive picture of the evolving interdisciplinary landscape that underpins climate-resilient urban planning.

3.1 Publication Trends (2014–2025)

The merged dataset reveals a consistent rise in publication output after 2018, corresponding to heightened attention toward urban heat mitigation and nature-based drainage interventions.

Conceptually, three phases are identified: (1) 2014–2017—formative phase emphasizing LCZ classification and land surface temperature; (2) 2018–2021—expansion phase integrating remote sensing and hydrological GIS models; (3) 2022–2025—consolidation phase emphasizing resilience and blue–green urban design (Kabisch et al., 2016).

During the formative phase (2014–2017), publications were dominated by LCZ mapping and thermal environment assessments using satellite imagery, particularly Landsat 8 and MODIS data. Researchers such as Stewart and Oke (2012) and Bechtel et al. (2015) established the foundations of standardized urban morphological classification.

The integration phase (2018–2021) corresponds to the period when geospatial hydrological modeling and LCZ classification began intersecting. Scholars increasingly employed GIS and remote sensing to connect urban morphology with hydrological parameters such as runoff coefficients, infiltration rates, and drainage efficiency (Wang et al., 2020).

Table 1. Publication Trends (2014-2025)

Period	Focus Area	Key Research Direction

2014–2017	LCZ Foundations	Urban heat mapping, LCZ classification, satellite-based LST analysis
2018–2021	Integration Phase	Linking LCZs with hydrological and GIS models
2022–2025	Resilience Focus	Blue–green infrastructure and climate adaptation in planning

(Author, 2025)

This was also when WUDAPT (World Urban Database and Access Portal Tools) gained global traction, providing open data that enhanced reproducibility and comparability of LCZ-based studies (Bechtel et al., 2019). The resilience-focused phase (2022–2025) reflects a paradigmatic shift toward planning-oriented applications. Studies increasingly framed LCZ and drainage interactions within the context of climate adaptation, sustainable cities, and ecosystem services (Sun et al., 2021). This transition underscores the recognition that mitigating urban heat and managing stormwater are not isolated technical challenges but interconnected spatial problems requiring holistic, morphology-informed solutions. The steady publication growth post-2018 also aligns with the Paris Climate Agreement (2015) and the United Nations' Sustainable Development Goals (SDG 11 & SDG 13), which call for climate-resilient, inclusive, and sustainable urbanization. The bibliometric trend thus mirrors both academic and policy-level convergence around integrated urban environmental management.

3.2 Keyword Co-occurrence and Density Analysis

Keyword co-occurrence analysis revealed distinct thematic clusters with overlapping areas between LCZ and drainage studies. High-frequency terms included 'Local Climate Zone', 'land surface temperature', 'climate change', 'drainage', 'flood risk', and 'blue-green infrastructure'. Figure 1 visualizes keyword density where yellow zones indicate research hotspots.

The Urban Climatology cluster reflects research focused on LCZ classification, microclimate regulation, and urban heat mapping (Stewart & Oke, 2012). The Hydrology and Drainage cluster captures the hydrological modeling domain, integrating runoff simulation, flood control, and stormwater infrastructure (Fletcher et al., 2015). The Spatial Modeling cluster bridges both domains through geospatial tools and satellite-derived indices such as NDVI, impervious surface mapping, and LULC analysis (Zhao et al., 2021). Finally, the Sustainability and Adaptation cluster signifies a growing planning-oriented strand of research linking urban form, resilience, and climate governance (Kabisch et al., 2016).

The convergence of climatological and hydrological clusters visually manifests in overlapping regions within the keyword map, underscoring a methodological and conceptual overlap. This reinforces the notion that LCZ-derived morphological data serve as valuable input parameters in hydrological modeling and drainage design, particularly for identifying urban heat–flood interaction zones (Zhong et al., 2021).

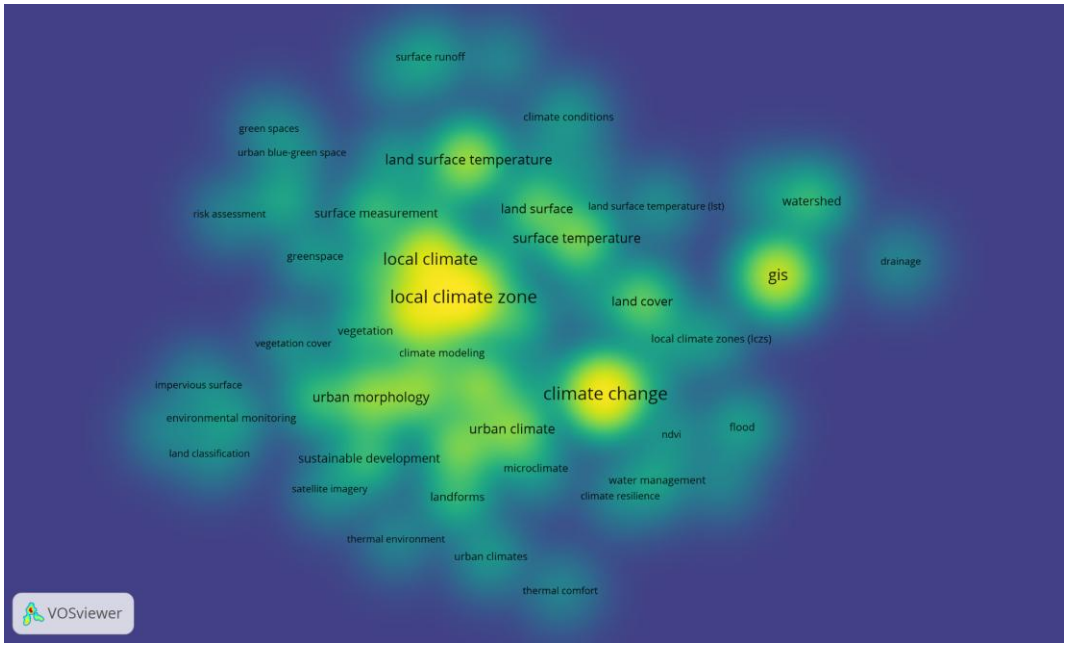


Figure 1. Keyword density visualization (VOS viewer)

Table 2. Thematic Keyword Clusters

Cluster Theme	Representative Keywords
Urban Climatology	LCZ, LST, thermal comfort, heat island, microclimate
Hydrology and Drainage	runoff, stormwater, flood, watershed, blue–green infrastructure
Spatial Modeling	GIS, NDVI, remote sensing, land cover, impervious surfaces
Sustainability and Adaptation	climate change, resilience, sustainable cities, urban form

(Author, 2025)

3.3 Author Collaboration and Network Patterns

The authorship density visualization (Figure 2) illustrates the global structure of collaboration within the LCZ–drainage research community. The network analysis highlights Demuzere, Bechtel, and Oke as central figures who significantly shaped the LCZ conceptual framework and its global dissemination. Their high centrality and interlinkages indicate strong influence in establishing methodological standards, particularly through WUDAPT initiatives (Bechtel et al., 2019; Demuzere et al., 2019).

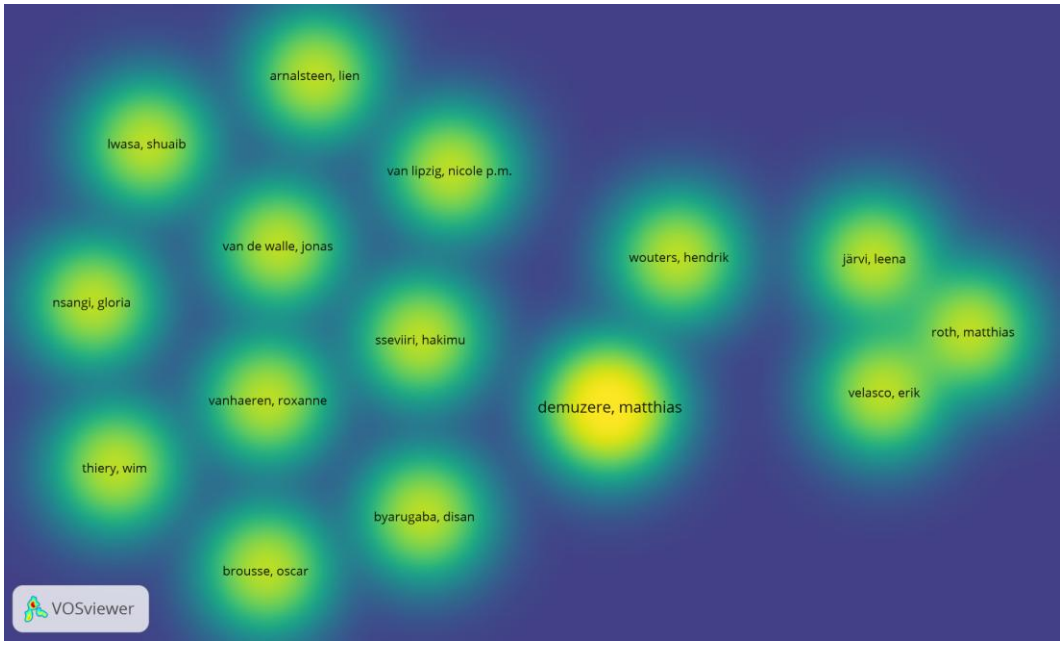


Figure 2. Author density visualization (VOS viewer)

Regional collaboration patterns show clear geographical clustering. European research groups dominate the field's early methodological and theoretical development, emphasizing urban climate standardization and thermal comfort analysis (Ching et al., 2019). Conversely, Asian research institutions, particularly in China, South Korea, and India, have emerged as leaders in applied studies that integrate LCZ analysis with hydrological modeling and flood resilience assessment (Zhong et al., 2021; Zhang et al., 2023).

A notable trend is the rise of Indian contributions post-2020, reflecting growing interest in applying LCZ and drainage coupling to medium-sized urban centers facing monsoonal flooding and heat stress. These studies often employ open-source data and GIS-based LCZ mapping to inform urban planning and stormwater management (e.g., Bhopal, Indore, Chennai).The collaboration map also reveals increasingly multidisciplinary teams involving climatologists, hydrologists, GIS specialists, and planners. This cross-sectoral cooperation signals the maturation of a new research paradigm, one that integrates microclimatic data and hydrological performance to support data-driven urban resilience planning.

3.4 Temporal Overlay and Emerging Trends

The temporal overlay map (Figure 3) shows that early publications (in blue) focused on LCZ typology and LST retrieval, while more recent works (in yellow) emphasize drainage resilience and integrated modeling. Emerging themes include coupling LCZ frameworks with hydrological simulations and implementing nature-based solutions for pluvial flood mitigation (Boguniewicz-Zabłocka et al., 2025).

The middle phase (2018–2021, shown in green) marks a transition toward integrating GIS-based hydrological simulations and climate modeling frameworks. During this period, studies began exploring relationships between impervious surface extent, vegetation fraction, and runoff dynamics, reflecting an emerging dialogue between climatology and hydrology (Demuzere et al., 2019; Wang et al., 2020).

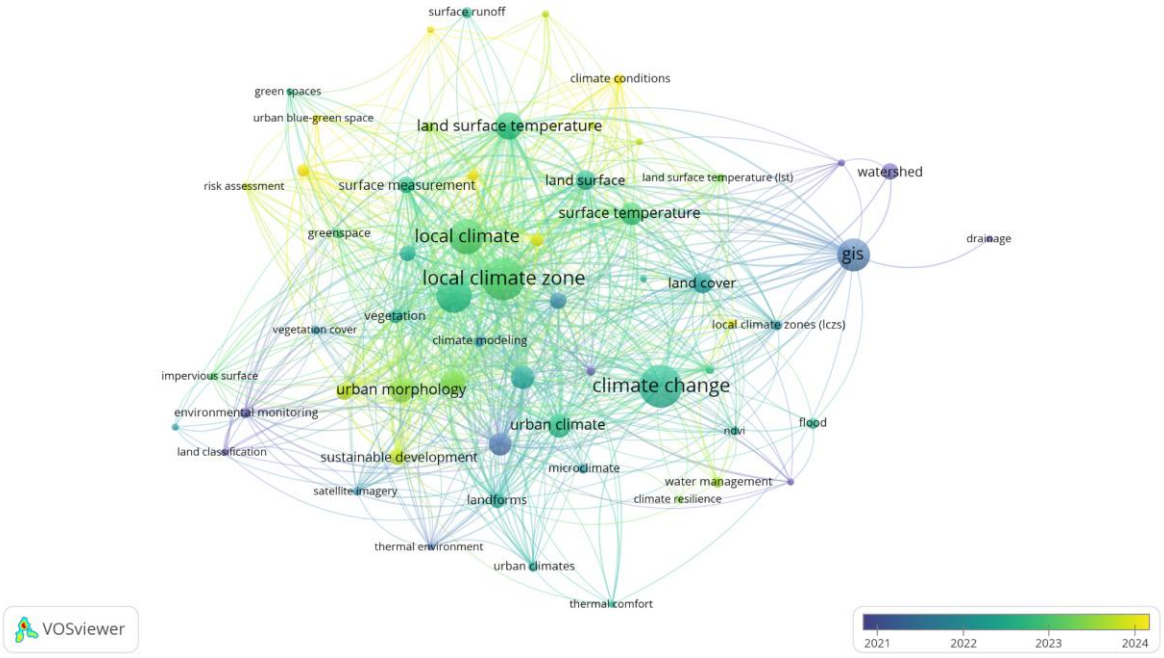


Figure 3. Temporal overlay visualization (VOS viewer)

Recent studies (2022–2025, shown in yellow) have increasingly focused on resilience-driven applications. Emerging themes include coupling LCZ frameworks with hydrological simulations, AI-assisted LCZ classification, and implementation of blue–green infrastructure for pluvial flood mitigation (Boguniewicz-Zabłocka et al., 2025). Researchers are now employing LCZ as an analytical layer in spatial decision-support systems for stormwater management and adaptive design.

This temporal progression demonstrates the co-evolution of climate and hydrology disciplines, from isolated analyses of heat or water flow toward a systems-oriented approach where both dimensions are understood as interdependent processes shaping urban sustainability.

3.5 Comparative Synthesis of LCZ and Drainage Domains

The bibliometric synthesis reveals that LCZ and drainage research, though historically distinct, are conceptually complementary and mutually reinforcing. LCZ research provides the morphological and climatic context, identifying areas prone to heat accumulation and reduced evapotranspiration, while drainage studies address the hydrological implications of those morphological patterns, such as surface runoff, infiltration deficits, and flood risk. This comparative synthesis illustrates how LCZ-based spatial data can enhance the precision of hydrological modeling by supplying standardized parameters such as impervious surface ratio, building geometry, and vegetation density.

Conversely, drainage models provide critical feedback on how surface form affects hydrological performance, enabling iterative design approaches for resilient urban planning (Zhang et al., 2023).
Conversely, drainage models provide critical feedback on how surface form affects hydrological performance, enabling iterative design approaches for resilient urban planning (Zhang et al., 2023).

Table 3. Comparative Synthesis of LCZ and Drainage Domains

Aspect	LCZ Research	Drainage Research
Primary Objective	Assess microclimate variations and heat island effects	Model surface runoff, flooding, and hydrological resilience
Key Tools	Remote sensing, GIS, WUDAPT, field measurements	Hydrological models, GIS, SUDS evaluation
Data Sources	Landsat, MODIS, in-situ temperature data	Rainfall data, DEMs, hydrological survey data
Recent Integration	LCZ-hydrology coupling for blue–green resilience	Urban morphology–drainage correlation via GIS-based models

(Author, 2025)

Ultimately, the convergence of LCZ and drainage methodologies reflects a broader paradigm shift in urban environmental research from fragmented assessments toward integrated morphological-hydrological frameworks. Such integration not only deepens scientific understanding but also equips planners and policymakers with actionable insights for designing climate-resilient, water-sensitive cities.

4. Limitations

While this study provides valuable insights into the intellectual evolution and thematic convergence of Local Climate Zone (LCZ) and urban drainage/blue–green infrastructure (BGI) research, several methodological and contextual limitations must be acknowledged.

First, the analysis is limited to Scopus-indexed literature, which, although comprehensive and widely used in bibliometric studies, may exclude regionally significant publications indexed in local databases such as CNKI (China), SciELO (Latin America), or Indiastat (India). Consequently, non-English, locally focused, or practice-oriented studies may be underrepresented. This limitation could particularly affect the representation of research from the Global South, where numerous case-based studies on urban flooding and climate adaptation exist in grey literature or institutional reports (Donthu et al., 2021).

Second, the exclusion filters applied to the drainage search string, designed to refine the scope toward urban resilience, may have inadvertently omitted some interdisciplinary works that bridge hydrology with ecology, soil science, or water quality management. Although these filters enhanced thematic precision, they potentially narrowed the diversity of perspectives that could enrich the holistic understanding of urban water systems.

Third, bibliometric tools such as VOS viewer offer strong capabilities for mapping patterns, co-authorships, and keyword linkages; however, they primarily operate on quantitative metadata and cannot capture the qualitative depth or methodological rigor of individual studies (Aria &

Cuccurullo, 2017). As a result, interpretations drawn from visualization outputs must be considered indicative rather than conclusive. Bibliometric analysis excels at identifying "what" and "how much" but not "how well."

Fourth, the time window (2014–2025), although chosen to capture the post-WUDAPT and modern hydrological modeling eras, excludes earlier foundational works on urban climatology and hydrology that predate the LCZ framework (e.g., Oke, 1987; Grimmond, 2007). This may slightly constrain the longitudinal understanding of how morphological and hydrological research evolved before the standardization of LCZ terminology.

Lastly, the study's reliance on author-assigned keywords introduces subjectivity, as inconsistent keyword selection or variations in terminology (e.g., "pluvial flooding" vs. "urban flood") may influence network clustering outcomes. Future bibliometric efforts could improve accuracy through manual keyword normalization, semantic text mining, or machine learning-assisted topic modeling, ensuring greater precision in cluster delineation (Zhang et al., 2023). Despite these limitations, the study establishes a strong foundation for understanding the interdisciplinary connections between urban climate and hydrology research and highlights opportunities for methodological and regional expansion in future work.

5. Conclusion and Future Directions

This bibliometric synthesis underscores a decisive transformation in how researchers conceptualize and address the coupled dynamics of urban climate and urban hydrology. The integration of the Local Climate Zone (LCZ) framework with drainage and blue–green infrastructure (BGI) studies represents a significant paradigm shift, from treating heat and water as separate environmental stressors to understanding them as interdependent phenomena within the urban system (Bechtel et al., 2019; Demuzere et al., 2019).

The results reveal a clear trend of convergence between LCZ and drainage research communities, driven by shared goals of climate resilience, sustainability, and adaptive planning. Initially, LCZ research advanced through standardized morphological mapping and remote-sensing applications aimed at understanding land surface temperature (LST) and urban heat island (UHI) variations. In parallel, drainage research evolved toward nature-based stormwater management, emphasizing the multifunctional role of blue–green infrastructure in mitigating floods and improving microclimates (Gill et al., 2007; Fletcher et al., 2015). Over the past decade, these two domains have increasingly intersected through the adoption of GIS-based modeling, remote sensing, and spatially explicit planning frameworks, paving the way for a holistic understanding of the urban environment.

This convergence also reflects a broader epistemological shift, from disciplinary specialization toward systemic integration, where urban form, surface properties, hydrological performance, and climatic feedbacks are analyzed in tandem. The combined LCZ–drainage framework enables planners to map urban vulnerability, identify heat–flood interaction zones, and prioritize adaptation interventions. For instance, LCZ maps can inform hydrological simulations by providing spatial parameters for surface roughness, albedo, and imperviousness, while hydrological models can validate LCZ classifications through runoff and infiltration performance metrics (Zhong et al., 2021).

The study's findings point toward an emerging research frontier centered on climate-responsive and water-sensitive urban design. The following future research directions are particularly relevant: Development of hybrid LCZ–hydrology simulation frameworks: Future work should focus on coupling microclimatic models (e.g., ENVI-met, WRF) with hydrological simulators (e.g., SWMM, HEC-RAS) to evaluate dynamic interactions between temperature, precipitation, and runoff in real-time (Wang et al., 2020).

Integration of LCZ maps with urban flood risk zoning: By overlaying LCZ typologies on flood-prone zones, researchers can better assess how morphological forms influence flood susceptibility, aiding in the creation of spatially adaptive urban zoning (Sun et al., 2021).Incorporation of socio-spatial and vulnerability data: Future frameworks should move beyond physical parameters to integrate socioeconomic vulnerability indices, exposure mapping, and accessibility metrics, thereby linking environmental modeling with climate justice and equity dimensions (Kabisch et al., 2016).

Contextual application in Indian mid-sized cities: Given their rapid growth and data scarcity, Indian cities such as Bhopal, Indore, and Nagpur present ideal testbeds for applying LCZ–hydrology integration. These cities face concurrent challenges of heat stress, pluvial flooding, and inadequate drainage, making them prime candidates for field validation of LCZ-informed BGI planning. Advancement of open data and participatory modeling: Encouraging community-driven LCZ mapping, combined with crowdsourced rainfall and flooding data, can democratize access to resilience planning tools, particularly in resource-limited settings. By synthesizing urban climatology and hydrological resilience, the integrated LCZ–drainage framework provides a scientific foundation for climate-adaptive urban planning. The insights gained from this study extend beyond theoretical relevance; they offer a practical decision-support system for policymakers, urban designers, and local governments striving to achieve sustainable, livable, and climate-resilient cities.

As cities continue to grapple with the twin crises of urban heat and urban flooding, bridging the LCZ and drainage domains will be essential to designing built environments that not only withstand climate pressures but also enhance ecological and human well-being.

References

1. Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007
2. Bechtel, B., Alexander, P. J., Bohner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., See, L., Stewart, I. D., & Verdonck, M. L. (2015). Mapping Local Climate Zones for a worldwide database of the form and function of cities. *ISPRS International Journal of Geo-Information, 4*(1), 199–219. https://doi.org/10.3390/ijgi4010199
3. Bechtel, B., Demuzere, M., Sismanidis, P., Fenner, D., Brousse, O., & Beck, C. (2019). Quality of LCZ maps and their suitability for climate studies. *Urban Climate, 28*, 100451. https://doi.org/10.1016/j.uclim.2019.100451
4. Boguniewicz-Zabłocka, J., Kiedrzyńska, E., & Ławniczak, A. (2025). Urban nature-based solutions for flood mitigation and thermal comfort improvement. *Sustainable Cities and Society, 109*, 104587.
5. Ching, J., Mills, G., Bechtel, B., See, L., Feddema, J., Wang, X., Ren, C., Brousse, O., Martilli, A., & Stewart, I. D. (2019). WUDAPT: An urban weather, climate, and environmental modeling infrastructure. *Urban Climate, 30*, 100498. https://doi.org/10.1016/j.uclim.2019.100498
6. Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A. G., Mittal, N., Feliu, E., & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green infrastructure. *Journal of Environmental Management, 146*, 107–115. https://doi.org/10.1016/j.jenvman.2014.07.025
7. Demuzere, M., Bechtel, B., & Mills, G. (2019). Global transferability of LCZ-based urban climate analysis. *Urban Climate, 27*, 46–63. https://doi.org/10.1016/j.uclim.2018.11.001
8. Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research, 133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070
9. Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R. M., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., & Viklander, M. (2015). SUDS, LID, BMPs, and WSUD: International research and practice in urban drainage. *Urban Water Journal, 12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314
10. 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. https://doi.org/10.2148/benv.33.1.115
11. Grimmond, C. S. B. (2007). Urbanization and global environmental change: Local effects of urban warming. *Geographical Journal, 173*(1), 83–88. https://doi.org/10.1111/j.1475-4959.2007.232.x
12. Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society, 21*(2), 39. https://doi.org/10.5751/ES-08373-210239
13. Kotharkar, R., Bagade, A., & Ramesh, A. (2021). Evaluating the role of Local Climate Zones in assessing thermal performance of Indian cities. *Urban Climate, 37*, 100828. https://doi.org/10.1016/j.uclim.2021.100828
14. Liu, Y., Yu, Z., & Guo, L. (2020). Urban stormwater management with blue–green infrastructure: A review of recent studies. *Water, 12*(10), 2819. https://doi.org/10.3390/w12102819
15. Liu, W., Chen, W., & Peng, C. (2015). Assessing the effectiveness of green infrastructures on urban flooding reduction: A spatial multi-scenario approach. *Water Research, 85*, 467–478. https://doi.org/10.1016/j.watres.2015.08.038

16. Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147*, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011
17. Oke, T. R. (1987). *Boundary Layer Climates* (2nd ed.). Routledge.
18. Qiao, X., Shen, Z., & Wang, Z. (2022). Integrating Local Climate Zones and hydrological modeling for stormwater management optimization. *Journal of Hydrology, 607*, 127555. https://doi.org/10.1016/j.jhydrol.2022.127555
19. Rizwan, A. M., Dennis, L. Y. C., & Liu, C. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences, 20*(1), 120–128. https://doi.org/10.1016/S1001-0742(08)60019-4
20. Shandas, V., Voelkel, J., Williams, J., & Hoffman, J. (2021). Integrating Local Climate Zones into stormwater planning for equitable resilience. *Sustainable Cities and Society, 65*, 102615. https://doi.org/10.1016/j.scs.2020.102615
21. Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society, 93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1
22. Sun, R., Chen, L., & Zhu, W. (2021). Evaluating the cooling and hydrological co-benefits of blue–green infrastructure using LCZ classification. *Urban Forestry & Urban Greening, 58*, 126959. https://doi.org/10.1016/j.ufug.2021.126959
23. Tait, S. J., & Ashley, R. (2020). Urban drainage and climate change: Towards water sensitive cities. *Water Science & Technology, 81*(8), 1591–1600. https://doi.org/10.2166/wst.2020.132
24. Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., ... & Li, F. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology, 54*(1), 75–84. https://doi.org/10.1007/s00484-009-0256-x
25. Thakur, J., & Paul, P. K. (2023). GIS-based analysis of LCZ impacts on urban flooding: A case study of Mumbai. *Environmental Monitoring and Assessment, 195*(6), 678. https://doi.org/10.1007/s10661-023-10743-9
26. Wang, Y., Zhang, Y., & Chen, J. (2020). Coupled urban climate and hydrological modeling for resilient planning. *Environmental Modelling & Software, 108*, 64–74. https://doi.org/10.1016/j.envsoft.2018.09.019
27. Xiao, Y., Mills, G., & Ren, C. (2022). Applying LCZ data to improve hydrological modeling accuracy in urban catchments. *Urban Climate, 43*, 101137. https://doi.org/10.1016/j.uclim.2022.101137
28. Zhang, L., Peng, J., & Liu, Y. (2023). Integrating Local Climate Zones with urban hydrological modeling for climate resilience assessment. *Sustainable Cities and Society, 97*, 104091. https://doi.org/10.1016/j.scs.2023.104091
29. Zhao, C., Zhou, D., & He, B. (2021). Quantifying the impacts of impervious surface expansion on urban hydrology: A meta-analysis. *Hydrological Processes, 35*(7), e14225. https://doi.org/10.1002/hyp.14225
30. Zhong, S., Du, X., & Ren, G. (2021). The role of Local Climate Zones in assessing pluvial flood risk in megacities. *Urban Climate, 39*, 100942. https://doi.org/10.1016/j.uclim.2021.100942
31. Zhou, D., Zhao, S., & Zhang, L. (2019). The impact of urbanization on surface heat and water balance in megacities. *Remote Sensing of Environment, 231*, 111–118. https://doi.org/10.1016/j.rse.2019.111118

FINAL REPORT VAISHNAVI SHRIVASTAVA 24209011105.pdf

by Anshuman Sahoo

Submission date: 12-Jul-2026 04:21PM (UTC+0530)
Submission ID: 2996684219
File name: FINAL_REPORT_VAISHNAVI_SHRIVASTAVA_24209011105.pdf (4.27M)
Word count: 35723
Character count: 220738

FINAL REPORT VAISHNAVI SHRIVASTAVA 24209011105.pdf

ORIGINALITY REPORT

5%	3%	4%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Ariva Sugandi Permana. "Urban Engineering", Routledge, 2025 Publication	
2	"Blue-Green Infrastructure for Sustainable Urban Settlements", Springer Science and Business Media LLC, 2024 Publication	
3	www.mdpi.com Internet Source	
4	pmc.ncbi.nlm.nih.gov Internet Source	
5	iieta.org Internet Source	
6	Rukhsana Sarkar, Asraful Alam, Azizur Rahman Siddiqui. "Agriculture and Climatic Issue in South Asia - Geospatial Applications", CRC Press, 2023 Publication	
7	Bernardino, Maria Francisca Silva Carvalho. "Exploring the Challenges and Opportunitie of Big Data in SMEs: A Bibliometric Analysis", ISCTE - Instituto Universitario de Lisboa (Portugal), 2024 Publication	
8	Pradeep Kumar, Rajeev Bhatla, Sudhir Kumar Singh, Arti Choudhary. "Geospatial Technologies - Environmental and Climate Science Applications and Challenges", CRC Press, 2026 Publication	
9	Shiv Mohan, Navneet Munoth, Neha Sharma. "Smart Buildings and Cities with Remote Sensing and GIS", CRC Press, 2025 Publication	
10	"Forestry for a Carbon-Neutral and Sustainable Future", Springer Science and Business Media LLC, 2026 Publication	
11	Tianhui Wu, Jianjun Bai, Ziyun Zhang. "Scale-dependent contributions of local and neighborhood influences on LCZ thermal variation", Sustainable Cities and Society, 202 Publication	

12 Ivan Secerov, Stevan Savic, Dragan Milosevic, Vladimir Markovic, Ivana Bajsanski. "Development of an automated urban climate monitoring system in Novi Sad (Serbia)", Geographica Pannonica, 2015
Publication

13 www.gbmrjournal.com
Internet Source

14 Sk Ajim Ali, Quoc Bao Pham, Yunqing Xuan. "Climate Change and Disadvantaged Communities - Challenges and Opportunities", CRC Press, 2025
Publication

15 dokumen.pub
Internet Source

16 Submitted to Sheffield Hallam University
Student Paper

17 essay.utwente.nl
Internet Source

18 scholar.ufs.ac.za
Internet Source

19 Iain D. Stewart, T. R. Oke, E. Scott Krayenhoff. "Evaluation of the 'local climate zone' scheme using temperature observations and model simulations", International Journal Climatology, 2014
Publication

20 www.tngcc.tn.gov.in
Internet Source

21 Submitted to Wageningen University
Student Paper

22 www.researchsquare.com
Internet Source

23 Xiaolong Yang, Liqing Yang, Depeng Huang, Liang Chen, Yunhao Yang, Yi Luo, Yang Liu, Jiaming Na, Hu Ding. "Revealing the Impact of Urban Morphology Evolution on the Urba Heat Island Effect in the Main Urban Area of Guangzhou: Insights from Local Climate Zones", Remote Sensing, 2025
Publication

24 Dileep Kumar Koshta, Ashu Jain. "A Study of Water Resource Management in Urban an Rural Areas of Jabalpur District", Shanlax International Journal of Commerce, 2019
Publication

25 ph.pollub.pl
Internet Source

26 Dima Seker, Nur H. Orak. "Adaptive decision-making: Bayesian Network Modeling for blue–green infrastructure selection in dynamic climate and land use context", Environmental Data Science, 2025
Publication

27 Submitted to Ministry of Water Institute
Student Paper

28 Submitted to UNICAF
Student Paper

29 Submitted to University of Sheffield
Student Paper

30 Iacopo Carnacina, Mawada Abdellatif, Manolia Andredaki, James Cooper, Darren Lumbroso, Virginia Ruiz-Villanueva. "River Flow 2024", CRC Press, 2025
Publication

31 Submitted to Institute of Technology, Sligo
Student Paper

32 Submitted to Jawaharlal Nehru Technological University
Student Paper

33 Michael A. Burayidi, Adriana Allen, John Twigg, Christine Wamsler. "The Routledge Handbook of Urban Resilience", Routledge, 2019
Publication

34 Mohamed A. E. AbdelRahman. "An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications", Rendiconti Lincei. Scienze Fisiche e Naturali, 2023
Publication

35 f-f-p.org
Internet Source

36 sainsburys.production.investis.com
Internet Source

37 scholars.ncu.edu.tw
Internet Source

38 www.geonika.cz
Internet Source

39 A.W. Hardin, Y. Liu, G. Cao, J.K. Vanos. "Urban heat island intensity and spatial variabilit by synoptic weather type in the northeast U.S.", Urban Climate, 2017
Publication

40 Lenard Kumwenda, Patsani Gregory Kumambala, Lameck Fiwa, Chikondi Makwiza et al "Evaluation of Hydrological Response to Land Use Land Cover Changes of Lufilya

Catchment", Physics and Chemistry of the Earth, Parts A/B/C, 2025
Publication

41 Nur H. Orak, Linda Smail. "A Bayesian Network model to integrate blue-green and gray infrastructure systems for different urban conditions", Journal of Environmental Management, 2025
Publication

42 Stéphanie Vandamme, Matthias Demuzere, Marie-Leen Verdonck, Zhiming Zhang, Friel Van Coillie. "Revealing Kunming's (China) Historical Urban Planning Policies Through Lo Climate Zones", Remote Sensing, 2019
Publication

43 "Greening Cities", Springer Science and Business Media LLC, 2017
Publication

44 Ay, Filiz. "Assessment of Spatial Temporal Variability of Urban Heat Island Effect : A Cas Study in the Central Districts of İzmir", Izmir Institute of Technology (Turkey)
Publication

45 Submitted to Visvesvaraya National Institute of Technology
Student Paper

46 Submitted to Durban University of Technology
Student Paper

47 Kim, Sung-Min, Yosoon Choi, Jangwon Suh, Sungchan Oh, Hyeong-Dong Park, Suk-Ho Yoon, and Wa-Ra Go. "ArcMine: A GIS extension to support mine reclamation planning" Computers & Geosciences, 2012.
Publication

48 Yizhao Yang, Anne Taufen. "The Routledge Handbook of Sustainable Cities and Landscapes in the Pacific Rim", Routledge, 2022
Publication

49 abys.adiyaman.edu.tr
Internet Source

50 Diana Mitsova, Ann-Margaret Esnard. "Geospatial Applications for Climate Adaptation Planning", Routledge, 2018
Publication

51 Michael Addaney. "Sustainable Urban Futures in Africa", Routledge, 2021
Publication

52 Pengming Feng, Youtian Lin, Guangjun He, Jian Guan, Jin Wang, Huifeng Shi. "A Dynami End-to-End Fusion Filter for Local Climate Zone Classification Using SAR and Multi-Spectrum Remote Sensing Data", IGARSS 2020 - 2020 IEEE International Geoscience an Remote Sensing Symposium, 2020
Publication

53 Yudan Liu, Chunxiao Zhang, Yazhou Qi, Hanguang Yu. "Regulating Effects of Blue–Gree Spaces on Land Surface Temperature Based on Local Climate Zones: A Case Study of Suzhou (2000–2022)", Land, 2026
Publication

54 ir2.chartnexus.com
Internet Source

55 mdpi-res.com
Internet Source

56 scholars.hkbu.edu.hk
Internet Source

57 Submitted to Cyprus University of Technology
Student Paper

58 Luiz Filipe Rodrigues Moreira, José Rodolfo Scarati Martins. "Analysis of the effects of th spatiotemporal distribution of intense rainfall on flood resilience in urban catchments" Journal of Hydrology: Regional Studies, 2026
Publication

59 minds.wisconsin.edu
Internet Source

60 Submitted to Cranfield University
Student Paper

61 Guang Xu, Xuan Zhu, Nigel Tapper, Benjamin Bechtel. "Urban climate zone classificatio using convolutional neural network and ground-level images", Progress in Physical Geography: Earth and Environment, 2019
Publication

62 Jia Hu, Yingbao Yang, Xin Pan, Qin Zhu, Wenfeng Zhan, Yong Wang, Wenyu Ma, Weizhor Su. "Analysis of the Spatial and Temporal Variations of Land Surface Temperature Base on Local Climate Zones: A Case Study in Nanjing, China", IEEE Journal of Selected Topics Applied Earth Observations and Remote Sensing, 2019
Publication

63 Marešová, Petra. "Transportní Procesy a Strukturální Změny v Uměle Vytvořených Technosolech", Czech Technical University, 2025
Publication

64 Submitted to University of Oklahoma
Student Paper

65 Yuan Sun, Keith W. Oleson, Lei Zhao, Gerald Mills, Cenlin He, Matthias Demuzere, Davic Topping, Ning Zhang, Zhonghua Zheng. "Enhancing Global-Scale Urban Land Cover Representation Using Local Climate Zones in the Community Earth System Model", Journal of Advances in Modeling Earth Systems, 2025

Publication

66 faolex.fao.org
Internet Source

67 repositorio.unal.edu.co
Internet Source

68 www.econstor.eu
Internet Source

69 www.jetir.org
Internet Source

70 www.nature.com
Internet Source

71 Geraldo Lavigne de Lemos. "An analysis of the bioenergy crops pathway to address emerging climate issues from the perspective of Nature-based Solutions", Universidade de São Paulo. Agência de Bibliotecas e Coleções Digitais, 2026
Publication

72 JinLing Quan. "Enhanced geographic information system-based mapping of local climat zones in Beijing, China", Science China Technological Sciences, 2019
Publication

73 Tan Yigitcanlar. "Algorithmic Urbanism for Climate Resilience - AI, Green Infrastructure, and Policy Innovation for Heat-Ready Cities", CRC Press, 2026
Publication

74 Tobi Eniolu Morakinyo, Oluwafemi Benjamin Obe, Gerald Mills, Olumuyiwa Bayode Adegun et al. "The impact of hazard indicator selection on urban heat risk assessment: evidence from two Sub-Saharan African cities", City and Environment Interactions, 2026
Publication

75 Uday Chatterjee, Avishek Bhunia, Jyothi Gupta, Krishnendu Gupta. "Sustainability and Urban Quality of Life - Research, Policy and Practice", Routledge, 2025
Publication

76 Xiwen Liang, Miaomiao Xie, Yuexin Liu, Huining Zheng, Jian Peng. " Nonlinear Impact of Socio-Ecological Drivers on Ecosystem Service Trade-Offs in the oyang ake asin ", Land Degradation & Development, 2026
Publication

77 dergipark.org.tr
Internet Source

78 gs.elaba.lt
Internet Source

79 largelandscapes.org
Internet Source

80 repositorio.ufmg.br
Internet Source

81 scicomm2023-001-site2.itempurl.com
Internet Source

82 wsj.westsciences.com
Internet Source

83 www.futuresamachar.com
Internet Source

84 www.knu.ac.in
Internet Source

85 "Urban Climates in Latin America", Springer Science and Business Media LLC, 2019
Publication

86 Avijit Sahay, Pallavi Upreti, Nikhil Roy. "Slow-Onset Hazards - Issue, Challenges, and Risk Reduction Strategies", Routledge, 2026
Publication

87 Chunhong Zhao. "LINKING THE LOCAL CLIMATE ZONES AND LAND SURFACE TEMPERATURE TO INVESTIGATE THE SURFACE URBAN HEAT ISLAND, A CASE STUDY OF SAN ANTONIO, TEXAS, U.S.", ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2018
Publication

88 Dahal, Dewasis. "Assessing Urban Flood Dynamics Using Data-Driven and Physically Ba Modelling Frameworks.", Southern Illinois University at Carbondale
Publication

89 Fahad Anwar[1], Lawal Billa[1], Kim Shan Wee[1]. "Long-Term Impacts of Vegetation and Urb Expansion on Local Climate: Evidence from NDVI, NDBI, and Climate Time Series (1992-2022)", Springer Science and Business Media LLC, 2026
Publication

90 Gergely Molnár, András Zénó Gyöngyösi, Tamás Gál. "Integration of an LCZ-based classification into WRF to assess the intra-urban temperature pattern under a heatwav period in Szeged, Hungary", Theoretical and Applied Climatology, 2019
Publication

91 Submitted to INES Ruhengeri
Student Paper

92 J. Geletic, P. Dobrovolny, M. Lehnert. "Statistical analyses of land surface temperature i local climate zones: Case study of Brno and Prague (Czech Republic)", 2017 Joint Urban Remote Sensing Event (JURSE), 2017
Publication

93 Kate Bishop, Linda Corkery. "Routledge Handbook of Urban Landscape Research", Routledge, 2022
Publication

94 Loukas Katikas, Vassiliki Vassilopoulou. "Reverse visual impact assessment (R-VIA) for offshore wind projects: An integrated spatial method for anticipatory, holistic and socia accepted planning", Environmental Impact Assessment Review, 2026
Publication

95 Meng, Xuli. "Enhancing Site-Scale Stormwater Management Through Real-Time Adapte Control System", University of Technology Sydney (Australia), 2025
Publication

96 Mona Wells, Ryan A. McManamay. "Climate Change Impacts in Texas - Integrated Analy and Adaptation", CRC Press, 2026
Publication

97 Submitted to Purdue University
Student Paper

98 Rachna Gangwar, Anurima Mukherjee Basu. "Emerging Agenda in Sustainable Infrastructure Development - Green Transition: Policy and Practice", Routledge, 2026
Publication

99 Sriram, Kirusha. "Development and Modeling of Conjunctive Green Infrastructure Systems.", Lamar University - Beaumont
Publication

100 Yantao Xi, Shuangqiao Wang, Yunxia Zou, XingChi Zhou, Yuanfan Zhang. "Seasonal surf urban heat island analysis based on local climate zones", Ecological Indicators, 2024
Publication

101 Zuetell, Emily J.. "Climate Resilient Communities in Data-Scarce Contexts: Operationaliz Remote Sensing and Machine Learning for Local Climate Risk Assessment.", Carnegie Mellon University
Publication

102 climate-neutral-city.eu
Internet Source

103 ehime-u.repo.nii.ac.jp
Internet Source

104 eprints.whiterose.ac.uk
Internet Source

105 journals.ametsoc.org
Internet Source

106 link.springer.com
Internet Source

107 mfuir.mfu.ac.th
Internet Source

108 nhess.copernicus.org
Internet Source

109 public-pages-files-2025.frontiersin.org
Internet Source

110 reference-global.com
Internet Source

111 www-emerald-com-443.webvpn.sxu.edu.cn
Internet Source

112 www.coursehero.com
Internet Source

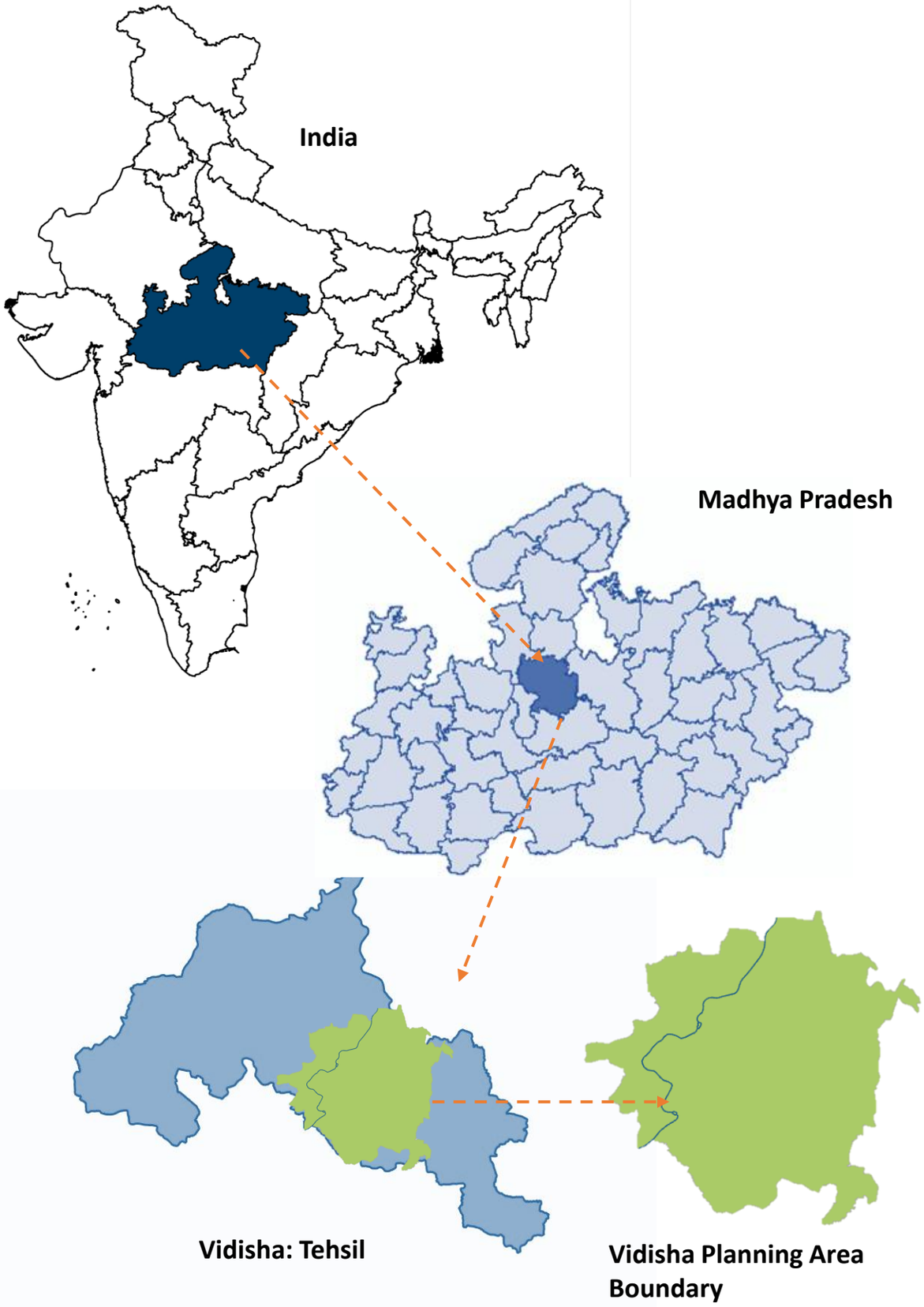
113 www.lib.kobe-u.ac.jp
Internet Source

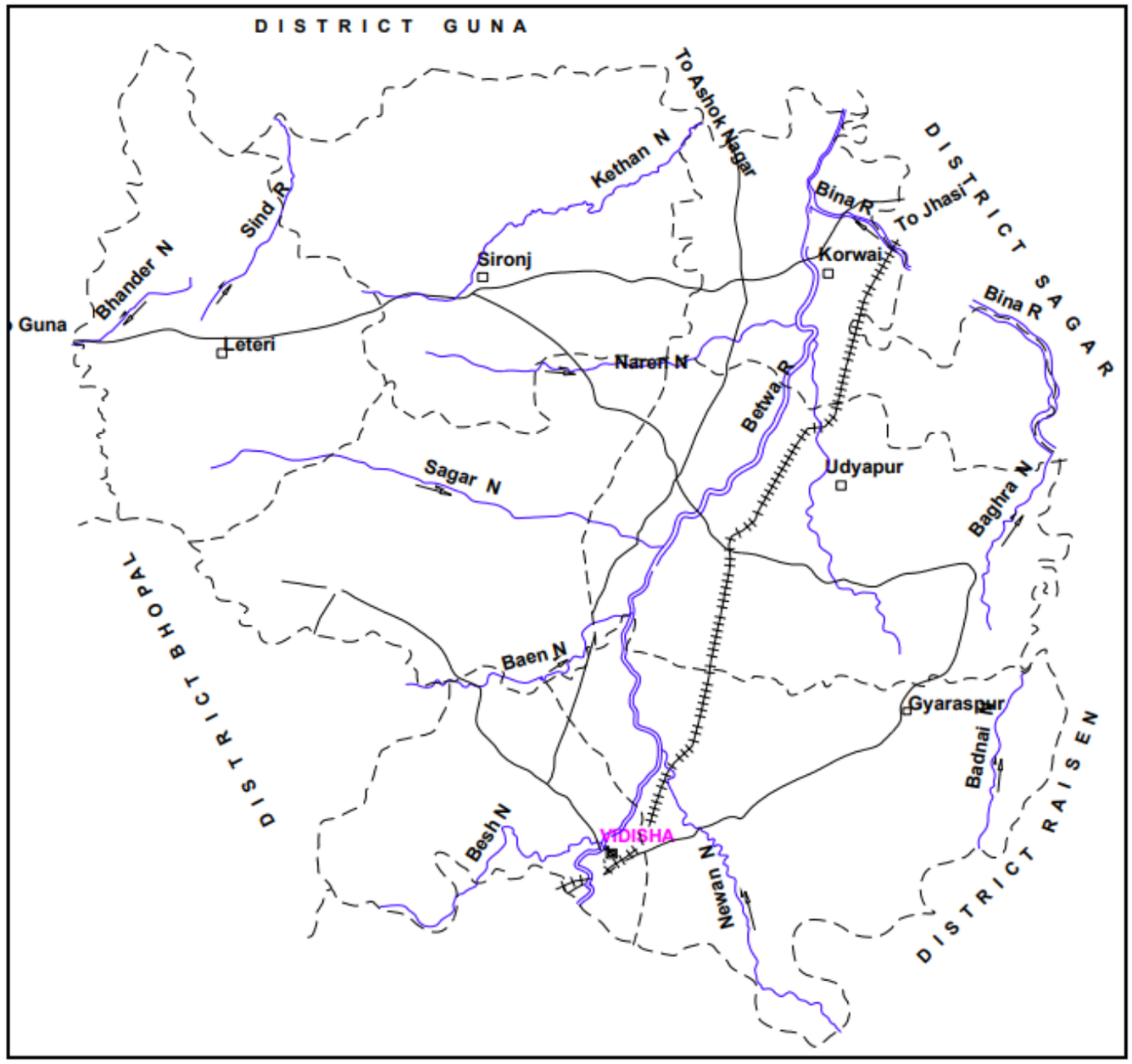
114 www.theseus.fi
Internet Source

Exclude quotes	Off	Exclude matches	< 8 words
Exclude bibliography	On		

STUDY AREA SELECTION AND REGIONAL SETTING MAP: VIDISHA, MADHYA PRADESH

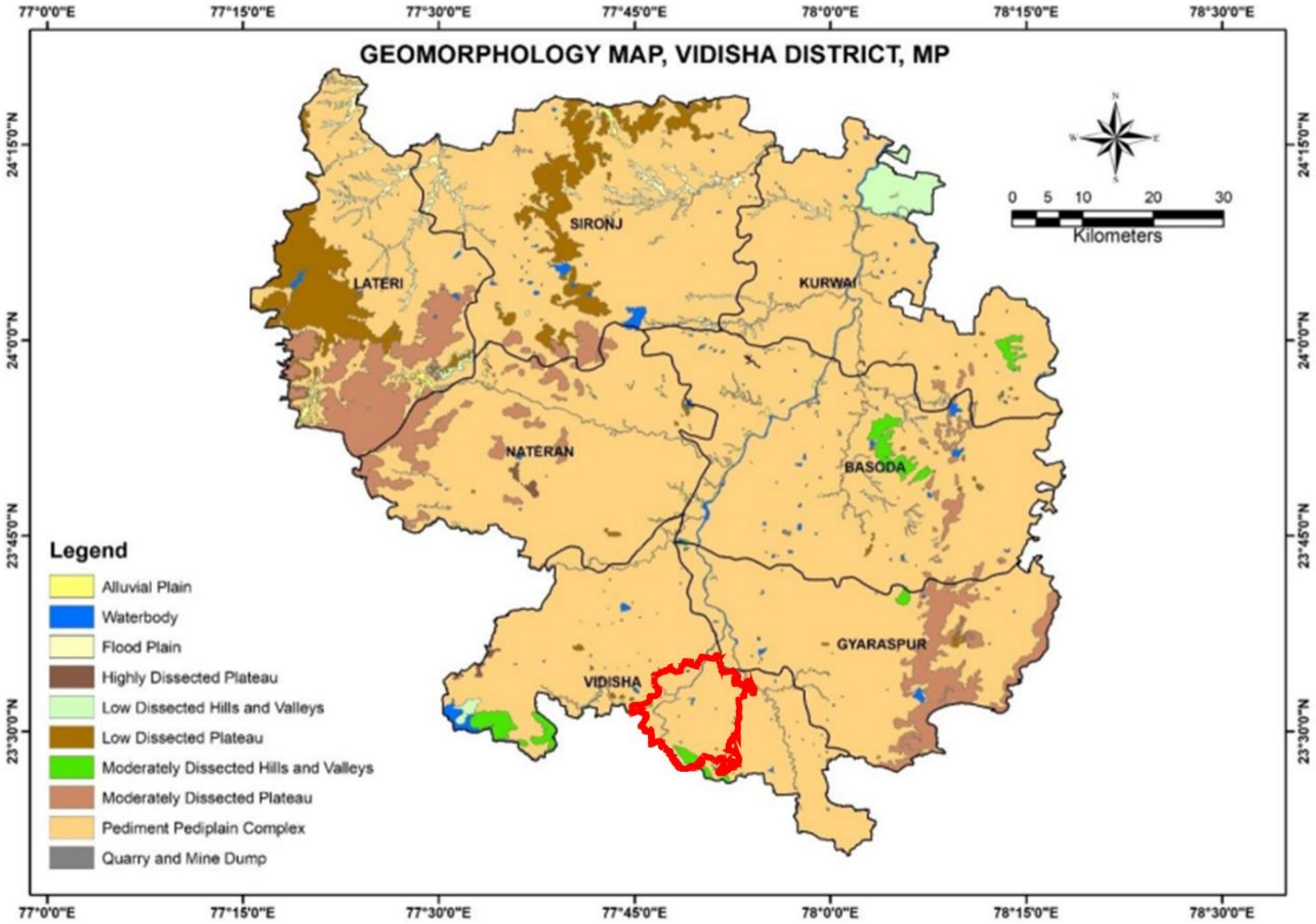
MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning



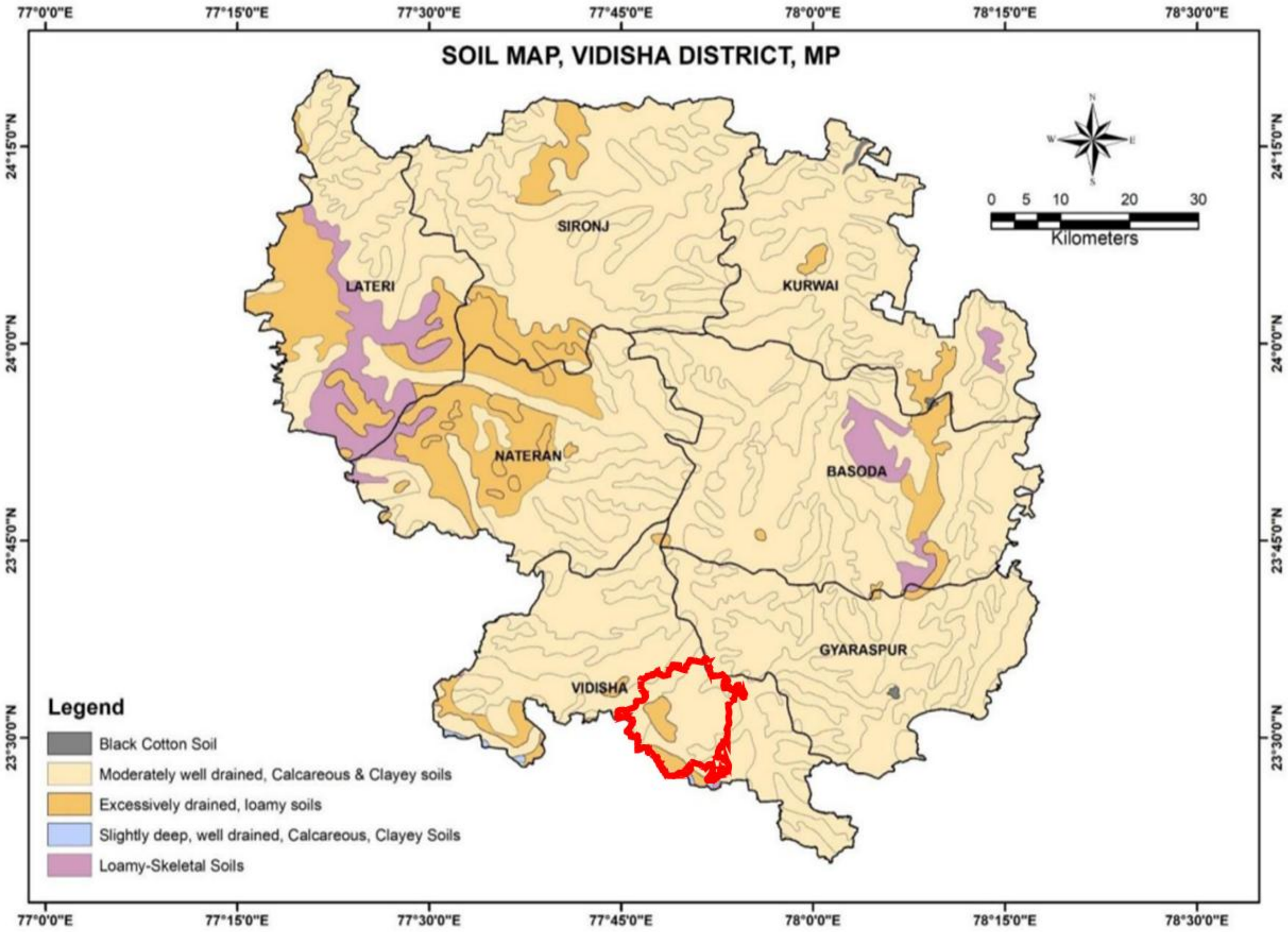


Regional Setting of Vidisha, Madhya Pradesh

GEOMORPHOLOGY MAP: VIDISHA, MADHYA PRADESH

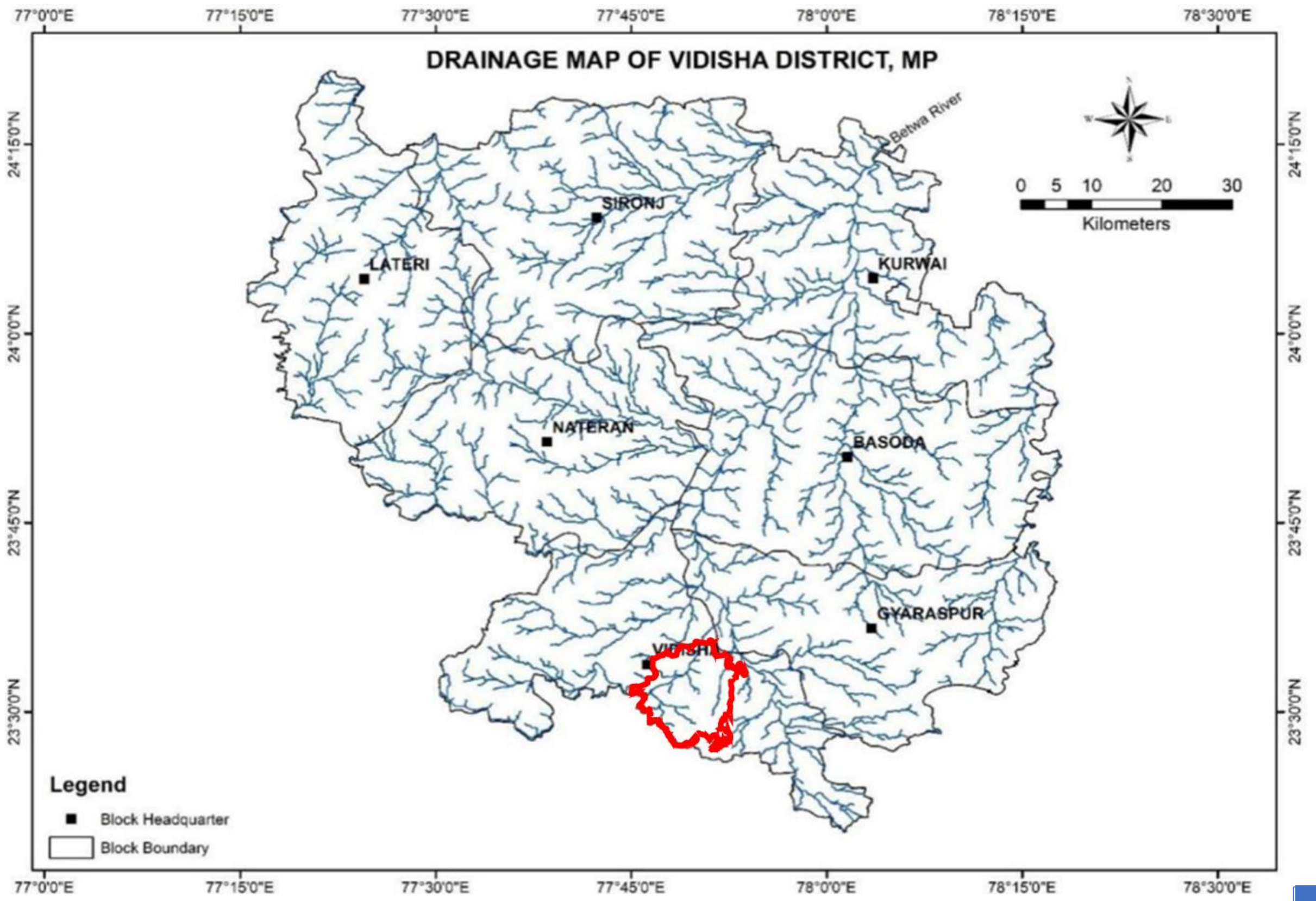


SOIL MAP: VIDISHA DISTRICT, MADHYA PRADESH



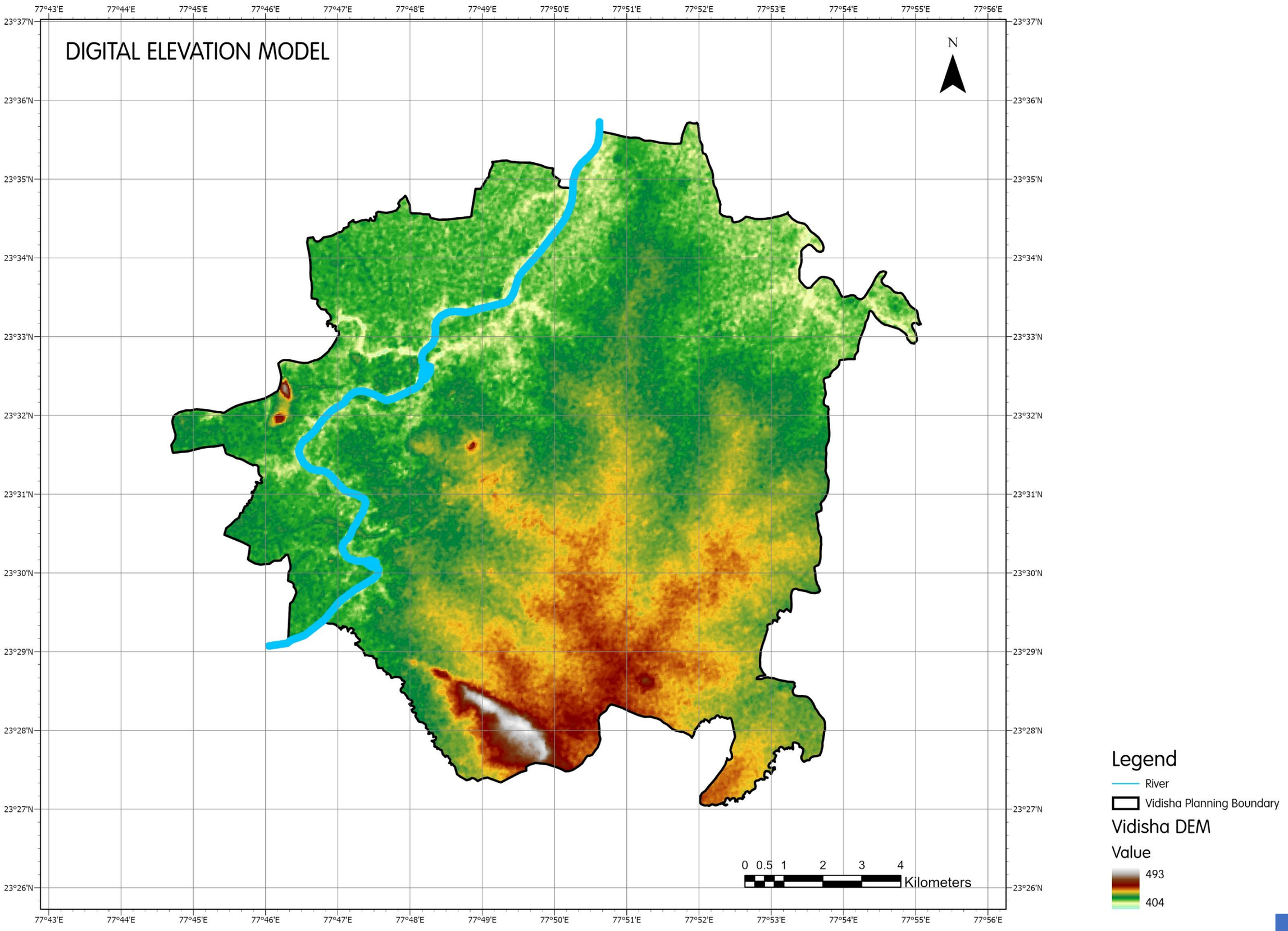
DRAINAGE MAP: VIDISHA DISTRICT, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning

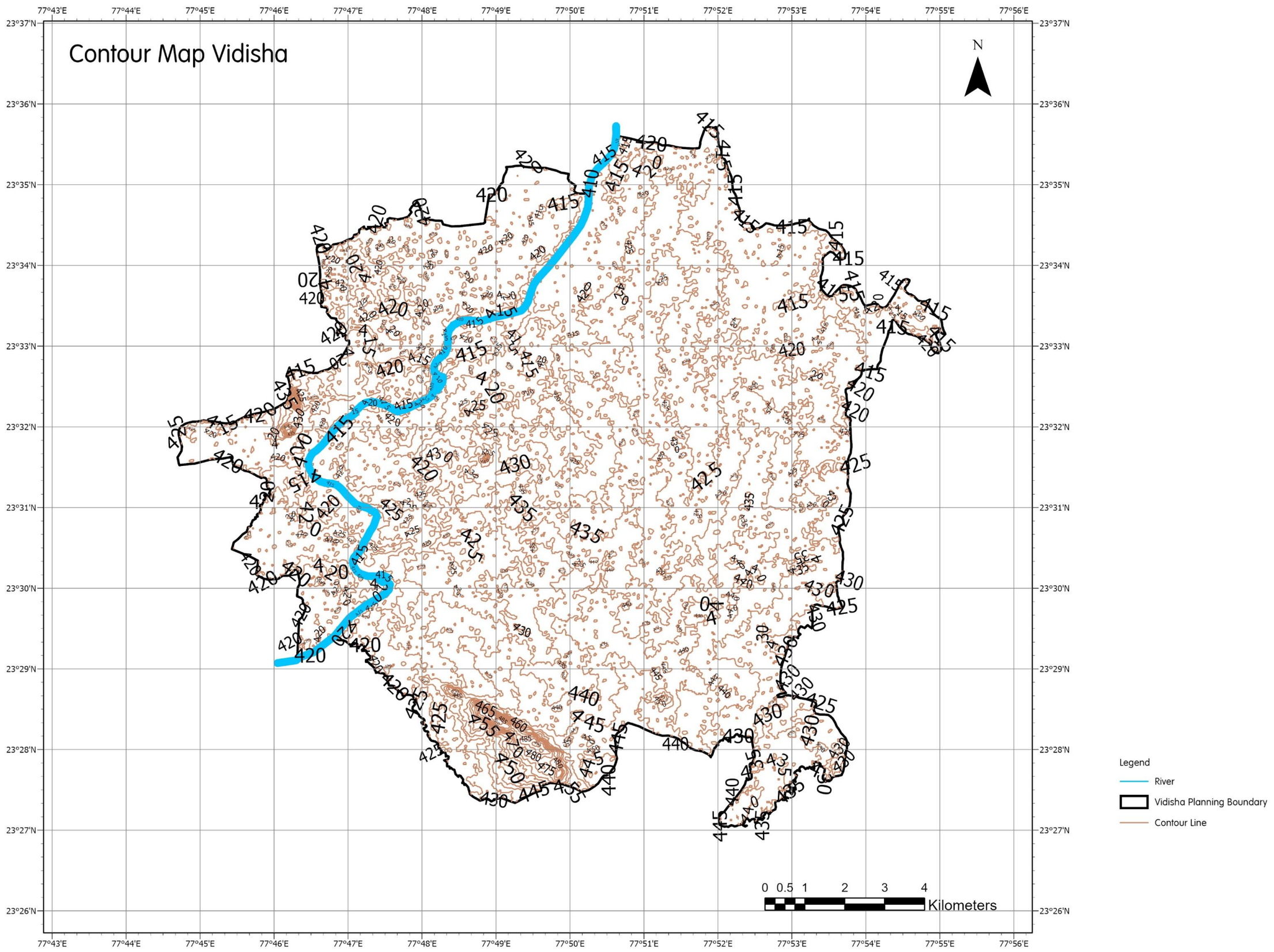


DIGITAL ELEVATION MODEL ANALYSIS MAP: VIDISHA, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning

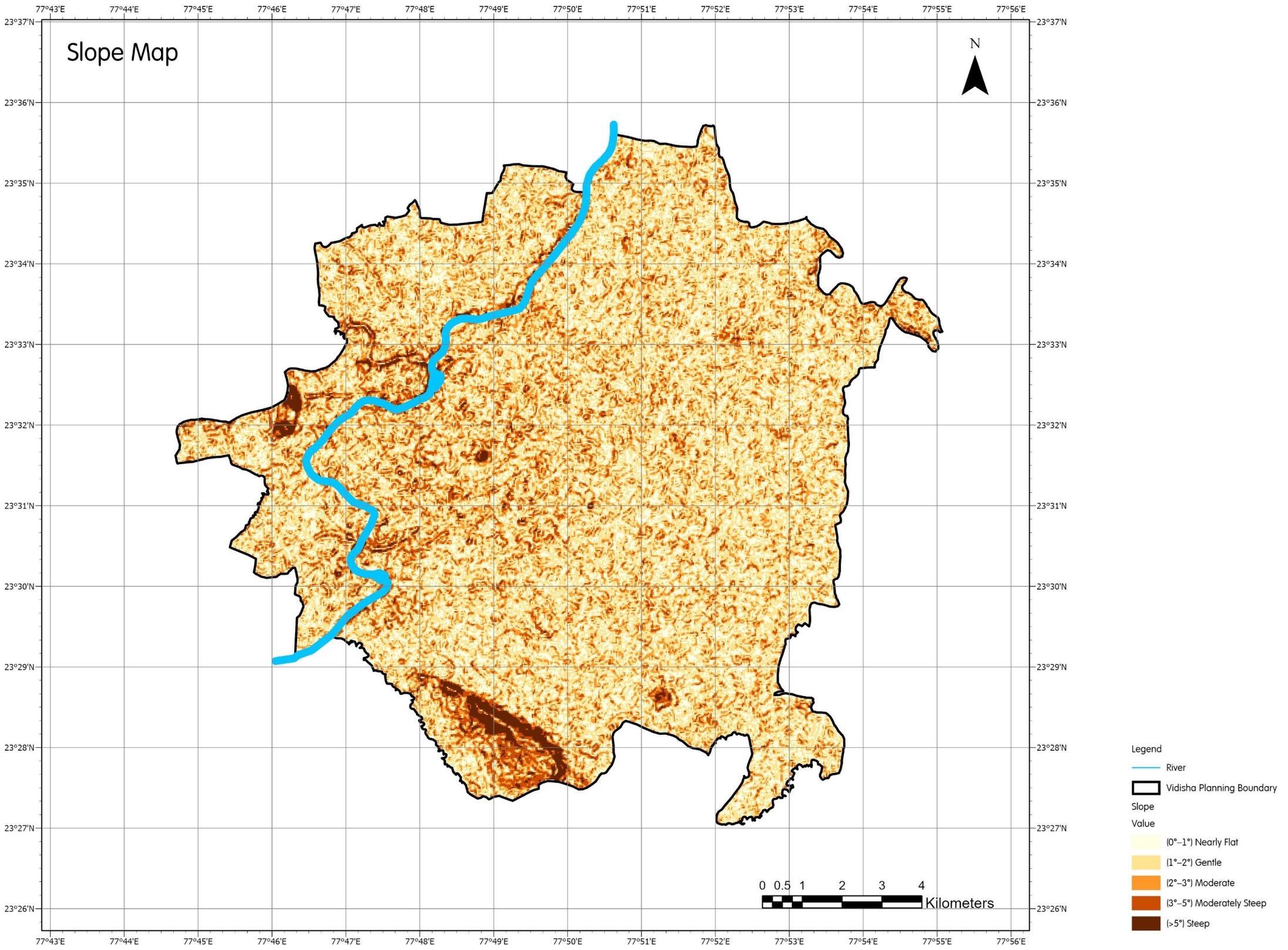


CONTOUR ANALYSIS MAP: VIDISHA, MADHYA PRADESH



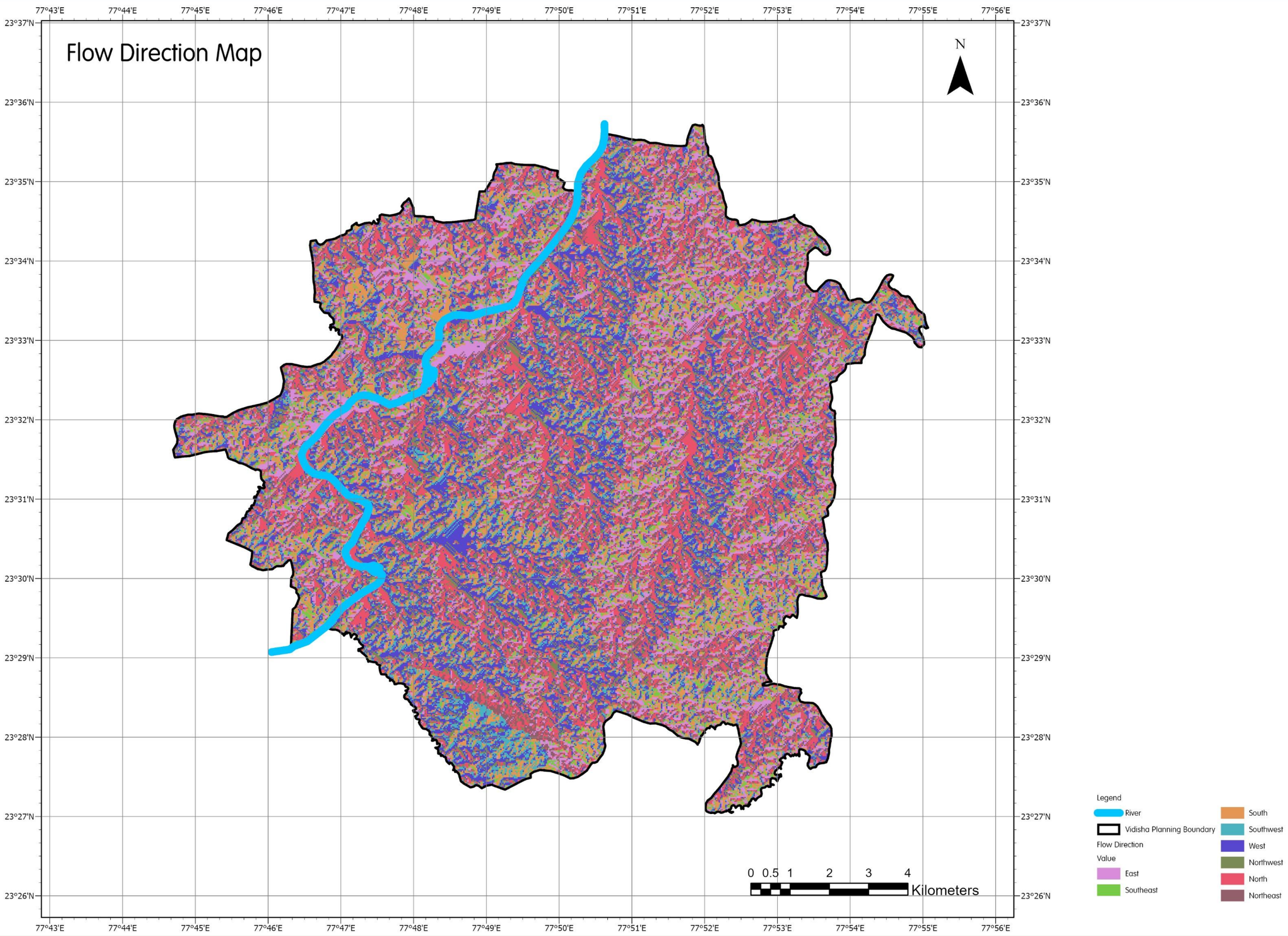
SLOPE ANALYSIS MAP: VIDISHA, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning



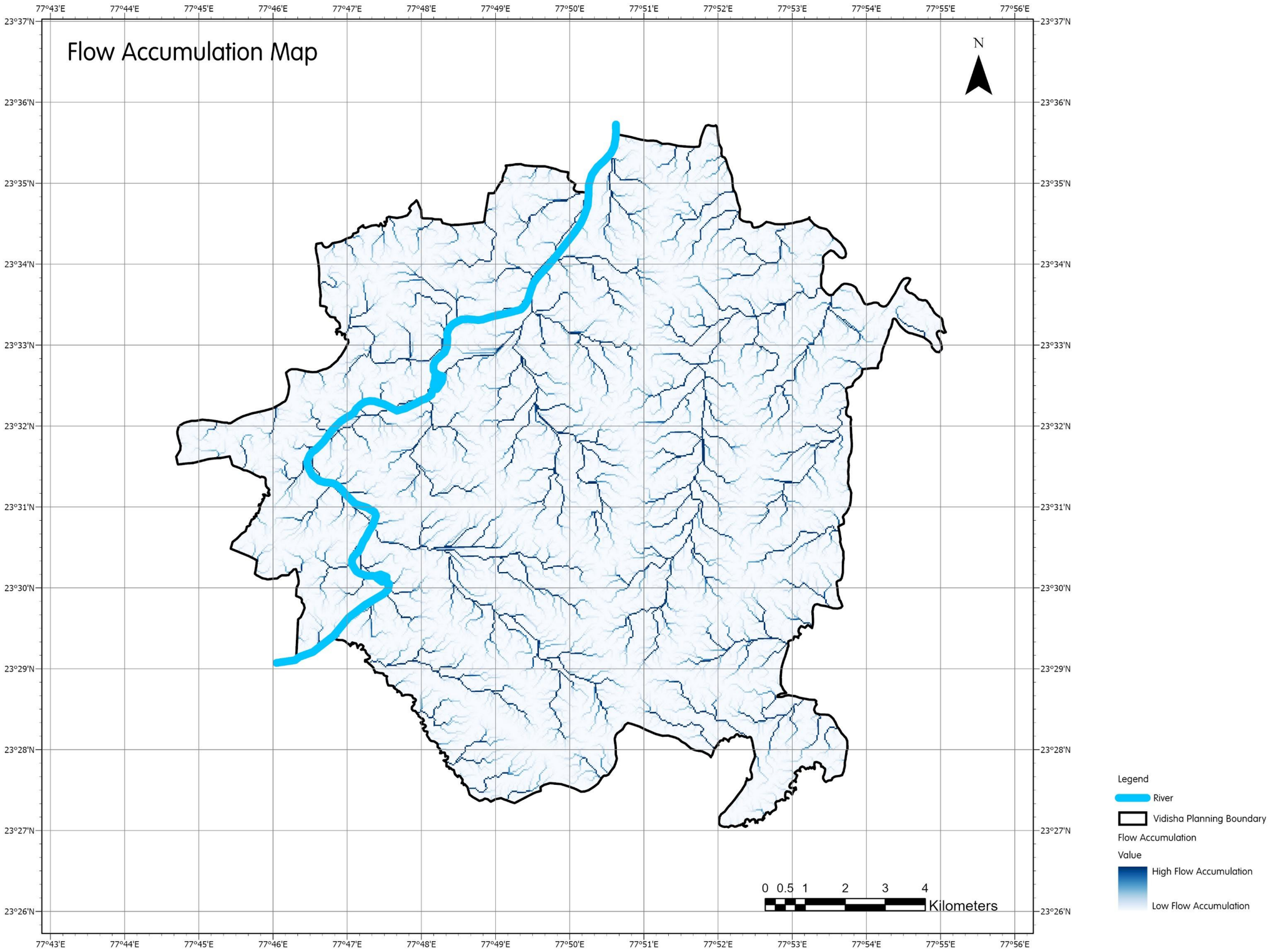
FLOW DIRECTION MAP: VIDISHA, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning



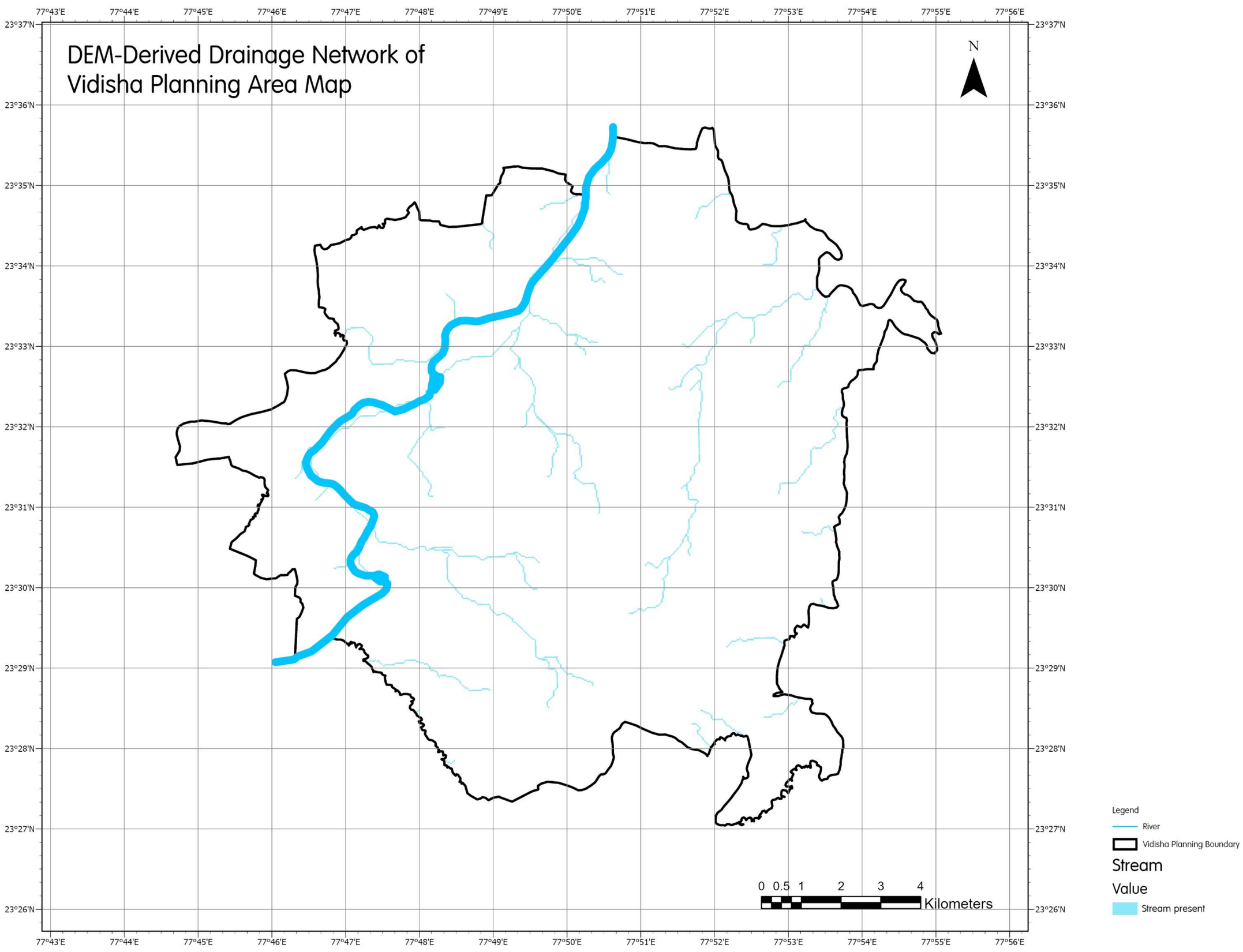
FLOW ACCUMULATION MAP: VIDISHA, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning

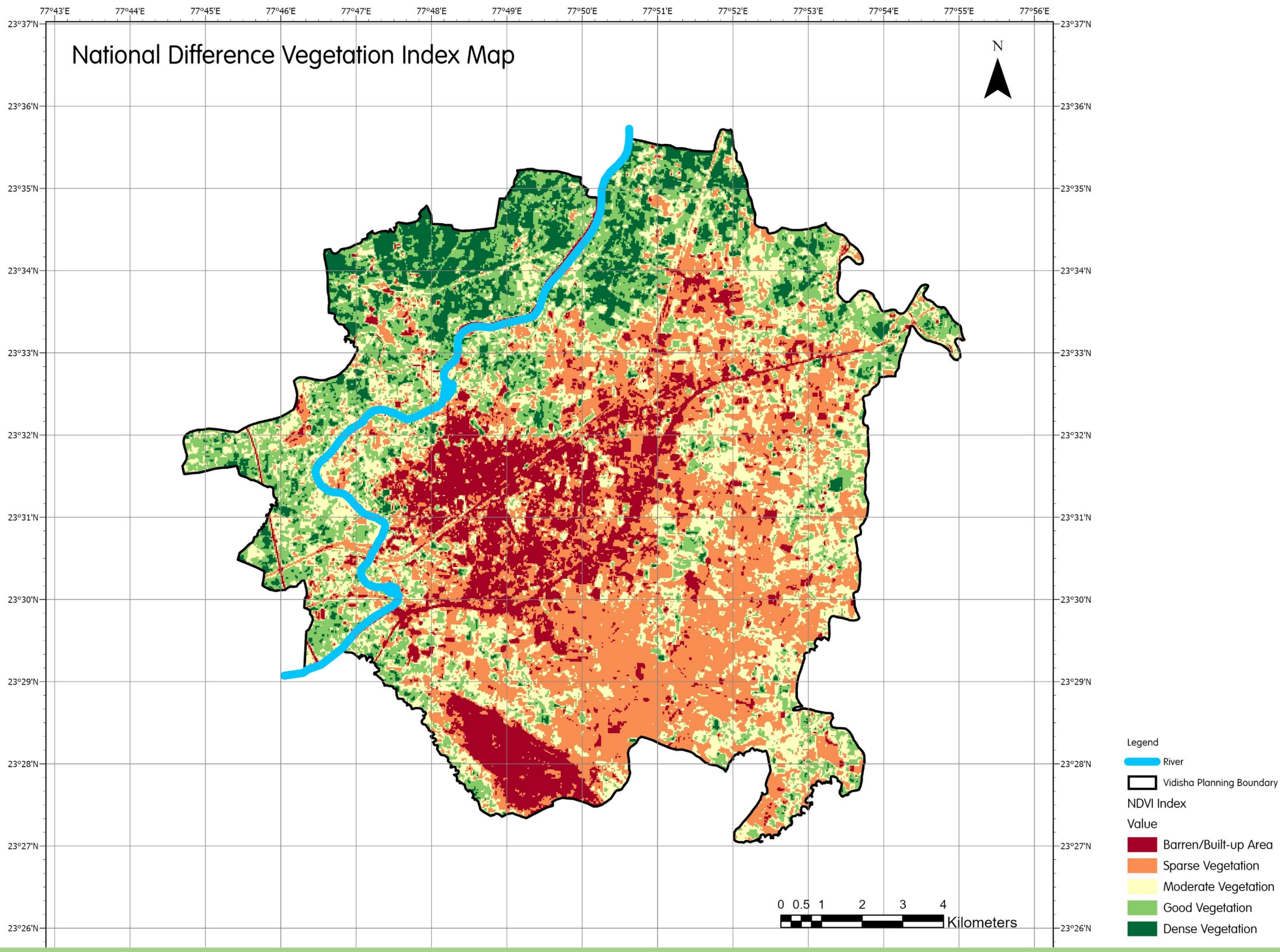


DEM DERIVED DRAINAGE NETWORK MAP: VIDISHA, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning

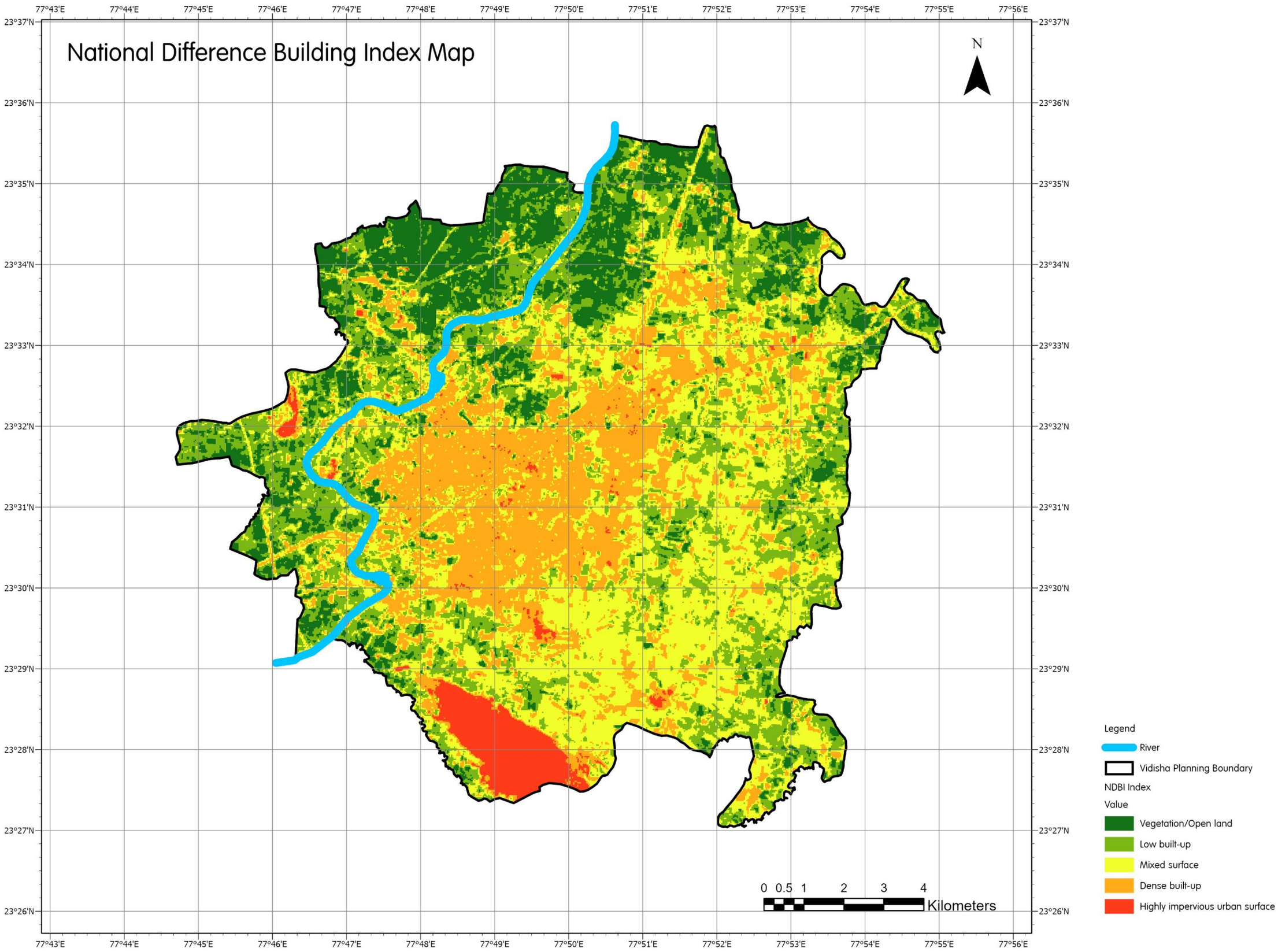


NATIONAL DIFFERENCE VEGETATION INDEX MAP: VIDISHA, MADHYA PRADESH

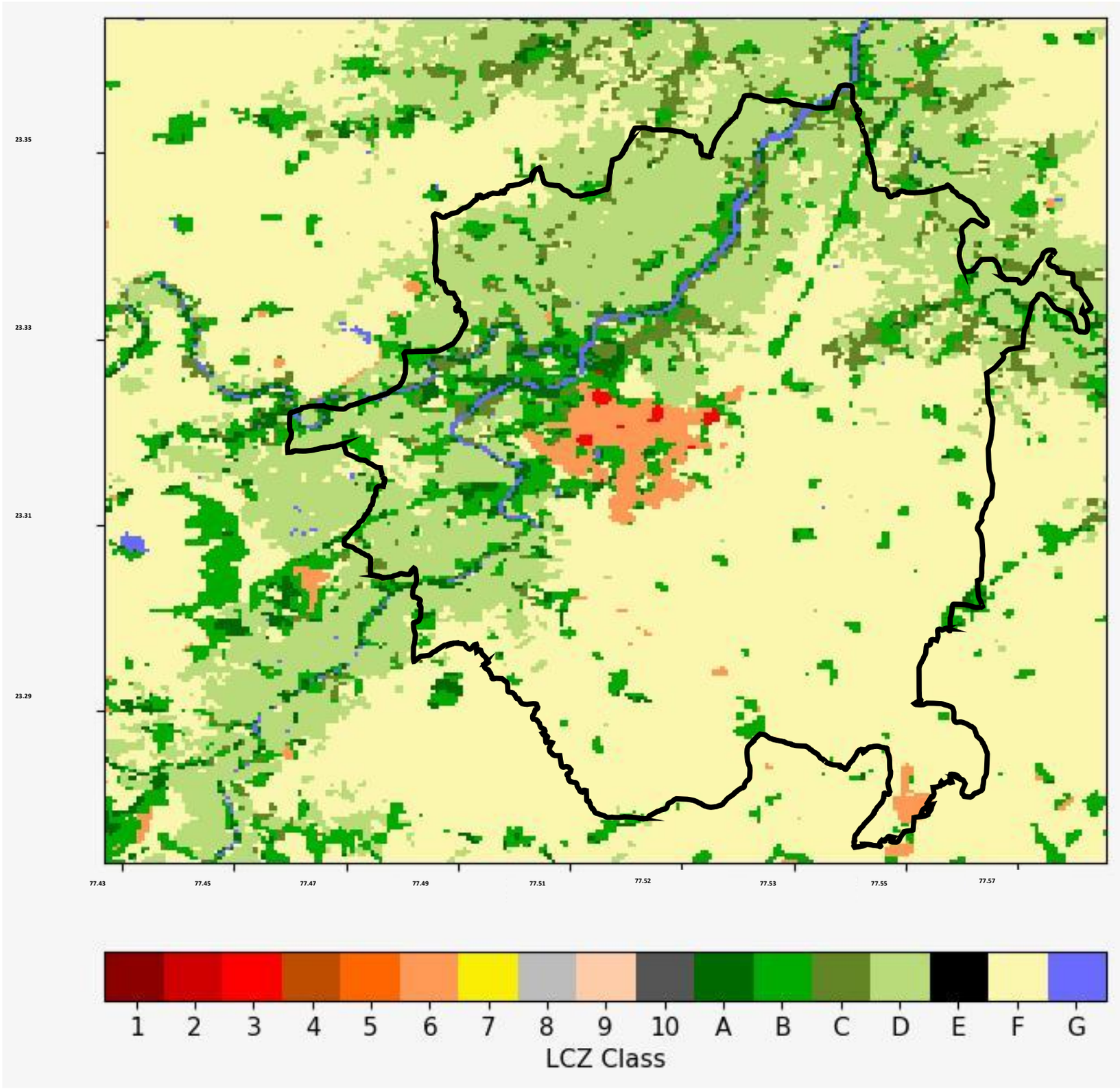


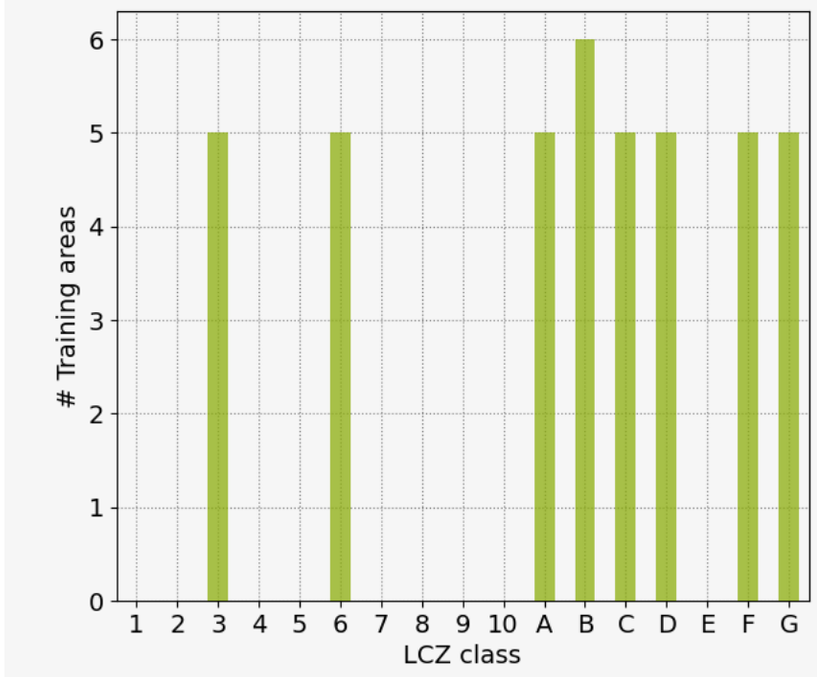
NATIONAL DIFFERENCE BUILDING INDEX MAP: VIDISHA, MADHYA PRADESH

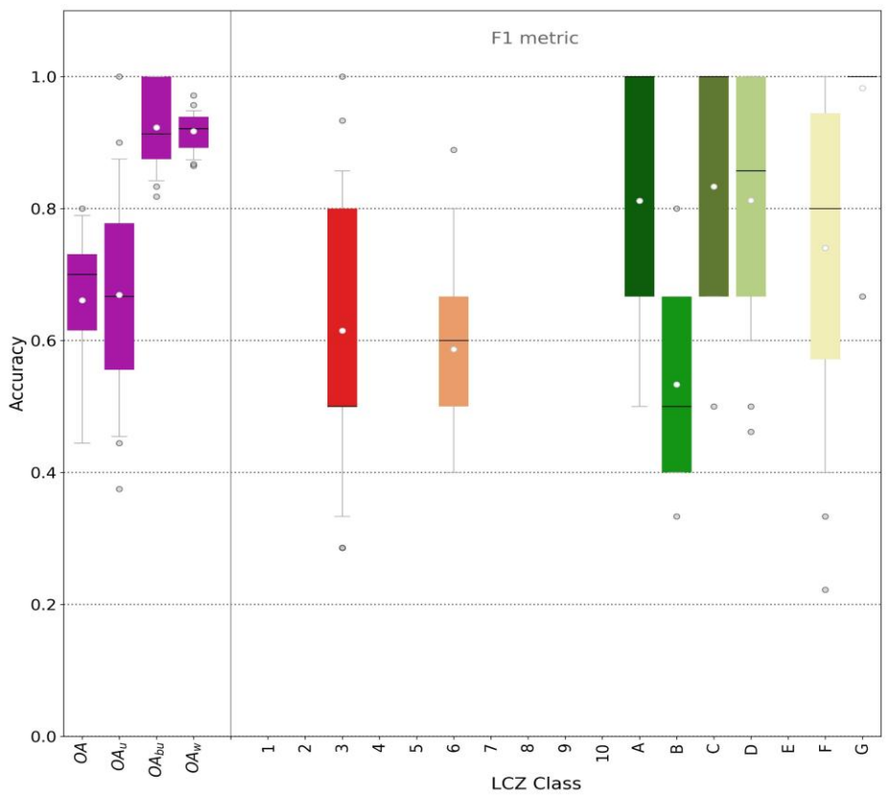
MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning



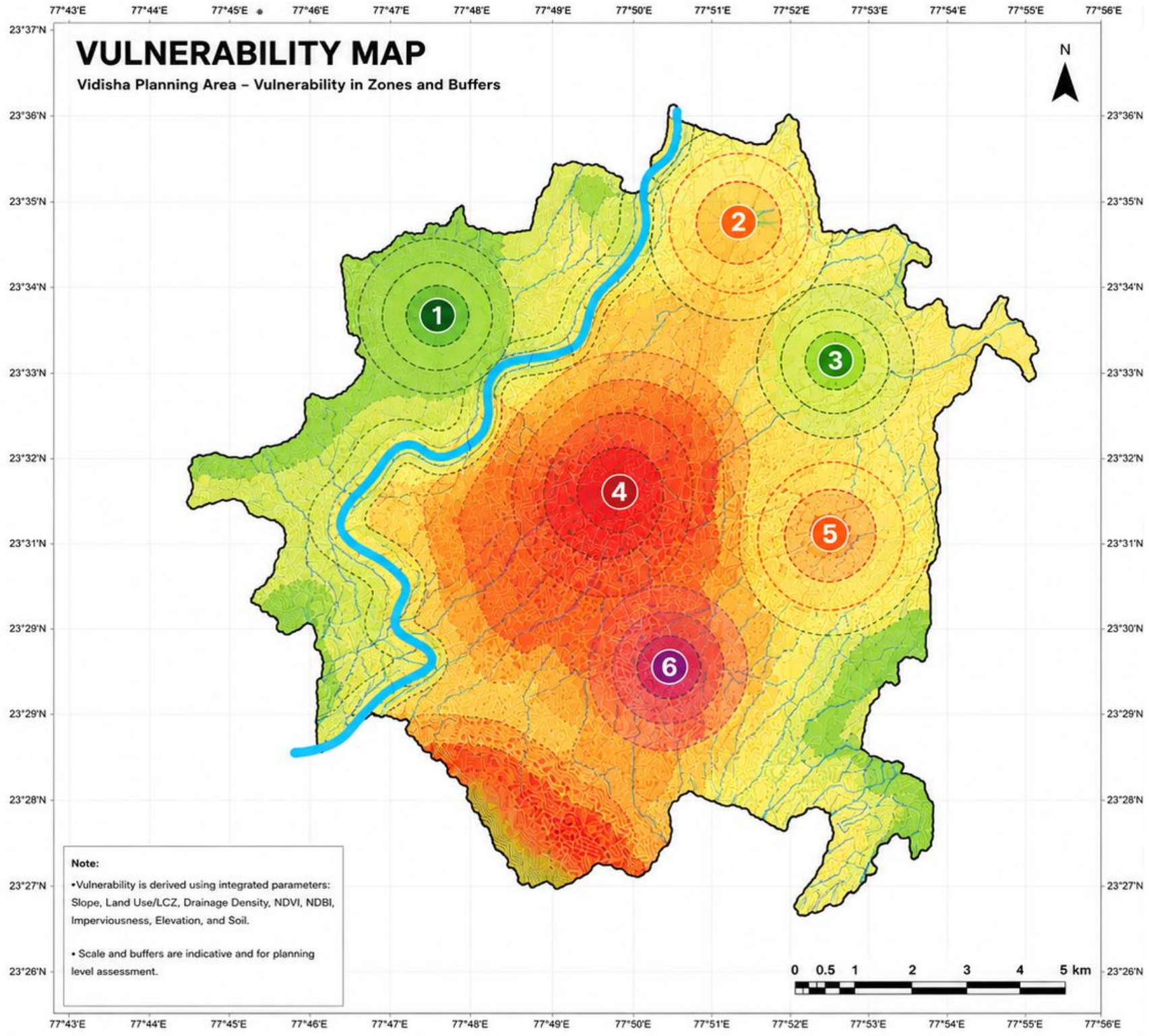
LCZ MAP: VIDISHA, MADHYA PRADESH







VULNERABILTY MAP: VIDISHA, MADHYA PRADESH



Legend

- River
- DEM-Derived Stream
- Vidisha Planning Boundary

Vulnerability Index

Value

- Very Low Vulnerability
- Low Vulnerability
- Moderate Vulnerability
- High Vulnerability
- Very High Vulnerability

Vulnerability Index : Methodology

Vulnerability index is derived using a weighted overlay of six thematic layers.

Parameters and Weights

1. Built-up (NDBI) : 0.25
2. Vegetation (NDVI) : 0.20
3. Slope : 0.15
4. Elevation (DEM) : 0.15
5. Drainage Density : 0.15
6. Proximity to River : 0.10

Higher index value indicates higher vulnerability.

Vulnerability Classes

Class	Index Range	Description
Very Low	0.00 – 0.20	Naturally protected areas with high vegetation, high elevation, low slope and away from rivers.
Low	0.20 – 0.40	Areas with low built-up and moderate biophysical risk.
Moderate	0.40 – 0.60	Transition zones with moderate built-up, slope and drainage influence.
High	0.60 – 0.80	High built-up areas, gentle slopes, low elevation and dense drainage influence.
Very High	0.80 – 1.00	Highly urbanized, low-lying areas near rivers and major drainage channels.

Proposal / Suggested Interventions

- **Very Low & Low Vulnerability Areas :** Conserve vegetation, restrict unplanned development, promote ecological buffers along streams.
- **Moderate Vulnerability Areas :** Implement sustainable urban drainage, rainwater harvesting, and land use regulation.
- **High & Very High Vulnerability Areas :** Prioritize stormwater infrastructure, drainage improvement, flood mitigation structures, riverfront management, and climate-resilient urban planning.

VULNERABILITY BY ZONE

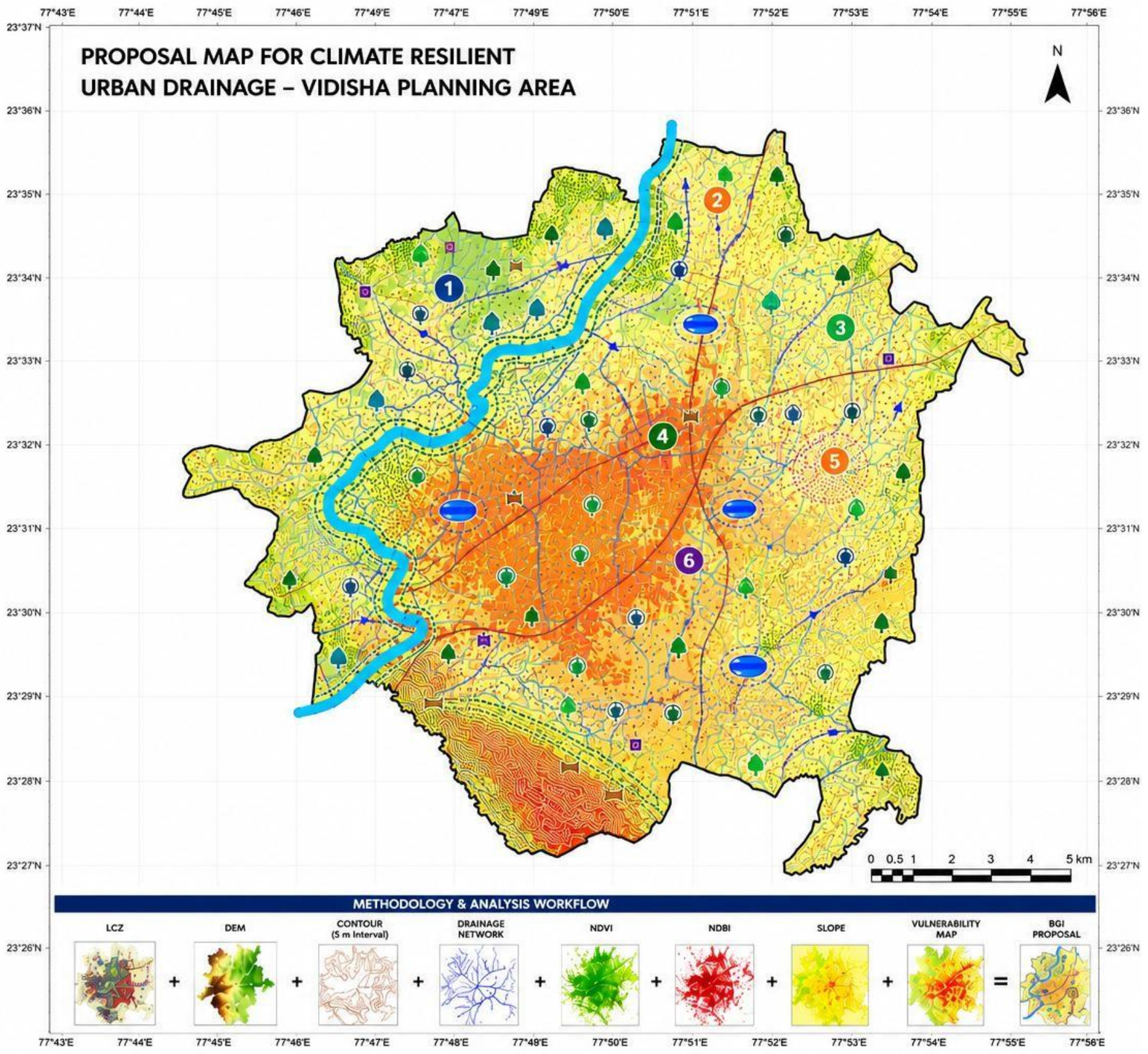
Zone	Vulnerability Level	Key Reasons
1	Low	Low density, good green cover, gentle slope, limited impervious.
2	Moderate	Moderate urbanization, undulating terrain, some runoff sensitivity.
3	Low to Moderate	Better drainage, presence of green spaces, moderate land use change.
4	Very High	High urban density, low infiltration, major runoff accumulation.
5	High	Rapid land use change, peri-urban growth, soil sealing.
6	High	Steep slopes in parts, fragile ecology, drainage convergence.

VULNERABILITY BY BUFFER

Buffer Type	Buffer Distance	Vulnerability Level
High Vulnerability Buffer	0 – 500 m	High
Moderate Vulnerability Buffer	500 – 1000 m	Moderate
Low Vulnerability Buffer	1000 – 1500 m	Low
Very Low Vulnerability Buffer	1500 – 2000 m	Very Low

PROPOSAL MAP: VIDISHA, MADHYA PRADESH

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)
मौलाना आजाद राष्ट्रीय प्रौद्योगिकी संस्थान, भोपाल (म.प्र.)
Department of Architecture and Planning



LEGEND

- River (Betwa)
- DEM-Derived Stream
- Surface Flow Direction
- Vidisha Planning Boundary
- Contour Line (5 m Interval)
- Drainage Network
- Water Bodies
- Riparian Corridor
- Urban Green Corridor
- Recharge Zone
- Afforestation Area
- Rainwater Harvesting Zone
- Flood Mitigation Zone

VULNERABILITY INDEX

Value

- Very Low Vulnerability
- Low Vulnerability
- Moderate Vulnerability
- High Vulnerability
- Very High Vulnerability

PROPOSED INTERVENTIONS

- Retention / Detention Pond
- Recharge Pit / Recharge Well
- Bioswale / Rain Garden
- Green Space / Urban Park
- Check Dam / Nalla Bund
- Contour Trench / Vegetative Swale
- Blue-Green Corridor / River Buffer (30–50 m)
- Stormwater Drain Improvement
- Permeable Pavement / Green Street
- Future Drainage Network

INTERVENTION ZONES

1. **Zone A** — Detention Basin (Tributary Junction)
2. **Zone B** — Retention Pond (North-Central)
3. **Zone C** — Detention Basin (East-Central Urban)
4. **Zone D** — Retention Pond (Central Urban)
5. **Zone E** — Rainwater Harvesting Zone (East)
6. **Zone F** — Flood Mitigation Zone (South)

METHODOLOGY & ANALYSIS WORKFLOW

LOCATION RATIONALE FOR RETENTION / DETENTION PONDS

Zone	Location Characteristics	Rationale
A	At confluence of western tributaries, gentle slope (1°–3°), low elevation	Intercepts upland runoff before entering Betwa; reduces peak flow and downstream flood risk.
B	Downstream of northern tributaries, gentle slope (1°–2°), low-lying area	Captures runoff from northern catchment; promotes recharge and flow moderation.
C	East-central urban area, low slope (1°–2°), existing drainage convergence	Handles urban stormwater, reduces waterlogging and supports recharge.
D	Central urban core, low slope (1°–2°), natural drainage pockets	Collects local runoff; supports groundwater recharge and downstream flow regulation.
E	East sector, gentle slope (1°–3°), low-lying patches	Promotes rainwater harvesting in built-up and peri-urban areas.
F	South sector, flood prone pockets, low elevation	Designated flood mitigation area for retention and sponging.

SLOPE BASED TREATMENT STRATEGY

> 5° (Steep)	Check dams, contour trenches, vegetative stabilization
3° – 5°	Recharge pits, contour bunds, bioswales
1° – 3°	Retention / detention ponds, bioswales, permeable surfaces
< 1° (Urban Lowlands)	Permeable pavements, rain gardens, recharge wells