Water Sensitive Urban Development: Planning Strategies for Conservation and Revival of Water Bodies, A Case of Mandsaur (M.P.)

MASTERS OF PLANNING

(Urban Planning)

by

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Water Sensitive Urban Development: Planning Strategies for Conservation and Revival of Water Bodies, A Case of Mandsaur (M.P.)

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by

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I hereby certify that the work which is being presented in the thesis entitled "**Water-Sensitive Urban Development: Planning Strategies for Conservation and Revival of Water Bodies, A case of Mandsaur (M.P.)"** in partial fulfillment of the requirements for the award of the Master of Planning (Urban Planning) and submitted in the Department of Architecture and Planning of the Maulana Azad National Institute of Technology, Bhopal is an authentic record of my own work carried out during the period from July 2025 to July 2026 under the supervision of **Dr. Charumitra Kapshe,** Professor, Department of Architecture and Planning, Maulana Azad National Institute of Technology, Bhopal.

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ABSTRACT

Urban water systems in Indian cities are facing increasing challenges due to rapid urbanization, population growth, and unplanned development. These factors have contributed to the degradation of traditional water bodies, inefficient water supply systems, reduced groundwater recharge, and inadequate drainage infrastructure. This study develops a Water Sensitive Urban Development (WSUD) based planning framework for the conservation and revival of urban water bodies in Mandsaur City, Madhya Pradesh. The study begins with a comprehensive analysis of the city's geographical, demographic, and hydrological characteristics. Mandsaur is influenced by the Shivna River and a network of traditional ponds and tanks that historically played a vital role in meeting the city's water requirements. However, these water bodies have experienced significant deterioration due to encroachment, pollution and siltation.

Both primary and secondary data sources were utilized to assess the existing water management scenario. GIS-based spatial analysis was employed to evaluate contours, drainage patterns, watershed characteristics, land use distribution, groundwater conditions, and the status of urban water bodies. The assessment identified several critical issues, including uneven water distribution, low-pressure supply zones, dependence on groundwater sources such as wells and hand pumps, declining groundwater levels, and inadequate integration of water bodies within the urban water supply system. Based on the findings, planning strategies has been proposed for the conservation and revival of water bodies. These include rainwater harvesting, groundwater recharge structures, storm water management interventions, ecological restoration of water bodies, desilting measures into the urban planning framework. The study further emphasizes the importance of combining traditional water management practices with modern planning approaches and GIS-based decision-making tools.

The research demonstrates that the application of WSUD principles can significantly improve groundwater recharge, enhance urban water security, restore degraded water bodies and support urban development. The study highlights the urgent need for the conservation and revival of urban water bodies in Mandsaur and provides a replicable framework for medium-sized Indian cities facing similar water management challenges.

सारांश

भारतीय शहरों में शहरी जल प्रणालियाँ तीव्र शहरीकरण, जनसंख्या वृद्धि तथा अव्यवस्थित विकास के कारण बढ़ती चुनौतियों का सामना कर रही हैं। इन कारकों ने पारंपरिक जल निकायों के क्षरण, अप्रभावी जलापूर्ति प्रणालियों, भूजल पुनर्भरण में कमी तथा अपर्याप्त जल निकासी अवसंरचना जैसी समस्याओं को जन्म दिया है। यह अध्ययन मध्य प्रदेश के मंदसौर शहर में शहरी जल निकायों के संरक्षण एवं पुनर्जीवन के लिए जल-संवेदनशील शहरी विकास (Water Sensitive Urban Development - WSUD) आधारित नियोजन रूपरेखा विकसित करता है। अध्ययन की शुरुआत शहर की भौगोलिक, जनसांख्यिकीय तथा जलवैज्ञानिक विशेषताओं के व्यापक विश्लेषण से की गई है। मंदसौर शहर शिवना नदी तथा पारंपरिक तालाबों एवं टैंकों के नेटवर्क से प्रभावित है, जिन्होंने ऐतिहासिक रूप से शहर की जल आवश्यकताओं की पूर्ति में महत्वपूर्ण भूमिका निभाई है। हालांकि, अतिक्रमण, प्रदूषण तथा गाद जमाव (सिल्टेशन) के कारण इन जल निकायों की स्थिति में उल्लेखनीय गिरावट आई है।

वर्तमान जल प्रबंधन की स्थिति का आकलन करने के लिए प्राथमिक तथा द्वितीयक दोनों प्रकार के आंकड़ों का उपयोग किया गया। समोच्च रेखाओं (Contours), जल निकासी प्रतिरूपों (Drainage Patterns), जलग्रहण क्षेत्र (Watershed) की विशेषताओं, भूमि उपयोग वितरण, भूजल स्थिति तथा शहरी जल निकायों की वर्तमान अवस्था का मूल्यांकन करने हेतु GIS आधारित स्थानिक विश्लेषण किया गया। इस मूल्यांकन में कई महत्वपूर्ण समस्याएँ सामने आईं, जिनमें जल वितरण की असमानता, निम्न-दाब वाले जलापूर्ति क्षेत्र, कुओं एवं हैंडपंप जैसे भूजल स्रोतों पर निर्भरता, भूजल स्तर में गिरावट तथा शहरी जलापूर्ति प्रणाली में जल निकायों का अपर्याप्त एकीकरण शामिल हैं। अध्ययन के निष्कर्षों के आधार पर जल निकायों के संरक्षण एवं पुनर्जीवन हेतु नियोजन रणनीतियाँ प्रस्तावित की गई हैं। इनमें वर्षाजल संचयन, भूजल पुनर्भरण संरचनाएँ, वर्षा जल निकासी प्रबंधन हस्तक्षेप, जल निकायों का पारिस्थितिकीय पुनर्स्थापन तथा गाद निकासी (Desilting) को शहरी नियोजन ढाँचे में सम्मिलित करना शामिल है। अध्ययन आधुनिक नियोजन दृष्टिकोणों तथा GIS आधारित निर्णय-निर्माण उपकरणों के साथ पारंपरिक जल प्रबंधन पद्धतियों के समन्वय के महत्व पर भी बल देता है।

यह शोध दर्शाता है कि WSUD सिद्धांतों का अनुप्रयोग भूजल पुनर्भरण में उल्लेखनीय सुधार, शहरी जल सुरक्षा को सुदृढ़ करने, क्षतिग्रस्त जल निकायों के पुनर्स्थापन तथा शहरी विकास को समर्थन प्रदान करने में महत्वपूर्ण भूमिका निभा सकता है। अध्ययन मंदसौर शहर में शहरी जल निकायों के संरक्षण एवं पुनर्जीवन की तत्काल आवश्यकता को रेखांकित करता है तथा समान जल प्रबंधन चुनौतियों का सामना कर रहे भारत के मध्यम आकार के शहरों के लिए एक पुनरुत्पादित (Replicable) नियोजन रूपरेखा प्रस्तुत करता है।

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TABLE OF CONTENT

CERTIFICATE OF PLAGIARISM ..... **iii**

CANDIDATE'S DECLARATION ..... **iv**

सारांश ..... **vi**

ACKNOWLEDGEMENT ..... **vii**

LIST OF FIGURES ..... **xiv**

LIST OF TABLE ..... **xvi**

LIST OF ABBREVIATIONS ..... **xviii**

CHAPTER 1: INTRODUCTION **1**

1.0 Background Study **1**

1.1 WSUD and Its Importance **3**

1.2 Current Status of Water Bodies in India **4**

1.3 Need for the Study **6**

1.4 Aim and Objectives **7**

1.5 Scope **8**

1.6 Limitations **9**

1.7 Methodology **9**

1.8 Case Selection Criteria **13**

CHAPTER:2- LITERATURE REVIEW **20**

2.0 Introduction **20**

2.1 Types of Water Bodies **21**

2.2 Water Bodies and Environmental Issues **23**

2.3 Pollution **23**

2.3.1 Domestic Pollution 24

2.3.2 Industrial Pollution 24

2.3.3 Solid-Waste Pollution 25

2.3.4 Sedimentation / Siltation Pollution 26

2.3.5 Thermal Pollution 27
2.3.6 Oil & Hydrocarbon Pollution 27
2.3.7 Heavy-Metal Pollution 28
2.3.8 Biological Pollution 28
2.4 Traditional Practices 28
2.4.1 Johads 30
2.4.2 Baolis/Stepwells 32
2.4.3 Tanks 34
2.5 Water Revival Strategies 35
2.5.1 Restoration of Traditional Water Systems 36
2.5.2 Ecological Restoration 37
2.5.3 Hydrological Improvements 38
2.6 Innovative Approaches 38
2.6.1 Floating Wetlands 39
2.6.2 Bioremediation Using Bacterial Cultures 39
2.6.3 Community-Led Restoration Projects 40
2.7 Pollution Mitigation Strategies for Water Bodies 40
2.7.1 Sewage and Wastewater Management 41
2.7.2 Bioremediation and Nature-Based Solutions 42
2.7.3 Preventing Encroachments and Solid Waste Pollution 42
2.8 Sustainable Planning Interventions 43
2.8.1 Enhancing Ecological Balance 44
2.8.2 Strengthening Groundwater Recharge 45
2.8.3 Detention Ponds 47
2.8.4 Bioswale 48
2.8.5 Building Community Resilience 49
2.9 Case Studies of Water Sensitive Urban Development 50

2.9.1 Jakkur Lake – A Water Sensitive Urban Development (WSUD) Model, Bengaluru, Karnataka 50
2.9.2 Alwar Johad Revival, Rajasthan Community-Based Water Conservation 52
2.9.3 Hussain Sagar Lake Restoration, Hyderabad, Telangana 55
2.9.4 Rajkot Rainwater Harvesting Initiative, Gujarat 57
2.9.5 ABC Waters Programme, Singapore 58
2.10 Government Initiatives for Water Conservation 60
2.11 Government Schemes for River Conservation and Rejuvenation in India 60
2.11.1. National River Conservation Plan (NRCP) 61
2.11.2. Namami Gange Programme 61
2.11.3. National Mission for Clean Ganga (NMCG) 62
2.11.4. Integrated River Basin Management Approach 62
2.12 Water Conservation Schemes and Programs 64
2.12.1 AMRUT (Atal Mission for Rejuvenation and Urban Transformation) 64
2.12.2 Smart Cities Mission 65
2.12.3 National Plan for Conservation of Aquatic Ecosystems (NPCA) 66
2.12.4 Swachh Bharat Mission (SBM) 66
2.13 Initiatives at City/Local Level 68
2.14 Land Use & Zoning Regulations 69
2.14.1 Building Bye-laws for Water Conservation 70
2.14.2 International Framework 72
2.15 National Framework 72
2.15.1 Traditional Water Bodies 72
2.15.2 Surface Water Bodies 73
2.16 State-Level Land Use and Zoning Regulations 74
2.16.1 On-Site Level Regulations 75
2.17 Learnings 76
CHAPTER 3-CASE STUDY MANDSAUR 79

3.0 Introduction **79**

3.1 Location **80**

3.2 Historical Evolution of Water System in Mandsaur **84**

3.2.1 Ancient–Medieval Period (Traditional Water Systems) 84

3.2.2 Medieval–Early Modern Period (Integrated Water Systems) 85

3.2.3 Colonial and Early Post-Independence Period (Transition Phase) 85

3.2.4 Modern Period (Post-1980s Urban Expansion) 85

3.2.5 Recent Phase (2000s–Present: Water Stress & Flood Events) 86

3.3 History of Water & Flood Events in Mandsaur **86**

3.4 Administrative Detail **87**

3.4.1 Ward Boundary 92

3.5 Demographic Detail **94**

3.5.1 Population 94

3.5.2 SC & ST Population 94

3.5.3 Child Population 95

3.5.4 Working Population 96

3.5.5 Occupational Structure 97

3.5.6 Slum and Squatter Areas 98

3.5.7 Sex Ratio 99

3.5.8 Literacy Rate 100

3.5.9 Ward Population 101

3.5.10 Density 103

3.6 Geographic Details **105**

3.6.1 Soil 105

3.6.2 Climate and Rainfall 106

3.6.3 Contour 108

3.6.4 Watershed 110

3.6.5 Drainage 112

3.6.6 Slope....113
3.7 Application of WSUD for Mandsaur....115
3.7.1 Lessons for Mandsaur Derived from Literature....123
3.8 Inferences....126
CHAPTER 4-DATA AND DATA ANALYSIS....127
4.0 Introduction....127
4.1 Water Bodies....127
4.1.1 Condition of Shivna River....129
4.1.2 Teliya Talaab....132
4.2 Water Quality....133
4.3 Other Surface Water Bodies....133
4.3.1 Ramghat Barrage....134
4.3.2 Kalabhata Dam....134
4.3.3 Local Ponds and Talabs....134
4.4 Integrated Surface Water System....135
4.5 Overhead Tank....135
4.6 Water Supply Network....140
4.7 Other sources....143
4.7.1 Well....143
4.7.2 Hand Pumps....145
4.8 Existing Water Management Initiatives in Mandsaur....147
4.9 Land use....147
4.9 Population Projection....150
4.10 Ward Ranking and Indicators....152
4.11 Ward Details....156
4.12 Findings....164
CHAPTER 5-PROPOSALS....165
5.0 Introduction....165

5.1 Proposals for Revival and Conservation of Water Bodies 165

5.1.1 Teliya Talaab 166

5.1.2 Shivna River 176

5.1.3 Tank inside masjid peripheral 179

5.2 Ward Level Proposals 182

5.3 City Level Proposals 189

5.4 Inferences 195

CHAPTER 6-RESULTS AND DISCUSSIONS 197

निष्कर्ष 200

References 201

LIST OF FIGURES

Figure 1 :Status of Water Bodies in India 5

Figure 2:Visual Diagram of Need of the Study 6

Figure 3: Methodology of Phase 1 10

Figure 4: Methodology of Phase 2 12

Figure 5:Water Stress Map of India 15

Figure 6: 2013 Google Earth Image Showing Condition of Water Bodies 16

Figure 7: 2020 Google Earth Image Showing Condition of Water Bodies 16

Figure 8: 2025 Google Earth Image Showing Condition of Water Bodies 17

Figure 9: Image of Johad.....31

Figure 10:Section of Rajon ki Baoli.....33

Figure 11:Image of Rain Garden 45

Figure 12:Image of Aquifier.....47

Figure 13:Detention Pond.....48

Figure 14:Image of Bioswale.....49

Figure 15: Before and After Image of Johads in Karauli 53

Figure 16: Image of Hussain Sagar Lake 55

Figure 17: Location Map 80

Figure 18: District Map of Mandsaur.....81

Figure 19: District Drainage of Mandsaur.....83

Figure 20: Planning Boundary.....90

Figure 21: 2001 Planning Boundary of Mandsaur 91

Figure 22: Ward Map of Mandsaur.....93

Figure 23: Pie Chart of Population based on Census (2011).....94

Figure 24: Ward Population Map.....102

Figure 25: Ward Density Map 104

Figure 26:Contour Map 109
Figure 27:Micro Watershed of Shivna River 110
Figure 28: Watershed of Mandsaur 111
Figure 29: Drainage Map 112
Figure 30: Slope Map 114
Figure 31: Location of Water Bodies 128
Figure 32: Condition of Shivna River 130
Figure 33: Image of Teliya Talaab 132
Figure 34: Location of OHT, STP and Raw Water Source 136
Figure 35: Density Map with OHTs Overlay 139
Figure 36: Water Supply Network of Mandsaur 142
Figure 37: Well Locations 144
Figure 38: Ground Water Dependency and Extraction Hotspots 146
Figure 39: LU/LC Map 2020 150
Figure 40: Talaab Buffer Map 166
Figure 41: Proposed Bioswale Location 173
Figure 42: Shivna River Encroachment 177
Figure 43: Shivna River Encroachment 178
Figure 44 : Shivna River Encroachment 179
Figure 45: Planning and Design Requirements for a Solar-Powered Aeration Fountain 180
Figure 46: Condition of Tank inside Masjid 181
Figure 47: Proposed Map for Tank 182
Figure 48: Image of Permeable Concrete Road Section 183
Figure 49: Proposed Map for Ward 3 184
Figure 50: Image of Well in Ward 10 185
Figure 51: Proposal for Well 186

Figure 52: Section of Permeable Paver 187

Figure 53: Cross-Section of a Well with Permeable Pavement for Rainwater Infiltration 188

Figure 54: Section Showing Process of Recharge Aquifers 190

Figure 55: Proposed Location for Recharge Wells 194

LIST OF TABLES

Table 1:Government Initiatives 67

Table 2:Takeaways from the Study 76

Table 3: Administrative Detail of Mandsaur 88

Table 4:Mandsaur District Block Details 89

Table 5: SC/ST Population 95

Table 6: Gender Wise Distribution of SC/ST 95

Table 7: Child Population 96

Table 8: Working Population Distribution Ward Wise 97

Table 9: Occupational Structure 98

Table 10: Sex Ratio 99

Table 11: Literacy Rate 100

Table 12: Water Table Depth 107

Table 13: Watershed of Mandsaur 110

Table 14: Detail List of Methods 1 116

Table 15: Detail List of Methods 2 118

Table 16: Detail List of Methods 3 121

Table 17: Water Quality of Mandsaur 133

Table 18: Details of OHTs 137

Table 19: Land Use 2001 147

Table 20: Sector Wise Water Demand Distribution 148

Table 21: Sector Wise Water Demand Distribution 2041 149

Table 22: Population Projection 151

Table 23: Estimated Population for 2021,2031 and 2041 152

Table 24: Ward-Wise Demographic and Population Density Analysis (2011 Census) % for Water Demand Calculation 153

Table 25: Parameters and Indicators for Ward 1 to 4 156

Table 26: Parameters and Indicators for Ward 5 to 8 157

Table 27: Parameters and Indicators for Ward 9 to 12 158

Table 28: Parameters and Indicators for Ward 13 to 16 158

Table 29: Parameters and Indicators for Ward 17 to 20 159

Table 30: Parameters and Indicators for Ward 21 to 24 160

Table 31: Parameters and Indicators for Ward 25 to 28 160

Table 32: Parameters and Indicators for Ward 29 to 32 161

Table 33: Parameters and Indicators for Ward 33 to 36 162

Table 34: Parameters and Indicators for Ward 37 to 40 163

Table 35: Detail Comparison of Ward 39 and Ward 22 169

List of Annexure

Annexure 1: Native Vegetation Suitable Species and their Ecological Role ……206

Annexure 2: Survey Questions……..……..…207

Annexure 3: Plagiarism Report……..……208

Annexure 4: All Maps……209

List of Abbreviations

Abbreviation	Full Form
ABC	Active, Beautiful, Clean
AKTC	Aga Khan Trust for Culture
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BOD	Biochemical Oxygen Demand
CGWB	Central Ground Water Board
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CRRT	Chennai Rivers Restoration Trust
CSE	Centre for Science and Environment
CPHEEO	Central Public Health and Environmental Engineering Organization
DEWATS	Decentralized Wastewater Treatment System
EC	Electrical Conductivity
EFI	Environmentalist Foundation of India
EPA	Environmental Protection Agency
GIS	Geographic Information System
GoI	Government of India
GPS	Global Positioning System
HOD	Head of Department
INTACH	Indian National Trust for Art and Cultural Heritage
IPCC	Intergovernmental Panel on Climate Change
IRBM	Integrated River Basin Management
IWA	International Water Association
JAW	Joint Action for Water
JBF	Jal Bhagirathi Foundation
JJM	Jal Jeevan Mission
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
JSA	Jal Shakti Abhiyan
KL	Kiloliter
LID	Low Impact Development
LU/LC	Land Use/Land Cover
MLD	Million Liters per Day
ML	Million Liters
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MoJS	Ministry of Jal Shakti
MP	Madhya Pradesh

NIUA	National Institute of Urban Affairs
NITI Aayog	National Institution for Transforming India
NLCP	National Lake Conservation Plan
NMCG	National Mission for Clean Ganga
NPCA	National Plan for Conservation of Aquatic Ecosystems
NRCP	National River Conservation Plan
NRSC	National Remote Sensing Centre
NRW	Non-Revenue Water
NWCP	National Wetlands Conservation Programme
OHT	Overhead Tank
PG	Postgraduate
PUB	Public Utilities Board (Singapore)
QGIS	Quantum Geographic Information System
SBM	Swachh Bharat Mission
SC	Scheduled Caste
SDG	Sustainable Development Goal
SDG 6	Sustainable Development Goal 6 – Clean Water and Sanitation
SDG 11	Sustainable Development Goal 11 – Sustainable Cities and Communities
SDG 13	Sustainable Development Goal 13 – Climate Action
SDG 15	Sustainable Development Goal 15 – Life on Land
ST	Scheduled Tribe
STP	Sewage Treatment Plant
SWM	Solid Waste Management
TBS	Tarun Bharat Sangh
TMC	Thousand Million Cubic Feet
ULB	Urban Local Body
UNEP	United Nations Environment Programme
UN	United Nations
UN-Habitat	United Nations Human Settlements Programme
UNSDG	United Nations Sustainable Development Goals
URDPFI	Urban and Regional Development Plans Formulation and Implementation Guidelines
VWSC	Village Water and Sanitation Committee
WOTR	Watershed Organisation Trust
WRI	World Resources Institute
WST	Water Science and Technology
WTP	Water Treatment Plant
WSUD	Water Sensitive Urban Development
WWF	World Wide Fund for Nature

CHAPTER 1: INTRODUCTION

1.0 Background Study

Water-Sensitive Urban Development (WSUD) represents an integrated approach to urban design, infrastructure, and planning that manages the entire water cycle including storm water, wastewater, groundwater, and potable supply within the built environment. It seeks to minimize environmental impacts, enhance water security, and promote sustainable urban livability (Brown, Keath, & Wong, 2009). As cities expand rapidly, the traditional separation between water management and urban planning has proven unsustainable. WSUD bridges this gap by embedding water considerations into the core of spatial planning and design processes, ensuring that cities evolve as resilient, adaptive, and ecologically balanced systems (Fletcher et al., 2015).

Urban water bodies such as lakes, ponds, rivers, and wetlands are crucial ecological assets that perform multiple environmental, social, and economic functions. They contribute to groundwater recharge, flood regulation, temperature moderation, and biodiversity enhancement. Moreover, these water systems carry cultural, aesthetic, and recreational significance, forming the backbone of many historical and contemporary urban settlements. However, due to rapid urbanization, industrial expansion, and unplanned land-use changes, these water bodies are increasingly threatened. Encroachments, pollution, and loss of catchment connectivity have led to their degradation, while poor institutional management has resulted in the undervaluation of water as a shared resource (Singh & Sharma, 2024). In many cities, water is treated as an unlimited commodity, leading to wastage and inefficiencies, with distribution losses often exceeding 40–50% (Singh & Rosado, 2024).

Urban planning frameworks play a transformative role in reversing these trends. Integrating water-sensitive strategies within Master Plans, Development Plans, and zoning regulations allows for the systematic protection, restoration, and long-term management of urban water assets (Singh, 2019). Both traditional practices and modern technologies offer valuable lessons. Indigenous systems such as tanks, baolis, johads, and temple ponds once served as sustainable models of water conservation, deeply rooted in social and climatic contexts (Agarwal & Narain, 1997; Joshi, 2019). Their principles of recharge, reuse, and community stewardship remain relevant today. In parallel, emerging technologies including decentralized wastewater

treatment (DEWATS), rainwater harvesting, bio-remediation, and GIS-based monitoring offer scalable solutions for sustainable urban water management (Sharma & Patel, 2021). Combining these traditional and contemporary approaches within WSUD provides a holistic framework for the revival and conservation of urban water bodies.

In India, WSUD as a formalized concept began gaining attention in the early 2000s through academic research, pilot projects, and policy initiatives such as the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), AMRUT, and the Smart Cities Mission (MoHUA, 2015). These programs, though not explicitly labeled under WSUD, incorporated its principles through water body rejuvenation, storm water management, and urban resilience strategies (Brown, Keath, & Wong, 2009).

India's first Census of Water Bodies (2018–19) reported 2.42 million water bodies nationwide, with 78% man-made and 22% natural. However, only 2.9% of these are located in urban areas, indicating a significant spatial imbalance (Ministry of Jal Shakti, 2023). This scarcity, compounded by urban sprawl, has intensified water stress in major cities. Issues such as groundwater depletion, contamination, and untreated sewage inflows into lakes and rivers are widespread (Sridhar, 2025). For instance, cities like Delhi, Mumbai, and Bengaluru depend on distant water sources, emphasizing the unsustainable nature of current supply models (Singh, 2022). Climate change further exacerbates these pressures, altering rainfall patterns and increasing both drought and flood risks. The World Resources Institute identifies several Indian states including Rajasthan, Punjab, Gujarat, and Madhya Pradesh as facing extremely high water stress, underscoring the urgency for water-sensitive urban planning.

Instead of relying solely on grey infrastructure, WSUD emphasizes nature-based solutions such as green roofs, bio-swales, retention basins, and constructed wetlands. These interventions not only manage stormwater and reduce flooding but also enhance biodiversity, improve air quality, and create vibrant public spaces. Global examples such as Singapore's ABC Waters Programme and Melbourne's city-wide WSUD initiatives demonstrate how aesthetic, ecological, and social goals can be achieved simultaneously through integrated planning (JAW, 2024).

1.1 WSUD and Its Importance

The concept of WSUD emerged in Australia and Europe as an integrated approach to managing the urban water cycle, aiming to minimize environmental impacts and improve urban resilience (Fletcher et al., 2015). Its core principles include sustainable water use, storm water management, and enhancement of urban livability. In India, WSUD is gradually being incorporated into urban planning frameworks, offering innovative opportunities for reviving degraded water bodies (Brown, Keath, & Wong, 2009).

In India, WSUD as a formalized concept began to gain attention only in the early 2000s, mainly through academic research and pilot initiatives (Sharma & Joshi, 2022). While the term "WSUD" was not explicitly used in early policies, its principles were embedded in various urban water management programs. Between 2005 and 2010, discussions in academic circles, particularly at IITs and research institutions, highlighted the importance of sustainable urban water systems (Kumar et al., 2020). The Jawaharlal Nehru National Urban Renewal Mission (JNNURM), launched in 2008, indirectly reflected WSUD principles by promoting sustainable urban water supply and sanitation practices (MoHUA, 2009). From 2011 onwards, the terminology of WSUD started appearing in urban planning research, influenced by global frameworks and case studies (Brown, Keath, & Wong, 2009). The introduction of the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) in 2015 and the Smart Cities Mission further strengthened this integration by focusing on storm water management, water body rejuvenation, and reuse strategies (MoHUA, 2015). More recently, WSUD has been explicitly incorporated into academic discourse, research dissertations, and pilot projects in Indian cities such as Bengaluru, Chennai, and Delhi (Singh & Rosado, 2024).

Importance of Water Sensitive Urban Development

Sustainable Water Management

Promotes the integrated management of the entire urban water cycle, including potable water, storm water, groundwater, and wastewater. It encourages efficient water use and reduces dependence on conventional water supply systems (Wong & Brown, 2009).

Groundwater Recharge

It enhances groundwater recharge by promoting infiltration through measures such as

recharge wells, permeable pavements, infiltration trenches, and bio-retention systems. This helps restore depleted aquifers and improves long-term water availability (Fletcher et al., 2015).

Flood Mitigation

WSUD reduces urban flooding by slowing, storing, and infiltrating storm water runoff close to its source. These measures decrease peak runoff volumes and reduce pressure on urban drainage systems (Lloyd, Wong, & Chesterfield, 2002).

Improvement of Water Quality

It improves the quality of storm water by filtering sediments, nutrients, and pollutants before they enter rivers, lakes, and groundwater systems. This contributes to healthier aquatic ecosystems and safer water resources (Fletcher et al., 2015).

Water Conservation

Encourages rainwater harvesting, storm water reuse, and water-efficient practices, reducing the demand for freshwater resources and improving urban water security (Wong & Brown, 2009).

Climate Change Adaptation

It increases the resilience of cities to climate change by managing extreme rainfall, reducing drought impacts, and supporting sustainable water availability under changing climatic conditions (Brown, Keath, & Wong, 2009).

Environmental and Social Benefits

Integrates green infrastructure such as wetlands, green spaces, and bio-retention areas into urban development. These features enhance biodiversity, improve urban aesthetics, reduce heat island effects, and provide recreational spaces for communities (Fletcher et al., 2015).

1.2 Current Status of Water Bodies in India

India's first Census of Water Bodies, conducted by the Ministry of Jal Shakti in 2018–19, identified a total of 2,424,540 water bodies across the country, with 78% categorized as man-made and 22% as natural as shown in Figure 1. Approximately 97.1% of these water bodies

are situated in rural areas, while only 2.9% are located in urban regions (Ministry of Jal Shakti, 2023). In Madhya Pradesh, the 2011 Census recorded 54,903 villages and 394 urban centers (Census of India, 2011). The state reported a total of 82,643 water bodies, with 81,012 in rural areas and 1,631 in urban areas (Ministry of Jal Shakti, 2023).

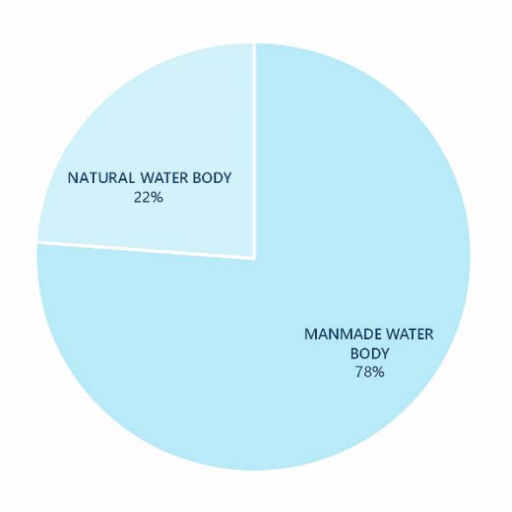


Figure 1 :Status of Water Bodies in India *Source: (India's first Water Census 2017-2018)*

India's urban centers are experiencing unprecedented growth, leading to increased demand for water resources. However, the capacity to augment supply is constrained by several factors, including declining groundwater levels, deteriorating water quality, and the pollution of water bodies. Groundwater contamination with metals such as fluoride, arsenic, and uranium, coupled with the inflow of untreated sewage and industrial effluents into rivers and aquifers, exacerbates the situation (Sridhar, 2025). Climate change further complicates matters by altering the hydrological cycle, resulting in erratic rainfall patterns and increased water consumption (Water Sustainability in Urban India, 2025).

In many Indian cities, the existing water supply infrastructure comprising piped water lines, drainage systems, and sewage treatment plants (STPs) is often inadequate. This insufficiency leads to overreliance on private, uncontrolled groundwater extraction, contributing to aquifer depletion and pollution. For instance, cities like Delhi and Mumbai import water from distances of 300 km and 150 km, respectively, highlighting the unsustainable nature of current water sourcing strategies (Singh, 2022).

1.3 Need for the Study

Urban water bodies are vital ecological assets that play an essential role in maintaining hydrological balance, recharging groundwater, regulating floods, supporting biodiversity, and moderating microclimates. However, rapid urbanization, industrial growth, and unplanned land-use changes have led to the severe degradation of these systems in Indian cities as shown in Figure 2.

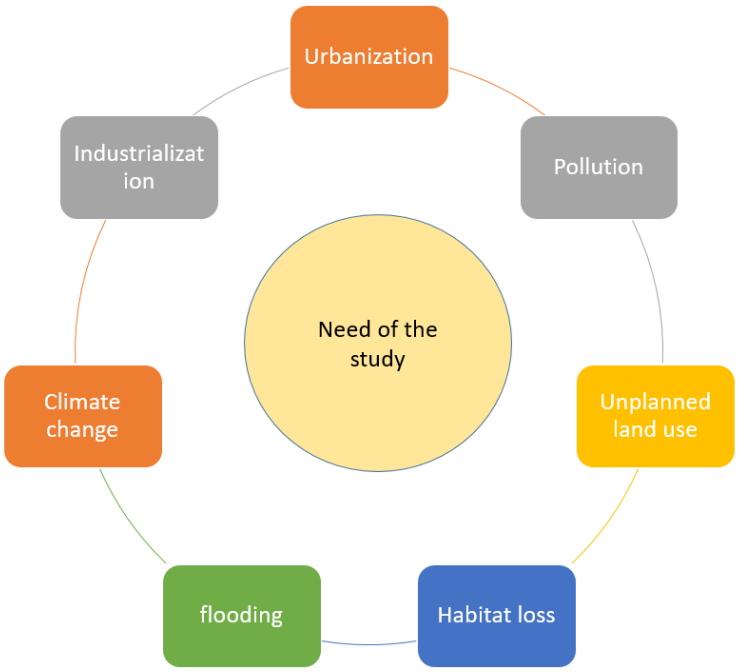


Figure 2:Visual Diagram of Need of the Study *Source: (Author,2025)*

Encroachment, pollution from untreated sewage and industrial effluents, and solid waste dumping have turned many natural water bodies into contaminated or shrinking ecosystems (Kumar et al., 2023). These conditions not only threaten urban water security but also disrupt ecological stability and reduce the overall quality of urban life.

The rapid urbanization acts as a primary driving force affecting the health and sustainability of urban water systems. When urban growth is not well-regulated, it leads to increased pollution levels, encroachment, and pressure on natural resources, which collectively degrade the quality of urban water bodies. However, effective urban planning and policy engagement can counter these impacts by integrating water-sensitive design, establishing buffer zones, and enforcing environmental regulations.

Furthermore, community engagement plays a mediating role in this system. Active public participation, awareness, and collective responsibility can help mitigate pollution and enhance conservation outcomes. The model therefore suggests that the state of urban water bodies depends on how well cities balance the pressures of urbanization with strong governance, inclusive planning, and community-driven environmental stewardship. (Kushwaha, Verma & Singh, 2023). Sustainable urban water management requires a synergistic relationship between policy, planning, community involvement, and pollution control**,** ensuring that rapid urbanization progresses without compromising ecological health.

Despite several government programs such as the National Lake Conservation Plan (NLCP), AMRUT, and the Smart Cities Mission, the degradation of water bodies continues due to fragmented governance, inadequate monitoring, and lack of integration between water management and spatial planning (MoHUA, 2015; MoEFCC, 2021). Current urban development practices often prioritize built infrastructure over ecological functions, treating water bodies as residual or developable land rather than as integral components of the city's natural system (Singh, 2019). This gap highlights the urgent need for a planning approach that combines ecological sustainability with urban design and policy frameworks.

The study is needed to establish a comprehensive, water-sensitive urban development model that integrates hydrology, ecology, and spatial planning principles to ensure the conservation and long-term management of urban water bodies. By evaluating existing conditions, identifying challenges, and formulating practical, context-specific strategies, this aims to strengthen the resilience of urban environments against water scarcity, flooding, and climate variability (Wong & Brown, 2008; Sharma & Patel, 2021). Thus, the study is crucial for promoting sustainable urban growth while restoring the ecological and social value of water bodies as living assets within the urban landscape.

1.4 Aim and Objectives

To develop Water Sensitive Urban Development planning strategy to revive and conserve the capacity of urban water bodies.

Objective-Phase 1

1. To study the current status and environmental issues affecting urban water bodies.

2. To review traditional practices and innovative approaches for conservation of water bodies.
3. To study revival and pollution-mitigation strategies, different schemes and programs for urban water bodies.
4. To study WSUD planning interventions for water bodies in urban areas.

Objective-Phase 2

1. To estimate the current and future demand of the city.
2. To evaluate types of water bodies and assessing their physical condition.
3. To evaluate options of revival and conservation of selected water bodies.
4. To study WSUD planning application of Mandsaur.

1.5 Scope

This study is divided into two phases. Phase 1 is primarily based on literature review and focuses on understanding the concept of Water Sensitive Urban Development (WSUD), types of water bodies, environmental issues, traditional water conservation practices, pollution mitigation measures, government initiatives, and sustainable planning interventions. Phase 2 is based on the selected case study of Mandsaur City and involves data collection, GIS-based spatial analysis, assessment of existing water resources and water demand, identification of key issues, and the formulation of Water Sensitive Urban Development based planning proposals. The study ultimately aims to develop practical WSUD planning strategies for the conservation and revival of urban water bodies within the municipal limits of Mandsaur.

1. Focus on urban water bodies (river, lakes etc.) located within the present municipal limits of a Class-1 city population 2 lakhs to 5 lakhs (Census,2011).
2. The study analyzes recent conditions, trends, and strategies up to 2025, alongside historical shifts.
3. The analysis will be detailed carried out at municipal area.
4. The study primarily focuses on groundwater recharge water of the city.

1.6 Limitations

1. Flood and disaster related data will not be extensively examined in this dissertation.
2. The study is confined to water bodies located within the municipal limits of the city.

1.7 Methodology

Phase 1

The literature review conducted in Phase 1 provides the basis for the subsequent methodology. A mixed-methods approach combining GIS and statistical analysis with interviews and field observations will be used to assess case studies on urban water-body revival. Insights from land-use analysis, policy review, and evaluation of traditional and modern interventions will support the development of a sustainable planning framework.

The methodology for Phase 1 is entirely based on literature review, case studies, and secondary data sources. All the information required for the study will be collected through published research papers, reports, policies, and existing datasets, which will further support and guide the analysis and proposal development in Phase 2. The methodology is systematically divided into three main parts objectives, Process, and Outcomes. The objectives define the scope and direction of the research; the process outlines the step-by-step methods such as literature review, bibliometric analysis, and Scopus-based study; and the outcomes highlight the expected results including typology identification, policy understanding, and formulation of sustainable planning strategies for the conservation and revival of urban water bodies.

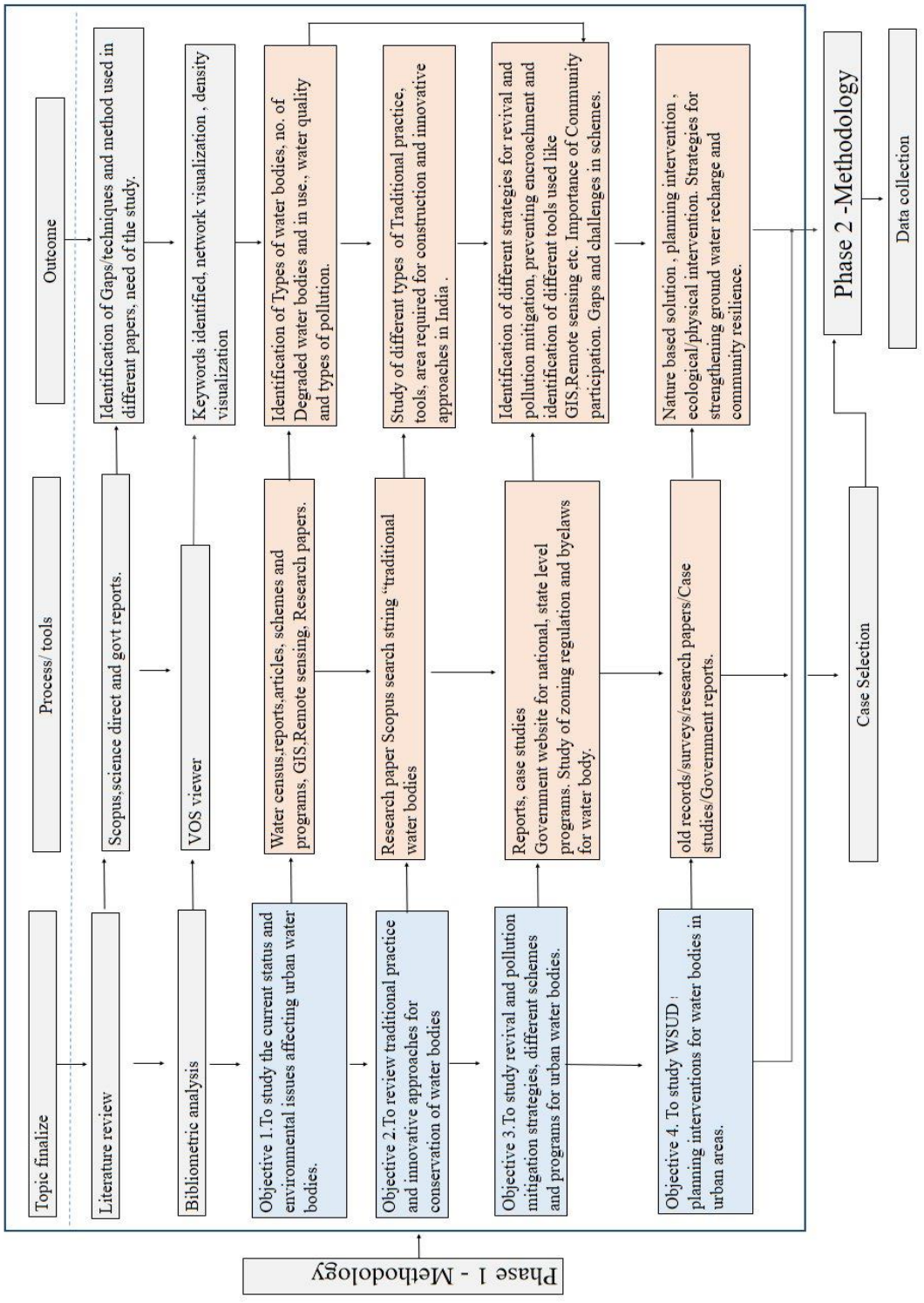


Figure 3: Methodology of Phase 1 *Source: (Author,2026)*

Phase 2

For phase 2 methodology, the data is being collected from primary survey and secondary survey also QGIS, Google earth etc. helps in achieving and marking relevant details in the map.

The methodology chart explains the complete research process followed in the study for conservation and revival of water bodies in Mandsaur using Water-Sensitive Urban Development (WSUD) principles. The methodology is divided into four major objectives.

The first objective focuses on documenting the types of water bodies and assessing their existing condition. For this, data related to hand pumps, overhead tanks, wells, ponds, tanks, and rivers were collected. GIS and Google Earth surveys were used to identify the number, shape, size, area, and surrounding conditions of water bodies.

The second objective aims to estimate future water demand and water consumption patterns. Population projection for the year 2041 was carried out using the incremental increase method under a quantitative approach. This helped in understanding ward-wise population contribution and future water demand requirements.

The third objective is to study the planning application for Mandsaur city. Detailed spatial data collection and field surveys were conducted to analyze the existing urban water management system. This stage helps in identifying issues related to water supply, drainage, groundwater dependency, and urban infrastructure, which further supports preparation of planning proposals.

The fourth objective focuses on evaluating options for the revival and conservation of selected water bodies. Mapping of selected water bodies was carried out through GIS and Google Earth analysis. Based on the findings, proposals were developed for restoration, conservation, groundwater recharge, and sustainable urban water management.

Overall, the methodology integrates field surveys, GIS analysis, population forecasting, and spatial planning techniques to develop WSUD-based strategies for improving urban water management and conserving traditional water bodies in Mandsaur city.

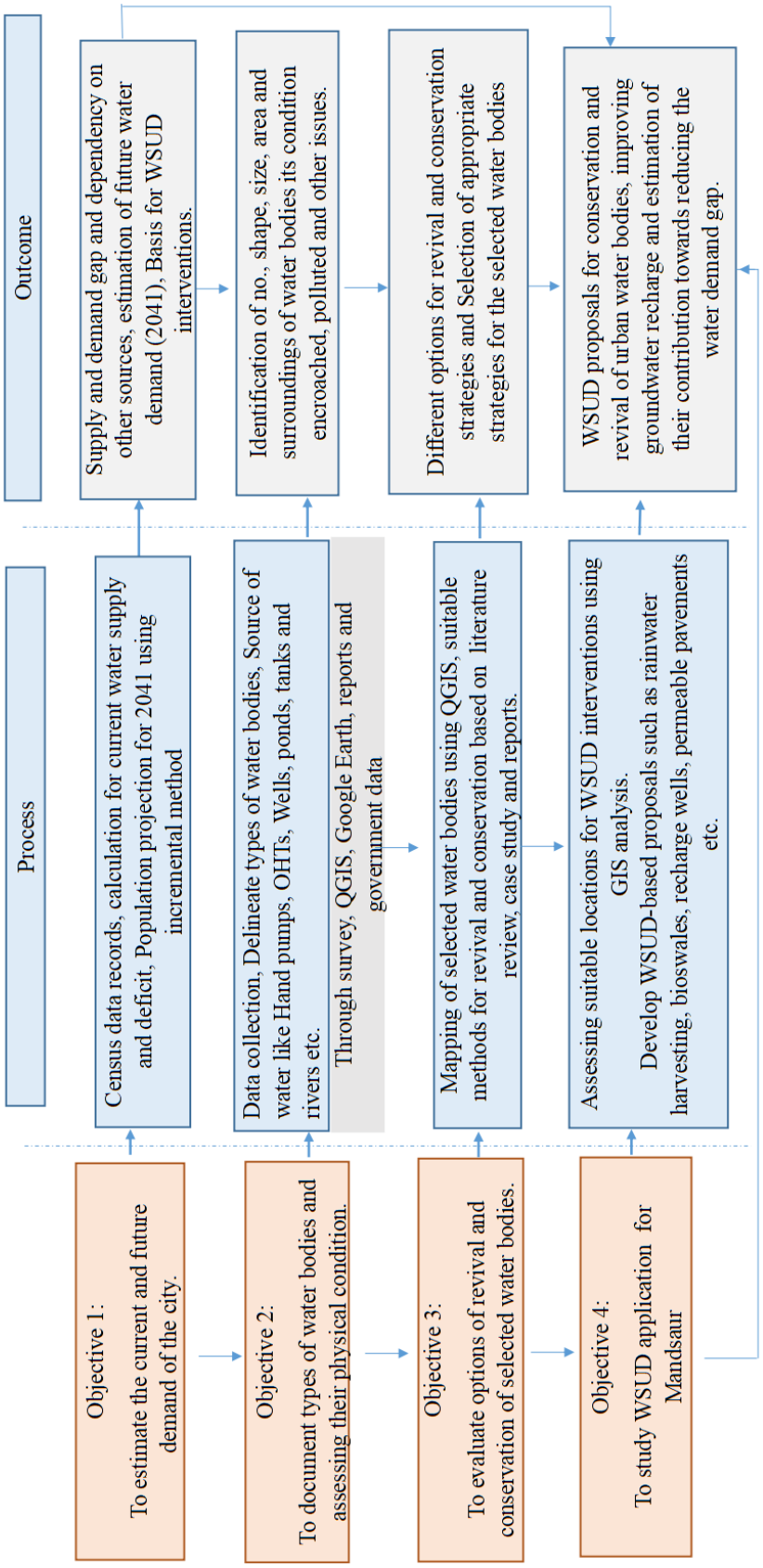


Figure 4: Methodology of Phase 2 *Source: (Author,2026)*

1.8 Case Selection Criteria

The selection of the city is based on following parameters that are drawn from the literature study are as follows,

1. Past water related issues faced by the city (scarcity, water clogging areas etc.)
2. Comes under over exploited area.
3. Historically developed around water bodies can be seen.
4. Declination of water bodies in the city.
5. Water Pollution and quality is questionable for drinking purpose.

Why Mandsaur?

It is an emerging medium town city, due to urbanization population is also increasing as it has a historical and religious significance. There are different types of water bodies present in the city in which shivna river plays very important role in fulfilling peoples basic need of water but it is affected by pollution and human activities such as illegal extraction, religious activity etc. which results in depletion of water body and thus arise the need for the WSUD.

Mandsaur lies within the Chambal River catchment, one of the major tributaries of the Yamuna. The region is hydrologically significant due to the presence of the Gandhi Sagar Dam, a key multipurpose water infrastructure project. The dam, constructed in 1960, has a gross storage capacity of 7.32 billion cubic meters and serves irrigation, hydropower, and regional water supply needs (Central Water Commission). The Catchment area is 22,584 km² and Reservoir surface area is 723 km².

This indicates that Mandsaur is not only locally dependent on water bodies but also plays a regional role in water resource management, making it suitable for WSUD-based planning.

Mandsaur city have potential for growth as it's a medium town city, due to urbanization and population growth the demand for water is also increasing in the city furthermore city has potential water bodies such as river, talaab, wells etc. which can fulfill the water demand of the city but they are declining and affecting ground water level. Mandsaur city comes under over exploited ground water area which shows the concern of potable water and need for waste water treatment. This study will help in identification of traditional and surface water body, there current condition and people dependency on it for drinking and waste water. its

surrounding, buffer area and factors affecting it, ward wise dependency. Techniques and strategies to conserve and revival it.

Mandsaur is tier 2 class 1 city with population 141,468 as per census 2011, Mandsaur comes in water stress area and in over exploited area which shown the corner of water as medium towns are growing rapidly due to urbanization population is also increasing and thus the need of water. but we have limited resource on earth extracting water results in decline of ground water level thus study will help in identification of no. of water bodies in the city , their existing condition and historic decline if any also ward wise dependency of which type of water bodies any issues, pollution cause ,its buffer area , land use etc. which will help in recommendation of pollution mitigation strategies, strategies for conservation and revival of water bodies before that population projection will be done using different methods for 2041 also current demand will be calculated for water bodies and after strategies how much will it cater in 2041.

Mandsaur has been selected as the case study city for this research mainly because it clearly reflects the water-related challenges being faced by many medium-sized Indian towns today. Although Mandsaur is not a metropolitan city, it is growing steadily due to urbanization, population increase, and expansion of residential and commercial areas. With this growth, the demand for water has increased significantly, while the availability of water resources remains limited.

The city lies in a water-stressed and over-exploited groundwater region as shown in figure 5, where excessive extraction has led to a noticeable decline in groundwater levels. This increasing dependence has raised concerns regarding long-term water security. At the same time, several natural and man-made water bodies such as ponds and tanks exist within the city, many of which are poorly maintained, polluted, or partially encroached upon.

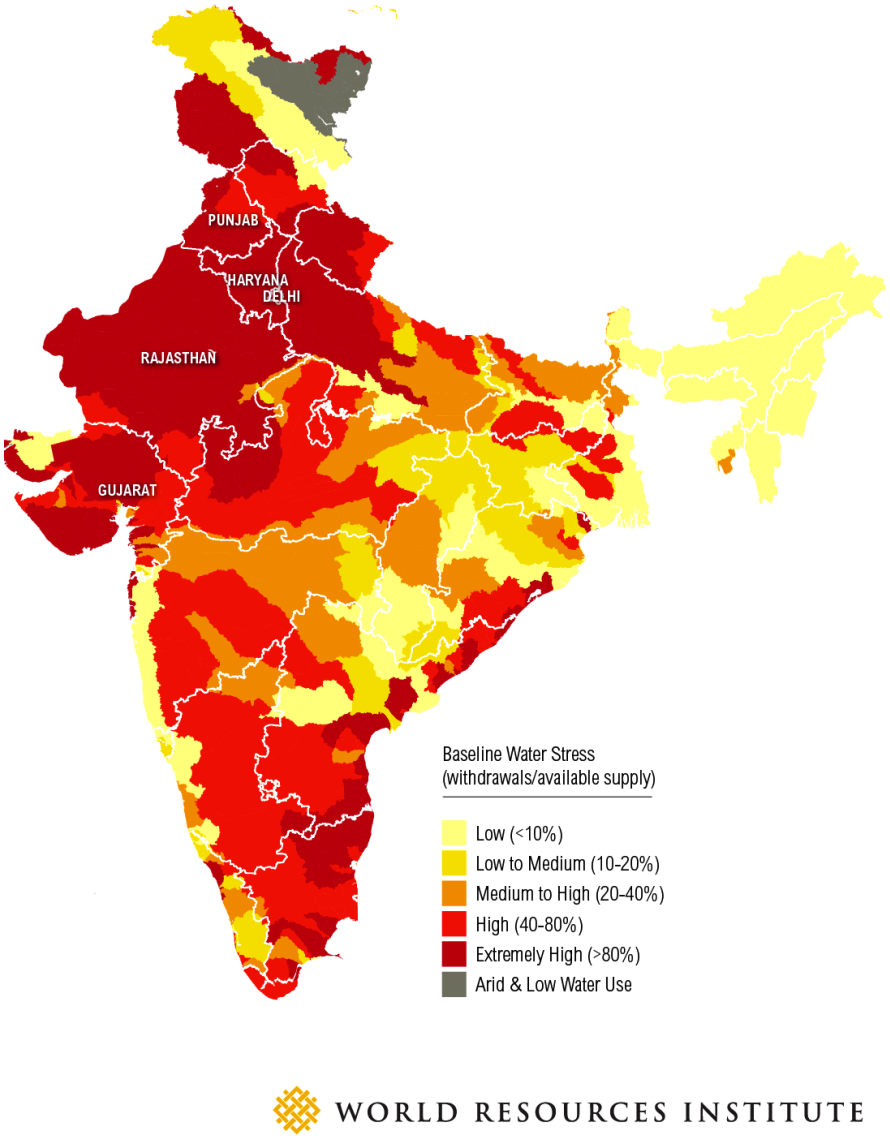


Figure 5:Water Stress Map of India *Source: (World Resource Institute report,2015)*

Historically, these water bodies played an important role in storing rainwater, recharging groundwater, and supporting local water needs. However, due to unplanned urban development, lack of proper drainage systems, and discharge of wastewater, their condition has deteriorated over time. This situation highlights the need for an integrated and sustainable approach to urban water management rather than relying only on groundwater extraction.

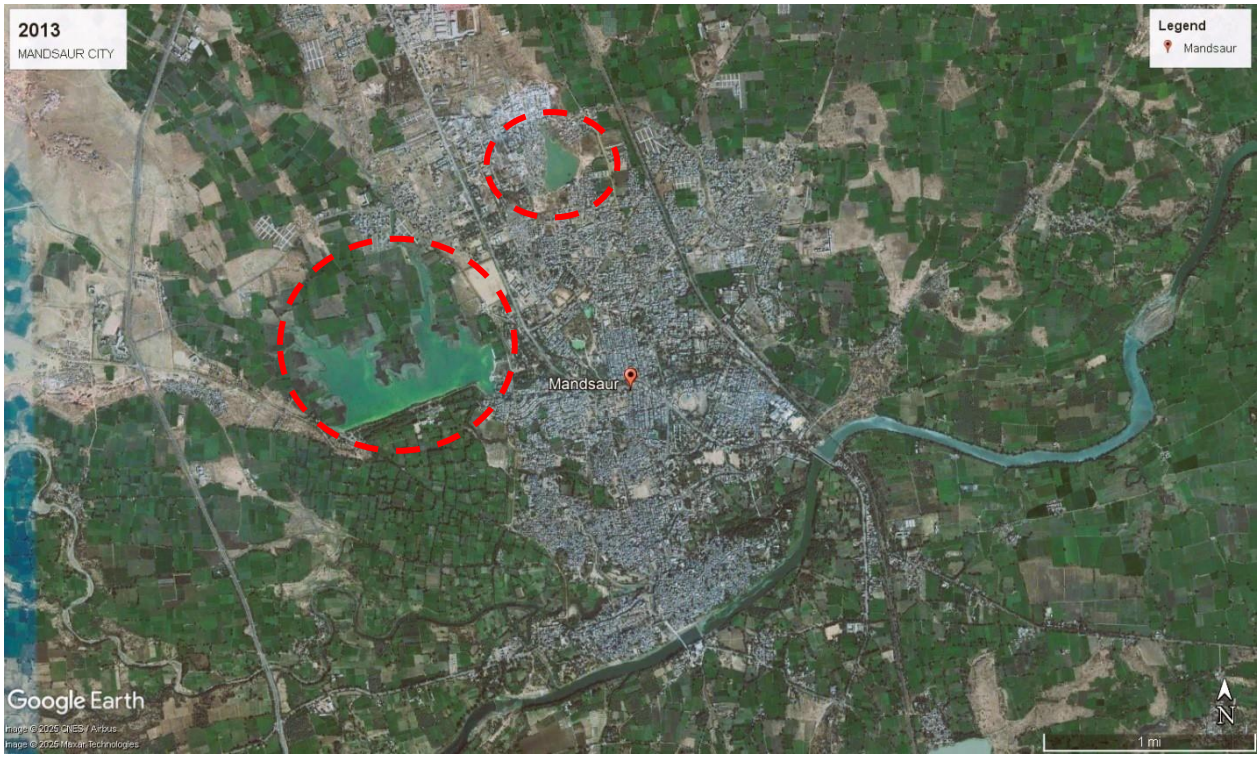


Figure 6: 2013 Google Earth Image Showing Condition of Water Bodies *(Source: Google Earth, 2013)*

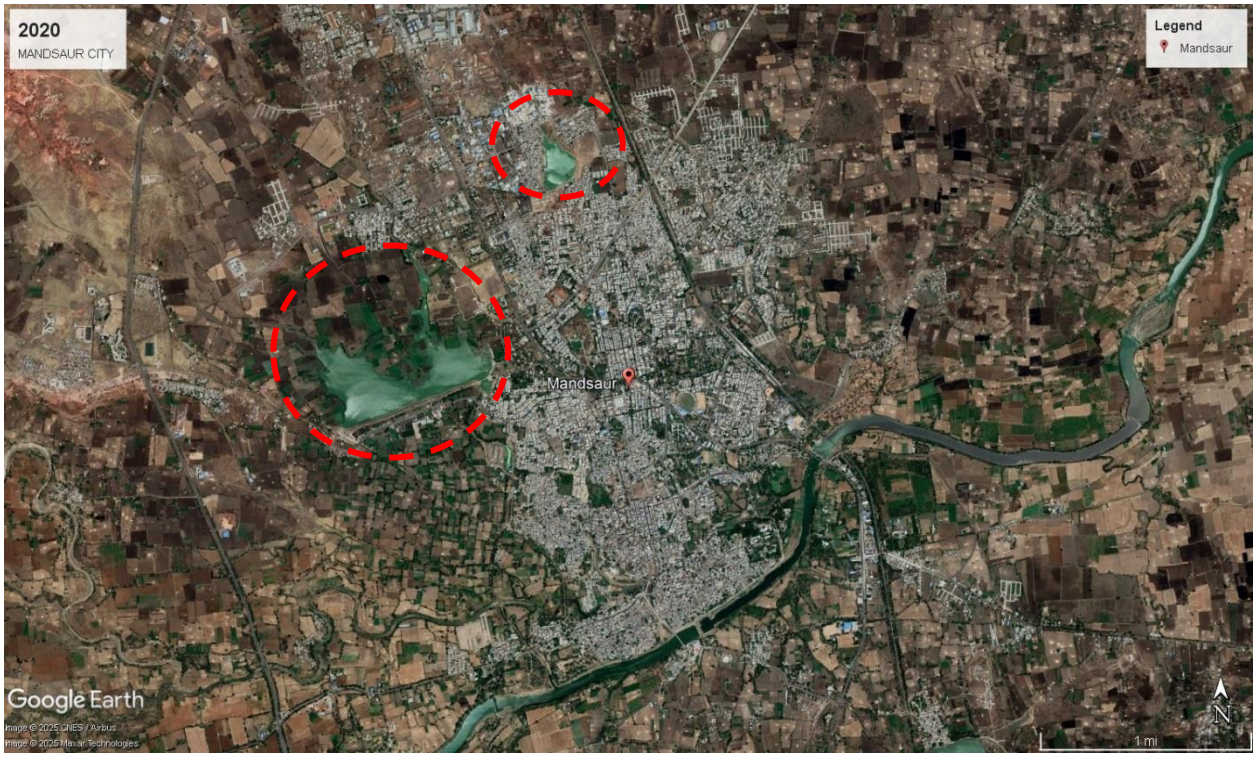


Figure 7: 2020 Google Earth Image Showing Condition of Water Bodies *Source: (Google Earth,2020)*

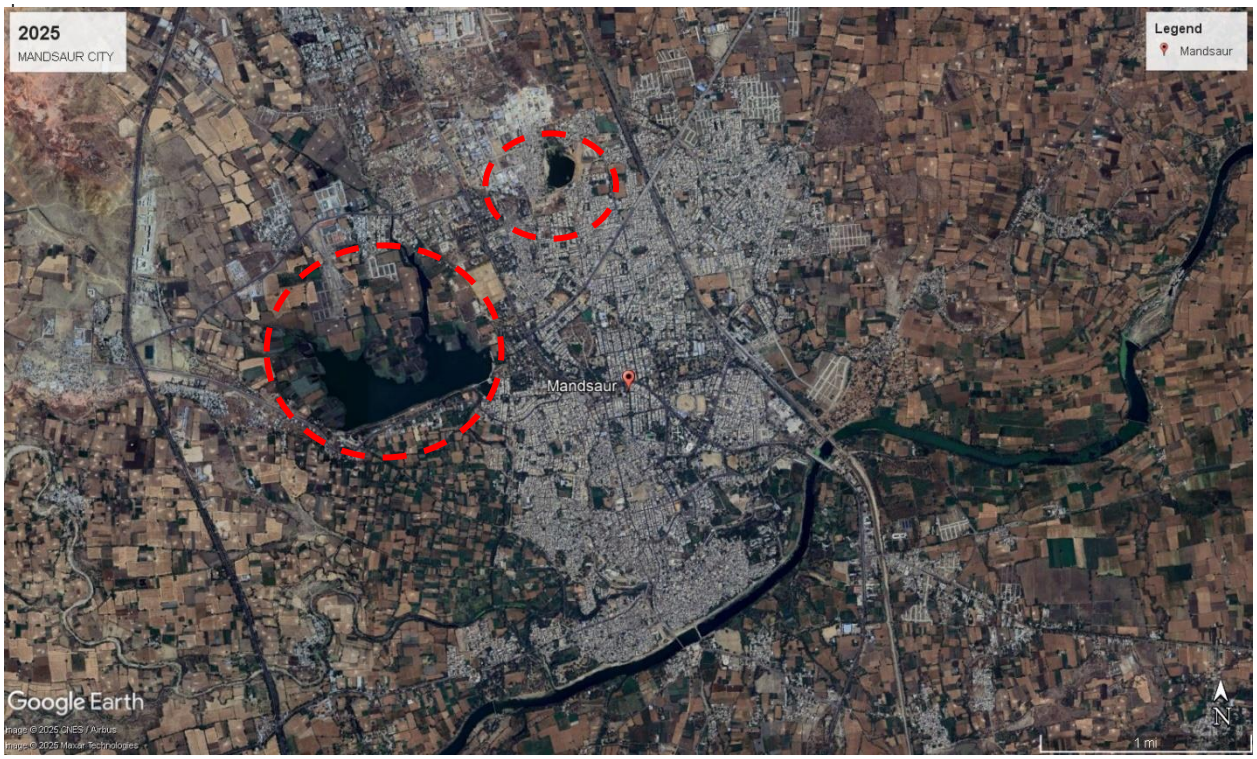


Figure 8: 2025 Google Earth Image Showing Condition of Water Bodies *(Source: Google Earth, 2025)*

Mandsaur provides a suitable scale for detailed study, as ward-wise variations in land use, population density, and water dependency can be clearly observed. The availability of basic municipal data and the presence of identifiable water bodies within the urban area further support its selection. Moreover, the issues observed in Mandsaur are similar to those found in many other medium towns across India, making the outcomes of this study relevant beyond the city itself.

Therefore, Mandsaur has been selected to explore how Water Sensitive Urban Development (WSUD) principles can be applied to understand existing conditions, identify issues related to urban water bodies, and propose planning strategies for their conservation and revival. The city offers an appropriate context to assess current water demand, future requirements, and the potential role of revived water bodies in meeting water needs up to the year 2041.

1.9 Overview of the Report

The thesis is into six chapters, each addressing a specific aspect of the research, progressing from theoretical understanding to analysis, proposal formulation, and conclusions.

Chapter 1 introduces the concept of Water Sensitive Urban Development and highlights the growing challenges associated with urban water management due to rapid urbanization and degradation of water bodies. It explains the need for the study, identifies the research gap, and presents the aim, objectives, scope, limitations, methodology, and case selection criteria. The chapter also justifies the selection of the city as the study area based on its increasing water stress, groundwater depletion, and deteriorating condition of urban water bodies.

Chapter 2 reviews national and international literature related to urban water bodies and sustainable water management. It discusses the types of water bodies, environmental issues affecting them, sources of pollution, traditional water conservation systems, and modern restoration techniques. The chapter also examines Water Sensitive Urban Development (WSUD) principles, government schemes, planning regulations, and successful case studies to identify planning interventions applicable to Indian cities. The findings from the literature form the conceptual framework for the research.

Chapter 3 presents the detailed profile of Mandsaur City. It covers the historical evolution of its water systems, administrative and demographic characteristics, geographical setting, climate, rainfall, topography, watershed, drainage pattern, and slope analysis. The chapter also evaluates the city's existing water resources and examines the applicability of WSUD principles based on its physical and environmental characteristics.

Chapter 4 evaluates the existing water management scenario in Mandsaur using both primary and secondary data. It assesses the condition of rivers, ponds, wells, hand pumps, overhead tanks, water supply infrastructure, land use, and groundwater dependency. GIS-based spatial analysis is used to examine the distribution of water bodies, drainage, and urban growth. Population projections, future water demand estimation, and ward-level analysis are also carried out to identify critical areas requiring planning interventions.

Chapter 5 is based on the findings of the previous chapters, this chapter proposes planning strategies for the conservation and revival of urban water bodies using WSUD principles. It recommends structural and non-structural interventions such as rainwater harvesting, recharge wells, bios wales, check dams, buffer zone development, ecological restoration, stormwater management, and policy measures. Ward-level and city-level proposals are prepared to improve groundwater recharge, reduce water stress, and enhance sustainable urban water management.

Chapter 6 summarizes the major findings of the study and discusses how the proposed WSUD strategies can improve groundwater recharge, restore degraded water bodies, strengthen urban water security, and support sustainable urban development. It evaluates the effectiveness of the proposed planning interventions, highlights the contribution of the research, and presents recommendations for integrating WSUD into future urban planning practices for Mandsaur and other medium-sized Indian cities facing similar water management challenges.

CHAPTER:2- LITERATURE REVIEW

2.0 Introduction

Water is essential for life and is deeply integrated into daily human activities; however, despite numerous programmes and awareness initiatives, the resource continues to be exploited and wasted (Sharma et al., 2016). With the finite availability of freshwater on Earth, the need for its prudent conservation and scientific management has become increasingly urgent (Sözer, 2022). In this context, water-sensitive design offers a critical pathway for promoting sustainable water use, ecological protection, and urban resilience (Avazpour, Osmond, & Corkery, 2024).

To explore the scope of Water-Sensitive Urban Development and strategies for the conservation and revival of water bodies, a structured literature review methodology was adopted. The review process began by identifying broad thematic domains, including urban water management, traditional water systems, ecological restoration, decentralized water-sensitive interventions, and policy frameworks regulating water bodies. A combination of qualitative and bibliometric approaches was employed to map research trends and identify keywords.

Multiple academic databases such as Scopus, Web of Science, and Google Scholar were systematically searched to extract peer-reviewed literature. Reference screening and organization were carried out using Mendeley, while bibliometric tools and AI-assisted platforms (such as ChatGPT and Perplexity) helped refine keywords, generate co-occurrence maps, and filter relevant research materials. In addition to academic sources, government reports, national policy documents, and international guidelines from agencies such as UN-Habitat, MoHUA, CPCB, and NIUA were reviewed to understand real-world interventions and policy directions.

The initial Scopus search string: (“restoration” OR “conservation” OR “management”) AND (“water bodies” OR “urban lakes” OR “ponds” OR “rivers” OR “wetlands” OR “traditional water systems”) AND (“sustainable development” OR “sustainability” OR “urban planning” OR “sustainable planning” OR “water-sensitive planning”) retrieved 607 documents, of which 71 were shortlisted based on relevance and screening criteria. Additional targeted searches

were conducted, such as “traditional water bodies,” which yielded 7 relevant India-specific studies, and “current status of water bodies,” which resulted in 9 key documents for further review. This multi-source, multi-tool approach ensured a comprehensive, globally informed understanding of the challenges and strategies related to urban water conservation and water-sensitive planning

The earliest paper identified in the review dates back to 1997, and the search strategy was designed to ensure that all literature relevant to the research topic was comprehensively captured.

The critical role of integrated, decentralized, and community-led approaches in the conservation and revival of urban water bodies in India. Verma (2022) emphasizes India's traditional water systems like stepwells and tanks as climate-responsive and socially embedded mechanisms, stressing the need to revive these systems for future resilience. Complementing this historical lens, Kushwaha et al. (2023) highlight the challenges of pollution, encroachment, and governance gaps in urban water bodies, calling for strong enforcement, ecological restoration, and community participation. At the micro-scale, Ramteke and Sarode (2025) demonstrate practical interventions such as decentralized wastewater treatment (DEWATS), bio-remediation, and aeration through a small-town lake revival example, proving how decentralized technologies and public engagement can successfully restore ecological health and livelihoods. Shah (2016) broadens the perspective by situating water body revival within a larger urban water governance and policy continuum, advocating for integrated surface-groundwater management, aquifer-based planning, and decentralized systems led by empowered ULBs. These findings align with global evidence that hybrid water systems grounded in community stewardship and decentralized treatment are more resilient and sustainable than centralized infrastructure-only models (Wong & Brown, 2009).

2.1 Types of Water Bodies

Water bodies vary by origin, hydrological function, and ecological characteristics. Broadly, they include natural and artificial systems. Natural water bodies include rivers, lakes, ponds, wetlands, estuaries, and springs—formed through geomorphic and hydrological processes (Lin et al., 2022). Artificial water bodies**,** such as reservoirs, tanks, canals, and check dams, are human-constructed to store rainwater, support irrigation, and regulate flows (Agarwal & Narain, 1997).

Urban water bodies are diverse in form and function. As per India's first Census of Water Bodies (2023), the distribution is:

- Ponds (82.2% of urban types)
- Tanks (12.1%)
- Lakes (1.6%)
- Reservoirs (0.4%)
- Water conservation structures such as percolation tanks and check dams (2.2%)

States like West Bengal, Tamil Nadu, Maharashtra, and Jharkhand lead in abundance and usage of specific types (Government of India, 2023). Water bodies are differentiated as natural (earthen, supporting filtration and recharge) and artificial (constructed using concrete/masonry, often less environmentally harmonious) (Sharma & Bharat, 2019).

About 1.6% (approximately 38,496) of the total water bodies were found to be encroached, meaning they are either fully or partially occupied for non-water-related activities such as construction, agriculture, or waste dumping (The Indian Express, 2023). Encroachment has been particularly severe in urban and peri-urban regions, where rapid development and weak enforcement of land and water regulations have led to the shrinking or complete disappearance of many traditional ponds and lakes.

In addition to encroachment, the census highlights that 83.7% (about 2.03 million) of India's total water bodies are currently "in use" for various purposes such as irrigation, aquaculture, drinking water, and industrial needs, while the remaining 16.3% (approximately 393,000) are classified as non-functional (Financial Express, 2023). These non-functional water bodies are primarily degraded due to siltation, pollution, eutrophication, drying up, or conversion of their catchment areas. The degradation often results from untreated sewage inflow, solid waste dumping, and reduced inflow caused by urban construction and groundwater over-extraction.

These figures highlight the urgent need for integrated and water-sensitive urban planning strategies to restore and sustainably manage India's degraded water bodies. The loss of functionality not only impacts local water availability and groundwater recharge but also disrupts ecological balance, exacerbating urban flooding and heat island effects (Ministry of Jal Shakti, 2023).

Rivers and streams function as dynamic freshwater channels transporting sediments, nutrients, and aquatic life. Lakes and ponds serve as storage reservoirs and biodiversity habitats. Wetlands including marshes and swamps—are among the most productive ecosystems, filtering pollutants, sequestering carbon, and supporting migratory birds (UN-Habitat, 2020). Village tanks and irrigation reservoirs historically supported agriculture and groundwater recharge in semi-arid regions of India (Gupta et al., 2021).

2.2 Water Bodies and Environmental Issues

Water bodies are essential ecological systems supporting biodiversity, human settlements, groundwater recharge, and socio-economic development. They function as natural regulators of hydrological cycles, controlling floods, sustaining agriculture, and maintaining micro-climatic balance (UN-Water, 2020). Historically, rivers, ponds, tanks, wetlands, and lakes formed the backbone of water security in both urban and rural landscapes (Agarwal & Narain, 1997). However, rapid population growth, urbanization, industrialization, and unsustainable land-use transformations have significantly degraded water ecosystems (Lin et al., 2022).

Pollution, encroachment, loss of catchment areas, and biodiversity decline have led to deteriorating water quality and shrinking storage capacity (MoEFCC, 2017). Urban lakes today receive untreated sewage, industrial effluents, storm water runoff, and solid waste, resulting in eutrophication, sedimentation, and ecosystem collapse (Das & Gupta, 2021). Climate change deepens these challenges, intensifying rainfall variability and extreme events, stressing both natural and built water infrastructure (IPCC, 2021). The decline of water bodies has wide social and economic impacts, especially on communities that depend on them for their daily needs. Therefore, it is important to understand the types of water bodies and the sources of pollution to plan better policies and effective restoration strategies.

2.3 Pollution

Water-body pollution refers to physical, chemical, and biological alterations that degrade water quality, disrupt ecosystem balance, and pose health risks (Lin et al., 2022). Key pollutants include domestic sewage, industrial effluents, agricultural chemicals, solid waste, plastic, heavy metals, and microbial contamination (MoEFCC, 2017). Pollution impacts vary by source and ecosystem type—rivers face continuous pollutant loads, whereas lakes experience accumulation and eutrophication (World Bank, 2018).

Understanding pollution categories is essential for designing targeted restoration interventions, as discussed below.

2.3.1 Domestic Pollution

Domestic pollution originates primarily from household wastewater generated through bathing, cooking, washing, and toilet activities. This wastewater typically contains organic matter, food residues, oils, detergents, micro plastics, pharmaceutical residues, and pathogens (Sharma & Singh, 2020). In rapidly growing urban areas, domestic sewage is one of the largest contributors to water-body contamination due to inadequate sewerage networks and insufficient wastewater treatment systems. According to the Central Pollution Control Board, a significant proportion of urban sewage nearly 60–70% is discharged untreated into lakes, rivers, and ponds in Indian cities (MoEFCC, 2017).

Common visible effects of domestic pollution include foul odour, floating scum, mosquito breeding, and fish mortality. Soap and detergent residues introduce surfactants and phosphates, which accelerate eutrophication and alter pH levels, affecting aquatic organisms (Das & Gupta, 2021). Human waste brings harmful bacteria, viruses, and protozoa into water bodies, raising the risk of water-borne diseases like cholera, typhoid, and diarrhea (World Bank, 2018).

Emerging contaminants such as antibiotics and micro plastics from households pose new environmental threats by fostering antimicrobial resistance and long-term ecological toxicity (Lin et al., 2022). To mitigate domestic pollution, decentralized wastewater technologies such as DEWATS, greywater recycling, community septic systems, bio-enzymatic treatment, and wastewater-polishing wetlands are increasingly promoted in planning frameworks. Behavior-change programs, better infrastructure, and strong municipal management are essential. In the end, proper treatment and handling of household wastewater is the most important step for restoring water ecosystems in both urban and rural areas in a sustainable and inclusive way.

2.3.2 Industrial Pollution

Industrial pollution is a major source of contamination in water bodies, particularly in regions with textile dyeing units, paper mills, chemical manufacturing, tanneries, pharmaceuticals, mining, and metal-processing industries. Industrial wastewater often contains toxic chemicals, heavy metals, solvents, acids, oils, suspended solids, and organic waste, many of which are hazardous and persistent in the environment (Lin et al., 2022). In India, industrial

clusters around Delhi, Vapi, Kanpur, Surat, and Ludhiana have been identified as critical pollution hotspots (MoEFCC, 2017). Effluents containing dyes, chromium, lead, arsenic, phenols, and other harmful compounds enter water bodies due to insufficient treatment or illegal discharge.

Industrial contaminants disrupt aquatic ecosystems through oxygen depletion, toxicity to fish and plankton, and bioaccumulation in food chains (Das & Gupta, 2021). Heavy metals can persist in sediments for decades and re-enter water columns during flooding or dredging, posing chronic toxicity risks to humans and animals. Water bodies contaminated with chemicals often exhibit discoloration, oily films, unpleasant odour, and absence of biodiversity. Industrial effluents can also reduce soil fertility when mixed with agricultural water, affecting crop productivity (Sharma & Singh, 2020).

Industrial wastewater contributes to groundwater contamination as poorly lined waste disposal pits allow toxic leachate infiltration. Local communities near industrial zones often suffer from health issues such as skin disorders, respiratory problems, cancer, and neurological illness due to contaminated water exposure (World Bank, 2018). Policies such as Zero-Liquid-Discharge (ZLD), Common Effluent Treatment Plants (CETPs), real-time digital effluent monitoring, and strict regulatory enforcement have been introduced to curb industrial pollution. However, infrastructure gaps and weak compliance remain challenges.

A sustainable approach involves industry-government-community partnerships, adoption of green technologies, eco-industrial parks, and circular-economy strategies such as industrial wastewater reuse. Strengthening monitoring mechanisms and environmental governance is critical to safeguarding water ecosystems from industrial pollution.

2.3.3 Solid-Waste Pollution

Solid-waste pollution refers to accumulation of household garbage, plastic waste, construction debris, electronic waste, biomedical waste, and litter around or inside water bodies (UN-Habitat, 2020). Rapid urbanization and inadequate waste-management systems cause water bodies in many Indian cities—such as Bengaluru, Delhi, and Hyderabad—to become dumping grounds, leading to ecological degradation and aesthetic decline (Das & Gupta, 2021). Open dumping blocks inlets, reduces water-holding capacity, and creates breeding grounds for mosquitoes and rodents.

Plastic waste, including polythene bags, bottles, and packaging, breaks into micro plastics, which are persistent and enter aquatic food chains (Lin et al., 2022). Construction and demolition debris fills lakes and ponds, contributing to encroachment and loss of natural storage capacity. In some areas, informal waste pickers and livestock feed near water edges, further disturbing ecosystems. When mixed with sewage, solid waste releases methane and other harmful gases during decomposition, lowering oxygen levels in water and causing fish kills (Sharma & Singh, 2020).

Biomedical waste and electronic waste introduce hazardous chemicals and pathogens, increasing public-health risks. Poor enforcement of municipal waste rules, informal waste dumping, and lack of community awareness exacerbate the issue. Policy reforms such as Swachh Bharat Mission, municipal SWM bylaws, segregation mandates, and lake-protection committees have improved management in some cities. Nature-based barriers, floating trash booms, and community-driven lake-cleaning campaigns have also shown success.

However, long-term mitigation requires proper waste-collection systems, recycling facilities, environmental policing, public engagement, and urban-design solutions like buffer zones and green belts. A multi-stakeholder approach involving municipal bodies, residents, NGOs, and planners is key to controlling solid-waste pollution and restoring ecological function and cultural value of water bodies.

2.3.4 Sedimentation / Siltation Pollution

Sedimentation occurs when soil particles, sand, and fine organic matter erode from upstream landscapes and accumulate in water bodies. Factors such as deforestation, unplanned urban construction, road building, mining, agricultural tillage, and storm water runoff accelerate erosion, leading to siltation (Agarwal & Narain, 1997). Sediment deposition reduces water storage capacity, shortens reservoir life, and alters the physical habitat of aquatic organisms.

Excessive sedimentation smothers aquatic plants, buries fish spawning grounds, and clogs fish gills, reducing biodiversity (Sharma & Singh, 2020). In lakes and wetlands, sediment layers trap nutrients, releasing them slowly and promoting long-term eutrophication (Lin et al., 2022). In urban storm water tanks, silt mixed with garbage and sewage forms sludge, releasing foul odour and methane.

In river systems, sediment load modification disrupts channel morphology, increases flooding risk, and destabilizes banks (World Bank, 2018). Mountain and foothill regions experience particularly severe sedimentation due to slope erosion, landslides, and sand mining. Climate-induced intense rainfall events further accelerate soil erosion (IPCC, 2021).

Mitigation strategies include catchment management, afforestation, contour trenching, silt traps, desilting, and check dams (Das & Gupta, 2021). Urban strategies include regulated construction, sedimentation basins, eco-drains, and permeable pavements. Traditional methods such as tank desilting and bund strengthening rejuvenate percolation and groundwater recharge. Scientific soil-erosion mapping and watershed-based planning ensure targeted intervention. Managing sedimentation is therefore fundamental for long-term functionality and ecological stability of water bodies.

2.3.5 Thermal Pollution

Thermal pollution results from discharge of heated wastewater from industrial facilities, power plants, and manufacturing units into water bodies. Elevated temperatures decrease dissolved oxygen levels, stress aquatic organisms, and alter ecological balance (Lin et al., 2022). Thermal stress makes aquatic species more vulnerable to disease and reduces reproductive capacity. Warm water also accelerates metabolic rates in fish, increasing oxygen demand while reducing supply (Sharma & Singh, 2020).

Climate change exacerbates thermal pollution, as heatwaves and changing rainfall patterns raise water temperatures in rivers, lakes, and reservoirs (IPCC, 2021). Urban heat-island effects further warm surface water in cities. Thermal inputs also stimulate algal blooms and microbial proliferation, worsening eutrophication. Sensitive species may migrate or die, reducing biodiversity.

Cooling towers, industrial heat-exchangers, and wastewater recycling can reduce thermal discharge. Riparian vegetation and shaded wetlands help regulate water temperature naturally (UN-Habitat, 2020). Regulatory monitoring, industrial standards, and climate-adaptive planning are essential for thermal-pollution control.

2.3.6 Oil & Hydrocarbon Pollution

Oil and hydrocarbon pollution arises from spills, industrial discharges, fuel leaks, vehicular runoff, and shipping activities. Oil forms a thin film on water surface, blocking oxygen

diffusion and light penetration, hindering photosynthesis and harming fish and plankton (Sharma & Singh, 2020). Hydrocarbon compounds are toxic, carcinogenic, and persistent. Contaminated sediments slowly release hydrocarbons back into the water, posing long-term ecological risks (Lin et al., 2022).

Biodegradation of oil reduces dissolved oxygen, further degrading habitat quality. Remediation techniques include oil booms, microbial oil-degrading cultures, bio-remediation, and constructed wetlands. Regulatory control and awareness at fuel stations, workshops, and ports are essential.

2.3.7 Heavy-Metal Pollution

Heavy metals such as mercury, chromium, cadmium, arsenic, and lead enter water bodies from tanneries, electroplating, textiles, fertilizers, mining, and e-waste (MoEFCC, 2017). These metals are non-biodegradable and accumulate in sediments and aquatic organisms. Bio-magnification causes chronic toxicity, neurological disorders, cancer, and developmental defects in humans and wildlife (Lin et al., 2022). Arsenic and fluoride groundwater contamination in parts of India pose severe public-health risks. Remediation methods include adsorption media, phytoremediation using aquatic plants, and sediment capping. Strict industrial monitoring and public-health surveillance are essential for control.

2.3.8 Biological Pollution

Biological pollution occurs when pathogens such as bacteria, viruses, fungi, protozoa, and parasites enter water bodies through sewage, animal waste, and runoff (World Bank, 2018). Contaminated water leads to diseases like cholera, dysentery, and hepatitis. Invasive aquatic species may also disrupt native ecosystems. Constructed wetlands, chlorination, UV disinfection, and source-control policies help reduce biological contamination. Community-driven sanitation and hygiene programs are equally critical

2.4 Traditional Practices

Water is a fundamental resource shaping human settlements, food systems, and ecological health. Historically, Indian communities created sophisticated water-management practices that worked in harmony with local geography and climate conditions (Agarwal & Narain, 1997). Unlike many modern centralized infrastructures, traditional systems followed a decentralized and participatory approach, emphasizing rainwater capture, groundwater

recharge, and community stewardship. These systems evolved naturally over centuries and offered resilience to droughts, seasonal variations, and environmental stresses (Gupta et al., 2012).

Traditional water-harvesting structures were not only physical assets but also social institutions. Local bodies such as *panchayats* and village collectives managed maintenance, water-sharing rules, and conflict resolution (Sharma & Singh, 2020). Their governance approach fostered accountability and ensured the equitable distribution of water. However, post-independence urban expansion, reliance on bore wells, and the introduction of large-scale engineered water systems led to the neglect of these historical structures (Singh et al., 2018).

In recent years, growing water scarcity, falling groundwater tables, and climate-change impacts have renewed interest in traditional practices. Studies indicate that combining indigenous techniques with modern hydrological tools – such as GIS-based watershed planning, eco-engineering, and nature-based solutions – yields long-term water security and ecosystem stability (Das & Gupta, 2021). Thus, revisiting traditional systems not only acknowledges cultural wisdom but also provides sustainable pathways for contemporary water management.

Traditional water-harvesting practices across India vary considerably across regions, shaped by local rainfall patterns, terrain, and socio-cultural values. Despite this diversity, these systems share core principles: decentralized storage, groundwater recharge, and community ownership of water resources (Gupta et al., 2021). Techniques such as johads in Rajasthan, stepwells in western India, and tank systems in the south illustrate an advanced understanding of watershed behavior, natural slopes, and soil permeability (Verma, 2022).

Local materials like stone, clay, and lime plaster were used to construct long-lasting structures tailored to the environment (Gorde, 2025). These systems efficiently captured monsoon water and reduced evaporation losses, improving soil moisture and sustaining agriculture even in drought periods. Importantly, these water structures were tied to cultural values and community rituals, reinforcing stewardship. Many tanks and ponds were associated with temples or village commons, establishing sacred and communal responsibility toward water (Singh & Sharma, 2019).

The decline of traditional systems is closely linked to policy shifts, land-use change, rapid urbanization, and growing dependence on mechanized water supply (Sharma & Singh, 2020).

Yet, empirical evidence shows that revived traditional systems are highly cost-effective and climate-resilient, particularly in semi-arid and drought-prone regions (Das & Gupta, 2021).

Modern planning frameworks now encourage integrating traditional knowledge with scientific data and community-based governance to enhance sustainability and equity in water management (UN-Habitat, 2020). Therefore, traditional practices remain foundational to hydrological planning and climate adaptation in India.

2.4.1 Johads

Johads are earthen embankments constructed to capture and store rainwater in natural depressions, primarily found in Rajasthan and Haryana. They function as decentralized water-harvesting systems that enable slow infiltration and groundwater recharge in regions facing low and erratic rainfall (Agarwal & Narain, 1997). Their design follows watershed contours to maximize runoff storage, prevent soil erosion, and support agriculture, livestock, and domestic use (Gupta et al., 2012).

A well-documented revival effort occurred in Alwar district, where community-led initiatives restored more than 8,000 johads over two decades. Groundwater levels reportedly rose by 3–6 meters, seasonal rivers re-emerged, and agricultural productivity significantly increased (Singh et al., 2018). These outcomes highlight the potential of traditional systems when supported by local participation, watershed planning, and ecological restoration. Johads also strengthen socio-ecological systems. They sustain vegetation, cool micro-climates, and support biodiversity in arid zones (Gorde, 2025). In many villages, farmers voluntarily contribute labour or financial support, reinforcing shared ownership and accountability (World Bank, 2018).

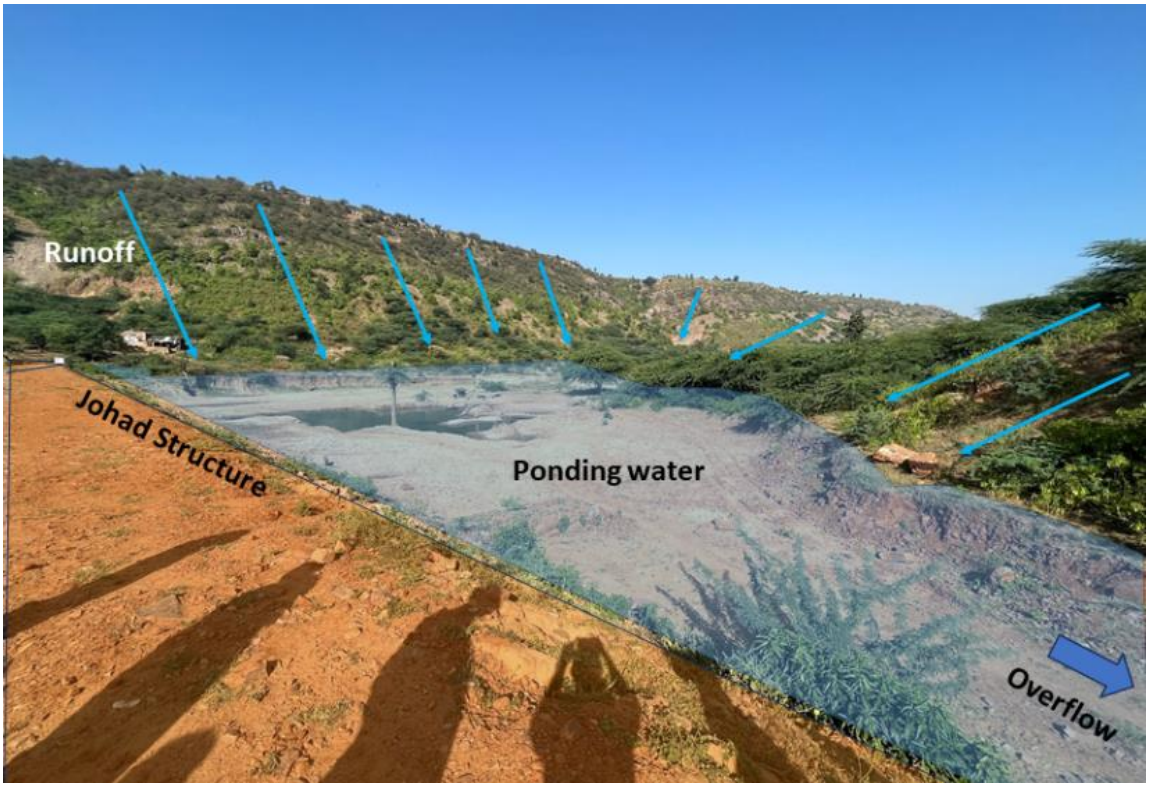


Figure 9: Image of Johad *Source: https://welllabs.org/neemli-jaltol-buttress-rajasthan-johads-water-conservation/*

Johads are traditionally constructed in semi-arid and arid regions with gentle slopes and porous sandy or alluvial soils that support groundwater recharge, making them particularly suitable in parts of Rajasthan, Haryana, and western India (Agarwal & Narain, 1997). They are typically built in common lands, pasture lands (gauchar), revenue wastelands, or agricultural fringes, where natural depressions or drainage lines allow efficient water accumulation (Kumar & Joshi, 2018).

Johads are most effective for rainwater harvesting, drought mitigation, groundwater recharge, and supporting livestock and agriculture, making them ideal for regions with low rainfall (300–600 mm) and high evapotranspiration (Sharma et al., 2020). The construction process usually involves identifying a natural catchment as shown in Figure 9, creating an earthen embankment, compacting soil layers, providing a spillway, and ensuring community participation in maintenance (Agarwal, 2001). Johads vary in size from small structures serving a single hamlet to larger ones covering 1–5 hectares of catchment area, depending on local hydrology and land availability (Kumar & Joshi, 2018). Funding typically comes from Panchayats, government watershed schemes, NGOs, or community contributions, as these systems rely on low-cost, locally available materials and collective labor (Sharma et al., 2020).

Johads can be built with low-cost materials like earth, stones, and clay, and funding usually comes from panchayats, government watershed schemes, NGOs, and community contributions**,** enabling high community ownership and sustainability (Gupta, 2011).

Johads generally require 0.5 to 2 hectares of land depending on the catchment size, soil type, and intended storage capacity, but in urban areas, smaller adapted forms—often 0.1 to 0.5 hectares—are used due to limited space and fragmented land parcels (Agarwal & Narain, 1997; Singh, 2020). Urban johads typically function as micro-recharge ponds placed within open spaces, institutional campuses, peri-urban pockets, or low-lying public land. The land requirement is also influenced by rainfall patterns, as higher-rainfall regions need smaller retention areas, while semi-arid climates such as Rajasthan or peri-urban Haryana demand larger basins to maximize recharge (Gupta & Kulkarni, 2019).

However, challenges include encroachment, lack of institutional protection, and competition from bore wells and private extraction (Sharma & Singh, 2020). Integration with modern tools like contour trenching, GIS mapping, and groundwater modelling can optimize johad placement and storage efficiency (Das & Gupta, 2021). When linked with local governance structures and watershed programmes, johads remain one of the most effective and low-cost climate-adaptive water-recharge systems in India.

2.4.2 Baolis/Stepwells

Baolis, also known as stepwells, are multi-level structures that enabled access to groundwater and stored rainwater in arid and semi-arid regions of western and northern India. Their tiered construction allowed water retrieval even as levels fluctuated, making them highly functional during prolonged dry seasons (Verma, 2022). In addition to serving hydrological functions, baolis played social and cultural roles—they acted as communal rest spaces, trading stops, and spiritual venues (Chowdhury et al., 2021).

Architecturally, baolis demonstrate remarkable engineering sophistication. They minimized evaporation through subterranean design, used stone masonry to prevent seepage, and featured ventilation and shade to maintain cool temperatures (Singh & Sharma, 2019). Examples include Rani ki Vav in Gujarat and Agrasen ki Baoli and Rajon ki baoli in Delhi as shown in Figure 10, are the iconic symbols of water architecture embedded with cultural heritage (UN-Habitat, 2020).

Figure 10 illustrates how a traditional Indian stepwell naturally cools its interior through passive ventilation and evaporative cooling. The pavilion domes at the surface release hot air upward, while the underground stepped corridors remain cool due to lower soil temperatures. Air circulates through the structure as warm air rises and escapes (stack effect), drawing in cooler air from below. The presence of water at the base further cools the surrounding chambers through evaporation.

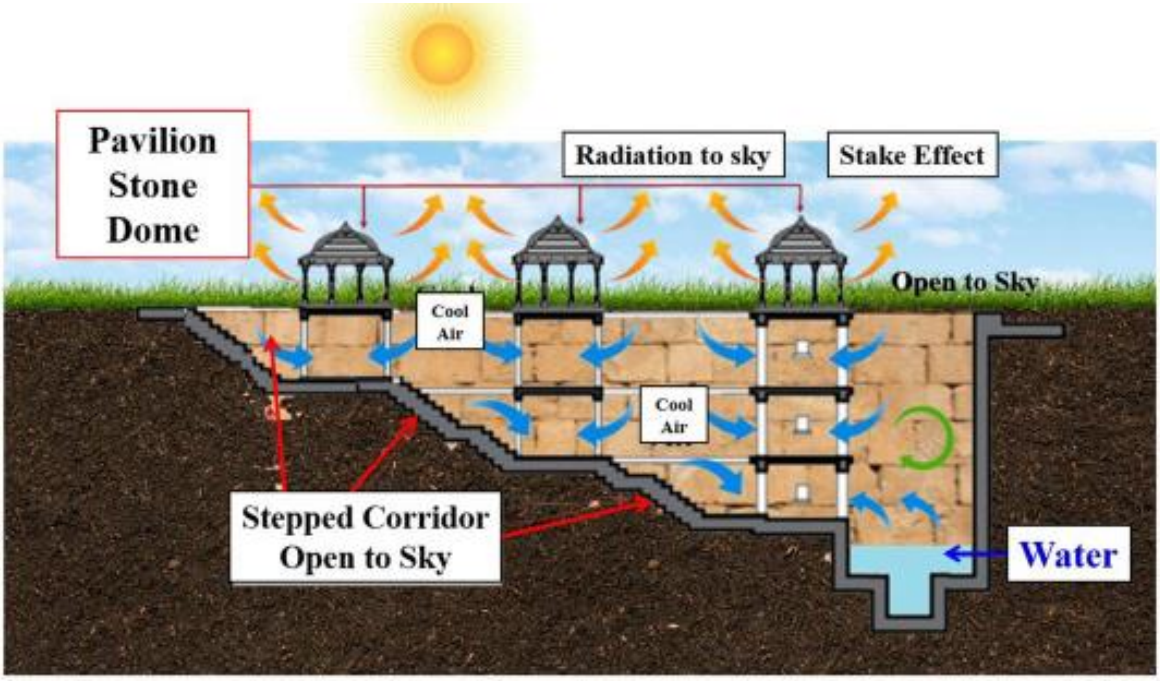


Figure 10:Section of Rajon ki Baoli *Source: https://www.sciencedirect.com/science/article/pii/S209526352400075X*

Over time, many stepwells fell into disuse due to piped water supply systems, bore well technology, and urban expansion (Singh et al., 2018). However, recent conservation initiatives have revived several baolis through desilting, structural reinforcement, and heritage-based tourism strategies (Patil & Lodhe, 2025). Restoration has shown improvements in water storage, groundwater recharge, and urban-heat mitigation (Das & Gupta, 2021).

Baolis highlight lessons in sustainable design, groundwater access, and thermal efficiency. Their revival demonstrates how traditional water architecture remains relevant for modern cities facing heat stress, declining aquifers, and water demand pressures. Integrating baolis into contemporary planning can support heritage conservation, eco-tourism, and decentralized water management frameworks.

2.4.3 Tanks

Traditional tank systems are widespread across southern and central India, particularly in Tamil Nadu, Karnataka, Telangana, and Andhra Pradesh. These earthen or masonry reservoirs captured monsoon flows, supported irrigation networks, and maintained groundwater regimes (Agarwal & Narain, 1997). Many tanks were interconnected, allowing surplus water to cascade into downstream systems, enhancing flood control and water distribution efficiency (Gupta et al., 2021).

The Kudimaramathu system in Tamil Nadu is a notable community-based governance model where farmers collectively maintained tanks, desilted channels, and reinforced bunds (Patil & Lodhe, 2025). Tanks served agricultural needs, fisheries, livestock, and domestic functions, and often held religious and cultural significance due to proximity to temples (Verma, 2022).

Traditional tanks generally require 1–5 hectares of land depending on their purpose, catchment size, and storage capacity, although larger community tanks may extend beyond 10 hectares in village settings (Agarwal & Narain, 1997). They are ideally constructed in gentle low-lying depressions, along natural drainage lines, or at the lowest point of a micro-catchment**,** where runoff can naturally accumulate. Suitable locations also include areas with clay or loamy soil to minimize seepage losses. The cost of constructing traditional tanks varies widely, but small to medium tanks typically require ₹5–25 lakhs, covering excavation, embankment construction, inlet–outlet systems, and community labour contributions (CSE, 2020). Tanks are particularly effective in semi-arid and arid climates of India such as Rajasthan, Karnataka, and Tamil Nadu where seasonal rainfall needs to be captured for year-round use, but they also perform well in tropical monsoon regions for groundwater recharge and flood moderation. Overall, traditional tanks are low-cost, climate-resilient structures that support irrigation, drinking water storage, groundwater recharge, and flood control.

Decline of traditional tanks began with the shift toward bore wells, land ownership fragmentation, and weak institutional support (Sharma & Singh, 2020). Many tanks were encroached, converted for urban development, or polluted due to unmanaged sewage inflow (Singh et al., 2018). Yet, evidence shows that restoring tanks increases crop productivity, improves groundwater tables, and strengthens flood resilience (Das & Gupta, 2021).

Government programmes such as Telangana's Mission Kakatiya and Tamil Nadu's Irrigated Agriculture Modernization Project emphasize desilting, bund strengthening, and community engagement (World Bank, 2018). Tanks are increasingly being integrated into nature-based urban planning as multifunctional storm-water retention zones, biodiversity pockets, and recreational green-blue corridors (UN-Habitat, 2020).

Thus, tanks represent both historical ingenuity and modern sustainability opportunities. Strengthening legal protection, watershed catchment restoration, and local participation are essential to securing their future.

2.5 Water Revival Strategies

Water-body revival strategies emphasize restoring the natural hydrological cycle, ecological functioning, and community relationship with water. Unlike conventional engineered interventions, contemporary restoration emphasizes watershed thinking — recognizing that protecting the catchment, inflows, and percolation pathways is essential for sustained revival (Das & Gupta, 2021). Restoration often begins with baseline surveys, bathymetric mapping, and water-quality assessments, followed by desilting, catchment protection, and eco-hydrological interventions (MoEFCC, 2017).

Bathymetric mapping refers to the process of measuring and visualizing the depth, shape, and underwater topography of water bodies such as lakes, reservoirs, ponds, and rivers. It helps identify variations in depth, sediment accumulation, underwater slopes, and storage capacity. Modern bathymetric surveys use echo sounders, GPS, drones, or sonar-based instruments to generate a digital depth model (DDM), which supports scientific analysis and planning. This technique is widely used for lake restoration, sediment assessment, flood modelling, and capacity estimation because it reveals how much a water body has degraded over time due to siltation or encroachment (Singh & Dhiman, 2020). In urban planning and water-sensitive development, bathymetric mapping serves as a critical tool for understanding the health and functional potential of water bodies, enabling targeted interventions for rejuvenation and sustainable management (Patel et al., 2023).

Three key pillars guide effective revival:

1. Restoration of traditional systems, such as tanks and johads, which historically facilitated recharge and local irrigation (Agarwal & Narain, 1997).

2. Ecological restoration, focusing on native vegetation (refer Table: A1), bio-diverse wetlands, and shoreline stabilization (Chowdhury et al., 2021).
3. Hydrological improvements including storm-water channel restoration, recharge pits, aeration, and permeable buffers (Sharma & Singh, 2020).

Successful models include rejuvenation of lakes in Bengaluru, step-tank revival in Tamil Nadu, and Mission Kakatiya tank restoration in Telangana, all of which improved groundwater levels, enhanced biodiversity, and supported rural livelihoods (World Bank, 2018). These experiences demonstrate that revival must integrate traditional wisdom, scientific tools, and long-term governance structures.

Community engagement and institutional convergence are central to revival efforts. Local stakeholder participation enhances accountability and ensures ongoing maintenance. Government programmes, CSR funding, and academic-technical partnerships further strengthen implementation. Thus, water revival strategies reinforce ecological resilience, improve climate-change adaptation, and re-establish water bodies as public environmental assets.

2.5.1 Restoration of Traditional Water Systems

Reviving traditional water systems bridges historical knowledge with contemporary climate challenges. Structures such as temple tanks, village ponds, baolis, and johads once formed the backbone of local hydrology across India (Agarwal & Narain, 1997). Their decline due to over-reliance on bore wells, infrastructure expansion, and institutional neglect has contributed to declining groundwater, flooding, and aquifer depletion (Singh et al., 2018).

Traditional revival involves desilting, bund strengthening, channel restoration, removal of invasive weeds, and protection of catchment boundaries. States such as Tamil Nadu, Karnataka, Telangana, and Rajasthan have demonstrated that rejuvenating tanks and ponds can significantly improve groundwater recharge, agricultural yield, and ecosystem services (World Bank, 2018). Cultural revival festivals at temple tanks, community cleaning drives, and school-based awareness further strengthens stewardship (Chowdhury et al., 2021).

Desilting is carried out by mechanically or manually removing accumulated silt from tanks, ponds, and lakes to restore their original storage capacity and improve water quality; this is commonly done using excavators, draglines, or community-led manual de-silt removal, which

also enhances groundwater recharge (Singh & Kumar, 2020). Strengthening the bund involves compacting the earthen embankment, repairing cracks, adding stone pitching, and providing turfing with grass to prevent erosion and seepage, ensuring long-term structural stability (Patil et al., 2019). Channel restoration focuses on clearing obstructions, re-establishing natural flow paths, stabilizing channel banks with vegetation, and improving inlet–outlet conditions to increase hydrological connectivity and reduce flood risks (Sharma & Thomas, 2021). Protecting the catchment boundary includes fencing vulnerable edges, preventing encroachment, regulating land use, controlling dumping, and introducing vegetative buffer zones to reduce sediment inflow and maintain ecological health (Verma, 2022). These combined strategies ensure the functional revival and sustainable management of traditional and urban water bodies.

Integrating modern tools such as GIS mapping, drone-based surveys, and hydro-geological modelling enhances the efficiency of traditional systems (Das & Gupta, 2021). In peri-urban areas, combining traditional ponds with decentralized wastewater treatment and wetland polishing creates hybrid systems capable of sustaining both ecological and community needs (Lin et al., 2022). Thus, restoring traditional systems is not simply heritage conservation but also it is a contemporary strategy for groundwater security, climate adaptation, and community empowerment.

2.5.2 Ecological Restoration

Ecological restoration aims to rebuild the natural functioning of water bodies by enhancing biodiversity, restoring vegetation, and reviving natural hydrological systems. Instead of purely engineering solutions, this approach adopts nature-based strategies like shoreline planting, wetland creation, and removal of invasive species (Das & Gupta, 2021). Native aquatic vegetation stabilizes soil, supports fish and avifauna, and increases water infiltration (Chowdhury et al., 2021). Constructed wetlands and floating bio-islands further help filter pollutants and strengthen ecological networks (Grochowska, 2020).

Cities such as Bengaluru and Hyderabad are incorporating lake-buffer greenbelts, stormwater wetlands, and biodiversity zones into restoration plans. These projects improve dissolved oxygen levels, reduce algal blooms, and create urban micro-climate regulation effects (UN-Habitat, 2020). Ecological restoration also includes riparian buffer development, treatment wetlands, silt traps, and habitat-enhancement measures like fish ladders and bird islands.

Challenges include land encroachment, urban stormwater pressure, and maintaining native species against fast-growing invasives. However, coordinated management, long-term monitoring, and citizen science programs can support ecological health. Ecological restoration restores water bodies as living ecosystems rather than mere storage reservoirs — enabling long-term sustainability and climate resilience.

2.5.3 Hydrological Improvements

Hydrological restoration involves strengthening the natural water cycle through stormwater capture, infiltration improvement, and protection of hydrological pathways. Key strategies include desilting lake beds to restore capacity, restoring feeder channels, creating recharge wells, and installing rainwater-harvesting systems (Sharma & Singh, 2020). Permeable pavements, infiltration trenches, and bio-swales reduce surface runoff and increase groundwater recharge (Das & Gupta, 2021).

Urban lakes often suffer from disrupted inlets and blocked stormwater drains; reopening natural inflow paths and creating detention ponds help manage floods and recharge aquifers (UN-Habitat, 2020). Aeration systems, fountains, and water circulation devices improve oxygen levels and prevent stagnation, especially in urban tanks (Grochowska, 2020).

Hydrological restoration requires both infrastructure and institutional measures: catchment demarcation, flood-plain zoning, and enforcement of buffer areas are essential to prevent encroachment-driven hydrological disruption (MoEFCC, 2017). Combined with traditional systems like bund strengthening and feeder-channel revival, hydrological measures create resilient blue-green networks.

2.6 Innovative Approaches

Modern water-management practices increasingly integrate ecological science, biotechnology, and digital monitoring to enhance traditional systems. Innovations such as constructed wetlands, floating islands, microbial remediation, and citizen-led lake restoration draw from ecological principles and hydrological cycles (Das & Gupta, 2021). These approaches emphasize low-energy, nature-based solutions aligned with Sustainable Development Goals and climate-resilient planning (UN-Habitat, 2020).

Digital technologies further support real-time monitoring. Tools like GIS, satellite imagery, and IoT-based sensors help map catchments, detect encroachments, and track water-quality

parameters (Grochowska, 2020). Hydrological modelling and smart metering guide efficient water distribution and recharge site selection.

Despite technological sophistication, research stresses that engineering solutions alone cannot revive water bodies without community engagement and policy integration (World Bank, 2018). Hybrid approaches combining community knowledge, traditional water wisdom, and modern innovation yield the best outcomes (Sharma & Singh, 2020).

2.6.1 Floating Wetlands

Floating treatment wetlands (FTWs) are buoyant platforms planted with aquatic vegetation that absorb nutrient pollutants and support beneficial microbes. These systems remove nitrates, phosphates, and suspended solids, making them effective for urban lakes and rural ponds (Grochowska, 2020). Successful installations in Bengaluru's Jakkur Lake and Delhi's Sanjay Lake demonstrate improved dissolved oxygen levels and revived aquatic ecosystems (Chanakya et al., 2019).

FTWs are low-maintenance, energy-free, and compatible with native plant species, making them suitable for decentralized lake management. Combining FTWs with aeration, sediment removal, and buffer vegetation enhances their performance (Das & Gupta, 2021). However, long-term success requires pollution-source control, community maintenance, and continuous monitoring.

2.6.2 Bioremediation Using Bacterial Cultures

Bioremediation leverages beneficial bacteria to break down organic pollutants in water bodies, reducing BOD and COD levels (Sahu & Arif, 2024). Microbial consortia are deployed in drains, lakes, and ponds, especially where sewage inflow causes eutrophication. Projects across South India show improved clarity, odour reduction, and ecological balance when microbial treatment is paired with aeration and constructed wetlands (Das & Gupta, 2021).

Bioremediation is cost-effective and environmentally friendly but requires consistent dosing, temperature suitability, and nutrient balancing (Sharma & Singh, 2020). It represents a scalable nature-based sanitation solution for rural tanks and urban lakes.

2.6.3 Community-Led Restoration Projects

Community-driven water restoration fosters shared responsibility, participatory planning, and long-term stewardship (Gupta et al., 2012). Notable models include johad revival in Alwar, lake rejuvenation in Bengaluru, and Kakatiya tank restoration in Telangana (World Bank, 2018). Communities contribute labour, funds, and monitoring, while technical support comes from NGOs, engineers, and environmental scientists (Patil & Lodhe, 2025).

Successful projects utilize public awareness campaigns, school outreach, women's self-help groups, and digital reporting tools (UN-Habitat, 2020). Challenges include urban land pressure, funding gaps, and institutional fragmentation (Sharma & Singh, 2020). Strengthening legal frameworks and community rights improves effectiveness.

2.7 Pollution Mitigation Strategies for Water Bodies

Urbanization, industrial growth, and land-use changes have significantly degraded natural and man-made water bodies in India. Lakes, tanks, ponds, and wetlands that historically served as vital recharge zones, flood buffers, ecosystems, and cultural spaces are now threatened by encroachment, pollution, and poor governance (MoEFCC, 2017). Urban water bodies in particular face challenges arising from untreated sewage inflow, solid-waste dumping, siltation, and loss of catchment areas (UN-Habitat, 2020). Consequently, many water bodies have experienced eutrophication, reduced storage capacity, biodiversity loss, and decline in groundwater recharge (Lin et al., 2022).

Recent policy emphasis in India has shifted toward nature-based solutions, hybrid watershed planning, and stakeholder collaboration. Scientific interventions such as ecological dredging, bioremediation, constructed wetlands, and stormwater harvesting are being increasingly integrated with traditional systems to revive degraded lakes and ponds (Das & Gupta, 2021).

Ecological dredging involves the selective extraction of nutrient-rich or polluted sediments to control eutrophication and restore water depth, while maintaining habitat stability (Zhang et al., 2020). The removed sediments are then dewatered, treated, or reused, depending on their contamination level ensuring that the restoration process supports long-term ecological recovery (Khan & Ansari, 2021).

At the same time, decentralized wastewater treatment and community stewardship programmes demonstrate that sustainable revival cannot depend solely on technology; restoring social and institutional engagement is equally vital (World Bank, 2018).

Pollution mitigation focuses on preventing contaminants from entering water bodies and restoring water quality through treatment and ecological processes. Untreated sewage remains a major cause of lake and pond degradation in India. Decentralized wastewater treatment systems (DEWATS), constructed wetlands, and aeration technologies help treat greywater and stormwater inflows (Chanakya et al., 2019).

Community-based lake committees, regulatory enforcement, and monitoring dashboards ensure compliance and long-term protection (MoEFCC, 2017).

2.7.1 Sewage and Wastewater Management

Effective sewage and wastewater management is essential for reducing pollution loads entering urban water bodies, particularly in rapidly growing Indian cities. One widely adopted approach is the use of Decentralized Wastewater Treatment Systems (DEWATS), which treat sewage at or near the source using gravity-based, low-energy processes such as sedimentation, anaerobic baffled reactors, planted gravel filters, and polishing ponds (Chanakya et al., 2019).

Sedimentation serves as the primary treatment step, where wastewater is slowed in settling tanks so that heavier solids sink as sludge and oils float, removing nearly half of suspended impurities and preparing the flow for biological processes (Kumari & Yadav, 2020). The partially clarified water then enters an Anaerobic Baffled Reactor (ABR), where it moves sequentially through multiple baffle-separated chambers; within these chambers, anaerobic microbes degrade organic matter and significantly reduce BOD and COD without the need for electricity, making ABRs highly effective for domestic sewage treatment (Sasse, 1998). The effluent then passes into a Planted Gravel Filter or constructed wetland—a gravel bed vegetated with species such as *Phragmites australis* or *Typha angustifolia*—where plant roots supply oxygen to microbial films that facilitate nitrification, pathogen reduction, and nutrient removal (Vymazal, 2011). Finally, the water enters a polishing pond, a shallow basin that uses sunlight, natural aeration, algae, aquatic plants, and microorganisms to complete purification by settling remaining particles and improving aesthetics and smell, producing treated water suitable for landscaping, agriculture, or groundwater recharge (Sharma et al., 2016).

DEWATS require minimal maintenance, operate without continuous electricity, and are particularly effective in peri-urban and informal settlements that lack sewer connectivity (CSE, 2020). Treated greywater can be reused for irrigation and landscaping, reducing freshwater demand (Lin et al., 2022).

Integrated wastewater treatment combining wetlands, microbial dosing, aeration, and sludge-removal pipelines improves water quality significantly when maintained consistently (Das & Gupta, 2021). Public-private-community partnerships are increasingly adopted for operation and maintenance (World Bank, 2018).

2.7.2 Bioremediation and Nature-Based Solutions

Bioremediation uses microbial cultures, enzymes, and eco-friendly compounds to break down pollutants without harsh chemicals (Sahu & Arif, 2024). Floating treatment wetlands further support nitrification and denitrification processes (Grochowska, 2020). Bio-filters, reed beds, and phytoremediation improve water quality cost-effectively and sustainably (Das & Gupta, 2021).

Nature-based solutions restore ecological functions, reduce algae growth, and improve dissolved oxygen levels. These approaches are scalable and ideal for rural ponds, temple tanks, and peri-urban lakes.

2.7.3 Preventing Encroachments and Solid Waste Pollution

Encroachment and solid-waste dumping are among the most persistent drivers of water-body degradation in rapidly urbanizing regions. Effective prevention begins with the scientific demarcation of lake and pond boundaries using cadastral maps, GPS surveys, and GIS-based overlays, which clearly define the legal extent of the water body and its catchment (MoEFCC, 2017). Once boundaries are established, buffer zones of 30–100 meters depending on state regulations—are enforced to prevent construction, soil filling, and road expansion near the water's edge. Physical interventions such as perimeter fencing, stone pitching, retaining walls, and vegetated buffers further discourage encroachment and stabilize fragile edges (UN-Habitat, 2020). To curb solid-waste pollution, municipalities increasingly rely on CCTV surveillance, drone monitoring, geo-tagged waste reporting apps, and regular patrols that deter illegal dumping and enable swift penal action. At the same time, decentralized waste collection points,

segregation units, and door-to-door collection systems reduce the likelihood of waste entering drains that lead to water bodies.

Regulatory enforcement alone, however, is insufficient. Long-term protection requires community stewardship through lake protection committees, school-level awareness drives, local monitoring groups, and citizen-science initiatives that report violations and help maintain lake edges (World Bank, 2018). Public participation also strengthens social vigilance, creating a sense of ownership that discourages encroachment and pollution. Together, these measures combining legal boundary protection, technological surveillance, ecological buffers, and community engagement form a comprehensive and sustainable strategy for safeguarding urban water bodies from shrinkage, contamination, and irreversible ecological loss.

2.8 Sustainable Planning Interventions

Sustainable planning interventions for urban water bodies focus on integrating these natural assets into the broader urban ecosystem in a manner that balances ecological health, social utility, and infrastructural efficiency. Urban water bodies, such as lakes, ponds, and wetlands, are no longer seen merely as storage reservoirs; they are multifunctional landscapes that contribute to biodiversity conservation, flood mitigation, microclimate regulation, and community well-being. When planned and managed effectively, they act as green-blue corridors that connect fragmented habitats, allowing flora and fauna to thrive even within dense urban settlements.

Water-Sensitive Urban Development (WSUD) provides a guiding framework for these interventions, emphasizing solutions that are both environmentally responsive and socially inclusive (Sharma & Bharat, 2019). WSUD promotes the integration of natural hydrological processes into urban planning, including storm water management, groundwater recharge, and pollution control. Through this approach, urban water bodies can support sustainable urban growth while maintaining ecological integrity.

The objectives of sustainable planning interventions are multi-fold. Firstly, they aim to enhance ecological balance by restoring native vegetation, improving water quality, and supporting habitat connectivity. Secondly, they focus on strengthening groundwater recharge, ensuring that urbanization does not compromise the natural replenishment of aquifers. Thirdly, they seek to build community resilience, engaging citizens in stewardship, education, and

participatory management practices. By combining these objectives, sustainable planning interventions create water bodies that are resilient to climate variability, urban pressures, and environmental degradation, thereby ensuring their long-term functionality and contribution to urban livability.

In essence, sustainable interventions transform urban water bodies from passive infrastructure elements into dynamic ecological, social, and hydrological assets, contributing to the overall sustainability and resilience of cities.

2.8.1 Enhancing Ecological Balance

Ecological balance in water bodies refers to maintaining natural interactions between water, vegetation, soil organisms, fish, birds, and microorganisms. Degraded lakes and ponds often exhibit eutrophication, invasive weed growth, loss of native biodiversity, foul odour, and reduced dissolved oxygen levels (Lin et al., 2022). Ecological restoration seeks to reverse these trends through nature-based strategies.

Key interventions include planting native aquatic vegetation, creating riparian green belts, restoring feeder channels, and introducing constructed wetlands and floating treatment wetlands to absorb nutrients and filter pollutants (Chanakya et al., 2019). Removal of invasive species such as water hyacinth and Prosopis juliflora significantly improves oxygen balance and ecological succession (Sharma & Singh, 2020). Aeration systems, bio-enzymes, and microbial remediation further support oxygenation and nutrient cycling.

Biodiversity parks, bird islands, pollinator gardens, and fish sanctuaries promote ecological diversity and convert water bodies into urban biodiversity hotspots (UN-Habitat, 2020). Integrating ecological buffers along lake edges prevents erosion, supports groundwater seepage, and provides habitats.

Monitoring using indicators such as Biological Oxygen Demand, Chlorophyll-a levels, and plankton diversity ensures adaptive maintenance. Additionally, community participation through citizen lake groups fosters long-term ecological stewardship.

The emphasis on ecological balance represents a shift from treating lakes merely as storage basins to recognizing them as living ecosystems critical to urban resilience, carbon sequestration, heat mitigation, and cultural identity. Thus, ecological restoration remains a cornerstone of sustainable water-body management.

2.8.2 Strengthening Groundwater Recharge

Groundwater recharge is vital for maintaining aquifers, sustaining agriculture, and stabilizing hydrological cycles. Urban expansion and impermeable built surfaces have significantly reduced natural percolation, leading to groundwater depletion (Agarwal & Narain, 1997). Strengthening recharge requires land-water-soil integration, watershed planning, and reactivation of traditional recharge structures.

Strategies include desilting ponds, rejuvenating tanks, deepening recharge wells, creating percolation pits, installing rainwater-harvesting systems, and restoring feeder inlets (Das & Gupta, 2021). Check dams, contour trenches, and gabion structures capture monsoon runoff in rural landscapes, while urban planning should promote permeable pavements, bios wales, rain gardens, and green roofs to enhance infiltration (Lin et al., 2022).

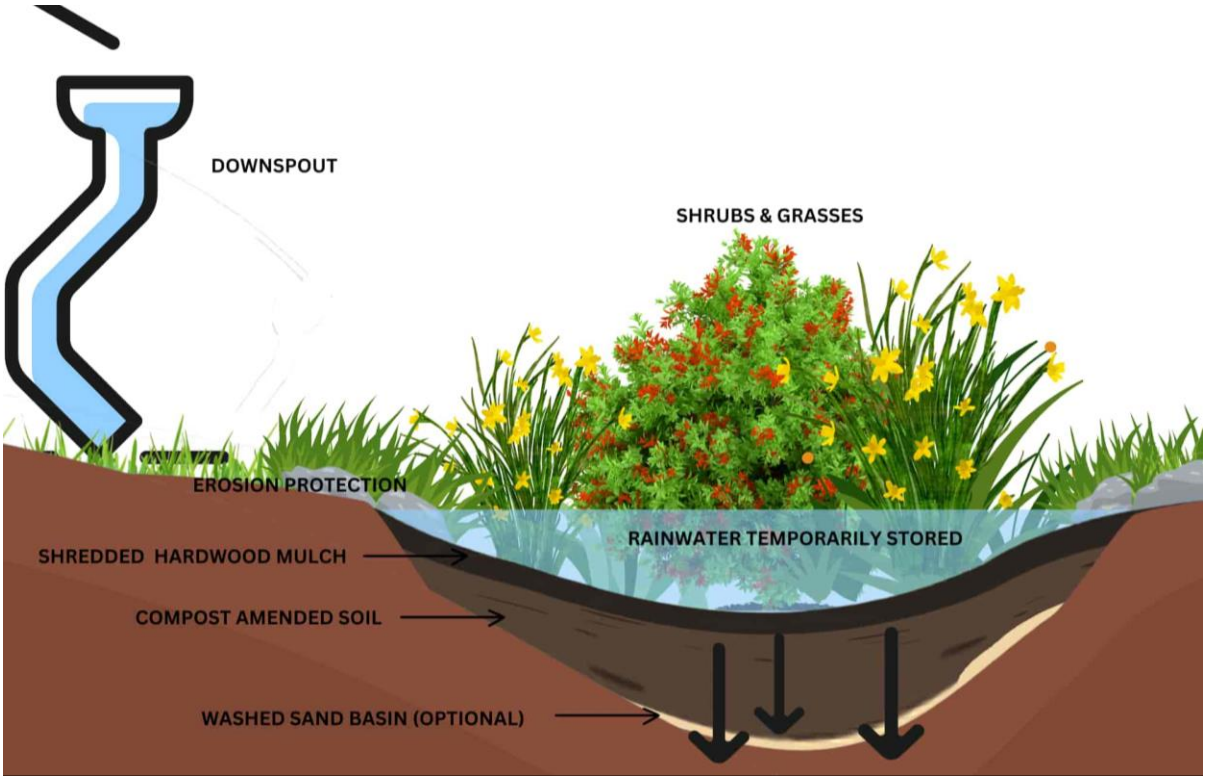


Figure 11:Image of Rain Garden *Source: https://warelandscaping.com/resources/rain-garden/*

A rain garden is a shallow, vegetated bio-retention feature as shown in figure 11, engineered to intercept, temporarily store, and infiltrate stormwater runoff generated from adjacent impervious surfaces such as rooftops, pavements, and driveways. Designed as part of Low Impact Development (LID) and Water-Sensitive Urban Development (WSUD) practices, rain

gardens enhance on-site hydrological performance by promoting infiltration, pollutant removal, and reduction of peak runoff volumes (EPA, 2022; Prince George's County, 1999). Site selection typically requires locating the rain garden at least 3 meters (10 feet) away from building foundations to prevent moisture intrusion. The area should possess a gentle slope (ideally 1–5%) to allow natural conveyance of runoff into the depression, while avoiding locations with buried utilities, septic fields, or compacted soil layers that may hinder infiltration (Minnesota Pollution Control Agency, 2021). The sizing of a rain garden is determined by the contributing drainage area and soil infiltration capacity. As a general design rule, the rain garden area should be approximately 20–30% of the catchment area draining into it to ensure adequate detention and infiltration of a typical storm event (EPA, 2022). For most residential parcels, this results in a functional rain garden size of approximately 9–28 m^2 (100–300 ft^2), depending on rainfall intensity, soil type, and runoff coefficients (Dietz & Clausen, 2005).

Traditional practices such as stepwells, baolis, and temple tanks historically supported aquifer recharge and can be revived using modern hydrogeological mapping and GIS models (Gupta et al., 2021). Through hydrogeological surveys, planners identify subsurface strata, aquifer depth, permeability zones, and historic recharge corridors to determine how much water these structures can capture and infiltrate. GIS tools allow detailed mapping of catchments, flow accumulation paths, slope gradients, and land-use changes to re-establish the original drainage networks that once fed these structures. By overlaying soil maps, groundwater fluctuation data, and digital elevation models (DEMs), engineers can determine the most efficient points for desilting, inlet restoration, and reconnection of traditional feeder channels. Modern techniques such as LiDAR, remote sensing, and groundwater modelling help estimate recharge potential and optimize structural repairs, ensuring that revived stepwells and tanks function effectively in today's urbanized environments. This integration of traditional knowledge with contemporary spatial technologies enhances water-storage capacity, improves infiltration, and restores cultural heritage structures as functioning components of the urban water cycle (Gupta et al., 2021). Policies requiring groundwater recharge in large buildings, industrial plots, and residential layouts ensure adoption at scale.

Strengthening recharge also supports base flow restoration in rivers, reduces flood risk, and buffers climate-driven drought cycles. Coupled with groundwater-monitoring sensors and participatory water budgeting, recharge programs enhance accountability and water equity.

An aquifer helps recharge a water body by letting water slowly move down through the soil into the groundwater as shown in image 12. This happens because water naturally flows from higher levels to lower levels.

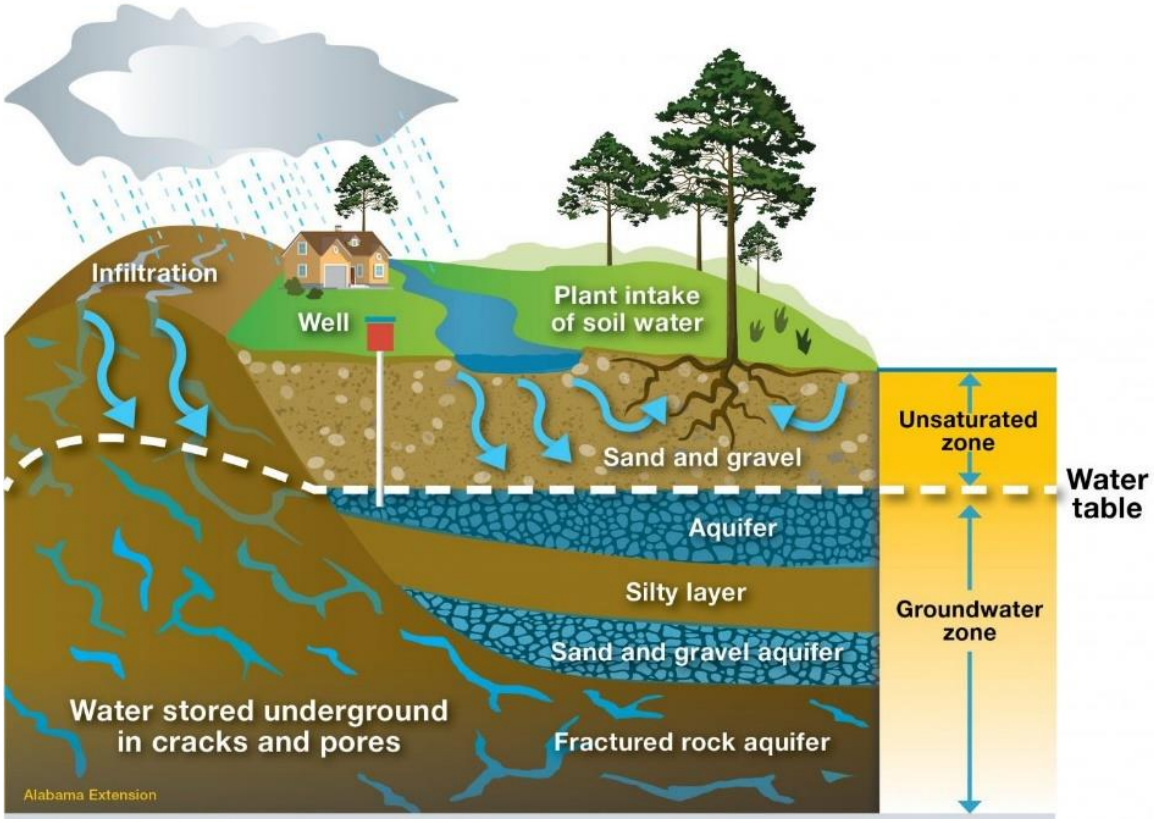


Figure 12:Image of Aquifier *Source: https://www.aces.edu/blog/topics/fish-water/what-is-an-aquifer/*

When a river or lake is connected to an aquifer, water can move back and forth between them. During the rainy season, extra water enters the ground and fills the aquifer. In dry seasons, the stored groundwater can move back to the river or lake. This process keeps groundwater levels stable and ensures water is available for a long time (Fetter, 2018; Sophocleous, 2002). Thus, reinforcing aquifer systems is a foundational strategy for achieving long-term water security in both rural and urban environments.

2.8.3 Detention Ponds

A detention pond is an engineered stormwater basin designed to temporarily store runoff during rainfall events and release it slowly to reduce peak flooding and downstream erosion (Hung, Aziz, & Murshed, 2012). It functions by receiving stormwater inflow from surrounding impervious areas, allowing sediments and pollutants to settle, and then discharging water

through a controlled outlet structure. Detention ponds are highly suitable for temperate, tropical, and semi-arid climates, where rainfall occurs in short, intense bursts and requires temporary storage; however, they are less effective in extremely arid regions with infrequent rainfall. Construction typically takes 2–6 months, depending on excavation depth, soil conditions, and landscaping requirements (U.S. EPA, 2020).

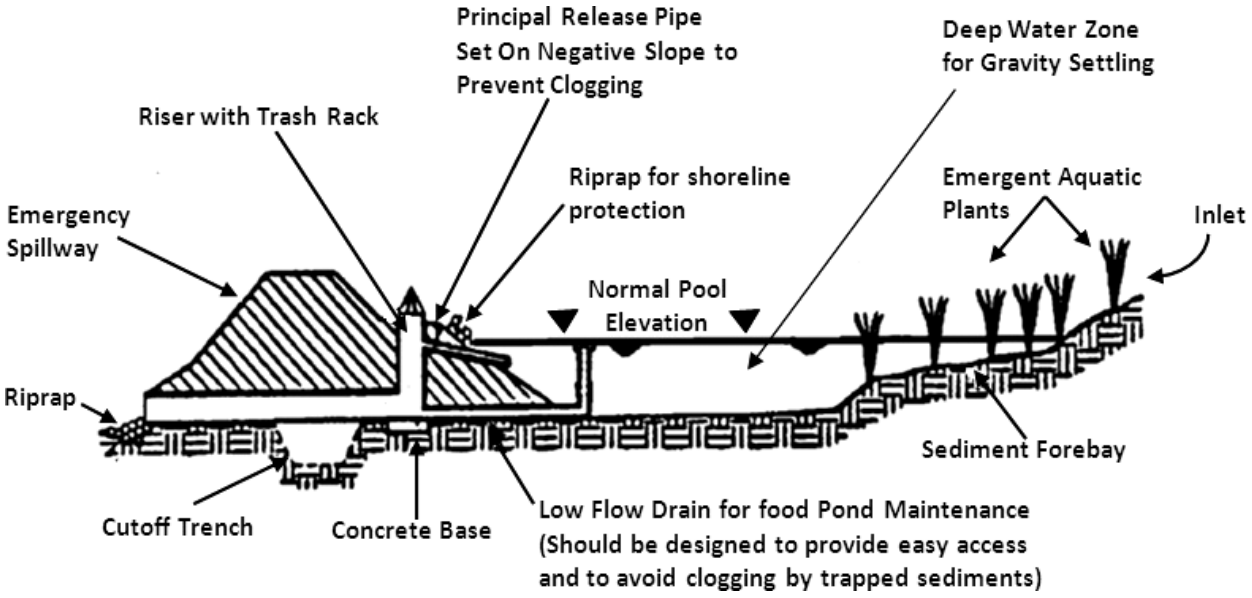


Figure 13:Detention Pond *Source: (Hung, Aziz, & Murshed, 2012)*

The approximate cost varies widely, ranging from ₹20 lakh to ₹2 crore (USD $25,000–$250,000) based on size, land availability, and engineering design. In addition to flood mitigation, detention ponds improve water quality by promoting sedimentation and vegetation-based filtration, while also enhancing groundwater recharge when designed with permeable bases (World Bank, 2020). Their ability to integrate with urban green spaces makes them essential elements of water-sensitive urban development and climate-responsive flood management as shown in image 13.

2.8.4 Bioswale

A bioswale is a shallow, vegetated channel designed to capture, slow, filter, and infiltrate stormwater runoff, using engineered soil layers, native plants, and gravel trenches to remove sediments, nutrients, heavy metals, and hydrocarbons from polluted urban runoff (Branković et al., 2019). Bioswales perform best in tropical, humid subtropical, and temperate climates, where consistent rainfall supports vegetation growth and enhances pollutant removal; they are also effective in semi-arid regions if drought-tolerant species are used (EPA, 2020). Bioswales

work through a multi-stage process: runoff enters the swale, slows down due to vegetation, infiltrates through soil and sand layers, filters contaminants through root zones, and finally drains through an underdrain system during peak events. Construction typically requires 1–3 months because of relatively low earthwork and simple planting requirements.

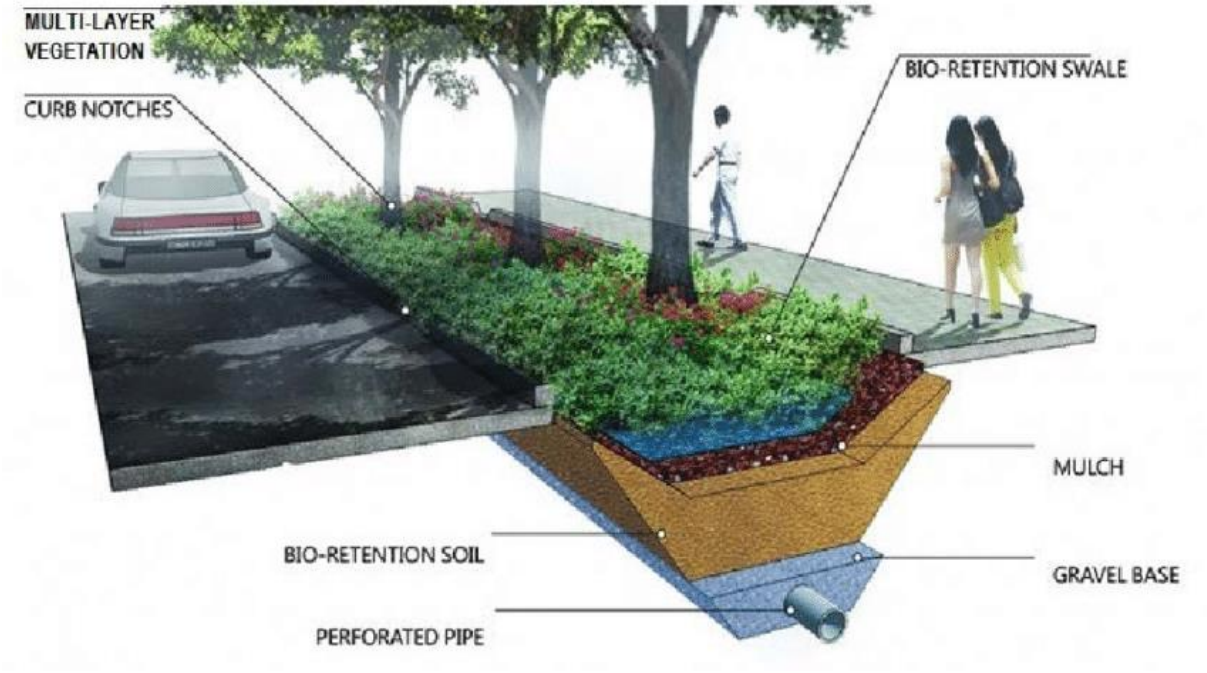


Figure 14:Image of Bioswale *Source: (Brankovic et al., 2019)*

Their cost is moderate, usually ranging from ₹5 lakh to ₹40 lakh (USD $7,000–$50,000), depending on length, depth, plant species, and subsurface drainage (Green Infrastructure Center, 2017). Bioswales are widely used along roadways, parking lots, campuses, and residential colonies due to their dual advantage of runoff control and water-quality improvement as shown in Figure 14. Their ecological benefits such as groundwater recharge, street cooling, biodiversity enhancement, and aesthetic improvement make them an essential element of modern green–blue infrastructure strategies.

2.8.5 Building Community Resilience

Community resilience refers to the capacity of local residents to manage, protect, and adapt water resources under socio-economic and climate stress. Historically, village and ward committees played crucial roles in maintaining ponds, tanks, and canals. The erosion of these systems has weakened collective water governance (Agarwal & Narain, 1997). Rebuilding resilience requires participatory structures, shared responsibility, and environmental education.

Strategies include establishing lake protection committees, watershed user groups, and women's self-help groups trained in water stewardship (World Bank, 2018). Community-driven initiatives lake cleaning, seed-ball plantations, water festivals, and school awareness programs create emotional and cultural attachment to water systems (Sharma & Singh, 2020).

Capacity building through workshops, real-time dashboards, citizen-science monitoring, and mobile-app feedback enhances transparency and trust. Social inclusion is essential—ensuring marginalized communities participate in decision-making and benefit from restored water resources. Thus, community-led governance is a crucial pillar of sustainable water-body restoration and ensures long-term stewardship, social equity, and cultural continuity.

2.9 Case Studies of Water Sensitive Urban Development

Case studies provide practical examples of the successful implementation of Water Sensitive Urban Development (WSUD) principles in different geographical and environmental contexts. They demonstrate various planning strategies, ecological restoration techniques, stormwater management approaches, groundwater recharge measures, wastewater treatment systems, and community participation models adopted for the conservation and revival of water bodies. The selected case studies include Indian examples with varying climatic and urban conditions, along with the internationally recognized ABC Waters Programme of Singapore as a best-practice reference. The key interventions, outcomes, and planning lessons from these case studies are analysed to identify suitable strategies that can be adapted for the conservation and revival of water bodies in the city.

2.9.1 Jakkur Lake – A Water Sensitive Urban Development (WSUD) Model, Bengaluru, Karnataka

Jakkur Lake is located in the northern part of Bengaluru, Karnataka, and is widely recognized as one of India's most successful examples of Water Sensitive Urban Development (WSUD). The lake forms part of Bengaluru's interconnected lake system and demonstrates how ecological engineering can restore urban water bodies while addressing wastewater treatment, groundwater recharge, biodiversity conservation, and recreational needs. The lake occupies an area of approximately 55 ha and receives treated wastewater from a 10 MLD Sewage Treatment Plant (STP) before the water enters the lake through a constructed wetland system (Ramachandra et al., 2018).

WSUD Interventions

The restoration of Jakkur Lake follows an integrated water management approach in which wastewater treatment is combined with natural ecosystem processes. Instead of discharging treated wastewater directly into the lake, the effluent first passes through a constructed wetland consisting of emergent macrophytes and an algal polishing pond. This natural treatment system removes suspended solids, nutrients, and organic pollutants before the water enters the main lake, thereby improving overall water quality (Ramachandra et al., 2018).

The restoration programme also included desilting of the lake, strengthening of embankments, construction of sedimentation traps, development of peripheral pathways, protection of lake boundaries, plantation of native vegetation, and creation of biodiversity zones. These interventions improved both the ecological functioning of the lake and its recreational value while enhancing community participation in lake conservation (BBMP, n.d.; CDD Society, 2019).

Water Management Strategy

The integrated treatment system at Jakkur Lake consists of four major components:

- Sewage Treatment Plant (STP) for primary and secondary wastewater treatment.
- Constructed wetland with emergent aquatic vegetation for nutrient removal.
- Algal polishing pond for further purification of treated water.
- Lake ecosystem acting as the final polishing and storage component.

The combined treatment system significantly improves water quality before discharge into the lake. Research conducted by the Indian Institute of Science (IISc) reported that the integrated wetland system achieved approximately 90% Biological Oxygen Demand (BOD) removal, 77% Chemical Oxygen Demand (COD) removal, and substantial reductions in phosphorus and nitrate concentrations, resulting in water quality that meets acceptable environmental standards (Ramachandra et al., 2018).

Outcomes

The restoration of Jakkur Lake has generated multiple environmental and socio-economic benefits, including:

- Continuous availability of water throughout most of the year.
- Improvement in surface water quality through natural treatment processes.
- Enhanced groundwater recharge in surrounding areas.
- Conservation of aquatic biodiversity, including fish, birds, and wetland vegetation.
- Reduction in pollution entering downstream lakes.
- Creation of recreational open spaces and environmental awareness among local communities.
- Sustainable reuse of treated wastewater, reducing dependence on freshwater resources.

The project demonstrates that integrating engineered infrastructure with natural ecosystems can significantly improve the resilience of urban water bodies while delivering multiple ecosystem services.

2.9.2 Alwar Johad Revival, Rajasthan – Community-Based Water Conservation

The Alwar Johad Revival is one of India's most notable examples of community-led water resource restoration through traditional rainwater harvesting techniques. The initiative was undertaken in the semi-arid district of Alwar, Rajasthan, where declining groundwater levels, deforestation, excessive mining, and the abandonment of traditional water harvesting structures had resulted in severe water scarcity and environmental degradation during the 1980s. In 1985, the non-governmental organization Tarun Bharat Sangh (TBS), under the leadership of Rajendra Singh, initiated a programme to revive the traditional Johad system with active participation of local communities (Tarun Bharat Sangh, n.d.; Kandpal & Kumar, 2003).

WSUD Interventions

A Johad is a traditional earthen check dam constructed across natural drainage channels to capture monsoon runoff. The restored Johads slow surface runoff, promote infiltration, reduce soil erosion, and recharge groundwater aquifers. The revival programme also included catchment area treatment, afforestation, soil conservation measures, protection of drainage channels, and community-based management of water resources.



Figure 15: Before and After Image of Johads in Karauli *Source: https://www.theearthandi.org/post/india-waterman-brings-solutions-to-a-drought-plagued-region?utm_source*

Unlike conventional engineering solutions, the project integrated traditional knowledge with watershed planning and local participation. The construction and maintenance of Johads were carried out through community involvement, ensuring long-term sustainability and equitable water sharing (Kandpal & Kumar, 2003).

Water Management Strategy

The Alwar Johad Revival adopted an integrated watershed management approach based on the following components:

- Construction and restoration of traditional Johads across seasonal streams.
- Recharge of groundwater through enhanced infiltration.
- Catchment protection through afforestation and soil conservation.
- Community participation in planning, construction, and maintenance.
- Regulation of groundwater use through village institutions.
- Restoration of natural drainage systems and river catchments.

Over the years, thousands of Johads were constructed or restored across villages in Alwar district. These interventions significantly increased groundwater recharge, expanded irrigated agricultural land, improved drinking water availability, and contributed to the revival of several seasonal rivers, including the Arvari, Ruparel, Sarsa, and Bhagani rivers (Tarun Bharat Sangh, n.d.; Kandpal & Kumar, 2003).

Outcomes

The Johad revival programme generated substantial environmental, social, and economic benefits, including:

- Significant increase in groundwater levels.
- Improved year-round availability of drinking and irrigation water.
- Revival of previously seasonal rivers.
- Reduction in soil erosion and surface runoff.
- Increased agricultural productivity and cropping intensity.
- Enhanced vegetation cover and biodiversity.
- Reduced seasonal migration due to improved rural livelihoods.
- Strengthened community participation in water governance.

The success of the initiative demonstrates that decentralized rainwater harvesting and community-led watershed management can effectively restore degraded landscapes while improving water security and ecosystem resilience.

2.9.3 Hussain Sagar Lake Restoration, Hyderabad, Telangana

Hussain Sagar Lake is a historic artificial lake located between Hyderabad and Secunderabad, Telangana as shown in Figure 16. Constructed in 1562 during the reign of Ibrahim Quli Qutb Shah, the lake originally served as the primary drinking water source for the city. However, rapid urbanization, industrialization, and population growth during the twentieth century resulted in the discharge of untreated sewage, industrial effluents, and solid waste into the lake, causing severe water pollution, eutrophication, sediment accumulation, and deterioration of aquatic ecosystems (Hyderabad Metropolitan Development Authority [HMDA], n.d.).



Figure 16: Image of Hussain Sagar Lake *Source: https://www.siasat.com/hydraa-works-to-restore-bum-rukn-ud-dowla-lake-by-november-end-3288609/?utm_source*

To restore the ecological health of the lake, the Government of Telangana, Hyderabad Metropolitan Development Authority (HMDA), Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB), and the Japan International Cooperation Agency (JICA) initiated the Hussain Sagar Lake and Catchment Area Improvement Project, adopting an integrated lake and catchment management approach (HMDA, n.d.).

WSUD Interventions

The restoration programme incorporated several Water Sensitive Urban Development (WSUD) principles aimed at improving water quality and restoring ecosystem functions. Major

interventions included interception and diversion of sewage entering the lake, expansion of sewage treatment infrastructure, construction of interceptor sewers along major drains, desilting of polluted sediments, shoreline protection, catchment management, solid waste control, and ecological restoration.

Stormwater drains were separated from sewage flows wherever feasible to reduce contamination during rainfall events. Measures were also implemented to reduce nutrient loading, control encroachments, improve public open spaces around the lake, and enhance recreational amenities while protecting the ecological integrity of the water body (HMDA, n.d.; Centre for Science and Environment [CSE], n.d.).

Water Management Strategy

The restoration strategy followed an integrated urban water management framework comprising:

- Interception and diversion of untreated sewage before it enters the lake.
- Expansion and upgradation of sewage treatment facilities.
- Construction of interceptor sewers along major inflowing drains.
- Removal of nutrient-rich sediments through desilting.
- Catchment area management to reduce pollutant inflow.
- Shoreline stabilization and protection against encroachment.
- Continuous water quality monitoring and lake management.

This integrated approach aims to improve lake water quality, restore ecological functions, reduce pollution loads, and enhance the recreational and environmental value of the lake for Hyderabad's urban population (HMDA, n.d.).

Outcomes

The Hussain Sagar restoration programme has contributed to significant improvements in urban lake management by reducing pollutant inflows, strengthening wastewater infrastructure, improving shoreline conditions, and promoting integrated catchment management. The project has enhanced recreational opportunities, increased public awareness regarding lake conservation, and established a framework for long-term restoration of one of

India's most important urban lakes. The restoration also highlights the importance of combining engineering solutions with environmental planning and institutional coordination for sustainable urban water management (HMDA, n.d.; CSE, n.d.).

2.9.4 Rajkot Rainwater Harvesting Initiative, Gujarat

Rajkot, located in the semi-arid region of Saurashtra, Gujarat, has historically experienced recurring water scarcity due to low and erratic rainfall, rapid urbanization, and increasing groundwater extraction. To improve urban water security, the Rajkot Municipal Corporation (RMC) and the Government of Gujarat have implemented several rainwater harvesting and groundwater recharge measures as part of integrated urban water management. These initiatives focus on maximizing local rainfall, reducing dependence on external water sources, and enhancing groundwater recharge through decentralized rainwater harvesting systems (Bhardwaj & Khosla, 2017).

WSUD Interventions

The Rajkot initiative incorporates several Water Sensitive Urban Development (WSUD) principles by promoting decentralized rainwater management across the city. The major interventions include:

- Mandatory rooftop rainwater harvesting in many new public and private developments.
- Construction of recharge wells and recharge shafts for groundwater replenishment.
- Development of check dams and percolation structures in peri-urban catchments.
- Stormwater diversion to recharge structures instead of direct disposal.
- Watershed development and conservation measures to reduce runoff and soil erosion.
- Public awareness programmes encouraging household-level rainwater harvesting.

These interventions emphasize source control of stormwater and groundwater recharge while reducing urban runoff losses.

Water Management Strategy

The rainwater harvesting programme follows an integrated water conservation approach consisting of:

- Collection of rooftop rainwater through gutters and downpipes.

- Filtration of collected runoff before groundwater recharge.
- Recharge of shallow aquifers through recharge wells and infiltration structures.
- Storage of excess runoff in local ponds, check dams, and percolation tanks.
- Integration of watershed management with urban drainage planning.

The programme aims to increase groundwater availability, improve water supply resilience, reduce dependence on distant water sources, and enhance sustainable management of urban water resources (Khandelwal et al., 2003).

Outcomes

The implementation of rainwater harvesting measures in Rajkot has contributed to improved groundwater recharge, enhanced utilization of locally available rainfall, reduced surface runoff, and increased public awareness regarding water conservation. The city's experience demonstrates that decentralized rainwater harvesting can strengthen urban water security in semi-arid regions while complementing conventional water supply systems. It has also encouraged the incorporation of water conservation measures into urban planning and building development (Bhardwaj & Khosla, 2017).

2.9.5 ABC Waters Programme, Singapore

The Active, Beautiful, Clean (ABC) Waters Programme was launched by the Public Utilities Board (PUB), Singapore, in 2006 to transform the country's drainage canals, reservoirs, and waterways into multifunctional blue-green infrastructure. The programme integrates stormwater management, landscape design, ecological restoration, and community spaces to enhance urban liveability while improving water quality and resilience. Rather than treating stormwater as a waste product, the ABC Waters Programme considers it a valuable resource that can be managed through nature-based solutions and integrated urban planning (PUB, 2018).

WSUD Interventions

The programme incorporates several Water Sensitive Urban Development (WSUD) principles through decentralized stormwater management and green infrastructure. Major interventions include:

- Bioswales for filtering and conveying stormwater runoff.

- Rain gardens (bioretention systems) to remove pollutants and promote infiltration.
- Constructed wetlands for stormwater polishing and ecological treatment.
- Permeable pavements to increase infiltration and reduce surface runoff.
- Green streets incorporating vegetated swales and roadside planting.
- Retention and detention ponds to regulate stormwater flow.
- Naturalized canals and river restoration to improve ecological functions.
- Riparian buffer vegetation for erosion control and habitat enhancement.

These interventions collectively reduce runoff volume, improve water quality, increase groundwater recharge where feasible, and enhance urban biodiversity.

Water Management Strategy

The ABC Waters Programme follows an integrated urban water management approach based on source control and decentralized treatment. Stormwater is managed close to its source through green infrastructure before entering drainage networks and reservoirs. This approach minimizes pollutant loads, delays runoff, increases infiltration, and enhances the recreational and ecological value of urban waterways (PUB, 2018).

Outcomes

Implementation of the ABC Waters Programme has resulted in significant environmental and social benefits, including:

- Improved stormwater quality before discharge into reservoirs.
- Reduction in urban flooding through enhanced stormwater retention.
- Increased use of green infrastructure across public developments.
- Improved biodiversity and ecological connectivity.
- Creation of attractive public spaces that encourage recreation and community engagement.
- Integration of water management with urban planning and landscape design.

The programme has become an internationally recognized model for sustainable urban water management and demonstrates how engineering and ecological approaches can be combined to create resilient cities.

2.10 Government Initiatives for Water Conservation

Government initiatives play a pivotal role in strengthening water governance, improving infrastructure, and enabling equitable resource distribution. In India, historical dependence on monsoon rainfall, rapid urbanization, and rising water demand have put immense pressure on natural and built water systems (MoEFCC, 2017). Recognizing these challenges, national and state authorities have launched comprehensive programs targeting surface-water rejuvenation, groundwater recharge, pollution control, sanitation, and community participation. These initiatives align with Sustainable Development Goals (SDG-6 & SDG-11) and emphasize integrated water-resource management, technological innovation, and decentralized planning (UN-Habitat, 2020).

Major national missions such as AMRUT, Smart Cities Mission, Swachh Bharat Mission, and Jal Jeevan Mission prioritize water infrastructure, lake revival, and household water security (NITI Aayog, 2021). Specialized programmes like the National Plan for Conservation of Aquatic Ecosystems (NPCA) focus on lake and wetland restoration through scientific and nature-based solutions. Land-use regulation and zoning frameworks further support water bodies by controlling encroachment, protecting floodplains, and mandating buffer zones (Sharma & Singh, 2020).

However, implementation challenges persist. Coordination gaps between municipal bodies, limited technical capacity, informal land use, and weak monitoring systems restrict program effectiveness. Continued success demands strengthening community participation, leveraging digital monitoring tools, adopting nature-based solutions, and promoting accountability across governance levels (World Bank, 2018). This chapter reviews key national schemes and spatial policies supporting water conservation in India.

2.11 Government Schemes for River Conservation and Rejuvenation in India

Rivers form the lifeline of India's ecological, social, and economic systems. However, rapid urbanization, industrialization, and population growth have led to severe pollution,

encroachment, and depletion of riverine ecosystems. To address these challenges, the Government of India has launched several schemes and missions aimed at the restoration, rejuvenation, and sustainable management of rivers**,** integrating both ecological and socio-economic dimensions.

2.11.1. National River Conservation Plan (NRCP)

The National River Conservation Plan (NRCP)**,** initiated in 1995 under the Ministry of Environment, Forest and Climate Change (MoEFCC)**,** is one of the earliest and most comprehensive river conservation programs in India. It evolved from the earlier Ganga Action Plan (1985) and was later expanded to include other major rivers such as the Yamuna, Godavari, and Cauvery.

The primary objectives of the National River Conservation Plan (NRCP) are to reduce river pollution, enhance water quality, and restore the ecological health of river systems. These goals are pursued through measures such as the establishment of sewage interception and treatment plants (STPs), implementation of solid waste management along riverbanks, development and beautification of riverfront areas, and promotion of community awareness and participation in conservation activities.

As of 2021, the NRCP has covered 39 rivers across 80 towns in 16 states, treating over 2,500 million liters per day (MLD) of wastewater (MoEFCC, 2021). Although the program significantly improved localized water quality, its effectiveness was often hindered by fragmented institutional coordination and inadequate operation of treatment facilities.

2.11.2. Namami Gange Programme

Launched in 2014, the Namami Gange Programme is a flagship initiative implemented by the National Mission for Clean Ganga (NMCG) under the Ministry of Jal Shakti. It adopts a comprehensive, basin-level strategy for the rejuvenation of the Ganga River, integrating pollution control, biodiversity restoration, and livelihood enhancement. Its key components include the development and rehabilitation of sewage treatment infrastructure in Ganga basin cities, river surface cleaning and solid waste management, industrial effluent regulation supported by real-time water quality monitoring systems, and afforestation along riparian zones coupled with wetland restoration efforts. The program places strong emphasis on community engagement through initiatives such as Ganga Praharis and collaborations with various civil

society organizations. As of 2023, more than 400 projects had been sanctioned, with a cumulative investment exceeding ₹30,000 crore, establishing it as one of the world's largest and most integrated river rejuvenation programs (NMCG, 2023).

2.11.3. National Mission for Clean Ganga (NMCG)

The NMCG, established in 2011 and restructured in 2016, serves as the implementing arm of the Namami Gange Programme. Its mandate includes ensuring effective coordination between central, state, and local agencies, and promoting integrated river basin management. NMCG functions under the National Ganga Council, chaired by the Prime Minister, reflecting the political and administrative importance of river conservation (MoJS, 2022).

The mission has introduced innovative models such as Hybrid Annuity Public–Private Partnerships (PPP) for the operation and maintenance of STPs, promoting financial sustainability. It also promotes nature-based solutions, including constructed wetlands**,** biodiversity parks, and bio-remediation technologies**,** aligning with global sustainability goals.

2.11.4. Integrated River Basin Management Approach

Integrated River Basin Management (IRBM) is a holistic planning and governance framework that manages water, land, and environmental resources at the scale of an entire river basin. It emphasizes ecological sustainability, cross-sector coordination, and participation of all stakeholders, including government agencies, local communities, and environmental institutions. By treating the basin as a connected hydrological unit, IRBM ensures decisions made upstream do not negatively affect downstream ecosystems, settlements, and livelihoods (Global Water Partnership, 2017).

Catchment Protection

In IRBM, catchment protection is achieved by regulating land-use activities in upper watersheds, promoting afforestation, and enforcing buffer zones along rivers and streams. Measures such as slope stabilization, soil conservation, and controlled agricultural practices reduce sedimentation, runoff, and erosion. Integrated watershed development programmes often include contour trenches, check-dams, recharge pits, and protection of natural drainage paths. These interventions help maintain base flow, reduce flood peaks, and prevent siltation in downstream wetlands and reservoirs (UNEP, 2016). Government agencies collaborate with

local panchayats and forest departments to monitor land conversion, ensure compliance with zoning regulations, and promote sustainable farming practices across the catchment.

Pollution Control

Pollution control under IRBM uses a combination of regulatory, technological, and institutional mechanisms. Key actions include installation of sewage treatment plants (STPs), effluent treatment plants (ETPs), and decentralized wastewater systems across the basin to prevent untreated discharge into rivers. Industries are monitored through strict effluent norms, real-time online monitoring systems, and periodic audits. Municipalities are mandated to enforce solid-waste segregation, prevent dumping in drains, and upgrade sewer networks. Additionally, non-point pollution sources—such as agricultural runoff—are addressed using measures like vegetative filter strips, organic farming promotion, and controlled fertiliser application. These strategies collectively reduce biochemical oxygen demand (BOD), nutrient loads, and toxic contaminants, improving water quality throughout the basin (World Bank, 2020).

Community Participation and Integrated Governance

A core pillar of IRBM is participatory governance, where citizens, farmers, industries, and local organisations are involved in decision-making. River basin committees are created to coordinate between departments such as irrigation, forestry, urban planning, and pollution control. Community groups support surveillance of encroachments, report illegal dumping, and take part in river-cleaning programmes. This decentralised governance system enhances transparency, strengthens accountability, and ensures the sustainability of interventions. Because decisions are taken collectively, conflicts between water users—such as agriculture, urban supply, and hydropower—are effectively resolved (Global Water Partnership, 2017).

Monitoring, Data Systems, and Adaptive Management

Integrated River Basin Management (IRBM) relies heavily on scientific data, including hydrological modelling, GIS mapping, water quality assessments, and climate vulnerability analysis. Continuous monitoring of river flows, groundwater levels, pollutant concentrations, and land-use changes helps authorities evaluate the effectiveness of interventions. Adaptive management ensures policies are periodically revised based on new data, community feedback, and environmental responses. This flexibility helps river basins remain resilient to climate

change, extreme rainfall, urban expansion, and long-term ecological degradation (UNEP, 2016).

2.12 Water Conservation Schemes and Programs

India has adopted a range of national missions and policy frameworks to address declining water quality, groundwater stress, and the rapid degradation of lakes, ponds, and wetlands. These programs integrate ecological rejuvenation, infrastructure development, wastewater management, and community participation to enhance urban and rural water security (MoHUA, 2015; MoEFCC, 2020). Initiatives such as AMRUT, the Smart Cities Mission, NPCA, and Swachh Bharat Mission collectively promote sustainable water-use practices by linking urban planning with green–blue infrastructure, pollution control, and climate resilience (World Bank, 2020; NITI Aayog, 2021). Together, these schemes illustrate a shift toward water-sensitive governance in India, emphasizing multi-sectoral coordination, technology-enabled monitoring, and long-term ecosystem restoration.

2.12.1 AMRUT (Atal Mission for Rejuvenation and Urban Transformation)

The Atal Mission for Rejuvenation and Urban Transformation (AMRUT), launched in 2015 by the Ministry of Housing and Urban Affairs, significantly strengthens urban water security by integrating water-body rejuvenation with objectives for water supply, sewerage, and stormwater management (MoHUA, 2015). Although not exclusively focused on lakes and ponds, the mission incorporates key ecological interventions such as desilting, catchment cleaning, restoring natural inlets and outlets, buffer-zone protection, and lakefront development to revive degraded urban water bodies (MoHUA, 2018). AMRUT adopts a water-sensitive urban planning approach by linking stormwater drainage systems with lake recharge through detention ponds, retention basins, bioswales, and the rejuvenation of natural drains, which collectively help reduce flooding and enhance infiltration (Sharma & Singh, 2020).

Pollution reduction is addressed through the expansion of sewer networks, decentralized wastewater treatment (DEWATS), and upgrading of STPs to prevent untreated wastewater from entering lakes and wetlands (World Bank, 2020). Implementation is guided through State Annual Action Plans (SAAPs) and Urban Local Bodies (ULBs), which conduct GIS mapping, prepare DPRs, and monitor project execution (MoHUA, 2017). Funding follows a central–state sharing pattern and converges with initiatives like Smart Cities and AMRUT 2.0, enabling

large-scale lake-restoration projects in cities such as Ahmedabad, Hyderabad, Bhubaneswar, Surat, and Bhopal (MoHUA, 2021). While AMRUT has significantly improved green–blue infrastructure, reduced pollution, and enhanced climate resilience, challenges remain in achieving basin-scale integration and long-term ecological monitoring; however, the mission forms a critical foundation for advancing water-sensitive urban development in India (Khosla, 2021).

2.12.2 Smart Cities Mission

The Smart Cities Mission (2015-present) promotes technology-enabled and environmentally resilient urban development. Several cities have undertaken lakefront development, rejuvenation of heritage tanks, STP-based lake restoration, and green corridor planning. Bengaluru, Pune, and Varanasi implemented rain gardens, cycle paths, floating wetlands, and rejuvenated ghats (MoHUA, 2021). GIS dashboards and sensor monitoring support pollution control and real-time lake management. The Mission reinforces that smart water management requires digital mapping, ecological design, and civic engagement.

Indian cities have undertaken major lake, pond, canal, and riverfront rejuvenation projects to improve ecological resilience and urban livability (Ministry of Housing and Urban Affairs [MoHUA], 2017). In Indore, for example, the redevelopment of the Kanh and Saraswati Rivers under SCM involved riverfront development, sewage diversion, and green-blue infrastructure, with investments of approximately ₹39 crore completed by 2020, and an additional ₹511 crore sanctioned in 2023 for comprehensive river cleaning (NIUA, 2023). Similarly, more than 75 water-body rejuvenation projects across multiple Smart Cities—covering desilting, embankment strengthening, buffer-zone protection, constructed wetlands, stormwater filtration, and real-time water-quality monitoring—are documented in national case-study compilations (NIUA, 2023). The planning and implementation mechanism operates through a Special Purpose Vehicle (SPV), where urban planners lead spatial integration, environmental assessment, catchment planning, and the design of green–blue infrastructure, while municipal administrations oversee funding, procurement, inter-departmental coordination, and long-term O&M (Centre for Financial Accountability [CFA], 2022). These projects have collectively improved groundwater recharge, reduced urban flooding, enhanced recreation and public spaces, supported biodiversity, and strengthened climate resilience, although long-term maintenance and encroachment management remain persistent challenges (MoHUA, 2019).

2.12.3 National Plan for Conservation of Aquatic Ecosystems (NPCA)

NPCA (2013-present) integrates the former National Lake Conservation Plan (NLCP) and National Wetlands Conservation Programme (NWCP). NPCA supports scientific restoration, biodiversity enhancement, pollution control, desilting, and shore-line protection for lakes and wetlands (MoEFCC, 2020). Emphasis is placed on nature-based solutions, hydrological protection, and community co-management. Projects include Dal Lake (J&K), Loktak Lake (Manipur), and Powai Lake (Mumbai). NPCA highlights the ecological value of wetlands as buffers against flooding, climate change, and biodiversity loss.

2.12.4 Swachh Bharat Mission (SBM)

Swachh Bharat Mission (2014-ongoing) focuses on sanitation, open-defecation free communities, faecal-sludge management, and solid-waste management. Cleaner sanitation systems directly benefit water bodies by reducing untreated waste inflow (NITI Aayog, 2021). In urban areas, measures include door-to-door waste collection, wetland buffers, segregation, and bio-methanization units.

The table 1 highlights that global, national, and state-level initiatives collectively aim to promote sustainable water management, yet their effectiveness varies across scales. Global frameworks like the SDGs and World Bank programs set broad sustainability goals but lack enforceability. National policies such as the National Water Policy (2012), Wetlands Rules (2017), and AMRUT emphasize integrated management, rejuvenation, and groundwater recharge but face weak implementation and limited ecological focus. State programs like Mission Kakatiya, Kudimaramathu, and Jalabhishek Abhiyan successfully revive traditional water systems through community participation, though maintenance and continuity remain challenges

Table 1:Government Initiatives

Level	Policy / Initiative	Key Features / Focus	Gaps / Challenges
Global	SDG 6**:** Clean Water and Sanitation. SDG 11: Sustainable Cities and Communities SDG 13**:** Climate Action SDG 15: Life on Land (UN Sustainable Development Goals)	Water & sanitation for all; protect and restore water-related ecosystems	Broad in scope, lacks direct enforcement mechanisms
	Global Groundwater & Urban Policy Studies (World Bank, IWA)	Integrates groundwater in urban planning	Voluntary guidelines, weak implementation in developing countries
National (India)	National Water Policy (2012)	Integrated water resources management, ecological needs, conservation	Non-binding, poor enforcement at state/city level
	Wetlands Rules (2017)	Identification, protection of wetlands	Implementation weak; encroachments continue
	AMRUT & AMRUT 2.0	Urban water supply, storm water management, water body rejuvenation	Focused on infrastructure, less on ecosystem services
	Atal Bhujal Yojana	Community-based groundwater management	Limited to select states, urban areas less covered
	Jal Shakti Abhiyan / Catch the Rain	Rainwater harvesting, recharge structures	Campaign-driven, continuity issues
State	Mission Kakatiya (Telangana)	Revival of tanks/lakes,desilting,community-led.	Maintenance after revival still weak.
	Kudimaramathu (Tamil Nadu)	Tank/lake revival with community	Limited funding, uneven outcomes

	State Water Policy (UP, MP, etc.)	Emphasizes recharge, conservation, ecological use.	Weak enforcement at ULB level.
	Karnataka Tank Conservation Bill (2025)	Revises buffer zones for lakes.	Reduces buffer, risks more encroachment
	Jalabhishek Abhiyan (Madhya Pradesh)	Desilting of old ponds, tank revival, rainwater harvesting; local participation.	Seasonal work, continuity missing.

Source: *Compiled by the author from UN (2015), World Bank (2020), IWA (2019), and Government of India policy documents (MoHUA, MoJS, CPCB, 2012–2025).*

2.13 Initiatives at City/Local Level

At the local and city level, several non-governmental organizations (NGOs), citizen groups, and municipal collaborations have undertaken effective initiatives for the conservation and rejuvenation of urban water bodies in India. In Bengaluru, organizations such as SayTrees Environmental Trust and Biome Environmental Trust have worked with the Bruhat Bengaluru Mahanagara Palike (BBMP) to restore urban lakes through de-silting, wetland creation, native plantation, and decentralized wastewater management (SayTrees, 2021; Biome, 2020). The Environmentalist Foundation of India (EFI), a youth-driven NGO, has restored more than 200 lakes across Chennai, Hyderabad, and Coimbatore through scientific desilting, biodiversity enhancement, and community participation (EFI, 2020). In Hyderabad, The Rainwater Project and Aga Khan Trust for Culture (AKTC) have implemented rainwater harvesting systems and ecological restoration of historical water structures such as those in the Qutb Shahi Tomb complex (AKTC, 2019; The Rainwater Project, 2021). Similarly, INTACH has contributed to heritage-linked water system restoration in Delhi and Ahmedabad, including the conservation of historic stepwells and tanks (INTACH, 2020).

In western India, Jal Bhagirathi Foundation (JBF) and Sahjeevan have revitalized traditional water systems in Rajasthan and Kutch, promoting local stewardship and traditional rainwater harvesting practices (JBF, 2020; Sahjeevan, 2019). Watershed Organisation Trust (WOTR) in Maharashtra and Neer Foundation in Uttar Pradesh have emphasized community-led watershed management, aquifer recharge, and water literacy programs (WOTR, 2020; Neer Foundation, 2018). In Delhi, Aga Khan Trust for Culture has also rejuvenated urban lakes at Sunder

Nursery, integrating landscape design with heritage conservation (AKTC, 2019). Moreover, citizen-led movements such as Namma Kere Namma Bengaluru and Youth for Parivartan in Patna demonstrate the growing role of community engagement in local water governance through lake clean-up drives and awareness programs (Youth for Parivartan, 2021).

Collectively, these initiatives reflect a shift toward participatory, ecosystem-based, and locally adapted approaches for water conservation in Indian cities. They demonstrate that sustainable outcomes emerge when technical restoration is combined with public participation, traditional wisdom, and continuous civic stewardship (CSE, 2021).

2.14 Land Use & Zoning Regulations

Land use and zoning regulations play a crucial role in safeguarding water resources, controlling surface runoff, and ensuring sustainable urban development. By regulating land use intensity, permissible activities, and buffer zones, these instruments help protect water bodies, recharge areas, and natural drainage systems from degradation caused by unplanned urbanization. Integrating water conservation objectives into statutory planning mechanisms such as Master Plans, Development Control Regulations (DCRs), and Environmental Management Plans ensures that urban growth aligns with hydrological and ecological sustainability (Singh, 2019).

At the national level, several frameworks guide land-use control for water protection. The Wetlands (Conservation and Management) Rules, 2017, under the Environment (Protection) Act, 1986, mandate the identification and notification of wetlands, delineation of core and buffer zones, and prohibition of activities such as reclamation, waste disposal, and construction within specified limits (MoEFCC, 2017). Similarly, the National Water Policy (2012) emphasizes the need for land-use zoning around floodplains, riverbeds, and recharge zones to maintain hydrological balance and water quality.

At the state and city levels, zoning regulations typically designate conservation zones, no-development zones, and green buffers along rivers, lakes, and drainage channels. These include maintaining minimum buffer distances (often 50–100 meters) from the high flood level or water body edge, restricting industrial and residential activities near water sources, and promoting green infrastructure such as bio-swales, pervious pavements, and infiltration parks. For example, under AMRUT (2015) and Smart Cities Mission, several cities have integrated

water body rejuvenation and stormwater management within their zoning and open space policies (MoHUA, 2015).

Furthermore, the Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines, 2014 recommend incorporating water bodies as part of ecological land-use categories within Master Plans, supported by regulations for catchment protection, low-impact development (LID), and rainwater harvesting (MoHUA, 2014). The Town and Country Planning Acts of various states also empower local planning authorities to reserve land for water conservation, stormwater detention, and recharge structures.

Effective zoning for water conservation requires a multi-scalar approach, integrating hydrological mapping, groundwater zoning, and land suitability analysis. The approach promotes water-sensitive urban design (WSUD) principles—ensuring that development respects natural drainage, preserves pervious surfaces, and minimizes pollution loads. When coupled with community participation and enforcement mechanisms, such land use and zoning regulations provide a robust framework for restoring and sustaining urban water ecosystems (Wong & Brown, 2008; Fletcher et al., 2015)

Land-use planning is fundamental for water-body protection. Urban encroachment, informal construction, and floodplain conversion contribute to ecological damage (Sharma & Singh, 2020). Integrated zoning ensures that urban expansion does not compromise ecological assets. However, strict monitoring, dispute resolution, and public awareness remain necessary to ensure compliance (UN-Habitat, 2020).

2.14.1 Building Bye-laws for Water Conservation

Building bye-laws are statutory instruments that regulate construction activities and development practices to ensure safety, functionality, and environmental sustainability within urban areas. In the context of water conservation, bye-laws serve as a critical regulatory mechanism to promote efficient water use, minimize wastage, and encourage sustainable management of stormwater and wastewater at the building and neighborhood scales. These bye-laws translate broader planning goals—such as those outlined in Master Plans and Development Control Regulations—into enforceable design and construction requirements (MoHUA, 2014).

Over the last two decades, several Indian states and urban local bodies (ULBs) have revised their building bye-laws to integrate water-sensitive design principles**.** The Model Building Bye-laws, 2016, issued by the Ministry of Housing and Urban Affairs (MoHUA), made rainwater harvesting**,** wastewater recycling**,** and groundwater recharge mandatory for specific building categories. According to these guidelines, all plots of 100 square meters or more must include provisions for rooftop rainwater harvesting and recharge pits, particularly in areas with groundwater scarcity (MoHUA, 2016). These bye-laws also promote the use of dual plumbing systems**,** which separate greywater (from baths and sinks) and blackwater (from toilets) to facilitate recycling and reuse for non-potable purposes such as landscaping, flushing, and irrigation.

At the state level, bye-laws often specify construction norms for water-efficient design. For example, the Delhi Building Bye-laws (2016) and Chennai's Development Regulations mandate on-site storm water management through percolation pits and detention tanks to reduce surface runoff and flooding (CPCB, 2019). Similarly, states like Maharashtra, Karnataka, and Tamil Nadu have included provisions requiring low-flow plumbing fixtures**,** recycling of greywater, and installation of treatment units for large residential, institutional, and industrial developments. These regulatory requirements are enforced during the building plan approval process, linking water conservation directly to urban development control mechanisms.

In addition to conservation, bye-laws also address stormwater and flood management. Urban areas are increasingly required to integrate sustainable drainage systems (SuDS) such as pervious pavements, green roofs, and bio-swales in building and site design to mitigate urban flooding and improve groundwater infiltration (Fletcher et al., 2015). These measures form the operational link between Water-Sensitive Urban Development (WSUD) and the building-level implementation of sustainable design practices.

However, despite strong legal provisions, the implementation and monitoring of these bye-laws remain a challenge. Many cities lack enforcement capacity, periodic audits, and citizen awareness. To strengthen compliance, integration with GIS-based monitoring systems**,** inclusion in occupancy certification procedures, and community participation programs are being recommended by recent planning frameworks (Singh & Rosado, 2024).

2.14.2 International Framework

Globally, several countries have institutionalized water conservation and protection through legally binding urban development bye-laws, planning codes, and environmental directives that promote Water-Sensitive Urban Development (WSUD) and surface water protection.

Melbourne's planning framework integrates water management directly into urban design, ensuring that every new development contributes to groundwater recharge and reduction of surface runoff (Fletcher et al., 2015).

The international examples demonstrate how bye-laws, zoning codes, and design regulations have transitioned from traditional engineering approaches to nature-based, water-sensitive frameworks. They emphasize decentralization, ecological restoration, and public engagement in managing traditional and surface water systems.

In many developing countries, traditional systems similar to India's tanks and ponds have been revitalized through local laws. For instance, in Indonesia and Thailand, traditional irrigation and pond networks are protected under municipal bye-laws that regulate catchment land use and prohibit infilling or conversion (World Bank, 2019). These frameworks emphasize community management and indigenous knowledge as key components of water conservation policies.

2.15 National Framework

In India, bye-laws and planning regulations for water conservation have evolved to address both traditional water systems and surface water bodies such as lakes, ponds, rivers, and wetlands. These frameworks are guided by central environmental legislation and implemented through state and local urban development authorities.

At the national level, the Model Building Bye-laws, 2016, issued by the Ministry of Housing and Urban Affairs (MoHUA), made rainwater harvesting**,** groundwater recharge, and wastewater recycling mandatory for buildings with plot areas above 100 square meters.

2.15.1 Traditional Water Bodies

Traditional water bodies in India have historically served as decentralized, community-managed systems for storage, recharge, and irrigation. However, rapid urbanization and neglect have led to their degradation. To address this, the Ministry of Housing and Urban Affairs

(MoHUA) and various state governments have incorporated traditional water systems into planning frameworks and bye-laws.

Under the Model Building Bye-laws (2016**)**, all new urban developments are required to integrate rainwater harvesting**,** groundwater recharge pits**,** and storm water management structures**,** reflecting the traditional principles of local water capture and reuse (MoHUA, 2016). Additionally, the Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines, 2014, encourage cities to map traditional tanks, baolis, and ponds within land use plans and reserve them as heritage and conservation zones (MoHUA, 2014).

Legal frameworks such as the Environment (Protection) Act, 1986**,** and the Wetlands (Conservation and Management) Rules, 2017, also indirectly safeguard traditional water systems by regulating land use changes, waste dumping, and construction within buffer zones (MoEFCC, 2017). The integration of traditional water conservation methods within contemporary bye-laws thus serves as an effective approach to reconnect urban areas with their hydrological heritage while ensuring long-term groundwater sustainability (Verma, 2022).

2.15.2 Surface Water Bodies

For larger surface water systems such as rivers, lakes, and wetlands India's bye-laws and zoning regulations focus on preventing pollution, protecting floodplains, and maintaining ecological balance. The National Water Policy (2012) and the Wetlands Rules (2017) mandate states to notify and protect wetlands, delineate buffer zones, and prohibit reclamation or waste disposal (MoEFCC, 2017). Similarly, the National Lake Conservation Plan (NLCP) and AMRUT Mission (2015) support urban lake restoration through catchment management, sewage diversion, and ecological landscaping (MoHUA, 2015; MoEFCC, 2021).

At the municipal level, Development Control Regulations (DCRs) and Master Plans incorporate zoning provisions to designate no-construction buffer zones (typically 50–100 meters) around lakes and riverbanks. These bye-laws restrict industrial activities, promote green buffers, and require on-site storm water infiltration to reduce surface runoff and pollution (Singh, 2019). Furthermore, decentralized wastewater treatment systems (DEWATS) and bio-remediation techniques are now included in local building regulations as sustainable approaches to protect surface water quality (Ramteke & Sarode, 2025).

2.16 State-Level Land Use and Zoning Regulations

At the state level, land use and zoning regulations are primarily implemented through the Town and Country Planning Acts**,** Regional Plans**,** and Master Plans, which define land use categories and development controls in accordance with ecological and hydrological considerations.

Most states in India, such as Madhya Pradesh, Tamil Nadu, Karnataka, and Maharashtra**,** have planning legislations that empower their respective Directorates of Town and Country Planning (DTCPs) or Urban Development Authorities to identify, protect, and regulate water bodies and drainage channels within planning areas. For example, under the Madhya Pradesh Nagar Tatha Gram Nivesh Adhiniyam (1973), development plans must earmark specific zones for water bodies, green buffers, and flood-prone areas**,** where construction and industrial activities are prohibited. Similarly, the Tamil Nadu Town and Country Planning Act (1971) includes land use zoning provisions for tanks, wetlands, and water supply catchments to prevent encroachment and ensure water quality (MoHUA, 2014).

State-level plans also integrate Wetland (Conservation and Management) Rules, 2017 under the Environment (Protection) Act, 1986, requiring state wetland authorities to delineate core and buffer zones around notified wetlands. These zones regulate activities such as land reclamation, waste disposal, and groundwater abstraction (MoEFCC, 2017). For instance, Kerala's State Wetland Authority enforces zoning restrictions on construction and mining within 50–100 meters of natural water bodies, protecting both surface and groundwater systems. Moreover, several states have incorporated watershed-based planning and water-sensitive zoning into their regional frameworks. For instance, Maharashtra's Regional Plans (2021–41) integrate hydrological mapping to identify groundwater recharge zones and protect them under "no development" or "restricted development" categories**.** Rajasthan has introduced special zoning regulations in its Urban Development Policy (2020) to protect traditional tanks (talabs) and stepwells by including them in heritage and conservation zones (Sharma & Patel, 2021).

Under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT)**,** state governments have been encouraged to adopt Water-Sensitive Urban Development (WSUD) principles in their Master Plans by incorporating buffer zones, eco-corridors, and floodplain restrictions (MoHUA, 2015). These regulations promote a regional understanding of water

systems and enable inter-departmental coordination between urban planning, irrigation, and environment departments.

2.16.1 On-Site Level Regulations

At the on-site or plot level, water conservation is operationalized through Development Control Regulations (DCRs)**,** Building Bye-laws, and Environmental Clearance (EC) conditions that guide construction and site design. The Model Building Bye-laws (2016) by MoHUA mandate rainwater harvesting**,** groundwater recharge**,** and wastewater recycling in buildings with plot areas exceeding 100 square meters. Local authorities such as the Delhi Development Authority (DDA)**,** Chennai Metropolitan Development Authority (CMDA)**,** and Bangalore Development Authority (BDA) have adapted these guidelines, requiring on-site storm water management systems like percolation pits, recharge wells, detention ponds, and permeable pavements (CPCB, 2019).

On-site zoning controls also involve setback and buffer regulations, where minimum distances are prescribed from water bodies or drainage channels. For example, the Bangalore Revised Master Plan (2031) stipulates buffer zones of 30–50 meters along lakes and 15 meters along primary drains, where only eco-restoration and landscaping activities are permitted (NITI Aayog, 2021). Similarly, Hyderabad's Development Control Rules (2016) restrict construction in flood-prone and low-lying zones and require developers to include storm water harvesting structures and silt traps within project boundaries. At the on-site level, green infrastructure and WSUD interventions—such as bio-swales, infiltration trenches, rain gardens, and vegetated buffers are increasingly integrated into planning permissions to manage runoff and enhance infiltration (Wong & Brown, 2008). Many urban local bodies also provide incentives**,** such as property tax rebates, for buildings that install functional water conservation systems (NITI Aayog, 2021).

Furthermore, Environmental Impact Assessment (EIA) guidelines for large-scale developments require site-level water management plans, mandating the conservation of natural drainage, treatment of wastewater, and preservation of natural water features within project boundaries (MoEFCC, 2021).

2.17 Learnings

The reviewed literature, case studies, and national policy frameworks reveal recurring patterns in the challenges faced by urban water bodies and the strategies required for their restoration. Scholars consistently highlight that rapid urbanization, ecological neglect, and inadequate wastewater management are primary drivers of water-body degradation in Indian cities (Kumar et al., 2023; Singh & Sharma, 2024). International examples further demonstrate the effectiveness of integrated planning, community participation, and blue–green infrastructure in enhancing ecological resilience and restoring degraded ecosystems (UNEP, 2016; Khosla, 2017). Similarly, national programs such as AMRUT, NPCA, and the Smart Cities Mission emphasize pollution control, hydrological restoration, and technology-enabled monitoring to strengthen water security (MoHUA, 2015; MoEFCC, 2020). To consolidate these insights, Table 2 synthesizes key themes emerging from literature, global and Indian case studies, and government schemes.

Table 2:Takeaways from the Study

Literature Insights	Case Studies (India & International)	Government Schemes	Key Inferences for Thesis
Rapid urbanization causes encroachment, sewage inflow, pollution, and degradation of water bodies (Kumar et al., 2023; Singh & Sharma, 2024).	Hussain Sagar Lake, Hyderabad – Pollution due to encroachment & waste inflow; restored via enforcement, STPs, geo-fencing.	NPCA (2013) – Integrated lake & wetland conservation with pollution abatement, desilting, STPs.	Water bodies degrade mainly due to unmanaged urban expansion; revival requires strong sewage control + catchment management.
Traditional systems (johads, tanks, kunds) were effective, low-cost, and decentralized (Agarwal & Narain, 1997; Sharma & Patel, 2021).	Johads Restoration, Alwar – Community-based revival raised groundwater & expanded agricultural land.	Mission Kakatiya (Telangana) – Restoration of 46,000+ tanks using traditional methods.	Combining traditional wisdom with modern technology produces sustainable and culturally rooted water management models.

Water-sensitive planning integrates hydrology, land use & stormwater systems (Khosla, 2017; Singh, 2019).	Cheonggyecheon Stream, Seoul – Integrated ecological + mobility planning restored stream and improved climate.	AMRUT (2015) – Emphasizes stormwater, sewerage, and waterbody rejuvenation.	Water bodies must be incorporated into Master Plans, zoning, and urban design—not treated as leftover spaces.
Pollution control requires STPs, DEWATS, monitoring & industrial compliance (UNEP, 2016; World Bank, 2019).	Charles River, USA – Major improvement after sewage diversion, industrial regulation, stormwater management.	Namami Gange Mission – Focus on STPs, industrial monitoring, community involvement.	Water-quality improvement depends on strict enforcement + modern treatment technologies + multi-stakeholder coordination.
Basin-scale planning is more effective than isolated lake-centric projects (GWP, 2017).	Lake Biwa, Japan Catchment-wide policies, sewerage systems, and governance restored water quality.	Integrated River Basin Management (IRBM) – Promoted under national water policies.	Managing the entire watershed (land use + drainage + wetlands) ensures long-term river/lake health.
Climate change increases stress on urban water systems (IPCC; Singh & Rosado, 2024).	China Sponge Cities Programme Uses blue–green infrastructure to manage floods, reuse water, reduce heat.	Smart Cities Mission Funds lakefronts, wetland parks, floating wetlands, stormwater reuse.	Blue–green infrastructure improves climate resilience, reduces flooding, enhances groundwater recharge.
Community involvement enhances monitoring & ensures sustainability (UN-Habitat, 2020).	Kandy Lake, Sri Lanka – Conservation improved by public awareness and volunteer programmes.	Jal Shakti Abhiyan Emphasizes community-led water conservation.	Successful restoration requires citizen participation, awareness, and shared ownership.
Technological tools (GIS, IoT sensors,	Hussain Sagar, Hyderabad Geo-fencing,	Smart Cities Mission (SCM)	Technology strengthens

hydrological models) support better monitoring and planning (Sharma & Patel, 2021).	CCTV, floating trash barriers for monitoring.	Introduces real-time monitoring, integrated command centres.	enforcement, data-driven planning, and long-term maintenance.

Source: Compiled by the author from secondary literature, case-study reports, and government policy documents (2024–2025).

Literature reviews mostly use tools like online databases, keyword searches, and reference managers to collect and organize information. Case studies use practical tools such as GIS maps, hydrological models, field visits, policy review, and comparison between places. Together, these methods help make the research more accurate, scientific, and useful for planning.

CHAPTER 3-CASE STUDY MANDSAUR

3.0 Introduction

This chapter presents a detailed study of Mandsaur city to understand its existing urban water systems and their relationship with both natural and built environments. Mandsaur has been selected as the study area due to its medium-sized urban character, the presence of significant water bodies, and the growing challenges of water scarcity, flooding, groundwater depletion, and environmental degradation. These conditions make the city an appropriate case for the application of Water Sensitive Urban Development (WSUD) principles and strategies. Special emphasis is placed on the natural and environmental characteristics of Mandsaur, including climate, rainfall, soil conditions, topography, watershed patterns, drainage networks, and water supply systems. These physical factors play a significant role in determining the movement, availability, and management of water within the city. Topographical features such as contours, slopes, and terrain conditions influence surface runoff, drainage efficiency, groundwater recharge, and the occurrence of waterlogging in low-lying areas.

The chapter provides an overview of the study area by examining the city's location, historical development, administrative structure, demographic profile, and physical characteristics. Understanding these aspects is essential for assessing the existing urban structure and identifying the factors that influence water management, infrastructure provision, and future urban development. The analysis helps establish a comprehensive understanding of the city's spatial and environmental context.

This also examines the importance of the Shivna River and other urban water bodies that form an integral part of Mandsaur's water system. Historically, these water bodies supported domestic water needs, groundwater recharge, flood regulation, and ecological balance. However, rapid urbanization, population growth, encroachment, pollution, and changing land-use patterns have contributed to their deterioration and reduced functionality. Understanding the present condition of these water resources is essential for developing effective conservation and management strategies.

3.1 Location

Mandsaur is located in the north-western part of Madhya Pradesh and comes under Mandsaur District. The district shares its boundaries with Rajasthan in the north and north-west, Neemuch District in the east, Ratlam District in the south, and Chittorgarh District in the west. Geographically, Mandsaur is part of the Malwa plateau region. The latitude 24.0768° N and longitude 75.0693° E of Mandsaur.

Location Map

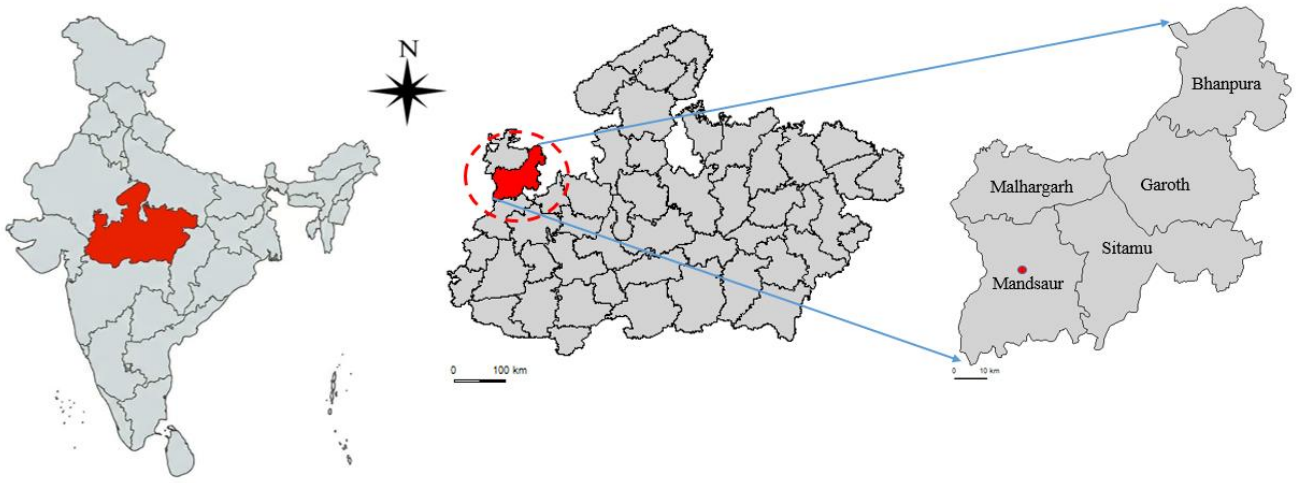


Figure 17: Location Map *Source: (Complied by Author from Survey of India,2025)*

At the city level, Mandsaur is surrounded by nearby villages, farms, and open land. These areas are important because rainwater from them flows into the city and helps recharge groundwater. The Shivna River flows through the city and acts as the main natural boundary and drainage line.

The boundary of Mandsaur is not just about administrative limits, but also about its connection with nearby rural areas and the river, which together affect water flow, drainage, and water availability in the city.

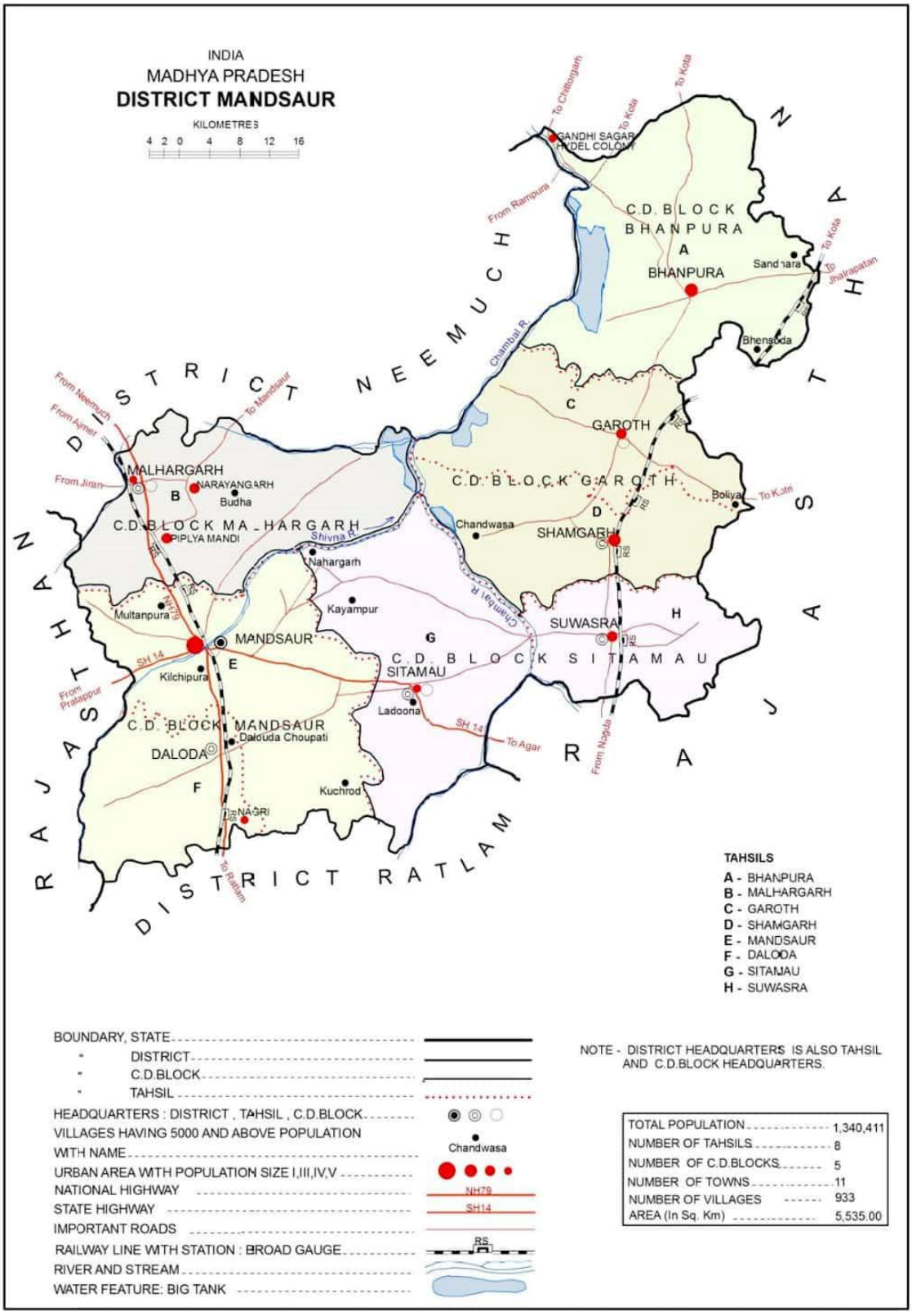


Figure 18: District Map of Mandsaur *Source: (CGWB Report, 2015)*

The Mandsaur District is divided into five main administrative blocks (tehsils), namely Mandsaur, Malhargarh, Sitamau, Garoth, and Bhanpura. Among these, the Mandsaur block includes the main urban area of the city, while the other blocks are largely rural or semi-urban in nature. These surrounding blocks play an important role in the region's water system, as they contribute to the catchment areas, groundwater recharge, and agricultural water use, which directly influence the water availability and hydrology of Mandsaur city.

Mandsaur district falls under Chambal river sub-basins. The river is broad, flat shallow valley with low gradient because the Chambal has reached the base level of erosion. Vertical erosion has reached and lateral erosion is taking place. Other tributaries of Chambal River are Retam, Shivna and Chhoti Kali Sindh.

The Dam maximum capacity, the water spreads across a massive 723 sq km or around 72300 hectares. The lake stretches up to 68 km in length and 26 km in width (widest point). It can hold up to 7.32 billion cubic meters of water. The dam captures the rainfall runoff from a massive regional catchment basin of over 22,500 sq km. the water comes from the primary source Chambal river, which originates from mhow and flows northwards.

To supply drinking water to Mandsaur city and around 920 villages the government uses the Gandhi sagar group water supply schemes. After purification the clean water is sent via gravity through a vast 1500 km network of smaller pipelines directly into master OHTs in Mandsaur city and villages directly tap water directly straight to households. The WTP built from this scheme has a design capacity of 136 MLD. The supply covers villages, Neemuch district and Mandsaur district providing tap connections to more than 240000 families around 10-12 lakh people. For farming water is systematically released from the dam's gates back into the Chambal river channel. Currently Mandsaur city receives 15-18MLD channeled to storage tanks. From these overhead tanks water flows through gravity into the internal city pipeline network.

During peak summers when shivna river often dries up completely, dropping the local water availability down to the critical levels.

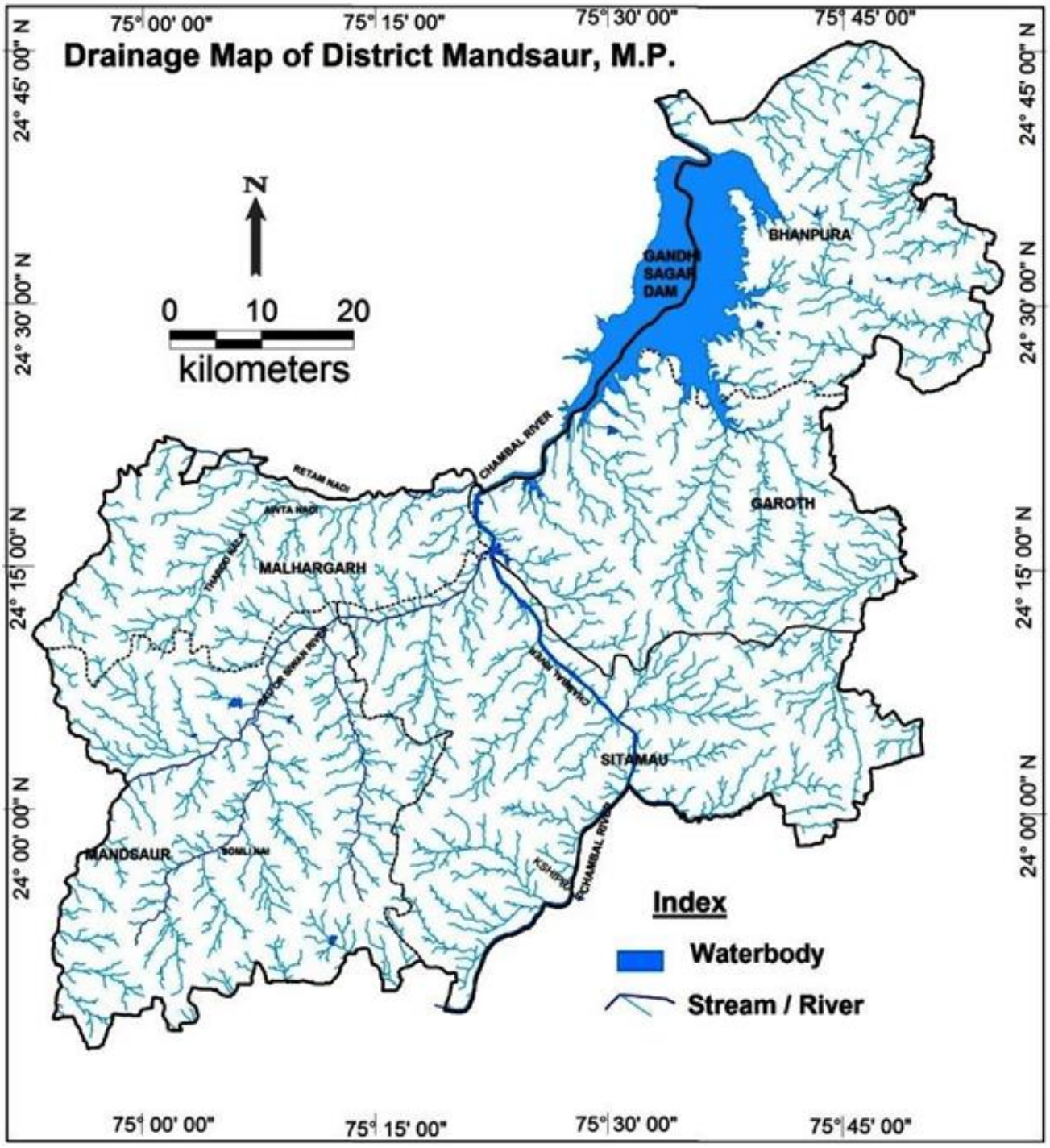


Figure 19: District Drainage of Mandsaur *Source: (CGWB Report,2015)*

3.2 Historical Evolution of Water System in Mandsaur

The water system of Mandsaur has changed a lot over time, moving from a natural and community-based system to a more centralized and infrastructure-based system. In earlier times, people depended on rivers, ponds, wells, and natural drainage, which worked together to store and recharge water in a balanced way. As the city grew, modern systems like pipelines, dams, and groundwater extraction became more common, and traditional water bodies were neglected. While these developments improved water supply, they also disturbed the natural water cycle by reducing recharge and blocking drainage paths. Today, this has resulted in two major problems—water shortage in dry seasons and flooding during heavy rains. This shows that the city has lost its natural water balance, and there is a need to combine traditional systems with modern planning to manage water more sustainably.

3.2.1 Ancient–Medieval Period (Traditional Water Systems)

Historically, Mandsaur developed along the Shivna River, which served as the primary source of water for domestic, agricultural, and socio-cultural activities (Government of Madhya Pradesh, 2023). Early settlements were located close to the river to ensure reliable access to water. Water management during this period was decentralized and community-driven**,** characterized by:

- Construction of ponds (talabs) and small reservoirs
- Use of wells and stepwells for drinking water
- Natural drainage channels directing rainwater into storage systems

Water bodies were closely integrated with cultural practices, especially around the Pashupatinath Temple, where riverbanks and ponds served both functional and religious purposes (Government of Madhya Pradesh, 2023).

These traditional systems reflect principles similar to modern Water Sensitive Urban Development (WSUD)**,** including local storage, natural recharge, and runoff minimization (UN-Habitat, 2018).

3.2.2 Medieval–Early Modern Period (Integrated Water Systems)

With the growth of settlements, water management systems became more structured and interconnected. During this period, there was a significant expansion of ponds and storage tanks, along with the development of river ghats and embankments to regulate water flow. The utilization of water for irrigation purposes also increased, reflecting a more systematic approach to water resource management. These integrated systems played a crucial role in ensuring water availability during dry seasons while also helping to reduce flood impacts through distributed storage mechanisms (CGWB, 2020). As a result, the city functioned as a hydrologically balanced system, where surface water, groundwater, and drainage networks were closely linked and worked in coordination (NRSC, 2019).

3.2.3 Colonial and Early Post-Independence Period (Transition Phase)

During the colonial era and the early years after independence, water management practices gradually shifted toward more centralized systems. This phase witnessed a growing dependence on groundwater sources such as wells and bore wells, while the upkeep of traditional ponds and storage structures declined. At the same time, engineered water supply systems began to be introduced, marking a transition in urban water management approaches. As a result, reliance on traditional water storage systems decreased, leading to a reduction in natural groundwater recharge and weakening of previously integrated water systems (CGWB, 2020).

3.2.4 Modern Period (Post-1980s Urban Expansion)

Rapid urbanization has brought significant changes to the water management system of Mandsaur. During this phase, major infrastructure developments were undertaken, including the construction of the Ramghat Barrage and Kalabhata Dam on the Shivna River. Additionally, there was a considerable expansion of piped water supply systems along with the development of storage infrastructure such as overhead tanks, which strengthened centralized water distribution networks (Mandsaur Municipal Council, 2023). These interventions, while improving water accessibility, also increased the city's reliance on centralized systems.

However, this transformation has led to several emerging challenges. The encroachment of ponds and natural drainage channels, along with the pollution of rivers and surface water

bodies, has adversely affected the natural hydrological system. Furthermore, rapid expansion of built-up areas has resulted in reduced infiltration, while the growing disconnect between drainage and storage systems has disrupted the natural water cycle. Consequently, these changes have contributed to the weakening of traditional integrated water management systems that once maintained hydrological balance in the city (CPCB, 2021).

3.2.5 Recent Phase (2000s–Present: Water Stress & Flood Events)

In recent decades, Mandsaur has been experiencing a dual challenge in its urban water system, characterized by both water scarcity and flooding issues. On one hand, the city faces increasing water stress due to declining groundwater levels, insufficient per capita water supply, and a growing dependence on groundwater sources during dry seasons (CGWB, 2020).

On the other hand, Mandsaur has also witnessed instances of urban flooding and waterlogging, particularly evident during the 2019 flood events. These incidents exposed critical issues such as the overflow of the Shivna River, inadequate drainage infrastructure, and the loss of natural buffering systems like ponds and water bodies (Government of India, 2019; CPCB, 2021).

3.3 History of Water & Flood Events in Mandsaur

Mandsaur has experienced several flood events in recent decades, primarily driven by intense monsoonal rainfall and compounded by urban development pressures. One of the most significant events occurred in 2019, when the district faced severe flooding due to heavy and continuous rainfall across western Madhya Pradesh. The Shivna River and nearby water bodies overflowed, leading to widespread inundation in both urban and rural areas. Transportation networks were disrupted, settlements were submerged, and waterlogging persisted for several days, highlighting the inadequate drainage capacity of the city (Government of Madhya Pradesh, 2020). Earlier, during the 2013 North India floods, Mandsaur, although not the epicenter, experienced rising river levels, localized flooding, and stress on its water infrastructure, indicating its vulnerability to regional hydrological events (India Meteorological Department [IMD], 2014).

The nature of flooding in Mandsaur is a combination of riverine, urban, and flash flooding. Riverine flooding occurs when the Shivna River exceeds its carrying capacity due to continuous rainfall and upstream inflows. Urban flooding is largely a result of inadequate storm water drainage systems, encroachment on natural drainage channels, and increasing impervious surfaces, which together cause severe waterlogging in low-lying wards. Additionally, flash flood tendencies are observed due to rapid runoff from built-up areas and reduced infiltration. These flooding patterns are influenced by both natural and anthropogenic factors. Natural causes include high-intensity, short-duration monsoon rainfall, relatively flat terrain in certain urban pockets, and limited natural drainage gradients. Human-induced factors such as encroachment along riverbanks and ponds, loss of traditional water bodies, conversion of permeable land into built-up areas, and the direct discharge of storm water and sewage into drains further aggravate the situation (Central Water Commission, 2019; Government of Madhya Pradesh, 2020).

These recurring flood events expose systemic weaknesses in the city's water management system. The existing drainage network is insufficient, natural water bodies no longer function effectively as buffers, and the carrying capacity of the Shivna River has been reduced due to siltation and encroachment. As a result, Mandsaur faces a paradoxical situation of flooding during the monsoon and water scarcity during the summer. From a Water Sensitive Urban Development (WSUD) perspective, flooding should not be viewed merely as a disaster but as a failure of urban design and planning. WSUD emphasizes that excess stormwater should be managed as a resource by capturing, storing, reusing, and enhancing infiltration, thereby transforming flood risks into opportunities for sustainable water management (Jha, Bloch, & Lamond, 2012; Wong & Brown, 2009).

3.4 Administrative Detail

Mandsaur is administratively located in Mandsaur district under Ujjain Division of Madhya Pradesh and is governed by a Municipal Council comprising 40 wards, falling under the Mandsaur parliamentary and assembly constituencies as shown in Table 3.

Table 3: Administrative Detail of Mandsaur

Administrative Unit	Details
State	Madhya Pradesh
Division	Ujjain Division
District	Mandsaur District
Tehsil / Block	Mandsaur Tehsil
City	Mandsaur
Governing Body	Municipal Council (Nagar Palika Parishad), Mandsaur
Number of Wards	40
Municipal Area	27.24 sq. km (2724 hectares)
Planning Area	114.7 sq. km (11470 hectares)
Population (Census 2011)	1.41 lakh
Population Density	5,000+ persons/sq. km (municipal area approx.)
Administrative Status	Class-I City
Region	Malwa Plateau Region
Primary River	Shivna River
Major Water Body	Teliya Talab
Water Supply Authority	Municipal Council & Public Health Engineering Department (PHED)
Drainage Authority	Municipal Council, Mandsaur
Main Water Source	Surface water (regional schemes) + groundwater
Climate Type	Tropical Wet and Dry (Semi-arid tendency)
Soil Type	Black Cotton Soil
Connectivity	Connected via State Highways and rail network

Nearby Cities & Distance	Neemuch – 50 km; Ratlam – 85 km; Ujjain – 165 km; Indore – 220 km

Source: Mandsaur Census Handbook, 2011

Block wise Number of Villages and Gram Panchayat

The table represents the block-wise distribution of villages and Gram Panchayats in Mandsaur district.

Table 4:Mandsaur District Block Details

Dist. Name	Name of CDB	Total No. of Villages	Total No. of Grampanchayat
Mandsaur	Bhanpura	101	45
	Malhargarh	168	78
	Garoth	203	91
	Mandsaur	220	119
	Sitamau	241	107
	TOTAL	**933**	**440**

Source: Mandsaur census handbook 2011

The municipal area of Mandsaur is approximately **2,724 hectares**, while the planning area extends to about **11,470 hectares**. This shows that the planning boundary is more than four times larger than the existing municipal area. The municipal boundary mainly includes the developed urban area where basic services like water supply and drainage are provided. Also the planning boundary as shown in figure 20, covers a much larger region, including surrounding villages, agricultural land, open spaces, and important natural features such as catchment areas and drainage systems. This boundary is important for long-term planning, as it considers land use, infrastructure expansion, water resources, and environmental protection. From a water management perspective, the planning boundary is more significant because it covers the catchment areas, natural drainage systems, and water bodies that influence the city's water supply and flooding conditions. Therefore, while the municipal boundary focuses on present administration, the planning boundary helps in managing future growth and ensuring sustainable water-sensitive development.

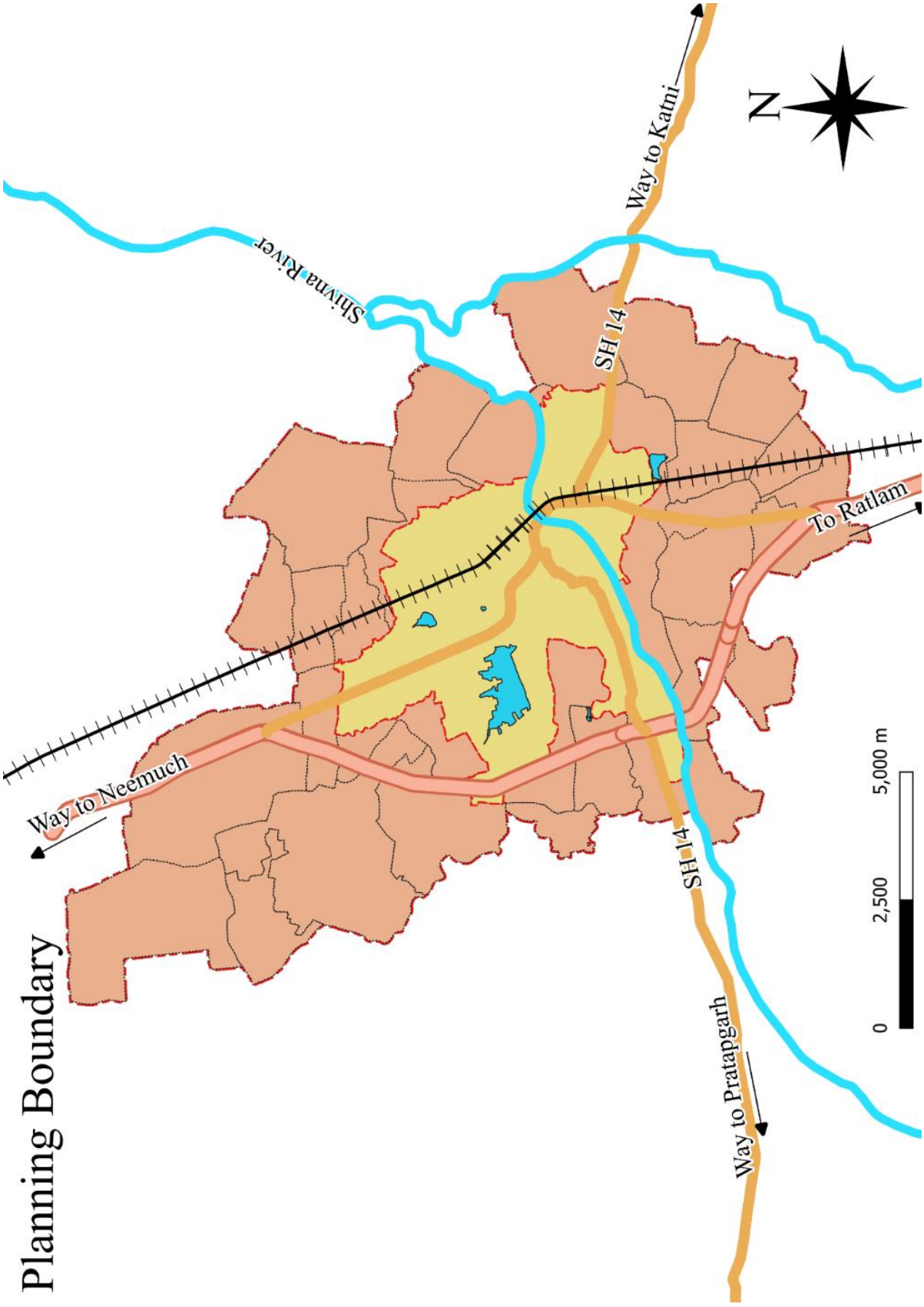


Figure 20: Planning Boundary *Source: Author's Compilation, using Survey of India (2025)*

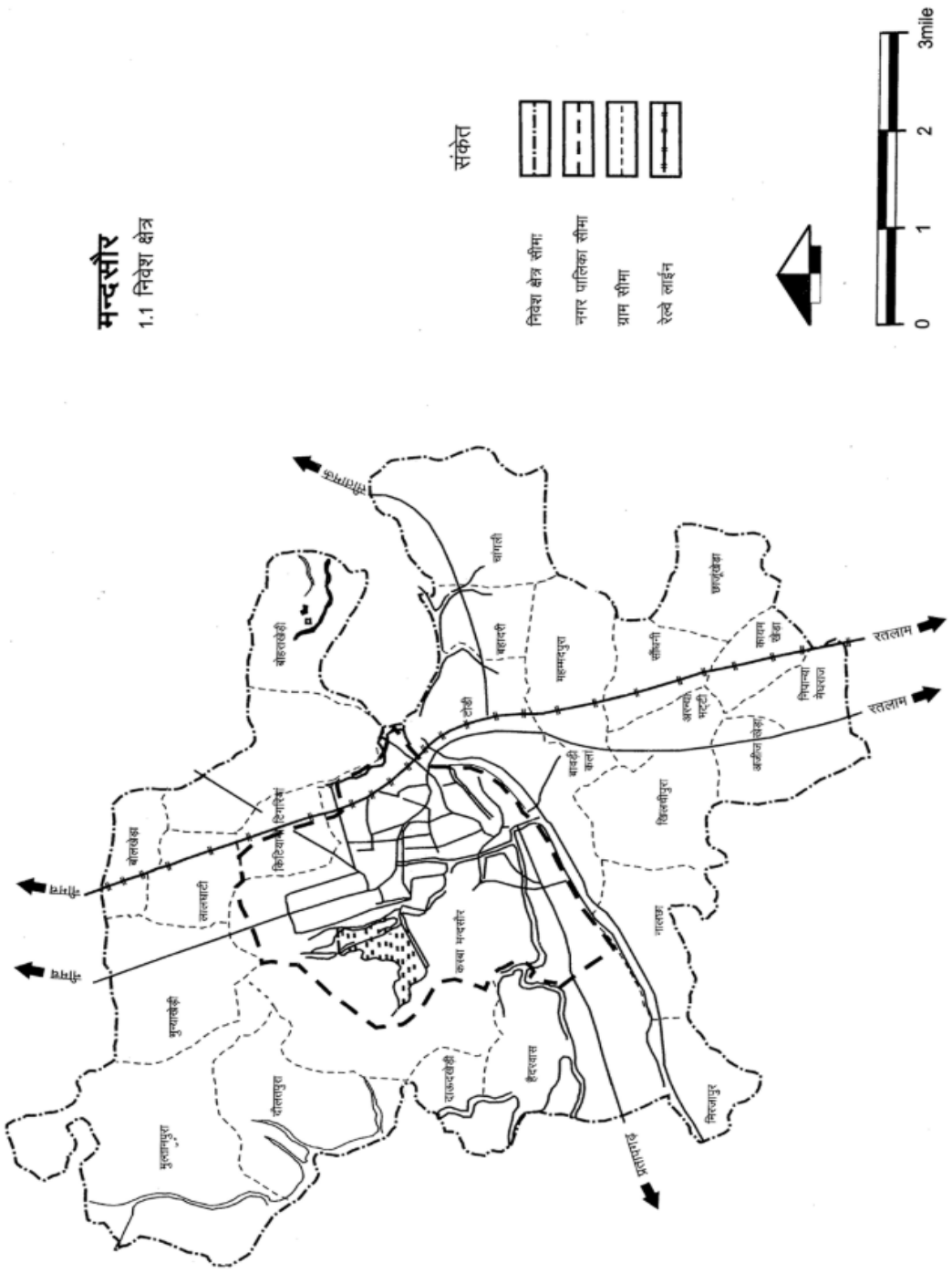


Figure 21: 2001 Planning Boundary of Mandsaur *Source: Mandsaur 2041 Draft Development Report ,2025)*

The 2001 Mandsaur Planning Boundary encompasses the existing municipal area along with surrounding villages to accommodate future urban expansion. The map highlights a centrally concentrated urban core supported by major road and railway networks, while the peripheral areas remain largely rural. The inclusion of surrounding settlements provides a framework for integrated land-use and infrastructure planning. From a WSUD perspective, the extended planning boundary offers an opportunity to conserve natural drainage systems, water bodies, and recharge areas before they are affected by urbanization.

3.4.1 Ward Boundary

Mandsaur Municipal Council is administratively divided into 40 municipal wards (Census, 2011) which serve as the basic units for local governance, planning, and service delivery.

The ward boundary map illustrates the spatial distribution of these wards within the municipal boundary. The city is well connected by State Highway (SH-14), major district roads, and a railway line passing through the central part of the city. The Shivna River flows along the eastern side of the city, while major water bodies, including Teliya Talab, are located in the southern and western parts of the municipal area. The ward boundaries provide the basis for ward-level analysis of population, water supply, drainage, land use, and other urban infrastructure.

The major water bodies in Mandsaur are located in Wards 2, 8, and 39. Teliya Talab is situated in Ward 39, the tank near the Masjid is located in Ward 2, and the tank inside the Masjid is located in Ward 8. These water bodies play an important role in the city's water system and have the potential to support groundwater recharge, stormwater management, and water conservation through appropriate WSUD interventions.

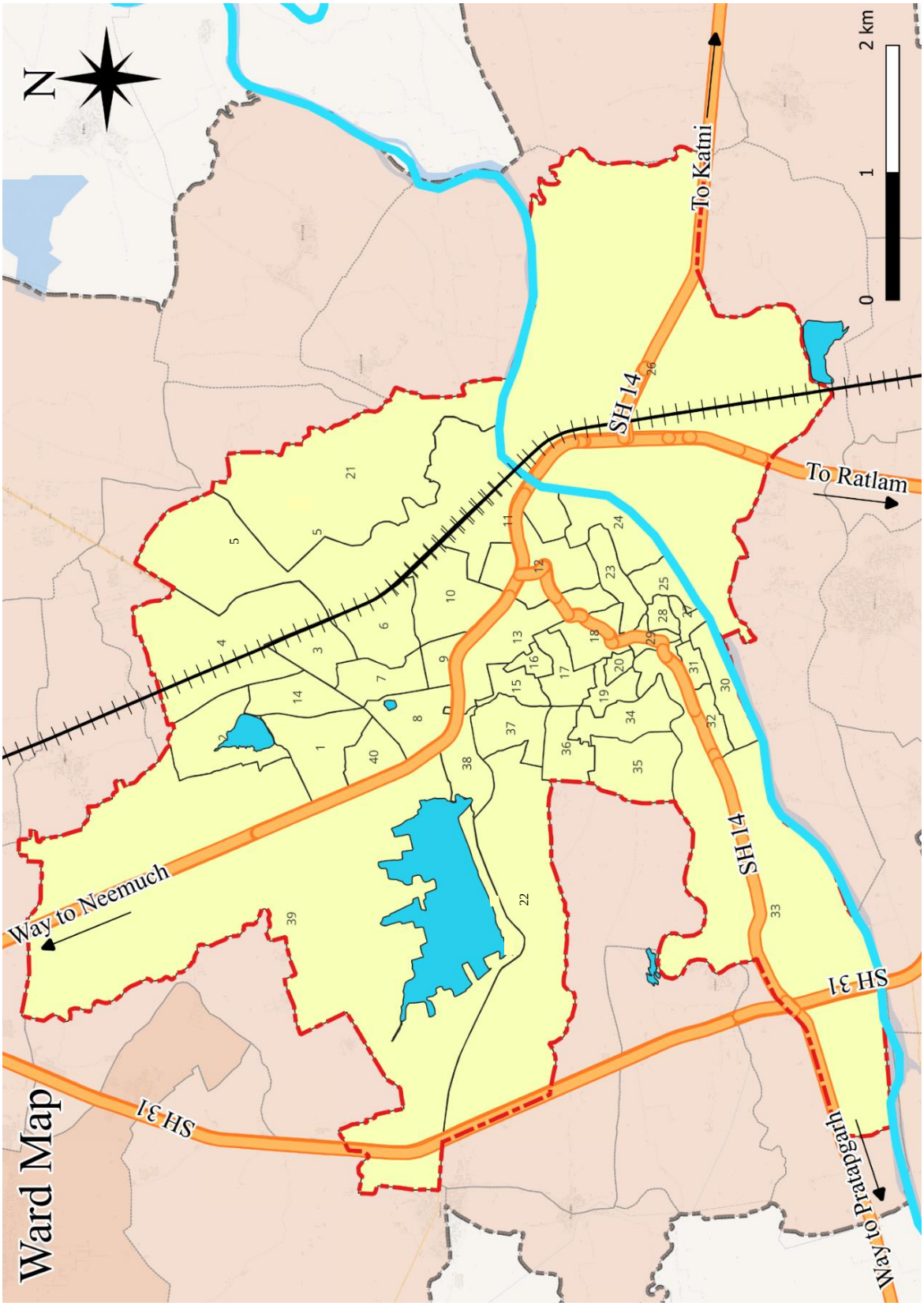


Figure 22: Ward Map of Mandsaur
(2025) and OpenStreetMap (2025)

Source: Compiled by the Author using Survey of India

3.5 Demographic Detail

This section presents the demographic profile of Mandsaur, including population distribution, sex ratio, child population, literacy rate, work participation, occupational structure, and ward-wise population. Demographic characteristics help in understanding the spatial distribution of the population and the socio-economic conditions of the city. This information forms the basis for estimating present and future water demand, assessing infrastructure requirements, and identifying priority areas for Water Sensitive Urban Development (WSUD) interventions.

3.5.1 Population

The city has 1,41,667 populations (Census, 2011) in which Male population is 72,488 and Female population is 69,179**.** This depicts that male population is more in no. and have 51% whereas female is 48%. It is nearly 50-50 spilt indicates a relatively balanced society.

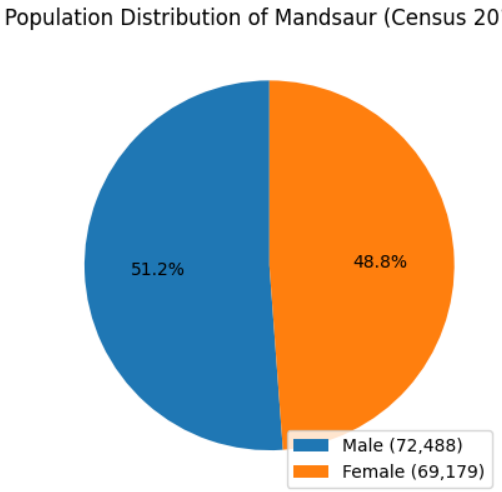


Figure 23: Pie Chart of Population based on Census (2011) *Source: Author's Compilation Based on Census of India (2011)*

3.5.2 SC & ST Population

Below table represents the SC/ST population distribution in Mandsaur city. The table indicates that Scheduled Castes form a larger share of the population (8.95%) compared to Scheduled Tribes (1.28%). This suggests that SC communities have a greater demographic presence in the city, while the ST population is relatively low.

Table 5: SC/ST Population

Category	Population	Percentage of Total Population
Scheduled Caste (SC)	12,684	8.95%
Scheduled Tribe (ST)	1,812	1.28%

Source: (Census, 2011)

Gender-wise Distribution

According to Census 2011, the Scheduled Caste (SC) population of Mandsaur is 12,684 (8.95% of the total population), while the Scheduled Tribe (ST) population is 1,812 (1.28%) as shown in Table 6. Both categories exhibit a nearly balanced gender composition, with only marginal differences between male and female populations. The relatively higher proportion of the SC population indicates that planning interventions should ensure equitable access to basic urban services, including water supply, sanitation, and environmental infrastructure.

Table 6: Gender Wise Distribution of SC/ST

Category	Male	Female
SC	6,384	6,300
ST	907	905

Source: (Census, 2011)

3.5.3 Child Population

The overall sex ratio of Mandsaur is 954 females per 1,000 males, which shows a fairly balanced population. However, some wards have a much lower sex ratio, with less than 800 females per 1,000 males. The child sex ratio (0–6 years) is even lower in some wards, dropping to 870 as shown in Table 7.. These demographic differences highlight the need for inclusive WSUD strategies that provide equal access to water supply across all wards, ensuring sustainable and equitable urban development.

Table 7: Child Population

S. No.	Child Population (0–6 years) Sex Ratio	Ward Numbers	Total Wards
1	500–600	—	—
2	601–700	—	—
3	701–800	—	—
4	801–900	2, 4, 5, 6, 9, 10, 11, 14, 18, 19, 24, 25, 26, 31, 33, 34, 37, 40	18
5	901–1000	3, 12, 15, 17, 20, 21, 22, 23, 28, 29, 30, 35, 39	13

Source: (Census, 2011)

3.5.4 Working Population

The working population of Mandsaur city is 43,571**.** This indicates the number of people engaged in various economic activities and occupations within the city. The work participation rate of the city is 34.70 percent, which reflects the overall economic condition of the city. The total number of households in the city is 22,729. On calculating the average number of working persons per household, it comes to 1.9 persons per household, which means that approximately 19 persons out of every 10 households are employed**.**

Working (Economic Participation) Population

The table illustrates the ward-wise distribution of the Work Participation Rate (WPR) within the municipal area of Mandsaur. Based on the percentage of the population engaged in economic activities, the wards have been categorized into three groups. A majority of the wards (22 out of 40) record a work participation rate between 30–35 percent, indicating a moderate level of workforce engagement. Another 16 wards fall within the 35–40 percent range, reflecting comparatively higher participation in economic activities and better employment opportunities. Only two wards, Ward 30 and Ward 40, exhibit a work participation rate exceeding 40 percent, signifying relatively strong economic activity in these areas.

The city's average work participation rate stands at 34.70 percent, indicating that a significant proportion of the population is economically active. The spatial variation in work

participation across wards reflects differences in employment opportunities, economic conditions, and livelihood patterns within the municipal area.

Table 8: Working Population Distribution Ward Wise

S. No.	Work Participation Rate (%)	Wards Included within Municipal Area	Total Number of Wards
1	30 – 35	1, 3, 4, 5, 6, 7, 10, 11, 13, 14, 15, 21, 22, 23, 25, 27, 28, 32, 34, 37, 38, 39	22
2	35 – 40	2, 8, 9, 12, 16, 17, 18, 19, 20, 24, 26, 29, 31, 33, 35, 36	16
3	Above 40	30, 40	02
	Average	**34.70**	**40**

Source: (Census, 2011)

3.5.5 Occupational Structure

The table presents the occupational structure of the workforce in the Mandsaur Municipal Area, showing the distribution of workers across different employment categories along with their percentage share and participation rate. The data indicates that the workforce is predominantly engaged in non-agricultural activities, with other workers accounting for 91.19 percent of the total workforce. This category includes employment in services, trade, commerce, transportation, administration, and other urban economic activities, reflecting the urban character of Mandsaur's economy.

In contrast, only a small proportion of workers are engaged in the agricultural sector. Cultivators constitute 1.66 percent of the workforce, while agricultural laborer's account for 2.65 percent, indicating a limited dependence on primary economic activities within the municipal area. Household industry workers represent 4.50 percent of the total workforce, suggesting the presence of small-scale and home-based industrial activities, though on a relatively modest scale.

The total workforce in Mandsaur comprises 45,530 workers, with an overall work participation rate of 321 workers per 1,000 populations. The occupational pattern clearly

demonstrates a transition from an agriculture-based economy towards a predominantly service- and commerce-oriented urban economy, highlighting the growing significance of secondary and tertiary sector activities in the city.

Table 9: Occupational Structure

S. No.	Category / Class	Workers within Municipal Area	Percentage (%)	Participation Rate (per 1000 population)
1	Cultivators	754	1.66	5.32
2	Agricultural Laborers	1205	2.65	8.51
3	Household Industry Workers	2052	4.50	14.49
4	Other Workers	41519	91.19	293.07
	Total	**45530**	**100.00**	**321.39**

Source: (Census, 2011)

3.5.6 Slum and Squatter Areas

The economically weaker sections of society residing in areas with inadequate housing and limited access to basic urban services are categorized as slum and squatter settlements. According to data provided by the Municipal Council, Mandsaur, approximately 5,975 households, comprising nearly 29,875 residents, live in such settlements within the city.The housing conditions in these areas vary significantly, with 35 percent of households living in pucca houses, 50 percent in semi-pucca houses, and 15 percent in kutcha houses. Due to inadequate infrastructure and services, these settlements face several challenges, including insufficient drinking water supply, poor sanitation facilities, inadequate road connectivity, and limited access to healthcare, education, and electricity. These deficiencies contribute to lower living standards and remain significant urban development concerns.

To improve the quality of life in slum and semi-slum areas, the Municipal Council, Mandsaur has proposed a comprehensive housing and infrastructure development programme with an estimated investment of ₹12.50 crore. The project aims to enhance essential urban services by upgrading drinking water supply systems, sewerage networks, roads, street

lighting, and public sanitation facilities, while also strengthening access to healthcare and educational infrastructure. Such interventions are expected to promote inclusive urban development and improve living conditions for vulnerable communities within the city.

3.5.7 Sex Ratio

The table presents the ward-wise distribution of the sex ratio in the Mandsaur Municipal Area. The majority of the wards (31 out of 40) have a sex ratio ranging between 901 and 1000 females per 1000 males, indicating a relatively balanced gender composition across most parts of the city. Additionally, four wards record a sex ratio exceeding 1000 females per 1000 males, reflecting a comparatively higher proportion of females in these areas.

However, variations in the sex ratio are evident across the municipal area. Two wards fall within the 801–900 range, while one ward records a sex ratio between 701 and 800. Furthermore, two wards have a sex ratio below 700 females per 1000 males, indicating a significant gender imbalance. These spatial disparities in sex ratio reflect varying demographic characteristics across wards and highlight the need for targeted social welfare measures, gender-sensitive planning, and community development initiatives in areas exhibiting lower female representation

Table 10: Sex Ratio

S. No.	Sex Ratio (Females per 1000 Males)	Ward Numbers	Total Number of Wards
1	> 1000	22, 27, 28, 38	04
2	901–1000	2, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 29, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40	31
3	801–900	3, 7	02
4	701–800	10	01
5	< 700	1, 13	02
	Total		**40**

Source: (Census, 2011)

3.5.8 Literacy Rate

The ward-wise literacy analysis shows that literacy levels improve across the city. Nine wards have a literacy rate between 60–70%, while 13 wards fall within the 70–80% category. The remaining 18 wards have a literacy rate above 80%, indicating that a large part of the city has relatively high literacy levels. Higher literacy can support the successful implementation of WSUD measures, as educated communities are more likely to participate in water conservation, rainwater harvesting, waste segregation, and protection of urban water bodies. However, wards with lower literacy levels may require additional awareness and community engagement programs to encourage participation in sustainable water management practices.

The following table shows the ward-wise literacy rate in Mandsaur.

Table 11: Literacy Rate

S. No.	Ward Numbers	Literacy Rate (%)	Total Number of Wards
1	1, 2, 3, 4, 5, 6, 7, 8, 9	60–70	09
2	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22	70–80	13
3	23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40	Above 60	18
	Total Wards		**40**

Source: (Census, 2011)

3.5.9 Ward Population

The Mandsaur Municipal Area is administratively divided into 40 wards, each exhibiting varying population characteristics. The ward-wise population distribution reveals a significant concentration of population in a few key areas of the city. Ward No. 2 has the highest population with 7,361 residents, followed by Ward No. 3 with 7,129 residents and Ward No. 5 with 6,813 residents. These wards represent some of the most densely populated parts of the city and are likely associated with the core urban area, characterized by greater residential concentration and commercial activity.

Similarly, Ward No. 37 and Ward No. 38 also accommodate relatively large populations, with 6,016 and 5,315 residents, respectively. The distribution pattern indicates that population is unevenly spread across the municipal area, with certain wards experiencing significantly higher concentrations than others. Such clustering of population can increase pressure on urban infrastructure and public services, including water supply, sewerage systems etc.

The ward population map further highlights this spatial disparity, showing higher population concentrations in the northern and central parts of the city. These densely populated wards are likely to generate greater demand for urban services and infrastructure. From a planning perspective, understanding the spatial distribution of population is essential for ensuring equitable service provision, and formulating targeted strategies for sustainable urban development and efficient water resource management in Mandsaur.

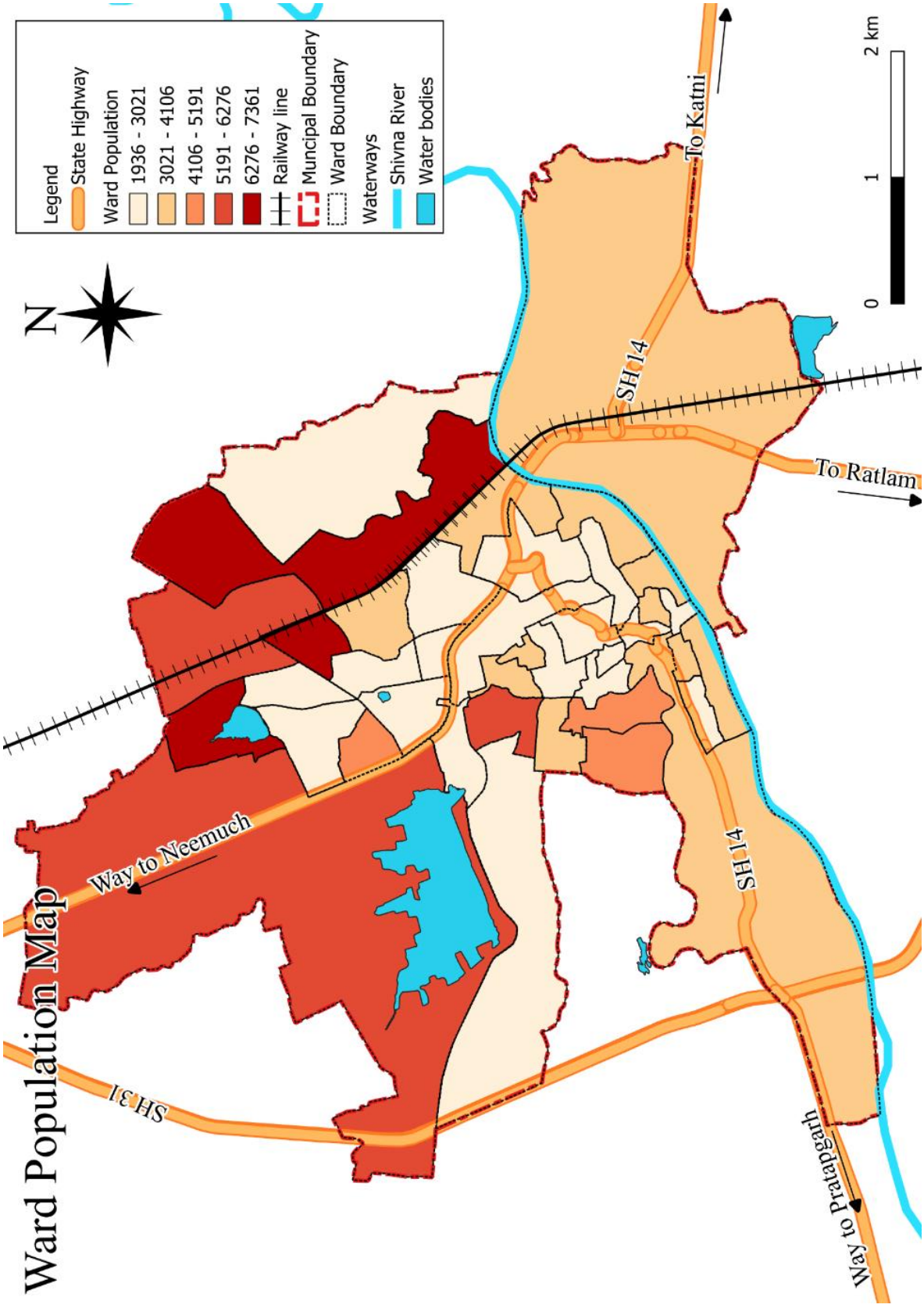


Figure 24: Ward Population Map *Source: : Compiled by the Author using Survey of India (2025) and OpenStreetMap (2025)*

3.5.10 Density

The map represents the ward-wise population density distribution of Mandsaur Municipal Area. It shows that the highest population density is concentrated in the central and southern parts of the city, while the northern and peripheral wards have comparatively lower population densities. This distribution indicates that the city has a compact urban core with intensive residential and commercial development, whereas the outer wards remain relatively less developed and have lower population concentrations.

High-density wards experience greater pressure on urban infrastructure, particularly water supply, sewerage, stormwater drainage, roads, and solid waste management systems. These areas also generate larger volumes of surface runoff due to the presence of extensive impervious surfaces, increasing the risk of waterlogging, localized flooding, and pollution of nearby water bodies. In contrast, the low-density peripheral wards have more open spaces and undeveloped land, providing opportunities for planned urban expansion and the integration of sustainable water management practices.

From a Water Sensitive Urban Development (WSUD) perspective, population density is an important indicator for prioritizing water management interventions. High-density wards require demand-side water management measures such as rooftop rainwater harvesting, permeable pavements etc. to reduce pressure on the existing water supply and drainage network. Increasing urban green spaces in these wards can further improve groundwater recharge.

Ward 3 is one of the most densely populated wards in Mandsaur and therefore requires priority attention in WSUD planning.as shown in Figure 25. The high concentration of population places significant pressure on the existing water supply, sanitation, and stormwater drainage infrastructure. To address these challenges, interventions such as rooftop rainwater harvesting, permeable pavements, bioswales, roadside green strips, decentralized wastewater reuse, and green open spaces should be implemented. These measures will reduce surface runoff, improve groundwater recharge, enhance water availability, and increase the resilience of the ward against urban flooding while promoting sustainable urban development.

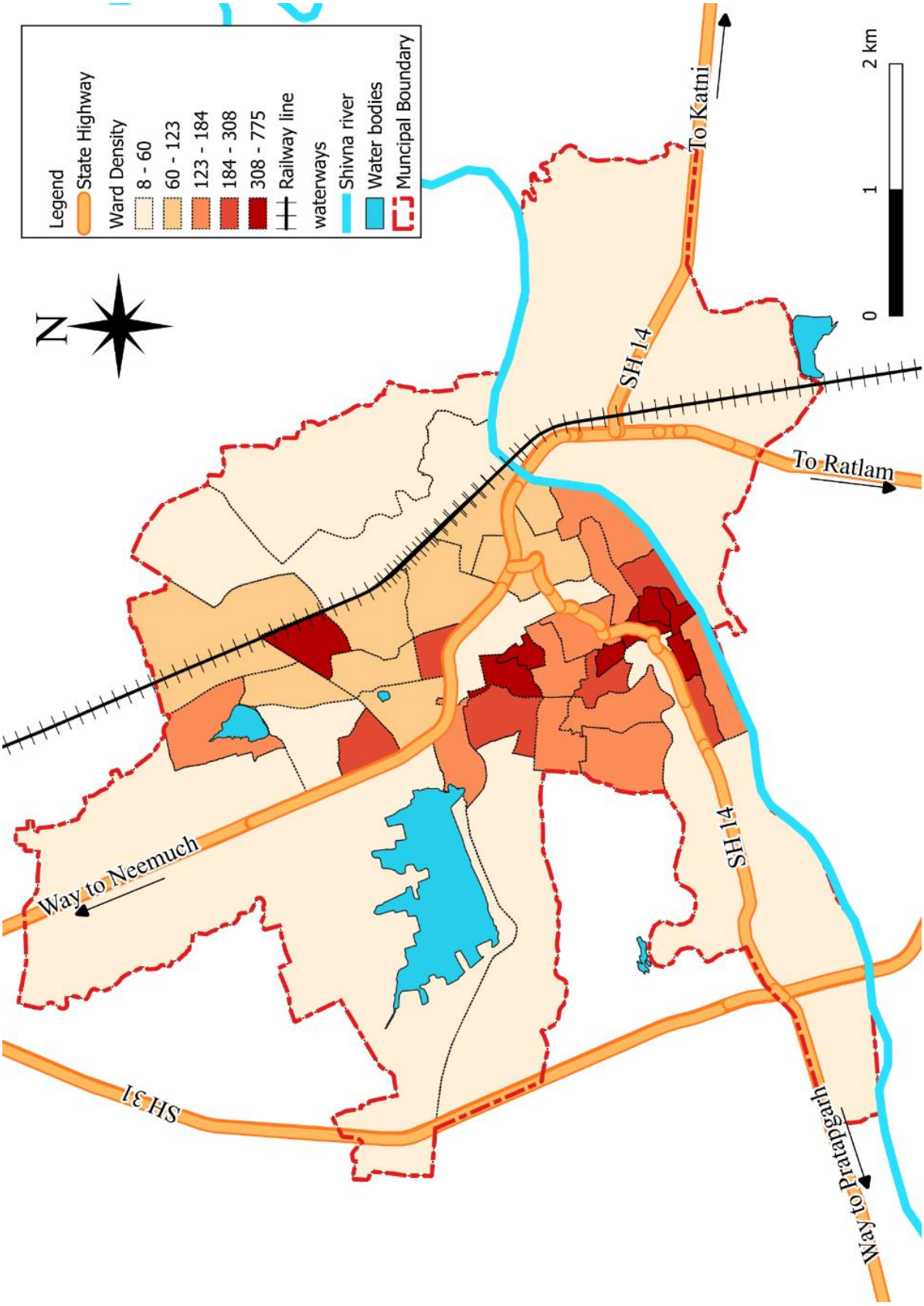


Figure 25: Ward Density Map *Source: Compiled by the Author using Survey of India (2025) and OpenStreetMap (2025)*

3.6 Geographic Details

The geographic features of Mandsaur are important to understand its water system and planning. The city mainly has black cotton soil, which can hold water but does not allow it to go underground easily. Because of this, water stays on the surface and causes runoff and waterlogging during the rainy season. Mandsaur has a hot climate with rainfall of about 700–900 mm, mostly during monsoon. Since rain comes in a short time, a lot of water flows away instead of recharging the ground, and high summer temperatures cause more evaporation and water shortage. The land slopes from north to south, so water naturally flows toward the Shivna River, which acts as the main drainage outlet. The area is mostly flat, so water can collect easily in low-lying areas and cause flooding. The city is part of the Chambal basin and has a natural drainage system connected to the river. All these factors affect water availability, drainage, and recharge, and are important for planning better water management in Mandsaur.

3.6.1 Soil

Mandsaur is predominantly characterized by black cotton soil (regur soil), which is derived from the basaltic rocks of the Deccan Trap region. This soil type is rich in clay minerals, particularly montmorillonite, and is known for its high-water retention capacity, low permeability, and pronounced shrink swell behavior (NBSS&LUP, 2019; ICAR, 2018). Due to its low infiltration rate, rainwater tends to remain on the surface, leading to increased surface runoff and waterlogging, especially during the monsoon season. The shrink–swell nature of the soil further affects the stability of drainage systems and built infrastructure.

From a Water Sensitive Urban Design (WSUD) perspective, these soil conditions significantly influence urban hydrology and planning strategies. The limited natural infiltration reduces groundwater recharge potential and necessitates the adoption of engineered recharge systems and surface storage solutions rather than relying solely on infiltration-based techniques (FAO, 2015). Additionally, the high runoff generated over such soils contributes to the transportation of pollutants into nearby water bodies, impacting their ecological health. Therefore, understanding the soil characteristics is essential for designing effective drainage systems and implementing sustainable water management strategies in Mandsaur.

3.6.2 Climate and Rainfall

Mandsaur experiences a tropical wet and dry climate characterized by extremely hot summers, a distinct monsoon season, and mild winters. The city receives an average annual rainfall of approximately 700–900 mm, with nearly 85–90% of the rainfall occurring between June and September. Rainfall events are generally intense and concentrated within short durations, resulting in high surface runoff and limited groundwater recharge.

During the summer season, temperatures often exceed 45°C, leading to high rates of evaporation and increased water demand. This contributes to seasonal water scarcity and places additional stress on available water resources. Winters are comparatively dry and moderate, with lower rainfall and comfortable temperatures.

From a Water Sensitive Urban Development (WSUD) perspective, Mandsaur's climatic conditions present both opportunities and challenges. The concentration of heavy rainfall during the monsoon season often overwhelms existing drainage infrastructure, causing localized flooding, waterlogging, and the transport of pollutants into rivers, ponds, and other urban water bodies. Conversely, prolonged dry periods and high evaporation rates result in reduced water availability and increased dependence on groundwater resources.

These climatic conditions highlight the need for integrated water management strategies that can capture, store, and reuse storm water during the monsoon season while ensuring water availability during dry periods. Measures such as rainwater harvesting, detention and retention systems, groundwater recharge structures, bioswales, and the restoration and expansion of urban water bodies are essential for managing runoff and enhancing water security. The implementation of WSUD principles can help reduce flood risks, improve groundwater recharge, conserve water resources, and strengthen the overall resilience of Mandsaur's urban water system.

Therefore, climate-responsive water management is crucial for the sustainable growth and development of Mandsaur. Effective planning and integration of WSUD strategies can support long-term water security, environmental sustainability, and urban resilience in the city.

Groundwater Level – Mandsaur (CGWB Data Depth to Water Table)

This table represents the pre-monsoon, post-monsoon and water table depth in mgbl.

Table 12: Water Table Depth

Season	Water Table Depth (m below ground level – mbgl)
Pre-monsoon (2020) March to May	4.3 – 22.8 m bgl
Post-monsoon (2019) October to November	0.4 – 8.9 m bgl

Source: (CGWB Hydrogeological Report, 2020-2021)

Inferences

Groundwater levels in Mandsaur exhibit significant seasonal variation and are highly dependent on monsoon recharge. Following the monsoon season, groundwater levels are relatively shallow, reaching approximately 0.4 m below ground level in some areas. However, during the pre-monsoon period, groundwater levels decline considerably, reaching depths of nearly 22 m below ground level. This substantial fluctuation indicates a strong dependence on rainfall for groundwater replenishment and highlights the vulnerability of the city's water resources to seasonal changes.

During the summer months, declining groundwater levels increase the dependence on deeper groundwater extraction to meet domestic and urban water demands. Continuous pumping from greater depths places additional stress on the aquifer system and contributes to groundwater depletion. At the same time, a significant proportion of the supplied water, estimated at approximately 25–40%, is lost as Non-Revenue Water (NRW). These losses occur due to leakage in distribution pipelines, unauthorized connections, inaccurate metering, and other unaccounted-for uses.

High levels of NRW increase the overall demand for water abstraction, creating a cycle of over-exploitation. As water losses rise, additional groundwater must be extracted to compensate for the deficit, resulting in further declines in groundwater levels. Excessive extraction can also adversely affect groundwater quality, particularly when water is drawn from

deeper aquifer layers. This often leads to increased concentrations of dissolved solids, nitrates, fluoride, and other contaminants, thereby reducing the suitability of groundwater for domestic consumption.

Addressing these challenges requires a dual approach involving both demand management and groundwater recharge. Reducing NRW through pipeline maintenance, leakage control, metering improvements, and efficient network management can significantly decrease unnecessary water losses. Simultaneously, the implementation of groundwater recharge measures such as rainwater harvesting, recharge wells, percolation pits, and the restoration of urban water bodies can enhance aquifer replenishment. Together, these interventions can help stabilize groundwater levels, improve water quality, and promote sustainable urban water management in Mandsaur.

3.6.3 Contour

The area around Mandsaur slopes downwards from the north to the south. It is about 420 to 430 meters high in the north. Goes down to 370 to 390 meters, in the south. This slope helps decide where the water flows. Water mostly moves from the northwestern areas to the lower southeastern areas.

The middle and southern parts of Mandsaur city are around 370 to 380 meters high. These areas collect water. Can get flooded easily. On the hand the northern and northwestern parts are higher up and do not hold much water. So, they usually let water flow away quickly.

The close contours in the northern area signal steeper terrain, while the more widely spaced contours across the central and southern zones point to gentler gradients with greater infiltration capacity. The contour layout also reveals natural valleys and drainage channels that funnel toward the lower-lying central portions before continuing southeast.

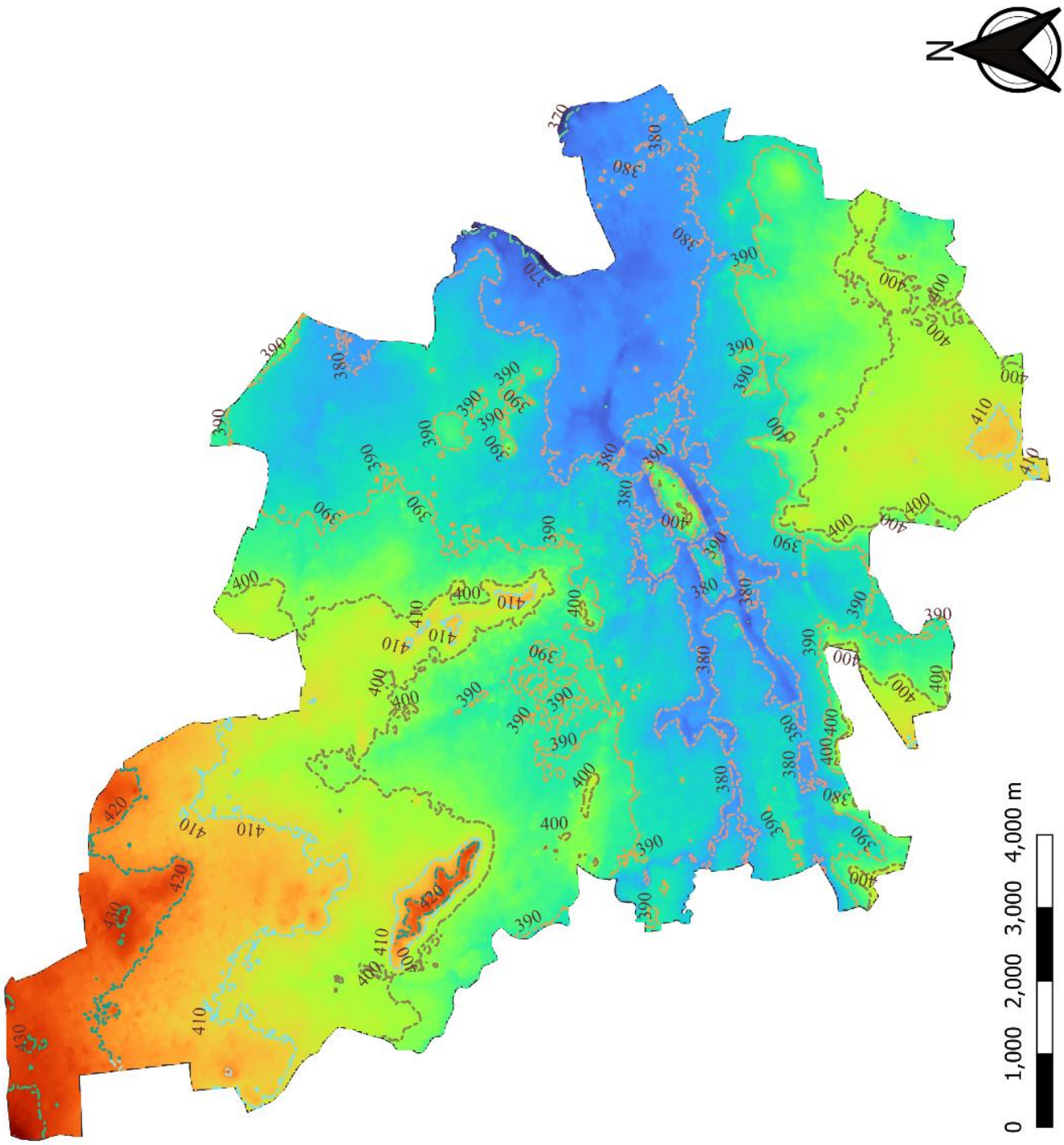


Figure 26:Contour Map *Source: Contours*
generated by the Author using Bhoonidhi DEM (2023)

3.6.4 Watershed

Mandsaur city is the part of bigger catchment of Chambal basin its area is 976 sq km. This table show the detail of catchment. The catchment of river shown in figure 27.

Table 13: Watershed of Mandsaur

Sub Basin Code	CHU
Basin Code	2A
Watershed Concatenated	C2ACHU19
Watershed Code	19
Area in sq km	976.85

Source: India-WRIS



Figure 27:Micro Watershed of Shivna River *Source: Compiled by the Author using Bhoonidhi DEM (2025)*

Below the figure represents the Mandsaur district boundary and catchment boundary in which city falls and surrounded catchments.

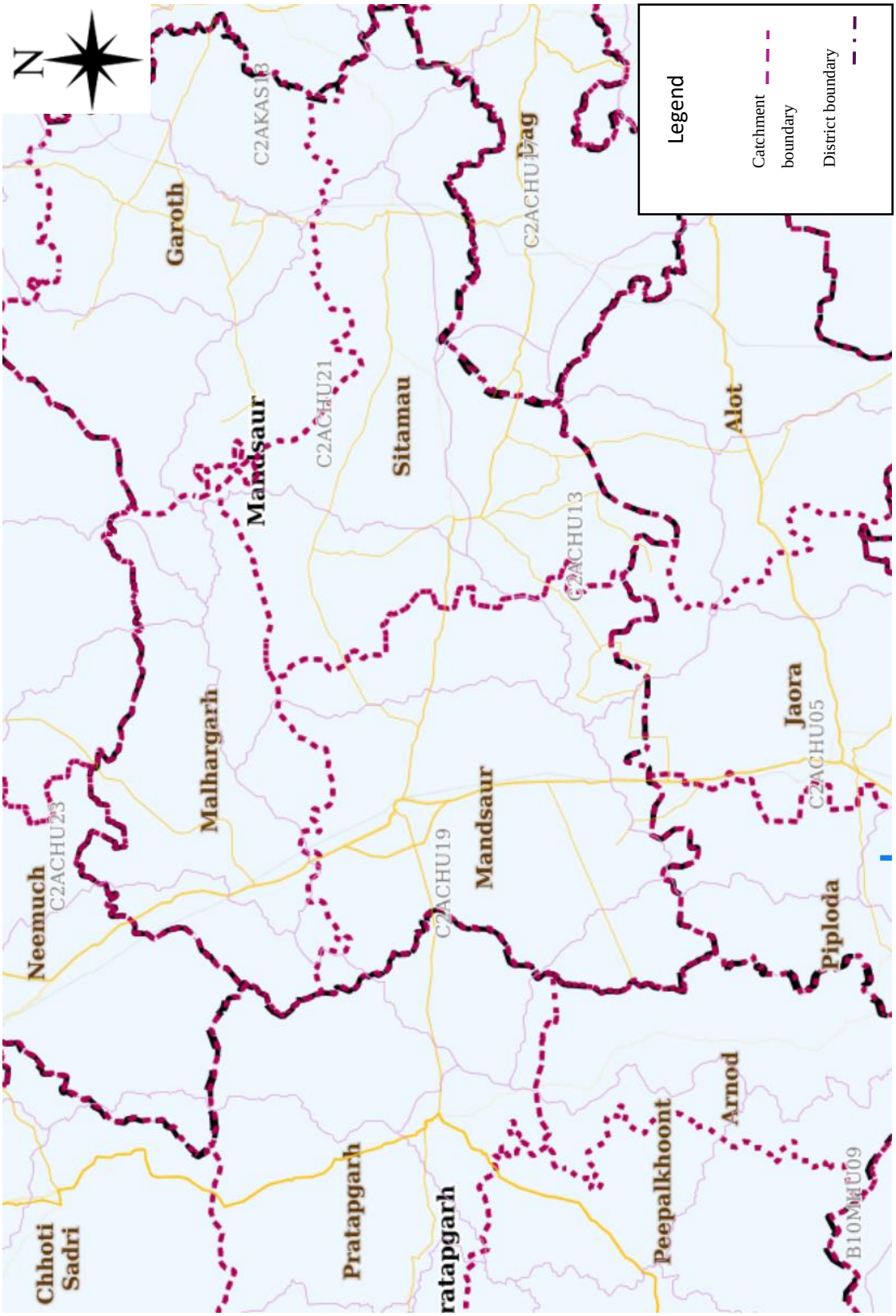


Figure 28: Watershed of Mandsaur *Source: NRSC, ISRO (2026)*

3.6.5 Drainage

The entire slope and terrain of the city are oriented toward the shivna riveras shown in the figure below, which act as the ultimate natural sink for the city's surface runoff and storm water. The city built on an upland plateau. The general slope guides water from the higher urbanized peripheral pockets down toward the river basin. Mandsaur city's internal natural drainage relies on a dendritic network of seasonal streams and major open drains that cut through various wards.

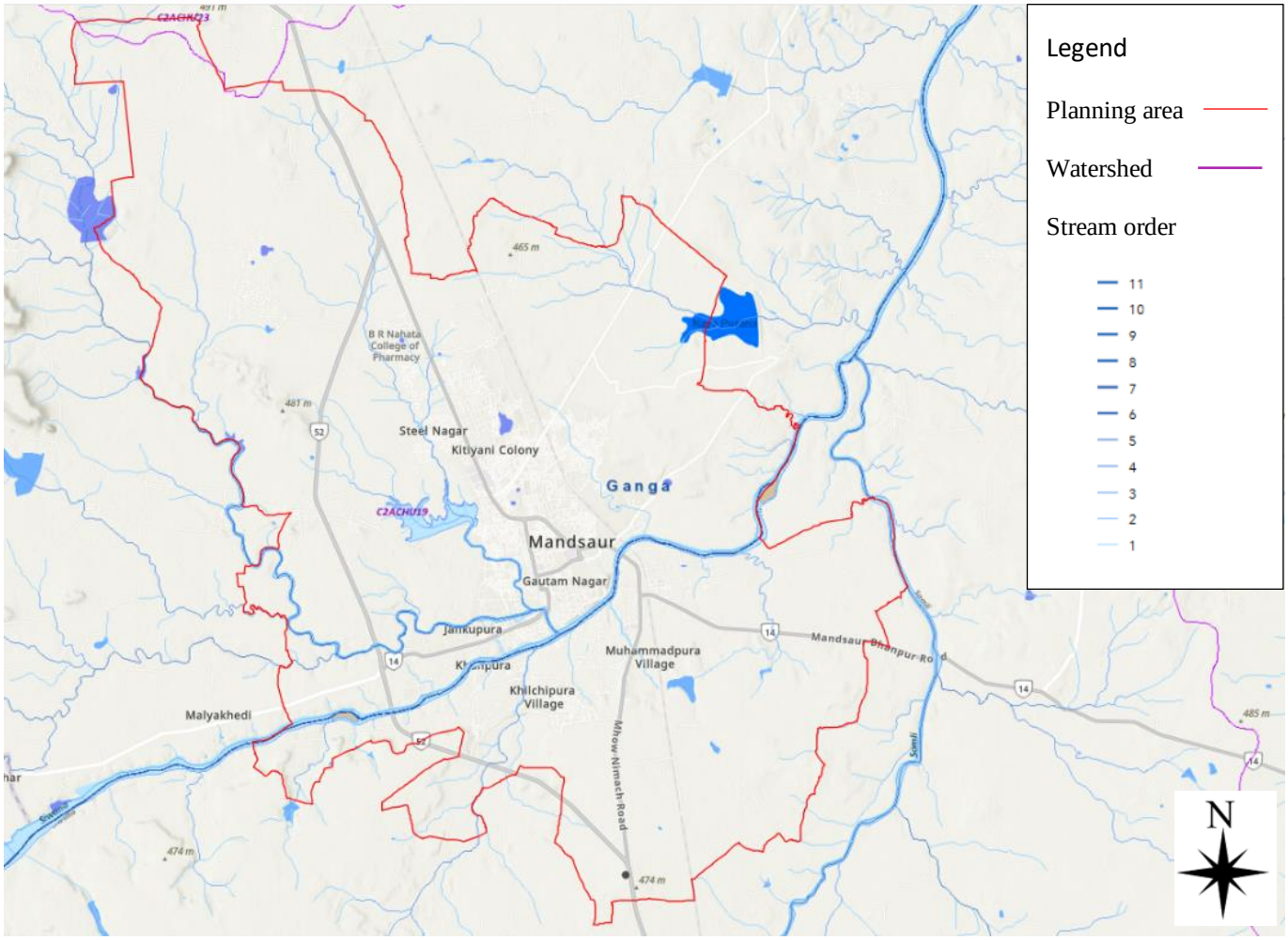


Figure 29: Drainage Map

Source: Compiled by the Author using Indian WRIS, (2021)

3.6.6 Slope

The landscape of Mandsaur is mostly flat. This is because the planning area is mostly deep red, which means it has low slope values, like 0.000779. There are some places where the ground's not so flat. The areas in yellow and green which means the ground slopes a bit. There are also some blue areas, which means the ground slopes a lot like around 20.5. These areas are probably near water or where water flows. In the part of Mandsaur there is a special area where the ground changes a lot. This area might be a divider for water that flows on the surface. The landscape of Mandsaur has this area that goes from north to south, like a line.

Inferences

Given the flat terrain, any residential areas falling within a 30-meter buffer of water bodies or drainage channels are at significant risk of waterlogging. The lack of natural steep gradients means water will likely stagnate rather than drain quickly during heavy monsoon events. The slopes identified in yellow/green highlight the natural paths for watershed delineation. These should be preserved as primary storm-water arteries to ensure that the "conservation and revival of water bodies" is successful.

Identification of Recharge and Collection Points

Areas with moderate slopes act as the primary conduits for surface runoff. These gradients indicate natural flow paths where rainwater will naturally collect before entering lower-lying water bodies. The extensive flat areas (deep red) are ideal for large-scale percolation. Since the velocity of runoff is lower in these zones, there is more time for water to infiltrate the soil, making them suitable for widespread recharge interventions.

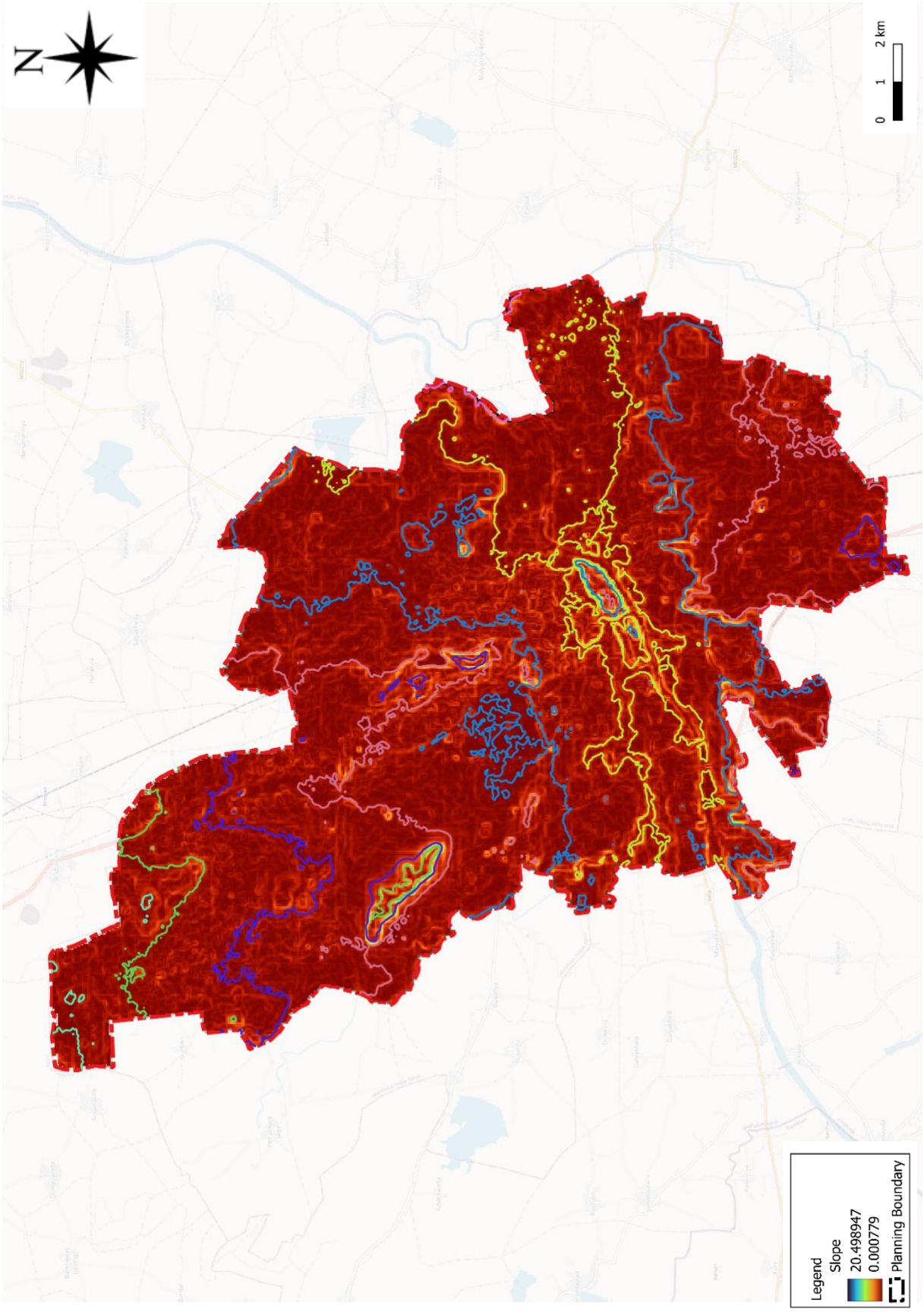


Figure 30: Slope Map

Source: Compiled by the Author using Bhoonidhi DEM (2023)

3.7 Application of WSUD for Mandsaur

As urbanization continues to reshape our landscapes, the concept of a Water Sensitive Urban Development (WSUD) has gained prominence as a holistic approach to address the challenges of water management in cities. It all refers to the land planning and engineering design approach that integrates the urban water cycle, including storm water, groundwater, and wastewater management and water supply, into urban design. This is done to minimize the environmental degradation as well as improve the look of the area by creating a circular economy of urban water use. Urban development using conventional approaches can have a negative impact on the natural water cycle. WSUD seeks to minimize this impact by integrating developments with a site's natural features and promoting the integration of storm water, water supply and sewage management. Application of these principles provides a cost-effective means to minimise impacts of development on waterways, provide places that are cooler and greener, and engage communities that are healthier and more connected to their waterways. Previously we have identified that a lack of capacity (willingness and ability), unsupportive organisational cultures, and restrictive policy environments can limit the potential for the WSUD approach to achieve desirable outcomes.

In urban environments, impermeable surfaces like roads, roofs, driveways, and walkways prevent water from soaking into the ground, resulting in storm water runoff. Additionally, the presence of vehicles and industrial activities in these areas contributes to the accumulation of pollutants on these surfaces. When it rains, this polluted runoff is funneled through drains, eventually reaching creeks and rivers, causing pollution and degradation to environmentally crucial systems. It is a solution designed to enhance urban areas' capacity to capture, treat, and recycle storm water, preventing it from polluting and harming our natural waterways and ensuring rain water is used in the environment in which is falls more efficiently

The study applies Water-Sensitive Urban Development (WSUD) principles in Mandsaur to develop sustainable planning strategies for the conservation and revival of urban water bodies. The planning applications focus on integrating water management with urban planning through GIS-based analysis of contour, watershed, drainage, slope, land use, and groundwater dependency. The study evaluates issues such as uneven water distribution, low-pressure zones, waterlogging, encroachment, pollution in the Shivna River, and excessive dependence on

groundwater extraction. In the context of WSUD, the research proposes planning interventions such as rainwater harvesting, recharge pits, bioswales, stormwater management systems, desilting of ponds and tanks, ecological restoration, and protection of natural drainage channels. It also emphasizes integrating traditional water bodies with urban infrastructure and improving groundwater recharge through sustainable land-use planning. Ward-level and city-level strategies are suggested to enhance urban resilience, reduce flood risk, conserve water resources, and promote long-term sustainable urban development in Mandsaur.

Below table represents a detailed list of methods that can be considered for the proposed interventions. From these, appropriate methods will be selected based on the evaluation of relevant parameters, the location of the water bodies, the characteristics of their surrounding areas, their existing conditions, and their suitability and application to the Mandsaur study area.

Table 14: Detail List of Methods 1

Parameter	Check Dam	Recharge Well	Deep Aquifer Recharge Shaft	Rooftop Rainwater Harvesting	Infiltration Trench
Objective	Store runoff & recharge groundwater	Recharge shallow aquifer	Recharge deep confined aquifer	Collect roof runoff for reuse/recharge	Infiltrate stormwater
Construction Time	1–4 months	7–20 days	20–45 days	3–10 days	7–15 days
Standard Sizes Available	H:1–5 m, L:5–100 m	Ø 0.5–3 m, D:10–40 m	Ø 0.5–2 m, D:30–100 m	Roof dependent	Width:0.5–2 m, Depth:1–3 m
Best Location to Propose	Seasonal streams	Parks, institutions	Over-exploited groundwater zones	Residential, schools, offices	Along roads & parking

Area Required	Medium–Large	4–20 m²	10–25 m²	Existing roof	Linear
Catchment Area Served	Watershed	Individual buildings	Large institutional area	Building	Roads
Soil Suitability	Rocky	Sandy/Loamy	Hard rock	All	Sandy/Loamy
Estimated Cost	₹2–50 lakh	₹50,000–3 lakh	₹3–15 lakh	₹20,000–5 lakh	₹1,000–3,000/m
Design Life	30–50 yrs	20–30 yrs	30–50 yrs	20 yrs	20 yrs
Maintenance Frequency	Annual	Every 6 months	Annual	Annual	Annual
Maintenance Cost	Low	Low	Low	Low	Low
Materials Required	Stone masonry, RCC	RCC rings, gravel, PVC	RCC casing, gravel, PVC	PVC pipes, filter, tank	Gravel, geotextile
Implementing Agency	Water Resources Dept.	Municipal Corporation	CGWB, Municipal Corporation	Municipal Corporation	Municipal Corporation
Funding Source	Jal Shakti, MGNREGA	AMRUT, CSR	Atal Bhujal Yojana	Building Owner, CSR	Smart City
Permissions Required	Irrigation Dept.	Municipal Approval	CGWB Approval	Building Approval	Municipal Approval
Water Recharge Potential	Very High	Very High	Very High	High	High

Limitations	Needs suitable stream	Clogging	High drilling cost	Limited by roof size	Clogging

Source: Compiled by the author based on Central Ground Water Board (2020), Central Public Health and Environmental Engineering Organization (2019), Bureau of Indian Standards (2002), Ministry of Jal Shakti (2020), and CIRIA (2015).

Table 15: Detail List of Methods 2

Parameter	Bioswale	Vegetation Strip	Rain Garden	Riparian Green Buffer	Detention Pond	Floating Wetland	Solar-Powered Aeration Fountain
Objective	Convey, infiltrate and filter stormwater runoff	Filter runoff and trap sediments	Infiltrate and treat stormwater	Protect riverbanks and improve water quality	Temporary flood storage	Improve lake water quality naturally	Increase dissolved oxygen using renewable energy
Construction Time	15–30 days	7–15 days	10–20 days	1–3 months	2–5 months	5–10 days	5–10 days
Standard Sizes Available	Width: 1–5 m, Depth: 0.3–1.0 m	Width: 1–10 m	10–500 m²	Width: 10–100 m	500–15,000 m²	Modular units: 1–20 m²	0.5–10 HP
Best Location to Propose	Road medians, highways,	Along roads, drains and lakes	Parks, institutions and residenti	Along rivers, lakes and canals	Flood-prone urban areas	Lakes, ponds and reservoirs	Urban lakes and ponds

	residential streets		al colonies				
Area Required	Linear strip	Linear strip	Small–Medium	Large linear corridor	Large	No additional land	Very Small
Catchment Area Served	Roads and neighbour hoods	Roads and open spaces	Local catchment	River corridor	Urban catchment	Water body	Water body
Soil Suitability	Sandy to Loamy	All soils	Sandy-Loam	Alluvial soils	All soils	Not Applicable	Not Applicable
Estimated Cost	₹1,000–4,000/m	₹300–1,000/m²	₹1,500–5,000/m²	₹5–30 lakh/km	₹10 lakh–1.5 crore	₹2,000–5,000/m²	₹2–15 lakh
Design Life	20 years	15–20 years	20 years	30–50 years	40 years	10–15 years	15–20 years
Maintenance Frequency	Quarterly	Seasonal	Quarterly	Annual	Annual	Quarterly	Monthly
Maintenance Cost	Low	Low	Low	Low	Moderate	Moderate	Moderate
Materials Required	Gravel, sand, topsoil, native plants	Native grasses, shrubs	Soil mix, mulch, gravel, native plants	Native trees, shrubs, fencing	Earthwork, spillway, RCC	Floating mats, coconut fibre, aquatic plants	Solar panels, aerator, battery, pump

Implementing Agency	Municipal Corporation	Municipal Corporation	Municipal Corporation	Forest Department, Municipal Corporation	Municipal Corporation	Municipal Corporation	Municipal Corporation
Funding Source	Smart City, AMRUT	CAMPA, Smart City	Smart City, AMRUT	CAMPA, State Forest Dept.	Disaster Management Fund	CSR, Lake Conservation Scheme	MNRE, CSR, Smart City
Permissions Required	Municipal Approval	Municipal Approval	Municipal Approval	Forest & Environment Clearance	Municipal Approval	Municipal Approval	Electrical Approval
Water Recharge Potential	Medium	Medium	High	Medium	Medium	None	None
Limitations	Needs regular vegetation maintenance	Requires irrigation during establishment	Requires space and maintenance	Land acquisition may be required	Large land requirement	Limited treatment capacity	Dependent on solar availability

Source: Compiled by the author based on CIRIA (2015), Public Utilities Board (PUB) Singapore (2018), Central Public Health and Environmental Engineering Organisation (CPHEEO, 2019), United States Environmental Protection Agency (USEPA, 2021), Central Ground Water Board (CGWB, 2020), and Central Pollution Control Board (CPCB, 2019).

Table 16: Detail List of Methods 3

Parameter	Water Quality Control to Prevent Biological Clogging	Desilting of Lakes/Ponds	Bio-retention Basin	Infiltration Basin	Soakaway Pit
Objective	Improve recharge water quality and prevent clogging of recharge structures	Restore storage capacity and improve water quality	Filter, store and infiltrate stormwater	Recharge groundwater by infiltrating stormwater	Dispose treated wastewater into soil
Construction Time	5–15 days	15 days–3 months	20–45 days	1–2 months	5–10 days
Standard Sizes Available	Filter chambers: 1–5 m^3	Depends on lake size	50–1000 m^2	100–5000 m^2	1×1×2 m to 3×3×3 m
Best Location to Propose	Before recharge wells, shafts and pits	Lakes, ponds, reservoirs	Parks, institutions, commercial areas	Parks and open spaces	Residential and institutional buildings
Area Required	Very Small	Existing lake area	Medium	Large	Small
Catchment Area Served	Recharge structures	Water body	Urban catchment	Urban catchment	Building plot
Soil Suitability	All soils	All soils	Sandy–Loamy	Sandy	Sandy/Loamy

Estimated Cost	₹30,000–2 lakh	₹100–500/m³ dredging	₹2,000–5,000/m²	₹5–50 lakh	₹15,000–80,000
Design Life	15–20 years	Repeated every 5–10 years	20 years	25 years	20 years
Maintenance Frequency	Quarterly	Every 3–5 years	Quarterly	Annual	Annual
Maintenance Cost	Low	Moderate	Low	Moderate	Low
Materials Required	Filter media, gravel, sand, silt trap	Excavators, dumpers	Soil mix, gravel, native vegetation	Earthwork, gravel, geotextile	Bricks, gravel, coarse aggregate
Implementing Agency	Municipal Corporation	Municipal Corporation	Municipal Corporation	Municipal Corporation	Municipal Corporation
Funding Source	AMRUT, Municipal Budget	MGNREGA, AMRUT, State Govt.	Smart City, AMRUT	AMRUT	Municipal Budget
Permissions Required	Municipal Approval	Municipal Approval	Municipal Approval	Municipal Approval	Municipal Approval
Water Recharge Potential	Indirect (Protects recharge systems)	High	High	Very High	High
Limitations	Requires regular cleaning	Temporary solution if catchment isn't managed	Needs regular vegetation maintenance	Requires large land area	May clog over time

Source: Compiled by the Author based on CPHEEO (2019), Ministry of Housing and Urban Affairs (MoHUA), Central Ground Water Board (CGWB, 2020), Central Public Health and Environmental Engineering Organisation (CPHEEO),

3.7.1 Lessons for Mandsaur Derived from Literature

The review of literature and selected case studies demonstrates that the conservation and revival of urban water bodies require an integrated approach combining ecological restoration, sustainable stormwater management, wastewater treatment, groundwater recharge, and community participation. Although the case studies represent different geographical and climatic conditions, they provide practical planning strategies that are applicable to the context of Mandsaur.

The restoration of Jakkur Lake highlights the importance of intercepting and treating wastewater before it enters water bodies. The use of constructed wetlands, sedimentation basins, vegetated buffer zones, and biodiversity restoration improves water quality while enhancing groundwater recharge and ecological resilience. These interventions can be adopted to improve the environmental condition of Mandsaur's lakes and the Shivna River (Ramachandra et al., 2018; BBMP, n.d.; CDD Society, 2019).

Key Lessons for Mandsaur

The Jakkur Lake model provides several planning strategies that can be adapted for the conservation and revival of water bodies in Mandsaur:

- Installation of sewage treatment facilities before wastewater enters lakes or rivers.
- Development of constructed wetlands at major drainage inlets for tertiary treatment.
- Provision of sedimentation basins to reduce silt inflow.
- Establishment of vegetated buffer zones around water bodies.
- Integration of stormwater management with groundwater recharge systems.
- Promotion of biodiversity through native plantation and habitat restoration.
- Community participation in long-term operation and maintenance.

The Alwar Johad Revival demonstrates the effectiveness of decentralized rainwater harvesting, recharge structures, catchment treatment, and community participation in restoring groundwater resources. The revival of traditional water harvesting systems and protection of natural drainage channels provide valuable strategies for improving water security and

strengthening local water management in Mandsaur (Kandpal & Kumar, 2003; Tarun Bharat Sangh, n.d.).

Key Lessons for Mandsaur

The Alwar Johad Revival offers several planning strategies that are applicable to water body conservation and groundwater recharge in Mandsaur:

- Restoration of traditional ponds and local water harvesting structures.
- Construction of small check dams and recharge structures in natural drainage channels.
- Protection and treatment of catchment areas to reduce sediment inflow.
- Integration of stormwater runoff with groundwater recharge systems.
- Promotion of community participation in planning, maintenance, and monitoring of water bodies.
- Use of nature-based solutions alongside conventional urban water infrastructure.

The Hussain Sagar Lake Restoration emphasizes integrated lake and catchment management through sewage interception, expansion of wastewater treatment infrastructure, desilting, shoreline protection, and continuous water quality monitoring. These measures illustrate the importance of coordinated institutional planning and pollution control for restoring urban water bodies (HMDA, n.d.; Centre for Science and Environment, n.d.).

Key Lessons for Mandsaur

The Hussain Sagar restoration provides several planning strategies applicable to water body conservation and revival in Mandsaur:

- Interception and treatment of sewage before discharge into lakes and rivers.
- Integration of lake restoration with catchment management.
- Periodic desilting and shoreline protection to improve storage capacity.
- Establishment of vegetated buffer zones to reduce non-point source pollution.
- Continuous water quality monitoring for adaptive management.
- Coordination among urban local bodies and water management agencies for long-term maintenance.

The Rajkot Rainwater Harvesting Initiative demonstrates how decentralized rainwater harvesting, recharge wells, rooftop harvesting, and watershed-based planning can improve groundwater recharge and urban water security. These measures are particularly relevant for Mandsaur, where increasing groundwater recharge and reducing dependence on external water sources are important planning objectives (Bhardwaj & Khosla, 2017; Khandelwal et al., 2003).

Key Lessons for Mandsaur

The Rajkot experience provides several planning interventions that can be adapted for Mandsaur:

- Mandatory rooftop rainwater harvesting in institutional, commercial, and residential buildings.
- Installation of recharge wells and recharge shafts in public open spaces.
- Integration of stormwater drainage with groundwater recharge structures.
- Construction of check dams and percolation tanks within the urban fringe.
- Public awareness and community participation in rainwater harvesting.

Although developed in Singapore, the ABC Waters Programme provides internationally recognized WSUD practices that are adaptable to Indian cities. Planning interventions such as bioswales, rain gardens, permeable pavements, green streets, constructed wetlands, and vegetated buffer zones offer effective nature-based solutions for improving stormwater management, reducing pollution, enhancing groundwater recharge, and strengthening urban ecological resilience. These approaches can be incorporated into the proposed planning strategies for Mandsaur (PUB, 2018).

Relevance to India and Mandsaur

Although the ABC Waters Programme was developed in Singapore, several of its planning principles have been adopted in Indian cities through Water Sensitive Urban Design (WSUD) and Nature-Based Solutions (NbS). These include the use of bioswales, rain gardens, permeable pavements, green streets, constructed wetlands, and vegetated buffer zones in urban water management projects.

For Mandsaur, the following concepts can be adapted:

- Bioswales along urban roads to convey and filter stormwater.
- Rain gardens in parks, institutional campuses, and public open spaces.
- Permeable pavements in parking areas and pedestrian pathways.
- Green streets integrated with roadside plantation and infiltration systems.
- Vegetated buffer zones around Teliya Talab, Shivna River, and other urban water bodies.

The literature indicates that successful water body conservation depends on integrating wastewater treatment, stormwater management, groundwater recharge, ecological restoration, and community participation within the urban planning process. These planning lessons form the basis for the Water Sensitive Urban Development (WSUD) strategies proposed for Mandsaur in the subsequent chapter.

3.8 Inferences

This chapter presents a comprehensive profile of Mandsaur City, highlighting its physical, environmental, socio-economic, and water resource characteristics. The analysis shows that although the city possesses diverse water bodies, including the Shivna River, ponds, tanks, wells, and hand pumps, increasing urbanization, groundwater over-extraction, and inadequate water management have resulted in declining water quality and reduced groundwater levels. The study of climate, topography, drainage, land use, and hydrogeological conditions indicates that Mandsaur has significant potential for adopting Water Sensitive Urban Development (WSUD) principles. The city's natural drainage pattern, existing water bodies, and rainfall characteristics provide opportunities for groundwater recharge, stormwater management, and ecological restoration. The findings of this chapter establish the baseline conditions of the study area and provide the foundation for detailed analysis and planning interventions presented in the subsequent chapters.

CHAPTER 4-DATA AND DATA ANALYSIS

4.0 Introduction

This chapter focuses on understanding how water is supplied, how it flows through the city, and the condition of water bodies. This analysis is important to identify existing problems and gaps in the system. The water supply system, including raw water sources, treatment plants, overhead tanks, and the distribution network is also studied. It helps in understanding how water reaches different parts of the city and whether all areas are getting proper supply. It also looks at other sources like wells and hand pumps, which are still used in some areas specially in peri urban areas. The condition of water bodies such as rivers, ponds, and tanks is also examined. Issues like pollution, encroachment, and siltation are identified to understand how these water bodies are being affected. These factors reduce their storage capacity, decrease in ground water level and ecological value.

The drainage system of the city is analyzed to understand how rainwater flows and this will further help in proposing the check dams. The relationship between drainage, watershed, and topography is also studied. Population data and water demand are also included to understand the pressure on the existing system. This helps in comparing the demand and supply of water. Overall, this chapter provides a clear picture of the current situation of water supply, drainage, and water bodies in Mandsaur. The findings from this analysis will be used in the next chapter to identify problems and develop necessary proposals.

4.1 Water Bodies

Mandsaur contains different types of water bodies, including traditional tanks and ponds located near mosques, as well as Teliya Talab, an artificial reservoir. Teliya Talab plays an important role in storing water, recharging nearby wells and hand pumps, and maintaining the groundwater table. These water bodies contribute significantly to the city's urban water system and provide opportunities for implementing Water Sensitive Urban Development (WSUD) strategies. The map below shows the location and existing condition of the major water bodies within the municipal area.

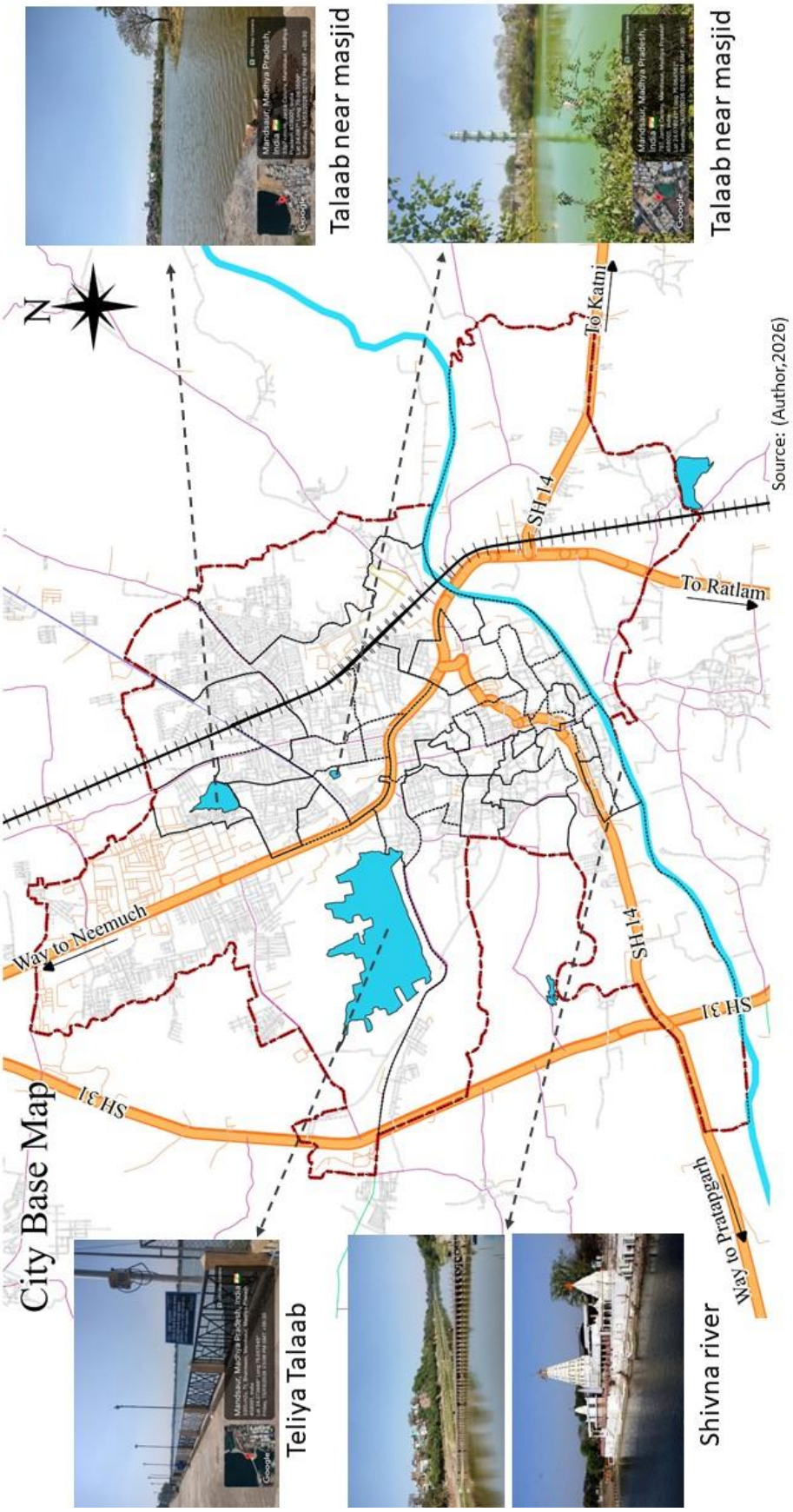


Figure 31: Location of Water Bodies *Source: Compiled by the Author using Survey of India (2025) and OpenStreetMap (2025)*

4.1.1 Condition of Shivna River

The shivna river in the city is facing serious pollution problems due to increasing urban activities as shown in Figure 32. The main reason for this is the direct discharge of untreated sewage into the river through open drains. Although it historically served as a clean water source and cultural space, rapid urbanization has significantly affected its health and functionality. Since the city does not have a fully developed sewerage system, wastewater from houses flows directly into the river, making the water highly contaminated (Central Pollution Control Board [CPCB], 2021). Apart from sewage, solid waste dumping along the riverbanks is another major issue. People often throw garbage such as plastic, organic waste, and debris near the river, which blocks the flow and worsens the pollution. Religious practices, like throwing flowers and idols into the river, also add to the pollution load (Ministry of Jal Shakti, 2020).

Because of these reasons, the water quality of the river is very poor. It has high levels of pollution indicators like BOD and COD, which show that the water contains a large amount of waste. At the same time, the oxygen level in the water (DO) is very low, which makes it difficult for fish and other aquatic life to survive. The presence of bacteria from sewage also makes the water unsafe for any human use (CPCB, 2021). The pollution is not the same everywhere in the river. The upstream part, before the river enters the city, is relatively cleaner. However, the middle part of the river within the city is the most polluted, as many drains discharge wastewater into it. After the river leaves the city, the downstream section shows slight improvement due to dilution, but the water is still not clean (National River Conservation Directorate [NRCD], 2019).

The condition of the river also changes with seasons. During summer, the water level becomes very low, and pollutants become more concentrated, causing bad smell. During the monsoon, the water flow increases and helps dilute the pollution, but it also brings more dirt and waste from the city. After the monsoon, the condition improves slightly but again becomes worse over time (CPCB, 2021). Another critical problem is encroachment along the riverbanks. Construction activities and informal settlements have reduced the natural width of the river, disturbing its flow and limiting its flood-carrying capacity. Also solid waste dumping along the banks further deteriorates the condition and blocks natural drainage paths.

The river also suffers from seasonal flow variation. During the dry season**,** water levels drop significantly, sometimes leaving stagnant polluted water in stretches of the river. In contrast, during the monsoon, the river receives heavy inflow, which can lead to overflow and localized flooding, especially where the channel is constricted. Overall, the Shivna River is no longer functioning like a natural clean river. Instead, it has become more like a drain carrying wastewater, especially within the city area. This shows the need for proper planning and measures to clean and protect the river.



Figure 32: Condition of Shivna River *Source: (Author,2026)*

The Shivna River constitutes the primary natural water spine of Mandsaur, playing a crucial role in shaping its hydrological, ecological, and cultural framework. Originating from the Malwa plateau, the river traverses the city before joining the Chambal River, forming part of the larger Chambal River Basin. With an approximate length of 102 km, it significantly influences both the urban and peri-urban landscape (NRSC, 2019; Government of Madhya Pradesh, 2023).

From a hydrological perspective, the Shivna River functions as the primary drainage channel, receiving surface runoff from surrounding catchments, particularly during the monsoon season. It also contributes to groundwater recharge through its floodplains and supports nearby wells and bore wells (CGWB, 2020). Additionally, the river supports urban water infrastructure by

feeding key structures such as the Ramghat Barrage and Kalabhata Dam, which are essential for municipal water supply (Mandsaur Municipal Council, 2023). Ecologically, the river sustains riparian vegetation and enhances biodiversity, while also contributing to local microclimate regulation (NRSC, 2019). Culturally, it holds significance due to its association with the Pashupatinath Temple, where ghats and riverbanks are actively used for religious and social activities (Government of Madhya Pradesh, 2023).

However, the river is currently under stress due to encroachment, untreated sewage discharge, reduced base flow during non-monsoon periods, and siltation, which collectively diminish its ecological and functional capacity (CPCB, 2021; CGWB, 2020).

Potential of Shivna River

The Shivna River has significant potential to contribute to Mandsaur's urban water supply if managed effectively. During the monsoon season, the river receives considerable runoff that can be utilized through water storage facilities, groundwater recharge structures, and riverbank infiltration systems. In addition to serving as a surface water source, the river supports groundwater replenishment and helps maintain the water table in surrounding wells and aquifers.

However, its present capacity is constrained by factors such as untreated wastewater discharge, solid waste dumping, encroachment along the riverbanks, and reduced flows during dry seasons. These challenges have affected both the quantity and quality of water available from the river. The adoption of Water Sensitive Urban Development (WSUD) measures, including wastewater treatment, development of riparian buffer zones, ecological restoration of the river corridor, rainwater harvesting, and recharge interventions, can help restore and enhance the river's functionality.

With appropriate conservation and management efforts, the Shivna River can play a vital role in improving water security, reducing dependence on groundwater resources, and supporting the future water needs of Mandsaur city.

4.1.2 Teliya Talaab

Teliya talaab is a large beautiful artificial lake. The area around the lake has developed with nice walking paths and it's a spot for locals to relax. It helps in maintain water level and act as a cooling spot for the area. It is almost critical source for recharging wells, hand pumps etc. making it conservation vital for the city's water security. The lakes cover an area of 120 hectares. The reservoir capacity is approximately 7.7 million cubic feet. The primary source of water is the southwest monsoon rainfall. When it rains, the water falling across its catchment area naturally flows downwards across the terrain, converging into the lake basin. The surface runoff is guided into the lake through a network of natural drainage lines and storm water channels. These channels act as a feeding arteries of the lake during the monsoon months, capturing water from the higher elevations of Mandsaur urban and semi urban fringes and emptying into the reservoir.



Figure 33: Image of Teliya Talaab

Source: (Author,2026)

4.2 Water Quality

The table represents the parameters its limit and city value. From the table it is observed that the PH is within safe range and EC/TDS reaches near permissible limit (2870 µS/cm) which is in high salinity also Hardness is approaching upper acceptable limit and fluoride touches 1.5 mg/L which is critical threshold (CPHEEO Manual, 2024).

Table 17: Water Quality of Mandsaur

Parameter	BIS Acceptable Limit	BIS Permissible Limit	Mandsaur Value (CGWB Mandsaur District Groundwater Report,2013)
pH	6.5 – 8.5	No relaxation	7.16 – 8.25
Electrical Conductivity (EC)	~750 µS/cm	~3000 µS/cm	609 – 2870 µS/cm
TDS	500 mg/L	2000 mg/L	~390 – 1830 mg/L
Total Hardness	200 mg/L	600 mg/L	200 – 500 mg/L (approx.)
Fluoride	1.0 mg/L	1.5 mg/L	0.5 – 1.5 mg/L
Nitrate	45 mg/L	No relaxation	20 – 100+ mg/L
Iron	0.3 mg/L	No relaxation	0.1 – 0.5 mg/L
Residual Chlorine	0.2 mg/L	0.5 mg/L	0 – 0.2 mg/L

Source: (CPHEEO Manual, 2024)

Nitrate exceeds 45 mg/L in many areas it is unsafe. Iron is Slightly above and chlorine is Often below required level results in disinfection issue.

4.3 Other Surface Water Bodies

Apart from the Shivna River, Mandsaur is supported by several other surface water bodies that contribute to the city's water resources. These include water storage structures such as Ramghat Barrage and Kalabhata Dam, as well as traditional ponds and reservoirs located within and around the urban area. Together, these water bodies play an important role in water storage, groundwater recharge, flood management, and ecological conservation. They

supplement the city's water supply system and help maintain hydrological balance, particularly during periods of high-water demand and seasonal variability. Understanding their functions and existing conditions is essential for developing sustainable water management and conservation strategies in Mandsaur.

4.3.1 Ramghat Barrage

The Ramghat Barrage is a key hydraulic structure constructed across the Shivna River to store and regulate water for urban consumption. It ensures a relatively stable water supply and supports groundwater recharge in adjacent areas (Mandsaur Municipal Council, 2023). Such structures play an important role in augmenting urban water availability, particularly in semi-arid regions.

4.3.2 Kalabhata Dam

The Kalabhata Dam serves as a major upstream storage system that supports both domestic and agricultural water requirements. It helps regulate seasonal variations in river discharge and mitigates flood risks by storing excess monsoon runoff (Government of Madhya Pradesh, 2023). The dam also acts as a buffer between rural catchments and urban demand systems.

4.3.3 Local Ponds and Talabs

Examples include the Pashupatinath Pond and Mirzapur Reservoir, which represent traditional decentralized water storage systems within the city.

These water bodies perform multiple critical functions:

- Storage reservoirs: They collect and store rainwater and surface runoff, reducing dependency on centralized supply systems (UN-Habitat, 2018).
- Groundwater recharge zones: Percolation from pond beds contributes to aquifer recharge, supporting local groundwater systems (CGWB, 2020).
- Flood mitigation: They act as retention basins, reducing peak runoff and minimizing urban flooding (CPCB, 2021).
- Ecological support: They sustain aquatic ecosystems and enhance biodiversity (NRSC, 2019).

- Cultural and social value: These ponds serve as spaces for religious and community activities, reinforcing cultural identity (Government of Madhya Pradesh, 2023).

Despite their importance, these water bodies face challenges such as encroachment, pollution, siltation, and inadequate maintenance, leading to reduced efficiency and storage capacity (CPCB, 2021).

4.4 Integrated Surface Water System

The surface water system of Mandsaur functions as an interconnected network linking catchment areas, ponds, drainage channels, the Shivna River, and storage structures like barrages and dams. Ideally, rainfall-generated runoff is first captured by local ponds, conveyed through drainage systems into the river, and regulated through hydraulic infrastructure.

However, rapid urbanization has disrupted this system, resulting in:

- Loss of intermediate storage systems
- Increased surface runoff
- Reduced groundwater recharge
- Direct discharge of pollutants into water bodies (Government of India, 2019; CPCB, 2021).

4.5 Overhead Tank

The spatial analysis of OHT locations and their 400 m buffers overlaid on ward density shown in Figure 32 shows that high-density wards 18, 19, 20, 23, 24, 28, 29, and 31 are concentrated in the south-central part of the city, particularly along the Shivna river corridor. Although multiple OHTs are present nearby, the buffer coverage in these wards is partial and overlapping rather than uniformly distributed. Central wards such as 10, 11, 12, 13, 15, 16, and 17 exhibit relatively better coverage with moderate density. In contrast, peripheral wards including 1, 3, 4, 5, 21, 22, 26, 33, 35, 36, 37, 38, 39, and 40 fall largely outside the effective service radius, indicating limited accessibility to water supply infrastructure.

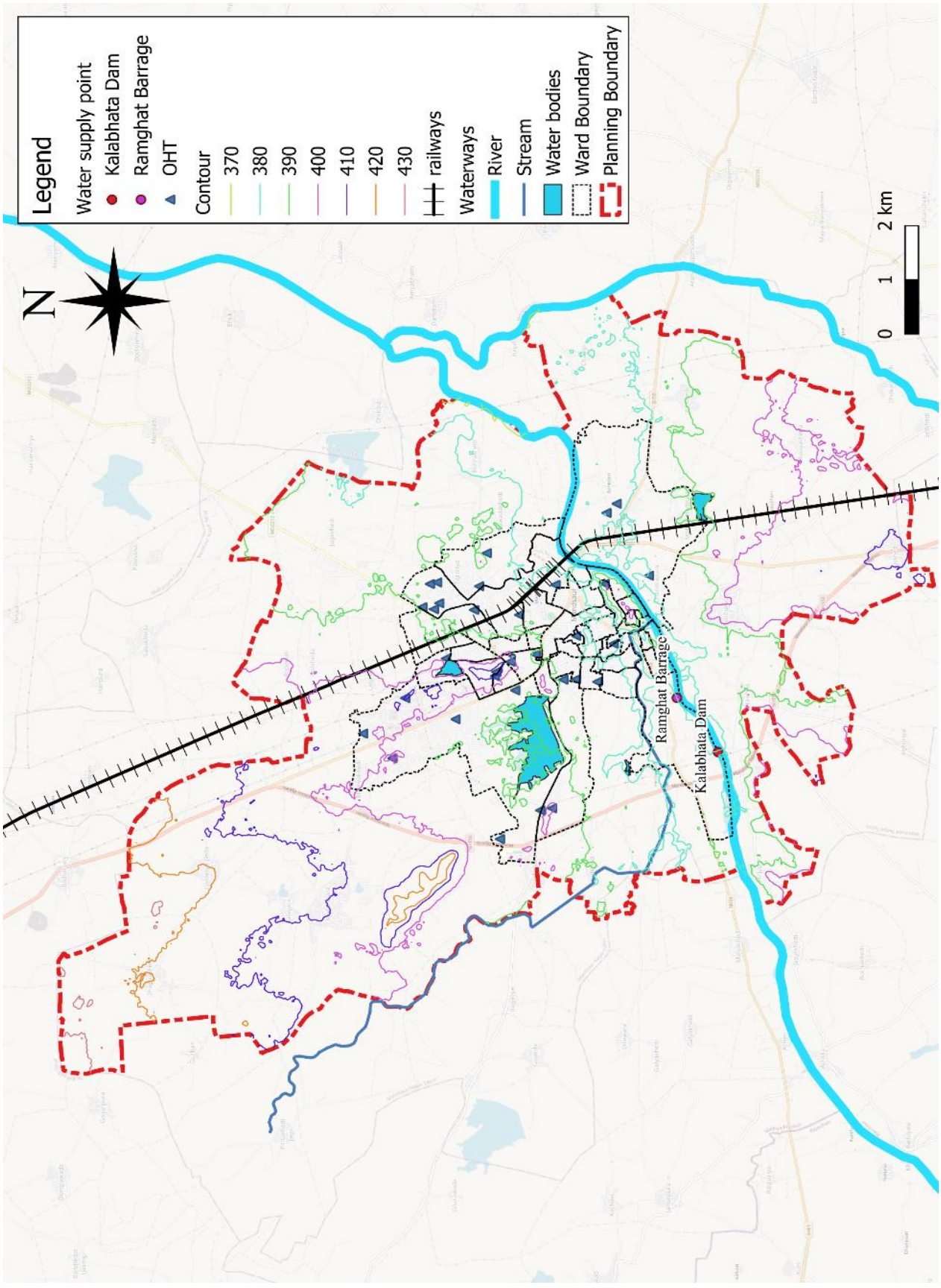


Figure 34: Location of OHT, STP and Raw Water Source (2025) and OpenStreetMap (2025)

Source: Compiled by the Author using Survey of India

Table 18 presents the details of the 17 Overhead Tanks (OHTs) in Mandsaur, including their storage capacities and staging heights. These OHTs form an important part of the city's water distribution system by ensuring adequate water storage and maintaining the required pressure for water supply across different service areas.

Table 18: Details of OHTs

S.No	Location	Capacity (KL)	Staging Ht. (m)
1.0	Ramghat SR	900	18
2.0	Ram Tekri	750	12
3.0	Sanjay Gandhi Udyan	900	18
4.0	Kityani	900	15
5.0	Dashrath Nagar	450	18
6.0	Balaganj	450	15
7.0	Janakpura	450	15
8.0	Gandhi Nagar	450	15
9.0	Meghdoot Nagar	450	15
10.0	Ridhyanand Nagar (500)	450	15
11.0	Abhinandan Nagar	450	18
12.0	New Abhinandan Nagar	450	18
13.0	Baser Colony	450	18
14.0	Kityani	1100	15
15.0	Narsinghpura	700	15
16.0	Kila	2600	15
17.0	Chandrapura	150	15
	Total	**12950 KL**	

Source: (Water Supply Audit Report, 2015)

The distribution of overhead tanks (OHTs) in Mandsaur city, including their location, storage capacity, and staging height. The total storage capacity of all tanks is about 12,950 KL. The largest tank is located at Kila with a capacity of 2600 KL, which acts as a major storage and distribution point. Several medium-capacity tanks, such as Ramghat SR, Sanjay Gandhi Udyan, and Kityani, have capacities between 900 and 1100 KL, while most of the other tanks have a capacity of 450 KL, indicating a decentralized water distribution system. The staging height of tanks ranges from 12 to 18 meters, which helps in maintaining adequate water pressure across different areas. Overall, the system shows a combination of centralized and distributed storage, but variation in capacity and location may lead to unequal water supply in some wards.

Problem Identification:

The below figure highlights inefficiency in water supply distribution. High-density wards (18, 19, 20, 23, 24, 28, 29, 31) face inadequate service coverage despite proximity to OHTs, leading to potential low pressure and unreliable supply due to high demand. Whereas central wards (10–17) show overlapping buffers, indicating inefficient placement of infrastructure. Meanwhile, peripheral wards (1, 3, 4, 5, 21, 22, 26, 33, 35–40) remain underserved, revealing a gap between infrastructure provision and urban expansion. This reflects a centralized system that is not aligned with population density and future growth patterns.

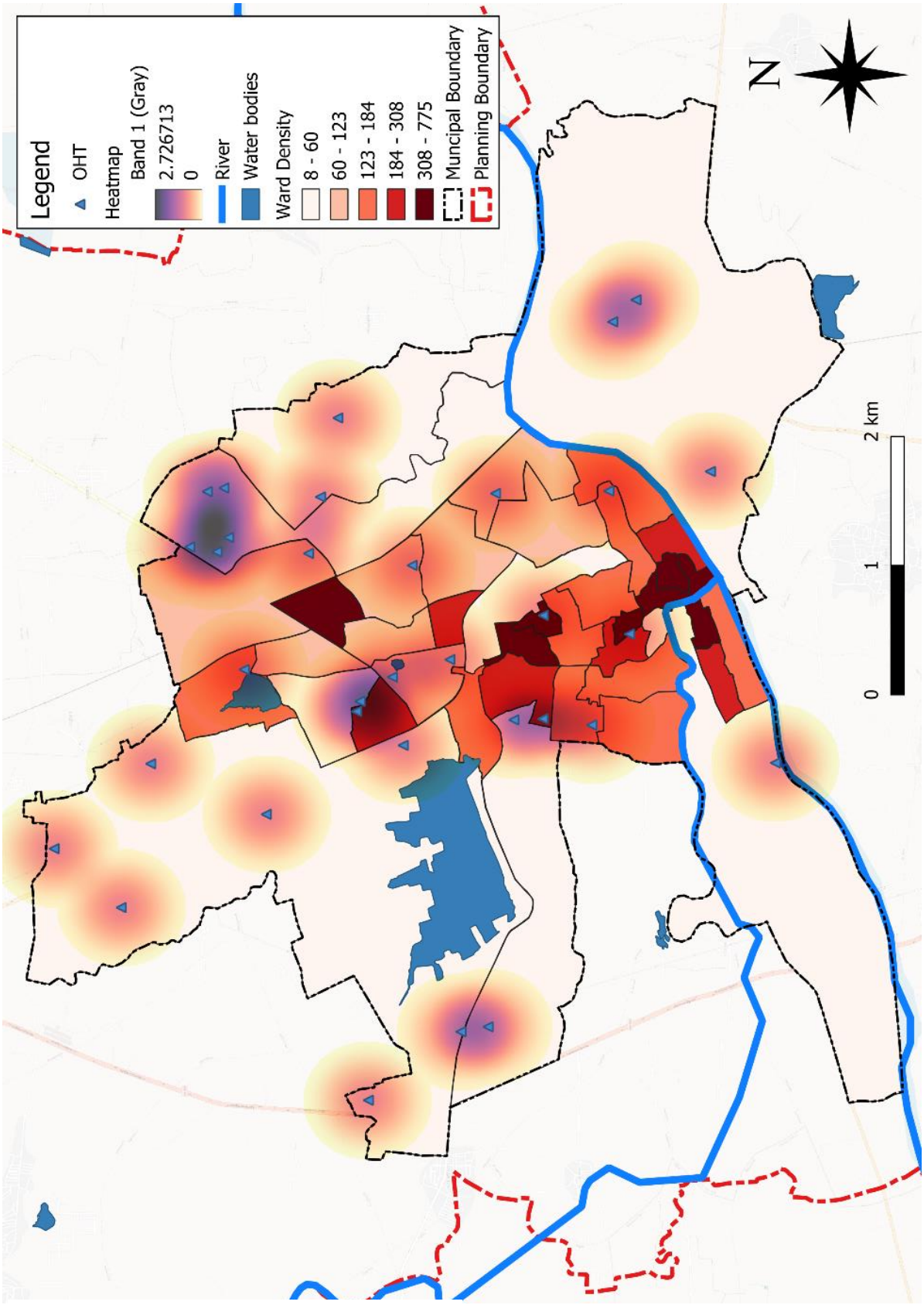


Figure 35: Density Map with OHTs Overlay *Source: Compiled by the Author using Survey of India (2025) and OpenStreetMap (2025)*

4.6 Water Supply Network

In Mandsaur, approximately 67.1% of households are connected to piped water supply receiving treated water, indicating a significant reliance on the formal municipal distribution system (Census,2011). However, only 4.6% of households depend on piped water from untreated sources, reflecting limited but critical gaps in water treatment and supply infrastructure (Census,2011). The remaining population relies on non-piped sources such as hand pumps, tube wells, and other alternative arrangements, highlighting a continued dependence on decentralized and often unregulated water sources.

This distribution pattern indicates that while a majority of the population has access to treated piped water, a considerable proportion still depends on non-piped and potentially unsafe sources, emphasizing the need for improved coverage, treatment, and equitable distribution within the urban water supply system.

In Mandsaur, the piped water supply system is primarily sourced from treated surface water, mainly obtained through regional supply schemes associated with the Gandhi Sagar Dam. Water is conveyed from the reservoir to treatment facilities, where it is processed before being stored in overhead tanks and distributed to households through the pipeline network.

In addition to this, groundwater sources such as tube wells and bore wells are used as supplementary inputs in certain areas, particularly where the main network is insufficient or demand is higher. These sources support the overall system but do not constitute the primary supply. Overall, the piped network in Mandsaur is largely dependent on treated surface water, with limited reliance on groundwater to bridge supply gaps.

The Shivna River flows through the urban area of Mandsaur and forms an important component of the city's natural hydrological system. However, it is not currently utilized as a primary source of piped drinking water due to concerns related to pollution and deteriorating water quality (Central Pollution Control Board, 2021). As a result, the city relies more on treated surface water from regional schemes and groundwater sources for its potable water needs.

At present, the river mainly functions as a storm water drainage channel and a receiver of urban runoff and wastewater discharge. The inflow of untreated sewage and solid waste has significantly degraded its water quality, making it unsuitable for direct consumption without adequate treatment (Ministry of Jal Shakti, 2020). Despite this, the river continues to play a crucial role in maintaining the city's drainage system by carrying excess runoff, especially during the monsoon season.

Even though it is not directly used for water supply, the river holds considerable environmental and hydrological significance. It contributes to groundwater recharge (historically), supports surrounding ecosystems, and acts as a natural drainage pathway within the urban fabric (Central Ground Water Board, 2019). However, its potential is constrained by issues such as encroachments along riverbanks, reduced flow during non-monsoon periods, and continuous pollution loads, which limit its effectiveness as a sustainable water resource (CPCB, 2021).

From a Water Sensitive Urban Design (WSUD) perspective, the Shivna River presents significant opportunities for conservation and revival. Through appropriate interventions such as pollution control, restoration of natural channels, and integration with urban storm water management systems, the river can be transformed into a valuable urban asset. This would not only enhance groundwater recharge and ecological health but also contribute to flood mitigation and sustainable water management in Mandsaur (UN-Habitat, 2018).

Below map shows the water supply network in the city with the location of WTP and raw water source location and OHTs. It is observed that WTP is in 390m whereas the city highest point is around 400m means pressure is being applied to supply to that elevated points OHTs and from that OHTs gravity is used to supply water.

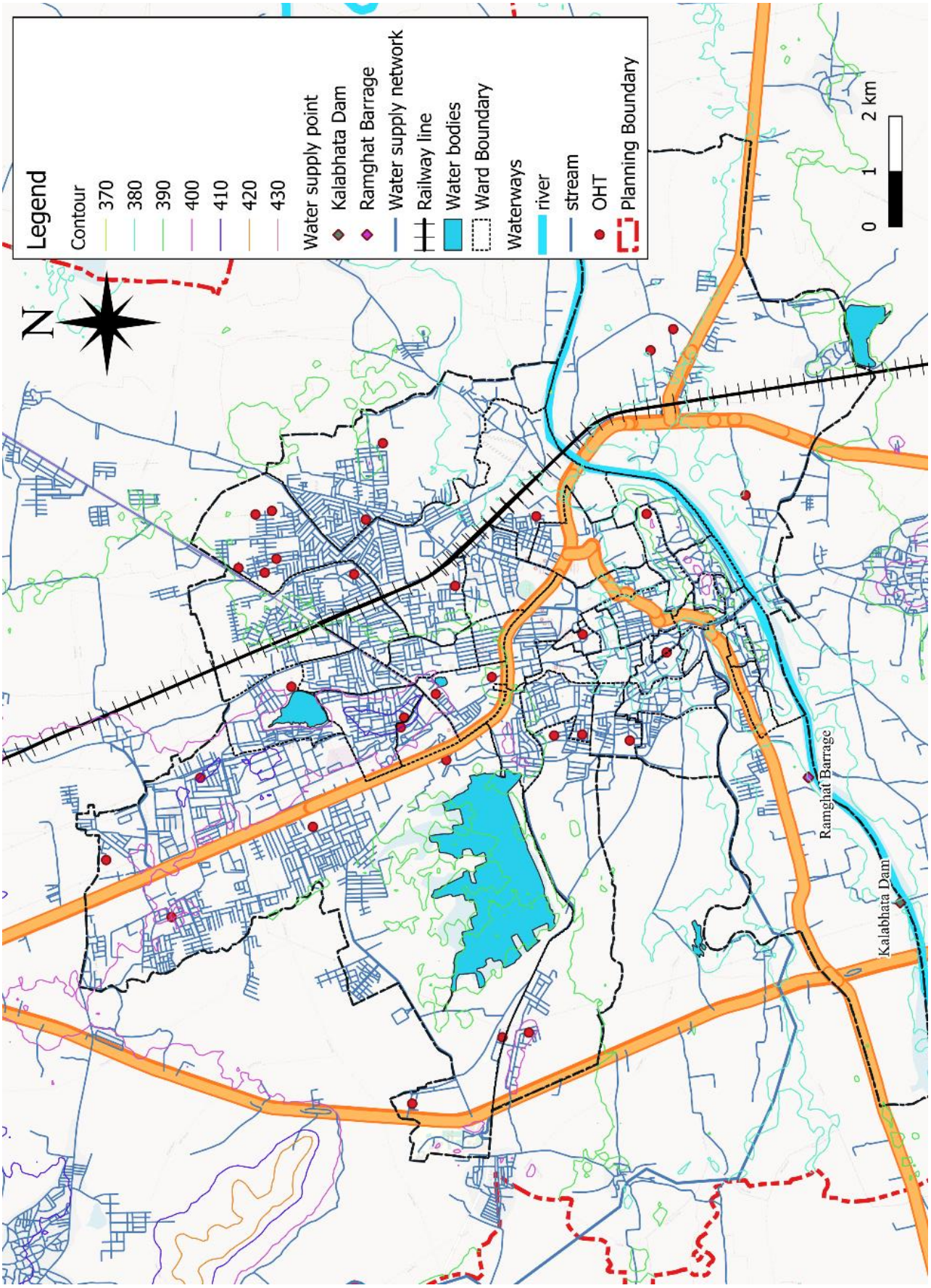


Figure 36: Water Supply Network of Mandsaur *Source: Compiled by the Author using OpenStreetMap (2025)*

4.7 Other sources

The other sources of water bodies such as well and hand pumps also examined for the city. These wells and hand pumps are also considered and used for drinking purpose in some wards, especially in peri urban areas the dependency is more on wells rather than supply network, thus their location is identified for analysis and further proposals will be given accordingly.

4.7.1 Well

Below map shows the location of wells inside the planning area. The map shows a dense distribution of blue dots (well locations) across the planning area of Mandsaur, with noticeable clustering in the central and southern parts, especially along the vicinity of the Shivna River and the low-lying green/yellow elevation zones. Less no. of wells is visible in the higher elevation north-western and peripheral orange-red zones, indicating lower groundwater accessibility or dependence in those areas. The wells appear more concentrated in built-up and agricultural interface zones rather than uniformly distributed.

Problem identification

The uneven spatial distribution suggests strong dependency on localized groundwater pockets, which may be over-exploited in high-density well clusters. Areas with sparse wells (higher elevation zones) likely face limited groundwater access or lower yield aquifers. This imbalance can lead to groundwater stress in central zones, declining water tables, and seasonal scarcity, especially where population density overlaps with high well concentration. It also indicates a lack of integrated planning for equitable groundwater recharge and distribution.

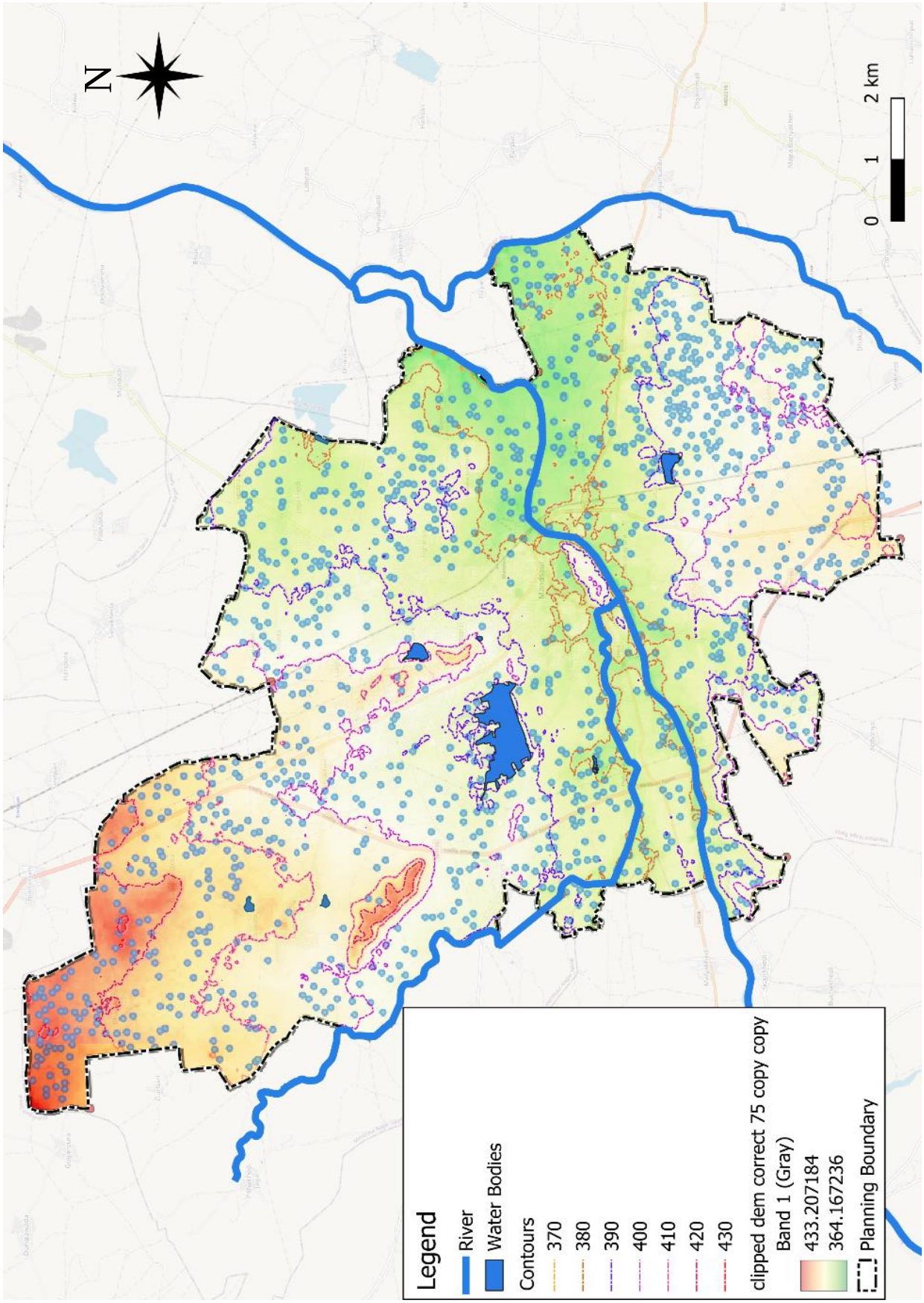


Figure 37: Well Locations *Source: Compiled by the Author using Bhoonidhi DEM (2023) and MP GIS Portal (2025)*

4.7.2 Hand Pumps

Figure 38 shows hand pump locations with buffer influence zones overlaid with a groundwater dependency heat map and planning boundary. The spatial pattern highlights where groundwater demand is concentrated and how service accessibility is distributed.

It is observed the hand pump locations are not evenly distributed across the planning area. A higher clustering is visible in the central and south-eastern parts of the city, which also correspond with higher heat map intensity zones (red–purple hotspots) indicating strong groundwater dependency. The buffer zones around hand pumps overlap significantly in these dense areas, suggesting relatively better access locally but also higher stress on limited sources. In contrast, the outer peripheral areas within the planning boundary show sparse or no buffer coverage, indicating poor service reach. The proximity of some hotspots to the river corridor also suggests indirect groundwater dependence near surface water interaction zones.

Problem Identification

The main issue highlighted is unequal spatial distribution of hand pump infrastructure, leading to over-dependence on a few clustered groundwater points. Areas outside buffer influence are likely facing limited access to potable groundwater sources, increasing travel distance and reliance pressure on existing hand pumps. The presence of multiple hotspots within overlapping buffers also indicates localized over-extraction risk, which may lead to declining groundwater levels, seasonal failure of hand pumps, and reduced sustainability of supply.

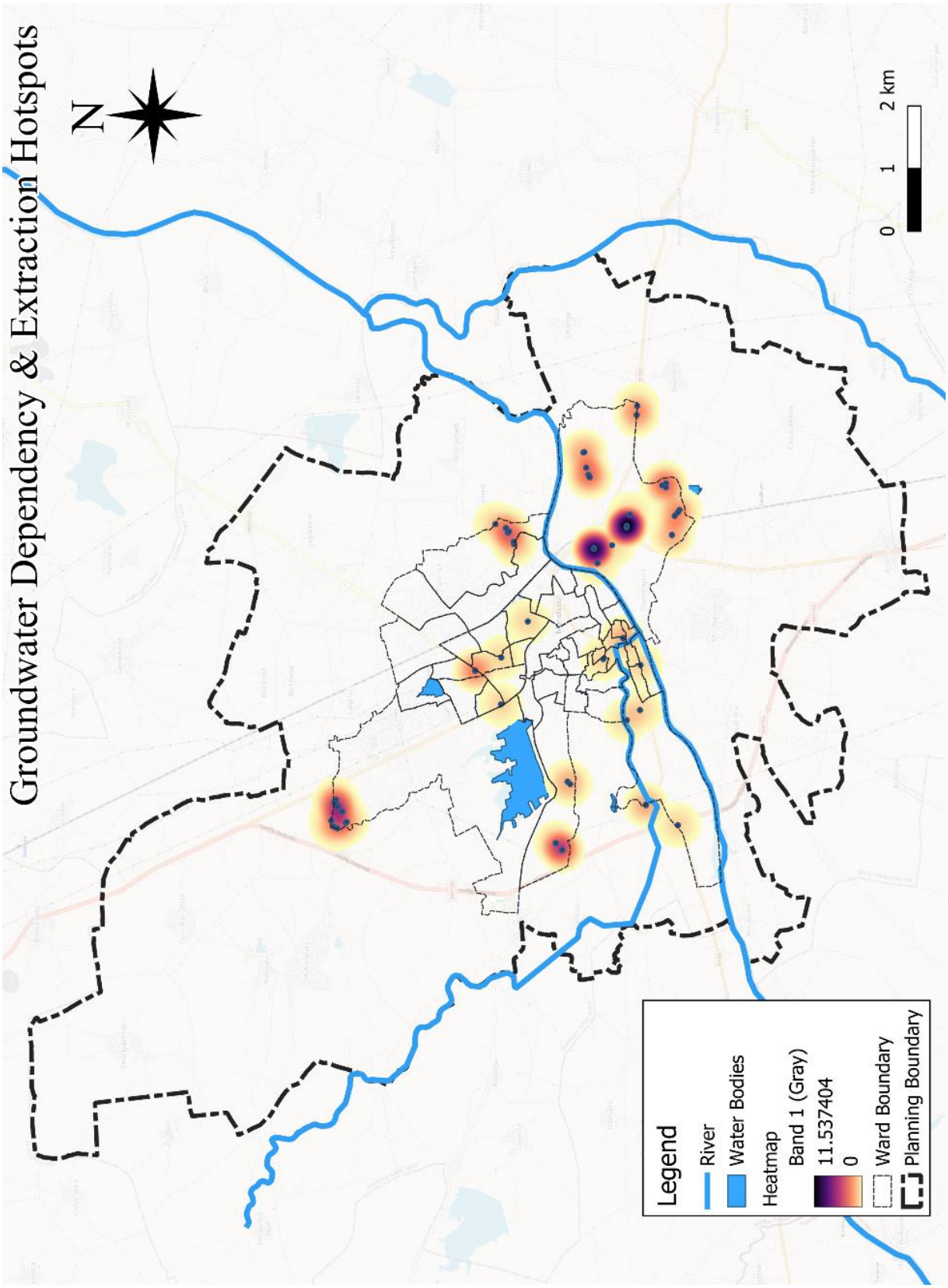


Figure 38: Ground Water Dependency and Extraction Hotspots *Source: Compiled by the Author using Survey of India (2025) and OpenStreetMap (2025)*

4.8 Existing Water Management Initiatives in Mandsaur

Mandsaur has initiated several water managements projects under AMRUT 2.0, including the rejuvenation of Teliya Talab, augmentation of water supply infrastructure, and development of an integrated sewerage system, these interventions primarily focus on conventional urban water infrastructure. A comprehensive Water Sensitive Urban Development (WSUD) framework integrating source-based stormwater management, green infrastructure, decentralized groundwater recharge, and nature-based solutions has not yet been implemented in the city. Therefore, there is significant potential to incorporate WSUD practices such as bioswales, rain gardens, permeable pavements, constructed wetlands, and riparian buffer zones into future planning proposals to enhance water security, improve water quality, and increase urban resilience

4.9 Land use

The land use distribution in Mandsaur city represents in table 19. Residential land use occupies the largest share, covering 395 hectares, which is about 52.46 percent of the total area, indicating that the city is mainly residential in nature. Transport and communication take up 17.26 percent of the land, showing the importance of road networks and connectivity. Commercial and industrial uses account for 11.29 percent and 7.97 percent respectively, reflecting moderate economic activity in the city. Public and semi-public land uses cover 8.10 percent, including facilities such as schools, hospitals, and government buildings. However, recreational land use is very limited at only 2.92 percent, indicating a lack of open and green spaces. Overall, the land use pattern shows a dominance of residential areas with relatively lower provision for recreation, which has implications for urban planning and quality of life.

Table 19: Land Use 2001

S. No.	Land Use Category	Area (Hectares)	Percentage (%)	Land Use Intensity (Hectares / 1000 Population)
1	Residential	395.00	52.46	3.04
2	Commercial	85.00	11.29	0.65
3	Industrial	60.00	7.97	0.46

4	Public & Semi-Public	61.00	8.10	0.47
5	Recreation	22.00	2.92	0.17
6	Transport & Communication	130.00	17.26	1.00
	Total	**753.00**	**100.00**	**5.79**

Source: *Based on Urban and Rural Investment Survey, 2001*

Sector-wise Water Demand Distribution

This distribution is prepared in accordance with the CPHEEO Manual on Water Supply and Treatment (MoHUA)**,** which recommends that urban water demand be categorized into domestic and non-domestic uses, with domestic consumption forming the dominant share (approximately 70–80%), while the remaining demand is distributed among commercial, institutional, industrial, and public/semi-public uses based on the character of the urban area.

Based on CPHEEO norms and urban planning standards:

Table 20: Sector Wise Water Demand Distribution

Sector	% Share		CPHEEO % (adopted)	Demand (MLD)	Description
Domestic	70–75%		72%	10.8 MLD	Household use (drinking, cooking, bathing)
Commercial	5–10%		8%	1.2 MLD	Shops, markets, hotels
Institutional	5–10%		7%	1.05 MLD	Schools, hospitals, govt buildings
Industrial	5–10%		8%	1.2 MLD	Small-scale industries

Public & Semi-public	5%		5%	0.75 MLD	Parks, street washing, firefighting
Total			100%	15.0 MLD	

Source: (CPHEEO, 2019)

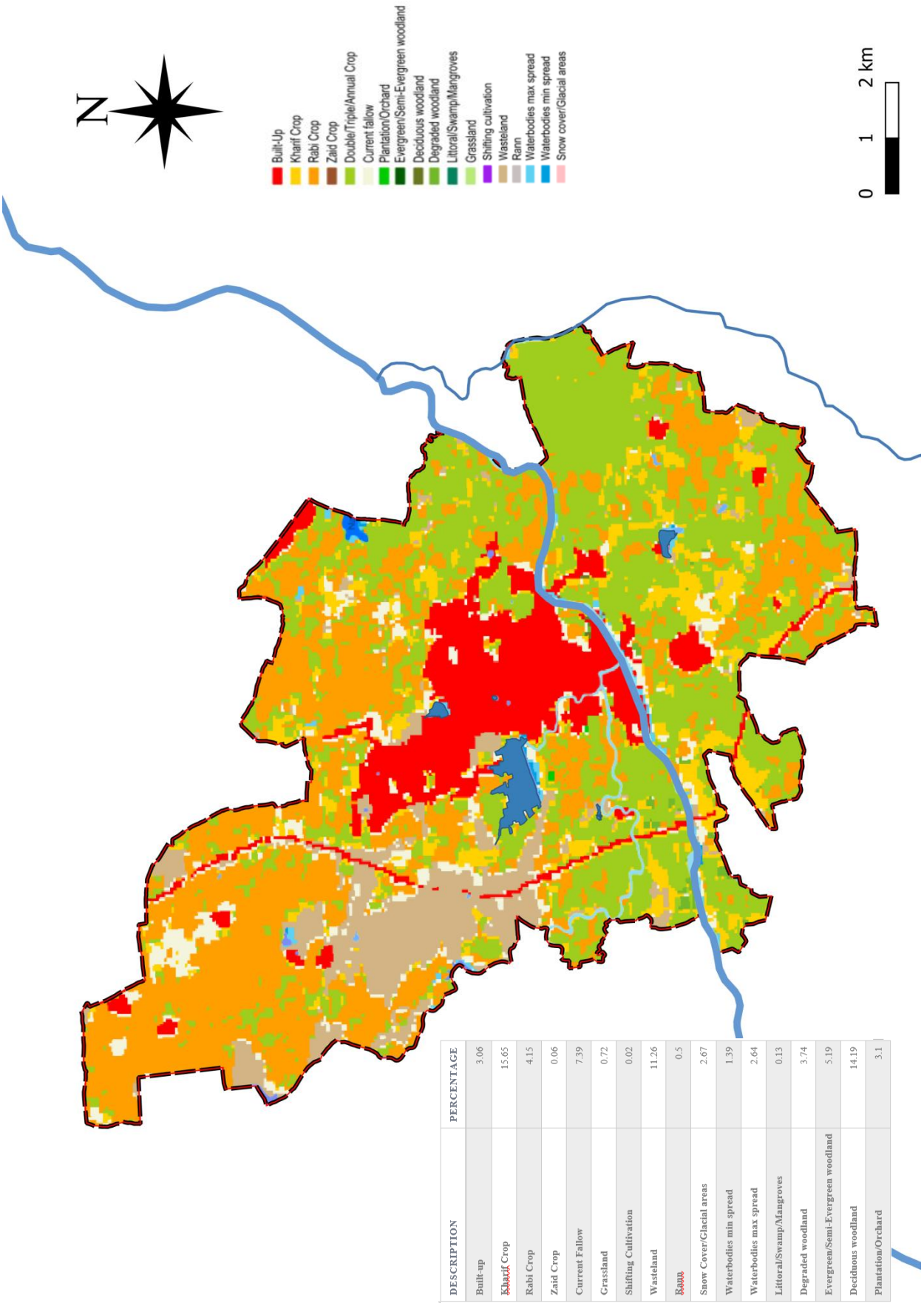
The projected water demand for Mandsaur city in 2041 is estimated to be 44 MLD refer section 4.10. The sector-wise distribution shows that domestic demand will continue to dominate, accounting for about 70 percent (30.8 MLD) of the total demand. Commercial and industrial sectors contribute around 8 percent each, reflecting increasing economic activities, while institutional and public uses account for 7 percent each due to expansion of urban services. This rising demand highlights the need for sustainable water management strategies, including efficient supply systems, wastewater reuse, and conservation of water bodies to meet future requirements.

Table 21: Sector Wise Water Demand Distribution 2041

Sector	% Share (CPHEEO)	Future Demand (MLD)
Residential	70%	30.8 MLD
Commercial	8%	3.5 MLD
Institutional	7%	3.1 MLD
Industrial	8%	3.5 MLD
Public & Semi-public	7%	3.1 MLD
Total	100%	44 MLD

Source: (Author, 2026)

The LULC map (2020) as shown in figure 39 highlights a dense built-up core surrounded by agricultural and vegetated land. The concentration of impervious surfaces in the central region increases surface runoff and reduces groundwater recharge, while peripheral zones offer significant potential for infiltration-based WSUD interventions.



DESCRIPTION	PERCENTAGE
Built-up	3.06
Kharif Crop	15.65
Rabi Crop	4.15
Zaid Crop	0.06
Current Fallow	7.39
Grassland	0.72
Shifting Cultivation	0.02
Wasteland	11.26
Rann	0.5
Snow Cover/Glacial areas	2.67
Waterbodies min spread	1.39
Waterbodies max spread	2.64
Littoral/Swamp/Mangroves	0.13
Degraded woodland	3.74
Evergreen/Semi-Evergreen woodland	5.19
Deciduous woodland	14.19
Plantation/Orchard	3.1

Figure 39: LU/LC Map 2020 *Source: Compiled by the Author using Bhuvan (2020)*

4.9 Population Projection

The table indicates a consistent increase in the population of Mandsaur from 34,541 in 1951 to 1,76,835 in 2011. The city experienced an average decadal increase of 23,716 persons and an average growth rate of 31.68%. The highest growth was recorded during 2001–2011, when the population increased by 59,280 persons, reflecting rapid urbanization and demographic expansion. This continuous growth highlights the increasing demand for urban infrastructure, water resources, and public services, emphasizing the need for conservation and revival of water bodies.

Table 22: Population Projection

S. No.	Year	Population	Decadal Increase (X)	Incremental Increase (Y)	Decadal Growth Rate (r) (%)
1	1951	34,541	—	—	—
2	1961	41,876	7,335	—	21.24%
3	1971	56,988	15,112	7,777	36.09%
4	1981	77,603	20,615	5,503	36.17%
5	1991	95,907	18,304	2,311	23.59%
6	2001	1,17,555	21,648	3,344	22.57%
7	2011	1,76,835	59,280	37,632	50.43%
Average			**23,716**	**10,389**	**31.68%**

Source: (Census,2011)

Mandsaur city has 28916 total households.

Population is projected using incremental method. The Formula used for Incremental Increase Method is:

$Pn=Po+nx+(n(n+1)/2)\ Y$

Estimated Population

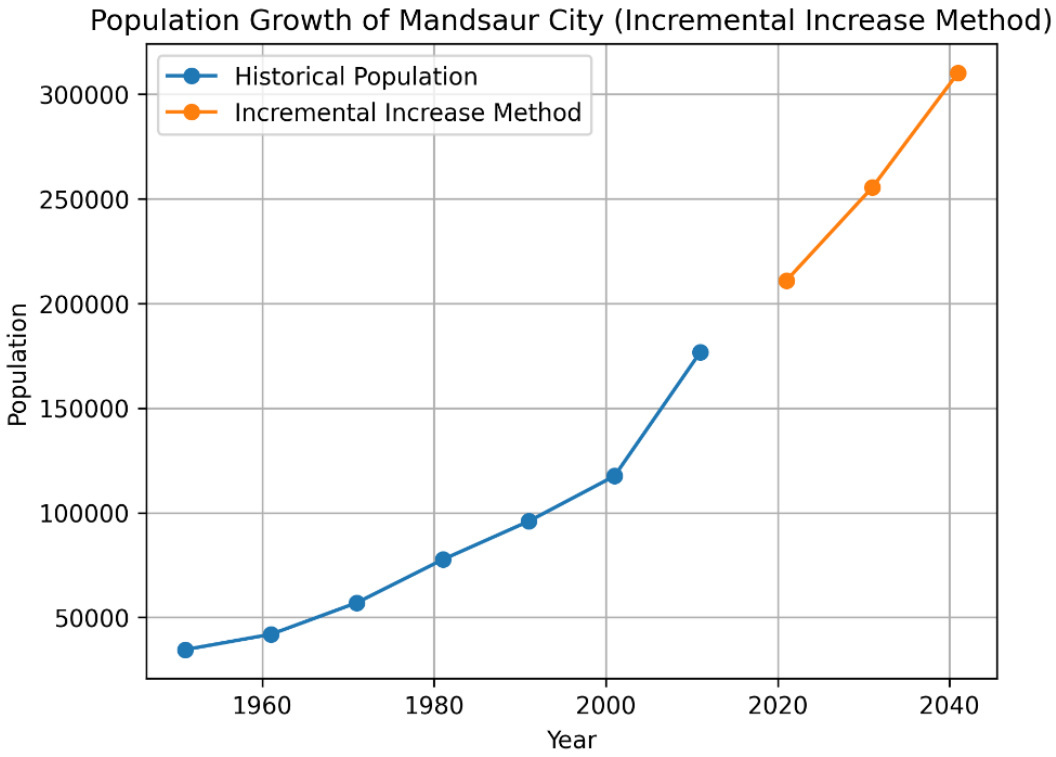
As per the calculation the city population in 2041 will be 310,317. Which is more than twice as compared to the population of 2011.

Table 23: Estimated Population for 2021,2031 and 2041

S. No.	Year	Incremental Increase Method
1	2021	210,940
2	2031	255,434
3	2041	310,317

Source: (Author,2026)

The graph indicates that Mandsaur city is expected to experience accelerated population growth in the coming decades. Using the Incremental Increase Method, the projected population for 2041 is estimated to reach approximately 3.0–3.1 lakh, reflecting increasing urbanization and expansion trends.



Source: (Author,2026)

4.10 Ward Ranking and Indicators

As per census 2011 population is 141667, calculating population % distribution ward wise, no. of household, population density and its comparison with 2001 ward wise population. This table presents a ward-wise demographic profile of the city showing population distribution,

number of households, population density (person per hectare), growth trend compared to 2001, and share in total population for each ward. It helps in identifying spatial variations in urban density and development, where some wards show very high density and rapid growth while others remain low density or stable. The data is useful for urban planning as it highlights pressure zones and expansion areas, which can guide infrastructure provision such as water supply, sanitation, and other basic services at the ward level for Mandsaur.

Table 24: Ward-Wise Demographic and Population Density Analysis (2011 Census) % for Water Demand Calculation

Ward No.	Population 2011(Census)	% of Total Population	No. of household	Population density Person/ha	Increased in population from 2001	2001 Population(Census)
1	2,840	2.01%	626	55	No	8120
2	7,361	5.20%	1600	184	No	6720
3	7,129	5.03%	1497	375	Yes	3717
4	5,746	4.06%	1192	61	Yes	3338
5	6,813	4.81%	1463	44	Yes	3335
6	3,519	2.48%	721	121	Yes	3076
7	2,025	1.43%	403	107	No	2329
8	2,284	1.61%	477	85	Yes	3608
9	2,087	1.47%	429	209	No	2325
10	2,844	2.01%	621	77	Yes	1679
11	4,012	2.83%	817	111	Yes	1796
12	2,769	1.95%	642	71	No	3408
13	2,097	1.48%	398	51	Yes	2113
14	2,416	1.71%	497	115	Yes	2894
15	3,102	2.19%	520	310	No	1823

16	3,875	2.74%	814	775	Yes	2917
17	2,940	2.08%	593	184	No	3039
18	2,701	1.91%	502	150	Same	2254
19	2,519	1.78%	576	252	No	2578
20	2,138	1.51%	445	534	Same	1789
21	1,936	1.37%	418	13	Yes	2001
22	2,412	1.70%	477	15	Yes	1963
23	2,852	2.01%	562	182	Yes	2128
24	3,981	2.81%	800	153	No	3745
25	3,399	2.40%	684	307	Yes	1860
26	3,922	2.77%	773	8	Yes	1755
27	2,568	1.81%	499	525	Yes	2040
28	3,264	2.30%	648	611	Yes	1929
29	2,349	1.66%	455	384	No	2125
30	3,237	2.29%	609	158	Yes	2102
31	3,290	2.32%	666	539	Yes	2165
32	2,722	1.92%	550	256	No	2937
33	4,104	2.90%	764	15	No	3615
34	4,197	2.96%	698	184	Yes	3052
35	4,725	3.34%	907	149	No	4786
36	3,298	2.33%	569	182	No	3714
37	6,016	4.25%	1233	261	Yes	3743
38	2,479	1.75%	538	124	No	4458
39	5,315	3.75%	1254	7.8	Yes	3529
40	4,384	3.09%	979	264	Yes	1050

Source: (Primary survey, 2026)

The total population of the city in 2001 was 1,17,555. As per the ward-wise distribution, the highest population concentration is observed in Wards 2, 3, 5, 37, and 39, while Wards 7, 9, and 21 represent the lowest population areas. The city has a total of 25,145 water supply connections distributed across all 40 wards, indicating the existing service coverage pattern and its relation to population distribution.

Future Water Demand

Calculating the water demand for water (2011)

1,41,667x80x1.8 =20.4 ML per capita per day

The municipal body supplies water at the rate of 60 litres per capita per day (as per standards its should be 80 LPCD multiplying with the factor 1.8 for medium town city)

Actual Supply:

141,667×60=8.4 MLD

Water Deficit:

20.4−8.4=12 MLD

City faces a significant deficit of ~12 MLD

This indicates water stress condition and use of tankers

Calculation for tankers:

If using 5,000 L tanker

12,000,000/5,000=2420 tankers/day (5000L tank price 600 rs =30 lakhs)

step 1: Number of tankers required

12,100,000/5,000=2420 tankers/day

Step 2: Total daily cost

2420×600=₹1,452,000 per day

Step 3: Monthly cost

1,452,000×30=₹43,560,000

4.35 crore per month

This is extremely expensive and unsustainable which indicates heavy financial burden, inefficiency of tanker based supply and need for infrastructure improvement. Even if revival lasts 15–20 years, cost analysis shows:

- Tankers (₹52 crores/year × 15 years) = ₹784 crore
- Revival (₹10–20 crore one-time) = much cheaper

4.11 Ward Details

Parameters are given to decide the ward which are lacking in water facilities. This tables will provide an idea of all 40 wards and their condition related to water.

Table 25: Parameters and Indicators for Ward 1 to 4

S.no	Parameters	**Ward 1**	**Ward 2**	**Ward 3**	**Ward 4**
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network Covered well hand pump	Majorly depend upon other sources like well, handpumps etc	Majorly depend upon other sources like well, handpumps etc	Majorly depend upon other sources like well, handpumps etc
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	Yes	No
4	Presence of water bodies in the ward	No	Yes	No	No

5	Current status (dry, encroached, polluted)	-	No	-	-
6	Pipeline coverage in %	94.5	12	35.3	9.5
7	Slum presence	No	No	Yes	Yes

Source: (Primary survey, 2026)

Table 26: Parameters and Indicators for Ward 5 to 8

S.no	Parameters	**Ward 5**	**Ward 6**	**Ward 7**	**Ward 8**
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Wells, handpumps and few dependency on Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No
4	Presence of water bodies in the ward	No	No	No	Yes
5	Current status (dry, encroached, polluted)	-	-	-	Polluted, odour
6	Pipeline coverage in %	25	74.4	91.5	100%
7	Slum presence	No	Yes	Yes	No

Source: (Primary survey, 2026)

Table 27: Parameters and Indicators for Ward 9 to 12

S.no	Parameters	Ward 9	Ward 10	Ward 11	Ward 12
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	Yes in summers	No
4	Presence of water bodies in the ward	-	No One well present And other hand pumps 3	-	-
5	Current status (dry, encroached, polluted)	-	Polluted , all hand pumps are in working stage	-	-
6	Pipeline coverage in %	86.3	88.4 %	92	85.8
7	Slum presence	No	No	Yes	No

Source: (Primary survey, 2026)

Table 28: Parameters and Indicators for Ward 13 to 16

	Parameters	Ward 13	Ward 14	Ward 15	Ward 16
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network and other sources.	Piped network	Piped network

2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No
4	Presence of water bodies in the ward	No	No	No	No
5	Current status (dry, encroached, polluted)	-	-	-	-
6	Pipeline coverage in %	88.5	69.8	70.5	85.8
7	Slum presence	No	No	No	No

Source: (Primary survey, 2026)

Table 29: Parameters and Indicators for Ward 17 to 20

S.no	Parameters	**Ward 17**	**Ward 18**	**Ward 19**	**Ward 20**
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No
4	Presence of water bodies in the ward	No	No	No	No

5	Current status (dry, encroached, polluted)	-	-	-	-
7	Pipeline coverage in %	88.1	96.7	92.2	79.4
8	Slum presence	No	No	No	Yes

Source: (Primary survey, 2026)

Table 30: Parameters and Indicators for Ward 21 to 24

S.no	Parameters	**Ward 21**	**Ward 22**	**Ward 23**	**Ward 24**
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No
4	Presence of water bodies in the ward	No	No	No	Yes
5	Current status (dry, encroached, polluted)	-	-	-	-
6	Pipeline coverage in %	81.6	57.4	89.2	74.4
7	Slum presence	No	No	No	No

Source: (Primary survey, 2026)

Table 31: Parameters and Indicators for Ward 25 to 28

S.no	Parameters	Ward 25	Ward 26	Ward 27	Ward 28
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No
4	Presence of water bodies in the ward	Yes	Yes	Yes	No
5	Current status (dry, encroached, polluted)	-	Polluted	-	-
6	Pipeline coverage in %	87.3	33.7	91	85.3
7	Slum presence		No		

Source: (Primary survey, 2026)

Table 32: Parameters and Indicators for Ward 29 to 32

S.no	Parameters	Ward 29	Ward 30	Ward 31	Ward 32
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No

4	Presence of water bodies in the ward	No	Yes	No	No
5	Current status (dry, encroached, polluted)	-	-	-	-
7	Pipeline coverage in %	92.5	88.3%	86.9	98.5
8	Slum presence	No	Yes	Yes	No

Source: (Primary survey, 2026)

Table 33: Parameters and Indicators for Ward 33 to 36

S.no	Parameters	**Ward 33**	**Ward 34**	**Ward 35**	**Ward 36**
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network and other sources	Piped network	Piped network	Piped network and other sources
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	No	No	No	No
4	Presence of water bodies in the ward	Yes	No	No	No
5	Current status (dry, encroached, polluted)	-	-	-	-
6	Pipeline coverage in %	61.5	84.6%	73.9	61.1
7	Slum presence	No	Yes	No	No

Source: (Primary survey, 2026)

Table 34: Parameters and Indicators for Ward 37 to 40

S.no	Parameters	Ward 37	Ward 38	Ward 39	Ward 40
1	Source of drinking water (well, bore wells, hand pumps, piped networks)	Piped network	Piped network	Piped network	Piped network
2	Supply frequency (daily/alternate etc.)	Alternate	Alternate	Alternate	Alternate
3	Dependency on tankers	Yes	No	No	yes
4	Presence of water bodies in the ward	No	No	Yes	No
5	Current status (dry, encroached, polluted)	-	-	Polluted encroached	-
6	Pipeline coverage in %	59.2%	86.2%	44.6	77.4
7	Slum presence	No	No	Yes	No

Source: (Primary survey, 2026)

A primary field survey was conducted to assess the existing water supply conditions in all 40 wards of Mandsaur. The assessment was carried out using selected parameters, including source of drinking water, water supply frequency, dependency on tankers, presence and condition of water bodies, pipeline coverage, and the presence of slum areas. These indicators help identify wards with inadequate water infrastructure and support the prioritization of WSUD interventions. The following tables present the ward-wise assessment of these parameters.

The ward-level analysis reveals that although Mandsaur has a city-wide piped water supply system, significant disparities exist in pipeline coverage, access to local water resources, and service reliability. Wards with low pipeline coverage, tanker dependency, slum presence, and degraded water bodies are more vulnerable to water stress and should be prioritized for future water management and infrastructure interventions

4.12 Findings

The analysis carried out in this chapter provides a detailed assessment of the existing water management scenario in Mandsaur City. The condition assessment of ponds, wells, hand pumps, drainage networks, and the Shivna River indicates that many traditional water bodies have been affected by encroachment, pollution, siltation, and lack of maintenance. Population projection and future water demand estimation further highlight the need for water management strategies to ensure long-term water security. The analysis identifies the critical issues and priority areas requiring intervention and forms the basis for developing appropriate WSUD-based planning proposals for the conservation and revival of urban water bodies.

CHAPTER 5-PROPOSALS

5.0 Introduction

This chapter presents the proposals developed for the conservation and revival of water bodies in Mandsaur city. The proposals are based on the findings from the previous chapters, including the analysis of water bodies, water supply systems, groundwater conditions, drainage patterns, land use, and future water demand. The study identified several issues such as declining groundwater levels, pollution of water bodies, encroachment, dependence on groundwater sources, and inadequate recharge of rainwater.

To address these challenges, a set of planning strategies has been proposed using the principles of Water-Sensitive Urban Development (WSUD). These strategies aim to improve water conservation and increase groundwater recharge.

It includes specific proposals for important water bodies such as the Shivna River and Teliya Talaab. Measures such as desilting, buffer zone protection, pollution control, ecological restoration, and recharge enhancement have been suggested to improve their condition and long-term sustainability. In addition, WSUD interventions such as bioswales, recharge wells, rainwater harvesting structures, and green infrastructure have been proposed to increase infiltration and reduce surface runoff.

Also presents ward-level and city-level proposals based on local conditions and future water demand up to the year 2041. These interventions have been strategically located to maximize groundwater recharge and improve the overall water management system. Together, the proposed measures provide a practical framework for conserving water resources, improving urban water security, and supporting the sustainable growth of Mandsaur city.

5.1 Proposals for Revival and Conservation of Water Bodies

Based on the analysis of the existing condition of water bodies, literature review, case studies, and Water Sensitive Urban Development (WSUD) principles, site-specific proposals have been developed for the conservation and revival of major water bodies in Mandsaur. The

proposals aim to improve water quality, enhance groundwater recharge, reduce pollution, and strengthen the long-term sustainability of urban water resources. The proposals focus on Teliya Talaab, Shivna River, and the pond located within the Masjid precinct, which have been identified as priority water bodies requiring conservation and restoration.

5.1.1 Teliya Talaab

An artificial reservoir used to recharge nearby wells and maintain the water table. This water body is also used as recreational purpose. Maximizing the ground water recharge potential of teliya talaab requires transforming it from a simple water storage basin into active highly infiltration engine.as the lake bed naturally accumulates fine slit and clay over time, it creates an impermeable barrier that blocks water from percolating downward. The below figure represents the buffer of 1km around teliya talaab and the location of wells and hand pumps inside the buffer area.

The calculations show the current water table rise in the wells and hand pumps compared to the projected levels for 2041.

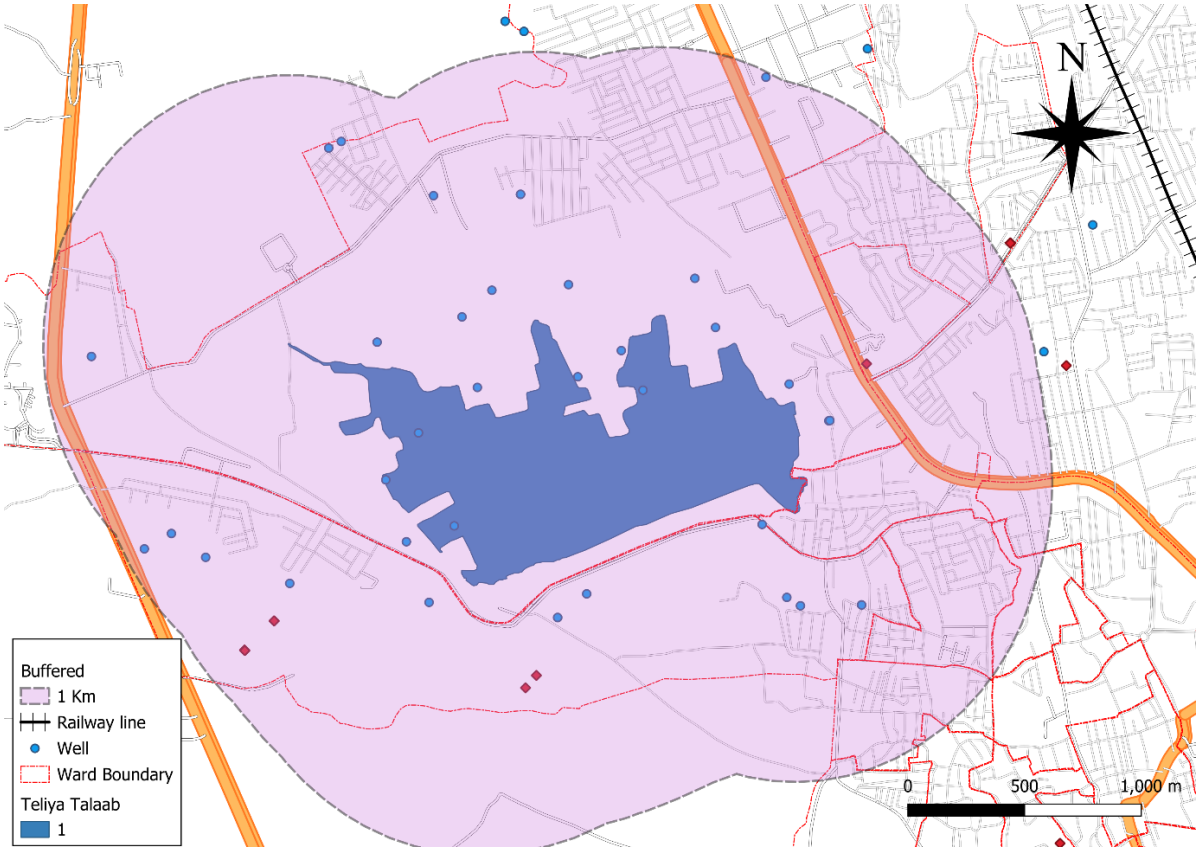


Figure 40: Talaab Buffer Map *Source: Compiled by the Author using OpenStreetMap (2025)*

Average Seepage-Based Groundwater Recharge Calculation

The final calculation is carried out by considering an **average seepage rate of 3 mm/day** (mean of 1 mm/day and 5 mm/day).

Groundwater Recharge and Water Table Rise Around Teliya Talab

The rise in groundwater level around a surface water body such as Teliya Talab is estimated using the Water Table Fluctuation (WTF) method, commonly applied in hydrogeology and groundwater studies.

Formula used

$$\Delta h = \frac{R_r + R_t - Q_g}{S_y \times A}$$

Δh: Change in groundwater level (water table rise) in meters

Rr: Recharge from rainfall

Rt: Recharge from pond/lake seepage (Teliya Talab)

Qg: Groundwater abstraction (wells and handpumps)

Sy: Specific Yield (storage capacity of aquifer, dimensionless)

A: Area of influence (study zone in m^2)

Calculations

- **Recharge from Pond Seepage (Rt):**

  105 hectares×3 mm/day×120 days

  Rt= **378,000 m^3**
- **Area of Influence (A):**

  1 km radius = **3,141,592 m^2**
- Recharge from Rainfall (Rr): Area x rainfall x infiltration rate

=3141592 m sq x0.8m x0.10

= 251,327 m³

- **Groundwater Extraction (Qg):**

  = 58,800 m³
- **Specific Yield (Sy):**

  = 0.03 (3%)

Using Water Table Rise Equation. The groundwater level fluctuation was estimated using the Specific Yield Method, which relates net recharge to the change in water table elevation over a defined area.

Average Calculation

$$\Delta h = \frac{R_r + R_t - Q_g}{S_y \times A}$$

Substituting values:

$$\Delta h = \frac{251,327 + 378,000 - 58,800}{0.03 \times 3,141,592}$$

$$\Delta h = \frac{570,527}{94,248} = \mathbf{6.05}\ \text{meters}$$

Based on average seepage conditions (3 mm/day) and a specific yield of 3%**,** the groundwater level within a 1 km radius of Teliya Talab is expected to rise by approximately:

6.05 meters (20 feet) after the monsoon season

- This result indicates that Teliya Talab acts as a strong groundwater recharge source for the surrounding area.
- It plays a crucial role in maintaining groundwater levels during dry and summer periods**.**
- The value (6.05 m) can be used as a baseline indicator for WSUD-based planning and recharge potential assessment.

Now for 2041

As demonstrated in Chapter 4, Wards 39 and 22 contribute 3.75% and 1.70% of their total populations, respectively. Assuming these identical percentages for the 2041 projections, both wards fall within a 1 km radius of the water body.

Table 35 : Detail Comparison of Ward 39 and Ward 22

Parameter	Ward 39	Ward 22
Population Share (%)	3.75%	1.70%
Projected Population (2041)	11,637	5,275
Pipe Network Dependency (%)	67%	60.2%
Groundwater Dependency (%)	33%	39.8%
Population Using Groundwater	3,840	2,100
No. of Wells	21	11
No. of Hand Pumps	1	4
Per Capita Consumption	60 LPCD	60 LPCD
Duration	120 days	120 days
Total Extraction (m^3)	27,648	15,120

Source: (Census, 2011)

Considering 67% dependency on the piped water supply and the remaining 33% dependency on groundwater sources.

Population Projection for 2041

- Total projected population of Mandsaur (2041): 310,317
- Ward A population share: 3.75%

310,317×0.0375=11,637

Projected population of Ward A in 2041 = 11,637 people

Groundwater Dependency (2041)

- Piped water supply dependency: 67%
- Groundwater dependency: 33%

11,637×0.33=3,840 persons

Population dependent on groundwater = 3,840 people

Ground water extraction volume

Assumptions:

- Per capita water consumption = 60 liters per day (lpcd)
- Duration = 120 days (dry/post-monsoon period)
- Source: 21 wells and 1 hand pump

Step 1: Daily Groundwater Consumption

$$3,840 \times 60 = 230,400 \text{ liters/day}$$
$$= 230.4 \text{ m}^3/\text{day}$$

Step 2: Total Extraction for 120 Days

$$230.4 \times 120 = \mathbf{27,648} \text{ m}^3$$

Combined ground water within 1 km

$$Q_g = Q_{g_WardA} + Q_{g_WardB}$$
$$Q_g = 27,648 + 15,120 = \mathbf{42,768} \text{ m}^3$$

Total ground water extraction in 2041 = 42768 m sq

Final water table fluctuation

Using rainfall recharge Rr=251327 m sq

Pond seepage Rt=378000 m sq (3mm/day)

Specific yield Sy= 0.03

Area = 3141592 m sq

$$\Delta h = \frac{R_r + R_t - Q_g}{S_y \times A}$$

$$\Delta h = \frac{251,327 + 378,000 - 42,768}{94,248} = \frac{586,559}{94,248} = \mathbf{6.22}\ \text{meters}$$

Final rise in ground water table 20.4 feet

Inferences:

Population in 2041 will be around 3.1 lakh in this case the rise in water table will not be sufficient. The proposals can be for conserving the talaab and for improving the ground water level. The following strategies can be adopted to increase the ground water level so that it can fulfill the future needs and reduces water stress inside the city.

Deep aquifer recharge shaft

To restore the depleted ground water table around teliya talaab, this proposal introduces a network of deep aquifer recharge shaft along the lake's perimeter to bypass its heavily silted impermeable clay bed. These vertical boreholes will feature centrally slotted casing pipe wrapped in a non-woven geotextile fabric and surrounded by an inverted filter media of graded boulders, gravels, and coarse sand.

To prevent the clogging from urban runoff each shaft will be engineered with a raised intake collar (20 cm above the bed level) ensuring that heavy sediments settle on the lake floor while only pre-filtered water is injected directly into the aquifer below. It raises the local water table, preventing nearby public hand pumps, residential bore wells, and running dry during the harsh summer months.

Standard urban deep aquifer recharge shaft used near water bodies, proposing 3 deep aquifer shaft inside 30 m buffer:

Diameter: 1–2 m

Depth: 30–50 m

Recharge capacity: approximately **50,000–1,00,000 liters/day** during monsoon

Annually, one standard recharge shaft can recharge around:

1 shaft = 5–10 ML/year

Controlling water quality to prevent bio-clogging

Ground water is highly sensitive to water quality. Chemical pollution and sewage trigger the growth of biological slime (algal mats and bacterial films) that physically seal off soil pores. Dividing the primary inlet zone of the lake using low crested earthen bunds to create the settling, populating this zone using plants like canna indica which strips out excess nutrient. This ensures the water that ultimately spread across the main lake bed is clean enough to percolate without creating a clogging bio-film.

Vegetation strips

Replacing concrete and barren banks with structured root networks improves soil permeability planting deep rooted, water tolerant native species like bamboo or Arjun tree along the bank and upper catchment areas act as biological plow. As their root grow, they physically fracture the compacted soil and accelerate the ground water recharge.

Bio swales

These directing the urban storm water runoff through gently sloped, densely vegetated channels(swales) before it hits the lake slows the water down, traps pollutants, and recharge before the water reaches teliya talaab.

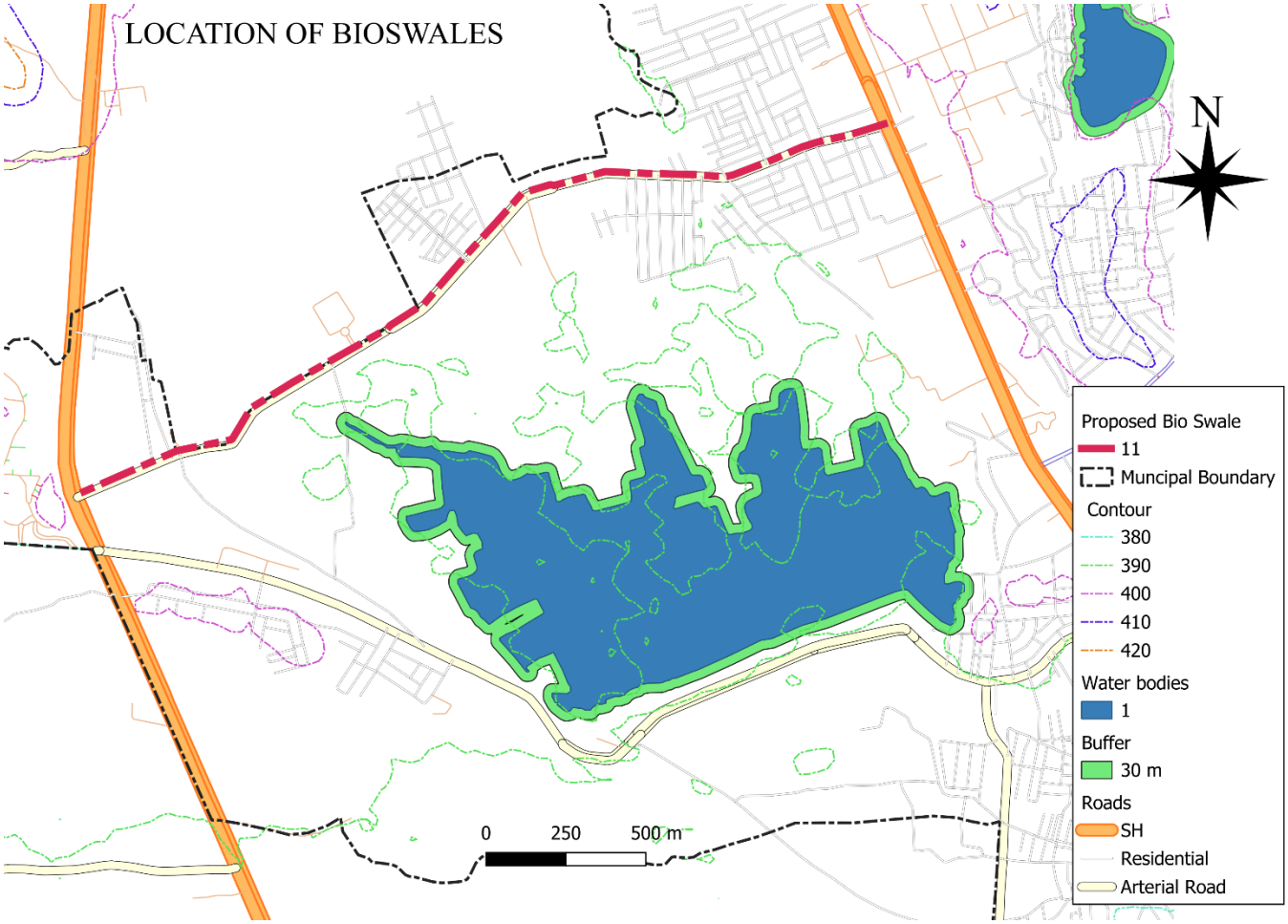


Figure 41: Proposed Bioswale Location *Source: Compiled by the Author using Bhoonidhi DEM (2023) and OpenStreetMap (2025)*

The selected 18 m wide road (2,405 m length) is located in the upper catchment (upstream/high elevation zone) of Teliya Talab, making it a critical hydrological control point**.** Unlike peripheral roads, this location functions as **a** primary runoff interception corridor**,** influencing both the quantity and quality of water reaching the lake.

1. Upstream Runoff Interception

Since the road lies along the natural slope directing flow toward the talab, it receives runoff not only from its surface but also from the entire upstream residential catchment.

Estimated peak discharge: **~433 L/s**

Without intervention → direct flow causes flooding and edge erosion near the lake

WSUD Impact:

The proposed 1.15 km bioswale network intercepts runoff at source, preventing excess water from reaching low-lying areas and significantly reducing downstream waterlogging.

2. Siltation Control at Source

The Malwa region is dominated by black cotton soil, which becomes highly erodible during rainfall.

Uncontrolled runoff → carries heavy silt into the talab

Leads to rapid loss of storage capacity

WSUD Impact:

bio swales act as sediment traps at upstream level, ensuring that only filtered, low-sediment water reaches the talab, thereby increasing its lifespan and maintaining depth.

3. Flow Velocity Reduction

Runoff moving along slope gains velocity, leading to:

Soil erosion

Infrastructure damage

WSUD Impact:

The bio swale system acts as a hydrological "speed breaker", where vegetation and soil media:

Reduce flow velocity

Dissipate kinetic energy

Promote gradual infiltration

4. Groundwater Recharge in Upper Catchment

Recharge is often concentrated near water bodies, but upper catchment zones typically have:

Lower water table

Higher recharge potential

WSUD Impact:

The proposed bioswale includes:

~2,07,900 liters subsurface gravel storage

This enables:

Temporary storage

Slow percolation

Regional groundwater improvement (not just local)

Result:
Improved groundwater blanket effect, supporting nearby wells and borewells during dry periods.

The bioswale system operates in three stages:

- **Inflow:** Runoff enters from road + upstream catchment
- **Filtration:** Engineered soil media removes silt and pollutants
- **Storage & Discharge:** Gravel trench stores water

Perforated underdrain pipe conveys filtered water safely toward the talab
So Located in the upstream catchment of Teliya Talab, the 1.15 km bioswale network along the 18 m road functions as a hydrological interceptor, capturing peak runoff (~433 L/s) and sediment at source. By integrating a 2.07 lakh-liter subsurface storage system, it reduces downstream flooding and erosion, enhances upper catchment groundwater recharge, and ensures the discharge of filtered, silt-free water into the lake.

Considering average annual rainfall of about **800 mm** in Mandsaur and a standard bioswale size:

Length = 50 m

Width = 2 m

Area = 100 m²

Estimated annual runoff captured:

100 m sq ×0.8 m=80 m3 (800 mm rainfall)

Since:

80 m3=80,000 liters

Considering runoff contribution from adjoining paved surfaces and infiltration from surrounding catchment, a 50 m bios wale can practically manage approximately:

1–3 lakh liters/year

Proposing 23 patches of 50 m =1.15 km length

then total annual storm water managed would be approximately:

23×(1–3) lakh=23–6.9 lakh liters/year

which equals:

2.3–6.9 ML/year

Twenty-three bios wale patches of 50 m length can collectively manage approximately 2.3–6.9 ML of storm water annually, contributing to runoff reduction and groundwater recharge under WSUD planning.

5.1.2 Shivna River

The Shivna River flows through Mandsaur city and serves as an important water resource for the region. However, the river corridor is surrounded by mixed land uses, including residential, commercial, and institutional developments, and several stretches have been affected by encroachment. These activities have reduced the ecological health of the river and limited its natural functions.

According to the applicable planning byelaws, a minimum 30 m buffer zone should be maintained on both sides of the river to protect the river ecosystem, improve water quality, and provide space for vegetation and green infrastructure. In Figures 43 and 44, the proposed 30 m buffer zone is shown by the red dotted line.

Residential settlements are present within the 30 m buffer zone of the Shivna River. The figures below show the locations of these encroachments.

The following proposals can be adopted for this case:

Zero liquid discharge

The biggest threat these houses poses to the shivna river is direct sewage disposal. The proposal should mandate the phytoremediation reed beds. No raw sewage from these 30 m home should enter the river.



Figure 42: Shivna River Encroachment *Source: Compiled by the Author using OpenStreetMap (2026)*

Riparian green buffer

The remaining open spaces between the houses and the water must be strictly converted into the bio shield using deep rooted vegetation. This traps soil prevents erosion and act as a natural filter run off.

Rainwater harvesting

Every rooftop must be retrofitted with a mandatory rainwater harvesting system connecting to a split trap and shallow recharge well, capturing water at the source.

Permeable paving mandate

Total concrete paving of courtyards, driveways, and setbacks with in the residential plots should be prohibited. Households must replace solid concreate with perforated grass pavers or gravel bedding. This ensures that the monsoon rain falling on private properties layout

immediately infiltrates into the ground rather than generating rapid, erosive surface runoff into the river.



Figure 43: Shivna River Encroachment *Source: Compiled by the Author using OpenStreetMap (2026)*

To remove the algae and improve the quality of the river the following proposals can be done to make river odor free and beautiful.

Solar powered aeration fountain:

Algae thrives in stagnant, low oxygen water. Increasing the dissolved oxygen do level helps natural aerobic bacteria decompose organic waste faster, suppressing algal dominance.

Proposing the solar powered floating aerators or fountains along the stagnant patches of the river bank near residential cluster and these fountains will continuously circulate and oxygenate the upper water column. The fountain stops the algae from forming thick suffocating green blankets. This helps in removing odors and make the river look clean and beautiful.

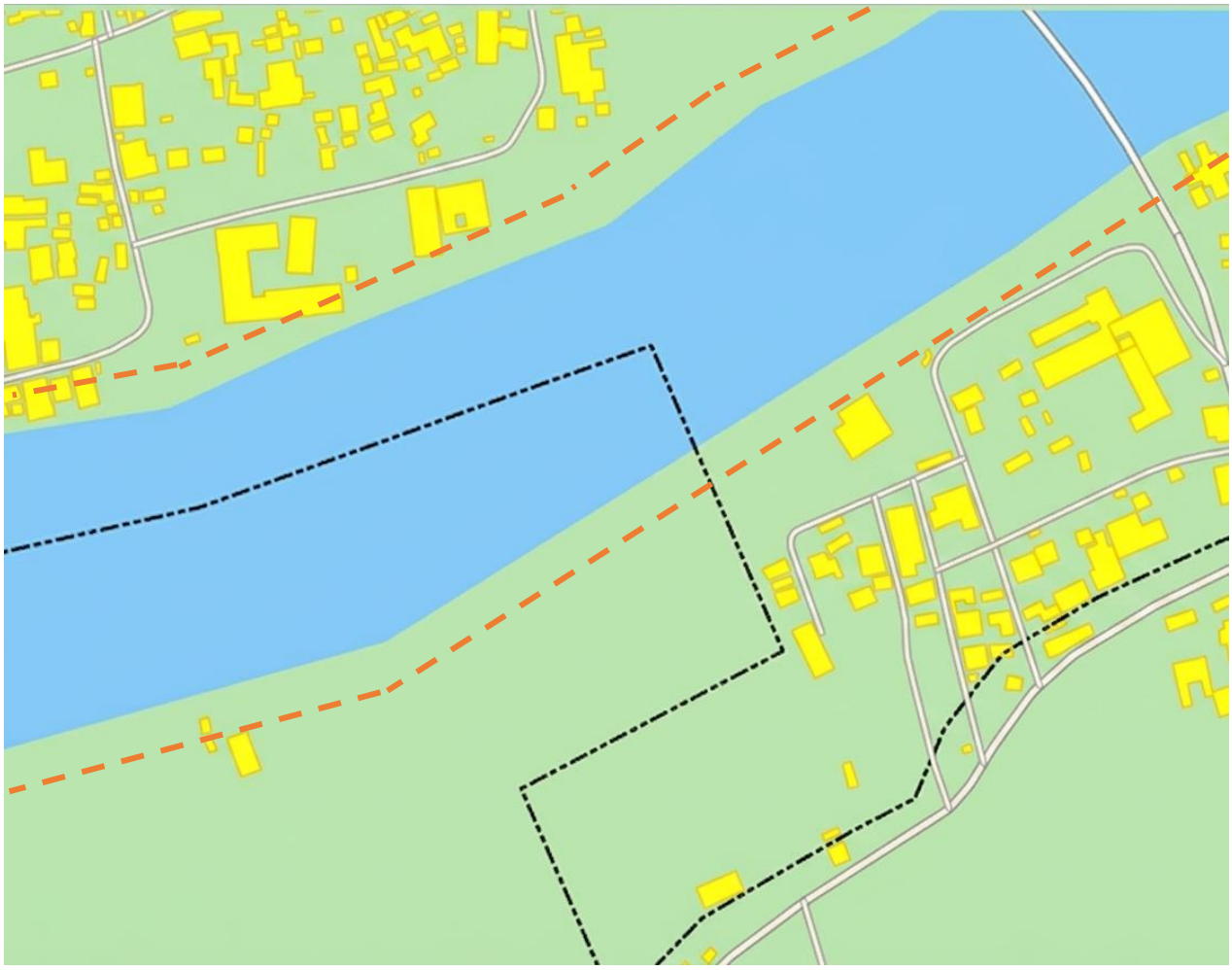


Figure 44 : Shivna River Encroachment *Source: Compiled by the Author using OpenStreetMap (2026)*

5.1.3 Tank inside masjid peripheral

The tank appears green in colour, as shown in Figure 46, and emits an unpleasant odour, indicating poor water quality due to algal growth and low dissolved oxygen levels. Although the tank is not used as a source of drinking water, it plays an important role in regulating the local microclimate, maintaining soil moisture, supporting groundwater recharge, and enhancing the surrounding environment. The water body is enclosed by a boundary wall, which helps protect it from direct encroachment.

To improve the water quality, a solar-powered aeration fountain is proposed as a sustainable WSUD intervention, requirements are mentioned in the table below. The aeration system increases the dissolved oxygen content of the water, promoting the growth of beneficial aerobic bacteria that naturally decompose organic matter. This process helps control algal growth,

reduce foul odour, and improve the overall ecological condition of the tank while operating with minimal energy and maintenance requirements.

Figure 45: Planning and Design Requirements for a Solar-Powered Aeration Fountain

Parameter	Requirement
Minimum tank area	500–1,000 m²
Recommended Tank area	2,000–5,000 m²
Tank area	4,879 m²
Floating platform footprint	2–4 m²
Clear operating radius	5–8 m around the fountain
Water depth required	Minimum 1.2–1.5 m
Effective aeration coverage	2,000–5,000 m² (depending on depth and water quality)
Solar panel area	4–8 m² (mounted on the float or nearby on land)

Source: Compiled by the author based on United States Environmental Protection Agency (USEPA, 2021), AquaMaster Fountains and Aerators (2023), Kasco Marine (2023), and Central Pollution Control Board (CPCB, 2019).

In addition, introducing native algae-eating fish species, such as guppies and small carp, is recommended as a biological water treatment measure. These fish feed on algae and mosquito larvae, helping to maintain cleaner water, reduce mosquito breeding, and improve the ecological balance of the tank without the use of chemical treatments. Together, these interventions contribute to the long-term conservation and sustainable management of the water body.



Figure 46: Condition of Tank inside Masjid *Source: (Author, 2026)*

The existing wild vegetation around the tank should be replaced with native species such as Arjun (Terminalia arjuna) and Karanj (Pongamia pinnata), which have comparatively lower leaf fall and are suitable for planting around water bodies. These trees should be planted at a minimum distance of 5 m from the edge of the tank to minimize the direct entry of leaf litter into the water. The area between the tank and the tree plantation should be developed with Vetiver grass or other native grasses to act as a vegetative filter strip. This grass barrier will trap sediments, litter, and pollutants carried by stormwater runoff before they reach the tank. Reducing the accumulation of organic matter in the water will help control algal blooms, improve water quality, and reduce unpleasant odours. In addition, the proposed plantation will enhance the aesthetic appeal of the water body, strengthen the shoreline, and improve the ecological value of the surrounding area.



Figure 47: Proposed Map for Tank *Source: Compiled by the Author using OpenStreetMap (2026)*

5.2 Ward Level Proposals

A decentralized and demand-based planning approach should be adopted. High-density wards (3,18, 19, 20, 23, 24, 28, 29, 31) should be prioritized for new OHTs, booster stations, and pipeline strengthening to improve service levels. In central wards (10, 11, 12, 13, 15, 16, 17), infrastructure should be optimized through pressure zoning and redistribution rather than adding new tanks. Peripheral wards (1, 3, 4, 5, 21, 22, 26, 33, 35–40) require network expansion and strategically located new OHTs aligned with future growth corridors. Additionally, wards along the river (23, 24, 25, 30, 31, 32) offer opportunities to integrate WSUD strategies such as decentralized storage, recharge systems, and treated wastewater reuse, ensuring a more sustainable and resilient water supply system.

Ward 3 is one of the most densely populated wards in Mandsaur and does not have any dedicated parks or green open spaces. The Master Plan 2041 also indicates a lack of recreational green areas within the ward as shown in figure 49. Due to the high population density and extensive built-up area, the ward experiences greater pressure on stormwater drainage and

groundwater recharge. As a WSUD intervention, permeable concrete pavement is proposed for roads, footpaths, and parking areas within the ward. Unlike conventional impervious pavements, permeable concrete allows rainwater to infiltrate directly into the underlying soil, thereby reducing surface runoff and enhancing groundwater recharge. It also minimizes localized flooding by decreasing the volume of stormwater entering the drainage network during heavy rainfall. In addition, the pavement acts as a natural filter by trapping sediments and pollutants before they infiltrate into the ground.

The proposed permeable concrete pavement contains approximately 15–35% interconnected voids, allowing rainwater to infiltrate directly through the pavement surface. During rainfall, water first passes through these interconnected pores and is temporarily stored in the underlying stone reservoir layer. It then gradually percolates through the geotextile and soil layers before reaching the groundwater table, thereby recharging the aquifer as shown in figure below. This process significantly reduces surface runoff, minimizes the burden on the stormwater drainage system, and enhances groundwater recharge while naturally filtering sediments and pollutants.

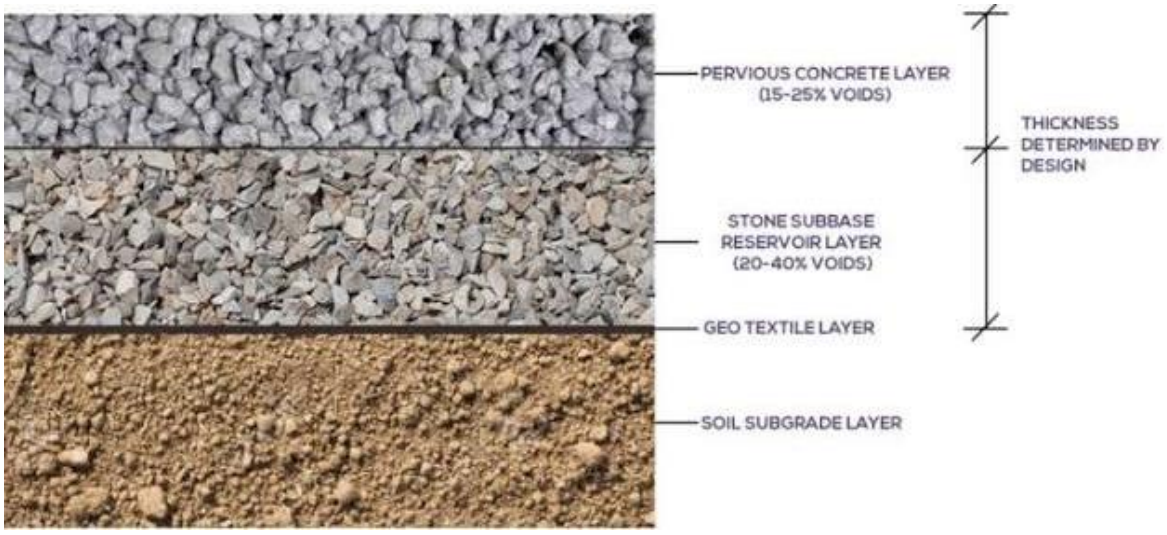


Figure 48: Image of Permeable Concrete Road Section
Source:https://www.researchgate.net/publication/342108095_Study_on_pervious_concrete_pavement_mix_designs

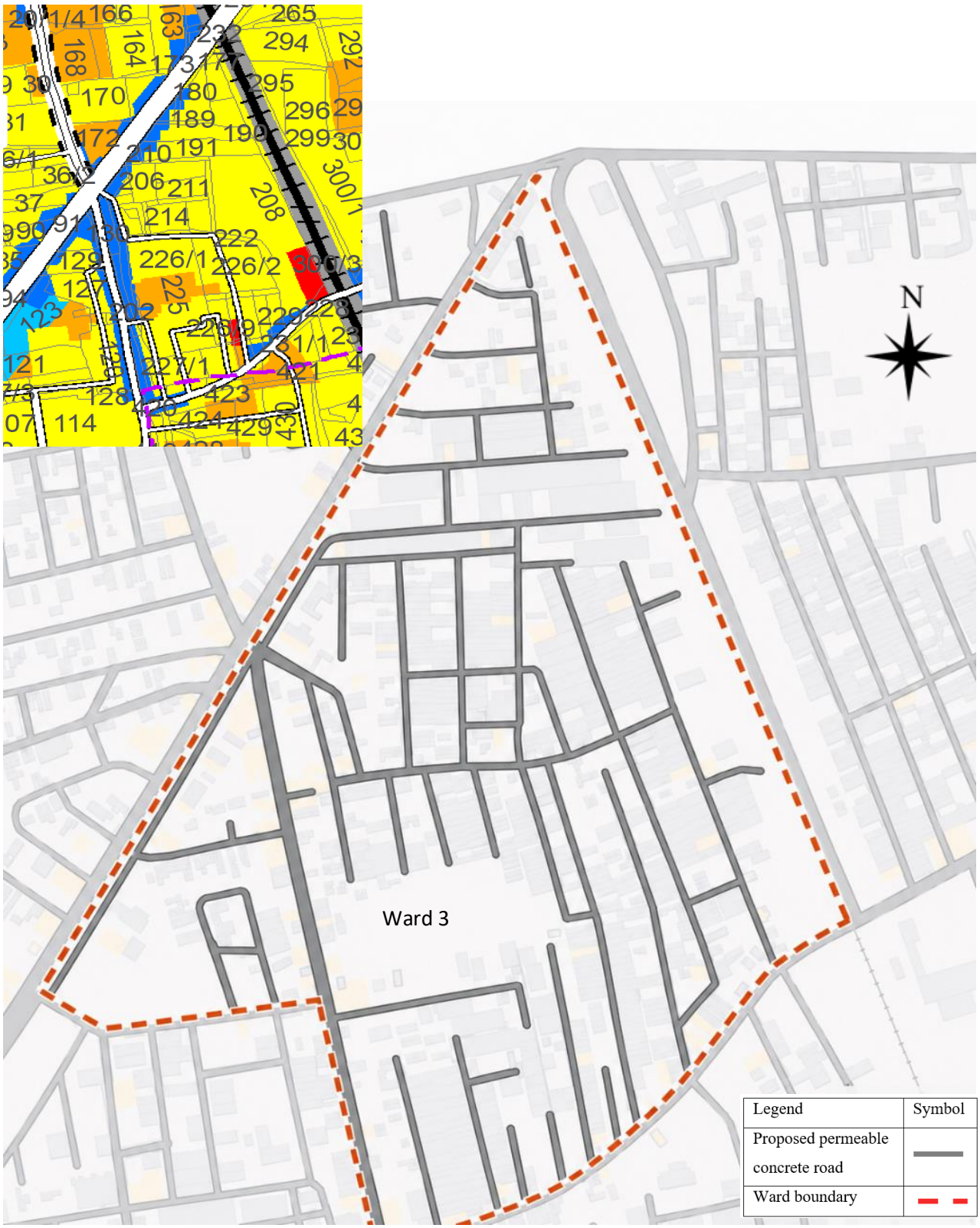


Figure 49: Proposed Map for Ward 3 *Source:* Compiled by the Author using OpenStreetMap (2026)

Wells

To improve groundwater recharge and enhance water security, new recharge interventions such as recharge wells, percolation pits, and rainwater harvesting structures should be prioritized, particularly in high-density and high groundwater extraction zones. These interventions will help reduce pressure on the existing aquifers, improve groundwater availability, and increase the resilience of the city's water supply system. In addition, elevated and under-served areas should be supported through decentralized water supply systems or the development of strategically located new wells, following detailed hydrogeological investigations to ensure their technical feasibility and long-term sustainability.

A field survey identified a total of five existing wells with concrete paving around them. Two wells are located in Ward No. 39, which is one of the most densely populated wards, two wells are situated in Ward No. 4, and one well is located in Ward No. 10 as shown in Figure below. The existing concrete paving around these wells limits natural infiltration and reduces their groundwater recharge potential. To enhance recharge, the impervious paving surrounding the wells can be replaced with permeable paving, and additional WSUD measures such as recharge trenches, recharge pits, vegetated filter strips, and rainwater harvesting systems can be integrated around the wells. These interventions will increase infiltration, improve groundwater replenishment, and support the sustainable management of local water resources.



Figure 50: Image of Well in Ward 10 *Source: (Author, 2026)*

Several wells in Mandsaur are surrounded by impervious concrete paving, which restricts the natural infiltration of rainwater into the ground. It is proposed that the existing concrete surface within a radius of 2–4 m around these wells be replaced with green spaces or permeable paving. This intervention will allow rainwater to infiltrate directly into the surrounding soil, thereby enhancing groundwater recharge and improving the sustainability of the wells.

The proposed green buffer around the wells will maximize on-site rainwater infiltration, actively recharge the underlying aquifers, and improve groundwater availability. In addition, the vegetation and soil layers will act as natural filters by trapping sediments and removing pollutants from stormwater before it enters the groundwater system. This will improve groundwater quality, reduce surface runoff, and enhance the environmental and aesthetic value of the surrounding area.

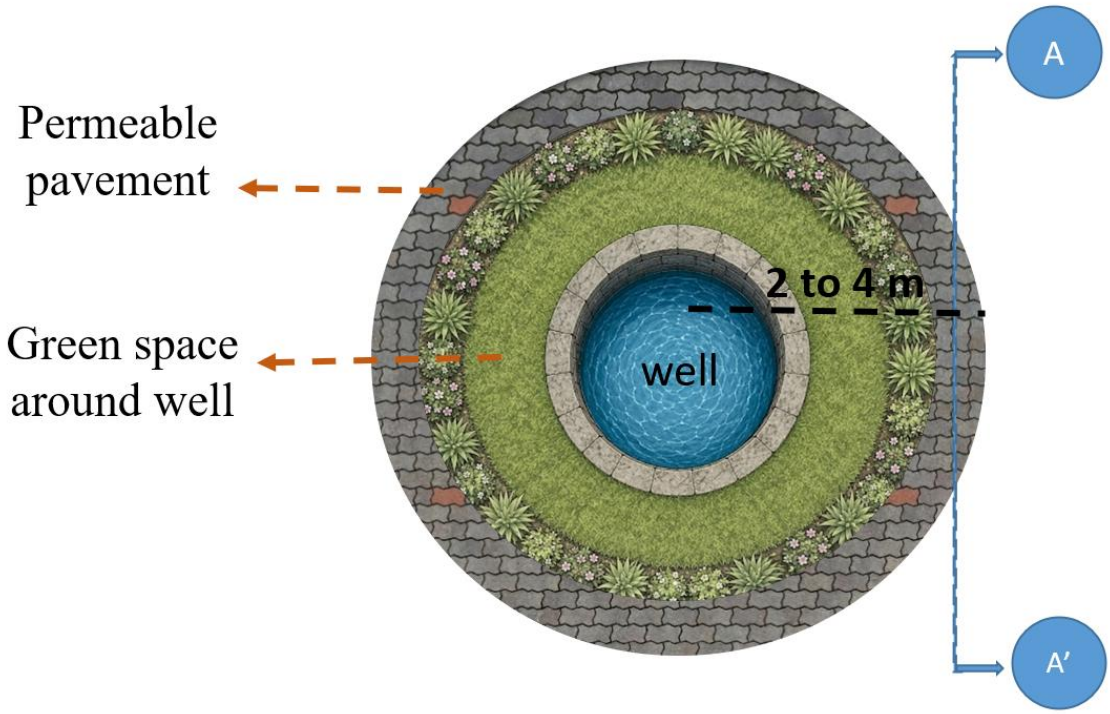


Figure 51: Proposal for Well *Source: (Author, 2026)*

Figure 52 illustrates the typical cross-section of a permeable paver system. The top layer consists of interlocking permeable paver units with drainage cells that allow rainwater to pass through the joints instead of flowing over the surface. Below the pavers is a bedding layer of coarse sand or fine aggregate, which provides structural support and facilitates the initial filtration of stormwater.

The base layer is made of clean, open-graded crushed aggregates with interconnected voids that temporarily store infiltrated rainwater. An optional geotextile layer may be provided to separate the aggregate from the native soil while preventing the movement of fine particles without restricting water flow. Beneath this lies the native subgrade, through which the stored water gradually infiltrates into the soil and eventually reaches the groundwater table, thereby recharging the aquifer.

This layered system reduces surface runoff, minimizes localized flooding, improves groundwater recharge, and naturally filters sediments and pollutants before they enter the subsurface. In addition, permeable pavers reduce the burden on the conventional stormwater drainage system and contribute to sustainable urban water management under Water Sensitive Urban Development (WSUD) principles.

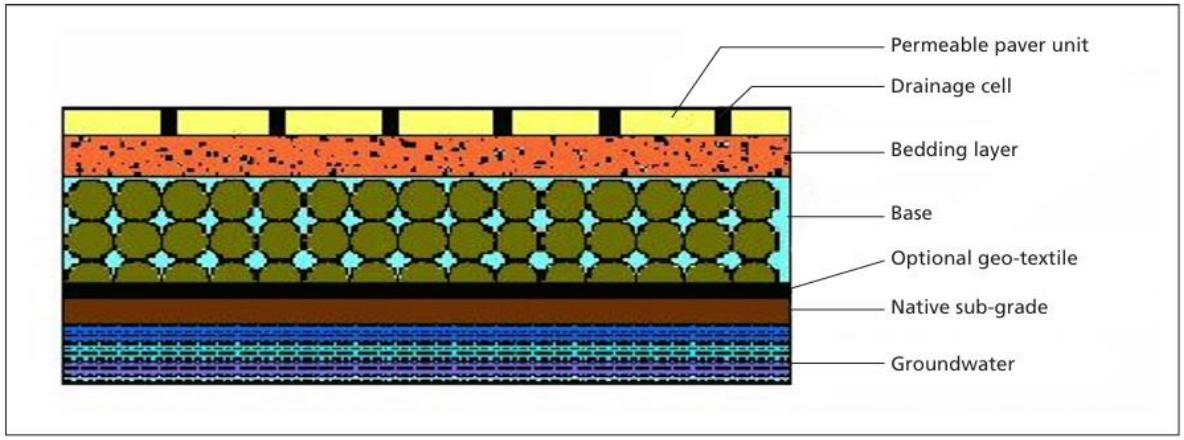


Figure 52: Section of Permeable Paver *Source: (CSE, 2016)*

During rainfall, water passes through the permeable pavers into the bedding layer and then enters the open-graded aggregate reservoir layer, where it is temporarily stored. The water gradually percolates through the geotextile filter layer into the surrounding soil.

As infiltration continues, the water moves vertically downward and laterally towards the well, increasing groundwater recharge and replenishing the underlying aquifer. The geotextile layer prevents the migration of fine soil particles into the aggregate layer, ensuring long-term performance of the system as shown in figure 53. This process also provides natural filtration, reducing sediments and pollutants before the water reaches the groundwater.

Replacing impervious concrete with permeable pavement around existing wells increases on-site rainwater infiltration, reduces surface runoff, minimizes waterlogging, and improves groundwater availability. This WSUD intervention also helps maintain the water level in wells, enhances groundwater quality through natural filtration, and promotes sustainable urban water management with minimal maintenance requirements.

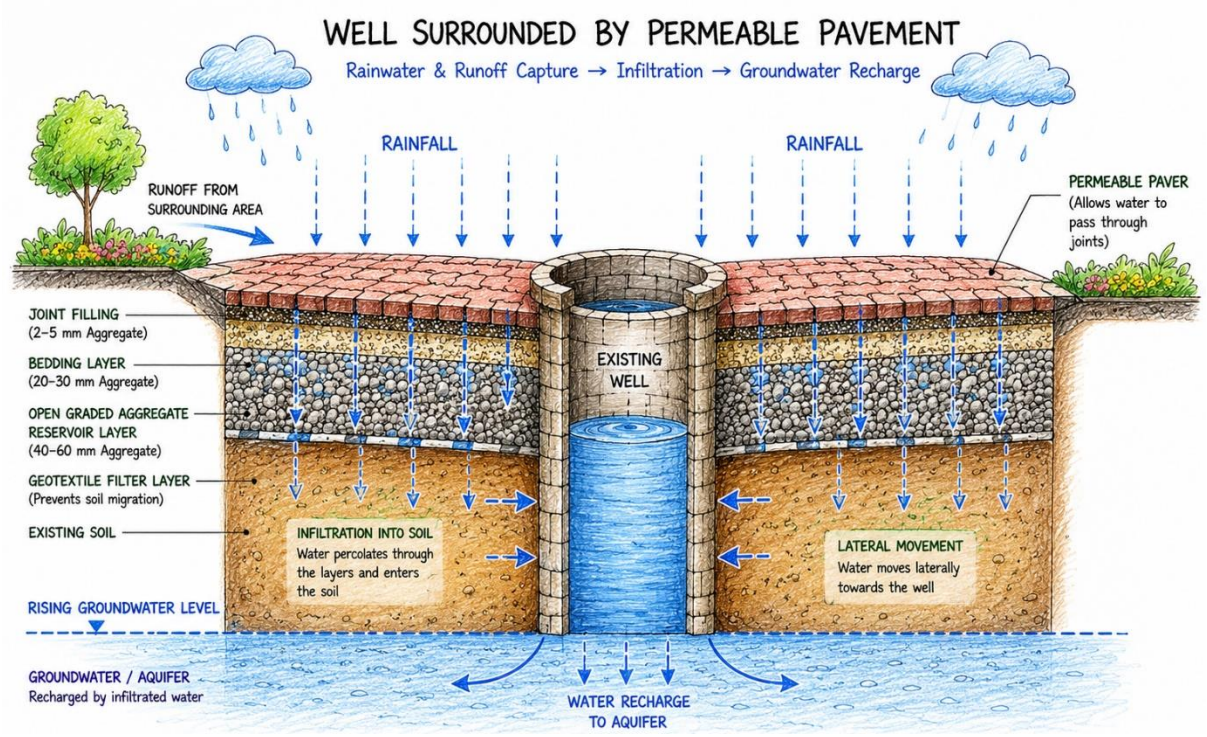


Figure 53: Cross-Section of a Well with Permeable Pavement for Rainwater Infiltration *Source: (Author, 2026)*

Hand pump

- Introduce new hand pump or recharge-supported bore locations in buffer-deficient peripheral zones to improve equity of access.
- Prioritize high-intensity heat map zones for artificial recharge structures (recharge pits, trenches, percolation tanks).
- Integrate hand pump clusters with WSUD interventions, especially near natural drainage and river-adjacent zones to reduce groundwater stress.
- Establish a 300–500 m service catchment standard check to identify underserved households.

5.3 City Level Proposals

The selection and placement of Water Sensitive Urban Development (WSUD) interventions in Mandsaur have been carried out based on land use, topography, drainage patterns, and the location of existing water bodies. This approach aims to enhance groundwater recharge, improve stormwater management, conserve urban water resources, and promote sustainable urban development. Different WSUD measures have been proposed according to the physical characteristics and suitability of each location to maximize their effectiveness.

Parks, playgrounds, and agricultural lands provide large pervious surfaces that are highly suitable for groundwater recharge.

Based on the drainage analysis, check dams are proposed along the third-order drainage streams, where they can effectively capture and store monsoon runoff. These structures slow the flow of stormwater, increase infiltration into the soil, recharge nearby wells and aquifers, reduce soil erosion and sediment transport, and provide temporary storage of rainwater during the monsoon season. As a result, check dams contribute to improving groundwater levels, enhancing water availability for irrigation and domestic use, and supporting the long-term revival of Mandsaur's water resources. Collectively, these strategically placed WSUD interventions provide an integrated approach to sustainable water management by improving water security, reducing flood risks, and enhancing the environmental quality of the city.

Implementation Framework:

The execution of the proposed check dams within the ephemeral streams of the Mandsaur urban and peri-urban areas falls under the jurisdiction of the Water Resources Department (WRD), Government of Madhya Pradesh. Administratively, such projects require a tripartite alignment involving the Office of the District Collector (Mandsaur) for land allocation and administrative sanction, the Executive Engineer of WRD (Mandsaur Division) for technical validation, and the Nagar Palika Parishad Mandsaur for local municipal clearance. Financially and structurally, these interventions align with the guidelines of the Central Government’s Jal Shakti Abhiyan and state-level water conservation schemes. Methodologically, the technical survey, Detailed Project Report (DPR) formulation, and statutory clearances demand a standard period of 2 to 3 months, followed by a physical construction phase of 3 to 4 months restricted strictly to the dry season to prevent hydrological disruptions.

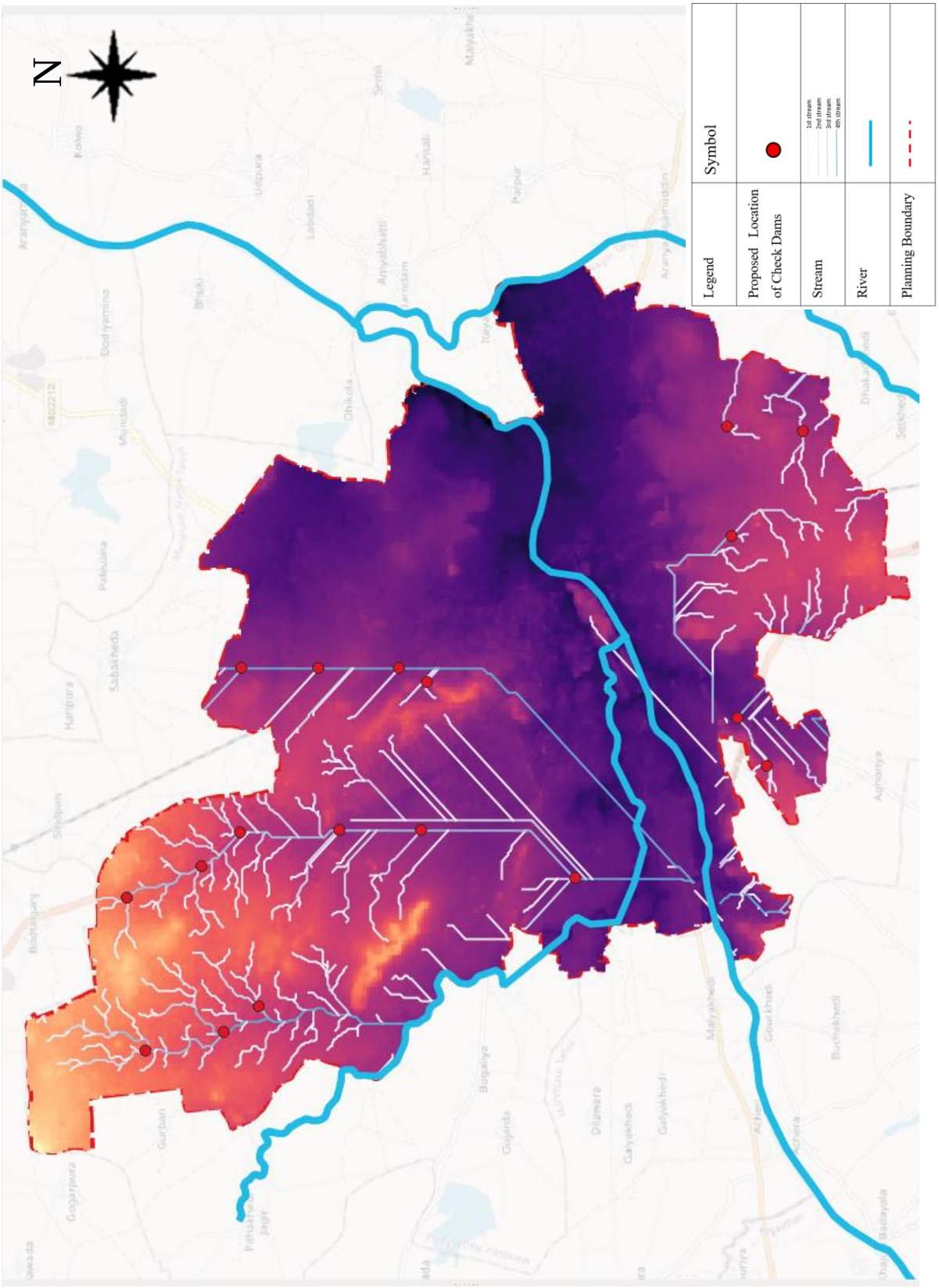


Figure 54: Section Showing Process of Recharge Aquifers *using Bhoonidhi DEM (2023)*

Source: Compiled by the Author

If the size and storage capacity of the check dam are increased, the number required will reduce significantly.

Consider a Large Check Dam

Standard larger urban/rural recharge check dam:

- Height: 4–6 m
- Length: 20–50 m , Width (top): 1–3 m , Foundation depth: 2–5 m
- Recharge capacity: 50ML/year

Cost 10-25 lakhs (CGWB, 2020)

Existing Water Deficit

11.9 MLD = 4380 ML/year

Number of Large Check Dams Required

4380 / 50 = 88 check dams

- By increasing the size and recharge capacity of check dams, the required number can be reduced to approximately 88 large check dams for addressing the current 11.9 MLD deficit.
- These can be strategically proposed along major drainage channels and watershed zones under WSUD planning.

Gabion check dams are recommended for Mandsaur due to their suitability for seasonal drainage channels and their effectiveness in enhancing groundwater recharge. Mandsaur is characterized by seasonal nalas, Deccan Trap basalt geology, and black cotton soil, where reducing runoff velocity and promoting infiltration are essential for sustainable water management. Gabion structures, constructed using galvanized wire mesh filled with stones, are permeable and allow water to pass gradually through the voids between stones. This reduces the flow velocity, promotes infiltration into the stream bed and surrounding aquifer, traps sediments, minimizes erosion, and improves groundwater recharge. In comparison to reinforced cement concrete (RCC) structures, gabion check dams are more economical, environmentally compatible, easier to construct using locally available materials, and can be repaired with minimal maintenance if damaged during heavy rainfall or flood events.

Therefore, gabion check dams are considered an appropriate WSUD intervention for groundwater recharge and watershed conservation in Mandsaur

Recharge wells

Recharge wells are proposed in WSUD planning strategies for the conservation and revival of water bodies because they play a crucial role in restoring the natural urban water cycle. In cities like Mandsaur, increasing built-up areas reduce natural infiltration and convert most rainfall into surface runoff, leading to groundwater depletion and waterlogging. Recharge wells help capture this runoff and directly transfer it into the subsurface, thereby enhancing groundwater recharge. This is especially important in basaltic regions where the natural recharge capacity is limited. By increasing groundwater levels, recharge wells support nearby wells, handpumps, and also maintain the hydrological balance of water bodies such as Teliya Talab. Additionally, they reduce pressure on drainage systems by lowering peak runoff and prevent the loss of rainwater as waste.

Due to their small space requirement, recharge wells are highly suitable for dense urban areas and can be easily integrated along roads, open spaces, and institutional lands. Thus, they serve as an effective, decentralized solution for improving water availability, reducing flood risk, and ensuring long-term sustainability of urban water systems.

The map illustrates the spatial distribution of proposed recharge wells integrated with the drainage network, road infrastructure, and topography. The wells are strategically located along runoff pathways and low-lying zones to maximize stormwater capture and groundwater recharge, thereby supporting the sustainability of nearby water bodies

Recharge well locations have been identified based on the Master Plan 2041 and existing as well as proposed land use patterns. Areas designated for parks and open spaces have been prioritized, as these provide suitable and unobstructed land for implementing recharge structures. In addition, the planning area exhibits a natural elevation gradient, where runoff flows from higher elevations towards lower-lying zones and water bodies.

Based on this topographic condition, recharge wells are strategically proposed along natural runoff pathways and in proximity to water bodies such as Teliya Talab, ensuring maximum capture of stormwater before it exits the system. This placement enhances groundwater

recharge efficiency by allowing water to percolate at critical locations where flow accumulation is highest.

To offset a projected deficit of 11.9 MLD, approximately 240 standard recharge wells may be required, considering an average recharge capacity of 50,000 liters/day per well under suitable hydrogeological conditions.

Furthermore, recharge wells are proposed in a clustered and chain formation, rather than as isolated units. This approach ensures continuous interception of runoff across the catchment and improves recharge performance at a larger scale. The clustering strategy is also supported by quantitative analysis, which indicates that a higher number of recharge structures is required to balance groundwater extraction and achieve sustainable water levels.

Overall, the spatial distribution of recharge wells reflects an integrated WSUD approach, combining land use planning, topography, and hydrological behavior to maximize groundwater recharge and support long-term water sustainability in the city.

Implementation Framework:

The decentralized deployment of recharge wells across public parks, institutional zones, and high-runoff urban sectors in Mandsaur City is governed by the Madhya Pradesh Bhumi Vikas Niyam (Rainwater Harvesting mandates) and AMRUT 2.0 guidelines. The primary executing and permitting agency is the Nagar Palika Parishad Mandsaur, operating under the direct authority of the Chief Municipal Officer (CMO). Technical consultation regarding aquifer depth and soil stratification must be vetted by the State Ground Water Department (Ujjain/Mandsaur Division) to ensure compliance with the Central Ground Water Authority (CGWA) safety standards. The institutional mechanism involves a fast-tracked approval process, where hydrogeological assessment and municipal sanctioning require 3 to 4 weeks, while the physical execution and integration with the stormwater network spans an estimated 1 to 2 months per cluster.

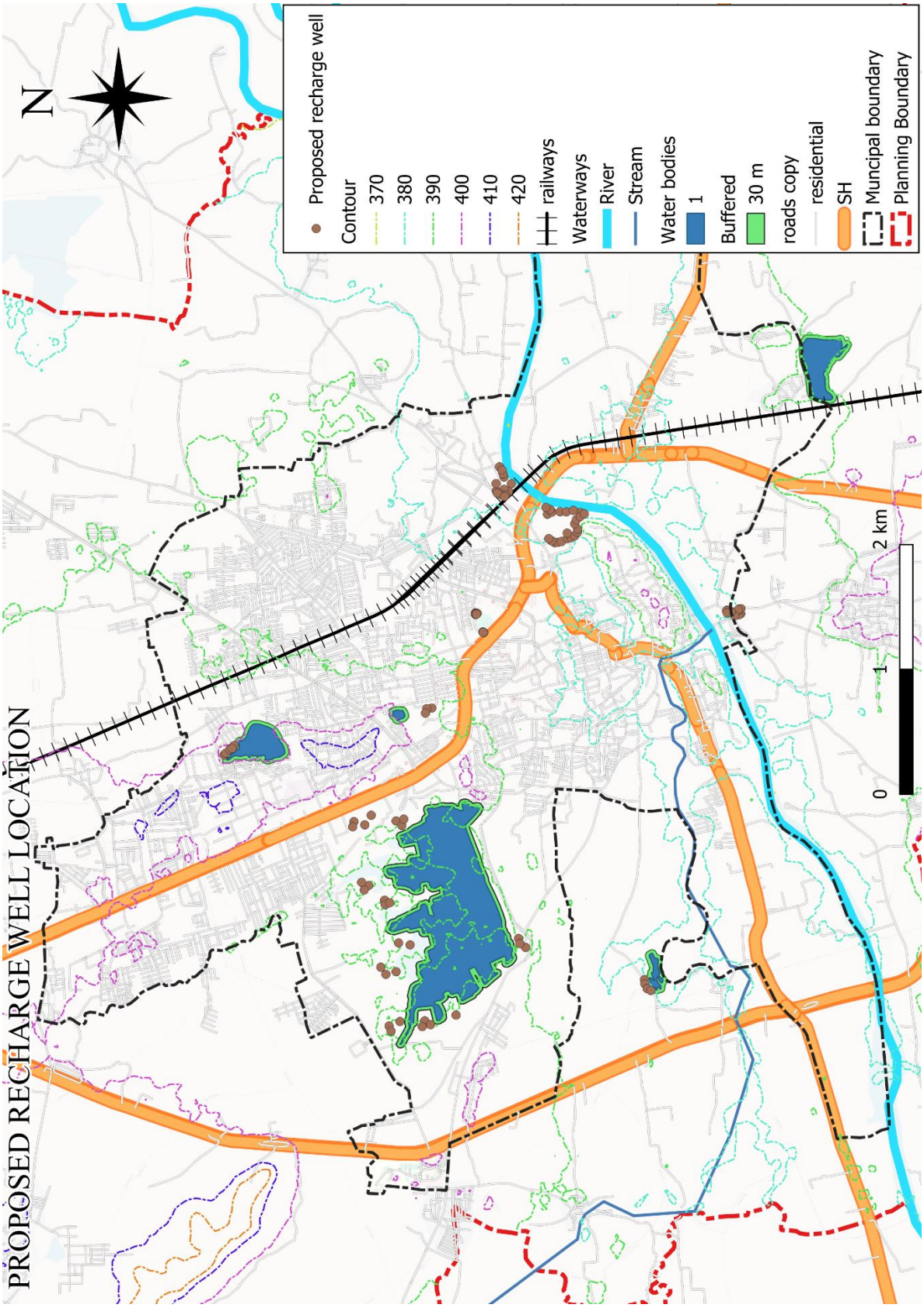


Figure 55: Proposed Location for Recharge Wells *Source: (Author, 2026)*

5.4 Inferences

The planning proposals developed in this chapter demonstrate the application of Water Sensitive Urban Development (WSUD) principles to address the existing water-related challenges in Mandsaur City. The proposed interventions focus on the conservation and revival of urban water bodies, enhancement of groundwater recharge, improvement of storm water management, rainwater harvesting, pollution mitigation, ecological restoration, and strengthening of the urban water supply system. Site-specific proposals have been formulated based on the existing condition, surrounding land use, and functional importance of individual water bodies. These interventions aim to improve water quality, increase storage capacity, reduce dependence on groundwater, and enhance the ecological and social value of urban water bodies. Collectively, the proposed strategies provide an integrated planning framework that promotes sustainable urban water management, strengthens climate resilience, and contributes to achieving long-term water security for Mandsaur City.

The quantitative baseline analysis successfully identified a severe water deficit of 11.9 MLD, culminating in an annual demand-supply gap of approximately 4,343.5 Million Liters (ML/year). Left unaddressed, this deficit poses a significant threat to the region's socio-economic and ecological sustainability.

To bridge this gap, this study proposes a multi-layered matrix of Water Sensitive Urban Design (WSUD) interventions. The combined engineering calculations demonstrate a highly viable pathway to water security through the following specific outcomes:

The implementation of a targeted Bioswale system surrounding the lake infrastructure will capture and filter localized surface runoff, contributing an estimated 6.9 Million Liters/Year to the local water budget.

Deep Aquifer Augmentation: Direct sub-surface structural interventions will facilitate a Deep Aquifer Recharge* mechanism, safely funneling an additional 10 Million Liters/Year directly into deeper geological strata to arrest macro-level groundwater depletion.

Macro-Scale Macro-Infrastructure (Alternative Scenarios for Complete Deficit Fulfilling): To completely neutralize the core 11.9 MLD (4,343.5 ML/year) deficit, two highly effective structural pathways have been engineered and evaluated:

Scenario A (Surface Storage): The strategic deployment of 88 Check Dams designed to harvest regional peak-flow streams, which successfully fulfills the entire annual deficit.

Scenario B (Distributed Sub-Surface Recharge): A decentralized network of 240 Artificial Recharge Wells, each engineered with a design capacity of 50,000 Liters/Day. This network generates a combined capacity of 12 MLD (aggregating to 4,380 Million Liters/Year), entirely bridging and exceeding the target deficiency.

Water Quality Maintenance: To complement these volumetric gains, Solar-Powered Aeration systems will be distributed across the primary surface storage nodes (the lake and check dam reservoirs) to enhance Dissolved Oxygen (DO) levels, prevent stagnation, and ensure the captured water is viable for secondary urban or ecological use.

Future Outlook and Long-Term Impact

Beyond fulfilling the immediate 11.9 MLD deficit, the long-term implementation of this WSUD model offers profound future benefits for the region:

Permanent Aquifer Rejuvenation: The dual action of the deep aquifer recharge system and the 240 recharge wells will steadily elevate the regional water table, lowering future energy costs associated with deep-well municipal pumping.

CHAPTER 6-RESULTS AND DISCUSSIONS

This study demonstrates that Mandsaur has significant potential for implementing Water Sensitive Urban Development (WSUD) due to the presence of the Shivna River, traditional tanks, Teliya Talab, wells, natural drainage channels, and suitable topography for groundwater recharge. However, increasing urbanization, encroachment around water bodies, inadequate stormwater management, declining groundwater levels, and pollution have reduced the efficiency of the city's natural water system. These challenges indicate that conventional water management practices alone are insufficient to meet future water demands and highlight the need for an integrated water-sensitive planning approach. The ward-level assessment revealed considerable variation in water infrastructure across the city. While most wards receive water through the piped network, several wards still depend on wells, hand pumps, and tanker supply, especially during summer. Pipeline coverage also varies significantly among wards, indicating unequal distribution of water infrastructure. High-density wards experience greater pressure on water supply, drainage systems, and groundwater resources because of higher population concentration and limited open spaces. In contrast, low-density wards and peripheral areas provide opportunities for groundwater recharge and future green infrastructure development.

The analysis of demographic characteristics further indicates that densely populated wards require greater investment in water supply, sanitation, stormwater drainage, and public open spaces. The absence of parks and green areas in some wards limits opportunities for natural infiltration and increases the extent of impervious surfaces. This emphasizes the importance of integrating WSUD measures such as permeable pavements, rain gardens, bioswales, and decentralized recharge systems within existing urban areas. GIS-based analysis of topography, slope, drainage, contours, and watershed characteristics proved highly effective in identifying suitable locations for WSUD interventions. The drainage network helped identify locations for check dams and recharge structures, while land use analysis supported the selection of parks, agricultural land, road corridors, and open spaces for infiltration-based measures. These spatial analyses demonstrate that scientific planning tools can significantly improve the efficiency and effectiveness of urban water management decisions. The assessment of existing water bodies revealed that several ponds and the Shivna River have experienced degradation due to sewage discharge, encroachment, siltation, algal growth, and poor maintenance. Although these water

bodies continue to contribute to groundwater recharge and the local microclimate, their ecological and hydrological functions have been considerably reduced. Maintaining buffer zones, controlling pollution, restoring natural vegetation, and improving stormwater quality are therefore essential for long-term conservation.

However, successful implementation of these interventions will require institutional coordination, community participation, adequate funding, regular maintenance, and continuous monitoring. Land availability in highly developed areas, public acceptance, and inter-departmental coordination may present implementation challenges. Therefore, a phased implementation strategy beginning with priority locations such as Teliya Talab, Shivna River, and high-risk wards is likely to achieve better long-term outcomes than city-wide implementation in a single phase.

Recommendations

Based on the findings of this study, several recommendations are proposed for improving water resource management and conserving water bodies in Mandsaur using Water Sensitive Urban Development (WSUD) principles. The proposed WSUD measures should be incorporated into future planning and development of Mandsaur. Existing water bodies, natural drainage channels, and groundwater recharge areas should be protected from further encroachment. Rainwater harvesting and groundwater recharge measures should be encouraged in residential, commercial, institutional, and public buildings to reduce dependence on groundwater and improve water availability. The conservation and restoration of existing water bodies should be given priority. Regular desiltation should be carried out to restore the storage capacity of lakes and ponds. A 30 m green buffer should be maintained around the Shivna River and other major water bodies wherever possible to reduce pollution, improve infiltration, and protect the surrounding environment. Native tree species and grass should be planted around water bodies to reduce soil erosion, filter stormwater runoff, and improve the aesthetic quality of the area. Direct discharge of sewage and solid waste into water bodies should be prevented to improve water quality.

Groundwater recharge should be enhanced by constructing recharge wells, recharge pits, infiltration basins, and rainwater harvesting structures at suitable locations identified through

the study. Existing wells surrounded by concrete paving should be modified by replacing the impervious surface within a 2–4 m radius with green space or permeable paving to improve rainwater infiltration and groundwater recharge. Parks, open spaces, and agricultural land should be utilized for recharge structures wherever suitable.

Permeable pavements should be introduced in highly built-up wards, especially where open spaces are limited. These pavements will reduce surface runoff, increase groundwater recharge, and improve stormwater infiltration. Bioswales should be developed along suitable roadside corridors to collect and filter stormwater before it enters the drainage network. Check dams should be constructed at suitable third-order drainage streams identified during the drainage analysis to reduce runoff velocity, increase groundwater recharge, and minimize soil erosion. Regular maintenance of recharge structures, permeable pavements, check dams, and water bodies is essential to ensure their effective functioning. Accumulated silt should be removed periodically from lakes, ponds, and recharge structures to maintain their storage capacity and recharge efficiency. Water quality and groundwater levels should also be monitored regularly to evaluate the effectiveness of the proposed interventions and support sustainable water management in Mandsaur.

Future Scope

The present study mainly focuses on planning-level WSUD interventions for Mandsaur. Future research can strengthen the proposed framework through detailed hydrological modelling, groundwater simulations, economic feasibility studies, and climate resilience assessments.

Future studies may include:

• Cost-benefit analysis of individual WSUD interventions.

• Development of a city-wide WSUD implementation manual.

• Replication of the proposed methodology in other medium-sized cities of Madhya Pradesh with similar climatic and hydrological conditions.

निष्कर्ष

यह अध्ययन मंदसौर में जल प्रबंधन से संबंधित बढ़ती चुनौतियों को Water-Sensitive Urban Development (WSUD) के सिद्धांतों के माध्यम से संबोधित करने पर केंद्रित है। अध्ययन यह दर्शाता है कि तीव्र शहरीकरण, जनसंख्या वृद्धि, प्रदूषण, अतिक्रमण तथा अव्यवस्थित विकास ने पारंपरिक जल निकायों को क्षतिग्रस्त किया है और वर्तमान शहरी जल प्रणालियों पर दबाव बढ़ाया है। यह शोध नदियों, तालाबों, टैंकों, कुओं तथा अन्य पारंपरिक जल प्रणालियों के ऐतिहासिक महत्व का अध्ययन करता है, जो कभी भूजल पुनर्भरण, बाढ़ नियंत्रण, पारिस्थितिक संतुलन तथा घरेलू जल आवश्यकताओं को पूरा करने में महत्वपूर्ण भूमिका निभाते थे। विशेष रूप से शिवना नदी तथा मंदसौर के अन्य जल निकायों पर ध्यान केंद्रित किया गया है, जो वर्तमान में प्रदूषण, गाद जमाव, अवैध जल दोहन तथा भूजल स्तर में गिरावट जैसी समस्याओं से प्रभावित हैं। चूंकि मंदसौर जल-संकटग्रस्त तथा अत्यधिक भूजल दोहन वाले क्षेत्र में आता है, इसलिए यह अध्ययन सतत एवं एकीकृत जल नियोजन की तत्काल आवश्यकता को रेखांकित करता है।

अध्ययन में साहित्य समीक्षा, GIS विश्लेषण, फील्ड सर्वे तथा द्वितीयक आंकड़ों पर आधारित मिश्रित पद्धति अपनाई गई है। इसमें कंटूर, वाटरशेड, ड्रेनेज, ढाल, भूमि उपयोग, भूजल निर्भरता, जल आपूर्ति अवसंरचना तथा वार्ड-स्तरीय जनसंख्या घनत्व का विस्तृत विश्लेषण किया गया। साथ ही जल गुणवत्ता, जल मांग, जल वितरण प्रणाली तथा कुओं और हैंडपंपों पर निर्भरता का भी मूल्यांकन किया गया। अध्ययन में असमान जल वितरण, अपर्याप्त ड्रेनेज प्रणाली, पुनर्भरण क्षेत्रों में कमी, जलभराव तथा भूजल दोहन पर बढ़ती निर्भरता जैसी प्रमुख समस्याओं की पहचान की गई है।

इन निष्कर्षों के आधार पर शोध में जल निकायों के संरक्षण और पुनर्जीवन हेतु शहर-स्तरीय तथा वार्ड-स्तरीय रणनीतियाँ प्रस्तावित की गई हैं। सुझाए गए हस्तक्षेपों में वर्षा जल संचयन, पुनर्भरण संरचनाएँ, वर्षाजल निकासी प्रबंधन प्रणाली, गाद हटाना, पारिस्थितिक पुनर्स्थापन तथा जल निकायों का शहरी अवसंरचना के साथ एकीकरण शामिल हैं। अध्ययन पारंपरिक जल प्रबंधन प्रणालियों को आधुनिक नियोजन उपकरणों और GIS आधारित विश्लेषण के साथ जोड़ने पर भी बल देता है। समग्र रूप से, यह शोध दर्शाता है कि WSUD के सिद्धांत शहरी लचीलापन बढ़ाने, भूजल पुनर्भरण को सुदृढ़ करने, जल निकायों के संरक्षण तथा मंदसौर जैसे मध्यम आकार के भारतीय शहरों में सतत शहरी विकास को समर्थन देने में महत्वपूर्ण भूमिका निभा सकते हैं।

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List of Annexure

Annexure 1**:** Native Vegetation Suitable Species and their Ecological Role

Table 1.1: Native Vegetation Suitable for Ecological Restoration Around Water Bodies

Vegetation Type	**Suitable Native Species & Their Ecological Role**
Aquatic Plants	*Typha angustifolia* (cattail) and *Nelumbo nucifera* (lotus) help in nutrient uptake, improve water quality, and support wetland biodiversity (Kumar & Singh, 2020).
Emergent Vegetation	*Phragmites karka* and *Cyperus rotundus* stabilize shallow edges, reduce erosion, and filter sediments (Sharma et al., 2018).
Riparian Shrubs	*Vitex negundo* and *Clerodendrum infortunatum* provide bank stabilization and habitat for pollinators (Patel & Joshi, 2019).
Riparian Trees	*Ficus religiosa*, *Azadirachta indica*, and *Syzygium cumini* improve soil moisture, regulate microclimate, and prevent bank collapse (Rao & Reddy, 2021).
Grass Species	*Cenchrus ciliaris* and *Saccharum spontaneum* bind soil effectively along slopes and prevent silt runoff into tanks and lakes (Meena & Jat, 2017).

Annexure 2: Survey Questions

Table 2.1: Questionaries for Municipal Council and PHED

S.No.	Questions
1	What are the major issues affecting the water bodies of Mandsaur?
2	What are the major sources of water supply for Mandsaur?
3	What is the major source of pollution entering lakes or the Shivna River?
4	What challenges do you face in conserving water bodies?
5	What is the ward wise water supply frequency in Mandsaur?
6	What is ward wise distribution of water sources (treated and untreated piped water, wells, handpumps, other sources)?
7	Which ward has the highest dependency on groundwater?
8	Are there any NRW or leakage estimates?
9	Has city considered Water Sensitive Urban Development or similar approaches?
10	What is the average duration of water supply in each ward?

Annexure 3: Plagiarism Report



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ORIGINALITY REPORT

8%	6%	5%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	citygreen.com	Internet Source
2	Ariva Sugandi Permana. "Urban Engineering", Routledge, 2025	Publication
3	Mohammad Karamouz, Ali Moridi. "Urban Water Engineering and Management", CRC Press, 2025	Publication
4	"Deltas Resilience", Springer Science and Business Media LLC, 2026	Publication
5	waterbydesign.com.au	Internet Source
6	www.mdpi.com	Internet Source
7	grokipedia.com	Internet Source
8	www.denta.co.in	Internet Source
9	cperiyar.org	Internet Source
10	"Urban Waterscapes", Springer Science and Business Media LLC, 2026	Publication
11	krishikosh.egranth.ac.in	Internet Source
12	"Water Security and Climate Change", Springer Science and Business Media LLC, 2026	Publication
13	www.bseindia.com	Internet Source
14	lg.treasury.gov.za	Internet Source
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Figure 3.1: Plagiarism report *Source: Turnitin*