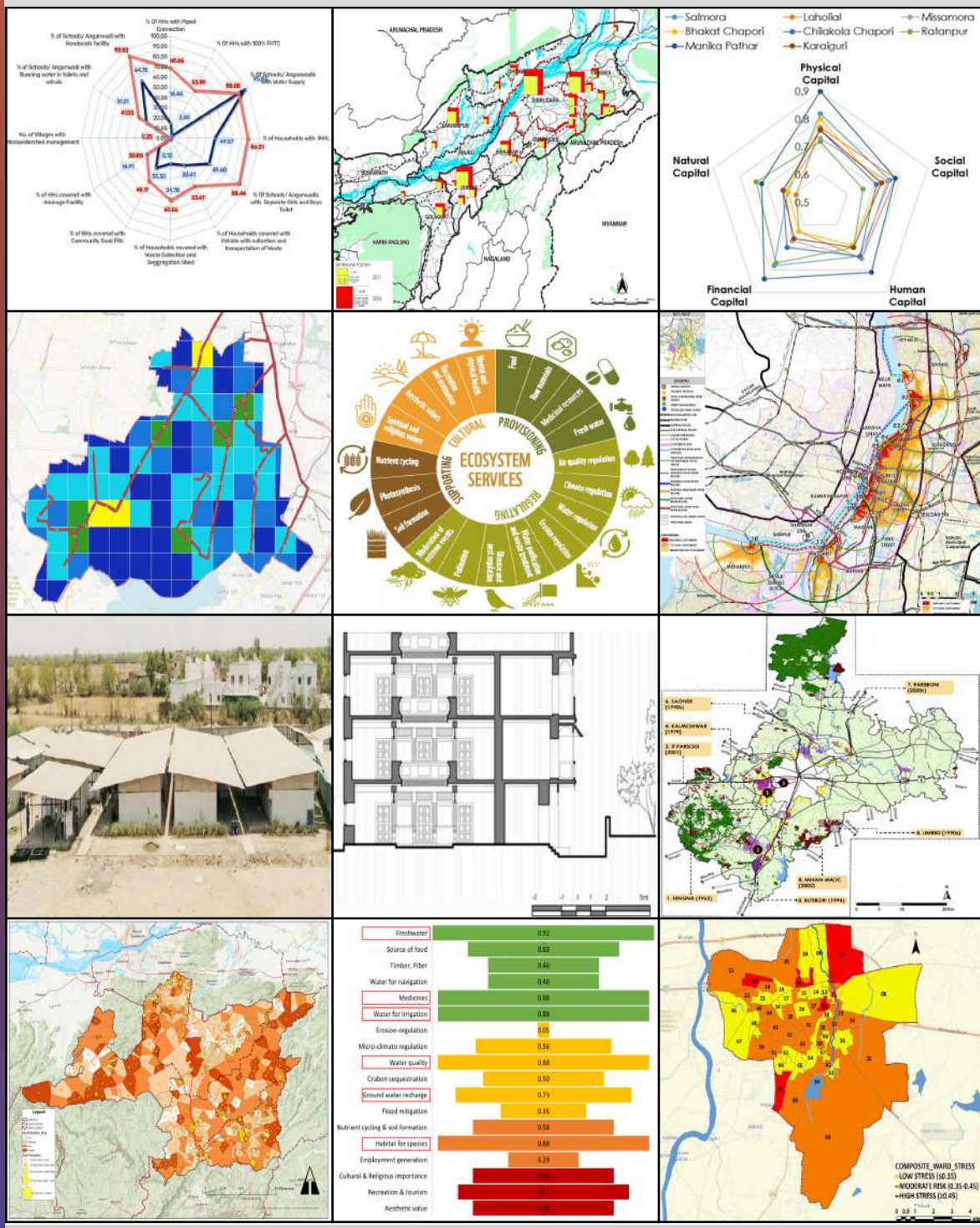
School of Planning and Architecture, New Delhi
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योजना तथा वास्तुकला विद्यालय, नई दिल्ली
संसद के अधिनियम के तहत "राष्ट्रीय महत्व का संस्थान" (शिक्षा मंत्रालय, भारत सरकार)

Sustainable Development for Human Settlements Indian Perspective



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SPACE, The SPA Journal of Planning and Architecture

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The School of Planning and Architecture, New Delhi is one of India's leading research and teaching institutions. School offers planning, architecture and design courses both at undergraduate, and postgraduate levels. While the Bachelor of Architecture course is one of the oldest courses in the country, a highly successful Bachelor of Planning course was started in 1989. From 2019 batch, option of Integrated Master of Planning program is now available for students admitted in Bachelor of Planning after third year. School offers two undergraduate degree programs, ten postgraduate degree programs and one integrated program. Doctoral programs are offered by all departments of studies.

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Editorial

Sustainable Development (SD) is now about four decades old, considering the 1987 publication of the report Our Common Future, produced by the World Commission on Environment and Development[1], as a reference. The historic United Nations Summit held in September 2015 in Paris adopted the 2030 Agenda for Sustainable Development – the 17 Sustainable Development Goals, the blueprint to achieve a better and more sustainable future for all.[2] This special issue of SPACE, The SPA Journal of Planning and Architecture, weaves around *Sustainable Development*. Twelve papers are curated and published; they form the content of this Special Issue on *Sustainable Development for Human Settlements: Indian Perspective.* The papers presented provide discourse on vital aspects that are fundamentally connected to multiple Sustainable Development Goals (SDGs) and offer insight into the *modus operandi* for the Indian subcontinent (see Figure 1 and Table 1).

CHITRAREKHA KABRE

(Editor)

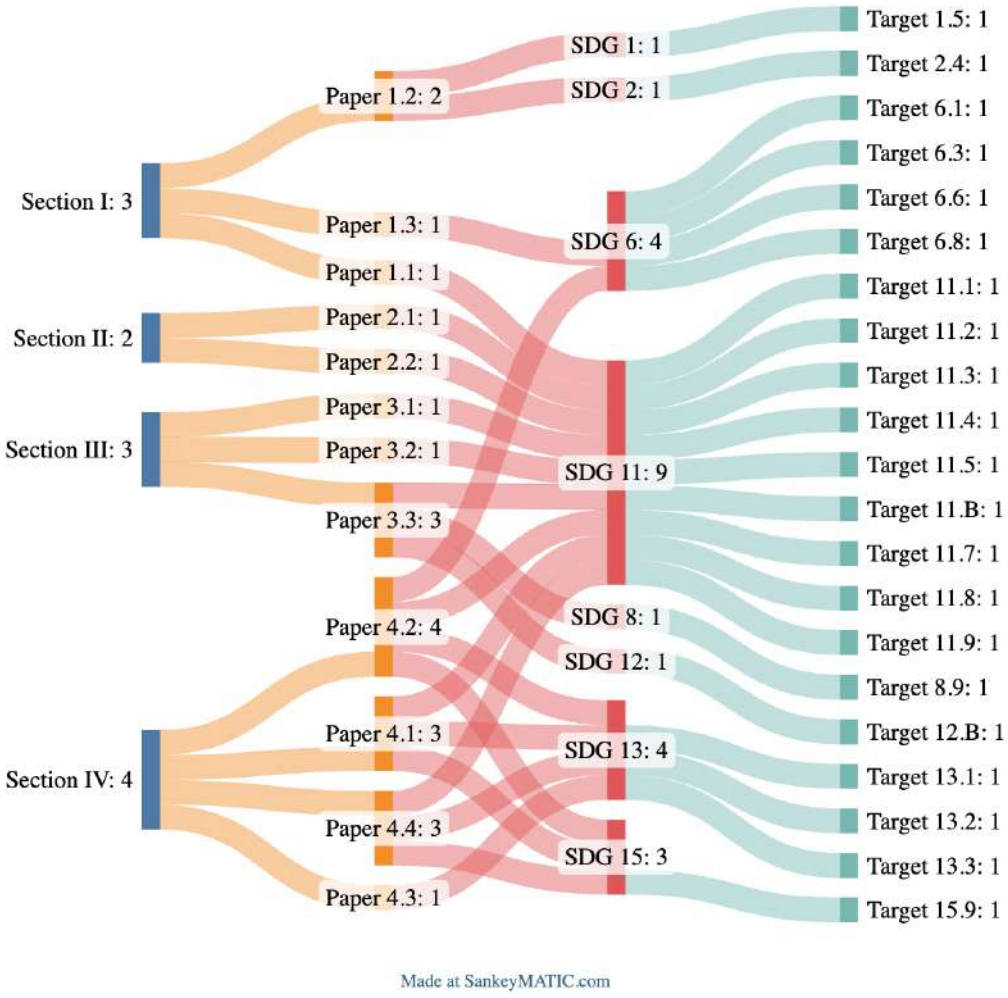


Figure 1. Mapping four sections and twelve papers with Sustainable Development Goals and the respective targets

"The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States."

[1] Brundtland, G. H. ed. 1987. *Our common future: report of the World Commission on Environment and Development*. Oxford University Press.

[2] https://www.un.org/sustainabledevelopment

Table 1. Mapping topics with the Sustainable Development Goals and the respective targets.

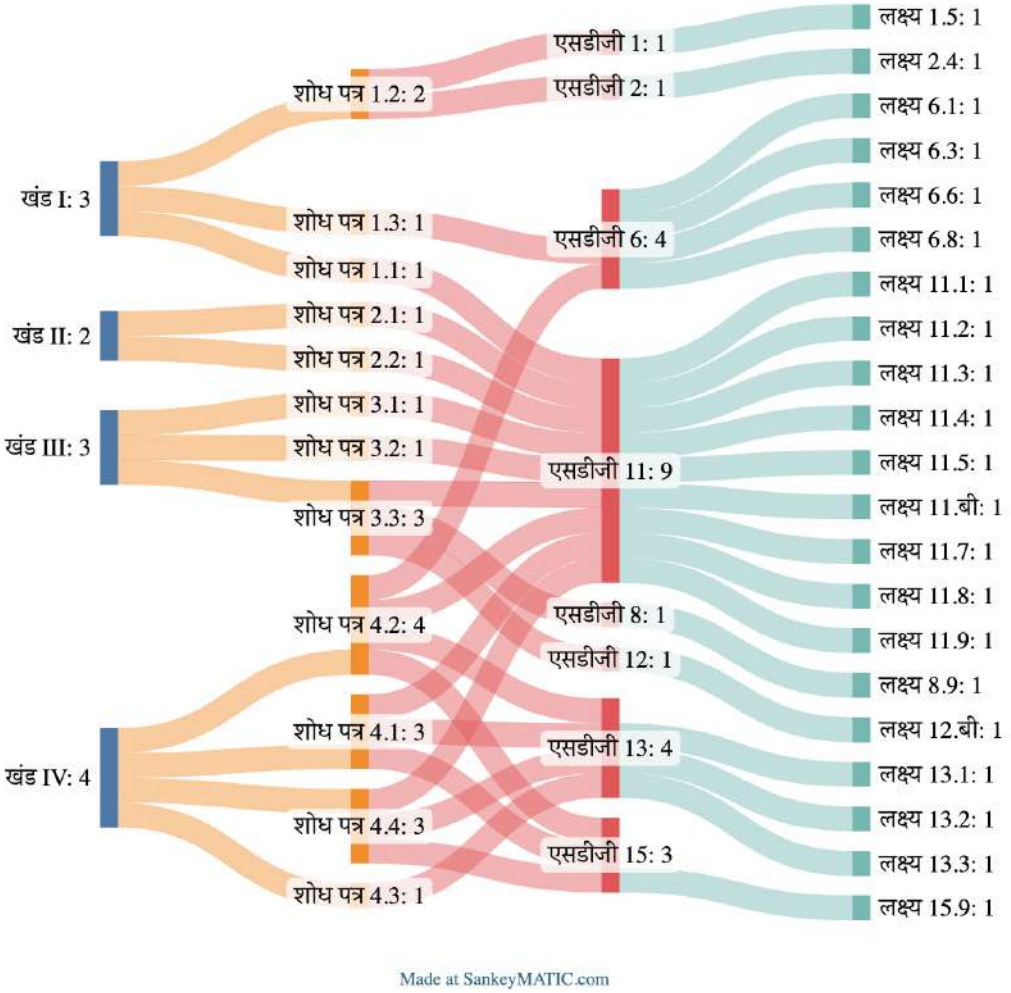
S. No.	Topic	SDG	Description	Target	Description
1.1	Potential of Dibrugarh as a Growth Pole for the Development of Upper Assam	11	Sustainable Cities and Communities	11.8	Strong national and regional development planning
1.2	Developing a Resilient Livelihood Framework for the Island District of Majuli, Assam	1	No Poverty	1.5	Build resilience to environmental, economic and social disasters
		2	Zero Hunger	2.4	sustainable food production and resilient agricultural practices
1.3	Localising SDG-6 Indicators for Water, Sanitation and Hygiene (WaSH): Case of Baran District, Rajasthan	6	Clean Water and Sanitation	6.8	Support Local Engagement in water and sanitation management
2.1	Planning for Public Transport System in Inaccessible Areas: Delhi	11	Sustainable Cities and Communities	11.2	Affordable and sustainable transport Systems
2.2	Integrating Waterways into the Public Transportation Network of Kolkata				
3.1	Assessing Housing Conditions for Construction Workers and Policy Frameworks: A case of Bengaluru	11	Sustainable Cities and Communities	11.1	Safe and affordable housing
3.2	Housing for Industrial Workers in the Nagpur Metropolitan Region				
3.3	Pilgrims' accommodation options in Gaya, Bihar	8	Decent Work and Economic Growth	8.9	Devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products.
		11	Sustainable Cities and Communities	11.4	Strengthen efforts to protect and safeguard the world's cultural and natural heritage
		12	Responsible Consumption and Production	12.B	Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products
4.1	Integrating Traditional Knowledge Systems in Spatial Planning for Climate Change Adaptation: A Case of Ri Bhoi District, Meghalaya	11	Sustainable Cities and Communities	11.9	Implement Policies for Inclusion, Resource Efficiency and Disaster Risk Reduction
		13	Climate Action	13.2	Integrate climate change measures into national/local policies and planning
		15	Life on land	15.9	Integrate Ecosystem and Biodiversity in Governmental Planning
4.2	Environmental Planning Strategies for Urban Rivers: A Case Study of Gurupura River in the Coastal City of Mangaluru	6	Clean Water and Sanitation	6.6	Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes
		11	Sustainable Cities and Communities	11.4	Protecting cultural and natural heritage
		15	Life on land	15.9	Integrate Ecosystem and Biodiversity in Governmental Planning
4.3	Climate Adaptation Plan for Jalgaon, Maharashtra	6	Clean Water and Sanitation	6.1	Safe and affordable drinking water
		11	Sustainable Cities and Communities	11.7	Provide access to safe and inclusive green and public spaces
		13	Climate Action	13.1	Strengthening resilience and adaptive capacity to climate-related disasters
4.4	City Resilience through Ecosystem Services: Bhubaneswar	11	Sustainable Cities and Communities	11.5	Disaster Resilience
				11.B	Disaster Risk Management
		13	Climate Action	13.3	Build Knowledge and capacity to meet climate change
		15	Life on land	15.9	Integrate Ecosystem and Biodiversity in Governmental Planning

संपादकीय

सतत विकास की अवधारणा अब लगभग चार दशक पुरानी है, यदि पर्यावरण और विकास पर विश्व आयोग[3] द्वारा 1987 में प्रकाशित रिपोर्ट 'अवर कॉमन फ्यूचर' को संदर्भ माना जाए। सितंबर 2015 में पेरिस में आयोजित ऐतिहासिक संयुक्त राष्ट्र शिखर सम्मेलन में सतत विकास के लिए 2030 एजेंडा–17 सतत विकास लक्ष्य, सभी के लिए एक बेहतर और अधिक सतत भविष्य प्राप्त करने की रूपरेखा को अपनाया गया हैं[4] ' स्पेस, एसपीए योजना और वास्तुकला' पत्रिका का यह विशेष अंक सतत विकास पर केंद्रित है। इसके लिए बारह शोधपत्रों का चयन और प्रकाशन किया गया हैं; वे सतत विकास पर इस विशेष अंक "*मानव बस्तियों के लिए सतत विकास: भारतीय परिप्रेक्ष्य*" की विषयवस्तु का निर्माण करते हैं। प्रस्तुत शोध-पत्र उन महत्वपूर्ण पहलुओं पर विमर्श प्रस्तुत करते हैं जो मूल रूप से कई सतत विकास लक्ष्यों से जुड़े हुए हैं और भारतीय उपमहाद्वीप के लिए कार्यप्रणाली की अंतर्दृष्टि प्रदान करते हैं (चित्र 1 और तालिका 1 देखें)।

चित्ररेखा काबरे

(संपादक)



चित्र 1. चार खंडों और बारह शोधपत्रों का सतत विकास लक्ष्यों और संबंधित लक्ष्यों के साथ मानचित्रण

"इस प्रकाशन की सामग्री को संयुक्त राष्ट्र द्वारा अनुमोदित नहीं किया गया है और यह संयुक्त राष्ट्र या उसके अधिकारियों या सदस्य देशों के विचारों को प्रतिबिंबित नहीं करती।"

[3] Brundtland, G. H. ed. 1987. *Our common future: report of the World Commission on Environment and Development*. Oxford University Press.

[4] https://www.un.org/sustainabledevelopment

तालिका 1. सतत विकास लक्ष्यों और संबंधित लक्ष्यों के साथ शोधपत्रों के विषयों का मानचित्रण

क्रम संख्या	विषय	एसडीजी	Description	लक्ष्य	Description
1.1	ऊपरी असम के विकास के लिए विकास ध्रुव के रूप में डिब्रूगढ़ की क्षमता	11	सतत शहर और समुदाय	11.8	मजबूत राष्ट्रीय और क्षेत्रीय विकास योजना
1.2	असम के माजुली द्वीप ज़िले के लिए एक लचीला आजीविका ढाँचा विकसित करना	1	गरीबी की पूर्णतः समाप्ति	1.5	पर्यावरणीय, आर्थिक और सामाजिक आपदाओं के प्रति लचीलापन विकसित करें
		2	भुखमरी की समाप्ति	2.4	सतत खाद्य उत्पादन और लचीली कृषि पद्धतियाँ
1.3	जल, स्वच्छता एवं स्वास्थ्य (वॉश) के लिए सतत विकास लक्ष्य-6 के संकेतकों का स्थानीयकरण: बारां जिला, राजस्थान	6	स्वच्छ जल और स्वच्छता	6.8	जल एवं स्वच्छता प्रबंधन में स्थानीय भागीदारी का समर्थन करें
2.1	दुर्गम क्षेत्रों में सार्वजनिक परिवहन प्रणाली की योजना: दिल्ली	11	सतत शहर और समुदाय	11.2	किफायती और टिकाऊ परिवहन प्रणालियाँ
2.2	कोलकाता के सार्वजनिक परिवहन नेटवर्क में जलमार्गों को एकीकृत करना				
3.1	निर्माण श्रमिकों और नीति ढांचे के लिए आवास की स्थिति का आकलन: बेंगलुरु का एक मामला	11	सतत शहर और समुदाय	11.1	सुरक्षित और किफायती आवास
3.2	नागपुर महानगरीय क्षेत्र में औद्योगिक श्रमिकों के लिए आवास				
3.3	गया, बिहार में तीर्थयात्रियों के लिए आवास विकल्प	8	सभ्य कार्य और आर्थिक विकास	8.9	लाभदायक और टिकाऊ पर्यटन को बढ़ावा देना.
		11	सतत शहर और समुदाय	11.4	विश्व की सांस्कृतिक और प्राकृतिक धरोहरों की रक्षा करें
		12	जिम्मेदार उपभोग और उत्पादन	12.बी	सतत पर्यटन की निगरानी के लिए उपकरण विकसित और कार्यान्वित करें
4.1	जलवायु परिवर्तन अनुकूलन के लिए स्थानिक योजना में पारंपरिक ज्ञान प्रणालियों को एकीकृत करना: री भोई जिले, मेघालय का मामला	11	सतत शहर और समुदाय	11.9	समावेशन, संसाधन दक्षता और आपदा जोखिम न्यूनीकरण के लिए नीतियां लागू करें
		13	जलवायु कार्रवाई	13.2	जलवायु परिवर्तन संबंधी उपायों को नीतियों और योजनाओं में एकीकृत करें
		15	स्थलीय पारिस्थितिक तंत्र की सुरक्षा	15.9	सरकारी नियोजन में पारिस्थितिकी तंत्र और जैव विविधता को एकीकृत करें
4.2	शहरी नदियों के लिए पर्यावरण योजना रणनीतियाँ: मंगलुरु की गुरुपुरा नदी का मामला	6	स्वच्छ जल और स्वच्छता	6.6	जल संबंधी पारिस्थितिक तंत्रों की रक्षा और पुनर्स्थापन करें
		11	सतत शहर और समुदाय	11.4	विश्व की सांस्कृतिक और प्राकृतिक धरोहरों की रक्षा करें
		15	स्थलीय पारिस्थितिक तंत्र की सुरक्षा	15.9	सरकारी नियोजन में पारिस्थितिकी तंत्र और जैव विविधता को एकीकृत करें
4.3	जलगाँव, महाराष्ट्र के लिए जलवायु अनुकूलन योजना	6	स्वच्छ जल और स्वच्छता	6.1	सुरक्षित और किफायती पेयजल
		11	सतत शहर और समुदाय	11.7	सुरक्षित और समावेशी हरित एवं सार्वजनिक स्थानों तक पहुंच प्रदान करें
		13	जलवायु कार्रवाई	13.1	जलवायु संबंधी आपदाओं के प्रति लचीलापन और अनुकूलन क्षमता को मजबूत करें
4.4	पारिस्थितिकी तंत्र सेवाओं के माध्यम से शहर की प्रत्यास्थता: भुवनेश्वर	11	सतत शहर और समुदाय	11.5	प्राकृतिक आपदाओं के प्रतिकूल प्रभावों को कम करें
				11.बी	Disaster Risk Management
		13	जलवायु कार्रवाई	13.3	जलवायु परिवर्तन का सामना करने के लिए ज्ञान और क्षमता का निर्माण करें
		15	स्थलीय पारिस्थितिक तंत्र की सुरक्षा	15.9	सरकारी नियोजन में पारिस्थितिकी तंत्र और जैव विविधता को एकीकृत करें

Guest Editorial

This special issue of SPACE, The SPA Journal of Planning and Architecture, contains twelve research papers organised into four thematic sections: sustainable regional development; sustainable mobility and urban transport systems; housing, livelihoods, and inclusive community and, climate and environmental resilience in planning. These contributions span diverse geographical regions in India and advance interdisciplinary knowledge. These research papers underscore the interconnectedness of infrastructure, ecology, mobility, livelihoods, participatory governance, and context-driven planning approaches in shaping an equitable and resilient landscape for urban and regional planning in India.

Section 1: Sustainable Regional Development

"Potential of Dibrugarh as a growth pole for the development of Upper Assam" investigates Dibrugarh's strategic role as a regional engine of socio-economic transformation and illustrates how connectivity, industrial linkages, and institutional capacities can collectively anchor balanced regional development. "Developing a resilient livelihood framework for the island district of Majuli, Assam" uses the Sustainable Livelihoods Framework and examines access to the five livelihood assets—physical capital, human capital, social capital, financial capital, and natural capital. It proposes strategic interventions such as capacity building, infrastructure development, strengthening social networks, income diversification, and community-led flood management. "Localising SDG-6 indicators for water, sanitation and hygiene (WaSH): case of Baran district, Rajasthan" uses a mixed-method approach to assess water supply, sanitation, and waste management in rural areas and proposes integrating Panchayat Development Indices with WaSH monitoring systems to generate relevant data and accelerate SDG-6 progress in rural regions.

Section 2: Sustainable mobility and Urban Transport Systems

"Planning for public transport system in inaccessible areas: Delhi" is based on an empirical study to assess the accessibility levels of Chhawala ward, a public transport-underserved area in Delhi and to evaluate the potential of the neighbourhood bus system as a feasible solution in it. "Integrating waterways into the public transportation network of Kolkata" uses cross-case studies and the Adaptive Large Neighbourhood Search (ALNS) tool to design ferry routes. Surveys measuring latent demand and performance metrics (travel time, emissions, accessibility) indicate that ferry operations, combined with last-mile transportation (e-rickshaws, cycleways, pedestrian links), can reduce average journey times by 40 percent, thereby serving underserved populations.

Section 3: Housing, Livelihoods, and Inclusive Communities

"Assessing housing conditions for construction workers and policy frameworks: a case of Bengaluru" evaluates housing provisions and precarious living conditions of migrant construction workers through the lens of safety, affordability, and accessibility. This study proposes a multi-scalar strategy: Aadhaar-linked national registration of construction workers, the integration of labour housing into Karnataka's State Housing Policy, and three models of affordable rental and permanent housing. "Housing for industrial workers in Nagpur Metropolitan Region" assesses the spatial and socio-economic determinants influencing workers' housing choices and proposes an integrated housing–transport–industry planning to ensure quality living environments for industrial labour. "Pilgrims' accommodation options in Gaya, Bihar" identifies gaps in pilgrims' infrastructure and proposes diversified, culturally sensitive lodging solutions to balance peak-season demand with long-term community impact.

Section 4: Climate and Environmental Resilience in Planning

"Integrating traditional knowledge systems in spatial planning for climate change adaptation: case of Ri Bhoi district, Meghalaya" uses the Sustainable Livelihood Framework to examine the spatial imprint and current state of TKS and suggests that spatial planning proposals—such as zoning adjustments, community mapping platforms, and incentive-based conservation schemes—are needed to integrate TKS into mainstream governance. "Environmental planning strategies for urban rivers: the Gurupura river case of Mangaluru" examines ecological degradation in coastal river systems and proposes a multi-scalar environmental planning approach that combines land-use regulation, watershed management, and pollution control. "Climate adaptation plan for Jalgaon, Maharashtra" presents a district-level climate adaptation blueprint integrating hazard mapping, vulnerability assessment, and sectoral resilience measures. "City resilience through ecosystem services: Bhubaneswar" draws on literature review, case studies, and policy interventions to examine the contribution of ecosystem services to strengthen urban resilience to cyclone-induced and intense-rainfall-induced urban flooding, focusing on the Indian coastal city of Bhubaneswar.

NILANJANA DASGUPTA SUR
(Guest Editor)

अतिथि संपादकीय

स्पेस, एसपीए योजना और वास्तुकला पत्रिका के इस विशेष अंक में बारह शोध-पत्रों को शामिल किया गया है, जिन्हें चार विषयगत अनुभागों में संगठित किया गया है: क्षेत्रीय विकास, सतत गतिशीलता, समावेशी आवास और जलवायु-अनुकूल योजना। ये योगदान भारत के अलग-अलग भौगोलिक क्षेत्रों तक फैले हुए हैं, और अंतर-विषयक ज्ञान को आगे बढ़ाते हैं। ये शोध-पत्र भारत में शहरी और क्षेत्रीय नियोजन के लिए एक न्यायसंगत और लचीले परिदृश्य को आकार देने में बुनियादी ढाँचे, पर्यावरण, आवागमन, आजीविका, सहभागी शासन और संदर्भ-आधारित नियोजन दृष्टिकोणों की परस्पर संबद्धता को रेखांकित करते हैं।

अनुभाग 1: क्षेत्रीय विकास एवं नगरीय समावेशन

''ऊपरी असम के विकास के लिए विकास ध्रुव के रूप में डिब्रूगढ़ की क्षमता'' यह सामाजिक-आर्थिक बदलाव के क्षेत्रीय इंजन के तौर पर डिब्रूगढ़ की रणनीतिक भूमिका का विवेचन करता है और बताता है कि कैसे संपर्क-सुविधा, औद्योगिक संबंध और संस्थागत क्षमताएँ सामूहिक रूप से संतुलित क्षेत्रीय विकास को आधार प्रदान कर सकती हैं। ''असम के माजुली द्वीप ज़िले के लिए एक लचीला आजीविका ढाँचा विकसित करना'' में सतत आजीविका ढाँचे का उपयोग किया गया है और पाँच आजीविका परिसंपत्तियों—भौतिक पूँजी, मानव पूँजी, सामाजिक पूँजी, वित्तीय पूँजी, और प्राकृतिक पूँजी—तक पहुँच की जाँच की गई है। इसमें क्षमता निर्माण, बुनियादी ढांचे का विकास, सामाजिक नेटवर्क को मज़बूत करना, आय के स्रोतों में विविधता लाना और समुदाय के नेतृत्व में बाढ़ प्रबंधन जैसे रणनीतिक उपाय सुझाए गए हैं। "जल, स्वच्छता एवं स्वास्थ्य (वॉश) के लिए सतत विकास लक्ष्य-6 के संकेतकों का स्थानीयकरण: बारां जिला, राजस्थान" ग्रामीण क्षेत्रों में जलापूर्ति, स्वच्छता, और अपशिष्ट प्रबंधन का आकलन करने के लिए मिश्रित- पद्धति का उपयोग करता है। साथ ही, पंचायत विकास सूचकांकों को WaSH मॉनिटरिंग सिस्टम के साथ जोड़ने का सुझाव देता है और ग्रामीण क्षेत्रों में सतत विकास लक्ष्य-6 की प्रगति को तेज करने तथा स्थानीय रूप से प्रासंगिक डेटा तैयार करने के लिए पंचायत विकास सूचकांकों को वॉश निगरानी प्रणालियों के साथ एकीकृत करने का प्रस्ताव करता है।

अनुभाग 2: सतत गतिशीलता और नगरीय परिवहन प्रणाली

"दुर्गम क्षेत्रों में सार्वजनिक परिवहन प्रणाली की योजना: दिल्ली" एक अनुभवजन्य अध्ययन पर आधारित है, जिसका उद्देश्य इसका दिल्ली के सार्वजनिक परिवहन से वंचित क्षेत्र छावला वार्ड की पहुंच के सुविधा स्तर का आकलन करना और इसमें स्थानीय बस प्रणाली की एक व्यवहार्य समाधान के रूप में संभावनाओं का मूल्यांकन करना है। "कोलकाता के सार्वजनिक परिवहन नेटवर्क में जलमार्गों को एकीकृत करना" में तुलनात्मक प्रकरण अध्ययनों और अनुकूली वृहत स्थानीय खोज उपकरण का उपयोग करके फेरी मार्गों का डिज़ाइन किया गया है। अव्यक्त मांग और निष्पादन मापक (जैसे यात्रा का समय, उत्सर्जन, अभिगम्यता) को मापने वाले सर्वेक्षण बताते हैं कि फेरी सर्विस को लास्ट-माइल ट्रांसपोर्टेशन, ई-रिक्शा, साइकिल ट्रैक और पैदल चलने वालों के लिए रास्तों जैसी सुविधाओं के साथ जोड़ा जाए, तो यात्रा के औसत समय में 40% तक की कमी लाई जा सकती है और उन लोगों तक भी सेवा पहुंचाई जा सकती है, जिन्हें अभी तक ये सुविधाएं नहीं मिल पा रही हैं।

अनुभाग 3: आवास, आजीविका और समावेशी समुदाय

"निर्माण श्रमिकों और नीति ढांचे के लिए आवास की स्थिति का आकलन: बेंगलुरु का एक मामला'' में सुरक्षा, सामर्थ्य और सुलभता के आधार पर प्रवासी निर्माण श्रमिकों के आवास प्रावधानों और अनिश्चित जीवन स्थितियों का मूल्यांकन करता है। यह अध्ययन एक ऐसी मल्टी-स्केलर रणनीति का सुझाव देती है जो आधार से जुड़े राष्ट्रीय रजिस्ट्रेशन, कर्नाटक की राज्य आवास नीति में मज़दूरों के लिए आवास को शामिल करने और किफायती किराए व स्थायी आवास मॉडल को बढ़ावा देने पर ज़ोर देती है। "नागपुर महानगरीय क्षेत्र में औद्योगिक श्रमिकों के लिए आवास" में श्रमिकों के आवास चयन को प्रभावित करने वाले स्थानिक एवं सामाजिक-आर्थिक कारकों का आकलन किया गया है। यह पत्र एकीकृत आवास-परिवहन-उद्योग योजना की आवश्यकता पर बल देता है, जिससे औद्योगिक श्रम को गरिमामय जीवन परिवेश सुनिश्चित किए जा सकें। "गया, बिहार में तीर्थयात्रियों के लिए आवास विकल्प" में तीर्थ-आवास अवसंरचना में खामियों का अध्ययन किया गया है। यह पत्र विविध, सांस्कृतिक रूप से संवेदनशील आवास समाधान प्रस्तावित करता है जो शिखर काल माँग को लंबकालीन समुदाय प्रभाव से संतुलित करता है।

अनुभाग 4: नियोजन में जलवायु और पर्यावरणीय लचीलापन

"जलवायु परिवर्तन अनुकूलन के लिए स्थानिक योजना में पारंपरिक ज्ञान प्रणालियों को एकीकृत करना: री भोई जिले, मेघालय का मामला" सतत आजीविका रूपरेखा का उपयोग करके टीकेएस की स्थानिक छाप और वर्तमान स्थिति की जांच करता है और सुझाव देता है कि स्थानिक योजना प्रस्ताव - जैसे ज़ोनिंग समायोजन, सामुदायिक मानचित्रण मंच और प्रोत्साहन-आधारित संरक्षण योजनाएँ - टीकेएस को मुख्यधारा के शासन में एकीकृत करने के लिए आवश्यक हैं। ''शहरी नदियों के लिए पर्यावरण योजना रणनीतियाँ: मंगलुरु की गुरुपुरा नदी का मामला'' तटीय नदी प्रणालियों में पारिस्थितिक क्षरण की जाँच करता है और एक बहु-स्तरीय पर्यावरण योजना दृष्टिकोण प्रस्तावित करता है, जो भूमि-उपयोग विनियमन, जलग्रहण क्षेत्र प्रबंधन और प्रदूषण नियंत्रण को एकीकृत करता है। ''जलगाँव, महाराष्ट्र के लिए जलवायु अनुकूलन योजना'' एक जिला-स्तरीय जलवायु अनुकूलन खाका प्रस्तुत करती है, जिसमें खतरा मानचित्रण, भेद्यता मूल्यांकन और क्षेत्रवार प्रत्यास्थता उपायों को एकीकृत किया गया है। "पारिस्थितिकी तंत्र सेवाओं के माध्यम से शहर की प्रत्यास्थता: भुवनेश्वर" साहित्य समीक्षा, मामले के अध्ययन, और नीतिगत हस्तक्षेपों पर आधारित होकर यह जांचता है कि पारिस्थितिकी तंत्र सेवाएँ चक्रवात-प्रेरित और तीव्र-वर्षा-प्रेरित शहरी बाढ़ के प्रति शहरी प्रत्यास्थता को मजबूत करने में कैसे योगदान देती हैं, जिसमें भारतीय तटीय शहर भुवनेश्वर पर ध्यान केंद्रित किया गया है।

नीलांजना दासगुप्ता सुर
(अतिथि संपादक)

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Potential of Dibrugarh as a Growth Pole for the Development of Upper Assam

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Abstract: Assam's development trajectory has long been characterised by persistent regional disparities, with Upper Assam consistently lagging behind Lower Assam across key socio-economic indicators. This imbalance presents a critical challenge to equitable regional development and underscores the need for spatially differentiated planning approaches. Situated within this broader concern, the present study explores the potential of Dibrugarh city to function as a growth pole capable of catalysing development in Upper Assam. Anchored in Growth Pole theory and supported by the concepts of urban hierarchy, the study addresses the central question: Can Dibrugarh serve as a functional nucleus to drive economic growth and reduce intra-regional disparity in Assam? The research first establishes the extent of development disparity through a district-wise comparative analysis. This is followed by an evaluation of urban centres' performance in Upper Assam using a Composite Functionality Index (CFI), developed through both primary and secondary data across domains including healthcare, education, trade and commerce, connectivity, and industrial base. Findings reveal Dibrugarh as the most functionally equipped urban centre in the region. A sectoral economic assessment further highlights the city's industrial strength in tea, oil and gas, plywood, and emerging sectors such as healthcare, education, and tourism. While Dibrugarh demonstrates clear functional and locational advantages, infrastructural and institutional limitations persist. The study recommends a revised settlement hierarchy, positioning Dibrugarh as a Regional Centre and potential Second Capital of Assam. The findings present a strategic direction to unlock spatial equity and catalyze integrated development across Upper Assam.

Keywords: Growth Pole; Urban Hierarchy; Composite Functionality Index; Regional Disparity; Dibrugarh

सार: असम के विकास मार्ग की विशेषता लंबे समय से निरंतर क्षेत्रीय असमानताओं द्वारा निर्धारित रही है, जहाँ ऊपरी असम लगातार निचले असम की तुलना में प्रमुख सामाजिक-आर्थिक सूचकों पर पिछड़ा हुआ है। यह असंतुलन समान क्षेत्रीय विकास के लिए एक गंभीर चुनौती प्रस्तुत करता है और स्थानिक रूप से विभेदित नियोजन दृष्टिकोणों की आवश्यकता को रेखांकित करता है। इसी व्यापक परिप्रेक्ष्य में प्रस्तुत अध्ययन डिब्रूगढ़ शहर की उस क्षमता की पड़ताल करता है, जिसके माध्यम से वह ऊपरी असम में विकास को प्रोत्साहित करने वाले एक विकास ध्रुव के रूप में कार्य कर सकता है। विकास ध्रुव सिद्धांत तथा शहरी पदानुक्रम की अवधारणाओं पर आधारित यह शोध केंद्रीय प्रश्न को संबोधित करता है: क्या डिब्रूगढ़ एक कार्यात्मक केंद्र के रूप में कार्य कर सकता है जो आर्थिक विकास को गति दे और असम के भीतर क्षेत्रीय असमानता को कम करे? अनुसंधान की शुरुआत जिलावार तुलनात्मक विश्लेषण के माध्यम से विकास असमानता की सीमा को स्थापित करने से होती है। इसके पश्चात, संयुक्त कार्यक्षमता सूचकांक के माध्यम से ऊपरी असम के शहरी केंद्रों के प्रदर्शन का मूल्यांकन किया गया है, जो स्वास्थ्य सेवा, शिक्षा, व्यापार एवं वाणिज्य, संपर्कता, और औद्योगिक आधार जैसे क्षेत्रों में प्राथमिक एवं द्वितीयक आंकड़ों पर आधारित है। निष्कर्ष स्पष्ट रूप से दर्शाते हैं कि डिब्रूगढ़ क्षेत्र का सबसे अधिक कार्यात्मक रूप से सुसज्जित शहरी केंद्र है। क्षेत्रवार आर्थिक मूल्यांकन से यह भी स्पष्ट होता है कि शहर की औद्योगिक शक्ति चाय, तेल और गैस, प्लाईवुड उद्योग, तथा स्वास्थ्य सेवा, शिक्षा और पर्यटन जैसे उभरते क्षेत्रों में विद्यमान है। यद्यपि डिब्रूगढ़ के पास स्पष्ट कार्यात्मक और भौगोलिक लाभ हैं, फिर भी बुनियादी ढाँचे और संस्थागत सीमाएँ बनी हुई हैं। यह अध्ययन एक संशोधित आवासीय पदानुक्रम की सिफारिश करता है, जिसके अंतर्गत डिब्रूगढ़ को एक क्षेत्रीय केंद्र और असम की संभावित द्वितीय राजधानी के रूप में स्थापित करने का प्रस्ताव है। अध्ययन के निष्कर्ष स्थानिक समानता को साकार करने और ऊपरी असम में समेकित विकास को प्रोत्साहित करने की एक रणनीतिक दिशा प्रस्तुत करते हैं।

मुख्य शब्द: विकास ध्रुव; शहरी पदानुक्रम; समग्र कार्यक्षमता सूचकांक; क्षेत्रीय असमानता; डिब्रूगढ़

1. Introduction

Assam's growth trajectory has remained spatially uneven, with persistent disparities between Upper Assam and Lower Assam in terms of socio-economic development. While Lower Assam has benefited from sustained public investment and greater integration into state-level decision-making, Upper Assam continues to lag across key indicators, including healthcare, education, infrastructure, and economic diversification. These imbalances pose a structural challenge to inclusive growth and demand spatially nuanced planning responses.

Upper Assam, despite its resource-rich profile and historical economic relevance, has witnessed fragmented urban development and institutional neglect. The region's urban centres have functioned mainly in isolation, lacking the necessary functional integration to drive broader regional development. In this context, there is a pressing need to identify a strategically located urban node that can catalyse growth across the region through targeted investment, spatial linkages, and institutional coordination.

This study examines the potential of Dibrugarh city to function as a growth pole for Upper Assam. Historically known for its tea

industry, oil and natural gas reserves, and strategic location along the Brahmaputra, Dibrugarh possesses the necessary economic and infrastructural base to anchor regional transformation. The research is grounded in Growth Pole Theory and draws on the concepts of urban hierarchy and spatial planning to frame its inquiry. By systematically assessing development disparities, evaluating functional capacities using a Composite Functionality Index (CFI), and mapping sectoral linkages, the study proposes a grounded strategy for leveraging Dibrugarh's potential to reduce intra-state disparities and promote regionally balanced development.

2. Strategies for Balanced Regional Development

Balanced Regional Development aims to reduce spatial disparities by promoting inclusive economic growth, infrastructural expansion, and institutional support across all regions. In India, the dominance of metropolitan centres such as Delhi, Mumbai, and Bengaluru has led to regional polarisation, leaving many peripheral, resource-rich areas underdeveloped. Addressing this imbalance requires decentralized development, stronger rural–urban linkages, and targeted spatial strategies.

The theory of Cumulative Causation (Myrdal 1957) highlights how developed regions continue to grow through spread effects (positive externalities that benefit adjacent areas) and backwash effects (draining resources from less developed regions). For instance, the economic success of cities like Hyderabad has extended to nearby towns through employment and supply chain linkages. However, the dominance of backwash effects often further marginalizes backward regions, unless checked by public policy. Myrdal strongly advocated state-led interventions to counteract free-market imbalances, such as infrastructure investment and the promotion of regional industrial hubs.

While acknowledging similar dynamics, Hirschman (1958) viewed regional inequality as a temporary and necessary phase of development. His Trickling-Down Effect explains how concentrated growth can eventually stimulate development in lagging areas, provided there are strong economic linkages and institutional support. However, the Polarisation Effect, where investment and talent remain confined to advanced areas, can undermine this process. Hirschman emphasized building interregional connections and strengthening secondary cities to facilitate broader growth.

3. Growth Pole Theory

The Growth Pole Theory (Perruoux 1955) is a foundational concept in regional development that posits that economic growth does not occur uniformly across geographical space but instead concentrates at specific points known as growth poles. These poles are typically characterized by dominant, propulsive industries that foster the growth of linked sectors through both forward and backward linkages. Perroux argued that economic space is not homogeneous, and growth spreads unevenly from these concentrated centers through complex transmission mechanisms (Perroux, 1955). His theory was heavily influenced by Schumpeter's (1940) view of development as a discontinuous process driven by innovation and structural shifts. According to this perspective, certain key industries or enterprises function as engines of development, initiating ripples that affect the broader economy to varying degrees.

Perroux's theory emphasizes unbalanced growth, acknowledging that not all regions benefit equally. Growth poles may enhance regional development if the periphery is well connected, but may also worsen disparities if spatial integration is weak. The roles of transportation infrastructure, industrial clustering, and intersectoral linkages are central to this framework. (Boudeville 1966) Later, Perroux added a spatial dimension to his abstract economic concept by situating growth poles in urban-industrial centers, thereby making the theory more applicable to real-world regional planning.

While Perroux's theory was instrumental in shaping regional economic thought, its application in underdeveloped, diverse socio-economic contexts such as India revealed certain limitations. Recognizing these, Indian planner R. P. Mishra proposed the Modified Growth Foci Concept, which adapted the original theory to the unique developmental needs of countries with vast rural populations and widespread spatial disparities (Mishra 1992). Mishra identified three critical weaknesses in Perroux's model: its excessive focus on industrialization, the limited scope of growth centers, and the lack of emphasis on social interaction and information diffusion.

Mishra's model proposed a five-tier hierarchy comprising growth poles, growth centres, growth points, service centres, and

central villages, with each node performing a distinct role in regional development—from large industrial hubs to rural service settlements. Unlike Perroux's original theory, which emphasised economic drivers, Mishra integrated social infrastructure, rural accessibility, and bottom-up development. This inclusive framework highlighted the importance of localized planning, service delivery, and community participation in achieving balance. By combining economic, spatial, and social dimensions, the modified growth foci model provides a context-sensitive and operational strategy to address India's persistent regional disparities (Mishra, 1992).

3.1 Policy and Planning Frameworks: Lessons for Regional Development

In addition to theoretical contributions, practical experiences from established planning frameworks in India provide valuable lessons for guiding regional development strategies in Upper Assam. The North Eastern Council (NEC) Regional Plan has emphasized the role of connectivity enhancement, industrial clustering, and cross-border linkages as key drivers for balanced growth in the Northeast. By highlighting the region's locational context and the need for coordinated interventions, the NEC framework underlines the importance of strengthening physical and institutional linkages to ensure that regional economic opportunities extend beyond individual growth nodes. (North Eastern Council (NEC) 2020)

The Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines, Volumes I and II, further provide a nationally recognized framework for urban and regional planning. These guidelines outline the importance of settlement hierarchy, functional service distribution, and integrated infrastructure as mechanisms for reducing disparities across regions. The emphasis on tiered urban systems directly resonates with the proposed Integrated Services Framework for Upper Assam (2045), wherein Dibrugarh is positioned as a Regional Centre supported by a network of sub-regional centres and service centres (Ministry of Housing and Urban Affairs (MoHUA) 2015).

Lessons can also be drawn from earlier regional development initiatives, such as the Integrated Development Planning of the Savitri Watershed and Mahad Taluka (Saini 2000). This case demonstrated the operationalisation of growth foci in resource-rich but underdeveloped areas through coordinated sectoral investments, institutional strengthening, and the application of a hierarchical settlement structure. The experience reinforces the view that growth pole strategies must be complemented by supportive institutional frameworks and people-centric service delivery to ensure that development benefits are diffused spatially across the wider region.

Insights can also be drawn from previous regional development initiatives, notably the Integrated Development Planning of the Savitri Watershed and Mahad Taluka (Saini and Sinha 1985). This initiative illustrated the practical implementation of a growth center in resource-rich yet underdeveloped regions through coordinated sectoral investments, strengthened institutional mechanisms, and the establishment of a hierarchical settlement system. The experience underscores that the success of growth center strategies relies on robust institutional frameworks and citizen-focused service delivery to ensure that development gains are effectively distributed across the broader region. Together, these policy frameworks and regional experiences strengthen the study's proposition that positioning Dibrugarh as a growth center must be accompanied by strategic investments, institutional mechanisms, and integrated service systems to achieve balanced development in Upper Assam.

3.2 Dibrugarh's Emerging Role in the Upper Assam Urban Hierarchy

Recent academic studies on Upper Assam increasingly highlight Dibrugarh's suitability to function as the primate city within the region's settlement hierarchy. These studies underscore the city's demographic dynamism, infrastructural and institutional depth, ecological significance, and growing role in economic diversification, all of which reinforce its capacity to serve as the apex of the regional hierarchy.

Das and Dutta (2025), in their analysis of the spatial patterns of urban growth in Dibrugarh, identify the city as the fastest-expanding urban centre in Upper Assam, driven by both natural growth and sustained in-migration from adjoining districts such as Dhemaji, Lakhimpur, and Tinsukia. Their findings point to a concentration of population, services, and employment opportunities that elevate Dibrugarh well above comparable centres such as Jorhat or Golaghat. The presence of high-order institutions, including Dibrugarh University, Assam Medical College, and a wide array of professional colleges, further consolidates its

primacy as an educational and healthcare hub for eastern Assam and neighbouring states.

Complementary evidence from Shah and Dutta (2024) highlights the ecological setting of Dibrugarh as a distinctive attribute. While the study documents the pressures faced by the district's wetlands from urban expansion, it also emphasizes the critical role these ecosystems play in flood regulation, water availability, and environmental stability. This combination of ecological assets and institutional awareness positions Dibrugarh more favourably than other Upper Assam towns, where environmental vulnerabilities remain less managed. From a planning standpoint, this enhances the city's suitability as an anchor for a sustainable growth pole strategy.

At the same time, studies on sectoral diversification reinforce Dibrugarh's potential to expand its economic base beyond tea and oil. Bordoloi (2024) identifies eco-tourism as a promising frontier, noting the district's tea estates, cultural heritage, and access to natural landscapes as unique comparative advantages. Such initiatives, if systematically integrated into regional planning, could strengthen backward linkages with agriculture, crafts, and hospitality, while also generating inclusive growth opportunities for local communities. These empirical insights position Dibrugarh as the most functionally advanced and strategically located urban centre in Upper Assam. Unlike Tinsukia, which remains narrowly industrial, or Jorhat, which is academically strong but lacks comparable industrial depth, Dibrugarh demonstrates a balanced profile of demographic centrality, infrastructural strength, institutional concentration, and ecological resilience. Its multimodal connectivity by air, rail, road, and inland waterways extends its influence well beyond district boundaries into Arunachal Pradesh and Nagaland, making it a natural primate city for the region.

The emerging body of research substantiates the argument that Dibrugarh is not simply one among several urban centres in Upper Assam but the most viable candidate to serve as the primate city. Its established dominance across demographic, institutional, and economic dimensions aligns with growth pole theory and validates its central role in anchoring a revised regional hierarchy.

4. Disparities in Development between Upper Assam and Lower Assam

Assam's regional development trajectory reflects a longstanding imbalance between Lower Assam and Upper Assam, with the former consistently outpacing the latter in socio-economic and infrastructural advancement. This divergence has resulted in a persistent developmental divide that continues to shape the state's spatial economy. Guwahati, the administrative and economic capital, anchors Lower Assam's dominance. It has benefitted from concentrated public investment, diversified economic functions, and superior urban and transport infrastructure, consolidating its position as the state's primate city. In contrast, Upper Assam, despite its rich natural resource base, remains structurally disadvantaged and institutionally under-supported.

Demographic distribution further reinforces this disparity. According to the Census of India 2011, Lower Assam had a population of approximately 136 lakhs, while Upper Assam had a population of approximately 75 lakhs (Government of India 2011). This numerical advantage has historically tilted political attention and resource allocation towards Lower Assam, strengthening its growth trajectory. The population density of Lower Assam's urban centres, particularly Guwahati, Nalbari, and Barpeta, has facilitated economies of scale in infrastructure and service delivery. By comparison, Upper Assam's population remains more dispersed, with its urban centres such as Dibrugarh, Jorhat, and Tinsukia unable to command a similar gravitational pull.

Lower Assam's advantage lies in its multi-nodal connectivity and diversified growth. The region has higher highway density, efficient rail infrastructure, and Assam's only international airport in Guwahati, which creates strong links with both national and international markets. Its economic activity spans a broad spectrum from manufacturing and retail trade to real estate, services, education, and logistics. This functional diversity fuels non-agricultural employment, encourages private investment, and facilitates urban expansion. Consequently, Lower Assam enjoys higher per capita income and improved living standards relative to other regions of the state. The gravitational pull of Guwahati, in particular, attracts talent, enterprise, and capital from across Assam, reinforcing cumulative development effects in and around the metropolitan core.

By contrast, Upper Assam's economy remains narrowly structured around extractive and plantation-based industries. The dominance of tea estates, oil refineries, and natural gas installations reflects its industrial heritage, but these sectors operate in relative isolation from local supply chains. They have limited capacity to generate forward and backward linkages that stimulate broader regional transformation. Secondary and tertiary sector activities remain underdeveloped, with small-scale manufacturing and formal services playing only a marginal role. Transport infrastructure, although present, lacks the density and quality necessary to foster strong intra-regional connectivity. Several districts remain poorly linked to markets, with rural areas in particular facing barriers in accessing higher-order services. As a result, Upper Assam continues to struggle with limited employment diversification, inadequate service delivery, and slower rates of urban growth.

This developmental imbalance, reinforced by demographic distribution and functional disparities, highlights the urgency of adopting spatially differentiated planning strategies. While Lower Assam consolidates its dominance under the shadow of Guwahati, Upper Assam requires a deliberate regional growth strategy anchored by a functional primate city capable of driving balanced development across the eastern part of the state. Urbanisation patterns reflect this asymmetry. Beyond Dibrugarh, Jorhat, and Tinsukia, urban growth in Upper Assam is modest and functionally thin. These towns offer some institutional presence as medical colleges, universities, and civic facilities, but fail to function as regional service hubs in the way Guwahati does for Lower Assam. A large portion of the population remains rural, dependent on primary activities, and has limited upward mobility. Outmigration, particularly of youth seeking education, healthcare, and jobs, further drains the region's human capital and entrenches its peripheral status. Social indicators mirror the lag in infrastructure and the economy. Literacy levels, school completion rates, and the number of healthcare centres are uneven and generally lower than in Lower Assam. Facilities are often centralized in a few towns, creating service deserts in surrounding rural tracts. As a result, regional disparities in human development become both a cause and consequence of economic marginalisation.

A region-wise disaggregation of Assam's Gross State Domestic Product (GSDP) further reinforces the regional disparity. Lower Assam, dominated by Guwahati and its adjoining districts, accounts for the largest share of GSDP, driven by its diversified economic base, concentration of administrative institutions, strength of the service sector, and better logistics. In comparison, Upper Assam contributes significantly less, despite hosting extractive industries such as oil and gas. This mismatch reflects the limited forward and backward linkages of its primary sector activities and the absence of a strong value-addition ecosystem. Moreover, the dominance of the informal sector, coupled with weak industrial diversification and lower service penetration, reduces Upper Assam's capacity to contribute meaningfully to the state's overall economic output (Government of Assam 2022).

A composite index constructed as part of this research reveals that Upper Assam is in a transitional tier, not as deprived as some frontier regions, yet lacking the dynamism of Lower Assam's urban-industrial corridor. The region holds latent potential: natural resources, pockets of skilled labour, existing institutional frameworks, and historical economic activity. However, without deliberate spatial strategies, these assets remain underleveraged.

4.1 Why Upper Assam?

Upper Assam occupies a unique developmental position within the state, neither at the forefront of progress like Lower Assam nor lagging like North Assam or Barak Valley. Its mid-tier status (Rank 3 in the Composite Index) positions it as an optimal candidate for strategic intervention. This intermediary placement suggests both existing institutional and infrastructural foundations and sufficient scope for catalytic development. Unlike the most developed regions, where additional investment yields diminishing returns, or the least developed regions, where absorptive capacity is a challenge, Upper Assam strikes a functional balance.

The region hosts key economic sectors, including tea, oil and gas, agro-processing, and emerging health and education services. Urban centres like Dibrugarh, Jorhat, and Tinsukia already serve as service hubs for surrounding districts and parts of neighbouring states. However, limited industrial diversification, patchy infrastructure, and slow urbanization continue to constrain its full potential. By targeting Upper Assam as a growth pole, Assam can reduce the overdependence on Guwahati and Lower Assam, address intra-state migration pressures, and spatially redistribute economic

activity. Strengthening connectivity, especially air and inland waterways, along with industrial and institutional investments, can elevate Upper Assam's role in Assam's growth narrative (Government of Assam 2024).

With focused planning and investment, Upper Assam can transition from a region of moderate performance to a strategic growth engine, catalyzing balanced development across eastern Assam and beyond

5. Dibrugarh District's Edge to Host a Growth Node in Upper Assam

Upper Assam, a vital sub-region of the state of Assam, comprises nine districts: Dibrugarh, Jorhat, Tinsukia, Sivasagar, Charaideo, Lakhimpur, Dhemaji, Majuli, and Golaghat. Rich in natural resources, industrial legacy, and agricultural output, this region contributes significantly to Assam's economy through sectors such as tea, oil, and gas, as well as agriculture. However, despite these strengths, development in Upper Assam is uneven; some districts boast high levels of urbanization, industrialization, and infrastructure, while others struggle due to geographic remoteness or environmental vulnerability.

To identify the most promising growth node within Upper Assam, the study adopted a comparative framework based on key demographic, economic, and infrastructure indicators. These include:

- Demographic Indicators: Population Density, Percentage of Urban Population and Literacy Rate.
- Economic Indicators: Workforce Participation Rate (WFPR), Worker Composition, Industrial Concentration, and Gross District Domestic Product (GDDP).
- Infrastructure Indicators: Road Density, Composite Educational Infrastructure and Healthcare Indices.

This analytical structure is rooted in François Perroux's Growth Pole Theory, which argues that economic growth tends to concentrate in specific geographic centers, or "poles," which then radiate development to surrounding areas. The central question is thus: which district, if developed as a node, has the capacity to uplift the rest of Upper Assam?

Among the districts studied, Dibrugarh stands out as the most suitable growth node, based on its strong performance across all selected indicators. On the demographic front, Dibrugarh has experienced a consistent rise in population density from 395 persons per sq. km in 2011 to 511 in 2024, indicating growing settlement and workforce availability. It has one of the highest urban population shares (over 15%), highlighting advanced urbanization and economic opportunities. The literacy rate, at 80.5%, is also among the highest in Upper Assam, driven by educational institutions such as Dibrugarh University and Assam Medical College.

In terms of economic indicators, Dibrugarh holds the highest industrial concentration in Upper Assam (24.71%). It is home to major oil and gas corporations, expansive tea estates, and emerging MSMEs. It also leads in GDP contribution among Upper Assam districts, signalling its economic centrality. Its workforce composition shows a significant proportion engaged in non-agricultural sectors, particularly industry and services, reflecting both employment diversity and economic depth.

Infrastructure development further strengthens Dibrugarh's case. It has the highest road density in the region (105.12 km per 100 sq. km in 2024), drastically improving regional accessibility. The district also tops the composite indices for both education and healthcare infrastructure, hosting the highest number of degree colleges, professional institutes, and specialized hospitals, including Assam Medical College, one of the oldest in India's northeast. Such facilities not only cater to local needs but also serve surrounding districts and neighbouring states, such as Arunachal Pradesh.

A key advantage of Dibrugarh is its strong regional connectivity, positioning it as the most strategically located urban centre in Upper Assam. The city is served by Mohanbari Airport, with direct flights to Delhi, Kolkata, and Guwahati, supporting passenger travel and time-sensitive activities in trade, healthcare, and industry. Complementing this are two major railway stations—Dibrugarh Town and Dibrugarh, situated on vital broad-gauge routes linking Upper Assam with Lower Assam, the Northeast, and national markets. Together with its highway network, these facilities extend Dibrugarh's accessibility and functional reach well beyond its district boundaries.

The city's road infrastructure further consolidates this advantage. National Highways (NH-37, NH-15, and NH-315) pass through Dibrugarh, ensuring smooth intra- and inter-

regional mobility. Most notably, the Bogibeel Bridge—a combined rail and road link across the Brahmaputra has emerged as a transformative piece of infrastructure. It provides seamless connectivity between Upper and North Assam while also opening direct access to Arunachal Pradesh. This integration enhances the movement of goods, services, and people, significantly expanding Dibrugarh's regional reach.

While other districts, like Jorhat and Tinsukia, also show promise, they lag in one or more critical areas, such as infrastructure, industrial concentration, or regional connectivity. Conversely, districts like Majuli and Dhemaji face acute geographic and infrastructural constraints, significantly limiting their growth potential. In terms of Gross State Domestic Product (GSDP) contribution, Dibrugarh, Tinsukia, and Jorhat are leading, but Dibrugarh holds a clear edge due to the multidimensional nature of its growth potential - a balance of industrial strength, service sector development, human capital, and strategic location.

5.1 Potential of Dibrugarh District over Other Districts of Upper Assam

Dibrugarh district emerges as the most viable candidate for establishing a growth pole in Upper Assam due to its unique convergence of demographic strength, economic diversity, and infrastructural depth (Figure 1). Demographically, it exhibits high literacy levels, robust workforce participation, especially among women and a stable urban growth pattern. These indicators highlight a capable, employable population, making it well-positioned to serve as a regional hub for talent and employment. In comparison, many other Upper Assam districts lack either institutional strength or demographic readiness.

Economically, Dibrugarh holds a pivotal position in Assam's industrial ecosystem. Known as the "Tea City of India," it is a key contributor to national tea exports and a major node in the petroleum and natural gas economy. With operational facilities by Oil India Limited, Assam Gas Company, and BCPL, the district generates both employment and strong inter-district economic linkages through its supply chains and industrial ecosystem.

Additionally, Dibrugarh's connectivity via highways, railways, the Bogibeel Bridge, and an airport enhances its accessibility and regional integration. With no other district offering such a balanced and strategic mix of functions, Dibrugarh stands out as the most suitable host for a growth pole in Upper Assam.

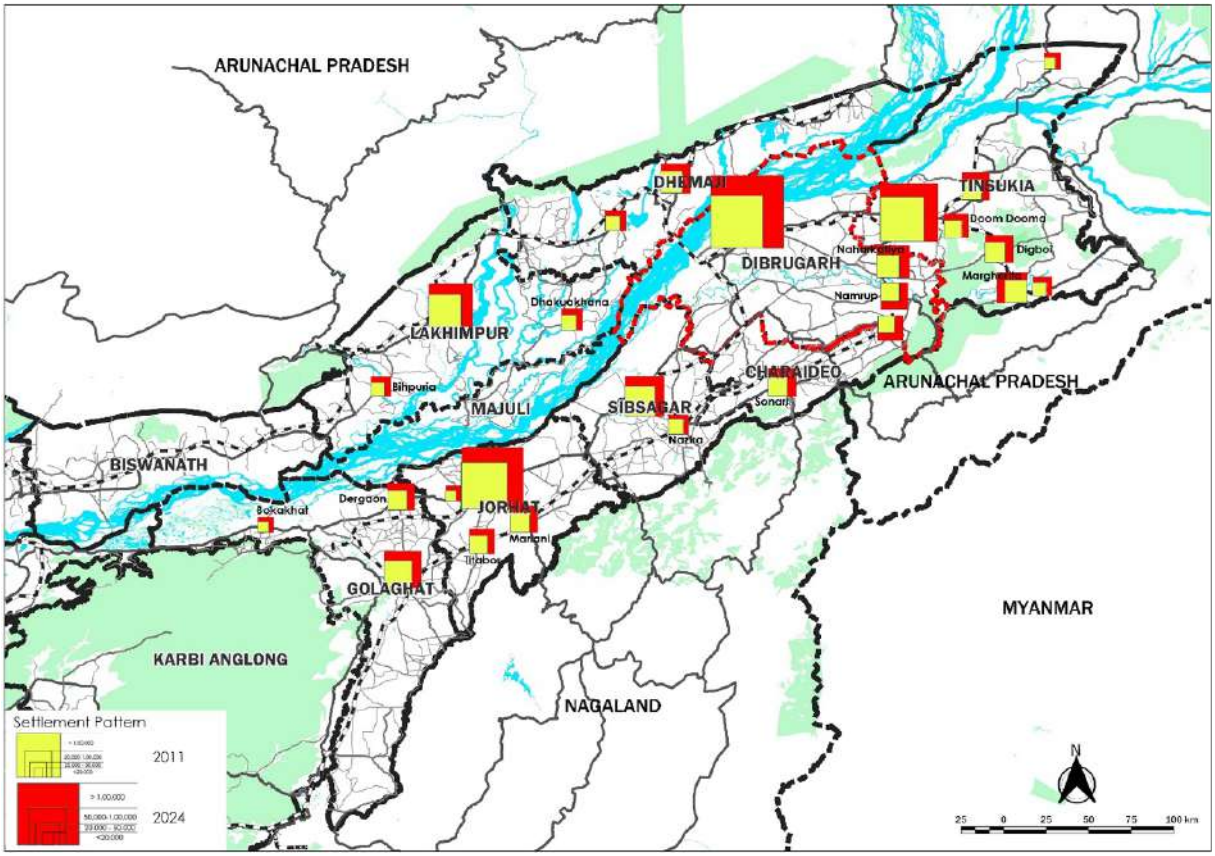


Figure 1. Settlement Pattern of Upper Assam, 2011-2024 (Kashyap 2025)

5.2 Settlement Pattern of Upper Assam, 2011 - 2024

Urban settlement patterns reveal the dynamics of regional growth through spatial distribution, functional hierarchy, and the evolution of urban centres. In Upper Assam, shaped historically by tea, oil, and river-based economies, these patterns have shifted with the expansion of infrastructure, institutions, and economic activities. By 2024, Dibrugarh's urban growth had expanded significantly beyond 2011 levels, consolidating its role as the region's primary urban anchor. Its increasing importance in healthcare, education, trade, and employment draws population and services from peripheral towns. Jorhat, Tinsukia, and Sivasagar continue to grow steadily as secondary centres, while North Lakhimpur, Dhemaji, and Golaghat are emerging as sub-regional nodes. Smaller towns such as Dergaon and Margherita show limited functional progress.

This hierarchical urban structure, led by Dibrugarh and supported by complementary nodes, reinforces the rationale for adopting a growth pole strategy centred on Dibrugarh. Its dominance across domains substantiates its potential to drive balanced regional development.

6. Composite Ranking of Settlements

Urban settlements in Upper Assam vary widely in their functional capacity, influencing regional development through the services they offer in education, healthcare, transport, and governance. To assess their relative importance, a Composite Functionality Index (CFI) was developed using four key indicators: the Education Facility Index (EFI), Medical Facility Index (MFI), Transport Facility Index (TFI), and General Facility Index (GFI)[5]. The study analyses 26 urban settlements (Class IV and above) based on population, infrastructure, and service distribution. Dibrugarh leads with a CFI score of 655.32, ranking highest in EFI, MFI, TFI, and GFI. Key institutions like Dibrugarh University, Assam Medical College, Mohanbari Airport, and multimodal connectivity drive its dominance.

Jorhat (359.83) and Tinsukia (336.18) follow in second and third ranks but trail significantly in healthcare and multimodal connectivity. Mid-tier towns like Sivasagar, Golaghat, and North Lakhimpur show moderate scores but lack all-around capacity. Several smaller settlements, such as Margherita, Bokakhat, and Dhakuakhana, score below 150, reflecting limited access to higher-order services.

The spatial hierarchy derived from the CFI (Table 1 and Figure 2) unequivocally establishes Dibrugarh as the functional apex of Upper Assam, backed by both quantitative metrics and qualitative depth. Its leading position across education, healthcare, transport, and governance substantiates its suitability as a regional growth pole. With a high composite functionality score, geographic centrality, and robust institutional presence, Dibrugarh stands out as the most strategically positioned candidate for this role. The resulting functional hierarchy clearly identifies it as a regional nucleus capable of driving growth through forward and backward linkages across economic and social domains. Strategic investments concentrated in Dibrugarh are likely to generate significant regional spillovers and enable integrated, inclusive development throughout Upper Assam.

Table 1. Ranking of Settlements in Upper Assam based on CFI (Kashyap 2025)

Town	EFI	MFI	GFI	TFI	CFI	Rank Order
Dibrugarh	266.5	71	111.7	206.2	655.3	1
Jorhat	101.3	45	59.8	154.1	359.8	2
Tinsukia	93.70	23	112.5	107.2	336.2	3
North Lakhimpur	89.20	22	36.4	84.1	231.9	4
Sivasagar	67.00	14	35.3	94.1	210.2	5
Golaghat	43.30	6	15.2	96.1	160.5	6
Titabor Town	46.64	3	9.65	84.1	142.9	7
Margherita	30.66	10	11.8	69.0	121.9	8
Dhakuakhana	33.54	1	9.61	72.0	116.4	9
Bokakhat	43.19	4	9.40	49.0	105.5	10
Silapathar	35.56	9	6.27	54.1	105.2	11
Sonari	28.70	3	7.28	60.1	99.43	12
Digboi	23.96	1	10.9	62.1	98.24	13
Dergaon	20.82	1	8.32	52.0	82.43	14
Duliajan Oil Town	26.73	1	10.4	37.0	75.41	15
Dhemaji	37.88	1	9.61	24.1	72.85	16
Bihpuria	22.95	3	6.52	37.1	69.11	17
Makum	27.41	0	8.32	32.0	67.73	18
Naharkatiya	25.11	5	10.7	22.0	62.46	19
Mariani	27.79	4	4.20	25.0	60.84	20
Nazira	26.23	0	7.56	25.0	58.79	21
Digboi Oil Town	10.33	1	4.15	42.0	57.77	22
Namrup	15.66	0	8.11	18.0	41.77	23
Doom Dooma	19.57	1	9.61	11.0	41.46	24
Lido Town	6.0	1	5.48	24.1	36.84	25
Chapakhowa Town	18.4	0	2.84	12.0	33.24	26
Kamalabaria N.C.	12.0	0	1.08	17.0	30.08	27

[5] GFI includes banking institutions, post offices, police stations, fire stations, community centres, markets, recreational facilities (stadiums, auditoriums, parks)

7. Dibrugarh City: Growth Pole for Upper Assam's Growth

Dibrugarh City, located on the southern bank of the Brahmaputra River, is one of the most historically significant and strategically positioned cities in Assam. Known as the 'Tea City of India', it has evolved from a colonial trade and administrative center into a modern-day hub of industry, education, healthcare, and regional governance. Its role today transcends the district level; it functions as a central urban node for Upper Assam and adjoining parts of Arunachal Pradesh and Nagaland, supported by its multimodal connectivity, riverine interface, and growing institutional and economic influence in the Northeast.

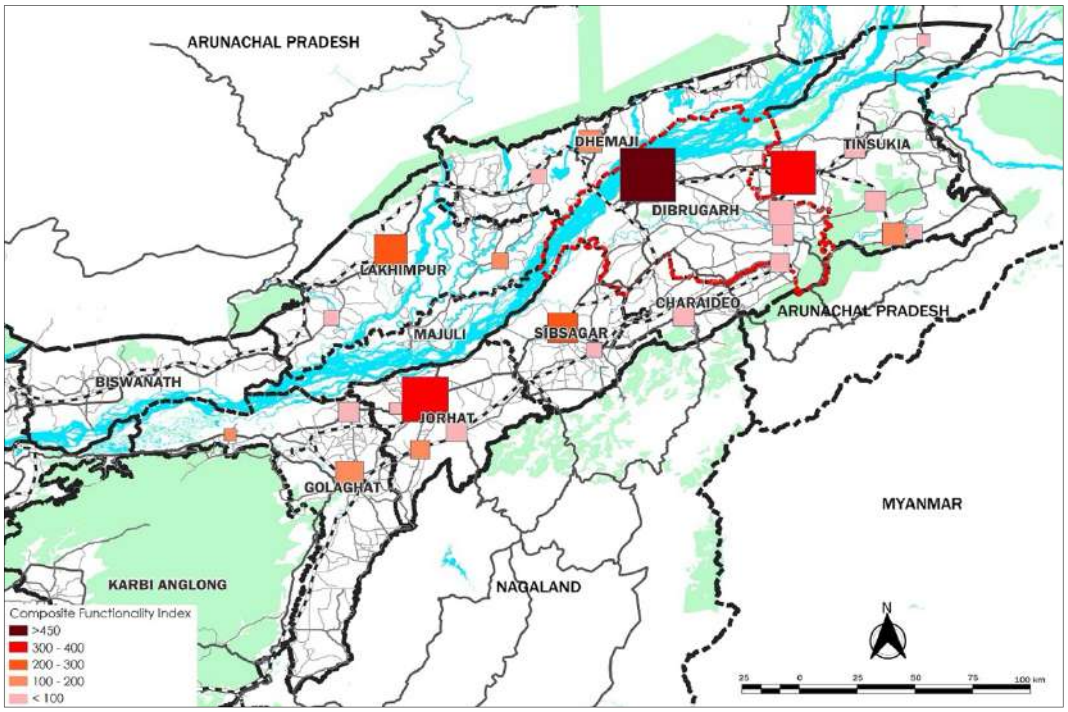


Figure 2. Ranking of Urban Settlements in Upper Assam, 2025 (Kashyap 2025)

Several factors position Dibrugarh as the most suitable candidate to serve as a regional growth pole for Upper Assam. The city's geographic centrality offers seamless accessibility to surrounding districts such as Tinsukia, Dhemaji, Sivasagar, Charaideo, and parts of Arunachal Pradesh. This location, combined with its extensive multimodal connectivity, including National Highways (NH-15, NH-37, NH-315), broad-gauge rail terminals, Mohanbari Airport, and the Bogibeel rail-road bridge, makes Dibrugarh a strategic mobility and logistics hub. These physical networks facilitate smooth inter-district movement of goods, people, and services, enhancing the city's capacity to anchor regional development.

Economically, Dibrugarh presents a diverse and resilient industrial ecosystem. It is a leading center for tea processing and export, petroleum and natural gas extraction, plywood and petrochemical manufacturing, and hosts a growing micro, small and medium enterprise (MSME) sector. Major public sector undertakings such as Oil India Limited and Assam Gas Company provide employment and industrial linkages across multiple districts. The presence of the Brahmaputra Cracker and Polymer Limited (BCPL) further adds value to downstream industries. These sectors collectively generate substantial forward and backward linkages, creating economic interdependence between Dibrugarh and its hinterland through supply chains, employment flows, and trade.

Institutionally, Dibrugarh has matured into a regional hub for both education and healthcare. The presence of premier institutions such as Dibrugarh University and Assam Medical College, along with a wide network of technical, professional, and degree colleges, draws students from across Upper Assam and bordering states. The city not only meets internal educational needs but also attracts academic migration from other districts, reinforcing its academic centrality. Similarly, with 22 specialty hospitals and several diagnostic centers, Dibrugarh provides advanced tertiary medical care to a large population base from Tinsukia, Golaghat, Dhemaji, Lakhimpur, and even Arunachal Pradesh and Nagaland. This service-based gravity is an essential quality of a functional growth pole.

Demographically, Dibrugarh exhibits a stable population base, a high literacy rate, a favourable Workforce Participation Rate (WFPR), and a growing urban population. This suggests a skilled and semi-skilled labour pool necessary to support industrial expansion, service delivery, and institutional growth. The rise in population density, particularly between 2011 and 2024, reflects the city's increasing regional importance and in-migration driven by economic and educational opportunities.

Functionally, Dibrugarh is deeply embedded in the regional urban hierarchy. Daily and weekly commuting patterns, especially via public transport, highlight its role as a regional service hub. The city's strong functional linkages with nearby towns and districts signify its institutional reach and socio-economic influence, aligning well with the principles of growth pole theory, which emphasize spatial centrality, service dominance, and capacity to generate development spillovers.

The Assam Government's decision to designate Dibrugarh as the state's second capital further strengthens the case for adopting it as the ideal regional growth pole, as it enhances its administrative importance and reinforces its central role in driving balanced regional development.

Dibrugarh's multi-dimensional strengths in infrastructure, economic diversity, institutional presence, and strategic location collectively validate its potential as a regional growth pole for Upper Assam. It already serves as a growth center by attracting population, investment, and services. With targeted planning and infrastructural upgrades, the city can catalyze balanced development.

8. Recommendations

Establishing Dibrugarh as a growth pole for Upper Assam's development demands a comprehensive, multidimensional policy framework that addresses existing limitations while unlocking the city's regional potential. The city already possesses considerable economic, infrastructural, and institutional strengths, but these must be reinforced through strategic planning, sectoral diversification, and spatial integration to achieve balanced regional development.

Dibrugarh's current industrial economy, although strong, is largely dependent on traditional sectors like tea, oil, and plywood. To transform the city into a dynamic growth pole, industrial diversification must be a core priority. New economic activities such as defence manufacturing, agro-processing, renewable energy, and electronics should be introduced through targeted policy interventions. Leveraging state-led schemes like the Assam Industrial Policy (2019) and Advantage Assam 2.0, Dibrugarh can attract forward-looking industries. The establishment of a Defence Manufacturing Zone and a Semiconductor Cluster would align Dibrugarh with national missions, enhance technological advancement, and generate employment for the region's educated youth. Dibrugarh's strategic location on the Brahmaputra, combined with its proximity to Arunachal Pradesh and Nagaland, provides an opportunity to establish the city as a logistics hub for Northeast India. Strengthening multimodal transport through a dedicated logistics park integrating air, rail, and road systems will enhance trade connectivity. Expanding Mohanbari Airport to include intra-state routes and destinations in the northeast can support regional tourism, healthcare access, and time-sensitive industrial activity. Such infrastructure development must align with the Assam Logistics and Warehousing Policy, 2022, and with national schemes such as Bharatmala Pariyojana.

With its rich tea heritage, natural landscape, and proximity to the Brahmaputra, the city can be developed into a major destination for tea tourism, river cruises, and cultural tourism. A dedicated Tea Tourism Circuit, heritage bungalows, cruise infrastructure, and wellness retreats will diversify the local economy and increase income from the service sector. These initiatives resonate with Swadesh Darshan 2.0 and can attract both domestic and international tourists.

Education and healthcare have historically defined Dibrugarh's regional prominence, and both sectors require further development to meet future demands. Dibrugarh should expand its educational ecosystem to include high-end institutions in fields such as artificial intelligence, data science, planning, and architecture. This aligns with Digital India and the AI for All Strategy. AI-ready data centers, industrial skill development centres, and innovation hubs will foster knowledge-driven economic growth. In healthcare, Dibrugarh already serves a significant patient population from Upper Assam and neighbouring states. The development of super-specialty hospitals modelled after AIIMS, along with patient guest houses, telemedicine services, and a dedicated air ambulance, can position the

city as a medical tourism hub for the Northeast. This supports the objectives of the National Health Policy, 2017, and strengthens Dibrugarh's regional healthcare role. Dibrugarh's functional linkages with districts such as Tinsukia, Sivasagar, Dhemaji, and North Lakhimpur must be strategically reinforced. This can be achieved by developing satellite towns with focused clusters of logistics, education, and health services. Enhancing these interdependent nodes will reduce development pressure on the urban core while improving access to opportunities in peripheral districts. Such a polycentric structure supports balanced development and fosters regional integration.

The policy vision is further articulated through the proposed Integrated Services Framework for Upper Assam, 2045 (Figure 3), which envisions a five-tier spatial and service hierarchy comprising Metro Centre, Regional Centre, Sub-Regional Centre, Service Centre, and Service Village. While Guwahati retains its position as the Metro Centre, Dibrugarh is designated as the Regional Centre, serving a population of 3 to 10 lakh. It anchors high-order functions such as Secretariat Extension, industrial parks, warehousing hubs, and super-specialty hospitals.

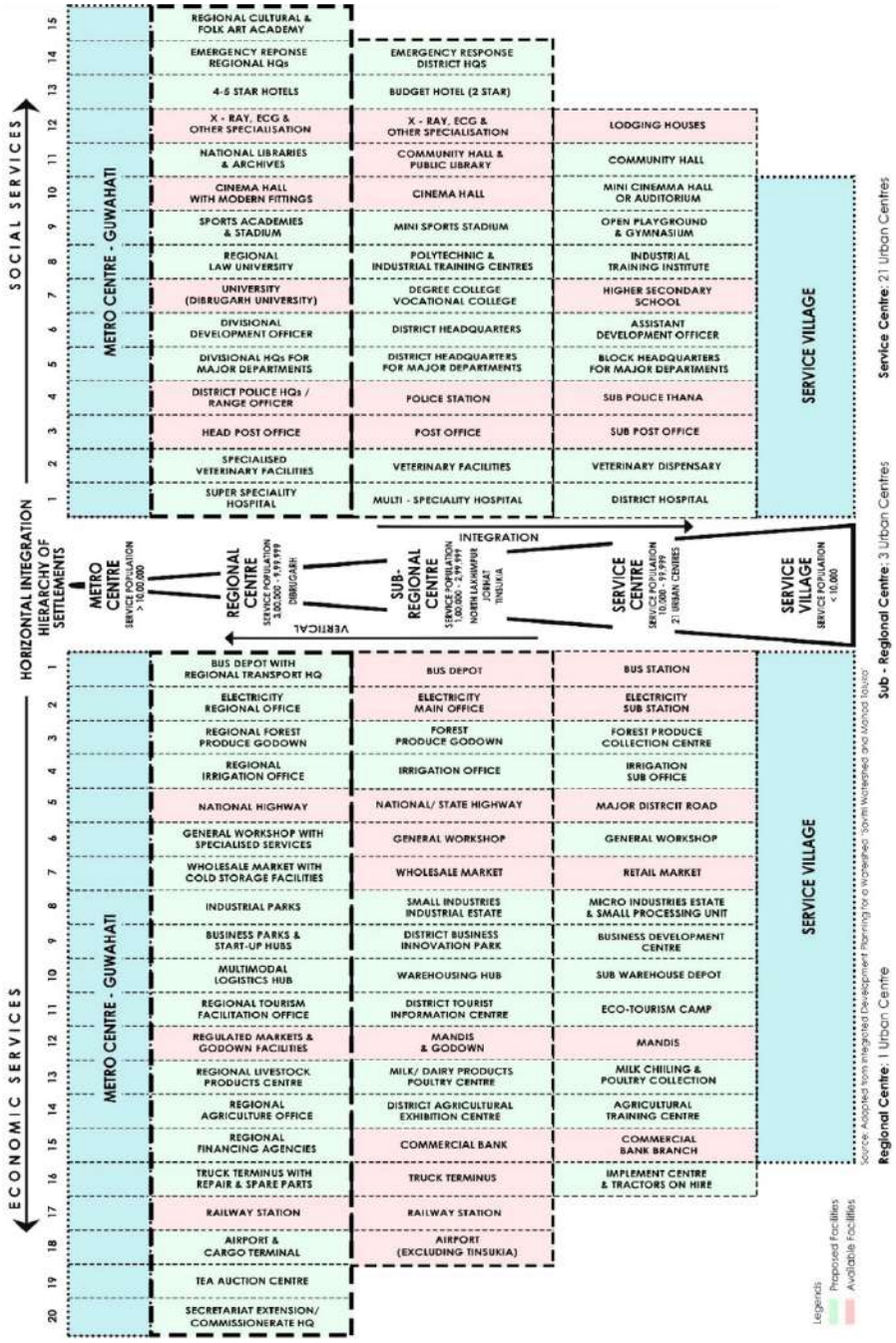


Figure 3. Proposed Integrated Services in Upper Assam, 2045 (Adapted from Saini and Sinha 1985)

Tinsukia, Jorhat, and North Lakhimpur serve as Sub-Regional Centres, hosting intermediate services like district hospitals and skill development institutes. Smaller towns serve as Service Centres and Villages, ensuring decentralized access to primary services such as healthcare, education, and market infrastructure.

The framework integrates both economic and social services across the tiers. On the economic front, high-value services such as tea auction centres, defence logistics hubs, and cargo terminals are planned for regional centres. Service villages will be equipped with essential facilities, such as general workshops and agricultural markets, to prevent marginalization. On the social front, universities, cultural complexes, and emergency response units are concentrated at higher tiers, while lower tiers guarantee basic education and healthcare facilities.

This vertical and horizontal integration of services ensures that development is both scalable and inclusive. Dibrugarh, as the Regional Centre, emerges as the anchor of this network, enabling the seamless flow of people, goods, and services across Upper Assam. Significantly, the Assam government's decision to establish a second capital complex in Dibrugarh adds administrative weight to its regional importance. This move enhances governance decentralization and institutional investment, making Dibrugarh the logical choice to lead the transformation of Upper Assam into a resilient and prosperous region.

9. Conclusion

The research confirms that Dibrugarh District is the most strategically positioned and functionally equipped candidate to act as the growth pole for Upper Assam. With its central location along the Brahmaputra, the city combines strong industrial capacity, connectivity, and institutional depth, leading the region in infrastructure and services, including education, healthcare, logistics, and administration, supported by a diversified economic base. The Composite Functionality Index (CFI) further validates Dibrugarh's dominance in regional service delivery.

Dibrugarh's functional influence extends beyond district boundaries to eastern Arunachal Pradesh and parts of Nagaland, generating strong forward and backward linkages with surrounding towns and industries. The Assam Government's designation of Dibrugarh as the second state capital reinforces its centrality and administrative role. With targeted investments in industrial diversification, multimodal logistics, education, and healthcare, Dibrugarh can anchor the proposed Integrated Services Framework for 2045 as the Regional Centre within a five-tier urban system, supporting balanced and future-ready development across Upper Assam and the wider Northeast.

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Developing a Resilient Livelihood Framework for the Island District of Majuli, Assam

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Abstract: Ecologically fragile and economically marginalized regions like riverine islands are acutely vulnerable to climate change and environmental degradation. Majuli District in Assam, the world's largest inhabited river island, faces recurring disruptions to livelihoods due to seasonal flooding, riverbank erosion, and limited infrastructure, all of which disrupt local livelihoods and exacerbate socio-economic vulnerabilities. This research addresses livelihood challenges in hazard-prone areas by developing a Resilient Livelihood Framework tailored to Majuli's unique socio-environmental context. Adopting a multidimensional and participatory approach, the research combines spatial, environmental, and socio-economic assessments using mixed methods and primary data from household surveys across a few flood-prone villages. The study evaluates access to the five livelihood capitals—physical, human, social, financial, and natural—within the Sustainable Livelihoods Framework. It constructs a Comprehensive Vulnerability Index based on exposure, sensitivity, and adaptive capacity. Findings indicate a heavy reliance on climate-sensitive agriculture and allied sectors, exacerbated by limited market access, inadequate economic infrastructure for these sectors, financial exclusion, and limited livelihood diversification. Households with lower access to livelihood capitals exhibit higher vulnerability and reduced coping capacity. However, opportunities exist in fish farming, animal husbandry, eco-tourism, and traditional crafts, which offer greater resilience to climatic shocks. The proposed framework recommends strategic interventions, including capacity building, infrastructure development, strengthening social networks, income diversification, and community-led flood management. This research contributes to the discourse on climate-resilient development and offers a scalable model for integrated and inclusive livelihood planning in ecologically sensitive regions. These recommendations are directly supported by household survey data and the constructed vulnerability index, which highlight the strongest areas of need and potential for resilience.

Keywords: Resilient Livelihoods, Livelihood Capitals, Vulnerabilities

सार: पारिस्थितिक रूप से नाज़ुक और आर्थिक रूप से हाशिए पर स्थित क्षेत्र, जैसे नदी द्वीप, जलवायु परिवर्तन और पर्यावरणीय क्षरण के प्रति अत्यधिक संवेदनशील होते हैं। असम का माजुली ज़िला, जो विश्व का सबसे बड़ा आबाद नदी द्वीप है, मौसमी बाढ़, नदी तट कटाव और सीमित बुनियादी ढाँचे के कारण आजीविका में बार-बार व्यवधान का सामना करता है, जिससे स्थानीय आजीविका तंत्र बाधित होते हैं और सामाजिक-आर्थिक संवेदनशीलताएँ और गहरा जाती हैं। यह शोध ऐसे आपदा-प्रवण क्षेत्रों में आजीविका से जुड़ी चुनौतियों को संबोधित करता है और माजुली के विशिष्ट सामाजिक–पर्यावरणीय संदर्भ के अनुरूप एक लचीली आजीविका रूपरेखा विकसित करता है। एक बहुआयामी एवं सहभागितापूर्ण दृष्टिकोण अपनाते हुए, यह अध्ययन मिश्रित विधियों के माध्यम से स्थानिक, पर्यावरणीय और सामाजिक-आर्थिक आकलनों को संयोजित करता है, जिनके लिए कुछ बाढ़ संभावित गाँवों में घरेलू सर्वेक्षण से प्राथमिक आँकड़े एकत्र किए गए हैं। अध्ययन, टिकाऊ आजीविका ढांचा के अंतर्गत पाँच आजीविका साधनो- भौतिक, मानव, सामाजिक, वित्तीय और प्राकृतिक तक पहुँच का मूल्यांकन करता है, और जोखिम अनावृत्ति, संवेदनशीलता तथा अनुकूलन क्षमता के आधार पर एक समग्र संवेदनशीलता सूचकांक का निर्माण करता है। निष्कर्षों से पता चलता है कि आजीविका मुख्यतः जलवायु-संवेदनशील कृषि एवं उससे जुड़ी गतिविधियों पर निर्भर है, जिसे सीमित बाज़ार पहुँच, इन क्षेत्रों के लिए आर्थिक बुनियादी ढाँचे की कमी, वित्तीय अपवर्जन तथा आजीविका विविधीकरण के अभाव से और अधिक जटिल बना दिया गया है। जिन परिवारों की आजीविका साधनो तक पहुँच कम है, वे अधिक संवेदनशीलता और कमतर निपटान क्षमता प्रदर्शित करते हैं। इसके बावजूद, मत्स्य-पालन, पशुपालन, इको-पर्यटन और पारंपरिक शिल्प जैसे क्षेत्रों में अवसर मौजूद हैं, जो जलवायु संबंधी आघातों के प्रति अधिक लचीलापन प्रदान कर सकते हैं। प्रस्तावित रूपरेखा में क्षमता निर्माण, बुनियादी ढाँचा विकास, सामाजिक नेटवर्क सुदृढ़ीकरण, आय के विविधीकरण तथा समुदाय-नेतृत्वित बाढ़ प्रबंधन जैसी रणनीतिक हस्तक्षेपों की अनुशंसा की गई है। यह शोध जलवायु-समुत्थानशीलता विकास पर चल रहे विमर्श में योगदान देता है और पारिस्थितिक रूप से संवेदनशील क्षेत्रों में एकीकृत एवं समावेशी आजीविका नियोजन के लिए एक विस्तारयोग्य मॉडल प्रस्तुत करता है। प्रस्तुत अनुशंसाएँ घरेलू सर्वेक्षण के आँकड़ों तथा निर्मित संवेदनशीलता सूचकांक द्वारा प्रत्यक्ष रूप से समर्थित हैं, जो सबसे अधिक आवश्यकता वाले क्षेत्रों और संभावित लचीलापन-क्षेत्रों को स्पष्ट रूप से रेखांकित करते हैं।

मुख्य शब्द: लचीली आजीविकाएँ, आजीविका साधन, भेद्यता

1. Introduction

Riverine islands, formed by sediment deposition from dynamic river systems, represent some of the most ecologically and socio-economically fragile landscapes. Due to their inherent geomorphological instability, these islands are highly susceptible to environmental hazards such as riverbank erosion and seasonal flooding. The degradation of riverine islands has severe consequences, including land loss, population displacement, livelihood disruptions, and the erosion of cultural and ecological assets. Countries like Bangladesh and India, particularly in the Brahmaputra basin of Assam (Sinha 2018), experience acute challenges in this regard. In Assam, Majuli Island—the world's largest inhabited riverine island (Sarkar 2022)—has witnessed dramatic shrinkage and socio-economic deterioration (Dutta 2024) due to

persistent erosion and flooding. The volatile behaviour of major river systems, such as the Brahmaputra, Ganges, and Mekong, continues to exacerbate vulnerabilities, necessitating urgent, sustainable interventions to enhance the resilience of riverine island communities (Mudasser 2020). This environmental crisis threatens the livelihoods of nearly 72 percent of the population (Dutta 2024), who primarily depend on the farm sector. With each passing year, land degradation and displacement further exacerbate economic instability (Dey 2012), food insecurity, and socio-economic disruptions in the region (Saikia 2020). Additionally, the lack of diversified income sources, inadequate disaster preparedness, and high dependence on old traditional agricultural practices deepen the socio-economic challenges (Sahay 2020), making it imperative to develop a Resilient Livelihood Framework tailored to the district's unique vulnerabilities.

2. Methodology

The research methodology follows a systematic, structured approach, beginning with the identification of the core problem that necessitates the study. Majuli faces unique environmental and socio-economic challenges—most notably, annual floods and severe riverbank erosion. In light of these vulnerabilities, this study seeks to develop a Resilient Livelihood Framework to enhance people's adaptive capacities and promote sustainable livelihoods in the district. To frame this study within a broader academic and practical context, an extensive literature review was conducted. The review focuses on multiple core areas: understanding the definitions and components of 'livelihoods' and 'resilience,' and examining global frameworks related to sustainable livelihoods. Additionally, the concept of 'vulnerability' was studied in depth, including its determinants and impacts on livelihoods, particularly in disaster-prone regions.

A mixed-methods approach was adopted in this study, using both primary and secondary data sources to comprehensively capture the dynamics of livelihoods and vulnerabilities in Majuli. Primary data was obtained through extensive household surveys, structured interviews, and focused group discussions conducted across eight strategically selected villages. These villages were chosen to reflect a diverse cross-section of Majuli's socio-economic profiles, geographic contexts, and degrees of exposure to environmental risks. This ensured that the data collected was both representative and contextually nuanced, capturing variations in livelihood conditions and resilience capacities across the district. Secondary sources include Census data, district handbooks, economic survey reports, and various government documents. For the analysis of existing livelihood patterns, data were collected on occupational structure, workforce participation, and sectoral contributions (primary, secondary, and tertiary). Each of the five capitals was assessed using specific indicators, including literacy rates, access to basic services, household income, participation in self-help groups, landholding size, and crop productivity. Simultaneously, data were also collected on various vulnerabilities affecting the region, categorized under socio-economic, environmental, infrastructural, and institutional dimensions. For data analysis, multiple tools and techniques were used, including stakeholder assessments, GIS tools for spatial mapping, statistical methods, and composite indexing. A Livelihood Capitals Index was created to evaluate the strengths and gaps within each capital, and a Comprehensive Vulnerability Index was developed to identify and quantify areas of highest vulnerability.

Based on these insights, strategic recommendations were formulated to address the most urgent vulnerabilities and reinforce each of the livelihood capitals. These proposed strategies ultimately form the foundation of the Resilient Livelihood Framework for Majuli, aimed at improving the adaptive capacity of its communities and ensuring long-term socio-economic sustainability in the face of recurring environmental stressors.

3. Concept of 'Livelihood' and 'Resilient Livelihood'

Livelihoods encompass the means, resources, and strategies individuals and households use to secure basic needs and cope with adversities (Chambers and Conway 1992). Over time, scholars have offered various conceptualizations that emphasize different dimensions. Chambers and Conway (1992) define a livelihood as comprising "capabilities, assets, and activities" essential for a means of living (Turner 2017), where sustainability lies in the ability to withstand and recover from shocks without undermining the natural resource base. Ellis (2000) similarly emphasizes assets and activities but stresses access, shaped by institutions and social relations, as central to livelihood dynamics. Scoones (1998) introduces the Sustainable

Livelihoods Framework (SLF), identifying five capital assets—human, natural, financial, physical, and social—as the foundation for diverse livelihood strategies, with outcomes shaped by the broader vulnerability context and mediated by policies and institutions. Rakodi (2002) expands this framework to urban contexts, highlighting the role of infrastructure and informal economies, while Bebbington (1999) emphasizes identity, empowerment, and governance, asserting that power structures mediate access to livelihood assets. These five capitals are assessed through specific indicators: human capital via education, training, and experience; natural capital through land, livestock, and access to environmental resources; financial capital by income, savings, and subsidies; physical capital through housing, transport, and infrastructure; and social capital through networks, community engagement, and societal roles (Sarkar 2016). The interdependence of these capitals means that a deficiency in one—such as limited financial access—can restrict others, such as investment in education or tools. For example, a farmer's livelihood depends not only on land (natural capital) but also on knowledge (human capital) and market access (physical capital). Understanding these interconnected dimensions allows for more targeted, sustainable interventions to enhance livelihood resilience (Scoones 1998, Ellis 2000, Bebbington 1999). Resilient livelihoods refer to the capacity of individuals, households, and communities to adapt to, withstand, and recover from economic, environmental, or social shocks without compromising long-term well-being (Chambers and Conway 1992, Das 2017). Characterized by flexibility, diversity, and sustainability, they ensure continuity of income and access to resources amid disruptions such as climate change, disasters, or economic crises (Shivakoti 2015). These livelihoods are sustained by five key capitals—human, natural, financial, physical, and social—and require institutional support through policies, credit access, and legal security (Scoones 1998; Ellis 2000). Indicators include income diversification, employment stability, adaptive capacity, and community networks (Chetry 2020). Ultimately, resilient livelihoods reduce vulnerability, prevent displacement, and promote recovery, ensuring that communities not only survive but thrive while preserving resources for future generations (Carney 1999).

Vulnerability denotes the extent to which a system or community is exposed and susceptible to external stresses, with limited capacity to recover (Wisner et al. 2004; IPCC 2001). It is shaped by factors including exposure, sensitivity, and adaptive capacity (Chambers 1989, Cutter et al. 2003). Exposure refers to the presence of people or assets in hazard-prone areas; sensitivity reflects how severely these systems are affected; and adaptive capacity represents the ability to cope and recover (IPCC 2001). Vulnerability adversely impacts livelihoods by exacerbating economic instability, restricting access to health, education, and natural resources, and undermining social resilience through inequality, displacement, and technological gaps. Flood vulnerability assessments typically use composite indices based on these dimensions. The Livelihood Vulnerability Index integrates health access, food insecurity, water scarcity, climate variability, and socio-demographic parameters (Hahn 2009). Similarly, the Flood Vulnerability Index includes indicators such as loss of land and jobs, disruption of health and transport services, and lack of access to early warnings (Sarkar 2022). Both frameworks emphasize that high exposure and sensitivity, coupled with low adaptive capacity, increase vulnerability (Haan 2012). Measuring these through quantitative indicators enables policymakers to identify at-risk populations and design targeted resilience strategies (IPCC 2001, Sarkar 2022, Hahn 2009).

4. Spatial and Environmental Conditions

Majuli district, with a total land area of 594.93 sq. kms. (Goswami 2018). It is highly prone to seasonal flooding and erosion (Konwar 2013), causing constant changes in its landmass (Gogoi 2020). It is bordered by Lakhimpur District to the north (across the Subansiri River), Jorhat to the south and west (across the Brahmaputra), and Dhemaji to the east (across both the Brahmaputra and Subansiri rivers) (Figure 1). The district's geography, shaped by the Brahmaputra, Subansiri, Kherkatia Suti, and numerous smaller tributaries, includes wetlands, oxbow lakes, and floodplains (Konwar 2018) that support agriculture, fisheries, and biodiversity. The flood data from 2016–17 to 2023–24 underscores the persistent and widespread nature of flood impacts across Majuli, with affected villages ranging from 164 to 196 and impacted families fluctuating between 21,945 and 28,456. This consistency in spatial extent, coupled with annual variation in intensity, highlights the chronic nature of flood risk in the district. Notably, 2020–21 witnessed the highest number of affected families (28,456), coinciding with intense

rainfall, significant embankment failures, and heightened erosion along the Brahmaputra.

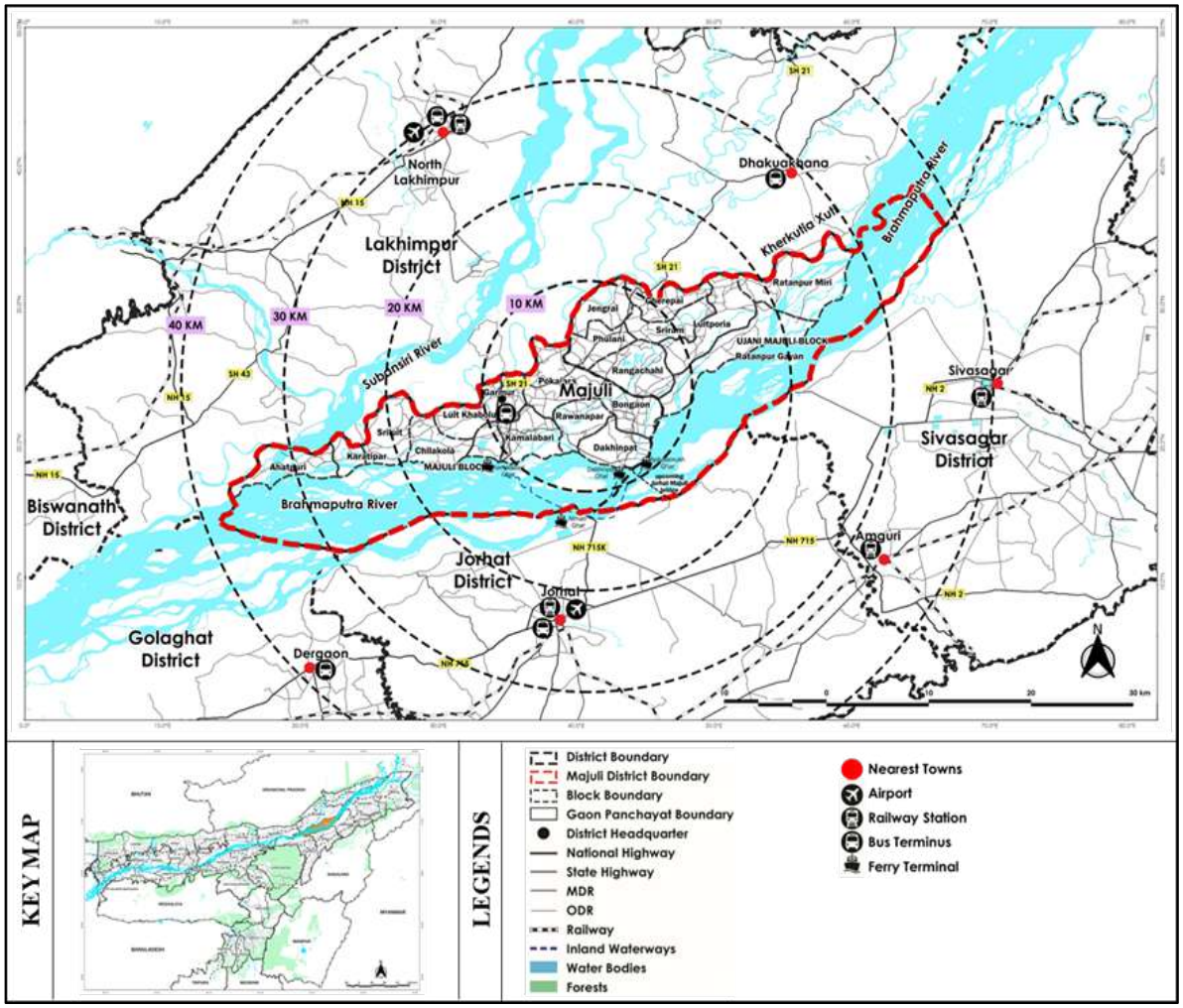


Figure 1. Map showing Administrative Boundaries and Major Connectivity Linkages; Source: (Kashyap 2025)

With its headquarters at Garmur, it operates through two Community Development Blocks—Majuli and Ujani Majuli—which manage governance, rural development, and public service delivery. The district comprises 20 Gram Panchayats, overseeing 248 villages, of which 14 are uninhabited due to recurrent floods and riverbank erosion. It lacks direct road connectivity to the mainland, and access is primarily via Jorhat, where travelers use ferry services from Nimati Ghat, or, from Dhakuakhana in Lakhimpur district to the north. National Highway 715K runs through Majuli (Kotoky 2003), connecting villages and administrative centers. A bridge under construction over the Brahmaputra at Nimati Ghat is set to provide direct road access to Jorhat, drastically improving year-round connectivity, emergency response, trade, and socio-economic development (Saikia 2024).

The population dynamics of Majuli district have shown varying trends over the decades, driven by a mix of demographic, environmental, and socio-economic factors (Lahiri 2012). Majuli's population has fluctuated notably over the decades. From 1991 to 2001, it grew at an annual rate of 1.26%, rising from 135,378 to 153,400. Growth slowed to 0.87% between 2001 and 2011, reaching 167,304, due to outmigration, floods, and erosion. However, from 2011 to 2023, the population surged to 217,858, reflecting a sharp increase with an annual growth rate of 2.22%, as per the Zilla Parishad's local census. The population of the district is entirely rural. Scheduled Tribes (STs) form a significant portion of the population, accounting for over 49 percent, with the Mishing being the dominant tribal group. The workers' composition and fourfold classification reflect a predominantly agrarian economy, with a high dependence on agriculture and allied activities for livelihood and limited diversification into the secondary and tertiary sectors.

5. Existing Livelihood Patterns

Majuli's economy is predominantly driven by the

primary sector (Deka 2024), with agriculture as the mainstay, supported by fertile alluvial soil. Residents engage in rice, mustard, pulses, and vegetable farming, as well as fish farming and animal husbandry. The secondary sector includes household industries like handicrafts, pottery, and traditional mask-making, reflecting the island's cultural heritage. The growing tertiary sector is fuelled by trade, basic services, and tourism, with spiritual sites and ecotourism boosting livelihoods through homestays, crafts, and tour services.

5.1 Primary Sector

The district showcases a diverse and productive agricultural and horticultural landscape, with paddy as the dominant crop, cultivated year-round across autumn, winter, and summer seasons. Winter paddy leads in terms of area and yield, while summer paddy shows the highest productivity. Other key crops include mustard, pulses, and potato, with potato being notably high-yielding. Horticultural crops, though occupying only 6 percent of cultivated land, display remarkable productivity, particularly sugarcane, papaya, pineapple, and banana, highlighting their potential for commercial expansion. Over the past two decades, agricultural land has grown modestly, while horticultural land has tripled, signalling a shift toward high-value cash crops such as sugarcane and turmeric. Despite this shift, traditional crops like paddy, mustard, and pulses still dominate. The agriculture sector in Majuli faces significant challenges that undermine productivity and sustainability. Frequent floods damage crops and livelihoods, while traditional methods and overreliance on rice increase vulnerability to climate and market shocks. Poor infrastructure, including inadequate roads, storage, and transport, limits market access and causes post-harvest losses. Small, fragmented landholdings and limited awareness of government schemes hinder mechanization and modernization. Strengthening infrastructure, improving farmer outreach, expanding access to credit, and promoting climate-resilient practices are essential to a more sustainable agricultural future in Majuli.

Majuli's abundant water resources support a thriving fishery sector, with traditional and modern practices like pond, cage, and paddy-cum-fish farming boosting rural incomes. High-value species and consistent production have created surpluses, with over 30% of households engaging in aquaculture. However, the lack of cold storage, processing, and transport infrastructure causes post-harvest losses and price instability. Similarly, livestock rearing—particularly piggery, poultry, and cattle—is a vital livelihood for small farmers and the Mishing community, offering income during floods and off-seasons. Women play a key role in backyard poultry and duck farming. Despite a large livestock base, the sector struggles with flood impacts, limited infrastructure, and poor market access. Investments in veterinary services, infrastructure, and cooperative support are essential for resilient and sustainable growth.

5.2 Secondary Sector

Household industries in Majuli form a vital part of the rural economy, blending livelihood support with cultural preservation. These small-scale, traditional, and skill-based industries include weaving, bamboo and cane craft, pottery, mask-making, and boat-building. Weaving is the most prominent, led by around 18,000 women, particularly in Mishing villages, producing traditional textiles. Bamboo and cane crafts support 500–550 households, mainly in Rangachahi and Bongaon, offering low-cost, eco-friendly products. Pottery in Salmora and mask-making at Samaguri Satra involve 200–220 and 75–100 households, respectively, showcasing unique techniques and cultural artistry. Despite their significance, these industries face common challenges, including seasonal flooding, outdated tools, poor market linkages, and inadequate infrastructure, training, and promotional support.

5.3 Tertiary Sector

The trade, commerce, and services sector in Majuli is a major source of livelihood, employing around 12,775 people. Weekly markets act as local economic hubs, and tourism-related services are expanding, engaging 1,750 workers. The MSME sector is vibrant, with over 1,500 trading units, 782 manufacturing units focused on crafts and food products, and 650 service units. However, growth is hindered by poor infrastructure, flooding, and limited access to credit. Agro-based industries show promise but require greater investment. Public services offer limited employment, while over 2,700 SHGs with 30,000+ members, mainly women, play a key role in fostering rural entrepreneurship. Majuli is one of Assam's top tourist destinations, renowned for its riverine landscape, cultural vibrancy, and spiritual legacy. Rooted in the 16th-century Vaishnavite movement, it is home to 22 active Satras that preserve classical dance, music, and theatre (Konwar 2013), including

Sattriya and Bhaona. Notable Satras like Auniati, Kamalabari, and Samaguri are cultural landmarks (Konwar, 2017). Listed on UNESCO's Tentative World Heritage List, Majuli offers a blend of spiritual, cultural, and ecological tourism with attractions such as Samaguri Satra (mask-making), Chakoli Beel (birdwatching), and Salmora (pottery). Eco-tourism and stays in Mishing tribal villages enhance the experience. Tourism has grown steadily, with over 40,000 domestic and 10,000 international visitors annually since 2022, of whome 73% are domestic.

6. Livelihood Capitals Assessment

This study undertakes a comprehensive assessment of the five core livelihood capitals, such as physical, human, social, financial, and natural, within flood-prone communities (Roy 2020) of Majuli District, Assam. A structured household survey was conducted across eight strategically selected villages—Salmora, Manika Pathar, Bhakat Chapori, Chilakola Chapori, Laholial, Missamora, Ratanpur, and Karaiguri—based on their vulnerability profiles as identified in the District Disaster Management Plan (Figure 2).

The findings reveal that physical capital is the most developed and accessible across the district (Figure 3), particularly in villages such as Manika Pathar, Salmora, and Bhakat Chapori, which benefit from relatively robust infrastructure, including housing, potable water, sanitation, and road connectivity. Human and social capitals exhibit moderate performance, indicating fair levels of education, skill development, community engagement, and institutional participation. However, disparities are evident, with some villages performing worse in these dimensions. Financial capital demonstrates mixed outcomes. While villages like Manika Pathar and Salmora show relative strength, others—such as Laholial, Karaiguri, and Bhakat Chapori—exhibit significant weaknesses, marked by limited income diversification, poor access to credit, and an overall lack of financial inclusion. Natural capital emerges as the weakest dimension, with most villages facing constraints related to small and fragmented landholdings, low livestock ownership, limited dependence on diverse natural resources, and a lack of multi-cropping practices.

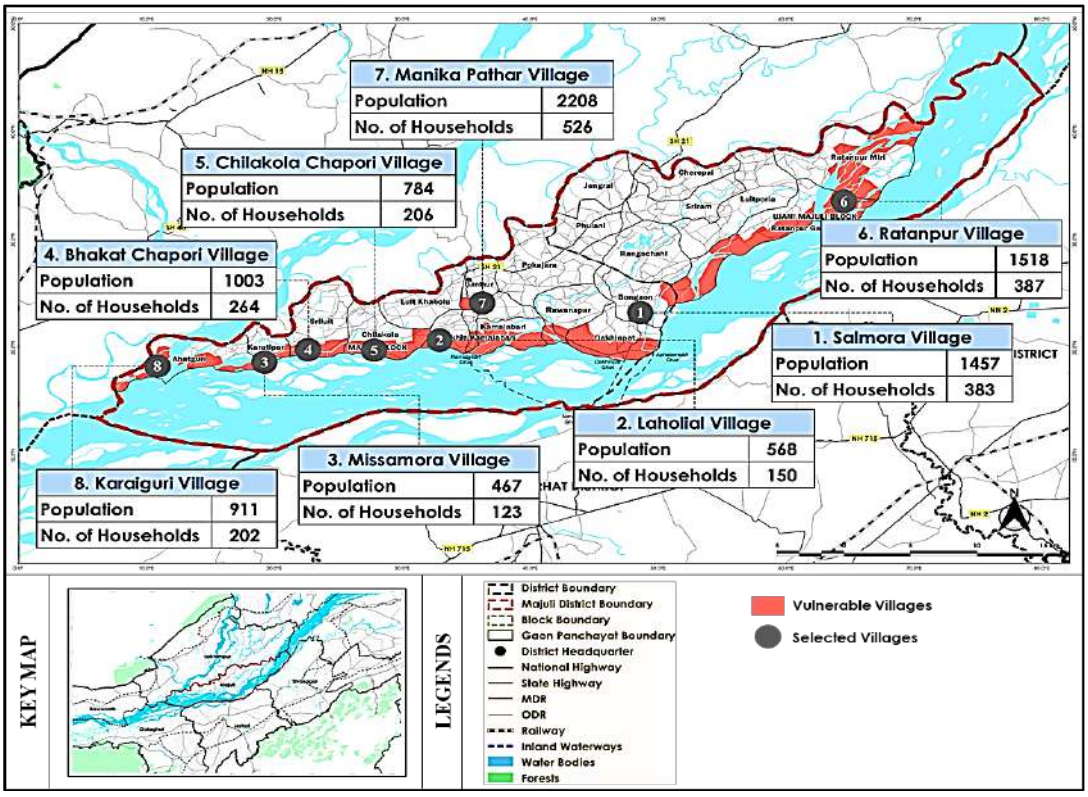


Figure 2. Map showing villages selected for the primary survey; Source: (Kashyap 2025)

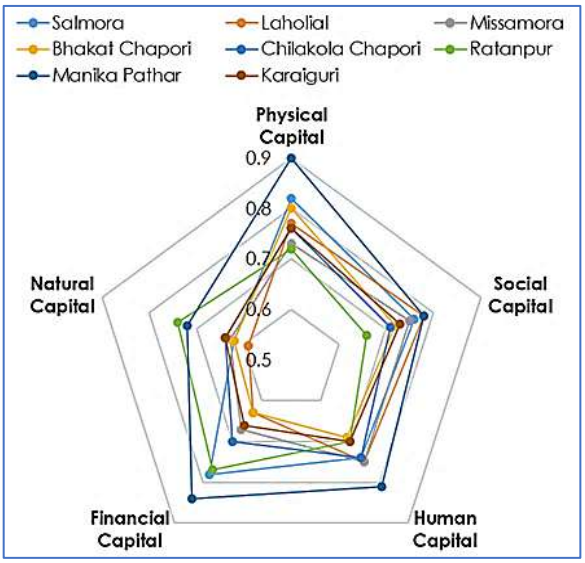


Figure 3. Livelihood Capitals Index Scores
Source: Kashyap 2025, Primary Survey - February 2025

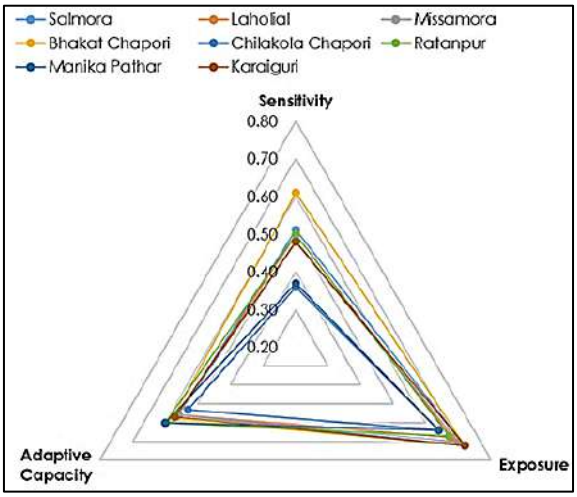


Figure 4. Comprehensive Vulnerability Index Scores
Source: Kashyap 2025, Primary Survey - February 2025

Villages exhibiting deficiencies in financial and natural capital require targeted strategies that improve access to financial services, support income diversification, and encourage sustainable resource management. Additionally, strengthening local institutions, expanding vocational training, and investing in climate-resilient infrastructure are essential to fortify human and social capital.

7. Comprehensive Vulnerability Index

To evaluate the resilience of flood-affected rural communities in Majuli District, this study employed a Comprehensive Vulnerability Index (CVI) that integrates two interrelated dimensions of risk: flood vulnerability and livelihood vulnerability (Islam 2001). The CVI framework is built upon three fundamental components—sensitivity, exposure, and adaptive capacity—which together capture the multifaceted nature of vulnerability in hazard-prone regions (Saha 2024, Talukdar 2021). Each component comprises multiple sub-aspects, operationalized through carefully selected indicators derived from primary household-level data.

The results reveal significant inter-village disparities in overall vulnerability (Figure 4). Bhakat Chapori is identified as the most vulnerable settlement, characterized by high sensitivity and exposure levels and only moderate adaptive capacity. These conditions indicate inadequate coping mechanisms in the face of flood-induced health risks and food insecurity. Salmora and Karaiguri also register high CVI scores, reflecting similar patterns of elevated exposure and constrained adaptive capacity. Laholial and Missamora fall into the moderately vulnerable category, necessitating targeted improvements in disaster preparedness, access to essential services, and institutional support. In contrast, Ratanpur demonstrates relatively low vulnerability, attributed to its comparatively stronger adaptive capacity, despite facing similar levels of flood exposure. Chilakola Chapori and Manika Pathar emerge as the least vulnerable villages in the sample. Their lower sensitivity and enhanced adaptive capacities, particularly in diversified livelihoods, community networks, and flood preparedness, contribute to their resilience.

Overall, while flood exposure levels remain uniformly high across all villages, it is the variation in adaptive capacity that significantly shapes differential vulnerability outcomes. Villages exhibiting robust livelihood strategies, effective community-based networks, and higher institutional responsiveness demonstrate enhanced resilience. These findings underscore the need for place-based and component-specific policy interventions. Enhancing health infrastructure, ensuring food and water security, and promoting localized flood management knowledge are critical to reducing vulnerability, particularly in high-risk villages such as Bhakat Chapori and Salmora.

8. Recommendations

The Resilient Livelihood Framework for Majuli aims to enhance community resilience by addressing vulnerabilities and promoting sustainable, adaptive livelihood strategies (Chambers 1992). Based on a detailed vulnerability index and assessment of livelihood capitals, the framework calls for a multi-pronged approach to reducing flood exposure and sensitivity while strengthening households' adaptive capacities. Rooted in the Sustainable Livelihoods Framework, it emphasizes holistic

development across five core capitals: physical, financial, human, social, and natural. Strengthening these interconnected assets is essential to safeguard livelihoods and advance inclusive, climate-resilient development.

Economic resilience involves sustaining and recovering livelihoods post-shock, supported by robust infrastructure, access to finance, skill-building, social enterprises, and fallback resources like fisheries and flood-resistant crops. Social resilience ensures community cohesion during crises. Relief-ready infrastructure, SHGs and community savings, education and healthcare access, cultural networks, and shared natural resources reinforce social strength. Environmental resilience draws on ecosystems to mitigate risk. Chang-ghars (raised houses), green livelihoods, traditional knowledge, local conservation efforts, and ecological restoration all enhance environmental stability. Institutional resilience reflects effective governance. Early warning systems, disaster financing, leadership development, participatory planning, and strong regulatory frameworks help communities respond to and recover from disasters.

To enhance livelihood resilience in flood-prone Majuli, four adaptive strategies are proposed. Climate-resilient agriculture promotes flood-tolerant crop varieties by blending traditional knowledge with innovation, strengthening natural and human capital. Livelihood diversification encourages activities like animal husbandry and rural enterprises, reducing reliance on agriculture and boosting income security, especially for women and youth. Skilled migration offers urban employment opportunities for local youth, enabling financial remittances and knowledge transfer back home. Localized disaster risk reduction (DRR) focuses on community-led initiatives such as early warning systems and embankment maintenance, leveraging institutional and social capital. Together, these strategies build economic, social, environmental, and institutional resilience, laying the groundwork for long-term sustainability.

The integration of a resilient livelihood framework into Majuli's planning processes offers a strategic pathway to enhance the district's adaptive capacity and disaster resilience. By embedding this framework into key plans such as the District Disaster Management Plan (DDMP), Majuli can shift from reactive relief efforts to proactive disaster risk reduction. Livelihood diversification, climate-resilient infrastructure, and protection of income sources can become core strategies against recurring floods and erosion. The Gram Panchayat Development Plan (GPDP) can localize these interventions, prioritizing flood-resistant agriculture, alternative livelihoods, and social protection schemes tailored to community needs. Simultaneously, the Annual Credit Plan by NABARD and Lead Banks can provide crucial financial support through targeted loans and grants for climate-resilient practices and rural enterprises. Strengthening ties with local financial institutions will also improve credit access for vulnerable households.

The framework targets four key outcomes: promoting income diversification to reduce dependence on climate-sensitive sectors; minimizing flood vulnerability through infrastructure and livelihood resilience; advancing sustainable development while preserving Majuli's ecological and cultural integrity; and fostering inclusivity by empowering women and youth in economic and disaster preparedness efforts. Together, these goals chart a course toward a more resilient, equitable, and self-reliant Majuli (Figure 5).

Majuli's resilience strategy centres on diversifying and climate-proofing rural livelihoods through certain integrated initiatives. Flood-resilient agriculture promotes short-duration, flood-tolerant crops (e.g., Bao Dhan, Khesari, and flood-resistant sesame); farmer-led demonstrations; a tailored PMFBY insurance variant; capacity building for early warnings and climate-smart practices; and adaptive research via a proposed Krishi Vigyan Kendra in Garmur. Market support includes upgraded rural markets, value addition, small agro-processing units, and a medium warehouse to reduce post-harvest losses.

The Livestock and Dairy initiative emphasise livestock producer organizations, asset support for improved breeds, dedicated logistics and a cold chain linking Majuli to regional markets, and small chilling plants and processing units to add value (ghee, paneer, smoked and processed meats), with training for hygienic processing and cooperative management.

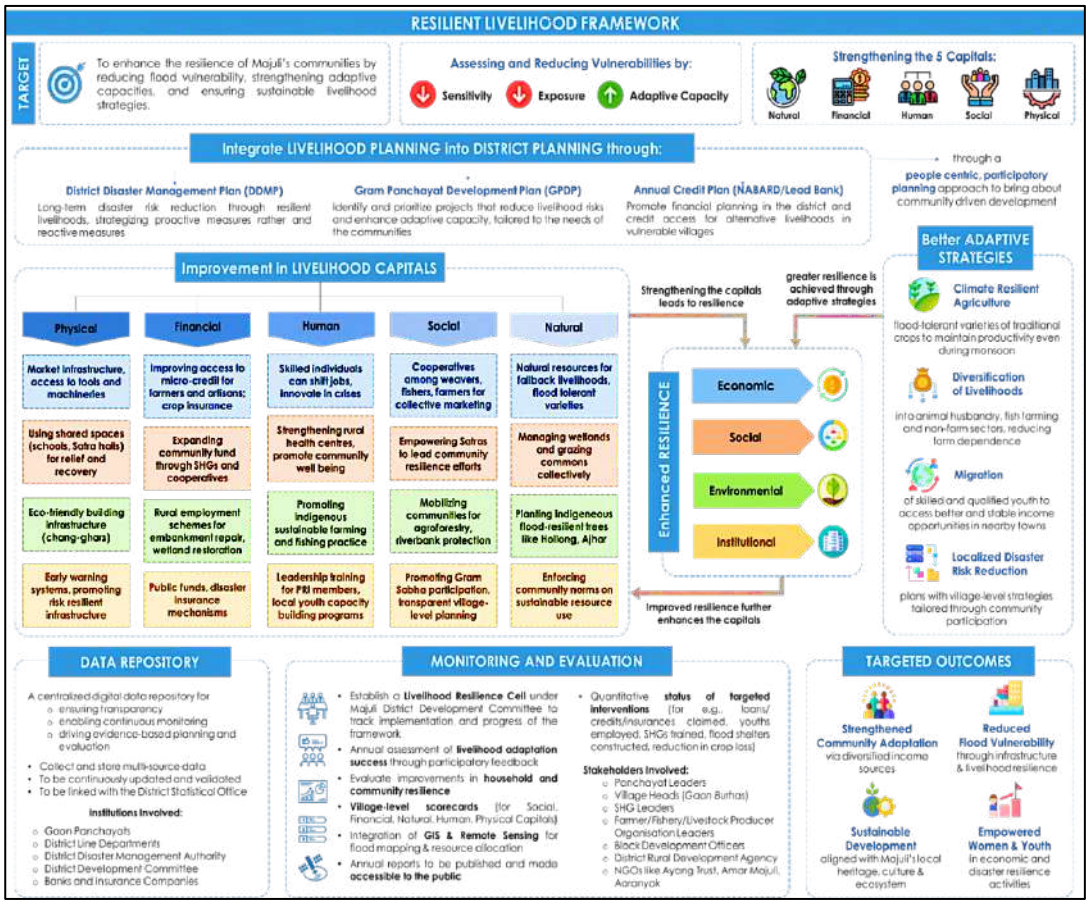


Figure 5. Proposed Resilient Livelihood Framework for Majuli District, Assam
Source: (Kashyap 2025)

Adaptive Fish Farming proposes dual production, river cage culture in pre/post-monsoon and secured beel/pond farming during peak floods, combined with integrated fish-farming models, gram-level hatcheries, and a fish seed bank, small cold storage units, and mobile cold vans to stabilize production and market access.

Women-led resilience focuses on clustering women into skill groups (agro-processing, fish processing, poultry, pickling), ASDM-led training in technical and business skills, finance linkages through SHGs and government schemes, and targeted enterprise locations to shift women into leadership and entrepreneurial roles. Eco-cultural tourism outlines a community-based circuit linking Satras, birdwatching, homestays, and guided experiences, supported by hospitality training, SHG engagement, eco-friendly infrastructure, and digital promotion. Rural craft clusters propose common facility centres, artisan *haats*, design mentorship, and e-commerce linkages. Community-based disaster risk management institutionalizes Community Disaster Management Groups for preparedness, early warning integration, youth training, resource mapping, and drills. Implementation will require phased financing, institutional coordination, iterative community-led learning, and monitoring.

This framework serves as the foundational structure for ensuring that each recommendation directly responds to the identified environmental and socio-economic vulnerabilities within the study area. The strategies herein have been thoughtfully formulated to address existing gaps, build on local capacities, and foster long-term resilience. By targeting specific dimensions of livelihood sustainability, such as diversification, gender inclusion, cultural capital, and disaster preparedness, these initiatives collectively aim to strengthen and secure the livelihoods of vulnerable communities in the face of recurring climate and development challenges.

Implementing the proposed interventions in Majuli will involve several interlinked challenges that must be acknowledged and managed. Unpredictable seasonal and extreme flood variability will threaten infrastructure continuity and project outcomes, requiring flexible, phased designs and contingency planning. Fragmented institutional mandates across agriculture, fisheries, disaster management, and tourism will slow coordinated action, so a cross-sectoral steering mechanism with clear role definitions

will be essential. Financial constraints and irregular funding will jeopardize the maintenance of cold chains, warehouses, and processing units, underscoring the need for blended finance, phased investment, and public–private partnership models. Weak market linkages, price volatility, and poor rural infrastructure (roads, electrification, and digital connectivity) will limit producers' ability to capture value unless they are matched with aggregation models, market intelligence, and targeted infrastructure upgrades. Limited local technical capacity for processing, cold-chain management, and enterprise development will necessitate sustained training and extension support via a KVK or similar institution. Social and cultural resistance to change, alongside gender and equity barriers, will slow adoption and will need to be addressed through farmer-led demonstrations, peer champions, targeted finance, and flexible training schedules for women. Finally, seasonal migration, regulatory bottlenecks, and broader climate uncertainty will complicate scaling and long-term viability, underscoring the importance of iterative pilot testing, scenario-based planning, and institutional buy-in before large-scale replication.

9. Conclusion

Grounded in a comprehensive study of Majuli's demographic, economic, and environmental landscape, this research integrates both secondary data and a robust empirical component through primary household surveys conducted across multiple villages. These surveys offered critical insights into local livelihood practices, vulnerabilities, coping mechanisms, and aspirations, ensuring that the strategies proposed are not only theoretically grounded but also contextually relevant and culturally sensitive.

The study advances an applied Resilient Livelihood Framework for Majuli by combining village-level empirical evidence with systems thinking around the five livelihood capitals. Its core contribution is twofold: an operational vulnerability index that captures sensitivity, exposure, and adaptive capacity across human, social, natural, physical, and financial capitals; and a set of context-tested livelihood pathways, flood-resilient cropping, integrated fisheries, diversified animal husbandry, non-farm microenterprises, and skill-linked seasonal migration paired with locally grounded disaster-risk reduction practices. Together, these components offer implementable entry points for resilience-building that are co-created with communities.

Policy implications are actionable, and district planning should mainstream livelihood resilience into development schemes by prioritizing investment in flood-adaptive infrastructure (e.g., raised platforms, flood-tolerant storage, and access routes); market and value-chain linkages for diversified products (especially fisheries and agro-processing); targeted financial instruments (microinsurance and tailored credit); and gender- and youth-responsive skills and governance programs that strengthen social capital. Formalizing community-based monitoring and embedding the vulnerability index into local planning cycles will ensure adaptive management rather than one-off interventions.

However, scaling the framework presents certain challenges. Majuli's riverine geomorphology, customary land practices, and cultural livelihoods mean interventions cannot be transplanted elsewhere without adaptation. Resource constraints, fragmented institutional mandates, and seasonal migration patterns also complicate scale-up. In practice, pilot programs will need phased financing, strong local intermediaries (NGOs or community organizations), and mechanisms to align the agriculture, fisheries, and disaster management departments. Future research should prioritize longitudinal evaluation of pilot resilience interventions when planning livelihoods, test the costs and market potential of new income options, and work directly with communities to understand impacts on women and different age groups.

In sum, while Majuli remains exposed to recurrent environmental shocks, this research demonstrates a pragmatic pathway for transforming vulnerability into adaptive capacity, not through external correction alone, but by enabling communities as active co-designers of resilient livelihoods. Realizing that pathway will require coordinated policy action, sustained financing, and iterative learning—steps that could make Majuli a replicable model for riverine resilience elsewhere.

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Localising SDG 6 Indicators for Water, Sanitation, and Hygiene

Case of Baran District, Rajasthan

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Abstract: Achieving Sustainable Development Goal 6 (SDG-6), ensuring universal access to safe water, sanitation, and hygiene, remains a major challenge in rural areas of developing countries due to systemic inequalities and weak infrastructure. This study focuses on Baran district in Rajasthan, a socio-economically marginalized, predominantly rural region identified as an "aspirant" category in India's SDG index. Despite national programs like the Jal Jeevan Mission and Swachh Bharat Mission, significant gaps persist in water supply, sanitation, and waste management, especially in tribal and remote areas. Using a mixed-methods approach, the research combines household surveys, stakeholder interviews, and Panchayat-level data to assess SDG-6 localization. Two villages, Barwa (high-performing) and Shubhdhara (low-performing), serve as case studies, revealing disparities driven by governance quality, water availability, and social inclusion. The study finds that national SDG indicators often miss key local realities, such as seasonal access to water, cultural sanitation norms, and gendered labour burdens. To bridge these gaps, the study proposes a localized indicator framework that emphasizes climate resilience, gender sensitivity, and participatory governance. Key metrics include water collection time, menstrual hygiene in schools, community asset management, and source resilience. The research recommends integrating Panchayat Development Indices with WaSH monitoring systems to generate more responsive, locally relevant data at the grassroots level and accelerate SDG-6 progress in rural and vulnerable regions.

Keywords: Sustainable Development Goal -6, Localization, Gender Sensitivity, Participatory governance

सार: सतत विकास लक्ष्य 6— अर्थात सभी के लिए सुरक्षित जल, स्वच्छता और स्वच्छ व्यवहार की सार्वभौमिक पहुँच सुनिश्चित करना — विकासशील देशों के ग्रामीण क्षेत्रों में अब भी एक प्रमुख चुनौती बनी हुई है। इसके कारणों में प्रणालीगत असमानताएँ और कमजोर बुनियादी ढाँचा प्रमुख हैं। यह अध्ययन राजस्थान के बारां ज़िले पर केंद्रित है, जो सामाजिक-आर्थिक रूप से वंचित तथा मुख्यतः ग्रामीण क्षेत्र है, और भारत के सतत विकास लक्ष्य सूचकांक में "अभिलाषी" (श्रेणी के अंतर्गत आते है। यद्यपि जल जीवन मिशन और स्वच्छ भारत मिशन जैसी राष्ट्रीय योजनाएँ लागू की गई हैं, फिर भी जलापूर्ति, स्वच्छता और अपशिष्ट प्रबंधन में विशेषकर जनजातीय एवं दुर्गम क्षेत्रों में उल्लेखनीय अंतराल बने हुए हैं। एक मिश्रित-पद्धति दृष्टिकोण अपनाते हुए, यह शोध गृहस्थ सर्वेक्षणों, हितधारक साक्षात्कारों, और पंचायत-स्तरीय आंकड़ों का उपयोग कर सतत विकास लक्ष्य 6 के स्थानीयकरण का आकलन करता है। दो गाँव — बरवा (उच्च प्रदर्शन) और शुभधारा (निम्न प्रदर्शन) — को प्रकरण अध्ययन के रूप में चुना गया है, जिनसे यह स्पष्ट होता है कि शासन की गुणवत्ता, जल की उपलब्धता, और सामाजिक समावेशन में अंतर विकास परिणामों को प्रभावित करता है। अध्ययन में यह पाया गया कि राष्ट्रीय सतत विकास लक्ष्य संकेतक अक्सर स्थानीय वास्तविकताओं को नज़रअंदाज़ कर देते हैं, जैसे मौसमी जल उपलब्धता, सांस्कृतिक स्वच्छता मानदंड, और लैंगिक श्रम भार। इन अंतरालों को पाटने हेतु अध्ययन एक स्थानीयकृत सूचकांक रूपरेखा प्रस्तावित करता है, जो जलवायु सहनक्षमता, लैंगिक संवेदनशीलता, और भागीदारीपूर्ण शासन पर बल देती है। मुख्य मापदंडों में जल संग्रहण में लगने वाला समय, विद्यालयों में मासिक धर्म स्वच्छता प्रबंधन, सामुदायिक संपत्ति प्रबंधन, और जल स्रोतों की लचीलापन को शामिल किया गया है। अध्ययन यह अनुशंसा करता है कि पंचायत विकास सूचकांक को वॉश निगरानी प्रणालियों के साथ एकीकृत किया जाए, ताकि अधिक संवेदनशील और स्थानीय रूप से प्रासंगिक आँकड़े ग्राम स्तर से एकत्र किए जा सकें। ऐसा करने से ग्रामीण एवं संवेदनशील क्षेत्रों में सतत विकास लक्ष्य 6की प्रगति को तेज़ी से आगे बढ़ाया जा सकेगा।

मुख्य शब्द: सतत विकास लक्ष्य 6, स्थानीयकरण, लैंगिक संवेदनशीलता, सहभागी शासन

1. Introduction

Access to safe drinking water, sanitation, and hygiene (WASH) is a critical determinant of human health and overall well-being. It extends beyond basic health needs, influencing livelihoods, educational attainment, and personal dignity, thereby contributing to the community's resilience and the sustainability of ecosystems. Ensuring safe WASH is essential, as contaminated water remains a leading cause of waterborne diseases such as diarrhoea. In contrast, inadequate sanitation practices, such as improper disposal of human waste, continue to contaminate key water sources, including groundwater and surface water used for drinking, agriculture, and domestic purposes (WHO n.d.-a).

Chemical pollutants in water further exacerbate these risks, whether of natural origin (e.g., arsenic and fluoride) or anthropogenic in nature (e.g., nitrates from agricultural runoff) (WHO, n.d.-b). Safe and sufficient WASH services also play a critical role in preventing and controlling Neglected Tropical Diseases (NTDs)

such as trachoma, soil-transmitted helminths, and schistosomiasis (WHO, n.d.-c). The substantial reduction in diarrheal mortality by nearly half during the Millennium Development Goal (MDG) period (1990–2015) underscores the transformative public health benefits derived from improvements in water and sanitation infrastructure (UNICEF and WHO 2015).

Advancing WASH services to safely managed standards, such as regulated piped water supply and properly treated sewer systems, has been shown to reduce disease burden and improve population health outcomes significantly (Prüss-Ustün et al 2019).

However, persistent gaps in WASH access cannot be understood solely through infrastructural or technical perspectives; they are deeply embedded within cultural, social, and gendered contexts that shape usage patterns and access inequalities. In many low- and middle-income settings, women and girls disproportionately bear the responsibility for water collection and household sanitation management, exposing them to physical strain, health hazards, and risks of harassment or violence, particularly in areas lacking safe sanitation facilities (Sorenson et al. 2011; Sommer et al. 2015). These gendered burdens not only constrain educational and economic participation but also perpetuate cycles of poverty and marginalization.

Furthermore, cultural taboos surrounding menstruation and sanitation often impede women's and girls' ability to manage menstrual hygiene with dignity, particularly where privacy and adequate facilities are lacking (Caruso et al. 2017; MacRae et al 2019). Consequently, addressing WASH challenges requires an integrated approach that accounts for socio-cultural norms, gender dynamics, and community participation to ensure equitable, inclusive, and sustainable outcomes.

2. Methodology

This study employs a mixed-methods research design to evaluate and enhance the localization of Sustainable Development Goal 6 (SDG-6) on Water, Sanitation, and Hygiene (WaSH) in the rural context of Baran District, Rajasthan, an aspirational district grappling with water scarcity and underperformance on WaSH indicators. The methodology is grounded in a contextual adaptation of national and subnational SDG indicators to better capture rural-specific challenges. Theoretical perspectives inform it on systems thinking, participatory governance, and gendered development. Specifically, the research draws upon the Sustainable Livelihoods Framework (Chambers and Conway 1992) and elements of Institutional Analysis and Development (IAD) theory (Ostrom 2005) to understand how systemic, operational, and social factors collectively shape WaSH outcomes at the local level. These theoretical models guide the formulation of research questions, the selection of indicators, and the interpretation of qualitative insights, ensuring that both institutional structures and community dynamics are analytically integrated.

An extensive literature review establishes the conceptual foundation, highlighting the interlinkages of SDG-6 with health, education, gender equality, and climate action. It also explores SDG localization frameworks, the relevance of Panchayat Development Indexing (PDI), and India's progress under NITI Aayog's SDG framework. The literature review and qualitative analysis are thematically structured using an inductive-deductive approach, in which recurrent themes such as governance, inclusivity, environmental resilience, and equity in service delivery are synthesized from both academic and policy sources.

Primary data is collected through structured household surveys; semi-structured interviews with local government officials, Village Water and Sanitation Committees (VWSCs), and community members; and supplemented by direct field observations. The household survey employs a stratified purposive sampling technique to ensure representation across socio-economic and demographic variations. Particular attention is given to the inclusion of women-headed households, households below the poverty line (BPL), and those with members with disabilities to capture intersectional vulnerabilities and differentiated WaSH experiences. Where such groups were underrepresented, the study acknowledges this as a sampling limitation that may influence the generalizability of findings.

Secondary data sources include official datasets from the Jal Jeevan Mission, the Swachh Bharat Mission, the Census of India, the National Family Health Survey (NFHS), and relevant academic and policy literature. Data triangulation between these primary and secondary sources strengthens the validity of findings and mitigates potential reporting biases.

The research follows a tiered analytical structure, beginning at the block level and narrowing down to two Gram Panchayats selected using a customized SDG-6 index: Barwa (Anta Block) as the top-performing and Shubhdhara (Shahbad Block) as the lowest-performing. Key indicators assessed include household access to piped water, functional toilets, handwashing and menstrual hygiene facilities, waste management systems, and the functionality of VWSCs. The presence and maintenance of WaSH infrastructure in schools and Anganwadis are also evaluated.

Quantitative data is analyzed using descriptive statistics and index-based scoring to identify disparities and trends. Qualitative data, derived from interviews and field observations, are examined through thematic analysis (Braun and Clarke 2006), guided by the theoretical frameworks mentioned above.

3. Understanding the Concepts Related to WaSH, SDG 6, and Localization

Clean water and proper sanitation are essential for sustainable development, shaping poverty alleviation, economic progress, and environmental well-being (United Nations, 2015a). Despite global efforts, major water-related challenges persist, including overuse of resources, pollution, and the growing impacts of climate change. Consequently, millions of people still lack access to safe drinking water and adequate sanitation—a situation further aggravated by the COVID-19 pandemic (United Nations, 2020a). The United Nations' 2030 Agenda for Sustainable Development, particularly Sustainable Development Goal 6, provides a framework for tackling these issues (United Nations, 2015a). To accelerate progress, the UN introduced the SDG 6 Global Acceleration Framework in 2020, aiming to drive faster and more coordinated action towards water security (United Nations 2020a). All stakeholders must work together and take decisive action to tackle the global water crisis and ensure the availability of safe and sustainable water and sanitation for all (United Nations 2015a).

The SDGs are not independent goals but rather interconnected components of a complex system. To achieve these goals, a comprehensive approach is required, one that integrates the social, economic, and environmental aspects of sustainability while staying within the limits set by planetary boundaries (United Nations, 2015a). The Stockholm Resilience Centre (2016) identified nine planetary boundaries that mark humanity's safe operating limits, encompassing areas such as climate change, biodiversity loss, and freshwater use. The framework visually illustrates the relationship between the SDGs and these planetary boundaries. The SDGs are grouped into three primary categories: Society, Economy, and Biosphere. This structure highlights the interconnectedness of these domains and their combined impact on both human well-being and the health of the planet (United Nations 2015a).

According to the United Nations Development Programme (UNDP), localization of the Sustainable Development Goals (SDGs) involves translating the global goals into locally relevant actions. This includes adapting, implementing, and monitoring progress at the sub-national level (UNDP 2016). Successfully implementing the 17 SDGs and 169 targets requires a localization approach that aligns with regional needs, including customized strategies and indicators (UNDP 2016). Such localization empowers local governments to drive sustainable development while allowing global goals to shape local policies (United Nations, 2015a). In particular, SDG 11, which focuses on sustainable cities and communities, is central to localization and reflects the growing importance of subnational actors in development efforts (United Nations 2015a). Integrating SDG 11 with urban-related targets from other SDGs promotes a coordinated, holistic framework (United Nations, 2015a).

4. Localisation of SDG 6 in rural areas

Localising Sustainable Development Goal 6 (SDG 6) involves tailoring global water and sanitation targets to the unique needs of rural communities (UNICEF 2021). This requires moving beyond national frameworks to address challenges such as dispersed populations, limited infrastructure, financial constraints, and reliance on rain-fed or groundwater sources (WHO 2019). Effective localization requires disaggregated local data to reflect the realities of marginalized groups and context-specific adaptations of SDG-6 indicators. For example, instead of focusing solely on piped water access, indicators should also include the sustainability of community-managed sources such as boreholes or protected wells (UNDP 2018). Similarly, sanitation metrics should account for the use and safe management of on-site systems such as improved latrines, which are more prevalent in rural settings (WHO 2019). Community participation is essential in planning, implementation, and monitoring to

ensure culturally appropriate and sustainable WASH solutions while fostering local ownership and capacity (UNICEF 2021). Integration of WASH goals into broader rural development sectors, such as health, agriculture, and education, is also critical, along with mobilizing appropriate financial and technical resources (WHO 2019). Ultimately, localization of SDG-6 seeks to make the global vision of water and sanitation for all a reality in rural areas through context-driven, inclusive, and sustainable approaches.

5. Rajasthan SDG 6 Indexing

Rajasthan's SDG 6 Index (2023-24) revealed substantial intradistrict disparities, with Baran lagging behind in indicators such as piped water supply, groundwater withdrawal, improved sanitation access, and waste processing efficiency. These gaps underscore the urgent need to develop tailored indicators and decentralized monitoring systems that reflect the realities of rural life.

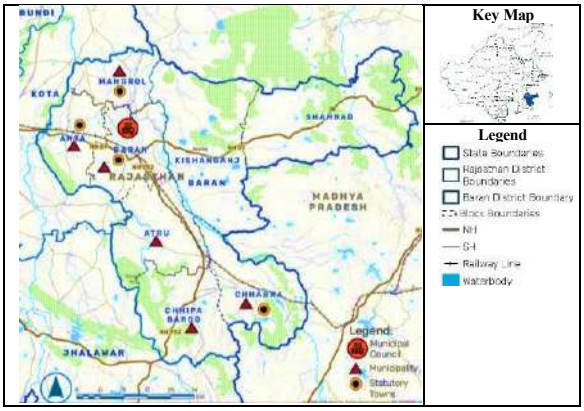


Figure 1: Map showing the administrative setup of Baran District. Source: (Kashyap 2025).

Baran spans 6,994 sq. km, has a predominantly rural character (97.5 percent), and is intersected by significant river systems like the Chambal, as well as areas affected by climate change, biodiversity loss, and freshwater use. The framework visually illustrates the relationship between the SDGs and these planetary boundaries (Figure 1). The SDGs are grouped into three primary categories: Society, Economy, and Biosphere. This structure highlights the interconnectedness of these domains and their combined impact on human well-being and the health of the planet and its tributaries (United Nations, 2015a). The district's physiographic features, including elevations and rocky soils such as sandstone and basalt, along with erratic rainfall distribution (650–1000 mm annually), present unique challenges for water accessibility and resource management.

Areas like Shahbad and Kishanganj, with high tribal populations and difficult terrain, face compounded challenges due to infrastructural inaccessibility and socio-economic marginalization. Moreover, groundwater over-extraction, especially in blocks like Atru, Baran, and Chhabra, coupled with poor recharge potential due to geological conditions, has severely stressed water availability. The Sustainable Development Goal 6 (SDG 6), which aims to "ensure availability and sustainable management of water and sanitation for all," faces significant implementation challenges in Baran District, Rajasthan. The district exhibits uneven progress across the various sub-targets of SDG 6, reflecting deep-rooted geographical, infrastructural, socio-economic, and institutional barriers, especially in its tribal and remote areas.

6. Sustainable Development Goal (SDG 6) Index

6.1 Inter-block SDG 6 Indexing

Using a customized SDG 6 Index with 12 indicators, the district was evaluated across all blocks. The indicators used are the following:

- Percentage of Households with Piped Water Supply Connection (PWS).
- Percentage of households having a 100 percent functional tap water connection.
- Percentage of Schools and Anganwadis with Drinking Water Facility.
- Percentage of Households with Piped Water Supply Connection in Particularly Vulnerable Tribal Group (PVTG) Villages.
- Percentage of Households with Functional Individual Household Latrines (IHHL).
- Percentage of Villages with Community Sanitary Toilets (CSTs).
- Percentage of Schools with Separate Girls'
- Toilet Facility
- Percentage of Open Defecation Free (ODF Plus) Villages
- Percentage of Solid Waste Management Assets
- Percentage of Greywater Management Assets
- Stages of Groundwater Development
- Micro Watershed Priority Areas

The highest achievement is seen in the proportion of villages with Village Water and Sanitation Committees (79.70 percent), followed by schools and Anganwadis with drinking water facilities (64.47 percent), and households with access to piped water supply connections in PVTG villages (59.69 percent).

Indicators like functional tap water connections (32.74 percent) and safe drinking water through PWS (18.69 percent) are notably lower. Critical infrastructure indicators, such as GWM assets (5.77 percent) and micro-watershed management (12.00 percent), show the weakest performance. Overall, while progress is visible in sanitation and committee formation, water accessibility and resource management remain significant challenges (Figure 2).

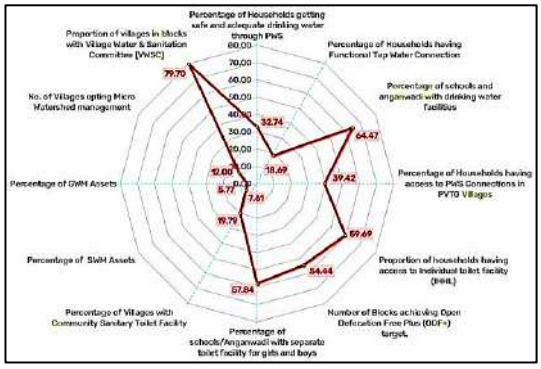


Figure 2. Performance of SDG 6 Indicators for Baran District at Inter-Block Level; Source: (Saxena 2025)

Anta Block emerged as the top performer (score: 51.04), earning the "Front Runner" classification due to strong infrastructure, road connectivity, and effective program implementation. In contrast, Shahbad Block scored lowest (15.37) and landed in the "Beginner" category due to its forested terrain, tribal demographics, low literacy, poor economic conditions, and severe water scarcity.

The district-wide averages further revealed weak areas: only 18.69 percent of households had functional tap connections, 19.79 percent of villages had CSTs, and the availability of GWM and SWM assets remained below 10 percent.

6.2 Panchayat Development Indexing (PDI): Localising SDG-6 at the Gram Panchayat level

From SDG-6, indexing two blocks, i.e., best and worst performing blocks, is selected to analyze the data further and compare the Gram Panchayat performance among the two selected blocks (Figure 3).

The analysis highlights a major shortfall in watershed management and a serious lack of household drainage infrastructure, both of which are emerging as the weakest areas in the region evaluated.

In contrast, there is a strong focus on improving WASH (Water, Sanitation, and Hygiene) infrastructure in educational settings, with indicators for schools and Anganwadi centers showing notably better performance (Figure 4). This highlights a strategic priority for enhancing educational environments and sanitary conditions for vulnerable groups.

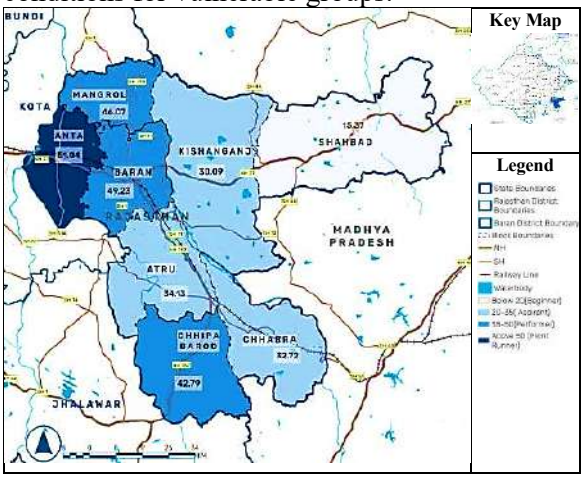


Figure 3. Map showing inter-block SDG-6 Indexing Source: (Saxena 2025)

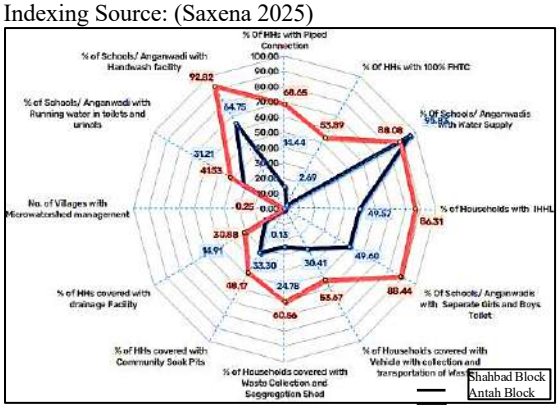


Figure 4. Performance of SDG-6 Indicators for Antah and Shahbad Blocks at Gram Panchayat Level
Source: (Saxena 2025), based on Primary Survey.

Among all areas, Shahbad block has the most severe deficiencies in water supply and drainage systems. These issues are further intensified by a low proportion of households having individual toilet facilities, reflecting the block's significant infrastructural vulnerability. In response, programs such as the Jal Jeevan Mission (JJM) and the Swachh Bharat Mission (SBM) are being implemented in Shahbad to improve infrastructure and ensure reliable access to safe drinking water.

6.3 Anta Block: Panchayat Development Indexing

Anta Block achieves the highest score in the Inter-block SDG 6 Indexing at 51.04, categorizing it as a "Front Runner." This strong performance is largely due to its well-developed infrastructure, extensive road connectivity that ensures access to remote areas, and the successful execution of key government programs such as the Jal Jeevan Mission (JJM) and Swachh Bharat Mission (SBM). The block's relatively higher

institutional capacity and service delivery efficiency further strengthen its position in ensuring equitable water and sanitation outcomes.

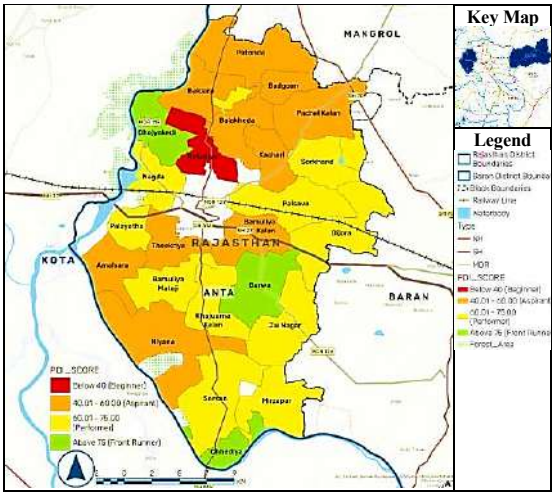


Figure 5. Map showing Anta Block: Panchayat Development Index; Source: (Saxena 2025).

The Gram Panchayats (GPs) in Anta Block are classified into five performance categories based on their composite scores: “Beginner” (below 40), “Aspirant” (40–60), “Performer” (60–75), “Front Runner” (75–90), and “Achiever” (above 90). Of the 24 GPs assessed in the block, only one falls into the Beginner category. In comparison, a substantial majority are distributed between the Aspirant (ten GPs) and Performer (ten GPs) categories. Three GPs have progressed to the front-runner level, indicating relatively stronger institutional capacity and service delivery outcomes.

Notably, none of the GPs have attained the Achiever category (Figure 5), suggesting that, while incremental progress is evident across the block, the highest performance benchmarks remain unmet. This pattern highlights both the potential and the gaps within the current governance framework. The clustering of GPs in the middle-performance bands underscores the need for targeted capacity-building interventions, enhanced resource allocation, and focused monitoring mechanisms to enable upward movement into higher performance tiers and foster more balanced and sustained development across the block.

6.4 Shahbad Block: Panchayat Development Indexing

Shahbad Block records the lowest SDG-6 Index score at 15.37, placing it in the "Beginner" category. This low score is linked to several challenges, including its large forest cover, a predominantly tribal population with lower literacy levels, limited economic opportunities, and frequent exposure to drought. There is a total of 36 gram panchayats in the Shahbad block.

Notably, none of the GPs has reached the "Performer," "Front Runner," or "Achiever" levels, indicating an urgent need for targeted, strategic interventions to improve the overall performance of all GPs in Shahbad Block.

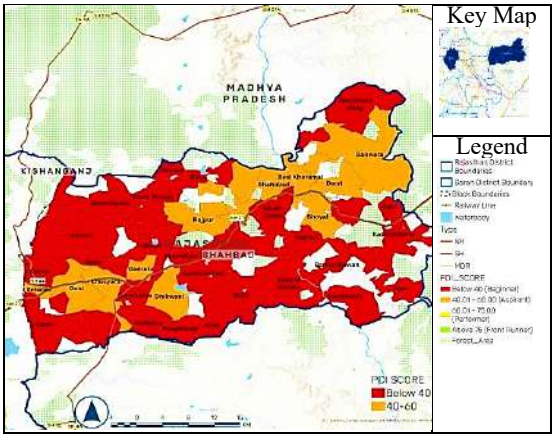


Figure 6. Map showing Shahbad Block: Panchayat Development Index; Source: (Saxena 2025).

Based on the Panchayat Development Index (PDI) analysis (Figure 6), Barwa Gram Panchayat in Anta Block ranks among the best-performing areas, falling within the Front Runner category (PDI Score: 75–90). This reflects significant progress across key development indicators and suggests that Barwa has implemented effective strategies in sanitation, water supply, and basic infrastructure. In contrast, Shubhdhara Gram Panchayat in Shahbad Block is among the worst-performing, placed in the beginner category (PDI score below 40). This indicates serious deficiencies in foundational development services and infrastructure, pointing to the urgent need for targeted interventions.

7. Recommendations

7.1 Governance Level Interventions

Governance-level interventions play a crucial role in effectively localising and implementing Sustainable Development Goal 6 (SDG-6), which focuses on clean water and sanitation. A multi-tiered institutional framework that integrates efforts from the district to the village level to ensure coordinated and data-driven water and sanitation governance.

A multi-tiered institutional framework (Figure 7) that integrates efforts from the district to the village level to ensure coordinated and data-driven water and sanitation governance. At the top, a central SDG cell at the district level collaborates with departments such as the Public Health Engineering Department (PHED) and the

Sanitation Department, each operating its respective SDG 6 wing.

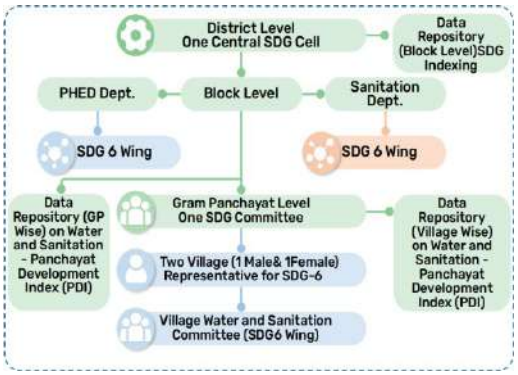


Figure 7. Institutional Framework; Source: (Saxena 2025)

These departments feed into block-level mechanisms and, further down, into the Gram Panchayat level, where a dedicated SDG committee ensures grassroots involvement. Each village is represented by one male and one female SDG 6 representative, promoting gender inclusivity. The Village Water and Sanitation Committee (SDG 6 Wing) plays a pivotal role in implementing local initiatives, supported by data repositories maintained at the GP, block, and village levels for tracking the Panchayat Development Index (PDI). This structure ensures a holistic, inclusive, and evidence-based approach to achieving SDG 6 outcomes.

7.2 Water Stewardship Initiative (WSI)

The Water Stewardship Initiative (WSI), developed by the Watershed Organisation Trust (WOTR), is a participatory framework aimed at improving water governance and ensuring water security in rural India. Emphasizing community-led management, the initiative promotes sustainable and equitable water use through local institutions, awareness-building, and the integration of scientific tools with traditional knowledge. Implemented across 10 Indian states, WSI includes components such as water budgeting, crop planning based on water availability, demand-side management, and village-level Water Stewardship Committees (WSCs). These committees, supported by trained community members, guide local water planning, encourage equitable use, and implement conservation measures. The initiative also involves capacity-building through workshops, training in interpreting hydrological data, and the development of decision-support tools to empower informed community action.

Despite its reach, WSI is yet to be introduced in Baran District, Rajasthan, a region facing severe water scarcity, erratic rainfall, and weak WaSH infrastructure, particularly in tribal and remote areas. Introducing WSI here can be transformative, involving collaboration with Gram Panchayats, VWSCs, SHGs, and civil society groups to embed water stewardship into local governance.

Using tools like Participatory Rural Appraisals and water resource mapping, communities can better assess water availability and plan accordingly. WSI also emphasizes gender inclusion and the empowerment of women, often primary water users. A strong monitoring mechanism tracks water usage and sanitation progress and facilitates data-driven decision-making, fostering transparency and accountability. Long-term benefits include enhanced climate resilience, decentralized governance in line with the 73rd and 74th Constitutional Amendments, and alignment with SDG 6. By localising water governance, WSI offers a scalable model for sustainable water management in Baran and similar rural contexts.

At the core of the initiative is the Water Stewardship Plan (Figure 8), which includes assessing village water health, water budgeting, harvesting and saving strategies, and setting social norms. A Village Water Management Team (VWMT) leads this process, engaging primary (local users), secondary (adjacent villages), and tertiary (influencers and policymakers) stakeholders. Rural youth, trained as Jal Sevaks and Sevikas, support the VWMT by raising awareness, mobilizing communities, managing data, and ensuring stakeholder representation. They play a vital role in systematically implementing the plan. The VWMT holds regular review meetings and ensures the Gram Panchayat and Gram Sabha ratify all plans. Tasked with executing the water stewardship plan, the VWMT aims to build self-reliant communities. The initiative aligns with district-level planning to promote coordinated, sustainable water governance. Overall, it fosters water literacy, community empowerment, partnerships, and equitable water use at the grassroots level.

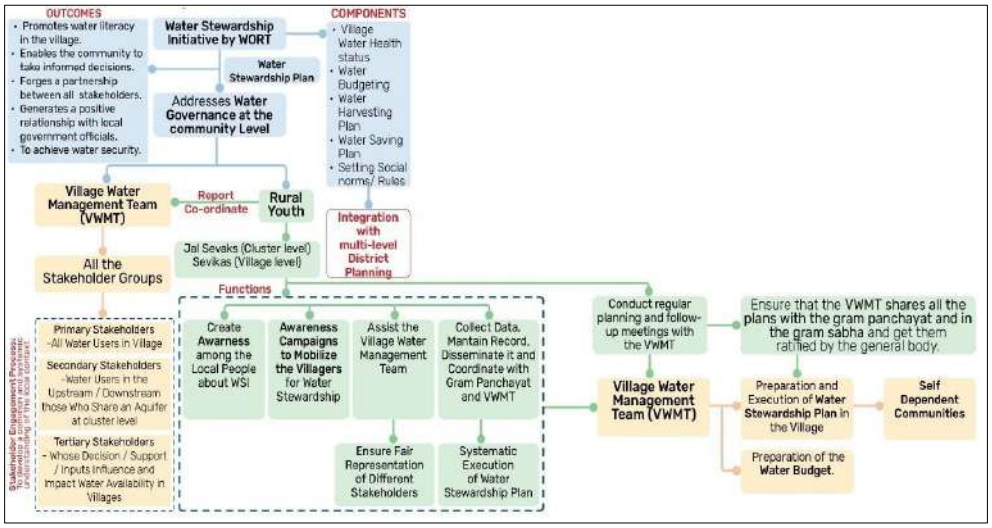


Figure 8. Water Stewardship Initiative Framework; Source: (Saxena 2025).

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7.3 Suggestions on Localising SDG 6 by Gender and Climate-Responsive Indicators Related to WaSH

The localization of SDG 6 at the grassroots level remains incomplete without the inclusion of gender- and climate-responsive indicators, which are currently absent from standard monitoring frameworks. This absence has resulted in the neglect of several crucial issues, particularly those that disproportionately impact women, girls, and climate-vulnerable communities. For instance, the burden of water collection often falls on women, affecting their health, education, and economic opportunities, yet this is rarely captured in conventional metrics.

Table 1. Gender and Climate-Specific Indicators

Gender-Specific Indicators	Climate-Specific Indicators
Target 6.1: Drinking Water	
The percentage of women or girls going more than 500m a day to fetch water from their households.	Percentage of the population with access to a climate/disaster-resilient water service.
Percentage of women/girls excluded from education/labour due to time spent fetching water.	Percentage of population whose water service has been impacted by an extreme event in the last 12 months.
	Percentage of schools whose water service has been impacted by an extreme event in the last 12 months.
Target 6.2: Sanitation and Hygiene	
Percentage of primary and secondary schools with menstrual hygiene management	Percentage of population with access to a climate/disaster-resilient sanitation service.
Percentage of schools with menstrual hygiene-related education, materials, and disposal options.	Percentage of the population whose sanitation service has been impacted by an extreme event in the last 12 months.
	Percentage of schools whose sanitation service has been impacted by an extreme event in the last 12 months.
Target 6.a: Capacity Building	
Capacity building for officials **and** elected representatives on violence against women while accessing water and sanitation facilities.	Capacity building for officials **and** elected representatives regarding climate- and disaster-resilient infrastructure services.
Percentage of women/girls based on awareness Campaigns on menstrual hygiene management	
Target 6. b: Participation	
Percentage of female members who participate in community-based WASH committees or other decision-making bodies.	

Source: (Saxena 2025).

Similarly, the impact of climate change on water availability, such as seasonal scarcity, droughts, and contamination, is not adequately reflected in existing indicators. To bridge this gap, it is imperative to introduce additional indicators that measure aspects like time spent by women collecting water, school absenteeism among girls due to inadequate menstrual hygiene facilities, the resilience of water sources to climate shocks, and the functionality of WaSH infrastructure during extreme weather events. Integrating such indicators will not only ensure a more inclusive and accurate assessment of progress toward SDG-6 but also enable more targeted, equitable, and sustainable policy interventions that respond to the specific needs of marginalized and climate-affected populations (Table 1).

Integrating such indicators will not only ensure a more inclusive and accurate assessment of progress toward SDG-6 but also enable more targeted, equitable, and sustainable policy interventions that respond to the specific needs of marginalized and climate-affected populations.

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Planning for Public Transport System in Inaccessible Area:
Case Study of Delhi

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Abstract: Public transport in underserved areas is crucial for promoting social and economic equality. However, many areas in cities still lack public transport services due to low demand, isolation, and financial constraints. To close this gap, a sustainable, financially feasible model is needed to improve accessibility and shared mobility. This paper is based on an empirical study to assess the accessibility levels of Chhawala ward, a public transport underserved area in Delhi and evaluate the potential of the neighbourhood bus system as a feasible solution in it. The empirical investigation conducted as part of this study reveals critical gaps in bus service, particularly in coverage and service frequency. The public transport accessibility levels, as indicated by the PTAL index, indicate that a large proportion of the area is classified as very low, demanding urgent intervention to improve the situation. The empirical study shows that long wait times limit mobility and encourage residents to use private vehicles, resulting in unsustainable mobility patterns. In response to these issues, the study proposes Neighbourhood Bus Service concept to improve last-mile connectivity. Some of the suggested measures include optimized route lengths, higher service frequency, and strategically placed bus stops to maximize coverage and impact. The public transport service model developed in the study aims to enhance public transport accessibility and lower vehicular emissions. The study also estimates the potential ridership of the proposed neighbourhood bus service using a discrete-choice model and the potential bus fleet requirements for the case study area and for similar low-density areas across Delhi. Overall, the study addresses to the state public transport service to underserved areas in an Indian city, and presents an inclusive, efficient, and environmentally friendly concept of neighbourhood bus service to improve public transport system accessibility levels and bus operations for the residents of low-density, underserved areas.

Keywords: Accessibility, low density, undeserved area, neighbourhood bus

सार: अल्प-सेवित क्षेत्रों में सार्वजनिक परिवहन सामाजिक और आर्थिक समानता को बढ़ावा देने के लिए अत्यंत आवश्यक है। तथापि, शहरों के अनेक क्षेत्रों में आज भी सार्वजनिक परिवहन सेवाओं का अभाव है, जिसका कारण कम मांग, अलगाव और वित्तीय चुनौतियाँ हैं। इस कमी को दूर करने के लिए ऐसी सतत और वित्तीय रूप से व्यवहार्य परिवहन तंत्र की आवश्यकता है जो पहुँच और साझा गतिशीलता में सुधार ला सके। यह शोध दिल्ली के छावला वार्ड, जो सार्वजनिक परिवहन के दृष्टिकोण से अल्प-सेवित क्षेत्र है, की पहुँच-स्तर का अनुभूतिमूलक मूल्यांकन करता है और इस क्षेत्र में स्थानीय बस सेवा को एक व्यवहार्य समाधान के रूप में परखता है। इस अध्ययन के अंतर्गत किए गए प्रायोगिक विश्लेषण से पता चलता है कि बस सेवा में गंभीर अंतराल मौजूद हैं, विशेषकर दायरा और सेवा आवृत्ति के संदर्भ में। सार्वजनिक परिवहन पहुँच स्तर के अनुसार, क्षेत्र का एक बड़ा हिस्सा अत्यंत निम्न पहुँच श्रेणी में आता है, जो तत्काल सुधारात्मक हस्तक्षेपों की आवश्यकता को रेखांकित करता है। अध्ययन से यह भी ज्ञात हुआ कि बस उपयोगकर्ताओं के लिए लंबे प्रतीक्षा समय के कारण गतिशीलता सीमित होती है, जिससे निवासी निजी वाहनों का अधिक उपयोग करने लगते हैं और यह असतत परिवहन प्रवृत्ति को जन्म देता है। इन समस्याओं के समाधान के लिए, अध्ययन स्थानीय बस सेवा की अवधारणा प्रस्तुत करता है, जिसका उद्देश्य अंतिम-दूरी संपर्क में सुधार लाना है। प्रस्तावित उपायों में - अनुकूलित मार्ग लंबाई, उच्च सेवा आवृत्ति, और रणनीतिक रूप से स्थित बस स्टॉप शामिल हैं, जिससे अधिकतम कवरेज और प्रभाव प्राप्त हो सके। अध्ययन में विकसित सार्वजनिक परिवहन सेवा मॉडल का उद्देश्य बस पहुँच स्तरों को बढ़ाना और वाहन उत्सर्जन को कम करना है। इसमें विभेदक विकल्प मॉडल के माध्यम से न केवल अध्ययन क्षेत्र के लिए, बल्कि दिल्ली के अन्य समान निम्न-घनत्व क्षेत्रों के लिए भी प्रस्तावित बस सेवा की संभावित सवारी तथा आवश्यक बसों की संख्या का भी अनुमान लगाया गया है। समग्र रूप से, यह शोध एक भारतीय शहर में कम सेवा वाले क्षेत्रों में राज्य सार्वजनिक परिवहन सेवा को संबोधित करता है और एक समावेशी, कुशल और पर्यावरण के अनुकूल स्थानीय बस सेवा की अवधारणा प्रस्तुत करता है, जो निम्न-घनत्व, कम सेवा वाले क्षेत्रों के निवासियों के लिए सार्वजनिक परिवहन प्रणाली की पहुंच के स्तर और बस संचालन में सुधार कर सकती है।

मुख्य शब्द: अभिगम्यता, निम्न घनत्व, अल्प-सेवित क्षेत्र, स्थानीय बस सेवा

1. Introduction

Public transport offers an affordable, environmentally friendly, and equitable means of transport for everyone. However, a significant challenge lies in addressing areas in cities characterized by poor public transport accessibility and limited urban connectivity (Hurni 2006). These areas, often geographically isolated or economically deprived, lack adequate public transport services, leaving them excluded from the benefits of urban mobility and perpetuating social and economic disparities.

It is well known that well-functioning public transport systems are key facilitators of sustainable urban development, economic progress, and social equity by alleviating traffic jams, reducing pollution, and conserving energy. In underserved transport-disadvantaged regions, public transport enhances social and economic inclusion, empowers communities, and boosts local economies by improving access to urban opportunities. Further, it enhances public transit use and reduces reliance on private vehicles, thereby lessening private-vehicle-related environmental impacts.

All these potential public transport benefits, however, are countered by a lack of understanding of reliable public transport systems in regions with low demand and minimal infrastructure. Further, there is a limited understanding of the unique challenges faced by transport-disadvantaged areas, particularly in geographically isolated or economically deprived regions. This also underscores the need to reexamine the economic sustainability of public transport systems in low-demand regions, where traditional high-capacity services may not be feasible.

2. Literature Review

Inaccessible public transport areas refer as locations with poor public transport accessibility and low levels of urban accessibility. (Hurni 2006). A review of global research on the subject reveals that one of the biggest obstacles is the sparsely populated or low-density regions with little to no demand for public transport. These places often lack the population density to make public transport economically viable (Poltimäe, H., Rehema, M., Raun, J. and Poom, A. 2022). In addition, the limited number of passengers in such areas, coupled with the long distances involved in travel, frequently render the routes frequently unprofitable, making it difficult to sustain operations (Mackett, R.L. and Thoreau, R. 2015).

To fill mobility gaps in public transport-inaccessible areas, some innovative practices have been implemented in different parts of the world. Demand Responsive Transit (DRT) is one such type of public transport system in which passengers are picked up and dropped off at their preferred locations within certain geographical boundaries (Paget-Seekins, L., Tironi, M. and Vasconcellos, E.A. 2021). Community or Neighbourhood Bus Services use smaller vehicles to navigate dense or underserved regions and offer subsidized fares (Sharman, M.J., Lyth, A., Ragaini, B.S., Johnston, F.H. and Palmer, J. 2019).

The literature indicates that the PTAL index is one of the most widely used approaches for measuring the accessibility of public transport systems in cities (Rajendran 2013). It is preferred for public transport accessibility measurement as it is fairly simple, transparent, and practical to use. Unlike sophisticated models, it uses color-coded contour maps, which are visually simple and easy to understand. PTAL includes all service supply factors, such as service frequency, “waiting time,” and “walk access.” The methodology includes defining Points of Interest (POIs), calculating Walk Access Time and Average Waiting Time, and converting them to Equivalent Doorstep Frequency (EDF). The sum of EDF values yields the Accessibility Index (AI), which is categorized into PTAL bands ranging from 1 (very low access) to 6 (high access). This approach helps planners address uncovered mobility areas and is highly efficient. (TfL 2010).

3. Study Methodological Approach

The present study adopts an eight-step methodological approach described as follows:

Stage 1: Problem Identification

Stage 2: Literature Review

Stage 3: Case study area selection and its profiling

Stage 4: Field studies and Analysis of the public transport system supply

Stage 5: Assessment of Public Transport Accessibility levels using PTAL

Stage 6: Socio-economic characteristics and Travel Patterns across varying PTAL Levels

Stage 7: Development of Public Transport Disadvantage Index

Stage 8: Development of Operation Plan for Proposed Neighbourhood Bus System

The present paper focuses on an immediate public transport improvement plan and does not consider the future development proposals.

4. Case Study Area Selection and its Profiling

To select the case study area, the Public Transport Accessibility map of Delhi was collected and analyzed, along with the socio-economic profiles of different wards of Delhi. Based on this mapping, the case study area was selected, taking into account parameters such as PTAL (Public Transport Accessibility Level), income groups, built-up area, population density, and land-use patterns (Figure 1 and Table 1).

Zone L in the peripheral area of Delhi was chosen as the focal area for the case study, as it has significantly low PTAL scores, indicating poor public transportation accessibility. Within Zone L, Chhawala ward was selected as the investigation case study area due to its socio-economic and spatial attributes.

Chhawala ward, a relatively underdeveloped area, had an estimated population of 81,500 in 2022. It spans 11,657 hectares, resulting in a gross residential density (GRD) of 98 people per hectare. The land use of Chhawala ward in 2025 will be dominated by agriculture (57%) with a minor share

of residential land use (7.1%) (Figure 1 and Table 1). The road infrastructure in Chhawala Ward comprises 398 km of roads across a 116.25 km² study area, yielding a road network density of 3.4 km/km².

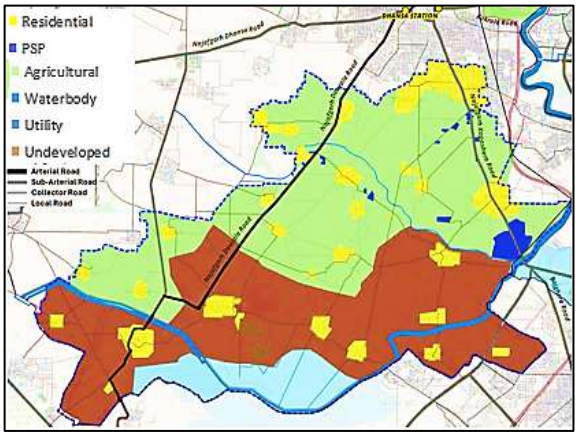


Figure 1. Existing Land use map of Chhawala ward Source: (Jain 2025)

Table 1. Distribution of Land use in Chhawala ward

Land use	Existing 2025 Area (Ha)	% Share
Residential	832	7.1
PSP	99	0.8
Transportation	35	0.4
Agricultural	6681	57.3
Waterbody	620	5.3
Utility	20	0.1
Undeveloped	3370	28.9
Green Belt		
Total	**11657**	**100**

Source: Survey by Jain (2025)

An illustration of the proposed Zonal Land Development Plan–I for Delhi 2021 is shown in Figure 2 and Table 2. As per the Zonal Development Plan 'L' for Delhi 2021, the total land area of 11,657 hectares in Chhawala Ward is largely earmarked for Green Belt use (28.9%), reflecting a strong emphasis on ecological conservation and open spaces. This is followed by Residential use (51.4%) and Public/Semi-Public uses (12.7%), indicating a planned urban expansion supported by adequate social and institutional infrastructure. Transportation networks and utility corridors are strategically integrated within the plan to support future population growth and enhance accessibility across the ward. The spatial allocation also aims to reduce land-use conflicts by clearly delineating development zones and environmentally sensitive areas. The proposed land use framework highlights a shift from the ward's predominantly agricultural, undeveloped character toward a more structured urban form, while retaining significant green and buffer zones to balance development and environmental sustainability.

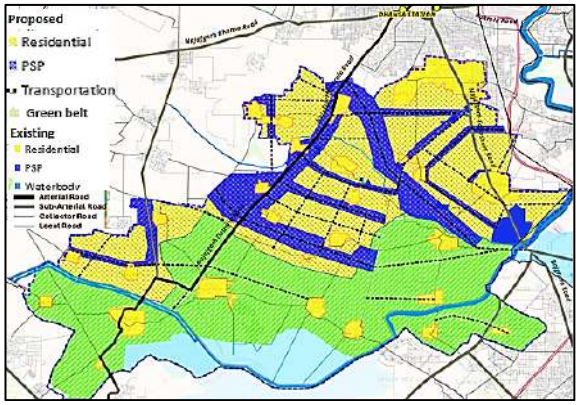


Figure 2. Proposed Land use map as per Zonal Development Plan L Delhi 2021; Source: ZDP L Delhi 2021

Table 2. Distribution of Land use according to ZDP L Delhi 2021; Source: ZDP L Delhi 2021

Land-use	Proposed ZDP 2021 Area (Ha)	% Share
Residential	5963	51.2
PSP	1484	12.7
Transportation	200	1.8
Agricultural		
Waterbody	620	5.3
Utility	20	0.1
Undeveloped		
Green Belt	3370	28.9
Total	**11657**	**100**

5. Field Studies and Public Transport Supply Analysis

5.1 Field Studies

The field studies conducted in this study comprise of a Household survey, a Public Transport User survey and a Stated Preference survey, which together provide essential quantitative insights into travel behaviour and demand assessment.

A household survey was conducted to capture socio-economic attributes, travel behaviour, and modal choices of users, with 128 households distributed across PTAL levels. The survey adopted a stratified simple random sampling technique to ensure representative coverage. Key outcomes included trip purpose, cost, duration, per capita trip rate, trip length, and preferred transport modes, offering insights into residents' accessibility issues and travel patterns.

The Public Transport User Survey aimed to assess the efficiency of existing transit systems in terms of supply-demand pattern, accessibility level and passenger access, and dispersal patterns. This was complemented by a public transit user and stated-preference survey, with 141 users enumerated across the PTAL levels. This segment evaluated user satisfaction and preferences, as well as PT trip characteristics in each zone.

The Stated Preference Survey was carried out to estimate the likelihood of commuters shifting from private to public transport under improved transit service conditions. The survey sample comprised 30 users from each mode and the outcome focused on understanding how factors such as travel time, reliability and cost influence modal shift.

These field studies allowed for a comprehensive evaluation of public transport accessibility and user expectations. The collected data is analysed to assess the socio-economic and travel characteristics of the population, PT usage patterns and the impact of accessibility on travel decisions of users.

5.2 Public Transport Supply Analysis

BUS NETWORK CHARACTERISTICS

The bus route network within Chhawala Ward spans 48.5 km, covering 12.2% of the total road network in the area. (Figure 3) The network density is 0.4 km/sq. km, which is comparatively lower than the average for Delhi NCT, which stands at 0.73 km/sq. km.

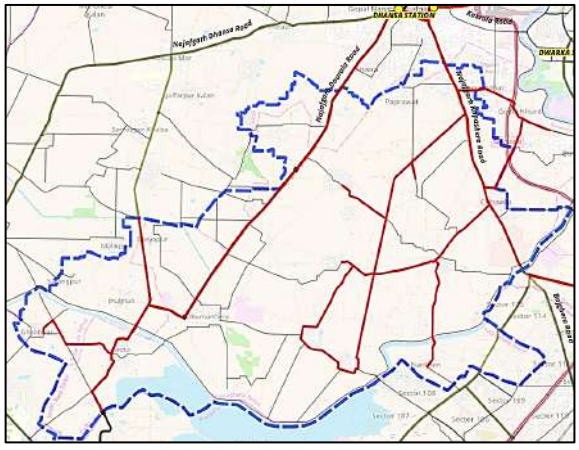


Figure 3. Existing Bus Network of Chhawala ward
Source: (Jain 2025)

BUS ROUTE CHARACTERISTICS

The bus route network in Chhawala Ward spans 406.8 km, across 65 routes. However, a significant observation is the high level of route overlap, 94% of the total bus route network overlaps, indicating inefficiencies in route planning and service distribution. About 63% of the routes operate with headways exceeding 60 minutes, reflecting long waiting times and poor service reliability.

BUS INFRASTRUCTURE CHARACTERISTICS

The bus system in the Chhawala ward has three major depots: Rewla Khanpur and Ghuman Hera. The closest major transit hubs are Najafgarh Bus Terminal (10 km) and Dhansa Metro Station (9.5 km). The ward has 47 bus stops, with an average distance of 1 km (0.4 - 2.7 km). The overall fleet of buses operating in the area is 218, and routes are mostly along the Najafgarh-Kapashera Road. Most bus routes (39) have a fleet size of 0–3 buses, and fewer than 5 routes have more than 10 buses, indicating lower route capacity.

BUS COVERAGE ANALYSIS

The bus coverage analysis of Chhawala reveals that of the total study area of 116.57 sq. km, about 54.7 sq. km (46%) is covered by public transport. With a projected population of 81,500, around 78% of residents fall within an 800-meter catchment area of PT services, leaving 19% without access to reliable public transport. The bus stop spacing has been set at 800 meters as it's a low-density area.

6. Assessment of Public Transport Accessibility levels (PTAL)

The existing public transport accessibility levels in the Chhawala ward have been analysed using a standard method, namely the "PTAL index," which incorporates variables such as walk times, scheduled and regular waiting times, total access time, and service frequency to generate a single accessibility score.

PTAL is a measure of public transport, connectivity that has been used in various planning processes in London for many years. For any selected place, PTAL indicates how well connected it is to public transport. It does not cover car trips. PTAL values are simple. They range from 0 to 6, with the highest value indicating the best connectivity. For historical reasons, the PTAL value of 1 is split into two categories (1a and 1b), and the PTAL value of 6 is split into two categories (6a and 6b). Altogether, there are nine possible values of PTAL: 0, 1a, 1b, 2, 3, 4, 5, 6a and 6b. PTAL values are usually presented in maps, where a predefined set of colours represents the different values. (TFL 2015)

Chhawala's ward PTAL map for 2025 shows that the region continues to experience poor public transport accessibility (Figure 4). It is seen that nearly 57% of the cases falls within PTAL 1a (very poor), while an additional 28% are classified as 1b (very poor) meaning that 85% of the region has no reliable PT service. Only 6% of the region achieves 'good' accessibility (PTAL 5) while only 1% reaches 'very good' (PTAL 6a). Nowhere in the Chhawala region is public transport accessibility rated 'excellent'. It is noticeable that while there are bus stops servicing the region, the region's

access time, service frequency and overall access time remain insufficient.

6.1 Socio-economic Characteristics

The socio-economic data analysis of households reveals that household sizes and incomes are relatively stable across different PTAL bands, with an average household size of 4.3 and an average monthly income of ₹30,000, respectively. However, the monthly expenditure of households on Transport tends to decrease from Rs. 3,611 in "poor PTAL "areas to Rs 2,349 in "Excellent PTAL" areas indicating the impact of improved accessibility levels on monthly household transport expenditures. The proportion of monthly household income spent on transport also falls from 12% to 7.7%, indicating the potential economic advantage households gain from improved public transport accessibility.

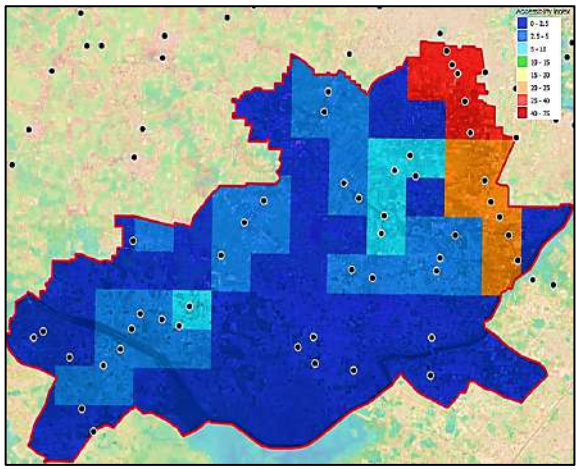


Figure 4. PTAL of Chhawala 2025
Source: (Jain 2025)

6.2 Mobility Levels

The mobility patterns have been analyzed in terms of per capita trip rates (PCTR), trip purposes, and trip lengths. It is observed that PCTR rises moderately with improved PTAL. At the same time, average trip length and average trip times for mechanized modes decrease, reflecting the use of a more sustainable form of transport. Work and education trip lengths decrease specifically, which implies that enhanced PTAL has the potential to reduce the need for lengthy commutes. Purpose-wise trip distribution reveals that the work trip purpose predominates across all PTAL bands, with a share of 57–58%. reflecting the use of public transport for largely work trips.

Modal share analysis reveals a dramatic shift from informal and private transport modes to formal public transport as PTAL values increase across various pockets in the study area. In the "Very Poor PTAL" bus accessibility areas, autorickshaws account for the largest modal share of commutes, while bus and metro use is scarce. As PTAL scores increase, the metro system emerges as the biggest mode, of commute with a share of 60% in Level 6 areas followed by buses at 19–20%. At the same time, dependence on private modes falls to negligible levels, reinforcing the fact that improved accessibility, as measured by PTALs, result in increased public transport use and a more sustainable urban mobility ecosystem.

The mobility pattern, in terms of trip lengths, indicates that the average trip length for bus and metro in higher PTAL zones is 29 km in Level 6, with average access trip lengths of 1.2 km. indicating the importance of first- and last-mile connectivity to the public transport system to ensure high utilization levels. Walking as an access and dispersal mode in high-PTAL zones is predominantly used, underscoring the need for improved walking infrastructure around mass transit systems stations and stops. In Levels 5 and 6, bus use increases, indicating the impact of higher bus coverage.

The Analysis of Variance (ANOVA) test reveals a statistically significant difference in the mean bus per capita trip rates across PTAL levels. The Post Hoc test shows significant differences in bus per capita trip rates between low (Levels 1–2) and high (Levels 5–6) PTAL areas, suggesting that improved public transport accessibility may boost bus usage. This confirms that better transport infrastructure leads to increased public transport adoption.

7. Development of Transport Disadvantage Index

A Transport Disadvantage Index (TDI), which is a composite metric, has been developed in the present study using a weighted scoring system proposed by Kelly et al. (2023). In the present study, TDI incorporates three key components: transport affordability (40%), Mobility (30%), and Transport accessibility (30%), respectively. Affordability refers to the income-to-transport cost ratio, while Mobility refers to the rate of transit ridership. Both Mobility and Affordability are captured through a four-tier Level of Service (LOS) classification and for Accessibility, the Public Transport Accessibility Level (PTAL) has been used. The TDI scores are calculated and classified as low (1–2.2), moderate (2.2–3.4), and high (3.4–4.6) with an overall TDI score ranging from 1 to 4.6 (Table 3).

Table 3. Scaling of TDI

TDI Range	TDI Level
1- 2.2	Low
2.2- 3.4	Moderate
3.4-4.6	High

Source: Jain 2025

For the existing 2025 scenario, Transport Expenditure Share from Income is 12% (Transport Affordability Scale 4), Transit Ridership Percentage is 50% (Mobility Scale 1), Public Transport Accessibility Level is 1 (Transport Accessibility Scale 6). The Transport Disadvantage Index Score is 3.7, resulting in a High Transport Disadvantage Index Level.

8. Development of an Operation Plan for the Proposed Neighbourhood Bus System

To solve last-mile connectivity problems in public transport-inaccessible areas, a neighbourhood bus service is needed. The proposed neighbourhood bus system, tailored for localized last-mile solutions, has gained greater stakeholder support, with 69% preferring it. The neighbourhood bus model aims to provide short, localized routes connecting residential areas to major public transit nodes, such as metro stations and bus terminals. This strategy improves access, curbs congestion, and minimizes reliance on private transport while supplementing available public transport facilities.

The proposed service is inspired by the Delhi Electric Vehicle Interconnector (DEVI) bus, launched in Delhi in May 2025. DEVI operates 9-meter electric buses that can carry 23 seated and 13 standing passengers, and are equipped with intelligent features such as GPS, CCTV, Wi-Fi, and emergency panic buttons. The fare system aligns with the AC DTC bus model, offering distance-based pricing and free travel for women under the Pink Pass scheme. By adopting these features, the proposed neighbourhood bus service intends to replicate DEVI's success while adapting it to local needs, prioritizing affordability, environmental sustainability, and safety.

8.1 Methodological Process for Neighborhood Bus Operational Plan

In the study a six-step process was developed and to propose the neighbourhood bus system (Figure 5). The first step involves examining current DEVI operations, assessing trip patterns, and determining principal origin-destination (OD) pairs for education and work before mapping principal transit points, such as bus stops and metro stations. This phase also determines trip generation and attraction points to prepare effective and responsive route networks. The second step is to estimate demand from stated-preference (SP) surveys that measure users' willingness to switch to the new service. The third step provides the operational structure, including the bus fleet size, performance measures, and infrastructure needs such as terminals and depots. Step four involves financial modelling to test the project's economic viability. The impact assessment, specifically for the Chhawala Ward, is the fifth step, and examines metrics such as vehicle kilometres travelled (VKT), carbon emissions, and improvements in the Transport Disadvantage Index (TDI). Finally, the sixth step incorporates stakeholder input to ensure the system meets the community's needs and the objectives of sustainability.

8.2 Development of Neighbourhood Bus Route Network Design

The proposed bus route network design is based on a thorough study of DEVI bus service implementation, with short, neighbourhood-level routes to ensure maximum efficiency and coverage. Further, mapping mode wise O-D pairs for private cars, PT, and IPT identified trip production and attraction centres which also aided in identifying potential bus routes.

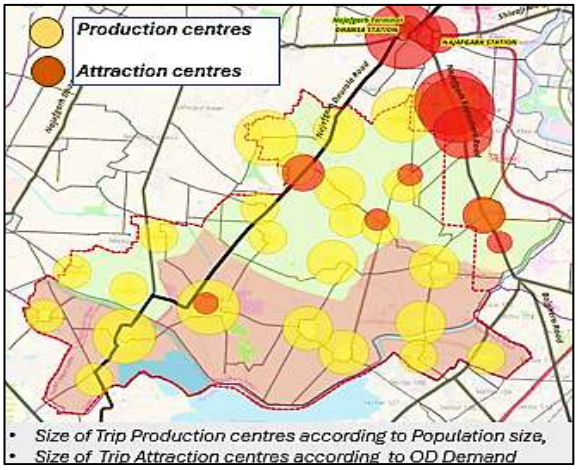


Figure 5. Production and attraction centres for Chhawala ward (Source: Jain 2025)

Based on the above-mentioned criteria nine bus routes are proposed covering a total of 84 km with a route overlap of 40% and a network density of 0.5 km/sq. km in Chhawala ward and comprises 14% of the road network (Figure 6 and Table 4). These cover the main metro stations (Dhansa, Najafgarh), main bus stops, commercial areas, and high-density residential areas. OD desire patterns are aligned with the neighbourhood routes to optimize connectivity and coverage. These corridors range in length from 6 km to 15 km,

linking important places such as the Najafgarh Metro Station and Najafgarh Terminal.

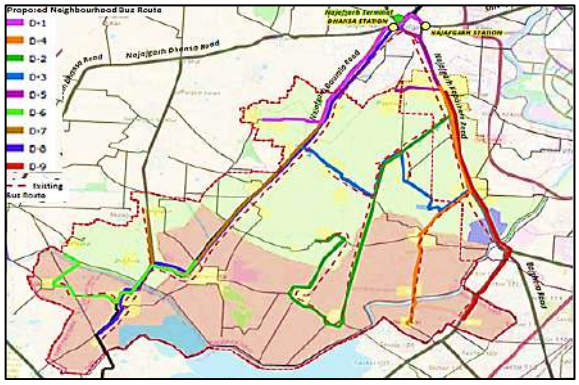


Figure 6. Existing bus routes and proposed neighbourhood Bus routes (Source: Jain 2025)

The proposed bus routes, along with their route lengths, are shown in Table 4.

Table 4. Proposed Routes of the system

Mode	Mode Share (%), Existing 2025	Trips, Existing 2025	Shift (%)	Shifted Trips
2W	30	10440	31	3236
Car	12	4176	12	501
IPT	7	2436	30	731
PT	48	17400	80	13920
Others	3	348		
Total	**100**	**34801**		**18389**

Source: (Jain 2025)

8.3 Assessment of Neighborhood Bus Passenger Demand using Stated Preference Survey

A stated preference (SP) survey was conducted to assess the potential use of the proposed bus system, using five major attributes: travel distance, travel time, waiting time, access time, and travel cost. A binary logistic regression model was used to estimate commuters' potential to switch from existing modes (private car, IPT, traditional buses) to the neighbourhood bus. Input parameters like acceptable waiting time (8 minutes), access time (10 minutes), and bus speed (15–18 km/hr) were inferred from DEVI's operational performance. Fares were similarly modelled to DEVI, from ₹10 for travel distances under 4 km to ₹25 for over 12 km.

Logistic regression outputs indicated that the model correctly predicted changes for 89.1% of two-wheeler users and 33.8% of existing bus users, with an overall good fit validated by the Hosmer-Lemeshow Test (p=0.879).

Analysis revealed that 31% of two-wheeler users (3,236 trips), 12% of car users (501 trips), and 30% of IPT users (731 trips), are likely to switch to the new bus system. Notably, 80% of current public transport users (13,920 trips) are expected to adopt the neighbourhood bus due to improved connectivity (Table 5).

Table 5. Modal shift towards proposed Bus service by the model

Route No.	Origin Destination	Route Length (km)
D-1	Khera-Najafgarh metro station	7
D-2	Shikarpur-Dinpur	14.5
D-3	Rewla-Dinpur	12.1
D-4	Nanakheri-Dinpur	9
D-5	Paprawat- Najafgarh metro station	6
D-6	Sarangpur-Ghumanhera	7.1
D-7	Malikpur-Najafgarh Terminal	13.8
D-8	Darulla-Najafgarh Terminal	15
D-9	Badusarai-Dinpur	8.6

Source: (Jain 2025)

An estimated 18,389 daily trips are expected to use the proposed neighbourhood bus system. After the introduction of the proposed neighbourhood bus system, the overall public transport modal share is likely to increase to 63%.

8.4 Development of Neighborhood Bus Operational Plan

To meet the anticipated passenger demand for the proposed neighbourhood bus system, an operational plan has been developed, with an estimated fleet of 27 electric buses operating on nine routes. For each route total ridership, frequency, capacity (km), load factor and EPK/CPK have been estimated, as shown in Table 6.

Table 6. Proposed Route operational Plan of Proposed Neighbourhood Bus service

Route No.	*Route Length (km)*	*Est. Pax/ Day*	*On Peak Headway (min)*	*Off Peak Headway (min)*	*Bus Fleet*	*Load Factor*	*EPK/CPK*
D-8	15	2491	15	25	4	0.7	1.1
D-3	12.1	2564	12	25	3	0.9	1.6
D-5	6	733	15	25	2	0.4	0.7
D-7	13.8	3004	12	25	4	0.8	1.4
D-2	13.8	2930	12	25	4	0.8	1.3
D-6	7.1	2051	10	20	3	0.8	1.3
D-1	7	1685	15	25	2	0.9	1.5
D-4	9	2198	12	25	3	0.8	1.3
D-9	8.6	733	15	25	2	0.4	0.7
Total		18389			27		

Source: (Jain 2025

Service headways range from 10 to 25 minutes, with peak-hour frequencies between 10 and 15 minutes, maximizing ridership. Route-level data indicate that top-performing routes, such as D-7 and D-2, have load factors of 0.8–0.9 and good financial performance (EPK/CPK over 1.3). In contrast, the shorter routes D-5 and D-9 have lower utilization and demand (load factor of 0.4). There

are 42 strategically situated bus stops proposed along the ward, around 900 meters apart, to provide coverage within 800 meters for all residents. Supporting bus infrastructure includes two depots at Ghuman Hera (11 buses) and Rewla Khanpur (16 buses) which need electrification.

9. *Impact Assessment of Proposed Neighborhood Bus Service*

The impact analysis of the proposed Chhawala neighbourhood bus service reveals significant improvements in public transport access, bus operational efficiency, and associated environmental benefits. Table 7 summarises the impacts of the proposed bus system in the study area, highlighting improvements in first- and last-mile connectivity, reduced travel-time variability, and a potential shift away from private motorised modes.

Table 7. Impact Assessment of Neighbourhood Bus

Aspect	Existing 2025	Proposed Neighborhood Bus Scenario
PT Share	50%	63% (26% ↑)
PTAL in a residential area	0-10 (Very Poor- Poor)	5-20 (Poor- Good)
PT Network Density (km/sq. km.)	0.4	0.5 (25% ↑)
Residential area coverage by PT	81%	97% (20% ↑)
Transport Expenditure Share from HH Income %	12%	11% (8%↓)
Average Waiting Time for PT	35 min	7.5 min (28 min ↓)
Average Access Time for PT	20 min (IPT-56%)	10 min walk

Source: (Jain 2025)

The residential public transport coverage increases from 81% to 97%, resulting in enhanced service coverage by 20%. Household transport spending decreases marginally from 12% to 11%, indicating greater affordability. Table 4 shows that the public transport share is expected to rise from 50% to 63%, reflecting a relative increase the bus system's modal share with the introduction of the neighbourhood bus service. It is observed that the average public transport waiting time falls significantly from 35 minutes to 7.5 minutes, and access time is reduced to half from 20 minutes to a simple 10-minute walk, enhancing convenience and customer experience. These improvements enhance the public transport system's accessibility and efficiency and reduce emissions.

Based on the revised Public Transport Accessibility Level (PTAL) categorizations, owing to introduction of proposed bus service it is seen that 70% of the region now lies under very poor to poor accessibility (PTAL 1a, 1b, and 2), with just 9% of the area having good access (PTAL 4) showing marginal improvements. PTAL scores in residential areas improve from an extremely poor 0–10 to a better 5–20 range while network density increases by 25% again revealing an improvement in overall public transport accessibility post-implementation of the proposed bus service. Figure 7 shows the revised PTAL values. The transition from the existing scenario to the "proposed neighbourhood bus scenario" results in likely decrease in Transport Expenditure share of Income from 12% (Affordability Scale 4) to 11% (Scale 3), Transit Ridership percentage from 50% (Mobility Scale 1) to 63% (Scale 1), and Public Transport Accessibility Level from 1 (Accessibility Scale 6) to 3 (Scale 4) respectively. As a result, the Transport Disadvantage Index Score improves from 3.7 (High level) to 2.7 (Moderate level) reflecting an overall reduction in transport deprivation due to the proposed Neighbourhood bus scenario.

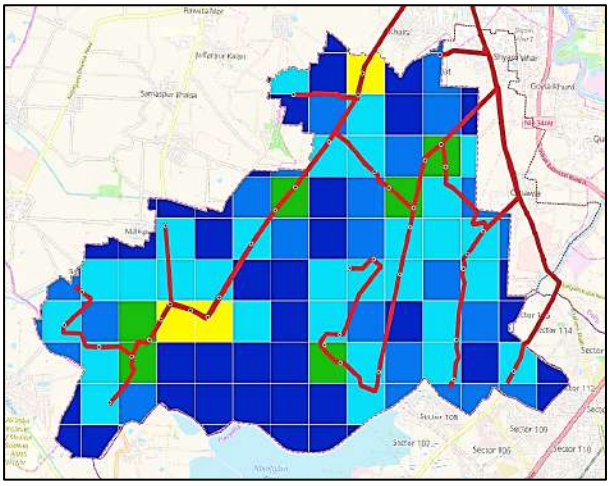


Figure 7. Revised PTAL values from Proposed Neighbourhood Bus (Source: Jain 2025)

Overall, it is inferred that the proposed neighbourhood bus intervention improves equity, supports sustainable transport, and reduces environmental impact in Chhawala's public transport-deprived areas.

10. Summing Up

This study concludes that underserved public transport areas, such as Chhawala in Delhi, with low PTAL levels, face significant mobility constraints, resulting in an unsustainable mobility environment. The proposed neighbourhood bus system as suggested in this paper is expected to enhance residents' mobility and reduce transport disadvantage. The findings from the empirical investigation carried out in this study reveal that the proposed neighbourhood bus system is likely to

improve accessibility levels, lower travel costs and offer a more reliable and environmentally friendly commuting option for daily commuters. Further, the proposed bus system is likely to reduce waiting and access times, thereby making public transport more appealing and ensuring better utilisation of transit assets. It is recommended that this methodological approach be extended to other unserved public transport areas in peri-urban areas of Delhi to develop a comprehensive neighbourhood bus system for such transport-disadvantaged and underserved areas.

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Integrating Waterways into the Public Transportation Network of Kolkata, India

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Abstract: The growing crises of congestion, climate fragility, environmental devastation, and social inequity have proven untenable to older forms of planning which are being reinforced in cities around the world. As the number of people living in cities is increases and infrastructure becomes overloaded, planners are switching to resilient, circular, and space-efficient systems. One such alternative is urban riverfronts, which serve as sources of low-carbon mobility corridors, adaptive reuse, and accessibility corridors. Urban waterways in cities such as Amsterdam, London, and Copenhagen are being combined with technology and multimodal planning to provide sustainable transport, reduce emissions, and improve global quality of life. In India, this mode of passenger movement has not been fully tapped in cities, despite a well-developed inland waterways system that has been marred by neglect, sparse investment, and divided governance. This paper fulfils that gap by presenting the case of Kolkata a colonial port city that has been dependent on the Hooghly River as a source of transport but which was subsequently deprioritized in preference for using cars. Kolkata is highly congested, has a very high level of air pollution, and faces last-mile connectivity and transportation inequities today, so the city's unused waterways are a very important resource. The study uses cross-case studies and the Adaptive Large Neighbourhood Search (ALNS) tool to design ferry routes. Surveys measuring latent demand and performance metrics (travel time, emissions, accessibility) indicate that if one combines ferry operations with last-mile transportation, e-rickshaws, cycle way, pedestrian links, then average journey times can be cut by as much as 40 percent and serve underserved populations. The paper recommends the following roadmap as part of an internationally recognized strategic venue for such ferries, including intermodality with rail and bus transportation, institutional coordination, and sustainability. The revival of waterways is not presented as a nostalgic idea but as a part of a mainstream transport policy, thus providing another model of resilient, inclusive, and low-carbon mobility that might be reproduced in Indian and Global South cities.

Keywords: Waterways; Public Transportation; Urban Infrastructure; Sustainability.

सार: संकुलन जलवायु संकट, पर्यावरणीय विनाश और सामाजिक असमानता के बढ़ते संकटों ने पारंपरिक नियोजन पद्धतियों को दुनिया भर के शहरों में अप्रभावी साबित कर दिया है। जैसे-जैसे शहरों में रहने वाली जनसंख्या बढ़ रही है और बुनियादी ढाँचा अतिभारित हो रहा है, नियोजकर्ता लचीली, चक्रीय और स्थान-कुशल प्रणालियों की ओर रुख कर रहे हैं। ऐसा ही एक वैकल्पिक समाधान शहरी नदी-तट हैं, जो कम-कार्बन गतिशीलता गलियारे, अनुकूली पुनः उपयोग और पहुँच गलियारों के स्रोत पाए गए हैं। एम्स्टर्डम, लंदन और कोपेनहेगन जैसे शहरों में शहरी जलमार्गों को तकनीकी प्रणालियों और बहु-माध्यम नियोजन के साथ संयोजित किया जा रहा है, ताकि सतत परिवहन सुनिश्चित किया जा सके, उत्सर्जन में कटौती की जा सके और विश्व स्तर पर जीवन की गुणवत्ता में सुधार लाया जा सके। भारत में, इस माध्यम से यात्री परिवहन का पूर्ण उपयोग अभी तक नहीं किया गया है, हालाँकि देश के पास एक सुविकसित अंतर्देशीय जलमार्ग प्रणाली है, जो अतीत में उपेक्षा, कम निवेश और विभाजित शासन के कारण उपयोग में नहीं आ रही है। यह शोध-पत्र उस अंतराल को भरता है और कोलकाता - जो एक औपनिवेशिक बंदरगाह शहर है - के उदाहरण को प्रस्तुत करता है। कोलकाता लंबे समय तक परिवहन के स्रोत के रूप में हुगली नदी पर निर्भर रहा है, किंतु बाद में कारों के उपयोग को प्राथमिकता देते हुए इसे हाशिए पर डाल दिया गया। आज कोलकाता अत्यधिक भीड़-भाड़ वाला है, वायु प्रदूषण का स्तर बहुत अधिक है, और शहर में अंतिम-मील संपर्कता तथा परिवहन असमानताओं की गंभीर समस्याएँ हैं। शहर में उपलब्ध अप्रयुक्त जलमार्ग इसलिए एक महत्वपूर्ण संसाधन का प्रतिनिधित्व करते हैं। अध्ययन में तुलनात्मक प्रकरण अध्ययनों और अनुकूली वृहत स्थानीय खोज उपकरण का उपयोग करके फेरी मार्गों का डिज़ाइन किया गया है। अप्रकट माँग को मापने वाले सर्वेक्षण और प्रदर्शन मापदंड (यात्रा समय, उत्सर्जन, पहुँच) से संकेत मिलता है कि यदि फेरी परिचालन को अंतिम-मील परिवहन, ई-रिक्शा, साइकिल पथ और पैदल मार्गों के साथ संयोजित किया जाए, तो औसत यात्रा समय में 40 प्रतिशत तक की कटौती की जा सकती है और अल्प-सेवित आबादी को सेवा प्रदान की जा सकती है। यह शोध-पत्र निम्नलिखित रोडमैप की सिफारिश करता है: अंतर्राष्ट्रीय स्तर पर मान्यता प्राप्त फेरी रणनीति, रेल और बस परिवहन के साथ अंतर-माध्यम संयोजन, संस्थागत समन्वय और स्थिरता। जलमार्गों का पुनरुद्धार केवल एक नॉस्टैलजिक विचार के रूप में प्रस्तुत नहीं किया जा रहा है, बल्कि मुख्यधारा परिवहन नीति का एक अभिन्न अंग माना जा रहा है। यह दृष्टिकोण लचीली, समावेशी और कम-कार्बन गतिशीलता का एक वैकल्पिक मॉडल प्रदान करता है, जिसे भारतीय और वैश्विक दक्षिण के अन्य शहरों में भी प्रतिलिपि किया जा सकता है।

मुख्य शब्द: जलमार्ग; सार्वजनिक परिवहन; शहरी अवसंरचना; संधारणीयता

1. Introduction

Transport choice is a micro-level decision, influenced by constraints on location and time, costs, regularity, perceptions and beliefs, and personal principles. These factors compel urban travelers to frequently use road-based transport systems, which contribute to traffic congestion and air pollution and reduce the productivity of public transport systems. In this context, integrating navigable waterways into urban transport networks, and incorporating them into transport plans and programs, as a transport modality, is sustainable and aligns with current travelers' choices and needs in urban mobility.

Kolkata performs well in fare affordability and lower CO_2 emissions. Still, it shows weaker performance in ferry connectivity and waterway travel speed, while Guwahati lags in accessibility and speed, yet performs better in operational efficiency and fare affordability (Table 1). These outcomes are derived using a normalization method that scales observed values to 0 (poor) to 1 (optimal) based on defined lower and upper benchmarks, enabling comparisons across cities with different contexts. The normalized KPI results for the three cities are presented in Table 2 (Huertas et al. 2021).

According to the International Finance Corporation (IFC 2020), shifting cargo transport from roads to waterways in Kolkata could prevent approximately 26,000 tonnes of CO_2 emissions annually. Extending this approach to passenger transport could further reduce emissions, shorten travel times, and offer economic benefits to commuters. However, the passenger transport potential of the Hooghly River within the Kolkata Metropolitan Area remains underutilized due to declining ferry usage, driven by inconsistent schedules, outdated infrastructure, and inadequate last-mile connectivity.

This research aims to evaluate the feasibility of incorporating water transport into Kolkata's public transit network while examining the infrastructure needs, user responses, and policy implications required for the transport system transition. The study conducts comparative travel-time evaluations, mathematical modelling, and case studies of global best practices. The findings will provide insights into how a well-integrated water transport system can complement existing urban public transport systems.

2. Scope and Structure of the Paper

This paper is grounded in the dynamic debate around sustainable and inclusive urban mobility to highlight the overlooked aspect of water-based transport in the Indian cities. Although the Kolkata Metropolitan Region is the case study for the paper, the multi-scalar nature of the analytical framework applies to spatial mapping, accessibility modelling, and institutional review. The paper is organized so that it passes through a conceptual background to empirical analysis and strategic policy suggestions, thereby allowing the unification of theory, approach, and conclusions. This solution enhances the rigor of the analysis and situates the study within the contemporary discussions of sustainability and decarbonization in the Global South.

3. Research Methodology

The evaluation method extends global urban mobility evaluations by incorporating factors specific to Indian cities. The key aspects include:

- Urban Mobility Performance Indicators: Analysing accessibility, environmental impact, governance, and mobility patterns.
- Multimodal Integration: Evaluating the combined performance of ferries with buses, trains, metros, autos, and non-motorized transport alongside each other.
- Environmental and Economic Viability: Assessing emissions, cost efficiency, and passenger demand.
- User Experience and Psychological Factors: Investigating user perceptions combined with psychological aspects as well as convenience aspects regarding traveller intentions to adjust their habits.

3.1 Performance Indicators for Sustainable Mobility

Using the assessment framework proposed by Huertas et al. (2021), this study evaluates sustainable mobility through a set of Key Performance Indicators (KPIs) structured around multiple pillars, including accessibility and regulatory integration, environmental performance, and mobility patterns. The selected indicators are benchmarked against lower and upper threshold values and normalised (Si) to allow comparison across Kolkata, Mumbai, and Guwahati despite differences in scale and context. This approach ensures methodological consistency while capturing city-specific variations in transport systems and governance structures.

These KPIs provide a consistent basis for assessing and comparing the performance of ferry-integrated urban transport systems in Indian cities. The indicators enable a comparative assessment of Kolkata, Mumbai, and Guwahati against each other and international benchmarks, using measures such as five-minute public transport accessibility, multimodal integration of ferry terminals, CO_2 emissions per passenger-kilometre, fare affordability, operating costs, congestion levels, and relative travel speeds of waterways versus road transport. A snapshot of these indicators, with upper and lower benchmark values, highlights performance gaps and opportunities for improvement, as presented in Table 1. The framework also allows for identifying trade-offs among efficiency, equity, and environmental performance across cities.

Kolkata shows relatively strong performance in fare affordability and lower CO_2 emissions per passenger-kilometre but performs weaker in ferry terminal connectivity and comparative waterway travel speeds, while Guwahati lags notably in accessibility and waterway speed, yet performs better in operational cost efficiency and fare affordability.

These performance levels for 2021 are derived using a normalisation method that converts observed values to a 0–1 scale based on defined lower and upper benchmarks, enabling comparison across cities with different contexts, as summarised in Table 2, where 0 indicates poor performance**,** and 1 indicates optimal performance

Table 1. Key Performance Indicators for three Indian Cities with Ferry Transport

Comprehensive Mobility Plan for Mumbai (2021) – MMRDA
RITES Study on Cost Comparison of Public Transport (2022)
Indian Institute of Management (IIM-A) Research Paper on Public Transport Economics (2021)
Ministry of Housing and Urban Affairs (MoHUA), 2023 – Service Level Benchmarks for Public Transport)

KPI Category	Indicator	Kolkata	Mumbai	Guwahati	Lower Benchmark	Upper Benchmark
Accessibility & Integration	% Population with 5-min access to PT	65%	80%	55%	40%	90%
Accessibility & Integration	% Ferry terminals with multimodal access	30%	50%	25%	10%	90%
Environmental Sustainability	CO_2 emissions per passenger-km (g)	120	90	140	180	50
Environmental Sustainability	Public transport modal share (%)	60%	70%	50%	30%	85%
Economic & Operational	Fare affordability (₹/km)	1.5	1.8	1.2	2.5	0.5
Economic & Operational	Operational cost per passenger-km (₹)	4	3.5	4.5	6	2
Mobility & Congestion	Road congestion index (delay per 10 km)	34 min	28 min	30 min	50 min	15 min
Mobility & Congestion	Waterway speed vs. road speed (km/h)	12 vs 18	15 vs 20	10 vs 16	8 vs 12	20 vs 25

Source: Question of Cities Report (2022)

Table 2. Key Performance Indicators for three Indian Cities with Ferry Transport (2021)

KPI Category	Indicator	Kolkata	Mumbai	Guwahati
Accessibility & Integration	% Population with 5-min access to PT	0.5	0.8	0.3
Accessibility & Integration	% Ferry terminals with multimodal access	0.25	0.5	0.19
Environmental Sustainability	CO_2 emissions per passenger-km (g)	0.24	0.6	0.13
Environmental Sustainability	Public transport modal share (%)	0.54	0.67	0.4
Economic & Operational	Fare affordability (₹/km)	0.67	0.53	0.87
Economic & Operational	Operational cost per passenger-km (₹)	0.67	0.83	0.5
Mobility & Congestion	Road congestion index (delay per 10 km)	0.53	0.73	0.67
Mobility & Congestion	Waterway speed vs. road speed (km/h)	0.29	0.47	0.13

* Each KPI is calculated using the normalization process

4. Conceptual and Theoretical Framework

This study draws on the principles of Sustainable Urban Mobility Planning (SUMP) and Transit-Oriented Development (TOD), which advocate comprehensive, multimodal, and people-centric transport systems. It positions inland waterways as low-carbon mobility corridors that can improve accessibility, inclusivity, and resilience while reducing congestion and emissions in dense urban areas, with the added benefit of enhancing institutional integration and access for peripheral communities.

5. Rationale for the Study

Global and Indian studies reveal a significant research gap in assessing inland waterway transport (IWT) within urban mobility systems, particularly passenger ferry services in India.

The existing literature largely focuses on freight and ports, overlooking institutional coordination, accessibility, user behaviour, environmental impacts, and multimodal integration. To address this gap, the paper proposes a KPI-based framework to evaluate Kolkata's IWT performance and its integration within the wider urban transport network.

6. Context Setting: Kolkata

Kolkata, a historic port city shaped by the Hooghly River, once relied heavily on ferries as part of its urban mobility system, connecting the city core with peripheral areas. Over time, a shift toward road-based transport, combined with rapid

urbanisation, led to congestion, air pollution, and growing transport inequities. Today, despite its potential, the ferry system remains underutilised due to poor multimodal connectivity, irregular services, weak last-mile infrastructure, fragmented institutional governance, and disruptions caused by fluctuating water levels (Figure 1 and Table 3). Given its dense urban form and river legacy, Kolkata is uniquely positioned to reintegrate waterways into its transport network to address mobility challenges and move toward a more resilient, low-carbon future.

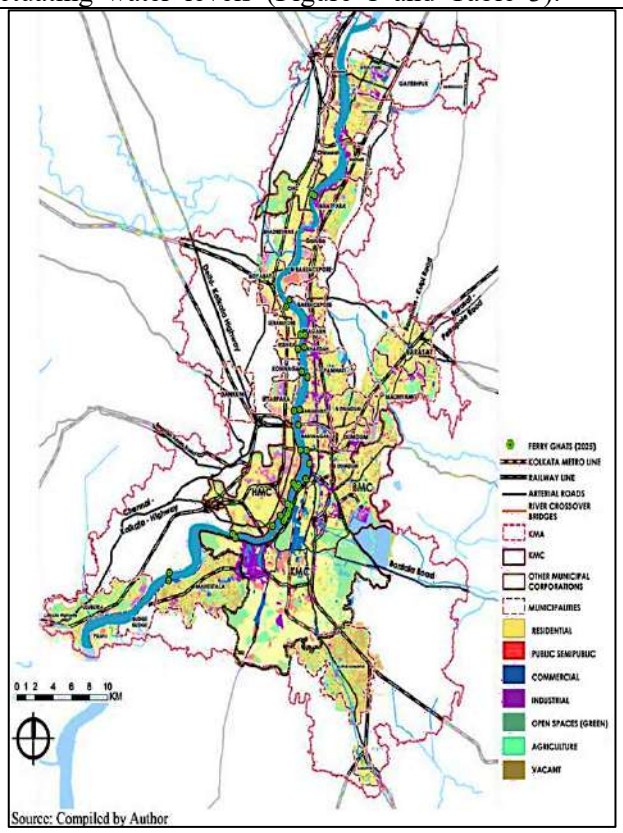


Figure 1. Transportation Network of KMA; Source: (Das 2025)

Table 3. Usage shifts in ferry usage in KMA

Parameter	Value
Total Length of River	90 KM
Total no. of crossover bridges	4 (Road) 1 (Railway)
2001 (As per CMP 2001-2025)	
Population	1.32 Crore (1,32,51,339)
Total no. of operational ferry ghats	72
Daily passenger traffic within the metro-core area	1,09,533
Outside the metro-core area	87,689
TOTAL Daily Passenger Traffic using ferry	1,97,222
2025 (As per primary survey and data collection)	
Population	2.11 Crore
Total no. of operational ferry ghats	33
TOTAL Daily Passenger Traffic using ferry	1,54,365 (21.73% decrease)
Operated by	(WBTC) under GoWB

Source: CMP 2001-2025 and Primary Survey

7. Key Determinants Influencing Inland Water Transport in Kolkata

Kolkata's inland water transport (IWT) system operates within a complex mix of urban, socio-economic, and environmental conditions that shape its viability as a transport mode. Understanding factors such as population density, travel behaviour, and modal preferences, policy and institutional frameworks, accessibility and infrastructure, and environmental impacts is essential to assess its performance and integration within the city's broader mobility network.

7.1 Population & Demographic Profile of Kolkata

Based on available demographic data, people in Kolkata rely heavily on public transport and non-motorized modes such as walking and cycling as their primary means of travel. The 2011 Census showed that public transport, along with NMT, accounted for 89% of daily work trips, the highest figure among all Indian metro cities, according to a CSE report. Kolkata's population has also shown a steady increase from 1,40,85,800 in 2011 (Census) to an estimated 1,58,45,200 in 2025 (World Population Review Report), reflecting continuous urban growth. This consistent rise over the past decade highlights increasing demographic pressure on urban infrastructure and transport systems.

7.2 Mobility Pattern of Kolkata

The rapid population growth in Kolkata has failed to receive the corresponding infrastructure development for public transportation systems. Table 4 shows that in 2025, para-transit accounted for the largest share of weekday PT/IPT trips in the Kolkata Metropolitan Area (41%), followed by rail-based transit (39%), while ferry services contributed only 1.4% of total passenger volume despite their significant potential. Despite the expansion of the metro rail network, it has not yet achieved comprehensive citywide integration. The Blue Line serves as Kolkata's main metro route, connecting major business areas, including Chandni Chowk, Dharamsala and Shyam Bazar. The metro transportation service frequency

remains inadequate to handle peak-hour demand, resulting in numerous passengers being crammed together. Overcrowding issues are intensified by the warm and humid climate, thus reducing the quality of life for daily commuters.

Table 4. Volume of Passengers Using PT and IPT Within KMA on Weekdays 2025

Mode	Passenger volume (in lakh)	Percentage
Private Bus	15	14%
Public Bus	3	3%
Tram / L.R.T	0.15	0%
Minibus	2	2%
Ferry	1.5	1.4%
Total (Surface Transit)	21.15	20%
Suburban Rail	35	33%
Metro Rail	5.5	5%
Circular Rail	0.65	1%
Total (Rail)	41.15	39%
Taxi/ App-Cab	1	1%
Auto Rickshaw	23	22%
Cycle Rickshaw	20	19%
Total (Para Transit)	44	41%
TOTAL PT/IPT USER	106.8	100%

Source: Hindustan Times 2024

Severe overcrowding on suburban trains and the reduction of tram services have increased reliance on auto-rickshaws and two-wheelers, worsening congestion and safety risks.

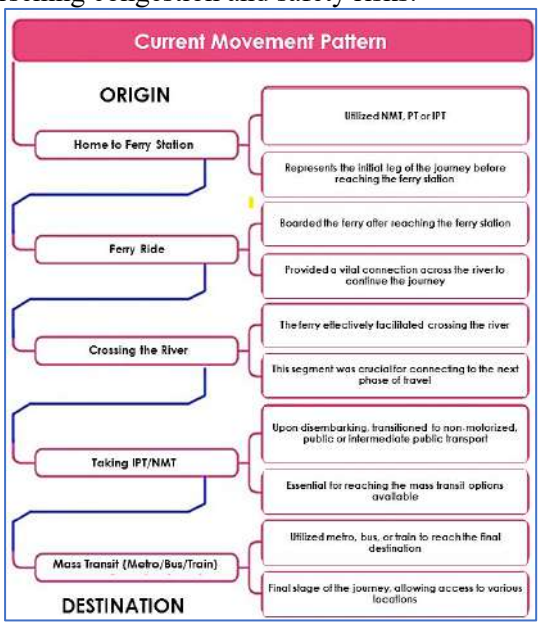


Figure 2. Current versus Proposed Movement Pattern of the commuters

To address these surface transport challenges, Kolkata urgently needs to optimise its waterway capacity, as leveraging river routes along the city's north–south growth corridor could help ease traffic congestion and improve mobility. The reasons being:

- River-dependent Commuters: Commuters from Serampore, Uttarpara, Rishra, Konnagar, and Baidyabati depend on ferries to cross the Hooghly River due to limited bridge connectivity and must transfer to other modes to reach Kolkata, resulting in longer travel times and higher costs, as shown in Figure 2.
- Economic Group Preferences for Waterways: With 60% middle-income and 30% low-income residents (Census 2011), ferry transport in Kolkata serves as an affordable mobility option, particularly for economically dependent commuter groups (Table 5).

Table 5. User Groups based on economy

Economic Group	Just Purpose	Comfort	Luxury	Cost Sensitivity
High-Income	✅	✅	✅	❌
Middle-Income	✅	✅	❌	✅
Low-Income	✅	❌	❌	✅

7.3 Government Policies Affecting IWT in Kolkata

In recent years, both the central and West Bengal governments have launched initiatives to strengthen inland waterways and ferry infrastructure in and around Kolkata. Key measures include the World Bank–supported Bengal Inland Water Transport, Logistics and Spatial Development Project to improve passenger and freight movement along the Hooghly River and to integrate river transport with urban development, along with the Harit Nauka guidelines promoting eco-friendly vessels. Complementary schemes, such as Jalvahak, aim to shift freight from congested roads to waterways. At the same time, state-level actions include developing new jetties near major bridges and installing smart fare gates at ferry ghats to improve access, efficiency, and multimodal integration.

7.4 Current Accessibility Situation of IWT in Kolkata

Despite recent policy initiatives, ground-level accessibility to ferry services in Kolkata remains uneven. Infrastructure upgrades under a major 2021 project, including new pontoons, improved boarding facilities, ramps, waiting areas, and digital ticketing, have enhanced comfort and accessibility, particularly for elderly and differently abled users, while smart gates have reduced boarding time at select ghats. However, ferry services continue to face challenges, including uneven jetty distribution, weak last-mile and multimodal integration, poor access roads, and limited-service frequency and reliability due to weather and operational constraints, making road-based transport more dependable for many

commuters.

7.5 Environmental Implications

Despite strong policy intent and recent IWT infrastructure upgrades in Kolkata, operational gaps remain. While initiatives such as new jetties, smart gates, and green vessel guidelines are positive, ferry accessibility is uneven, feeder connectivity is weak, and integration with metro, bus, and para-transit networks remains limited. Service frequency and reliability are inconsistent, particularly during peak hours and in adverse weather, making road transport less dependable, while large-scale adoption of green passenger vessels remains limited. Strengthening multimodal integration and operational efficiency is therefore essential to make IWT a mainstream and inclusive urban transport mode in Kolkata.

8. Current Mobility Performance (KPI): Kolkata

Building on the analytical framework, this study assessed the 2025 performance of Kolkata's inland water transport system using a three-step methodology comprising data collection, KPI-based evaluation, and route optimisation. The KPI framework examined accessibility, infrastructure quality, reliability, environmental performance, and inclusivity against national and international benchmarks. At the same time, GIS-based isochrone mapping and an Adaptive Large Neighbourhood Search (ALNS) model were used to identify catchment gaps and integration issues, and to optimise routes and last-mile connectivity.

Table 6. Current Normalized KPIs for Kolkata (KMA) (2025)

KPI Category	Indicator	Normalized Value (Si)
Accessibility & Integration	Ferry terminal connectivity with multimodal hubs	**0.25**
	Population within 5-min access	Low (patchy coverage)
Environmental Sustainability	CO_2 emissions per passenger-km	**0.24**
	Use of green technology (hybrid/solar)	Negligible
Economic & Operational Efficiency	Fare affordability	**0.67**
	Operating cost efficiency	0.35–0.40
Mobility & Congestion	Speed of waterways vs road	**0.29**
	Ferry modal share (KMA)	1.4% of daily trips (~1.5 lakh passengers)

The results indicate mixed system performance: despite strong fare affordability (0.67) and a low carbon footprint per passenger-kilometre (0.24), the ferry system underperforms in accessibility and multimodal integration (0.25), exhibits low comparative travel speeds (0.29), and remains underutilised, accounting for only 1.4% of trips in the Kolkata Metropolitan Area, thereby limiting its contribution to sustainable urban mobility (Table 6).

9. Actionable Roadmap for Sustainable Waterway Integration: Kolkata

9.1 Identifying Route for Improvements

The proposed route improvements focus on directly linking peripheral municipalities of the Kolkata Metropolitan Area with ferry points near major business districts through integration with intermediate public transport, improved feeder services, signage, scheduling, and integrated ticketing and smart mobility tools, enabling ferries to function as a reliable complement to existing public transport (Figure 3).

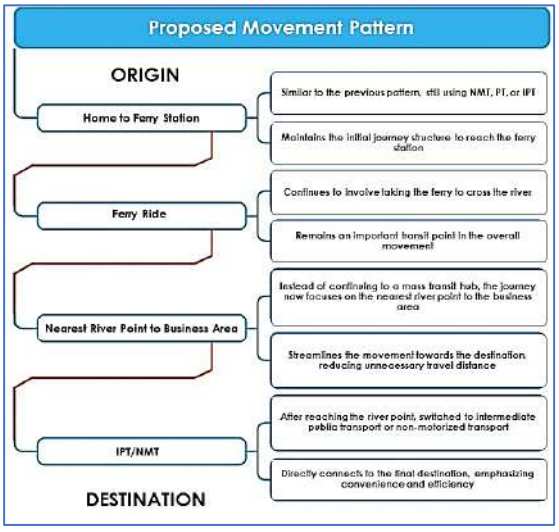


Figure 3. Proposed Movement Pattern of the Commuters

9.2 Identifying High-Impact Ferry-Based Mobility Interventions

To identify targeted, high-impact interventions to strengthen ferry-based mobility in the Kolkata Metropolitan Area, this analysis first mapped major economic centres and commuter demand patterns through primary surveys. By examining agriculture, manufacturing, services, trade, and IT hubs alongside existing transport performance, the study highlights current dependence on congested road and rail networks. It reveals gaps where direct ferry connections can significantly improve accessibility and reduce travel time. Building on this purpose, priority origin–destination pairs were identified to assess corridors where a modal shift to

waterways is both feasible and effective. The proposed ferry routes along the Hooghly River, supported by last-mile connectivity such as autos, e-rickshaws, shuttle services, and pedestrian links, demonstrate the potential to cut travel times by up to 50%, relieve pressure on bridges and metro corridors, and position ferries as a reliable, sustainable component of daily urban mobility in KMA (Figure 4).

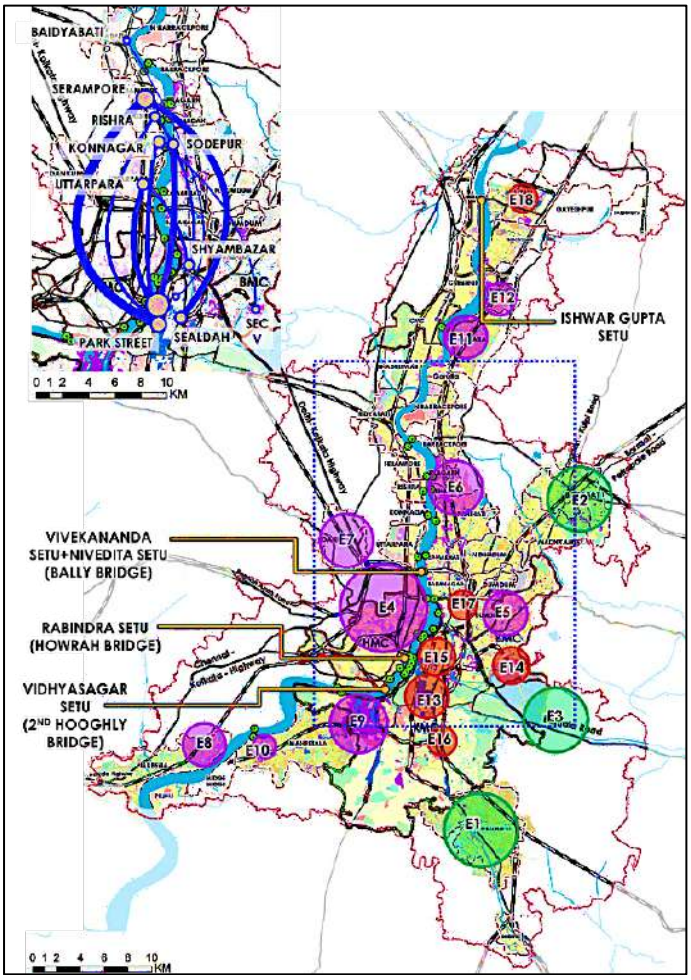


Figure 4. Economic Areas and the top 10 O-D pairs originating outside Kolkata Municipal Corporation Compiled after Primary survey (Das 2025)

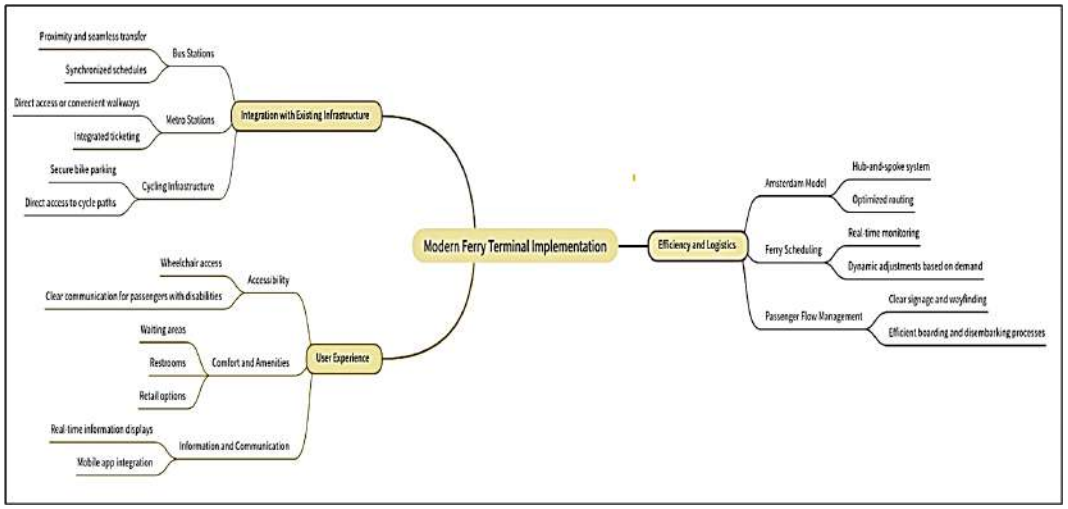


Figure 5. Infrastructure Implementations at the Ferry Terminals (Das 2025)

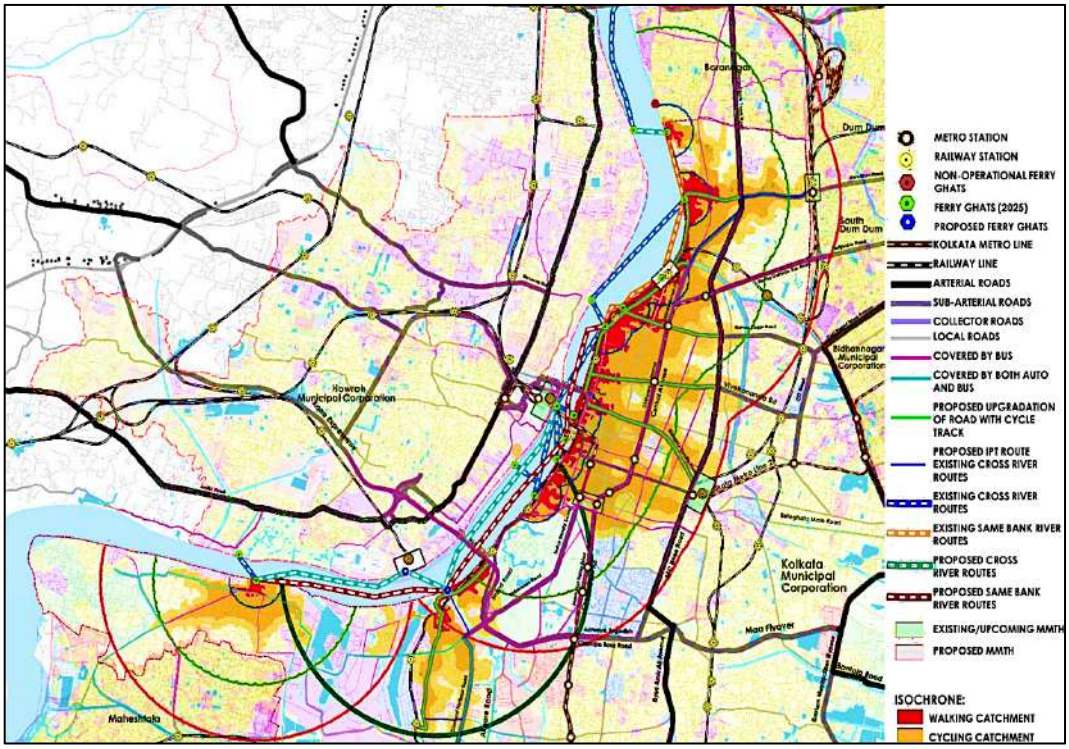


Figure 6. Post- proposal Isochrone showing an increase in Catchment Area for Ferry usage; Source: Das 2025

9.3 Modal Shift Potential

This analysis demonstrates the potential of inland waterways to enable a meaningful modal shift from congested road-based transport to more sustainable alternatives in Kolkata. Drawing on Koningsveld et al., the Amsterdam case illustrates how integrating water-based transport with electric last-mile mobility can reduce operating costs, vehicle loads, and inner-city travel distances.

Applying these lessons to Kolkata, a passenger-oriented two-echelon model is proposed, in which ferries serve longer cross-river and corridor movements. At the same time, intermediate and non-motorised modes support last-mile access. This approach is further strengthened through route optimisation techniques, such as the Adaptive Large Neighbourhood Search (ALNS), to synchronise ferry schedules with other modes, improve reliability, and maximise system efficiency, underscoring the strong potential of waterways to support sustainable urban passenger transport.

9.4 Infrastructure Planning

Modern ferry terminals should be implemented as multimodal transportation hubs, functioning much like Amsterdam's logistics hubs while being properly integrated with bus and metro stations. These terminals must be designed to efficiently handle passenger flows, incorporate smart ticketing systems, and provide safe, accessible boarding facilities. The proposed design elements and interventions are illustrated in Figure 5, which demonstrates how upgraded ferry terminals can act as strategic nodes in Kolkata's urban mobility network.

9.5 Environmental Benefits

Promoting electric or hybrid ferries, as Amsterdam did with electric vehicles, to reduce carbon emissions and noise pollution. The transition towards sustainable urban mobility necessitates the adoption of environmentally friendly transportation systems.

The latest generation of ferries, including solar- and hybrid-powered models, offers significant benefits over diesel ferries in modern ferry transportation systems Kerala launched "Aditya," a solar-powered ferry which became a leading example of sustainable transportation on inland waterways.

9.6 First- and Last-Mile Access to Ferry Terminals

The isochrone analysis of Kolkata reveals severe road congestion and uneven accessibility, with highly fragmented 5–10-minute travel-time zones across the primary road network. With roads covering only about 6% of the urban area, low travel speeds lead to long delays (20–60 minutes one way), leaving many dense neighbourhoods beyond short-access thresholds to rapid transit and highlighting how congestion constrains mobility.

Improving first- and last-mile connectivity to ferry terminals is therefore critical for expanding accessibility catchments, as many residents

currently lack convenient access to ferry ghats due to fragmented sidewalks, missing cycle infrastructure, and inadequate feeder services. Targeted interventions such as safe pedestrian links, protected cycling routes with parking, dedicated feeder transit, and coordinated schedules, ticketing, and real-time information with bus, metro, and para-transit, can substantially expand the 5–10-minute catchment area, strengthen multimodal integration, and position waterways as a viable component of Kolkata's mass transit system.

9.7 Expanding Catchments: Ridership, Equity, and Modal Shift Benefits

Expanding the 5–10-minute catchment areas around ferry terminals can significantly increase ridership, promote equity, and encourage a modal shift in Kolkata's transport system (Figure 6). Improved first- and last-mile connectivity can bring underserved and peripheral communities, many of them low-income, within easy reach of ferry services, making waterways an affordable and attractive travel option. Evidence shows that even modest expansions in service coverage can yield substantial ridership gains, while shifting trips from roads to ferries helps reduce congestion, emissions, and travel delays. Overall, wider ferry catchments support a more inclusive, sustainable, and efficient multimodal urban mobility system.

10. Post-Recommendation Mobility Framework (KPI) for Kolkata

Following the proposed interventions, such as route optimization through ALNS, deployment of green and hybrid ferries, improved last-mile connectivity, feeder services, smart ticketing, and better integration with metro and bus systems, Kolkata's ferry transport KPIs are projected to improve significantly.

Accessibility and integration could rise from 0.25 to 0.75, with the effective 5–10-minute catchment area nearly doubling. Environmental sustainability will improve as CO_2 emissions per passenger-km increase from 0.24 to 0.7–0.8, while particulate emissions drop with solar- and hybrid-powered ferries, similar to Kerala's Aditya model.

In terms of economic and operational efficiency, fare affordability will remain stable at 0.67–0.7, while operating cost efficiency may increase from 0.35 to 0.6–0.7, driven by lower fuel use and maintenance costs. For mobility and congestion, waterway speed could rise from 0.29 to 0.65–0.7, ferry modal share could increase from 1.4% to 8–10% of daily trips (10–12 lakh commuters), and congestion on bridges and arterial roads could ease by 15–20%. Collectively, these improvements would position ferries as a central pillar of Kolkata's sustainable and inclusive mobility strategy (Table 7).

Table 7. Future KPI Potential for Kolkata (Post-Recommendations)

KPI Dimension	Indicator	Current Value (Si)	Future Potential (Si)
Accessibility & Integration	Multimodal ferry terminal integration	0.25	0.75
	Population within 5–10 min catchment	Low	Doubled coverage
Environmental Sustainability	CO_2 emissions per passenger-km	0.24	0.7–0.8
	PM & NOx emissions	High	Drastically reduced
Economic & Operational Efficiency	Fare affordability	0.67	0.67–0.70
	Ferry modal share of daily trips	1.4% (~1.5 lakh)	8–10% (~10–12 lakh)
	Road congestion relief	Minimal	15–20% reduction

11. Key Findings

The discussion separates descriptive (e.g., commuter distribution, frequency of routes, and travel time) and interpretive (activity) findings that connect efficiency of operations to institutional capacity and form of the cities. A benchmarking example of KPIs with Kochi Water Metro shows how the current fleet design, integrated ticketing, and real-time tracking have enhanced the ridership and financial sustainability, and can serve as an actionable model for the system in Kolkata. Policy recommendations are formulated into three phases:

- Short-Term (0–5 years): Infrastructure revival, fleet modernization, and safety compliance.
- Medium-Term (5–10 years): Intermodal integration, unified ticketing, and digital platforms.
- Long-Term (10+ years): Network expansion, climate resilience measures, and smart mobility alignment.

12. Conclusion

This study concludes that integrating inland waterways into Kolkata's urban transport system is both a strategic necessity and a sustainable opportunity. Using KPI benchmarking, isochrone

analysis, and ALNS-based route optimisation, the research demonstrates that ferry-based transport, when supported by strong multimodal integration, first- and last-mile connectivity, coordinated governance, and phased policy interventions, can significantly reduce congestion, emissions, and mobility inequities. International best practices, particularly the Kochi Water Metro, demonstrate that with institutional coordination, modern fleets, and digital integration, Kolkata's underutilised waterways can be transformed into an efficient, low-carbon, and inclusive mobility corridor, reconnecting the city to the Hooghly River and strengthening long-term urban resilience.

Acknowledgements

The author gratefully acknowledges the faculty members of Department of Urban Planning, SPA New Delhi, particularly Dr. Sanjukta Bhaduri, for their constructive inputs. The author is thankful to the residents of Kolkata who participated in the surveys and stakeholder consultations, whose insights significantly informed the research. Gratitude is also expressed to the author's family for their constant encouragement and support.

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Assessing Housing Conditions for Construction Workers and Policy Frameworks:

A case of Bengaluru

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Abstract: In India, the construction industry is a major source of employment, engaging around 70 million workers who play a vital role in the country's development. Bengaluru, as a major urban growth centre, attracts a large influx of migrant construction workers who often live in precarious, inadequate housing conditions. Despite existing guidelines and welfare schemes, many workers continue to reside in overcrowded, unsafe environments lacking essential infrastructure. This research addresses the central problem of substandard housing for construction labourers in Bengaluru by evaluating existing policies, identifying implementation gaps, and examining ground realities. This study employs a combination of methods, including firsthand surveys, field inspections of labour settlements and public spaces, and case studies encompassing various scales and developer profiles. Analytical tools include comparative analysis of accommodation types (on-site vs. off-site), infrastructure quality assessment, and socio-economic profiling of workers. Key findings reveal discrepancies between policy provisions and their implementation, with affordability and regulatory leniency undermining housing standards. The research also identifies systemic issues in worker registration, cess collection, and benefit distribution under the BOCW Act. This study proposes a multi-scalar strategy that emphasises Aadhaar-linked national registration, the integration of labour housing into Karnataka's State Housing Policy, and the promotion of affordable rental and permanent housing models. The study concludes that inclusive and enforceable housing policies are vital for improving workers' welfare, sustaining construction productivity, and enabling equitable urban development.

Keywords: Construction workers, migrant labour, BOCW Act, Bengaluru, worker housing, policy gaps

सार: भारत में निर्माण उद्योग रोजगार का एक प्रमुख स्रोत है, जो लगभग 7 करोड़ श्रमिकों को संलग्न करता है, जो देश के विकास में महत्वपूर्ण भूमिका निभाते हैं। बेंगलुरु, एक प्रमुख शहरी विकास केंद्र होने के नाते, बड़ी संख्या में प्रवासी निर्माण श्रमिकों को आकर्षित करता है, जो प्रायः अस्थिर और अपर्याप्त आवासीय स्थितियों में जीवनयापन करते हैं। हालाँकि दिशानिर्देश और कल्याणकारी योजनाएँ विद्यमान हैं, फिर भी अनेक श्रमिक अत्यधिक घनीभूत, असुरक्षित और आवश्यक बुनियादी सुविधाओं से वंचित आवासों में रहने के लिए बाध्य हैं। यह शोध बेंगलुरु में निर्माण श्रमिकों के निम्नस्तरीय आवास की केंद्रीय समस्या को संबोधित करता है और मौजूदा नीतियों, क्रियान्वयन की खामियों तथा जमीनी वास्तविकताओं का मूल्यांकन करता है। अध्ययन में विभिन्न विधियों का संयोजन किया गया है, जिनमें प्रत्यक्ष सर्वेक्षण, श्रमिक बस्तियों और सार्वजनिक स्थलों का क्षेत्र निरीक्षण, तथा विभिन्न पैमानों और डेवलपर प्रोफाइल को समाहित करने वाले मामले(प्रकरण अध्ययन) शामिल हैं। विश्लेषणात्मक उपकरणों में आवास के प्रकारों (साइट पर बनाम साइट के बाहर) की तुलनात्मक समीक्षा, बुनियादी ढाँचे की गुणवत्ता का मूल्यांकन, और श्रमिकों की सामाजिक-आर्थिक प्रोफाइलिंग को सम्मिलित किया गया है। मुख्य निष्कर्षों से स्पष्ट होता है कि नीति प्रावधानों और उनके क्रियान्वयन के बीच उल्लेखनीय अंतर मौजूद हैं, जहाँ सामर्थ्य और नियामकीय ढिलाई आवास मानकों को कमजोर करती हैं। शोध में बी.ओ.सी.डब्ल्यू. अधिनियम के अंतर्गत श्रमिक पंजीकरण, उपकर संग्रहण, और लाभ वितरण प्रक्रियाओं में निहित संरचनात्मक समस्याओं की भी पहचान की गई है। शोध एक बहु-पैमानी रणनीति प्रस्तावित करता है, जिसमें आधार-संलग्न राष्ट्रीय पंजीकरण, श्रम आवास को कर्नाटक की राज्य आवास नीति में एकीकृत करना, तथा सस्ती किराये की और स्थायी आवासीय मॉडलों को बढ़ावा देना शामिल है। अध्ययन निष्कर्ष निकालता है कि समावेशी और प्रभावी रूप से लागू की जाने वाली आवास नीतियाँ श्रमिकों के कल्याण में सुधार, निर्माण क्षेत्र की उत्पादकता को बनाए रखने, और न्यायसंगत शहरी विकास को सक्षम बनाने के लिए अपरिहार्य हैं

मुख्य शब्द: निर्माण श्रमिक, प्रवासी आवास, बीओसीडब्ल्यू. अधिनियम, बैंगलोर, श्रमिक कल्याण

1. Introduction

The construction industry significantly boosts India's economy, accounting for approximately 9% of the GDP and providing jobs to close to 70 million people. Bengaluru, a fast-growing metropolitan city, relies heavily on migrant construction labour to fuel its rapid urban development. However, despite their critical role, construction workers often live in unsafe, overcrowded, and temporary accommodations lacking basic services.

This study explores the housing conditions of construction workers in Bengaluru, highlighting gaps in policy implementation and on-ground realities. It assesses government interventions, such as the BOCW Act, and examines housing typologies through detailed case studies.

The aim is to propose feasible, inclusive housing models that can be integrated into state housing policies, ensuring dignity and welfare for this essential workforce.

2. Construction Sector in India

The construction industry plays a crucial role in India's economy, accounting for roughly 8–9% of the GDP and providing employment to more than 50 million people. It ranks as the second-largest source of employment in the country, following agriculture. Rapid urbanisation and government schemes such as PMAY, the Smart Cities Mission, and the National Infrastructure Pipeline (NIP) have significantly boosted construction activity.

Despite its importance, the sector is largely informal. Workers face temporary jobs, low wages, unsafe working conditions, and a lack of welfare facilities. The sector is divided into general building, heavy construction, and special trade contractors. Employment ranges from micro to large enterprises, and contractors are classified based on public or private sector involvement. States like Uttar Pradesh, Maharashtra, and Karnataka have the highest construction employment. However, poor regulation and inadequate worker housing remain major challenges. Addressing these issues is essential to ensure workers' well-being and sustaining sectoral growth.

Rapid urbanisation in Bengaluru, India's third-largest megalopolis, has heightened the demand for housing, yet the very workers who build the city remain excluded from dignified living conditions. Nearly 50% of urban land is expected to be devoted to residential use by 2025, highlighting the urgency of addressing the housing shortage for construction workers (Figure 1).

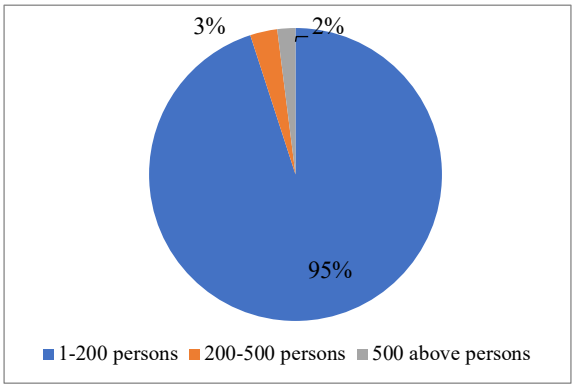


Figure 1. Distribution based on employment
Source: (Pal 2025)

The indignity of construction workers living in slum-like conditions while building modern housing for others underscores a paradox within urban development. Ensuring adequate housing for construction workers is not merely a welfare issue but a matter of restoring dignity and social justice.

3. Labour

The construction sector in India relies heavily on a vast, diverse labour force, primarily comprising unorganised workers. The workforce (Figure 2) is broadly categorised into two segments:

- Organised Sector: Comprising workers employed in formal establishments with secure contracts, social security, and legal protection.
- Unorganised Sector: Representing approximately 92% of India's total workforce, this sector includes informal, contract, daily-wage, and migrant labourers. Workers in this category face job insecurity, irregular wages, unsafe working conditions, and limited access to welfare schemes.

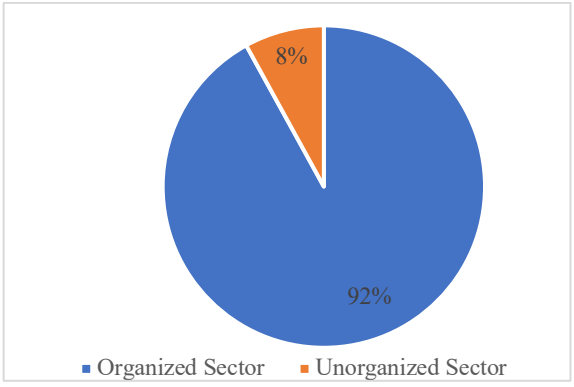


Figure 2. Workers Categorisation
Source: (Pal 2025)

Construction workers in the industry (Figure 3) are a major subset of unorganized labour who are often subject to hazardous working conditions, a lack of benefits, and limited legal oversight. These challenges highlight the pressing need for targeted interventions to improve their welfare and living standards.

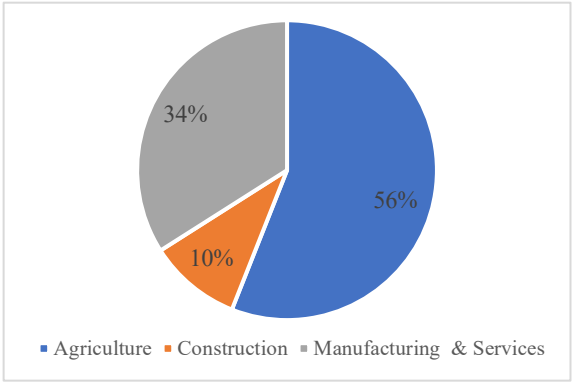


Figure 3. Construction Industries in India
Source: (Pal 2025)

4. Profile of Construction Workers

Construction workers constitute a diverse and essential segment of India's informal labour force, especially in the growing urban construction sector. Their employment is predominantly casual and insecure, with workers hired on a daily wage basis or through intermediaries without formal contracts. Many are employed as Naka workers, sourced from informal hiring points in cities, while others work under labour contractors on larger institutional projects (Figure 4).

Based on skill levels, the majority are unskilled (79%), followed by semi-skilled (13%) and skilled (8%), reflecting limited access to training and education. Gender disparities are evident, as women make up 30–40% of the workforce but are largely confined to low-paying, physically demanding tasks with no recognition or protection.

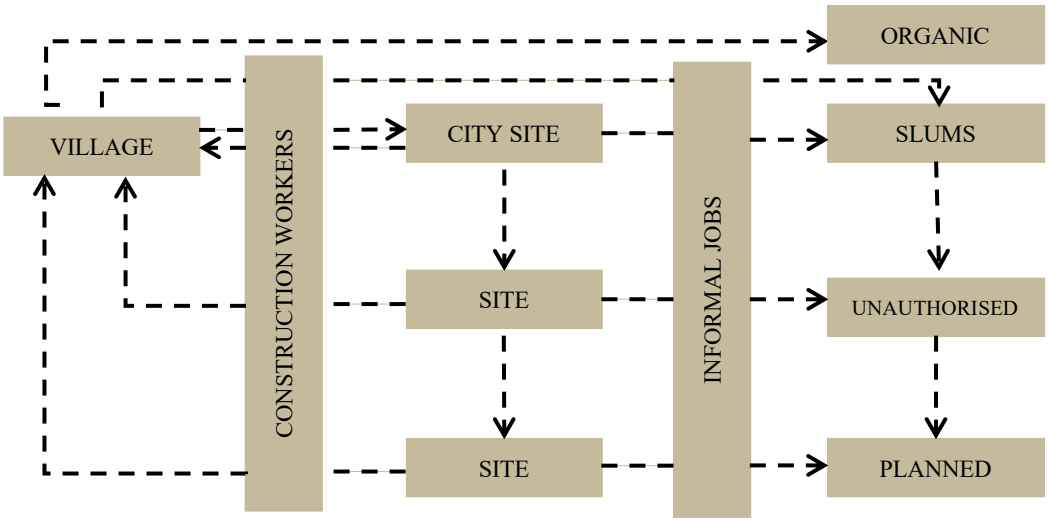


Figure 4. Flow Chart for the movement of workers

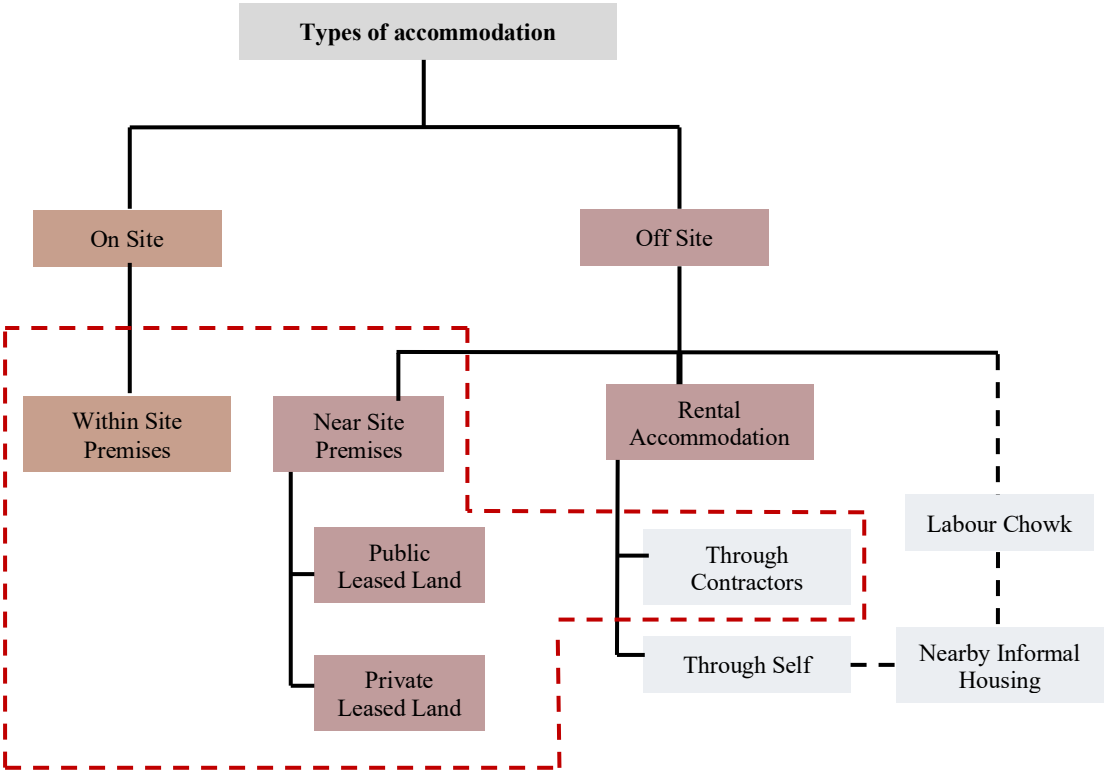


Figure 5. Types of accommodation

The workforce is further segmented into three categories: Naka/mandi workers, institutional workers involved in large-scale formal projects, and those in the intermediary segment, employed through middlemen. Migration plays a central role in shaping the construction labour force, as many workers move across states and regions in search of employment opportunities. These migrant workers often lack local identification, stable income, and adequate housing, which

makes them particularly vulnerable to exploitation and exclusion from welfare schemes. The precarious nature of their employment, coupled with poor working and living conditions, underscores the urgent need for comprehensive policy frameworks and housing solutions that address their specific needs and vulnerabilities.

5. Construction Workers Accommodation

Construction workers in Bengaluru often live in informal, inadequate housing near worksites. Accommodations are mostly of two types: on-site temporary shelters made of tin or tarpaulin sheets, and rented informal rooms, both lacking basic amenities. Most settlements face poor access to water, sanitation, electricity, and waste disposal. Toilets are few or absent, leading to unsafe and unhygienic conditions, especially for women and families (Figure 5).

Although the BOCW Act (1996) mandates adequate housing and facilities, enforcement remains weak, with minimal inspections and compliance. Field visits revealed cramped spaces, the absence of childcare, and unsafe environments for women and children.

6. Literature Studies

A comparative study of two significant initiatives focused on providing better accommodation for construction workers in India. These examples serve as precedents and models for addressing the housing needs of migrant labourers in urban contexts.

6.1 Kutumb, Bhubaneswar – 2017

The initiatives undertaken by the Bhubaneswar Development Authority (BDA) and Nebula Infraspace in Ahmedabad serve as significant precedents in the domain of organised housing for construction workers.



Figure 6. Layout Plan (Bhubaneswar's Smart City Proposal)

As part of Bhubaneswar's Smart City Proposal (Figure 6), the BDA developed a rental housing complex to accommodate 200 migrant construction workers per unit, with a total project cost of ₹5.64 crores. The design comprises Ground + 3 floors on a 0.365-acre plot, providing a total built-up area of 37,645 sq. ft. Key facilities include strategically placed drinking water points, nine "Aahar Centers" offering affordable meals, a dining hall with a capacity of 140 people, community spaces, and 12 family rental units. This initiative aims to prevent slum formation, enhance workers' living conditions, and improve the overall urban environment. By integrating housing with essential social infrastructure, the project demonstrates a scalable model for worker welfare within formal urban planning frameworks. It also highlights the role of public-sector intervention in addressing migrant housing needs in rapidly growing cities.

6.2 Avaas by Nebula Infraspace, Ahmedabad – 2016

Similarly, the Avaas project (Figure 7), initiated in 2016 by Nebula Infraspace in Ahmedabad, in collaboration with Hatch Workshop and NGOs like Saath, represents a private-sector-led model emphasising inclusive and humane housing.



Figure 7. Labour Colony Accommodation; Source: Nebula Infraspace in Ahmedabad

It features two types of rooms: 3×3m for four people and 3×6m for eight, constructed from galvanised iron sheets with mesh-covered, ventilated openings. The project incorporates bio-digester toilets, separate sanitation for men and women, clean drinking water, a community kitchen, shaded courtyards, designated male cooking zones, and a crèche for children. The design philosophy prioritises comfort, safety, gender inclusivity, and dignity for labourers.

These case studies illustrate how partnerships among government bodies, private developers, and civil society can deliver liveable, hygienic, and secure accommodations for migrant workers. A comprehensive strategy integrating social infrastructure, sanitation, nutrition, and thoughtfully designed community spaces significantly enhances worker satisfaction and

promotes their integration into urban life. Moreover, alignment with labour welfare policies and the leveraging of corporate social responsibility (CSR) funds are critical to the successful implementation and sustainability of such initiatives.

7. Legal and Policy Framework:

7.1 Legal and Policy Framework for Construction Workers' Welfare and Housing

The construction sector in India, despite being the second-largest source of employment, remains one of the most informal and unregulated labour markets. This section critically examines the legislative provisions, schemes, and institutional mechanisms governing the welfare and housing of construction workers, with a particular focus on migrant labourers in Karnataka. It identifies gaps between policy intent and implementation and examines the effectiveness of welfare mechanisms, including registration systems, cess collection, and housing schemes.

- The Inter-State Migrant Workmen (Regulation of Employment and Conditions of Service) Act, 1979: This Act governs the conditions under which migrant workers are recruited and employed across state boundaries. It mandates basic entitlements such as:
- Accommodation, journey allowances, and displacement benefits.
- The Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Act, 1996 (BOCW Act): A landmark legislation that defines welfare and safety standards for workers employed in the construction sector. Key provisions include:
    - Section 32: Provision of drinking water
    - Section 33: Adequate toilet facilities
    - Section 34: Safe and hygienic accommodation
    - Section 35: Establishment of crèches for workers' children
    - Section 37: Access to canteens
    - Sections 18 & 22: Creation and responsibilities of State Welfare Boards
    - Section 12: Mandatory worker registration as beneficiaries
- The Building and Other Construction Workers Welfare Cess Act, 1996: Introduces a cess of 1% on the cost of construction projects exceeding ₹10 lakhs. The funds collected are to be exclusively used for the welfare of registered construction workers. Despite the progressive intent of these laws, implementation at the ground level remains fragmented. The unorganised and transient nature of the workforce makes enforcement and monitoring especially challenging.

7.2 Implementation Framework in Karnataka

Karnataka has institutionalized welfare delivery through the Karnataka Building and Other Construction Workers Welfare Board (KBOCWWB). This Board is responsible for:

- Registering workers who have completed a minimum of 90 days of construction work.
- Disbursing benefits related to housing, health, education, maternity support, pension, and death compensation.

As of 2025, Bengaluru has registered approximately 5.77 lakh workers, with active registrations accounting for only 66% of that number. The lack of periodic renewal, inadequate contractor compliance, and poor digital tracking contribute to under-registration and exclusion from benefits.

7.3 Systemic Issues and Gaps

The legislative intent is weakened by inadequate implementation mechanisms and insufficient coordination among stakeholders, giving rise to the following key challenges:

- Low Registration Rates: Many workers remain unaware or excluded due to cumbersome procedures and insufficient documentation.
- Underutilization of Welfare Cess: Karnataka has consistently underused its cess funds, with less than 6% of collected resources reaching beneficiaries.
- Inadequate Monitoring and Accountability: No robust digital system exists to track cess collection, fund flows, and benefit distribution in real time.
- Lack of Inter-agency Coordination: Disconnect between contractors, government departments, and welfare boards delays benefit delivery.
- Housing Provision and Urban Integration: Construction workers in Bengaluru, especially migrants, face acute housing insecurity. On-site temporary shelters are legally required, yet in practice, they frequently fail to meet standards or are not provided. Off-site rental accommodation remains unaffordable due to rising urban land costs and the absence of worker-focused rental policies.

The inclusion of construction workers in urban housing policies remains marginal. Efforts

such as ARHCs have shown promise but lack scale and sustainability. The integration of labour housing into the Karnataka State Housing Policy and city-level development plans is essential to mainstream their housing needs.

8. Study Area

Bengaluru, a rapidly expanding urban centre and a prominent hub for construction and infrastructure, spans 8,005 sq. km and is projected to have a population of 1.82 crore. The city's population has grown significantly due to high migration rates, particularly of rural construction workers seeking employment. With 5.77 lakh registered construction workers in Bengaluru alone, the need for adequate labour housing has become urgent. This section establishes Bengaluru as an ideal study area due to its urban dynamics and construction-driven growth. Case studies were selected based on project scale, developer type, location, duration, workforce size, affordability, and government policies, offering a comprehensive perspective on the varied accommodation conditions of construction workers across the city.

9. Case Studies

The case studies conducted in the research provide a critical lens into the living conditions, welfare infrastructure, and policy implementation affecting construction workers in Bengaluru (Figure 8). Each case exemplifies a different typology of worker housing, from formal on-site accommodation to informal off-site settlements, revealing the disparities and challenges that persist despite existing regulations.



Figure 8. View of the Labour colony and room

The Konadasapura BDA Project, a large-scale government-led housing scheme, reflects the most structured approach to worker accommodation. With 16 residential towers under construction and a dedicated on-site labour colony, it accommodates 700 workers and is designed to accommodate 2,500. While the colony has basic facilities such as toilets, a canteen, a first-aid centre, and biometric check-in systems, the infrastructure remains inadequate, with only 10 toilets for 700 workers and no private sanitation facilities. Though the project attempts to comply with welfare norms, it still falls short of the standards set by the Building and Other Construction Workers (BOCW) Act, particularly in sanitation and space (Figure 9). This highlights a systemic issue even in projects backed by public authorities.



Figure 9. On-site accommodation of the workers
Source: (Pal 2025)

In contrast, DNR Highline, a high-end private residential development, demonstrates a stark neglect of worker welfare. Out of 750 construction workers, only 80 are accommodated on-site in makeshift hutments made of temporary materials (Figure 10). The site lacks basic facilities, such as a canteen, proper toilets (only 2 for the entire colony), and health centres. There is no formal layout or safety planning, which showcases the private sector's tendency to overlook worker welfare despite the scale and profitability of the project. This case emphasises the urgent need for regulatory enforcement and monitoring in the private construction sector.



Figure 10. On-site accommodation with no other facilities
Source: (Pal 2025)

The Singapura Lake Redevelopment Project, managed by the BDA in collaboration with Arpan Associates, represents a small-budget public ecological project. While the labour housing is on-site, only 15–20 of 50 workers are

accommodated, and the facilities are extremely limited: there are no toilets, fire safety provisions, or health services (Figure 11). The absence of even basic amenities in a government-run project underscores the need for better integration of welfare planning, into non-residential public works.



Figure 11. Off-site workers' accommodation, a slum area in BTM Layout

A different perspective emerges from Raghavendra Colony (Figure 12), a migrant settlement in BTM Layout. Here, workers are not housed by any employer but live in informal rented accommodations, often with their families. The housing is substandard, built with temporary materials like asbestos sheets and mud flooring. Sanitation and water supply are shared and inadequate, and the area suffers from poor road infrastructure and open drainage. Despite its long-term nature, this off-site housing remains completely outside the formal welfare framework, underscoring migrant workers' exclusion from urban planning policies and formal housing schemes.



Figure 12. Construction workers at Labour Chowk

Finally, the Labour Chowk in J. P. Nagar presents the most precarious living and working conditions. It serves as a daily meeting point for Naka workers, and casual labourers hired informally. These workers, mostly male and ranging from skilled to unskilled, live in temporary rented or shared spaces with poor amenities. Without formal contracts, they are excluded from benefits under welfare boards or housing schemes. Their transient lifestyle and lack of employer accountability make them particularly vulnerable, representing the informal edge of the urban labour market.

In conclusion, the five case studies collectively expose a systemic failure to provide dignified housing for construction workers. While on-site accommodations offer proximity to work, they often lack in quality, sanitation, and privacy. Off-site informal settlements provide slightly more permanence but remain outside legal frameworks. The disparity between public and private sector initiatives is stark, with private developers showing minimal commitment to worker welfare. Across all cases, the gap between policy and implementation is significant, calling for urgent reforms in enforcement, funding allocation, and the integration of construction worker housing into mainstream urban planning policies.

10. Findings and Analysis

The study's findings highlight the contrasting conditions between construction site workers and Naka (labour chowk) workers (Figure 13). While Naka workers often earn slightly more due to flexible daily wages, they face irregular employment and lack social security.

In contrast, site workers receive more stable monthly payments but are bound to the contractor's schedule, leaving little room for flexibility. The employment structure across sites is highly hierarchical, with multiple layers of contractors, subcontractors, and supervisors, which often complicates accountability.

A typical day for construction workers begins early in the morning, around 7 am, and ends late in the afternoon. Site workers tend to have fixed schedules and specialised tasks, whereas Naka workers perform general labour on an as-needed basis. Both groups work in physically demanding environments, often under poor safety conditions and with limited access to basic amenities. The workers' aspirations reveal a strong desire for improved living conditions. Most dream of owning a two-room house and eventually returning to their native villages, although younger workers show some interest in settling in urban areas. However, awareness of government housing schemes and benefits remains low among them.

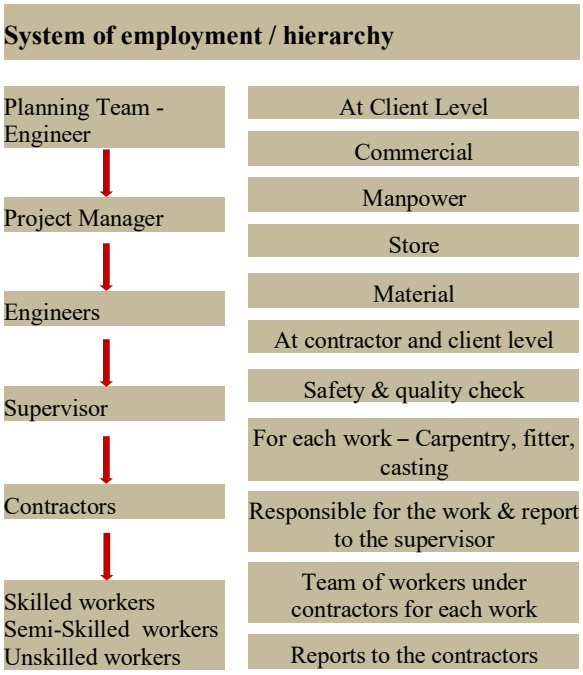


Figure 13. System of Employment

The study also identifies a clear need for adequate and permanent housing. Younger workers (under 35) tend to accept temporary housing arrangements due to their mobile lifestyle and work nature. As they age, especially after 35, they increasingly seek stable, secure living spaces, often influenced by family responsibilities and career stability. This reflects a transition from a phase of high adaptability to a need for rootedness.

A comparative analysis of five case studies shows that most worker accommodations—both on-site and off-site—fail to meet the space standards set by the Building and Other Construction Workers (BOCW) Act, which mandates a minimum of 2.2 m² per person. Most of the housing units analysed had overcrowding issues, with available area per person falling as low as 1.6 m². Furthermore, welfare facilities such as toilets, kitchens, and first aid rooms were either insufficient or poorly maintained. The analysis also reveals that government-backed projects tend to provide better housing conditions than private or informal sector projects. Overall, this section underscores the pressing need for policy reforms, the enforcement of housing standards, and the education construction workers about their rights and entitlements to ensure dignified living conditions.

11. Issues and Potentials

It provides a comprehensive analysis of the gaps between the Building and Other Construction Workers (BOCW) Act, 1996, and the actual living and working conditions of construction workers in Bengaluru. While the BOCW Act was legislated to protect the welfare, safety, and rights of construction workers, especially through mandates on registration, the provision of amenities, and the utilisation of welfare funds, its ground-level implementation reveals stark inadequacies.

A major issue is the low registration rate among workers, largely due to a lack of awareness, language barriers, and rigid eligibility conditions such as the requirement to prove 90 days of employment, which is often impossible for informally hired “Naka” workers. Although the Act mandates that developers ensure registration and welfare provision, there is no enforcement mechanism to hold them accountable, and workers fear job loss or retaliation if they attempt to access these rights.

The Act also outlines specific provisions for decent housing, sanitation, drinking water, first aid, crèches, and safety measures, but these are rarely adhered to. On-site accommodations typically fall short of minimum space requirements, lack separate cooking areas, toilets, and hygiene facilities, and are constructed with low-grade materials. Off-site accommodations, often in informal settlements, are overcrowded, costly, and unsafe—conditions that run counter to the welfare-driven principles of the BOCW Act.

Furthermore, while cess is collected under the Act to fund worker welfare, the study highlights that only a negligible portion is used, and there is little transparency or accountability in how funds are managed. Discrepancies between state welfare boards and local labour departments further weaken implementation.

Despite these challenges, this identifies significant potential reforms that could align practice with the BOCW Act’s vision. These include multilingual, Aadhaar-linked digital registration systems; frequent registration drives at labour chowks and construction sites; proper mapping of active sites using geo-tagging and GIS; and inclusion of construction worker housing in state housing policies and urban planning frameworks.

The study urges stronger institutional accountability through inter-agency coordination and the creation of monitoring bodies. Ultimately, while the BOCW Act provides a robust legal structure for construction worker welfare, this section illustrates that only through better implementation, accountability, and integration with housing and planning policies

can its full potential be realised, ensuring dignity and equity for this vulnerable workforce.

12. Recommendations

To address this, the study proposes policy-level reforms. The primary objective is to ensure that migrant workers, including those from other countries, are not deprived of the benefits to which they are entitled to during the registration process. There is a pressing need for the government to facilitate inter-state coordination and to restructure Welfare Boards to make them more responsive, inclusive, and transparent in their functioning. These institutions should be tasked with overseeing housing quality and ensuring optimal utilisation of funds (Table 1).

Table 1. Utilisation of Cess

1. Pension and Social Security Provisions

- Pension Scheme for Workers:
  - Construction workers will be enrolled in pension scheme to ensure financial security upon retirement by using cess fund.
- Death Benefits and Family Support:
  - In case of a worker's death, their dependents (spouse, children, or parents) will receive compensation, and they will be enrolled in the pension scheme as beneficiaries.
- Unemployment Fund:
  - A fund to provide construction workers with unemployment benefits in case they are laid off due to a lack of work or during off-seasons.

2. Health and Well-being Provisions

- Mandatory Health Insurance:
  - Construction workers have access to government-subsidized health insurance, covering both work-related injuries and general health needs.
- Regular Health Check-ups:
  - Employers are required to conduct mandatory health check-ups for workers even after retirement with special focus on occupational diseases .
- Mental Health Support:
  - Create a mental health support program for workers to deal with stress, depression, and trauma related to work, including access to counseling and support services.

3. Education and Skill Development Provisions

- Educational Scholarships
  - Government shall allocate scholarships for the children of construction workers to pursue primary, secondary, and higher education.
- Skill Development and Vocational Training
  - Employers must contribute to training programs that help workers acquire new skills and enhance existing ones and offer free certification for trained workers.
- Construction Worker Educational Support
  - Provision for workers to access free or subsidized education (primary to technical) including skills, technical workshops, and safety certifications

4. Housing Provisions

- Affordable Housing for Workers
  - Government shall provide low-cost housing or housing subsidies for construction workers, with priority given to those who have been in the industry for a minimum number of 5-8 years.
- Temporary Worker Accommodation
  - Employers must provide temporary shelters with essential amenities for workers employed on construction sites for more than three months.
- Housing Fund
  - Establish a specific Housing Fund using cess to provide financial support for workers to build homes or access affordable housing.

Source: (Pal 2025)

A major recommendation is to amend the Building and Other Construction Workers (BOCW) Act, originally enacted in 1996 and updated in 2025. The revision proposes broadening the scope of the Act to encompass comprehensive social security provisions, including health insurance, pension plans, educational assistance for workers' children, and, most importantly, access to safe and dignified housing. The revised Act also proposes that Welfare Boards should take the lead in monitoring housing quality, allocate specific funds for this, and ensure that infrastructure standards, such as sanitation, water, ventilation, and structural safety, are met.

In terms of operational improvements, this research proposes establishing a Labour Housing and Inclusion Policy. This would include a new, inclusive registration model with decentralised processes to make it easier for workers to register. Additionally, dedicated facilitation centres should be set up to assist with registration, applications, and grievance resolution. The inclusion of online application platforms will further streamline the system, enabling more workers to access benefits efficiently.

To improve the effectiveness of Welfare Boards, the report calls for standardized templates and clearly defined procedures. These improvements would enhance the Board's administrative capacity and allow better monitoring and transparency. In parallel, collection mechanisms for cess from contractors and developers should be improved to ensure adequate funding. The utilization of these funds must prioritize housing and pension schemes, with strict accountability measures in place.

Another focus of the recommendations is on pension schemes. The BOCW Welfare Board is urged to take responsibility for implementing pension schemes using cess funds. The report also suggests providing death benefits and other forms of social security to the families of deceased workers, ensuring long-term protection and stability.

The study proposes a funding model that emphasises the need for multi-stakeholder involvement. It recommends collaboration among government departments, such as Labour, Housing, and Social Justice, alongside private players, unions, and NGOs (Figure 14). Local needs should drive funding allocation, and cess funds should be transparently accounted for and audited periodically. A detailed accommodation model is also suggested (Figure 15). The model incorporates both on-site and off-site housing options, tailored to the nature, duration, and location of employment. For temporary or short-term jobs, transitional housing such as modular units is proposed. These are low-cost, quick to deploy, and eco-friendly, ensuring that even short-term workers have access to dignified living conditions near work sites.

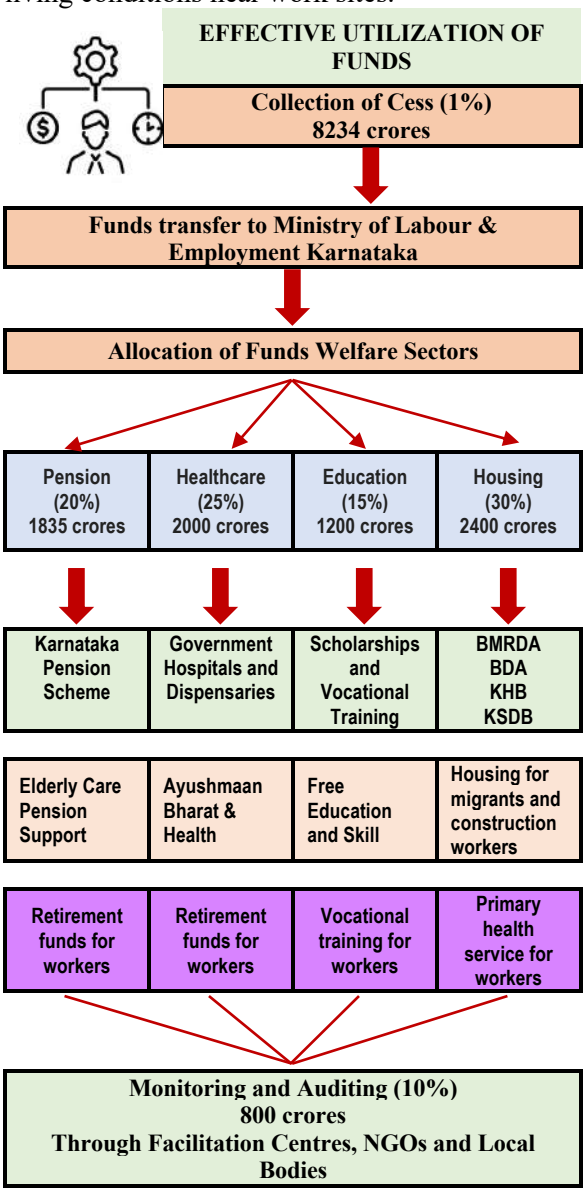


Figure 14. Framework of Utilization of funds
Source: (Pal 2025)

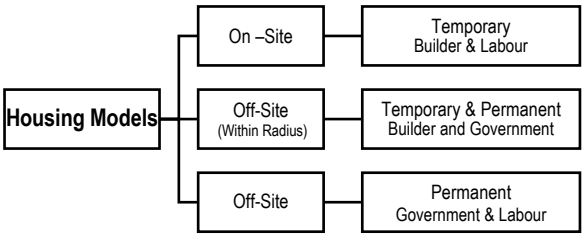


Figure 15. Proposed housing models for construction labour

The report advocates for the inclusion of "Housing for Construction Workers" within the Karnataka State Housing Policy and Action Plan. This policy inclusion will institutionalize the government's responsibility to provide worker housing. Programs under this inclusion should support the development of public rental housing, especially near work zones, and offer incentives to builders who participate in such schemes. Temporary accommodations are suggested in the form of prefabricated and modular housing that is quick to set up and environmentally sustainable. Rental housing schemes should offer flexible payment structures, such as weekly or monthly rent, to suit workers' income patterns. These accommodations should be managed and regulated by the BOCW Welfare Board and made available only to registered workers to avoid misuse.

Financial assistance is a key component of the rental housing model. The report recommends offering tax incentives and housing subsidies to construction workers. Cess funds can also be used to extend long-term benefits, particularly for workers who have completed more than 15 years of service, enabling them to transition from rental to ownership models and improve their housing security.

12.1 On Policy Frameworks (Delhi vs. Karnataka Rules)

A comparative analysis of the Delhi Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Rules, 2002, and the Karnataka Rules, 2006, reveals a critical gap: while the Delhi provisions explicitly include financial support for workers' housing, the Karnataka Rules lack such measures. The Delhi framework's inclusion of a housing grant of ₹3 lakh, conditional on continuous membership and years of service, offers a model for Karnataka to emulate in extending comprehensive benefits to its construction workforce.

12.2 On Governance & Implementation

Despite the BOCW Act (GOI 1996), housing

provision remains absent from Karnataka's framework, underscoring the need for legislative amendments to integrate housing as a core welfare entitlement. Activism by NGOs, trade unions, and worker cooperatives could play a transformative role in advocating for such amendments, ensuring that welfare boards truly serve the needs of their members."

12.3 Key Takeaways and Strategic Way Forward

Including housing provisions within the Karnataka Building and Other Construction Workers' Rules would address a key policy gap and align welfare measures with workers' realities in Bengaluru. Promoting affordable permanent housing, modular eco-friendly units, and transitional housing, supported by policy and institutional reforms, can significantly improve construction workers' living conditions.

13. Conclusion

The study finds that, despite the construction sector's critical role in urban growth, the living and working conditions of construction workers, particularly migrants, remain severely inadequate due to the weak and fragmented implementation of existing welfare frameworks, such as the BOCW Act, 1996. Most workers reside in temporary on-site or off-site shelters with limited access to basic services, and housing provision is largely dependent on builders' willingness rather than enforceable norms. Gaps in cess collection, poor utilization of welfare funds, and the absence of a centralized registration system further exclude workers from social security and entitlements. The study calls for integrating construction worker housing into urban and state housing policies through inclusive rental and permanent housing models, stronger institutional mechanisms, mandatory housing provisions in project approvals, and a national Aadhaar-linked registration system, advocating a rights-based approach that recognizes workers as integral to the urban ecosystem.

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Housing for Industrial Workers in Nagpur Metropolitan Region:

Socio-economic and Physical Study of Industrial Workers' Housing

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Abstract: Nagpur, a growing industrial and logistics hub in central India, hosts over 1.58 lakh industrial workers across eight major industrial zones like Hingna, Butibori, and Umred. Many of these workers are migrants seeking affordable housing near their workplaces. However, despite rapid industrial growth, there has been a severe lack of housing provisions for these workers. Residential development within industrial layouts was not permitted by official policies until 2009, and MIDC guidelines still do not contain such clauses. Unauthorised housing in neighbouring villages and squatter colonies are examples of unplanned settlements resulting from this policy gap. The majority of public housing is situated outside of cities and lacks basic amenities and connectivity. Overcrowding, inadequate sanitation, and restricted access to healthcare and education are all problems faced by workers in informal settlements. The study emphasises the critical connection between industrial productivity, worker health, and suitable housing. Government and private sector intervention is clearly needed, according to a field-based study conducted across a variety of housing typologies. The major recommendations emphasize the need to integrate worker housing into MIDC and urban planning regulations, establish a regularly updated migrant worker registry, promote rental housing options suited to a mobile workforce, and include a dedicated section on industrial worker housing in regional development plans. Ensuring adequate housing is not merely a welfare concern but a critical requirement for sustainable industrial growth and workforce stability in Nagpur.

Keywords: Workers Housing; Industries; Rental Housing; Migrant workers.

सार: नागपुर, जो मध्य भारत का एक उभरता हुआ औद्योगिक और लॉजिस्टिक केंद्र है, में हिंगणा, बुटीबोरी और उमरेड जैसे आठ प्रमुख औद्योगिक क्षेत्रों में लगभग 1.58 लाख औद्योगिक श्रमिक कार्यरत हैं। इनमें से बड़ी संख्या में श्रमिक प्रवासी हैं, जो अपने कार्यस्थल के निकट किफायती आवास की तलाश में रहते हैं। तेज़ औद्योगिक विकास के बावजूद इन श्रमिकों के लिए समुचित आवास प्रावधानों की गंभीर कमी रही है। 2009 तक आधिकारिक नीतियों के अंतर्गत औद्योगिक भू-उपयोग विन्यास में आवासीय विकास की अनुमति नहीं थी, और वर्तमान में भी एम.आई.डी.सी. के दिशा-निर्देशों में श्रमिक आवास से संबंधित स्पष्ट प्रावधानों का अभाव है। परिणामस्वरूप, आस-पास के गाँवों में अनधिकृत आवास तथा झुग्गी-बस्तियाँ जैसी अनियोजित बस्तियाँ इस नीतिगत अंतर का प्रत्यक्ष द्योतक हैं। अधिकांश सार्वजनिक आवास शहरों के बाहरी हिस्सों में स्थित हैं, जहाँ मूलभूत सुविधाओं और समुचित संपर्क व्यवस्था की कमी है। अनौपचारिक बस्तियों में रहने वाले श्रमिकों को अत्यधिक घनत्व, अपर्याप्त स्वच्छता, तथा स्वास्थ्य और शिक्षा सेवाओं तक सीमित पहुँच जैसी समस्याओं का सामना करना पड़ता है। अध्ययन, औद्योगिक उत्पादकता, श्रमिकों के स्वास्थ्य और उपयुक्त आवास के बीच महत्वपूर्ण अंतर्संबंध को रेखांकित करता है। मैदान-स्तर पर विभिन्न आवास प्रकारों के बीच किए गए सर्वेक्षण-आधारित विश्लेषण से यह स्पष्ट होता है कि सरकार और निजी क्षेत्र, दोनों के लक्षित हस्तक्षेप की तत्काल आवश्यकता है। प्रमुख अनुशंसाएँ इस बात पर बल देती हैं कि श्रमिक आवास को एम.आई.डी.सी. तथा शहरी नियोजन विनियमों में समाहित किया जाए, नियमित रूप से अद्यतन होने वाला प्रवासी श्रमिक पंजी विकसित किया जाए, अस्थिर कार्यबल के अनुरूप किराये के आवास विकल्पों को बढ़ावा दिया जाए, तथा क्षेत्रीय विकास योजनाओं में औद्योगिक श्रमिक आवास पर एक पृथक अध्याय शामिल किया जाए। उचित आवास सुनिश्चित करना केवल कल्याण से जुड़ा मुद्दा नहीं, बल्कि नागपुर में सतत औद्योगिक विकास और स्थिर श्रम-बल की बुनियादी पूर्व-शर्त है।

मुख्य शब्द: श्रमिकों के लिए आवास; उद्योग; किराये के आवास; प्रवासी श्रमिक।

1. Introduction

Nagpur, a developing hub in central India, hosts a substantial population of Industrial workers employed across sectors, such as manufacturing, logistics, and trade. Housing is a fundamental requirement for these workers, many of whom are migrants seeking affordable, accessible accommodations near their workplaces.

The Nagpur Metropolitan region's industrial boom has put further strain on the area's housing supply, as these Industrial areas attract many migrants. There are currently around 1,58,000 Industrial workers in the Nagpur region alone. Nevertheless, not much is being done to give these Industrial workers a place to live. Negligence on the part of both the government and the industrialists towards Industrial workers has ultimately resulted in a shortage of adequate housing options for these economically weak workers. While Industrialisation is integral to a region's substantial and sustained economic development, Industrial progress depends largely on the health and efficiency of its workers. It is quite evident that housing and health are interconnected, and that both influence the efficiency of their occupants.

This article examines how the interdependence of housing and Industrialization are specifically about Industrial workers in the Nagpur Metropolitan region. For this purpose, case

studies were identified to cover all available housing typologies for Industrial workers, and data were collected mainly through a primary survey. This data was then analysed to understand the issues and potential of existing and future settlements. It revealed the tremendous need for intervention by the government and private bodies for improving the situation of Industrial workers' accommodation in the region. It was observed that the issues were not limited to the non-availability of housing units for Industrial workers, but also to shortcomings in the provision of basic amenities and facilities, as well as a lack of health and education infrastructure, all of which need to be addressed.

Rental housing aligns with the needs of mobile workers who prefer flexibility over permanent ownership. Access to affordable housing enhances productivity by reducing commuting stress. Proper housing contributes to better health and safety for workers, improving overall quality of life. Since these industries employ a large, steadily increasing workforce, the situation is only going to worsen unless there is intervention.

The paper examines governmental and private interventions, laws, regulations, and development plan provisions for housing industrial workers, with a particular focus on industrial growth and housing development in the Nagpur Region. Also examines the housing options and circumstances that are now accessible to industrial workers in the Nagpur Region.

2. City Profile

The Nagpur Metropolitan Region (NMR) is a strategically located urban–industrial region in central India, serving as a major logistics, manufacturing, and administrative hub with strong rail, road, and air connectivity (Figure 1). Anchored by Nagpur, the region plays a critical role in regional economic integration, industrial growth, and urban expansion in Maharashtra. As in many other cities, Nagpur's industrial development is divided into planned and unplanned areas, each with unique characteristics and impacts on the environment and infrastructure.

The NMR Region has eight industrial estates in all. Of these, seven estates—Hingna, Kalameshwar, Umred, Saoner, Butibori, Parseoni, and IT Parsodi—are under the purview of MIDC (Maharashtra Industrial Development Corporation). MIHAN, a division of MADC (Maharashtra Airport Development Company), is the last one. As of 2025, the NMR region's entire industrial area comprises about 6,648 hectares. Eighty-seven percent of the entire region is planned, whereas thirteen percent is dispersed and unplanned.

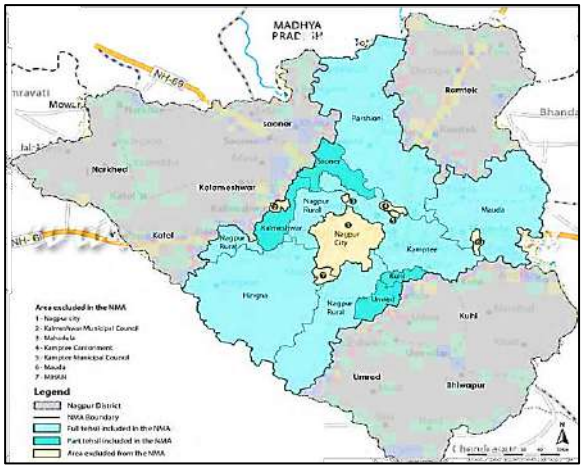


Figure 1. Nagpur Metropolitan Region Map.

3. Need and Relevance

A sizable community of industrial workers across a range of industries, including manufacturing, logistics, and trade, calls Nagpur home, a developing industrial and logistical hub in central India. For these workers, many of whom are migrants looking for accessible, reasonably priced housing close to their places of employment, housing is a basic necessity. One of the main issues with the current housing supply in Nagpur is the growing demand for worker housing. The way the government responds to worker needs and socioeconomic limitations is unconcerned.

4. Housing situation in Nagpur Metropolitan Region, 2025

The distribution of population across different residential typologies, organic, planned, and unplanned, highlighting their respective subsystems and population shares in the Nagpur Metropolitan Region was studied (Table 1).

Table 1. Population based on Housing subsystem

Typology	Subsystem	Population	%
Organic	Old City	2,98,546	9.30
Organic	Urban Village	2,18,946	6.82
Planned	Public Housing	67,565	2.10
Planned	Private Housing	5,49,823	17.12
Planned	Co-operative Housing	3,98,643	12.41
Planned	Employer Housing	84,653	2.64
Unplanned	Slum	11,06,594	34.46
Unplanned	Unauthorized Layouts	4,86,513	15.15
Total		**32,11,283**	**100.00**

It was observed that unplanned settlements, particularly, slums and unauthorized layouts, accounted for a significant proportion of the total urban population.

4.1 Informal Housing Dominance

Survey findings reveal that more than 65% of industrial workers reside in unauthorized or informal settlements, including slums and urban villages. These housing typologies are characterized by inadequate access to basic infrastructure, including sanitation, safe drinking water, and reliable connectivity.

4.2 Rental Housing Stress

Monthly rental costs range from ₹7,000 to ₹22,000, placing a significant financial burden on low-income industrial workers earning less than ₹10,000 per month, rendering formal rental housing largely unaffordable.

4.3 Infrastructure Deficits

In Nagpur, a substantial proportion of industrial workers live in substandard housing conditions, often in makeshift structures or temporary hutments that lack durability, safety, and essential services.

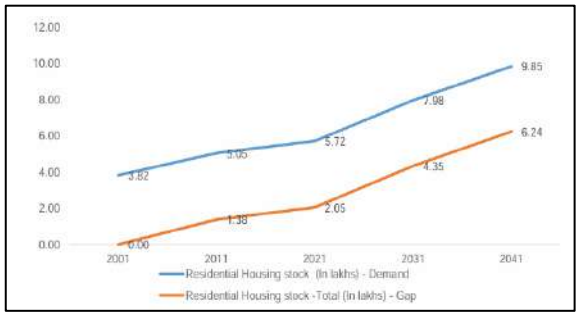


Figure 2. Housing Demand and Gap (Sarda 2025).

According to the projected housing demand trends illustrated in Figures 2 and 3, the city is expected to require nearly 10 lakh residential units by 2041, reflecting a steady increase in household formation over the next four decades. However, the projected growth in the total housing stock does not keep pace with this demand. As per the assessment, the city will need to add approximately 6 lakh additional dwellings to bridge this shortfall. Taking into account the existing housing stock and the proportion of aging and structurally deteriorating units, the housing demand–supply gap is estimated at 6.24 lakh units by 2041. This widening gap underscores the cumulative impact of population growth, limited new housing supply, and housing obsolescence over time. The study, therefore, examines the city's underlying assumptions and long-term housing requirements over a 30-year horizon to inform future planning and policy interventions (NIT 2015).

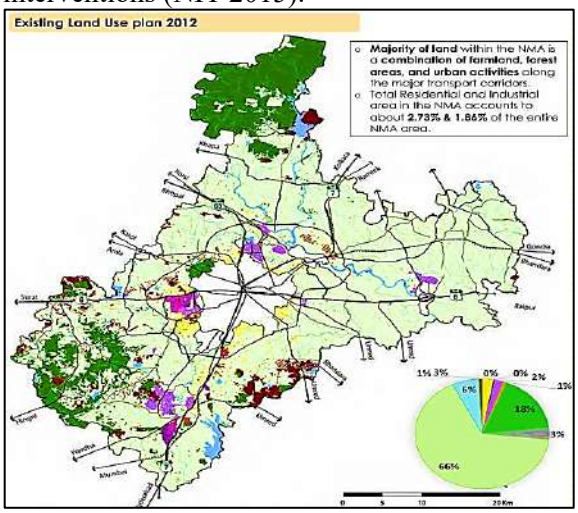


Figure 3. Existing Land Use Plan 2012 (Sarda 2025).

4.4 Issues

There is no formal provision for worker housing within MIDC layout-level guidelines, resulting in overcrowding driven by low incomes and the unaffordability of formal housing. The absence of basic amenities such as water supply, sanitation, roads, healthcare, and educational facilities further exacerbates living conditions, forcing workers to reside in squatter settlements and unauthorized urban areas. This situation is compounded by an uncoordinated institutional response and a persistent policy vacuum, resulting in delays in completing of essential infrastructure projects, including road development, sewerage systems, and electricity provision.

5. State Policy for the Development of Industrial Estates

MIDC was founded in 1962 as the Government of Maharashtra's principal industrial infrastructure development agency under the M.I.D.C. Act 1961 to establish industrial zones for planned, methodical industrial growth.

Spread over approximately 66,274 hectares, the Maharashtra Industrial Development Corporation (MIDC) has developed 289 industrial areas across Maharashtra. With an industrial land bank exceeding 2.5 lakh acres and proposals to add nearly 40,000 hectares over the next five years, MIDC constitutes one of the largest industrial land reserves in the country. A review of the MIDC Development Control Regulations (DCRs) from 1999 to the Comprehensive Development Control and Promotion Regulations (CDCPR) 2023 indicates an evolving yet limited emphasis on residential

provisions in industrial areas. Before 1999, there were no specifically notified Development Control Regulations for MIDC areas in Maharashtra (Figure 4).

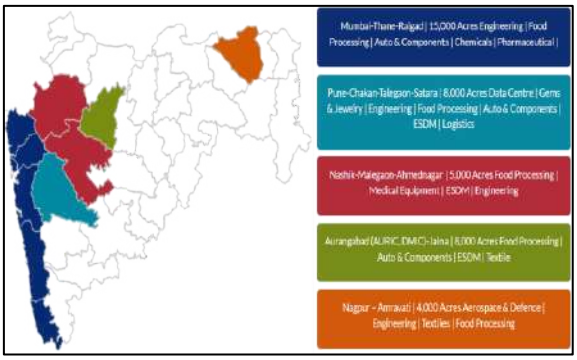


Figure 4. MIDC in the State of Maharashtra (Sarda 2025).

The guidelines for MIDC areas were based on state and local policy from 1962 to 1999. MIDC realized in the 1990s that its industrial regions needed to be developed in an organized manner. The Development Control Regulations (DCRs) for areas notified by MIDC, where MIDC served as the Special Planning Authority, were approved by the Maharashtra government on January 7, 1999. These rules offered thorough instructions for construction and development projects in MIDC areas. The establishment of Integrated Industrial Areas (IIAs) became more prevalent in the early 2000s. The state government approved new Development Control Regulations specifically designed for these IIAs on August 31, 2009.

MIDC introduced the Comprehensive Development Control and Promotion Regulations (CDCPR-2023) in July 2023. This extensive document, which reflects modern urban planning ideas, updated and consolidated earlier standards. The most recent standards do not mandate worker housing, but they allow up to 10% of space for necessary staff quarters. Although PMAY and ARHC offer inexpensive housing frameworks, NMR's Development Plan makes no mention of worker housing at the layout level.

6. Industrial Development in NMR

Nagpur is the third-largest city in Maharashtra, with an extensive industrial base spread across 6,648 hectares in 8 estates. These estates collectively employ over 1.58 lakh workers. Despite planned industrial growth, housing development has lagged. As in many other cities, Nagpur's industrial development is divided into planned and unplanned areas, each with unique characteristics and effects on the environment and infrastructure (Table 2). About 5,784 hectares make up the entire planned industrial area in the NMR region (2025). The eight industrial estates that make up the Nagpur Metropolitan Region's economic core are dominated by the Butibori Industrial Estate. The entire territory, developed on land authorized for MIDCs, is occupied by more than 2,300 operating industrial units. One of the NMR's industrial parks, MIHAN, is also a state government initiative that fosters economic development in the Nagpur region. A SEZ and an international airport are also part of the MIHAN project. The project, covering 4354 hectares, will be developed by Maharashtra Airport Development Company Ltd. (MADC). MADC has the following proposal under the MIHAN project: a special economic zone (SEZ) featuring residential areas and an international airport that will serve as a cargo hub.

Table 2. Planned and Unplanned Industrial areas

PLANNED	UNPLANNED
Planned Industrial areas are developed with proper infrastructure, zoning, regulations, and environmental considerations. MIDC typically develops these	Unplanned Industrial areas develop without formal approval or infrastructure planning. These often emerge due to the growth of small-scale industries or workshops in urban or peri-urban areas.
Type – Large and Medium-scale	Type – Small-scale, often Scattered
Area – 5,784 Ha (87%)	Area – 864 Ha (13%)
Examples– Hingna, Butibori, Kalameshwar, etc.	Examples– Lakadganj, Wadi, Kamptee Road, etc.

Eight industrial estates, Hingna MIDC, Kalameshwar MIDC, Umred MIDC, Saoner MIDC, Butibori MIDC, Parseoni MIDC, IT Parsodi MIDC, and MIHAN MIDC, are located inside the Nagpur Metropolitan Region, as indicated on the map below (Figure 5).

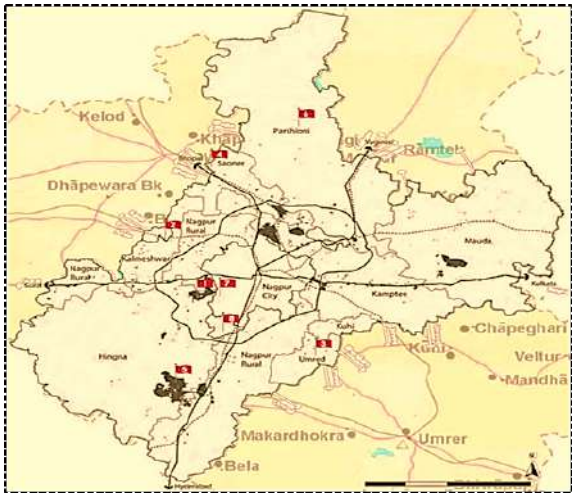


Figure 5. Industrial Estates in NMR

Table 3. Details of Industrial areas

S. No.	Industrial Estate	Year	Area (Ha)		Worker's Population (Assumed)		Type of Industrial Estate
1.	Hingna	1962	746	12.90%	30,893	19.54%	Major
2.	Kalameshwar	1979	111	1.91%	4,634	2.93%	Growth Centre
3.	Umred	1990's	326	5.63%	13,902	8.78%	Growth Centre
4.	Saoner	1990's	74	1.28%	3,089	1.95%	Growth Centre
5.	Butibori	1994	2,421	41.86%	1,00,404	63.43%	Major
6.	Parseoni	2000's	12	0.21%	834	0.53%	Minor
7.	IT Parsodi	2001	12	0.21%	712	0.45%	Minor
8.	MIHAN (MADC)	2002	2,082.	36.00%	3,832	2.42%	Growth Centre

Source: (Sarda 2025)

According to Table 3, Butibori MIDC is the largest MIDC area, Butibori has the largest worker population, and the IT Parsodi MIDC area has the highest residential land rates. The areas with the fewest workers and land area are Parseoni and IT Parsodi. With a total industrial area of 5,784 hectares, the NMR region is home to 1,58,300 industrial workers.

7. Institutional and Policy Perspectives on Industrial Worker Housing

In the state of Maharashtra, central programs such as the Subsidized Industrial Workers Housing 1960 and the Revised Integrated Housing Scheme 2016 are not effectively implemented. Affordable housing is the goal of programs like the Pradhan Mantri Awas Yojana (PMAY); however, implementation is sluggish.

Although housing for industrial workers is included in the Maharashtra State New Housing Policy and Action Plan, 2015, the Maharashtra State Industrial Cluster Development Scheme (MSI- CDP) for 22–23, and the updated MIDC laws, it is not implemented because it is not required. There is no housing provision in the Nagpur Metropolitan Region - City Development Plan. In contrast, the Delhi Master Plan stipulates that 20% of the total land area within the pattern must be set aside for residential use.

Every industrial plot's housing implementation should comply with the updated standards, which ought to be made mandatory. The government must produce model projects to encourage private developers to build rental housing because mass rental housing is still a relatively new idea.

The government can offer tax breaks to businesses that provide employee housing. One option under PPP models is to develop dormitory-style lodgings for employees.

7.1 Concept of Safe Accommodation (NITI Aayog)

SAFE Accommodations consists of long-term, dorm-style housing specifically designed for industrial workers, located close to their workplaces. This lodging, which is rented directly to employees or their employers, includes with basic services, such as food, laundry, and dispensary facilities, as well as utilities like electricity, water, and sanitary facilities.

Family housing is not considered SAFE accommodation. Although there is a significant need for such housing for supervisory staff in factories across multiple industries, this initiative focuses on the most pressing needs of entry-level workers, where there are the greatest gaps in market-based solutions. SAFE accommodation units cannot be sold to employers or employees, nor can ownership be transferred.



Figure 6. Safe Accommodation (Sarda 2025).



Figure 7. Worker's accommodation (Sarda 2025)

The SAFE accommodation (Figure 6) initiative seeks to improve labour mobility and productivity by providing affordable worker housing, supported by tailored regulations. It also aims to create a market-driven framework that enables private developers to deliver such accommodation with viable returns (Figure 7). By formalising worker housing within the

planning system, the initiative reduces informality, overcrowding, and locational mismatch between jobs and housing. Additionally, it strengthens urban economic efficiency by ensuring a stable, proximate workforce for key employment clusters while easing pressure on existing residential neighbourhoods.

8. Case Study Analysis of Major Industrial Estates in Nagpur Metropolitan Region

This case study examines selected industrial estates in the Nagpur Metropolitan Region to understand their spatial growth, scale of development, and associated population dynamics. The analysis focuses on how the year of establishment and land area of each estate influence worker concentration and housing demand (Figure 8 and Table 4).

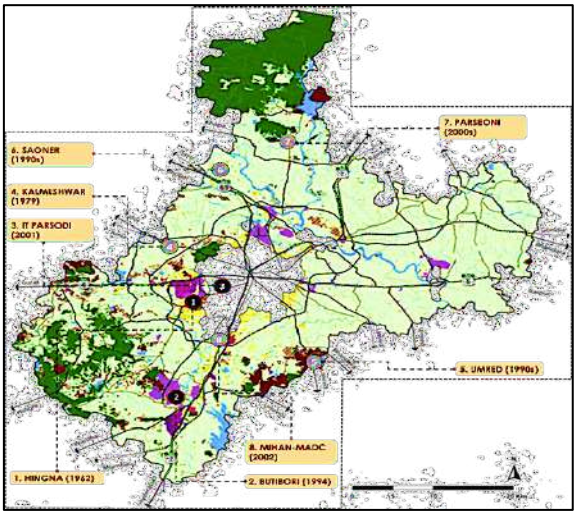


Figure 8. Case study location

Table 4. Area and Population-2025 (Census)

Industrial estate	Year	Area (ha)	Population
HINGNA	1962	746.00	30,893
BUTIBORI	1994	2428.00	1,00,404
IT PARSODI	2001	12.00	712

Table 5. Residential and Industrial Land Use

Industrial estate	Residential area		Industrial area	
	Area (ha)	%	Area (ha)	%
HINGNA	2.37	0.31%	532.10	71.35%
BUTIBORI	95.90	3.90%	1563.6	64.40%
IT PARSODI	0.00	0.00%	9.35	80.20%

8.1 Hingna MIDC

Hingna MIDC includes a formal MHADA housing colony; however, a significant number of workers reside in nearby unauthorized settlements such as Rajiv Nagar. These areas are characterized by overcrowding, inadequate sanitation, and a lack of tenure security.

8.1 Butibori MIDC

In Butibori MIDC, the CIDCO colony remains the only formal residential settlement for workers. Surrounding settlements such as Bori and Takalghat lack basic infrastructure and secure tenure, compelling workers to live in substandard conditions.

8.2 IT Parsodi MIDC

Housing in IT Parsodi MIDC is predominantly informal, with most workers residing in slum settlements such as Subhash Nagar, which lack planned infrastructure and secure tenure.

However, in all selected industrial estates, there is a stark imbalance between residential and industrial land uses (Table 5). Residential land accounts for a negligible share of 0 to 3.9%, while industrial use dominates, exceeding 64% in all cases, underscoring the limited provision of formal worker housing in industrial areas.

POLICY LEVEL ISSUES

Only 2.37 hectares (0.31%) of the property is used for residential uses, while MHADA primarily provides housing. Industrial workers were given preference, but they are not required to buy it; it can be sold to anyone inside or outside the industrial estate. Workers sold their homes and relocated to neighboring slums and unauthorized colonies during the five-year lock-in period.

LAYOUT LEVEL ISSUES

Maharashtra only addresses with plot-level regularization; there is no policy for layout-level regularisation, and the procedures are slow and irregular. Insufficient social infrastructure, residents experience inconvenience when there are no markets, healthcare facilities, community areas, or open spaces. Unplanned and hazardous development: Traffic and safety risks are caused by narrow roadways, densely packed housing, and irregular plots. Absence of a systematic garbage collection system. Unregulated garbage disposal often leads to pollution and health risks. Encroachment on public land: They are at risk of being evicted because they are situated on government property, railroad tracks, and road reserves.

DWELLING UNIT LEVEL ISSUES

Poor building quality: Structural instability results from the use of inferior materials.

Development Control Regulation (DCR) violation. No illegal balcony projections or side or rear setbacks. Lack of a standard design, the unit sizes are not consistent. Lack of ventilation and natural light because the openings face only the street.

Dilapidation of Houses: Need for Maintenance for Kaccha and Old Houses. The main problems are seepage and dampness. Plots are divided among families. The lack of sufficient parking space is a problem because the roadways are narrow and there are no parking setbacks within the plot, leaving no parking spots available for residents. The building has dark areas and poor space optimization.

Table 6. Existing Industrial workers' housing options (Primary Survey).

Industrial Estate	Worker's Residential Area (Within MIDC)		Worker's Residential Area (Outside MIDC)	
	FORMAL	INFORMAL	LOCATION	TYPOLOGY OF HOUSING
HINGNA (1962)	Employer's Housing & Mhada Colony	Squatters & Gaothan	Wadi	Slums
			Rajiv Nagar	Authorised Colony
			Pardhi Nagar	
BUTIBORI (1994)	CIDCO, Indo rama, Lokmat & KEC Colony	Squatters & Gaothan	Takalghat	Urban Villages
			Bori	Authorised Colony
IT PARSODI (2001)	None	Squatters	Subhash Nagar	Notified Slum

SOCIO-ECONOMIC CHARACTERISTICS

The majority of the workers are migrant laborers, and mostly aged 18–30. About 30% of these workers are literate. Their present residence (informal settlements) is approximately 0–5 km away. About 30% are casual laborers. (roughly) 85% of the employees use walking or bicycling as their primary mode of transportation. mostly the Rs. 5000–15000 family income range (Table 6).

HOUSING CHARACTERISTICS

According to the primary poll, these workers require rental housing. Kutcha dwellings and ground-level buildings make up the majority of the structures. The commercial, PSP, and recreational areas do not adhere to the standards and conventions. They are disorganized and scattered.

INFRASTRUCTURE CHARACTERISTICS

There is no municipal water supply because the settlements were created by industrial development and are located outside of the city center; instead, MJP (Maharashtra Jeevan Pradhikaran) and gram panchayats provide the water. Villages and squatter settlements lack maintained sewer pipes. Open defecation is a concern in some places. Problems with solid garbage being dumped and burned in most places, promptly. Illegal electrical connections are made by squatters and in villages. Internal roads are not maintained. Most of the time, no thought is given to parking, and cars are left on the streets. Due to the lack of planned housing for workers, social infrastructure—such as health, education, and convenience stores—is a significant issue for workers, who must travel up to three to five kilometres to access these services.

DWELLING UNIT CHARACTERISTICS

The majority of the rooms are overcrowded beyond their capacity. In the dwelling unit, there is no privacy. The apartments lack functional bathrooms and toilets. In the slums, the living units lack a distinct kitchen area. The size deviates from the usual even when it is present.

Since growth has not occurred in accordance with standards, light and ventilation in homes are significant issues in villages and squatter settlements. Tin sheets, bamboo, mud, tarpaulin, bricks, asbestos sheets, and other temporary or semi-permanent materials are frequently used to build houses. Large families are frequently housed in small, claustrophobic one- or two-room apartments. Health risks result from high population density and limited space per person.

A cross-case comparison reveals that formal housing is scarce, informal housing is widespread, and infrastructure provision is inconsistent. Worker satisfaction correlates with proximity to work and availability of amenities.

ISSUES AND POTENTIAL

At the central level, schemes like PMAY and ARHC are poorly implemented. There is no dedicated rental-housing policy or tax incentives for worker housing, leading to regulatory delays and low uptake. At the state level, MIDC norms lack mandatory housing provisions at the layout-level. Even where housing is allowed within industrial plots, it is limited to 10% of the land area and is not enforced. Policies like Maharashtra's Housing Action Plan (2015) mention industrial worker housing but do not mandate it. At the city level, the absence of dedicated housing in development plans, poor coordination among agencies, and a lack of worker assessments have led to urban sprawl and informal settlements near industrial areas.

At the Cluster and settlement levels, areas have evolved without proper planning and lack essential infrastructure, such as open spaces,

commercial zones, and public amenities. Most dwellings are low-rise, densely packed, and rented, as workers typically own homes in their native villages. Infrastructure in these settlements— like roads, sewage, waste management, and parking—is inadequate and poorly maintained. Social infrastructure (health, education) is also lacking. The root cause of these issues is that these settlements were not originally planned to accommodate the influx of migrant industrial workers.

Despite these challenges, the study identifies potential solutions:

- Mandating housing components within MIDC layouts through amendments in the 2023 CDCPR.
- Promoting public-private partnerships (PPP) for building dormitories and rental blocks.
- Developing integrated village and settlement plans to accommodate workers.
- Using government land and converting vacant housing stock into affordable rental options.
- Introducing model rental housing projects and flexible, safe, and well-ventilated housing designs for workers.
- All design standards must be considered when creating new housing units for industrial personnel.
- To preserve quality of life, liveable room sizes must be included, and overcrowding must be minimized.
- To offer options for design flexibility, space use, and space availability rather than a standard unit design. When planning and developing housing for industrial workers, it is important to consider their living unit requirements.
- The two main factors that must be given adequate consideration when improving informal settlements or building new homes for industrial workers are safety and security.

9. Recommendations

9.1 Housing Models for Industrial workers in Existing Industrial areas

MODEL 01 – DORMITORIES

Identify vacant plots owned by NMRDA, preferably within a 5 km radius of the existing Industrial areas and develop Dormitories for Industrial workers on a PPP model (80% of the plot area for Industrial workers' housing and 20% for a commercial component).

- Construction – By NMRDA in partnership with private developers.
- Incentives – Private developers will be allowed to develop 20% area of the plot as commercial.
- Allotment/rental basis – After construction, the project will be handed over to NMRDA, which will, in turn, put it on rent for Industrial workers working in the area. NMRDA can identify these workers through the registry.
- Operation & Maintenance – The cost of O&M is to be derived from the rent taken from the workers.
- Modification in – PMAY 2.0 (ARHCs) and NMRDA Development plan.

MODEL 02 – URBAN VILLAGES

Integrating villages within the 5 km. radius of Industrial areas with the planned development to prevent haphazard growth with an influx of migrant population. This can be achieved through the Village Redevelopment Plan.

- Construction – By NMRDA.
- Incentives – Redeveloped layouts with improved infrastructure.
- Allotment/rental basis – The landowners can put their properties on rent for industrial workers.
- Operation & Maintenance – The landowner should be mandated to provide O&M for their properties.
- Modification in – NMRDA Development plan.

MODEL 03 – SLUMS AND SQUATTER SETTLEMENTS

Redevelopment of existing squatter settlements in and around Industrial areas on vacant plots available within 5 km of industrial area. This can be done in PPP (80% for relocated housing and 20% for commercial).

- Construction – By NMRDA in partnership with private developers.
- Incentives – Private developers will be allowed to develop 20% area of the plot as commercial.
- Allotment/rental basis – NMRDA can develop a rent-to-own model to allot the newly developed flats to the Industrial workers squatting in and around Industrial areas.
- Operation & Maintenance – An RWA can be formed by the residents who take up O&M with guidance from the NMRDA.
- As per PMAY 2015 (1st vertical – In-situ slum rehabilitation ISSR).

9.2 Housing Models for Industrial workers in Future Industrial areas

MODEL 04 – INDUSTRIAL AREAS (LAYOUT LEVEL)

In every new Industrial area, a minimum 20% of the area should be reserved for residential use. Of this 20%, certain percentages should be reserved exclusively for the construction workers' housing and the remaining percentages should be given to developers for profit.

- Construction – MIDC (Maharashtra Industrial Development Corporation)
- Incentives – Augmentation of services
- Allotment/rental basis – After construction, the project will be handed over to NMRDA, which will, in turn, put it on rent only for industrial workers working in that area.
- Operation & Maintenance – The cost of O&M is to be derived from the rent taken from the workers.
- Modification in – CDCPR-2023 guidelines for MIDC areas.

MODEL 05 – INDUSTRIAL PLOTS (PLOT LEVEL)

An industrialist with more than 2.023 ha (5 acres) of land must provide accommodation for housing at least one-third (33%) of their workers within their industrial plot. For this purpose, a minimum 5% area within the industrial plot premises should be provided for the construction of dormitories.

- Construction – Industrialist/ Industrial plot owner
- Incentives – Adequate fiscal incentives should be provided to Industrialists who build housing apart from the mandatory provisions.
- Allotment/rental basis – Industrialists/ plot owners can rent these to their Employees.
- Operation & Maintenance – Industrialist/ Industrial plot owner
- Modification in – CDCPR-2023 guidelines for MIDC areas.

10. Conclusion

The study of industrial worker housing in the Nagpur Metropolitan Region highlights a persistent mismatch between rapid industrial growth and the provision of adequate, affordable housing for the workforce. Despite the presence of multiple industrial estates employing over 1.5 lakh workers, integrated planning for worker accommodation remains largely absent at both policy and layout levels. Case studies of Hingna, Butibori, and IT Parsodi MIDC estates reveal a heavy reliance on informal housing, including slums and unauthorized settlements, characterized by poor infrastructure and substandard living conditions. Although schemes such as PMAY and ARHC offer policy frameworks for affordable and rental housing, their on-ground implementation has been limited. At the same time, MIDC regulations continue to treat housing as optional rather than integral.

The study identifies systemic challenges, including policy inertia, weak institutional coordination, and regulatory gaps, that result in infrastructure stress, unplanned settlements, and compromised living conditions at the cluster and dwelling-unit levels. At the same time, significant opportunities for reform exist through strengthening MIDC regulations, promoting rental and worker housing models, and leveraging public–private partnerships to transition from informal to formal housing without displacement. The findings underscore that worker housing is not a peripheral welfare issue but essential urban infrastructure critical to industrial productivity and social equity. Addressing this gap through an integrated, multi-scalar approach involving government, industry, planners, and communities is essential for achieving inclusive and sustainable industrial growth in Nagpur.

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Pilgrims' Accommodation Options in Gaya, Bihar:

Issues, Potentials, and Recommendations for Inclusive Religious Tourism Infrastructure

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Abstract: Pilgrimage tourism in India is witnessing a resurgence, with cities like Gaya in Bihar emerging as key religious destinations for both domestic and international visitors. However, the accommodation infrastructure in Gaya, particularly for low-income pilgrims, has not evolved at the same pace. This article evaluates the current scenario of pilgrim housing in Gaya and Bodh Gaya, maps the diversity of options available, and analyses spatial, economic, and policy challenges. Drawing on field data, government policies, academic research, and development plans, the study identifies critical gaps in supply, affordability, cultural integration, and service quality. The article proposes a multi-scalar, multi-stakeholder approach to address these challenges, ranging from adaptive reuse and heritage-sensitive development to fiscal incentives, zoning reforms, and community participation.

Keywords: Pilgrim Housing, Religious Tourism, Bodh Gaya, Homestay, Affordable Accommodation

सार: भारत में तीर्थ पर्यटन में एक पुनरुत्थान देखा जा रहा है, और बिहार के गया जैसे शहर घरेलू एवं अंतर्राष्ट्रीय दोनों तरह के तीर्थयात्रियों के लिए प्रमुख धार्मिक गंतव्य के रूप में उभर रहे हैं। तथापि, गया में—विशेषकर निम्न-आय वर्ग के तीर्थयात्रियों के लिए—आवासीय बुनियादी ढाँचा समान गति से विकसित नहीं हुआ है। यह लेख गया और बोधगया में तीर्थयात्री आवास की वर्तमान स्थिति का मूल्यांकन करता है, उपलब्ध विकल्पों की विविधता को मानचित्रित करता है, और स्थानिक, आर्थिक तथा नीति-संबंधी चुनौतियों का विश्लेषण करता है। क्षेत्रीय सर्वेक्षण डेटा, सरकारी नीतियों, शैक्षणिक अनुसंधान और विकास योजनाओं पर आधारित इस अध्ययन में आपूर्ति, सामर्थ्य, सांस्कृतिक एकीकरण और सेवा गुणवत्ता में गंभीर कमियों की पहचान की गई है। लेख इन चुनौतियों को संबोधित करने के लिए एक बहु-स्तरीय, बहु-हितधारक दृष्टिकोण प्रस्तावित करता है — जिसमें अनुकूली पुनः उपयोग और धरोहर-संवेदनशील विकास से लेकर वित्तीय प्रोत्साहन, भू-उपयोग नियमों में सुधार, और सामुदायिक भागीदारी तक विभिन्न उपाय शामिल हैं।

मुख्य शब्द: तीर्थयात्री आवास, धार्मिक पर्यटन, बोधगया, होमस्टे, किफायती आवास

1. Introduction

Pilgrimage is one of the oldest and most sustained forms of travel in human history. In India, it is deeply interwoven with the everyday religiosity of people and continues to be a significant driver of domestic tourism. Cities like Gaya, which host sites of pan-Indian and international religious importance, are witnessing a rise in annual footfall due to infrastructural investments and growing spiritual interest.

However, this growth in footfall has not been accompanied by an equitable increase in accommodation infrastructure, particularly for low-income, long-stay, or culturally specific pilgrims. Most planning and tourism development frameworks have either over-commercialized accommodation or failed to integrate traditional housing typologies such as dharmshalas, ashrams, and community-managed lodges.

This article takes Gaya as a case study to interrogate the contemporary realities of pilgrim accommodation and proposes interventions rooted in planning, policy, and design.

2. Contextual Framework: The Sacred Urbanism of Gaya and Bodh Gaya

Gaya is one of the most important Hindu and Buddhist pilgrimage destinations in India. The Vishnupad Temple, associated with the Pitru Paksha rituals, draws lakhs of pilgrims annually, while Bodh Gaya, located just 10 km away, hosts the Mahabodhi Temple, a UNESCO World Heritage site and a cornerstone of the Buddhist circuit. The urban fabric of Gaya is layered with sacred geographies, community-controlled spaces (notably by the Gayawal Brahmins), congested cores, and seasonal spatial demands.

Bodh Gaya, on the other hand, has a relatively more planned and internationally influenced layout, with monastic accommodations and meditation centers catering to Buddhist pilgrims from Sri Lanka, Thailand, Myanmar, and beyond.

The diversity of pilgrims varying in income, duration of stay, cultural background, and ritual needs necessitates a nuanced and pluralistic accommodation strategy, which is currently lacking.

3. The Spatial and Cultural Landscape of Gaya

Gaya district, situated in southern Bihar, holds deep spiritual, historical, and cultural importance for Hinduism, Buddhism, and Jainism. It lies along the Phalgu River, framed by low hills and forests, giving it both strategic and symbolic prominence in India's sacred geography. The district functions as a regional hub for pilgrimage as well as commerce, linking surrounding rural areas with national and international religious tourism (Figure 1).

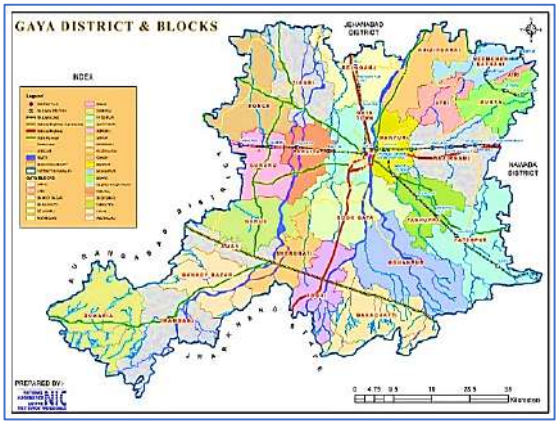


Figure 1. Map of Gaya District

3.1 Geography & Connectivity:

Positioned around 24.8° N latitude and 85.0° E longitude, Gaya rests at an elevation of approximately 111 meters above sea level. The terrain alternates between fertile plains and rocky uplands, punctuated by hills such as Brahmayoni, Ramshila, and Pretshila, each associated with legends and rituals.

The city's accessibility has strengthened its role as a pilgrimage center:

- Airways: Gaya International Airport, Bihar's only international airport, offers seasonal direct flights to Buddhist-majority countries (Thailand, Myanmar, Bhutan, and Sri Lanka) and domestic connections to Delhi, Kolkata, and Varanasi.
- Railways: Gaya Junction is a major stop on the Howrah–Gaya–Delhi Grand Chord Line, linking the town to all major Indian metros. Special trains operate during Pitrapaksha and other pilgrim events.
- Roadways: National Highways NH-22 and NH-83 connect Gaya to Patna, Nalanda, Rajgir, and Varanasi, forming part of the Buddhist and Hindu pilgrimage circuits.

3.2 History

The formation of Gaya's historic core (Andar Gaya) dates to 1548, when a Mughal-era land grant to the Panda community facilitated the development of a walled settlement. This political arrangement created a specialized religious economy centered around ancestral rituals and hospitality. Over time, the city's identity became inseparable from its ritual functions and priestly institutions.

3.3 Demographics and Economy

As per Census 2011, Gaya Town recorded an urban population of about 474,000, with projections for 2025 estimating over 635,000 residents. Growth has been driven by natural increase, seasonal in-migration during pilgrimage events, and expansion of municipal boundaries to absorb peri-urban settlements.

The housing deficit is significant: in 2025, approximately 97,796 households are estimated against only 79,412 dwelling units, creating a shortfall of nearly 26,800 units. This shortage is compounded by the seasonal surge of visiting pilgrims.

3.4 Geographic Setting

Gaya, located in eastern Bihar, is a town of major religious and historical significance, situated about 100 km south of Patna in the Magadh region, which holds deep associations with Hinduism, Buddhism, and Jainism (Figure 2).

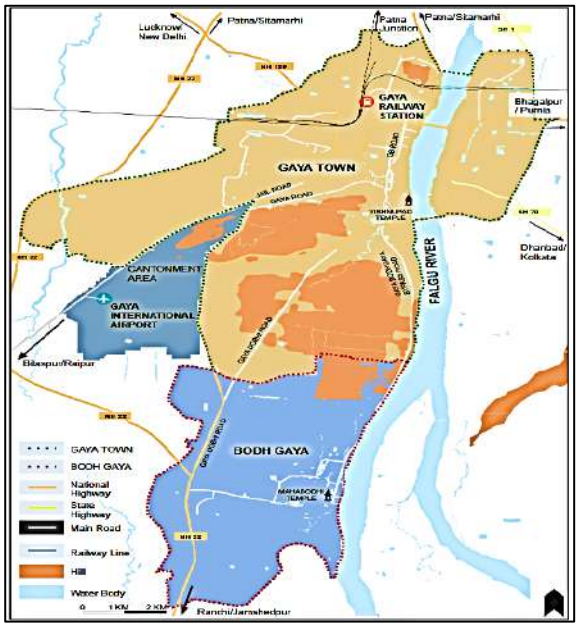


Figure 2. Map highlighting Gaya Town and Bodh Gaya; Source: (Varulica 2025)

3.5 City Profile: Gaya Town

Geographically, the town lies at 24.8° N latitude and 85.0° E longitude on the western bank of the Phalgu River. The surrounding landscape is dotted with hills such as Brahmayoni, Pretshila, and Ramshila, each tied to sacred narratives and ritual practices. The topography combines fertile alluvial plains with rocky uplands, and the average elevation of around 111 meters lends the town a modest variation in terrain.

3.6 Connectivity and Accessibility

Gaya's well-developed multimodal transport system makes it highly accessible to both domestic and international pilgrims.

- Airways: Gaya International Airport (GAY), the only international airport in Bihar, operates seasonal flights to countries including Thailand, Myanmar, Bhutan, and Sri Lanka, along with regular domestic services to Delhi, Kolkata, and Varanasi.
- Railways: Gaya Junction, one of Bihar's busiest railway stations, lies on the Howrah–Gaya–Delhi Grand Chord Line, providing direct links to major Indian cities. Additional trains are scheduled during pilgrimage seasons to handle increased demand.
- Roadways: The city is integrated into the national network through NH-22 and NH-83, ensuring connectivity to Patna, Rajgir, Nalanda, and Varanasi, which together form a wider religious circuit.

3.7 Population Growth Trends

According to the 2011 Census, Gaya recorded an urban population of 474,093 (Figure 3). Between 2001 and 2011, the city experienced a population growth rate exceeding 60%, significantly higher than the national average. This expansion can be attributed to natural growth, seasonal migration linked to pilgrimage activities, employment opportunities in tourism and trade, and the annexation of peri-urban settlements into municipal limits. The overall population density is approximately 78 persons per hectare.

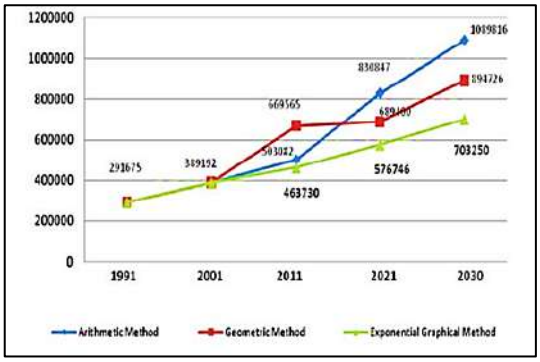


Figure 3. Population Projection for Gaya Town

3.8 Households and Housing Stock

By 2025, the number of households is projected to reach 97,796, compared with a housing stock of 79,412 units. This mismatch (Table 1) results in an estimated shortage of about 26,800 units, underscoring a serious deficit in residential supply within the town.

Table 1. Housing Scenario of Gaya Town

Parameters	Value
Urban Population	635,678
Total Households	97,796
Existing Housing Stock	79,412
Housing Shortage	26,841 units

Source: (Varulica 2025)

4. Andar Gaya – The Walled Medieval Settlement

Andar Gaya, the walled medieval settlement, is organized into 14 traditional mohallas (neighbourhoods). Each mohalla historically contained baithaks (ritual and cultural spaces) and homes of the Gayawal Panda families. The settlement's compact form reflects its role as both ritual hub and residential enclave (Figure 4).

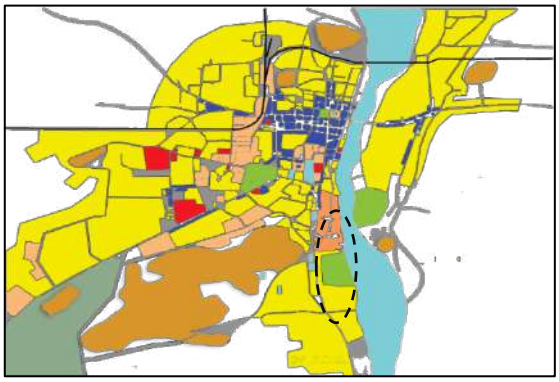


Figure 4. Map highlighting Andar, Gaya

Prominent ghats such as Brahmani, Gayatri, Deo, and Kantahi continue to anchor ritual practices. Today, Andar Gaya remains the cultural heart of pilgrimage, with around 60% of Hindu pilgrims choosing to stay in this core during their visit.

4.1 Spatial Organization

The map reveals a densely organized settlement characterized by clear spatial divisions into 14 distinct mohallas (neighbourhoods) of varying sizes (Figure 5). It also identifies several prominent ghats within the areas.

The ghats include Brahmani Ghat, Kantahi Ghat, Gayatri Ghat, Badrinath Ghat, Chaudhary Ghat, Sangath Ghat, Deo Ghat, and Shamshan Ghat, highlighting the area's functional and cultural significance as illustrated in Figure 5.

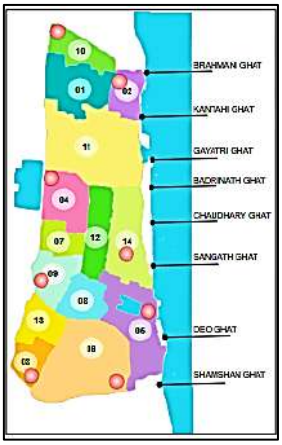


Figure 5. Map of Andar Gaya highlighting 14 Mohallas with their Baithaks and Ghats along the Falgu River

4.2 Demographic and Pilgrim Accommodation Patterns

The spatial distribution of pilgrim accommodation and its relationship with demographic patterns within Andar Gaya shows a strong concentration of lodging facilities around historically significant mohallas and ritual nodes, reflecting long-standing socio-cultural hierarchies, patterns of settlement, and proximity to key pilgrimage sites. Approximately 60% of Hindu pilgrims visiting Gaya stay within Andar Gaya, underscoring its central role in the city's pilgrimage infrastructure and its continued importance as the primary accommodation zone for religious visitors.

Table 2. List of Mohallas, Baithaks, and Number of Panda Houses

S. No.	List of Mohalla	List of Ancient Baithaks	Number of Panda
1	Bauar Chaura		7
2	Brahmani Ghat	Chajja Baithak	2
3	Dakshin Darwaja	Sorha Baithak	0
4	Daunapur	Dawa Baithak	6
5	Devghat	Deo Ghat Baithak	9
6	Karselli	Baijnath Baithak	8
7	Kathgachi	-	5
8	Krishna Dwarka	-	10
9	Muncha	Chandchaura Baithak	8
10	Nadra Ganj	Chotki Baithak	0
11	Naua Gadhi	Mahanbhog Baithak	10
12	Panchmahalla	Panchmahalla Baithak	13
13	Sisodiya Chaura	Beguliya Baithak	3
14	Uper Dih	Chaudhari Ghat Baithak	8
			91

The 14 mohallas together contain a total of 91 panda houses, though their distribution is uneven (Table 4). Panchimapalla has the highest concentration with 13 panda houses, followed by Krishna Dwarka and Naua Gadhi with 10 houses each, indicating their prominence within the pilgrimage network. In contrast, mohallas such as Dakshin Darwaja and Nadfa Ganj do not have any panda houses.

This uneven distribution likely reflects historical settlement patterns, social hierarchies, and proximity to key ritual and pilgrimage sites, shaping both residential structure and service provision within Andar Gaya while also influencing present-day accessibility, density patterns, and infrastructure stress in the core areas.

4.3 Gayawal Community: Cultural and Religious Functions

The Gayawal Brahmins serve as hereditary priests responsible for conducting the pind daan and shraddha rituals. Their relationship with pilgrims is governed by the jajmani system, wherein patrons return across generations to the same priestly lineage. While the community once numbered over 1,400 families, only about 91 remain active today.

Each family maintains detailed genealogical records of pilgrims, reinforcing long-standing bonds of trust. Their residences, which double as homestays, form an essential yet informal component of Gaya's accommodation system.

4.4 Baithaks: Ritual and Cultural Spaces

Baithaks in Andar Gaya function as intimate spaces for discourse, ritual preparation, and cultural performance, with some closely associated with significant traditions such as the evolution of the musical form Thumri. These small-scale institutions blur the boundaries between private ritual, cultural production, and accommodation. Land use in Andar Gaya is predominantly residential, with commercial activities largely concentrated along the peripheral main roads (Figure 6). The area also encompasses the sacred Vishnupad Temple, a major pilgrimage site, and serves as the residential base for the Gayawal Pandas—the traditional priests of Gaya—further reinforcing its religious, cultural, and residential significance.



Figure 6. Land Use Map of Andar Gaya

4.5 Location of Houses of Pandas, catering to people from different regions.

The houses of Gayawal Pandas in Andar Gaya are spatially distributed according to the regions and communities they traditionally serve, reflecting long-established lineage-based and patronage networks. This locational pattern facilitates continuity of ritual practices and enables pilgrims from different regions to access priests associated with their ancestral or regional affiliations (Figures 7).

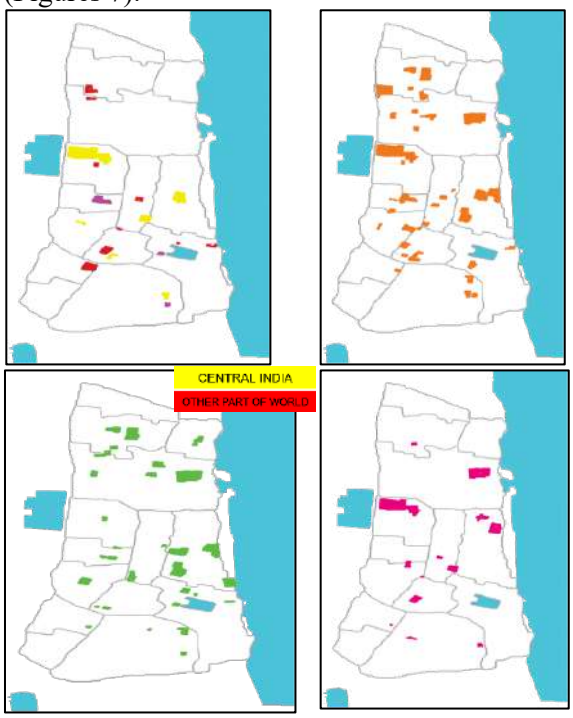


Figure 7. Central India & Other Parts of the World

4.6 Typical Panda Home Architecture

The architecture of Panda houses is highly distinctive and organized vertically according to function. The ground floor, known as the Jajman Floor, serves as a reception and ritual workspace, with shared kitchens and bathroom facilities for pilgrims. The first floor, or Mehman Floor, is reserved for pilgrim accommodation and houses the storage of ritual records and documents. The second floor, referred to as the Pakwan Floor, constitutes the private family domain, including kitchens and living spaces, and remains inaccessible to outsiders. At the heart of these houses is a central courtyard supported by timber columns, which acts as the social and ritual core of the dwelling. Together, these homes operate as unique homestays that combine ritual services with accommodation, where payments are made through Dakshina (ritual donations) that vary according to family traditions and the financial capacity of pilgrims (Figure 8).

While Andar Gaya retains its ritual vibrancy, it faces challenges of congestion, inadequate sanitation, and shortage of formal facilities. The reliance on panda houses and dharmshalas for pilgrim housing underscores the need for integrated planning that acknowledges cultural traditions while addressing modern urban pressures.

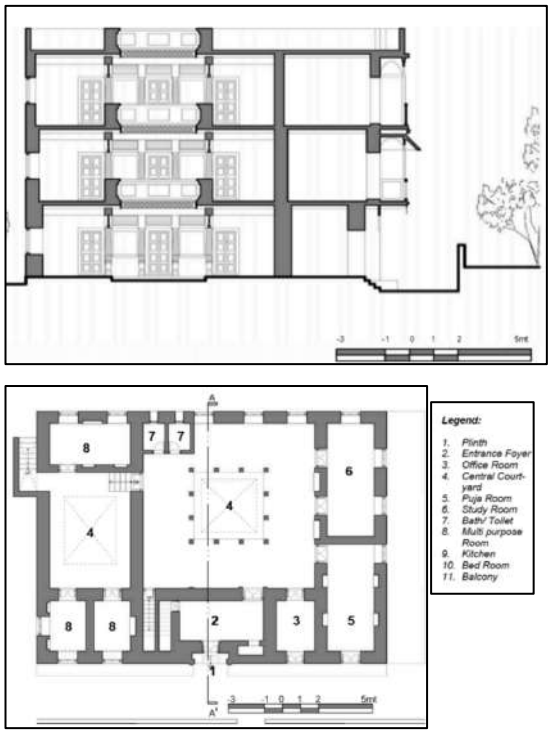


Figure 8. Floor plan and section of Panda house

5. City Profile: Bodhgaya

5.1 Geographic Setting

Bodh Gaya, situated about 12 kilometres south of Gaya Town in southern Bihar, lies along the banks of the Niranjana (Phalgu) River. Its geographical coordinates are approximately

24.7° N latitude and 84.99° E longitude, with an elevation of around 113 meters above sea level. The settlement is surrounded by gently rolling terrain and farmland. Although smaller in scale than Gaya Town, Bodh Gaya commands immense global importance as one of the foremost Buddhist pilgrimage destinations.

5.2 Historical and Religious Significance

Bodh Gaya is revered as the site where Prince Siddhartha achieved enlightenment beneath the Bodhi Tree, becoming Gautama Buddha and giving rise to Buddhism as a religious and philosophical tradition. Key spiritual and heritage landmarks include:

- The Mahabodhi Temple Complex is a UNESCO World Heritage Site and a fine example of ancient temple architecture.
- The Bodhi Tree – regarded as a direct descendant of the tree under which Buddha attained enlightenment.
- International Monasteries – numerous monasteries built by countries such as Thailand, Japan, Myanmar, Sri Lanka, Bhutan, Vietnam, and Tibet, serving as cultural and spiritual centres for visiting pilgrims.

This sacred significance makes Bodh Gaya a magnet for both domestic and international visitors, positioning it as a global hub for religious and spiritual tourism.

5.3 Connectivity and Accessibility

Despite its modest size, Bodh Gaya enjoys excellent connectivity owing to its religious prominence.

- Airways: The nearby Gaya International Airport, located about 8 km away, offers seasonal international flights linking Bodh Gaya to Buddhist-majority nations such as Thailand, Myanmar, Japan, and Sri Lanka, along with domestic routes.
- Railways: Gaya Junction, 12 km from Bodh Gaya, is the closest major railway station, from which visitors typically continue their journey by road.
- Roadways: The town is linked to Gaya, Patna, Rajgir, and other urban centres through state highways and local road networks. Last-mile connectivity is facilitated by shared autorickshaws, buses, and taxis.

5.4 Administrative Structure

Governance in Bodh Gaya falls under a Nagar Panchayat, classified as a semi-urban local body within Bihar's Department of Urban Development and Housing. The town spans about 19.6 square kilometres and is subdivided into 19 wards, each represented by an elected member.

5.5 Population and Density Trends

According to the Census of India 2011, the recorded urban population of the area was approximately 38,439, with a population density of about 19.38 persons per hectare (Figure 10). However, this figure fluctuates significantly due to seasonal variations, as the floating population increases dramatically during major Buddhist events such as Buddha Purnima and Kalachakra, often rising to between 100,000 and 500,000 people or more.

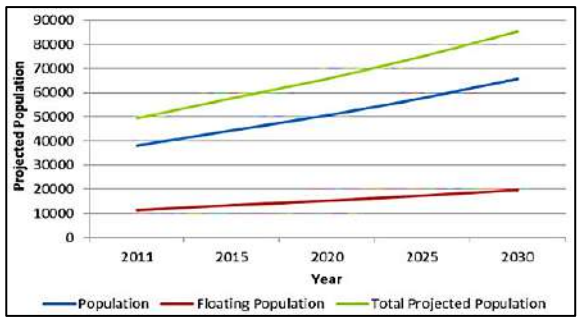


Figure 10. Population Projection of Bodhgaya

5.6 Households, Housing Stock, and Shortage

The demand for housing in Bodh Gaya arises not only from its residents but also from long-term spiritual visitors, monks, scholars, and service providers. Current estimates indicate a shortage of nearly 4,000 housing units, a considerable deficit for a town of this scale (Table 3).

This gap disproportionately affects low-income and migrant workers who form the backbone of the local tourism and hospitality sector, as well as extended-stay visitors such as monks, volunteers, and spiritual seekers.

Table 3. Housing Scenario of Bodhgaya

Indicators	Value
Total Population	51,515
Total Households	8,586
Existing Housing Stock	6,079 units
Estimated Housing Shortage	3,896 units
Average Household Size	5.5 persons

It also impacts pilgrims who rely on informal or overcrowded accommodation, particularly during peak pilgrimage seasons when demand far exceeds available capacity.

6. Profile of Pilgrims and Patterns of Stay

6.1 Pilgrim Footfall Analysis

A PILGRIM FOOTFALL IN GAYA TOWN

Gaya Town, being a sacred Hindu pilgrimage centre, experiences consistent footfall throughout the year, with a sharp rise during specific religious events. The town is particularly known for the Pind Daan ceremonies, held during the Pitri Paksha Mela, attracting lakhs of domestic pilgrims annually.

MONTHLY FOOTFALL PATTERN: Peak domestic tourist inflow occurs during September and October, coinciding with Pitri Paksha, a major Hindu ritual period that draws large numbers of pilgrims. A smaller increase in visitor numbers is also observed in December, likely linked to the holiday season and associated travel. In contrast, foreign tourists tend to visit during the cooler months from November to February, although their numbers remain relatively modest when compared to nearby Bodh Gaya.

ANNUAL TOURIST NUMBERS (2023 & 2024): The analysis of annual tourist numbers for 2023 and 2024 (Table 4) shows that domestic tourists dominate overall visitation, accounting for more than 90% of the total footfall. Foreign tourist arrivals remain comparatively low and are largely concentrated in the period between October and December.

Table 4: Annual Tourist Numbers (2023 and 2024) (Gaya Town);

Year	Domestic Tourists	Foreign Tourists	Total
2023	1,037,085	87,899	1,124,984
2024 (till Dec)	922,485	61,820	984,305

Source: Bihar Tourism Statistics

DOMESTIC TOURIST FOOTFALL (Figure 11) in the city is largely ritual-centric and highly seasonal, closely aligned with the Hindu religious calendar. Consequently, the city must be equipped to manage sharp surges in demand for accommodation, sanitation, crowd control, and transportation during events such as Pitri Paksha. In contrast, foreign tourists tend to be more leisure-oriented and climate-sensitive, showing a clear preference for travel during the winter months.

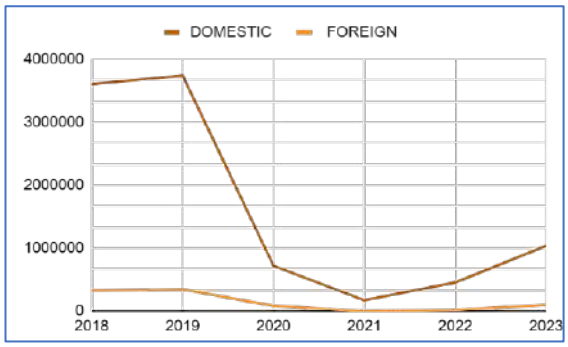


Figure 11. Annual Tourist Inflow of the Last 5 Years in Gaya Town; Source: Author

B PILGRIM FOOTFALL IN BODH GAYA

Bodh Gaya, as the place of Buddha's enlightenment, is a globally recognized spiritual destination. It attracts both domestic and international Buddhist pilgrims, especially from East and Southeast Asian countries, as well as Western spiritual tourists. Compared to Gaya Town, Bodh Gaya exhibits a more balanced ratio of foreign and domestic tourists.

MONTHLY FOOTFALL PATTERN (2023 & 2024): Domestic tourism typically peaks between October and January, coinciding with major Buddhist festivals and winter vacation periods. Foreign tourist arrivals show a pronounced increase in December and January, aligning with global Buddhist events and favourable climatic conditions. Additionally, large-scale events such as the Kalachakra ceremony or international monastic retreats, when scheduled, result in sharp but temporary surges in visitor numbers.

Table 5. Annual Tourist Numbers (2023 & 2024) (Bodhgaya)

	Domestic Tourists	Foreign Tourists	Total
2023	1,068,160	71,273	1,139,433
2024 (till Dec)	1,813,491	71,713	1,885,204

Source: Bihar Tourism Statistics

ANNUAL TOURIST NUMBERS (2023 & 2024): The annual tourist arrivals in Bodh Gaya for 2023 and 2024 show a substantial increase in total visitors in 2024 compared to the previous year (Table 5). The data highlights the dominance of domestic tourists, who account for the vast majority of footfall, while foreign tourist numbers remain relatively modest.

Foreign tourists account for nearly 48% of the total visitor footfall, representing a significantly higher proportion compared to Gaya Town (Figure 12). Overall, the data indicates a strong year-on-year growth trend in both domestic and foreign tourist arrivals.

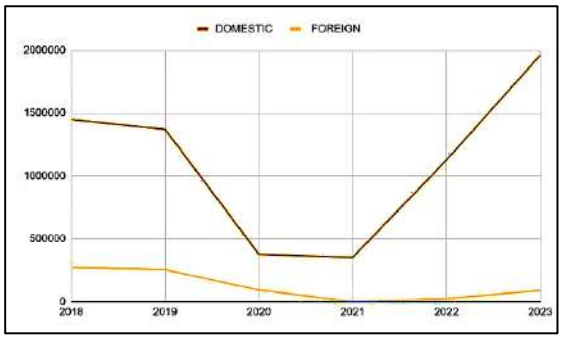


Figure 12. Annual Tourist Inflow of the Last 5 Years in Bodhgaya; Source: Bihar Tourism Statistics

6.2 Types of Pilgrims

Based on field data, pilgrims in the study area can be broadly classified into short-stay Hindu pilgrims who visit for one to two days for rituals such as Pitru Paksha and Pind daan and long-stay Hindu pilgrims who remain for over a week for Shraddha rites or festival-based visits. International Buddhist pilgrims typically stay for 10 to 30 days in monasteries or guesthouses between October and March, while domestic Buddhist pilgrims have shorter, group-based visits concentrated around winter festivals. In addition, spiritual tourists and researchers tend to be long-term, budget-conscious visitors who prefer homestays or rental accommodation.

6.3 Seasonal Demand

The Hindu peak season from August to October, particularly during Pitru Paksha, witnesses a sharp rise in demand for dharmshalas and guesthouses. Similarly, the Buddhist peak season from October to March transforms Bodh Gaya into a major centre for international retreats. These overlapping pilgrimage cycles create significant spatial and temporal pressure on existing infrastructure, especially around the Vishnupad precinct and the Mahabodhi Temple surroundings, often leading to congestion, short-term accommodation shortages, and strain on transport, sanitation, and public services.

7. Data collection and analysis

7.1 Existing Accommodation Options and Their Limitations

A GAYA TOWN

Gaya Town offers a diverse accommodation base of approximately 39,000 rooms, dominated by guest houses and Gayawal priest homestays (26% each), followed by budget hotels (21%), with luxury hotels forming only 5% of total capacity (Table 6).

Table 6. Accommodation Types and Capacity, Gaya town

Accommodation Type	Total Rooms	Percentage of Total
Luxury Hotels	1,950	5.0%
Mid-Range Hotels	4,680	12.0%
Budget Hotels	8,190	21.0%
Guest Houses	10,140	26.0%
Dharamshala	1,560	4.0%
Homestays at Gyawali Priest	10,140	26.0%
Ashrams & Math	2,340	6.0%
TOTAL	39,000	100%

Source: Primary Survey by Author

Pilgrims largely prefer budget hotels (30%), dharmshalas (21%), and priest homestays (20%), reflecting strong price sensitivity, as affordability and comfort are the primary selection criteria, followed by proximity to pilgrimage centres and availability. Accommodation tariffs range from ₹50–300 per night in ashrams to ₹5,000–12,000 in luxury hotels, with value for money rated highest in dharmshalas and priest homestays. Occupancy peaks during the Pitrapaksha Mela, reaches moderate levels during regular seasons, and drops significantly during extreme summer and winter months, while most pilgrims rely on recommendations from priests or local community networks when choosing accommodation.

B BODH GAYA

The accommodation landscape comprises 537 establishments with a total capacity of about 19,000 beds, dominated by hotels, which account for over 63% of total capacity, followed by guest houses and dharmshalas (Table 7). This skew towards hotel-based accommodation indicates a formal, market-oriented supply structure, with limited capacity in low-cost and seasonal lodging segments that primarily serve pilgrims and short-stay visitors.

Table 7. Accommodation Types and Capacity, Bodh Gaya

Accommodation Type	Number of Establishments	Maximum Beds	Percentage of Total
Hotels	160	12,000	63.2%
Guest Houses	220	7,500	18.4%
Dharamshala	43	2,000	10.5%
Monasteries	14	1,000	5.3%
Homestays	100	500	2.6%
TOTAL	**537**	**19,000**	**100%**

Source: Primary Survey by Author

Within the hotel category, budget hotels form the largest segment, while luxury hotels constitute a smaller share with significantly higher tariffs. Pilgrims show a strong preference for dharmshalas and budget hotels, primarily driven by affordability, comfort, and proximity to pilgrimage centres. Stay experiences vary across

categories, with safety and amenities rated highest in luxury hotels and monasteries and value for money highest in dharmshalas. Accommodations are heavily clustered within a 2 km radius of the Mahabodhi Temple and reach peak occupancy during the winter festival season, reflecting the strong spatial and seasonal concentration of demand.

7.2 Pilgrim Accommodation Quantum (Peak and Average)

A GAYA TOWN

Under an average scenario, Gaya Town receives approximately 3,000 pilgrims per day with varying lengths of stay, generating about 12,300 pilgrim-days of demand.

While the overall accommodation supply shows a net surplus, the demand–supply analysis reveals a mismatch across accommodation types. Luxury, mid-range, and budget hotels; guest houses; and priest homestays exhibit substantial surpluses, whereas dharmshalas and ashrams face notable shortages, indicating a gap in affordable and spiritually oriented accommodation despite adequate overall capacity (Table 8).

Table 8. Accommodation Supply Vs. Demand, Gaya Town

Accom. Type	Available per day	Preferred Accom. %	Demand per day	Shortage/ Surplus
Luxury Hotels	1,950	5%	840	+1,110 (surplus)
Mid-Range Hotels	4,680	10%	1,680	+3,000 (surplus)
Budget Hotels	8,190	22%	3,696	+4,494 (surplus)
Guest Houses	10,140	12%	2,016	+8,124 (surplus)
Dharamshala	1,560	21%	2,520	-960 (shortage)
Homestays at Gayawal's Priest	10,140	15%	3,528	+6,612 (surplus)
Ashrams & Maths	2,340	15%	2,520	-180 (shortage)
TOTAL	39,000	100%	16,800	+22,200 (net surplus)

Source: Primary Survey by Author

PEAK SEASON (PITRAPAKSHA MELA): During the Pitrapaksha Mela, Gaya Town experiences a peak monthly footfall of approximately 120,000 pilgrims, resulting in an estimated daily demand of about 12,600 pilgrims based on varying lengths of stay. Although the aggregate accommodation supply shows a substantial net surplus during the peak period, the demand–supply analysis highlights significant imbalances across accommodation types. While luxury, mid-range, and budget hotels, guest houses, priest homestays, and government accommodations register large surpluses, acute shortages persist in dharmshalas and ashrams. This indicates that, even during peak seasons, the critical challenge lies not in total capacity but in the limited availability of affordable and spiritually aligned accommodation preferred by pilgrims (Table 9).

Table 9. Accommodation Supply vs. Demand (Peak)

Accom. Type	Available per day	Preferred Accom. %	Demand per day	Shortage/ Surplus
Luxury Hotels	1,500	5%	980	+520 (surplus)
Mid-Range Hotels	4,500	10%	1,960	+2,540 (surplus)
Budget Hotels	9,000	20%	3,920	+5,080 (surplus)
Guest Houses	10,000	10%	1,960	+8,040 (surplus)
Dharamshala	1,500	20%	2,940	-1,440 (shortage)
Homestays at Gayawal's Priest	10,000	15%	3,920	+6,080 (surplus)
Ashrams & Maths	2,500	15%	2,940	-440 (shortage)
Accom. at the government	11,000	5%	980	+10,020 (surplus)
TOTAL	50,000	100%	19,600	+30,400 (net surplus)

Source: Primary Survey by Author

B BODH GAYA

Under an average scenario, Bodh Gaya receives around 5,500 pilgrims per day, generating a minimum of about 11,000 pilgrim-days based on varying lengths of stay. While the overall accommodation supply shows a net surplus, the demand–supply assessment reveals significant shortages in dharmshalas and homestays, which are the most preferred accommodation types. In contrast, luxury, mid-range, budget hotels, guest houses, and monasteries exhibit substantial surpluses, indicating a mismatch between available capacity and pilgrim accommodation preferences (Table 10).

PEAK SEASON: During the peak season, Bodh Gaya receives an estimated 2,50,000 pilgrims per month, translating to an average daily demand of about 17,500 pilgrims based on varied lengths of stay. The demand–supply analysis indicates an overall net shortage of accommodation during this period, with acute deficits in dharmshalas, homestays, and luxury hotels, which are highly preferred by pilgrims (Table 11). While mid-range and budget hotels and guest houses show surpluses, the mismatch between pilgrim preferences and available accommodation types underscores the need for expanding affordable and spiritually oriented lodging options during peak periods.

Table 10. Accommodation Supply Vs Demand

Accom. Type	Available per day	Preferred Accom. %	Demand per day	Shortage/ Surplus
Luxury Hotels	1,197	10%	1,100	+97 (surplus)
Mid-Range Hotels	4,788	10%	1,100	+3,688 (surplus)
Budget Hotels	5,985	20%	2,200	+3,785 (surplus)
Guest Houses	3,420	15%	1,650	+1,770 (surplus)
Dharamshala	2,090	40%	4,400	-2,310 (shortage)
Homestay	570	20%	2,200	-1,630 (shortage)
Monasteries	950	5%	550	+400 (surplus)
TOTAL	19,000	100%	13,200	+5,800 (net surplus)

Source: Primary Survey by Author

Table 11. Accommodation Supply vs. Demand (Peak)

Accom. Type	Available per day	Preferred Accom. %	Demand per day	Shortage/ Surplus
Luxury Hotels	1,197	10%	1,750	-553 (shortage)
Mid-Range Hotels	4,788	10%	1,750	+3,038 (surplus)
Budget Hotels	5,985	20%	3,500	+2,485 (surplus)
Guest Houses	3,420	15%	2,625	+795 (surplus)
Dharamshala	2,090	40%	7,000	-4,910 (shortage)
Homestays	570	20%	3,500	-2,930 (shortage)
Monasteries	950	5%	875	+75 (surplus)
TOTAL	19,000	100%	21,000	-2,000 (net shortage)

Source: Primary Survey by Author

8. Issues across Scales

The accommodation sector in Gaya is constrained by multiple interrelated challenges across policy, city, and infrastructure levels. At the policy level, the absence of a dedicated Master Plan or Tourism Development Plan, fragmented implementation of central schemes, and the exclusion of religious institutions from formal planning frameworks limit coordinated development. At the city level, the lack of defined lodging zones, wayfinding systems, parking, sanitation, and solid waste management—particularly in the old city—creates operational stress around accommodation clusters. These issues are further compounded by infrastructure gaps, including the absence of planned sewage and greywater systems in the Vishnupad area, poor fire safety, ventilation, and accessibility in dharmshalas, and inadequate road and pedestrian infrastructure. Additionally, weak regulatory oversight results in limited enforcement of building codes, absence of gender- and senior-friendly lodging standards, and widespread informality, with many accommodations operating outside taxation and registration systems.

9. Potentials and Strategic Opportunities

Despite existing challenges, several opportunities can be leveraged to improve pilgrim accommodation in Gaya. Regularizing and expanding homestays under state schemes can strengthen the supply of low-cost lodging, while adaptive reuse of vacant residential structures near pilgrimage cores offers quick and scalable solutions. Integrating the Gayawal priest community as local tourism entrepreneurs through capacity building can enhance service quality, and interventions such as smart signage, digital booking systems, and sanitation kiosks can significantly improve the pilgrim experience. Additionally, upgrading dharmshalas through PPP models aligned with PRASHAD guidelines can raise accommodation standards without compromising their religious character.

10. Scenarios for Future Accommodation

Under a business-as-usual approach, continued reliance on informal accommodations and ad hoc hotel development is likely to perpetuate shortages and erode cultural identity. In contrast, policy-driven interventions—such as PPP-based dormitories, seasonal tent cities, incentivized homestays, and adaptive reuse—can significantly reduce shortages and create inclusive infrastructure. An integrated urban development approach that embeds pilgrim housing within master plans, digital platforms, safety standards, and multi-stakeholder governance offers a resilient and replicable model for pilgrimage towns.

11. Recommendations

Need for Strategic Intervention: The growing pilgrim inflow, especially during peak ritual seasons, requires a systematic, phased strategy combining new construction, temporary facilities, and policy reforms to expand affordable accommodation.

Development of New Accommodation: Low-cost, purpose-built accommodation should be developed near transit hubs and temple precincts using culturally sensitive designs with shared amenities. These facilities may include permanent low-rise guesthouses as well as seasonal modular or tent-based shelters to cater to peak inflows. Land and zoning strategies should identify dedicated pilgrim housing zones,

leverage temple trust and government land, and establish land banks for long-term development. A public–private partnership (PPP) model is recommended, wherein the government provides land, trunk infrastructure, and incentives, while private entities finance, construct, and manage the facilities. Affordability can be ensured through tariff caps, slab-based pricing, and digital booking platforms integrated with subsidies, alongside sustainability and inclusivity measures such as passive design, use of local materials, and universal accessibility.

Adaptive Reuse of Non-Affordable Accommodation: Vacant or underutilized hotels should be temporarily repurposed during peak seasons through capped-tariff agreements, dormitory-style retrofits, pilgrim voucher systems, and off-season leasing of unused wings.

Multi-Level Government Interventions: Central and state governments should leverage dedicated tourism and temple-corridor funding, offer fiscal incentives for homestays and dharmshalas, revise homestay policies for seasonal licensing, and prioritize supporting infrastructure and digital promotion. Religious and tourism policies should be integrated through PRASHAD and Bihar Tourism Policy provisions, while positioning Gaya–Bodh Gaya within multi-faith pilgrimage circuits and strengthening hospitality skill development.

Local Bodies & Municipal Actions: Urban plans should earmark pilgrim accommodation zones, enable temporary facilities during peak periods, adopt single-window digital governance, and collaborate with private players for low-tariff room availability.

Other Recommendations:

- Accommodation Monitoring: Implement real-time monitoring of occupancy and pilgrim inflows to anticipate shortages.
- Infrastructure Upgrades: Upgrade older lodges with improved sanitation, lighting, safety, and reliable utilities.
- Accessibility and Inclusivity: Ensure ramps, lifts, women-friendly facilities, and safe spaces for vulnerable groups.
- Waste and Water Management: Introduce sewage treatment, rainwater harvesting, and segregated waste systems.
- Food and Water: Provide hygienic kitchens and affordable meal services across accommodation clusters.
- Digital Access and Information: Deploy QR-based navigation, smart signage, and integrated information platforms.
- Heritage Sensitivity: Retain the cultural identity of Panda houses and baithaks through sensitive retrofits and digitized registration for monastic accommodations.

12. Conclusion

The study on pilgrim accommodation in Gaya, Bihar highlights the pivotal role of pilgrimage in shaping urban form and infrastructure in heritage cities, while revealing persistent gaps in affordable, culturally appropriate, and season-responsive lodging. Despite recent policy and infrastructure initiatives, shortages of low-cost accommodations such as dharmshalas and homestays continue to cause overcrowding during peak seasons, even as higher-end hotels remain underutilized. The research concludes that a dual strategy—expanding affordable accommodation and repurposing existing facilities—supported by integrated policy, multi-level governance, and community participation, is essential to create a sustainable, inclusive, and socially equitable pilgrim accommodation system in Gaya.

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Integrating Traditional Knowledge Systems in Spatial Planning for Climate Change Adaptation:

A Case of RI Bhoi, Meghalaya

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Abstract: The RI Bhoi district in Meghalaya faces mounting climate-related challenges—from unpredictable rainfall patterns and seasonal floods to rising ambient temperatures—that increasingly endanger ecosystems and rural livelihoods. Although global and national policy frameworks acknowledge the value of Traditional Knowledge Systems (TKS) in addressing climate change, their use in local spatial planning remains limited. In the RI Bhoi, TKS historically informed not only forest and water resource stewardship but also the selection of settlement locations based on ecological cues and community memory of hazards. However, such practices are diminishing under the strain of rapid urban growth, shifting land rights, and generational disconnect. This paper uses the Sustainable Livelihood Framework to examine the spatial imprint and current state of TKS across the district and to explore the underlying reasons for their decline. It finds that villages which still apply TKS-based siting and ecological norms demonstrate stronger resilience to climate risks, while those where these systems have weakened face heightened exposure. Through climate trend analysis, participatory mapping, and local field insights, this study shows how TKS erosion correlates with increased vulnerability. It concludes with spatial planning proposals—such as zoning adjustments, community mapping platforms, and incentive-based conservation schemes—to integrate TKS into mainstream governance. By linking traditional ecological practices with forward-looking planning, the study offers a grounded approach to climate adaptation suited for data-scarce, hazard-prone regions like RI Bhoi.

Keywords: Traditional Knowledge Systems, Spatial Planning, Climate Change Adaptation, Sustainable Livelihoods.

सार: मेघालय के रिभोई ज़िले को जलवायु से संबंधित बढ़ती चुनौतियों का सामना करना पड़ रहा है — अप्रत्याशित वर्षा प्रतिमानऔर मौसमी बाढ़ से लेकर बढ़ते तापमान तक — जो पारिस्थितिकी प्रणालियों और ग्रामीण आजीविका को क्रमशः जोखिम में डाल रही हैं। यद्यपि वैश्विक और राष्ट्रीय नीति रूपरेखाएँ जलवायु परिवर्तन से निपटने में परंपरागत ज्ञान प्रणालियों के मूल्य को स्वीकार करती हैं, किंतु स्थानीय स्थानिक नियोजन में इनका उपयोग अभी भी सीमित है। रिभोई में, परंपरागत ज्ञान प्रणालियों ने ऐतिहासिक रूप से न केवल वन और जल संसाधनों के प्रबंधन को निर्देशित किया, बल्कि पारिस्थितिक संकेतों और आपदाओं से संबंधित सामुदायिक स्मृति के आधार पर बस्तियों के स्थान-निर्धारण में भी मार्गदर्शन दिया। किंतु तीव्र शहरीकरण, बदलती भूमि-अधिकार प्रणाली, और पीढ़ीगत विच्छेद के दबाव में ऐसी प्रथाएँ क्षीण हो रही हैं। यह पत्र सतत आजीविका रूपरेखा का उपयोग करते हुए पूरे ज़िले में परंपरागत ज्ञान प्रणालियों के स्थानिक प्रभाव और वर्तमान स्थिति की जांच करता है, तथा इनके ह्रास के अंतर्निहित कारणों की खोज करता है। यह पाता है कि जो गाँव अभी भी परंपरागत ज्ञान प्रणालियों आधारित स्थान-निर्धारण और पारिस्थितिक मानदंडों को लागू करते हैं, वे जलवायु जोखिमों के प्रति अधिक मजबूत लचीलापन प्रदर्शित करते हैं, जबकि जहाँ ये प्रणालियाँ कमजोर पड़ गई हैं, वहाँ उच्च जोखिम का सामना करना पड़ रहा है। जलवायु प्रवृत्ति विश्लेषण, भागीदारीपूर्ण मानचित्रण), और स्थानीय क्षेत्र-आधारित अंतर्दृष्टि के माध्यम से, यह अध्ययन यह दर्शाता है कि परंपरागत ज्ञान प्रणालियों के क्षरण से संवेदनशीलता में वृद्धि कैसे संबंधित है। यह भूमि-उपयोग क्षेत्रीकरण, सामुदायिक मानचित्रण मंच, और प्रोत्साहन-आधारित संरक्षण योजनाओं जैसी स्थानिक नियोजन सिफारिशों के साथ समाप्त होता है, ताकि परंपरागत ज्ञान प्रणालियों को मुख्यधारा शासन में एकीकृत किया जा सके। परंपरागत पारिस्थितिक प्रथाओं को भविष्य-केंद्रित नियोजन के साथ जोड़कर, यह अध्ययन रिभोई जैसे डेटा-अभाव और आपदा-प्रवण क्षेत्रों के लिए उपयुक्त जलवायु अनुकूलन का एक आधार-संवेदनशील दृष्टिकोण प्रस्तुत करता है।

मुख्य शब्द: पारंपरिक ज्ञान प्रणालियाँ, स्थानिक नियोजन, जलवायु परिवर्तन अनुकूलन, सतत आजीविकाएँ

1. Introduction

Climate change is no longer a distant projection for the Indian Himalayan Region (IHR), but an immediate and evolving reality with profound social and ecological consequences. In RI Bhoi district, Meghalaya, its effects are increasingly evident in shifting land-use patterns, disrupted seasonal cycles, and declining ecosystem services. Local communities report that monsoon rains now arrive unpredictably, with sudden downpours causing flash floods and soil erosion, while prolonged dry intervals affect planting schedules and water availability. A 30-year rainfall trend analysis conducted as part of this research confirms this perceived erraticism, revealing increasing intra-seasonal variability and delayed monsoon onset in several years. (IMD Data 1992-2022).

RI Bhoi's geography—marked by upland ridges, rolling mid-slopes, and fertile valley plains—shapes both its vulnerabilities and its opportunities. (Figure 1) locates Meghalaya within the broader Indian Himalayan Region, providing critical geographical context for the study area. This positional understanding is key, as RI Bhoi's climatic and ecological sensitivities are strongly influenced by its placement within this high-risk environmental zone. Flash floods along the Umiam and Umsiang rivers and landslides on unstable terrain remain recurring concerns, increasingly influenced by land-use

change and infrastructure expansion. Rapid urbanization around Nongpoh, linear development along highways, and the conversion of community-managed landscapes into private holdings are altering not just physical terrain but also the traditional social-ecological systems (Government of Meghalaya 2021).

Traditional Knowledge Systems (TKS) have long provided resilient, and locally attuned responses to environmental uncertainty. In RI Bhoi, TKS practices include sacred grove conservation, shifting (Jhum) cultivation, bamboo drip irrigation, and communal water stewardship, as well as strategic settlement siting guided by generations of ecological memory. Older villages, as verified through oral histories, Participatory Rural Appraisal (PRA) exercises, and spatial analysis, are typically located on mid-slopes or ridge lines—areas that reduce flood and landslide risk while ensuring access to perennial springs and stable soils (Laloo 2017).

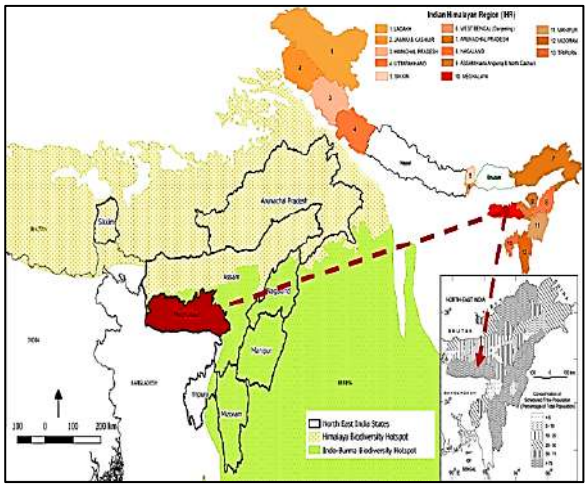


Figure 1. State of Meghalaya within the Indian Himalayan Region (Prepared by the Author based on data from Meghalaya Basin Management Agency 2025)

These systems continue to structure forest use, protect ecological buffers, and sustain cooperative disaster responses. Far from static tradition, TKS represents a dynamic framework for resilience passed down and adapted over generations (UNDP 2022). At the policy level, both international and national frameworks increasingly recognize the role of traditional knowledge in adaptation. The Intergovernmental Panel on Climate Change (IPCC), the Convention on Biological Diversity (CBD), and India's Biological Diversity Act and Forest Rights Act call for the inclusion of indigenous knowledge in governance and planning (IPCC 2023, CBD 2000, Government of India 2002). The Sustainable Development Goals (SDGs), particularly those related to sustainable cities (Goal 11), climate action (Goal 13), and life on land (Goal 15), further affirm the relevance of TKS for resilience and sustainability (United Nations 2015).

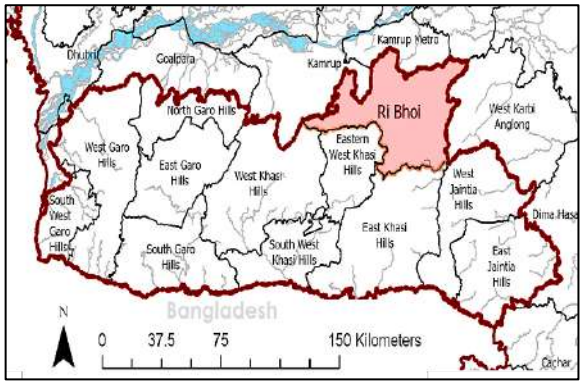


Figure 2. Map showing the RI Bhoi district of Meghalaya (Prepared by the author based on data from Meghalaya Basin Management Agency, 2025)

In Meghalaya, the State Action Plan on Climate Change (SAPCC) emphasizes TKS as a key driver of resource conservation and climate adaptation (Government of Meghalaya 2014). Under the Sixth Schedule of the Indian Constitution, autonomous councils, such as the Khasi Hills Autonomous District Council (KHADC), are empowered to legislate on land and forest management, often integrating traditional institutions such as the Dorbar Shnong (Village Council), into formal governance (Tribal Research Institute 2022). Spatial planning in RI Bhoi is currently governed by the Meghalaya Town and Country Planning Act (1973), which provides the statutory framework for land-use zoning and development control. However, formal planning processes rarely incorporate TKS or engage with customary systems, resulting in fragmented governance and weakened spatial logic at the ground level. Figure 2 presents the administrative boundaries and topographical features of the RI Bhoi district, establishing the spatial frame of analysis used throughout the study. The district's varied terrain—ranging from uplands to river valleys—visibly supports the discussion on differential vulnerability and TKS application.

Despite growing policy recognition, the operational integration of TKS into district-level spatial planning remains limited. Participatory mapping and PRA exercises reveal that the ecological rationale behind traditional siting is increasingly being sidelined under pressure from road expansion, market forces, and land tenure shifts. Sacred groves and water commons are being encroached upon or disconnected from settlements, and new development increasingly

occurring in previously avoided hazard-prone areas. Younger residents in peri-urban areas report limited awareness of TKS principles, reflecting generational gaps and changing livelihood priorities (UNDP 2022, Tribal Research Institute 2022).

This erosion has significant implications for RI Bhoi's ecological balance, disaster risk, and social cohesion (Figure 3). The district was also classified as an Aspirational District by NITI Aayog in 2018. Government reports and local testimonies document an increasing impact of floods, resource stress, and infrastructure disruption in areas where traditional spatial logic has weakened (Office of the Deputy Commissioner, RI Bhoi 2023). These patterns underscore the need for a more grounded understanding of how spatial and environmental risks are evolving and how TKS can be mainstreamed as a living logic for climate adaptation.

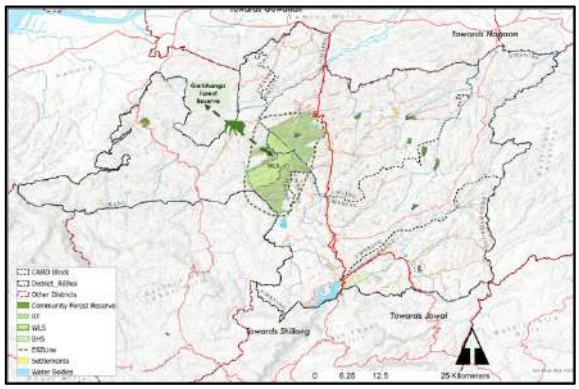


Figure 3. Map showing sacred groves, RF, BHS, ESZ, and Community Forests in RI Bhoi (Prepared by the author based on data from Wildlife Division, Forest Department, Khasi Hills Division Meghalaya 2025)

2. Methods

Accordingly, this paper investigates the changing multi-hazard risk landscape of RI Bhoi, using a combination of historical climate data, spatial mapping, and community narratives to assess where and how vulnerabilities are intensifying. It adopts the Sustainable Livelihood Framework (SLF) to evaluate the role of TKS in maintaining natural, social, human, physical, and financial capital—and how the loss these capitals affect adaptive capacity (UNDP 2012, World Bank 2008).

By integrating climatic data, spatial evidence, and grounded ecological knowledge, this research argues for embedding TKS into formal planning as an operational tool for climate resilience. The study documents observed climate variability and its impacts on land use and livelihoods in RI Bhoi, while analysing the spatial expression of Traditional Knowledge Systems (TKS) in resource protection and settlement siting through mapped and case-based evidence. It further investigates the drivers and patterns of TKS erosion and their correlation with increasing exposure and reduced adaptive capacity. It concludes by proposing spatial planning interventions, including zoning reforms, siting guidelines, participatory mapping platforms, and incentive mechanisms to integrate TKS into regional planning strategies.

Together, these stages aim to demonstrate that revitalizing and mainstreaming TKS through spatial planning is not only feasible but essential for climate adaptation in RI Bhoi and other data-scarce, climate-sensitive landscapes across the Global South.

Field evidence was incorporated through PRA checks (FGDs, transects) and stratified household surveys in two villages of choice. Building on this validation, traditional practices were compiled and assigned a TKS rating across four dimensions: effectiveness along the hazard pathway, feasibility/adoption, continuity of use, and ecosystem–livelihood co-benefits—scored 1–5, min–max scaled to 0–1, and averaged (equal weights). To quantify benefits, TKS Valuation followed a Payment for Ecosystem Services framework, monetising TKS's services using replacement/avoided-cost/market price methods. In parallel, village-scale multi-hazard was aggregated into Hazard (H), Exposure (E), Sensitivity (S), and Adaptive Capacity (AC) using for each hazard (flood, cyclones) and an equal-weight mean for the composite index (Cutter et al. 2003).

$$R = H + E + V \quad (1)$$

$$V = S - A \quad (2)$$

$$R_{Multi\text{-}Hazard} = (F_{lood} + C_{yclone})/2 \quad (3)$$

3. Traditional Knowledge Systems: Resource Protection and Settlement Siting

Traditional Knowledge Systems (TKS) in RI Bhoi are not merely inherited rituals or folklore; they are the operational foundation of community-led landscape management, risk reduction, and spatial logic. These systems, shaped by generations of observation and ecological interaction, continue to influence how communities organize settlements, conserve resources, and adapt to environmental changes. Spatial mapping and field surveys conducted for this study confirm that TKS in RI Bhoi is

expressed across many interconnected domains: natural resource protection, settlement siting, and hazard risk moderation (Tribal Research Institute 2022). Unlike externally imposed planning paradigms, TKS is embedded in the everyday structuring of land and water systems—transmitted orally, refined through practice, and adapted to evolving conditions (UNDP 2022).

3.1 Sacred Groves, Sacred Water bodies, and Community Forests

Among the most visible expressions of TKS are the sacred groves (law Kyntang, law Lyngdoh) and sacred water bodies, which are protected by clan rules, taboos, and customary rituals (Shangpliang 2010). These groves are often located near springs, ridgelines, or forested hillocks and serve both ecological and spiritual functions. They are governed by rules maintained by the village Dorbar (council) or designated clan custodians and are not open to extraction or disturbance. In Khasi society, which follows a matrilineal lineage, clan mothers and elder women often play a crucial role in safeguarding sacred sites, transmitting ecological rituals, and mediating resource norms. This gendered custodianship reinforces TKS continuity across generations and strengthens the communal ethic of environmental stewardship.

Closely associated with sacred groves are sacred water bodies—springs, ponds, or rivulets whose purity is protected by belief systems that forbid washing, pollution, or overuse (Laloo 2017). These features collectively form ecological sanctuaries within the landscape, safeguarding biodiversity, preserving groundwater recharge, and ensuring the availability of high-quality water for downstream use (Khonglah 2010). In addition, many villages maintain community forests under customary ownership. These forests are managed for rotational use, firewood, fodder, and minor forest produce, with clear spatial boundaries and collectively enforced usage rules (Government of Meghalaya 2021). Unlike sacred groves, which are strictly conserved, community forests adopt a shared governance model that balances conservation and sustainable extraction. The distribution of sacred groves, Reserved Forests (RF), Biodiversity Heritage Sites (BHS), and Ecologically Sensitive Zones (ESZ), as mapped in Figure 3 illustrates the spatial embedding of TKS across RI Bhoi. These zones, still governed by community rules and ritual norms, form a vital ecological web that supports biodiversity and water security.

3.2 Nature, Stewardship, and Interdependence in Khasi Practice

The relationship between the Khasi community and its environment is one of interdependence. Nature is seen as animate, with hills, springs, forests, and soil imbued with spirit and memory (Laloo and Momin 2015). This worldview underpins practices like shifting cultivation (jhum), bamboo irrigation, and water commons—each shaped by a sense of environmental reciprocity and balance.

In Jhum, land is returned to after a fallow cycle that allows soil and vegetation to regenerate. The process respects topography, slope, and existing trees stand, forming a mosaic landscape where human use and natural succession co-exist (Indian Journal of Traditional Knowledge 2006). Bamboo drip irrigation, still used in select hillside villages, exemplifies adaptive design using ecological materials, channelling spring water to household gardens and paddy fields over long distances using split bamboo pipes. Water commons—springs, ponds, and stream segments—are governed by intricate customary rules. Extraction schedules and maintenance responsibilities arise from community norms that view water as both shared and sacred. Many of these water sources are linked to ancestral spirits, reinforcing the cultural and spiritual foundation of their stewardship (Laloo 2017). Together, these practices reflect a Khasi ethic of care, observation, and restraint—where land, water, and forests are governed not only by rules but by deeply embedded relationships of belonging and responsibility.

3.3 Settlement Siting: The Spatial Expression of TKS

Settlement siting in RI Bhoi follows strong ecological logic, integrating land use with ecosystem care. Older villages are typically located on mid-slopes or ridges, reducing flood and landslide risks while maintaining proximity to perennial springs, with sacred groves positioned uphill to function as catchments and windbreaks. PRA exercises and spatial analysis confirm that TKS-informed villages are generally located between 700–1,200 meters in elevation, on gentle to moderate slopes, and within 500 meters of reliable water sources, which minimize erosion, improve drainage, and ensure sustained water access without disturbing catchment vegetation (UNDP 2012). Table 1 outlines the key ecological and topographic parameters guiding traditional settlement siting in RI Bhoi.

3.4 Architecture and Layout as Extensions of TKS

The physical layout of traditional Khasi villages reflects ecological adaptation. Figure 4 and Table 1 capture the spatial typologies of settlements across RI Bhoi. It visually contrasts TKS-aligned hill and ridge settlements.

Houses built on stilts allow rainwater to pass underneath, reduce flood damage, and create shaded storage areas. Locally sourced materials such as bamboo, timber, and thatch ensure environmental compatibility and easy repair (Laloo and Momin 2015). Village layouts follow contours, promoting natural drainage and reducing erosion. Public spaces are centrally located and multifunctional—serving as gathering places, drying grounds, and cultural venues. Walkways and communal paths respect slope gradients, and homes are spaced to reduce fire risk and maintain airflow. Settlement clusters maintain visual and ecological proximity to sacred groves and forest buffers, integrating cultural and environmental functions.

This architectural coherence, combined with the ecological sensitivity of settlement planning, illustrates how TKS remains a living form of spatial intelligence, continuing to shape resilient landscapes.

Table 1. Parameters for Settlement Siting in RI Bhoi

Parameter	Settlement Siting
Elevation	Settlements are mainly concentrated in low to mid-elevation zones, offering better accessibility and a favourable climate. High elevation areas remain largely uninhabited due to terrain challenges and remoteness.
Slope	Most buildings are located on gentle to moderate slopes, reducing the risk of landslides and construction difficulty. Steep slopes are mostly avoided, indicating slope-aware site selection.
Topography and Drainage	Settlements are placed on elevated or gently sloping areas, ensuring natural drainage and minimizing flood risk. Low-lying depressions and valleys are largely avoided for habitation.
Faults and Lineaments	Some settlements are near geological lineaments, which may offer groundwater advantages but pose seismic risks. These areas require structurally resilient construction and careful monitoring.

Prepared by the Author 2025

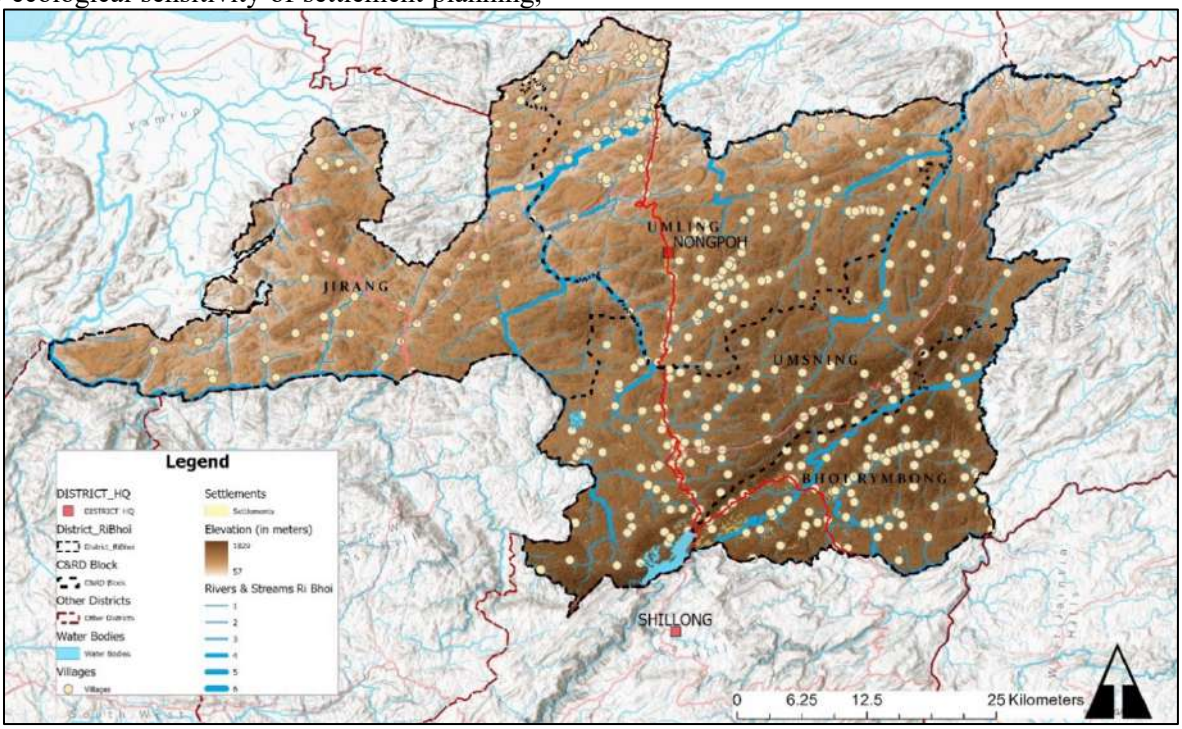


Figure 4. Correlation between elevation, topography, water bodies, slope, and settlements in RI Bhoi (Prepared by the author based on data from Google Earth Engine, WRIS and USGS)

4. Multi-Hazard Risk in RI Bhoi: Evolving Exposure in a Changing Landscape

While Traditional Knowledge Systems (TKS) have historically guided communities in RI Bhoi toward environmentally resilient living, the district's contemporary hazard profile is undergoing a marked shift. Climate variability, land use change, and ecological degradation are collectively altering the spatial dynamics of risk (IPCC 2023). This section analyses evolving multi-hazard risks—specifically flooding, landslides, and increasing cyclonic winds—and

their interaction with traditional spatial logic. Figure 5 illustrates this interaction hazards, and human settlements highlighting the at-risk habitations.

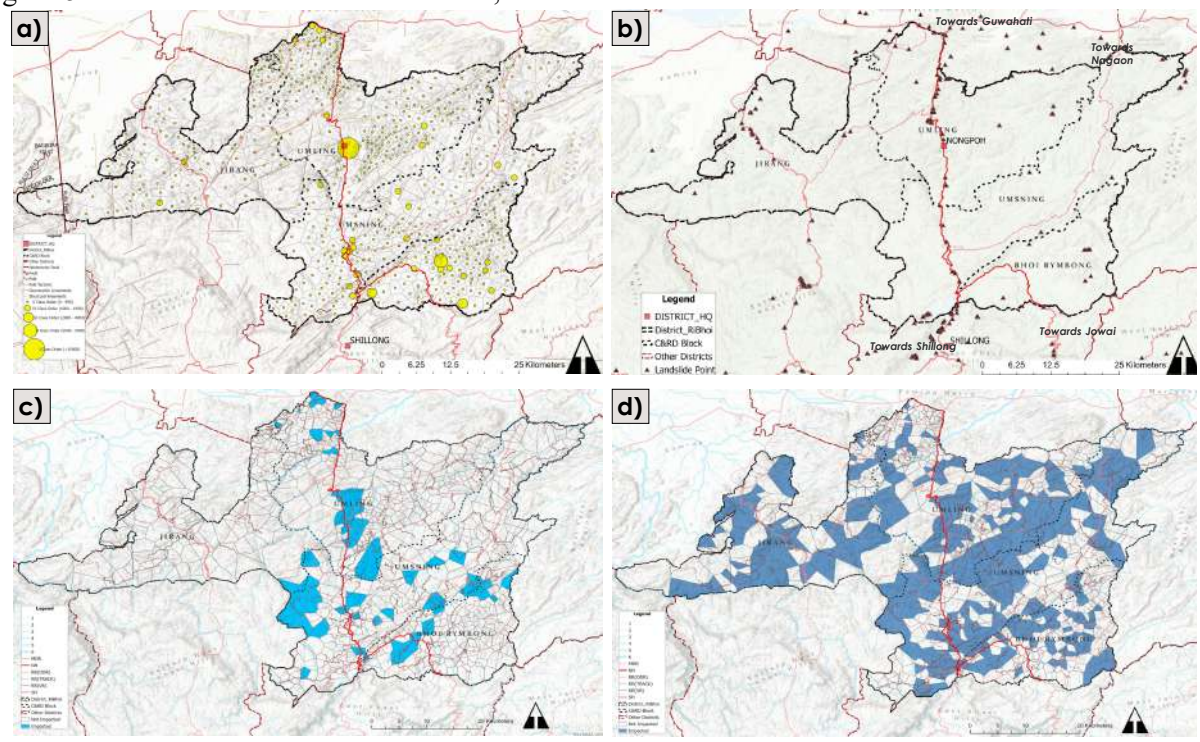


Figure 5. a) Faults, folds, and Settlements (Prepared by the author based on data from Bhukosh GSI, 2025); b) Landslide incidences; c) Flood-inundated villages; d) Villages impacted by cyclonic events (Prepared by the author based on data from the District Disaster Management Plan of RI Bhoi 2022)

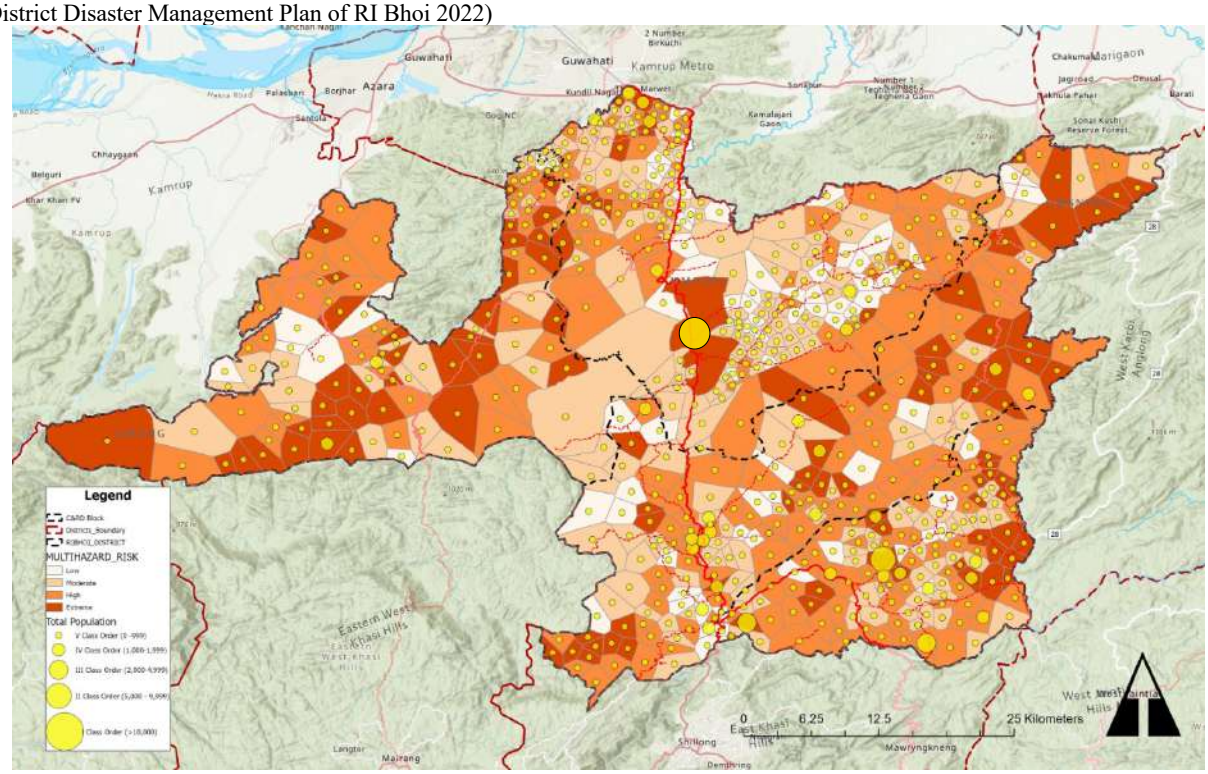


Figure 6. Multi-hazard Risk Map of RI Bhoi with overlay of village-wise total population (Prepared based on Census 2011)

4.1 Rainfall Variability and Climate Trends

Rainfall trends over the past 30 years reflect rising intra-seasonal variability, irregular monsoon onset, and short-duration high-intensity events (MoEFCC 2015, IMD Data 1992-2022). Although annual rainfall volumes remain consistent with long-term averages, the clustering of precipitation into fewer days has led to higher runoff, increased erosion, and stress on drainage systems. These patterns are particularly disruptive where land use change has reduced forest cover or altered natural infiltration zones (Forest Survey of India 2021).

4.2 Flooding and Waterlogging in Valley Zones

Settlements along the Umiam, Umsiang, and Umran river systems are increasingly susceptible to flash floods and seasonal waterlogging. Many peri-urban expansions now occupy flood-prone zones that were traditionally kept fallow or used only seasonally, indicating a departure from TKS-informed risk aversion. Field surveys revealed blocked natural drainage channels, undersized culverts, and stagnant water bodies in low-lying areas with poor percolation capacity.

4.3 Landslide Risk on Slopes and Cut Terrains

Landslides have been reported in areas where roads or housing projects have destabilized slope profiles. Mid-slope settlements—once considered safe by traditional norms—are now at higher risk due to tree felling, vertical slope cutting, and highway expansion. Slope mapping and field evidence indicate a growing landslide footprint in ecologically disturbed locations.

4.4 TKS and Cyclone Risk: Gaps and Complementary Measures

Cyclonic winds have emerged as a growing concern over the past decade. Historically, the Khasi Hills were shielded from coastal storm systems; however, changing wind patterns now bring more intense pre-monsoon and monsoon storms to the region (UN 2015). Roof damage, tree fall, and structural collapse have become more frequent, particularly in traditional bamboo and thatch homes. While these structures are well-adapted to rainfall and terrain, they remain vulnerable to wind uplift and displacement. Sacred groves, despite their ecological density, do not mitigate horizontal wind speeds across settlements. Furthermore, early warning systems, structural retrofitting measures, and community-level preparedness remain underdeveloped. This gap underscores the need for hybrid approaches that integrate TKS with engineered resilience—such as cyclone anchors, cross-bracing, and low-profile roof designs (Bernus and Chase 1990).

4.5 Multi-Hazard Risk Assessment

The multi-hazard scoring is computed at the village scale. Indicators are min–max normalised (0–1) and grouped into four components—hazard, exposure, sensitivity, and adaptive capacity—for two hazards: floods and cyclones. Table 10 outlines the aspect-wise parameters used for scoring. Hazard uses the relevant physical layers: flood-susceptibility for flooding and wind-hazard for cyclones. Exposure captures people/assets at risk: total population, population density, share of agricultural workers, and dependence on critical springs. Vulnerability is calculated using two aspects – Sensitivity and Adaptive Capacity. Sensitivity reflects predisposition to harm: sex ratio, proportion of marginal workers, work-participation rate, share of temporary houses, and absence of drainage, reliance on natural water sources, built-up percentage, barren-land percentage, and soil acidity. Adaptive capacity represents buffers that limit loss: facility score, health facilities, literacy, improved/treated water, household lighting/electricity, clean fuel, road density, forest cover, surface-water extent, number/condition of good springs, and presence of Community Led Landscape Management Project interventions by Meghalaya Basin Management Agency. Within each component, normalised indicators are averaged to obtain the component score. The per-hazard village risk is Hazard + Exposure + Vulnerability. Vulnerability = (Sensitivity − Adaptive Capacity) (same scale), and the overall multi-hazard score is the unweighted mean of the three per-hazard risk scores so that no single hazard is over-weighted.

4.6 Land Use Change and Amplified Risk

Land transformation has amplified all of the above hazards. Commercial farming, deforestation, and urban sprawl have displaced ecological buffers such as bamboo groves, rotational jhum fields, and riparian vegetation, reducing the land's capacity to regulate hydrology and stabilize soil. These hazards now co-occur in cascading sequences—where loss of vegetative cover intensifies flooding, which in turn destabilizes slopes—most evident in peri-urban belts and highway corridors where the spatial logic of TKS has broken down (Government of Meghalaya 2014). Figure 6 overlays multiple hazards—floods, landslides, and cyclones—highlighting that areas diverging from TKS-informed siting exhibit significantly higher vulnerability.

4.7 Spatial Discontinuity and Divergence from TKS in Recent Settlements

New settlements that disregard traditional siting principles exhibit consistently higher exposure to climate hazards. These areas—often densely built, poorly drained, and socio-ecologically fragmented—lack the resilience seen in older villages where TKS continues to guide decisions. Participatory Rural Appraisal (PRA) findings suggest that younger generations in these newer zones have limited knowledge of traditional siting norms, contributing to vulnerability

(Government of India 2002). In contrast, villages aligned with TKS experience lower hazard losses, greater water security, and stronger social cohesion.

Table 3. Parameters for Multi-Hazard Risk Assessment

Aspect			Flood	Cyclone
			Parameters	
Hazard		Extreme Events	Flood Susceptibility	Cyclone Proneness
			Landslide incidences	
Exposure		Villages	Population – Exposed to the risks	
Vulnerability	Sensitivity	Social & Economic	Sex Ratio - Females as a vulnerable group	
			Population Density - Higher Density is more sensitive	
			Agriculture Cultivators - Dependent on Climatic Conditions	
			Working Population – Marginal Workers	
			Workforce Participation Rate	
			Asset Index	
		Physical Infrastructure	LULC –Built Up Area - More built-up increases vulnerability	
			Houses – Temporary Structures are more vulnerable to floods and cyclonic storms	
			Sanitation & Drainage	
		Environment	LULC - Jhum & Barren Land – Degraded Land increases vulnerability	
			Forest-Forest Fires- Forest Degradation	
			Water-HH dependents on Natural sources of drinking water.	
			Ground Water – Spring - Critical and Poor-quality Springs	
			Soil Acidity - Low Productivity	
	Adaptive Capacity	Infrastructure	Facility Score - Better Resilience	
		Awareness	Literacy Rate - Climate & Social Awareness	
		Health	Health Centres - Access to Healthcare	
		Water	Improved Water Sources - Less dependent on surface water	
		Fuel	Clean Fuel - Less dependent on forests for Fuel wood	
		Accessibility	Road density of All-weather Roads - More accessibility	
		Green Area	Forest Cover - Better Recharge, Resilience & Ecosystem Services	
			Sacred Groves, Community forests - Preserved Forests by Community	
		Surface Water	Water bodies - Sink Area and Microclimate Regulation ECS	
			Sacred water bodies - Preserved Water Bodies by Community	
		Ground Water	Springs - Good quality springs	
		Initiatives	JFM & CLLMPs - Community Engagement	

5. Erosion of TKS: Drivers, Survival Patterns, and Consequences

Despite their proven role in sustaining ecological balance and reducing exposure to hazards, Traditional Knowledge Systems (TKS) in RI Bhoi is increasingly under pressure. As climate risks intensify and socio-economic structures transform, many communities are finding it difficult to maintain the cooperative frameworks and spatial reasoning that have historically guided their decisions on land use, settlement, and resource protection. Figure 7 provides a fishbone diagram representation of the drivers contributing to TKS erosion in RI Bhoi.

It categorizes pressures into socio-cultural, institutional, economic, and environmental factors, offering a structured lens through which the complexity of decline is understood. This decline is more than a cultural concern; it signals the weakening of a key system of adaptive governance, with direct consequences for resilience (Berkes 2012).

5.1 Drivers of TKS Erosion: From Customary Logic to Market Pressures

A combination of changes in land tenure, livelihoods, governance, and the environment is driving the weakening of TKS in RI Bhoi. One major factor is the growing emphasis on individual landownership and market-based agriculture. Where land was once communally managed, households now take independent decisions about settlement and farming, often ignoring slope, elevation, and drainage considerations that were previously embedded in the land.

Urban growth and the spread of highways have introduced a new spatial logic—one that favours accessibility and market potential over ecological suitability. Settlements have expanded along transport corridors, increasingly occupying floodplains and unstable slopes.

In many cases, older residents recall that these areas were avoided in the past due to their known hazards, yet today they are prized for commercial potential (Menon and Kohli 2019).

Traditional institutions like the Dorbar Shnong (village council) have also lost authority due to overlapping statutory institutions and a widening generational disconnect. Enforcement of community boundaries, whether for sacred groves or shared water sources, has weakened as formal planning frameworks seldom acknowledge these customary norms (Lyngdoh and Nongkynrih 2014).

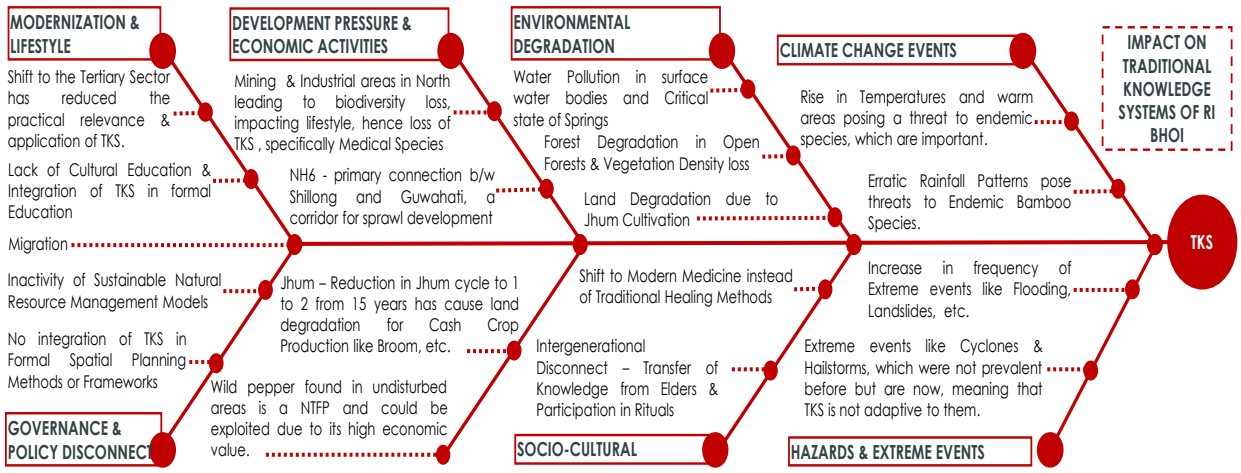


Figure 7. Fishbone Analysis - What is impacting the TKS in RI Bhoi?

Knowledge transmission has declined, too. Elders participating in Participatory Rural Appraisal (PRA) exercises repeatedly stated that younger generations have limited familiarity with traditional logic for siting, forest use, or sacred waterbody rituals. Urban influences, migration, and the push toward cash economies have all contributed to this thinning of ecological memory. Climate change has accelerated this erosion. The increasing frequency of extreme rainfall and cyclonic events has eroded confidence in older knowledge systems. Many hazards now exceed the adaptive scope of TKS. In some villages, traditional housing and grove maintenance are being abandoned in favour of externally funded infrastructure, even when these interventions are ecologically mismatched (IPCC 2023).

5.2 Patterns of Survival and Breakdown Across Communities

The erosion of Traditional Knowledge Systems (TKS) in RI Bhoi is uneven, with clear spatial patterns emerging from fieldwork and participatory assessments. Using a TKS Survival Rating developed for this study, villages were assessed across domains such as agriculture, forest and water management, settlement siting, disaster knowledge, and intergenerational transfer.

Upland and interior villages show high TKS survival, where traditional siting norms, sacred spaces, and collective resource governance remain integral to daily life. In contrast, peri-urban and highway-adjacent settlements exhibit low survival, marked by fragmented sacred sites, declining traditional practices, and weakening knowledge transmission. Transitional villages retain some rituals and institutions but show declining enforcement of communal rules. Sector-wise analysis reveals that while cultural and governance practices remain relatively strong, climate adaptation, water management, disaster preparedness, and settlement logic are significantly eroding, posing risks to long-term resilience. These patterns point to priority zones for intervention, while also identifying areas where TKS can still serve as a strong foundation for adaptive spatial planning.

5.3 Valuing What Remains: Ecosystem Services and Social Cohesion

Traditional Knowledge Systems (TKS) in RI Bhoi provides significant economic benefits alongside their cultural and ecological value, particularly by supporting climate adaptation and sustainable livelihoods for vulnerable households. Using a Payment for Ecosystem Services (PES) framework, the study estimates the economic value of TKS-linked products and services—such as indigenous silk, medicinal plants, bamboo tools, pest control, and groundwater recharge through sacred groves—based on market values and replacement costs. The findings show that the potential annual loss per household due to TKS erosion ranges from ₹23,700 to ₹42,500, amounting to nearly one-fourth to two-fifths of Meghalaya's per capita income. This highlights TKS as a functional economic system that reduces dependence on external inputs, buffers households against market and climate shocks, and supports low-cost adaptation. Beyond material benefits, TKS also strengthens social cohesion and collective governance, enhancing community capacity for disaster preparedness and recovery.

5.4 Why TKS Loss Matters in a Multi-Hazard Landscape

As climate risks intensify in the Indian Himalayan Region, the erosion of Traditional

Knowledge Systems (TKS) in RI Bhoi signifies not only cultural loss but also the weakening of a vital buffer against environmental hazards. The decline of TKS has increased exposure to flash floods, landslides, water scarcity, and cyclonic winds by undermining traditional practices of safe settlement siting, forest governance, and protection of sacred groves that once regulated runoff and erosion. Field surveys and satellite evidence show a shift toward construction and monoculture in hazard-prone areas, heightening slope instability and flooding. TKS erosion is further linked to social fragmentation in peri-urban zones, loss of intergenerational knowledge, and reduced collective capacity to respond to shocks. While emerging hazards reveal limits in traditional building systems, the findings point to the need for hybrid approaches that integrate TKS-based spatial logic with modern engineering and early warning systems, making TKS revitalization central to long-term climate adaptation in RI Bhoi.

6. Recommendations

The findings of this study underscore that Traditional Knowledge Systems (TKS) in RI Bhoi are not peripheral—they are central to climate resilience, resource governance, and the spatial logic of settlements. Their erosion is not merely a cultural concern but a direct threat to ecological stability and community safety. Addressing this requires deliberate, multi-scalar interventions that embed TKS within formal spatial planning, institutional structures, and incentive frameworks. The following proposals chart a pathway to operationalize this integration.

6.1 Zoning and Legal Recognition of TKS-Rich Landscapes

Traditional Knowledge Systems (TKS) in RI Bhoi is closely embedded in groves, forests, jhum landscapes, water commons, and ridge-line settlements, all of which are increasingly threatened by construction, mining, and speculative land use. To safeguard these culturally and ecologically sensitive areas, the study proposes a zoning framework that recognizes TKS-rich zones as ecological commons or cultural heritage areas. Based on field assessments, a land suitability matrix (Table 6) classifies terrain into low, moderate, and high development suitability, linked to parameters such as elevation, slope, proximity to springs, sacred site density, and ecological buffers. For example, areas above 900 m or near sacred groves are identified as low-suitability zones for development but appropriate for eco-tourism and biodiversity stewardship, while areas with gentle slopes and stable settlement patterns are classified as high-suitability zones.

Table 6. Activity Matrix based on Suitability Zones

Activity	Low Suitability Zone	Moderate Suitability Zone	High Suitability Zone
Conservation (Forests, Sacred Groves)	✓ Permissible	✓ Permissible	⚠ Buffer Protection Only
Agriculture / Horticulture	✗ Prohibited	✓ Permissible	✓ Permissible
Urban / Built Development	✗ Prohibited	⚠ Limited (low-density only)	✓ Permissible
Eco-Sericulture / Eco-Tourism	✓ Permissible	✓ Permissible	✓ Permissible
Mining / Quarrying	✗ Prohibited	✗ Prohibited	⚠ Conditional (community-regulated)
Infrastructure (Roads, Utilities)	⚠ Limited (low-impact only)	✓ Permissible	✓ Permissible
Sacred Water Body Use	✗ No Extraction (conservation only)	⚠ Limited Use (with regulation)	✓ Permissible
Traditional Craftsmanship / Cultural Use	✓ Permissible	✓ Permissible	✓ Permissible
NTFPs / Community Forest Use	✓ Permissible (regulated)	✓ Permissible	✓ Permissible

6.2 Hazard-Responsive Zoning for TKS-Based Climate Resilience

To address multiple emerging hazards—cyclonic winds, flooding, and erosion—zoning must go beyond topography and ecological logic. This study maps risk overlays using field-verified flood zones, cyclone-prone corridors, and deforested slopes to capture compound risk patterns. Based on this analysis, four key hazard categories are defined, including flood-prone, cyclone-prone, and multi-hazard zones, as illustrated in Figure 8, to support more risk-informed spatial planning.

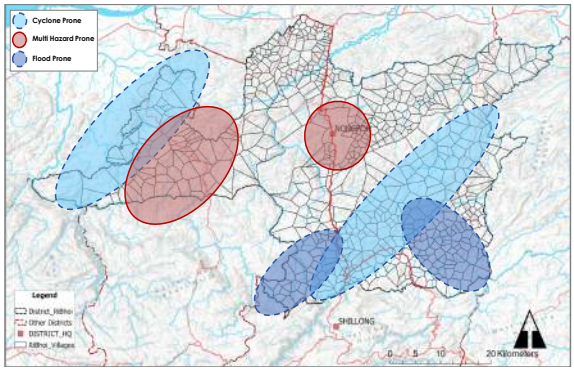


Figure 8. Proposed Hazard Responsive Zoning Map of RI Bhoi (Prepared by the Author, 2025)

Each zone warrants differentiated strategies. In cyclone-prone areas, settlement layout should incorporate wind corridors, diagonal bracing in buildings, and vegetative windbreaks using resilient bamboo species. In flood-prone zones, riverside buffers should be restored using

indigenous vegetation such as Syzygium cumini and Ficus religiosa, while built-up areas must be stilted or elevated (TERI 2018).

6.3 Settlement Siting Guidelines Rooted in TKS

To reduce climate vulnerability and align development with resilience goals, district and block-level planning must adopt TKS-informed settlement siting guidelines. In RI Bhoi, Traditional Knowledge Systems have long guided habitation placement based on elevation, slope, drainage, and water access, thereby avoiding hazard-prone areas and preserving ecological balance. These principles should be institutionalized through formal planning frameworks. Future settlements should prioritize mid-slope elevations between 700 and 1,200 meters, which offer reduced flood and landslide risk while maintaining access to springs and favourable microclimates. Low-lying floodplains, steep hilltops, and areas near geological faults should be designated exclusion zones for permanent habitation. Construction should be limited to gentle slopes below 15 degrees, with layouts following natural contours to support drainage and reduce erosion. Settlements should remain within 500 meters of reliable water sources, preserve sacred groves and forest buffers, and adopt climate-resilient housing forms such as raised or stilted structures. Embedding these TKS-based principles into zoning regulations, hazard maps, and approval processes can ensure that future settlement growth is ecologically sound, culturally rooted, and climate-resilient.

6.4 Strengthening and Revitalizing Traditional Institutions

Traditional institutions such as the Dorbar Shnong (Village Council) play a central role in land stewardship and ecological decision-making in RI Bhoi through their customary authority over sacred groves, springs, and community lands. This role has weakened due to administrative overlap, reduced community participation, and poor integration with formal planning systems. To reverse this trend, Dorbars should be formally recognized as key actors in district-level resilience planning, as outlined in the Responsibility Matrix (Table 7), with responsibilities for managing TKS Conservation Zones, protecting spring-sheds, and enforcing settlement siting norms in coordination with line departments. Strengthening Dorbar institutions through capacity building in participatory planning, mapping, and ecological monitoring—along with greater inclusion of youth and women—can reinforce locally rooted governance. Institutionalizing Dorbar involvement in spatial planning and conservation decisions repositions Traditional Knowledge Systems as operational frameworks for climate resilience and sustainable land management in RI Bhoi, Meghalaya.

Table 7 Proposed Matrix for Integrating TKS in Spatial Planning for Climate Adaptation

Aspect	Spatial Planning Parameter	Climate Adaptation Parameter	TKS Parameter
Natural Capital	**Climate**	Climate variability, temperature rise, extreme events	Flora & fauna indicators, astronomical cycles
	Water Resources – Surface & Ground	Water security, flood & drought resilience	Sacred water bodies, hydrology practices
	Land	Landslides, land degradation, erosion	Terracing, bunding, vegetative measures
	Forests & Wildlife	Forest fire, biodiversity conservation	Sacred groves, community forest management
Human Capital	**Demography and Socio-economic**	Gender roles, literacy, infrastructure access	Indigenous practices, oral traditions
Financial Capital	**Agriculture & Allied Sectors**	Livelihood security, NTFPs, climate-smart farming	Composting, cropping calendar, and organic practices
	Household Industries	Raw material access, product quality	Organic dyeing, weaving skills
Physical Capital	**Water**	Irrigation, harvesting, and access equity	Check dams, bamboo drip irrigation
	Settlement / Disaster Resilience	Multi-hazard planning, vernacular adaptation	Vernacular architecture, bamboo technology
Social Capital	**Inclusive Governance**	Access to institutions, community-led management	*Dorbars (councils)*, sacred forest rules, JFMCs

7. Conclusion

Protecting and revitalising Traditional Knowledge Systems (TKS) in RI Bhoi is not cultural nostalgia but a strategic pathway for climate adaptation, ecological balance, and spatial justice. The study shows that villages where TKS remain active—through forest governance, water stewardship, and settlement siting—demonstrate greater resilience to climatic stress. At the same time, areas experiencing TKS erosion face higher hazard exposure and resource degradation. Embedding TKS into mainstream planning requires recognising TKS landscapes in zoning, aligning settlement planning with traditional siting rules, empowering Dorbar institutions, and valuing ecosystem services sustained by these systems. Such integration must

be locally driven, with youth, women, and knowledge custodians playing a central role in sustaining living practices rather than static documentation. The paper argues for mutual integration, where TKS actively shape formal planning and governance to improve outcomes. While TKS alone may not address all emerging risks, targeted policy support, PES-based valuation, and community-led spatial planning can significantly enhance resilience. Beyond RI Bhoi, formally recognising and resourcing TKS within planning and hazard frameworks offers a cost-effective, equitable adaptation strategy for climate-vulnerable regions.

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Ecosystem Service Dependency Analysis of River and Forest Systems

A Case of the Gurupura River Basin, Mangaluru

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Abstract: In ecologically sensitive areas, development spouts that tend to be unplanned result in overexploitation and degradation of natural ecosystems. River and forest ecosystems in Dakshin Kannada's Gurupura River Basin play a vital role in the sustainability of surrounding settlements. This study seeks to understand how rural and urban communities depend on these ecosystems for a broad spectrum of services, including food, water, flood protection, cultural values, and ecological support. While it is commonly understood that the nature of ecosystem services is well established, it is important to see how dependence on these services varies across space and settlement types. Comprehending such patterns is important to ensure planning that balances conservation and development. The study chooses a spatial approach, buffering the river and the forest, to quantify the degree of ecosystem service dependence of the surrounding villages. The services are classified into four types: provisioning, regulating, supporting, and cultural (MEA 2005). Secondary data and field surveys are utilized to rank, normalize, and map dependence levels. Findings indicate that villages surrounding the forest are heavily dependent on provisioning and supporting services, particularly for necessities such as fuel, food, and water. Alternatively, settlements surrounding the river, and urban settlements in general, are more dependent on regulatory and cultural services, such as flood mitigation and recreation. These differences highlight the importance of place-based planning responses. By mapping dependency, this study offers a useful tool for integrating ecosystem services into land-use planning and river management, especially for west-flowing rivers that are often overlooked in national planning efforts.

Keywords: Ecosystem services, Dependency mapping, Gurupura River, Forest and River ecosystem, Spatial planning.

सार: पारिस्थितिक रूप से संवेदनशील क्षेत्रों में विकास परियोजनाएँ अक्सर अनियोजित होती हैं, जिससे प्राकृतिक पारिस्थितिकी प्रणालियों का अत्यधिक दोहन और क्षरण होता है। दक्षिण कन्नड़ के गुरुपुरा नदी बेसिन में नदी और वन पारिस्थितिकी प्रणालियाँ आसपास की बस्तियों की स्थायित्व में महत्वपूर्ण भूमिका निभाती हैं। यह अध्ययन यह समझने का प्रयास करता है कि ग्रामीण और शहरी विभिन्न समुदाय खाद्य, जल, बाढ़ सुरक्षा, सांस्कृतिक मूल्यों और पारिस्थितिक समर्थन जैसी विस्तृत श्रृंखला की सेवाओं के लिए इन पारिस्थितिकी प्रणालियों पर कैसे निर्भर हैं। जबकि आमतौर पर समझा जाता है कि पारिस्थितिकी सेवाओं की प्रकृति सुस्थापित है, यह महत्वपूर्ण है कि यह देखा जाए कि इन सेवाओं पर निर्भरता स्थान और बस्ती के प्रकारों के अनुसार कैसे भिन्न होती है। ऐसे पैटर्नों को समझना संरक्षण और विकास के बीच संतुलन सुनिश्चित करने के लिए नियोजन के लिए महत्वपूर्ण है। अध्ययन एक स्थान-संबंधी दृष्टिकोण अपनाता है, नदी और वन के चारों ओर बफर क्षेत्र निर्धारित करके आसपास के गाँवों की पारिस्थितिकी सेवाओं पर निर्भरता की मात्रा का परिमाणन करता है। सेवाओं को चार प्रकारों में वर्गीकृत किया गया है: प्रावधानीकरण, नियामक, सहायक और सांस्कृतिक। द्वितीयक आँकड़ों और क्षेत्र सर्वेक्षणों का उपयोग निर्भरता स्तरों को स्थान देने, सामान्य बनाने और मानचित्रित करने के लिए किया जाता है। निष्कर्षों से संकेत मिलता है कि वन के आसपास स्थित गाँव पूरक और सहायक सेवाओं पर अत्यधिक निर्भर हैं, विशेषकर ईंधन, खाद्य और जल जैसी मूलभूत आवश्यकताओं के लिए। इसके विपरीत, नदी के आसपास की बस्तियाँ और सामान्य रूप से शहरी बस्तियाँ बाढ़ नियमन और मनोरंजन जैसी नियामक और सांस्कृतिक सेवाओं पर अधिक निर्भर हैं। ये अंतर स्थान-आधारित नियोजन प्रतिक्रियाओं के महत्व को रेखांकित करते हैं। निर्भरता को मानचित्रित करके, यह अध्ययन भूमि-उपयोग नियोजन और नदी प्रबंधन में पारिस्थितिकी सेवाओं को एकीकृत करने के लिए एक उपयोगी उपकरण प्रदान करता है, विशेषकर पश्चिम-प्रवाहित नदियों के लिए, जिन्हें राष्ट्रीय नियोजन प्रयासों में अक्सर नज़रअंदाज़ किया जाता है।

मुख्य शब्द: पारिस्थितिक तंत्र सेवाएं, निर्भरता मानचित्रण, गुरुपुरा नदी, वन और नदी पारिस्थितिक तंत्र, स्थानिक योजना

1. Introduction

Understanding how communities rely on natural ecosystems is essential for designing resilient environmental planning strategies. In rapidly urbanizing regions, this dependency becomes even more pronounced, particularly where ecosystem services underpin daily life, agricultural productivity, and regional water security. In other words, there is a direct linkage between livelihood, biodiversity, ecosystem services and poverty. Whilst ecosystem services are usually the environmental benefits human beings receive from nature; biodiversity enables their supply. These benefits enable them to live life better and enhance their quality of life. The Gurupura River Basin in coastal Dakshina Kannada is one such region, where the interconnectedness between local populations and the surrounding forest and riverine ecosystems has direct implications for both ecological sustainability and human well-being (Kumar et al. 2019).

A mapping technique based on quantification has been adopted to assess the dependency of the human population (including inhabitants and those residing near natural ecosystems such as forests, wetlands, and rivers) on the benefits they provide. This study focuses specifically on

assessing the dependency of rural communities on ecosystem services across forest and river ecosystems in the Gurupura River basin. The ecosystems in question perform critical functions, providing drinking and irrigation water, supporting agriculture, offering medicinal resources, regulating microclimates, recharging groundwater, and mitigating floods. These functions are captured through the lens of the four categories of ecosystem services defined by the Millennium Ecosystem Assessment (2005): provisioning, regulating, supporting, and cultural services. The identification and prioritisation of ecosystem services are based on a literature review, an environmental observation technique, and a primary survey conducted by the authors.

By mapping and quantifying these dependencies, the research seeks to inform more ecologically sensitive spatial planning in a region where ecological degradation, climate risks, and increasing land-use pressure threaten the very systems on which local communities depend. Unlike conventional environmental assessments, which often consider ecosystem functions in isolation, this study employs a spatially explicit, community-centred approach. It evaluates how the intensity of human dependency on ecosystem services varies across geographic buffers and hydrological subzones, using primary survey data and field observations to score and normalize these relationships.

Focusing on the rural landscape, the study assesses two major systems: forest ecosystems, analysed within ecologically sensitive buffer zones, and riverine ecosystems, studied within micro-watersheds along the 5th-order stream of the Gurupura River. Each service is evaluated using a set of indicators, weighted, and analysed using the Analytical Hierarchy Process (Saaty, Vargas and St. 2022) to develop a comparative spatial understanding of service dependency. This paper lays the groundwork for further discussion of prioritising of conservation actions, policy frameworks, and land-use strategies that acknowledge and support these vital human-ecosystem interdependencies.

Though extensive literature exists on ecosystem services, very few have directly measured human dependency across the west-flowing river basins of India through a spatial lens. Whilst urban Gurupura, a sub watershed of the larger Netravati River basin, needs pollution redressal, the Rural Gurupura river, which is defined in the context of the study as the river with its channel, riparian zone, and areal subunits – watersheds including human settlements and anthropogenic activities within the watersheds lying outside the urban territorial limits of Mangaluru (planning and municipal area) and other urban areas. This includes all such forest areas within the Gurupura Basin in the Western Ghats, from the ESZ of Kudremukh National Park, where it originates, to where it flows for 60.42 kms before entering the planning area of Mangaluru, which supports the human population and its livelihoods. The river is an integral component of their culture, and its ecological health is sustained by the interaction between the blue (streams and waterbodies in the sub watershed) and the green (forests). Understanding the ecological health of both forest and river ecosystems is deemed imperative for the sustained delivery of ecosystem services that determine the quality of life of the dependent human population. This is also deemed essential for other living organisms, which it supports through ecosystem services.

Though in contemporary discourse the role of ecosystem services is duly emphasised, they are rarely integrated into the spatial planning approaches (both in regional and urban planning). Whilst natural ecosystems deliver a host of ecosystem services, with people being directly dependent on them, they are often overlooked in the framing of development projects. The purpose of the current research is ‘conservation of natural resources and finding ways to improve ecological health’ ensuring the delivery of ecosystem services and contributing to spatial planning to develop a scientifically informed, integrated framework. This shall enable the design of commensurate policies that minimize the negative externalities of development and lay a foundation for ecologically balanced development. However, in order to achieve the mentioned objective, one needs to “measure”. This research addresses the gap, by presenting dependency-based mappings of the ecosystem services of the Gurupura River Basin, intertwining primary observations from the site, secondary data, and various spatial data with a buffer- and micro-watershed-based GIS framework. Furthermore, coupling the Analytical Hierarchy Process (AHP) with spatial dependency analysis is a methodological addition that facilitating a structured, replicable, and systematic approach to ordering ecosystem services based on people's dependency. In the process, the research contributes academically through the refinement of methodologies used to assess ecosystem services, and practically through the development of a planning-relevant tool that shall contribute to decision-making

regarding land-use change and conservation measures.

2. Literature Review

The recognition that ecosystems are not just natural entities but life-support systems for human wellbeing gave rise to the concept of ecosystem services. These are the benefits people obtain from ecosystems, ranging from food, fresh water, and fuelwood to flood control, soil fertility, and spiritual value. Millennium Ecosystem Assessment 2005 (Figure 1) provided a global framework that categorizes these services into four types: "provisioning, regulating, supporting, and cultural."

This framework has become foundational in both ecological science and planning practice. Provisioning services refer to tangible outputs such as food, timber, and freshwater. Whilst the regulating services include controlling climate, water flows, and disease vectors, the supporting services sustain fundamental ecological processes such as nutrient cycling and primary production. Further, the cultural services relate to non-material benefits such as recreation, aesthetic values, and spiritual significance. Together, these categories offer a structured lens to understand how ecosystems sustain both rural and urban societies.

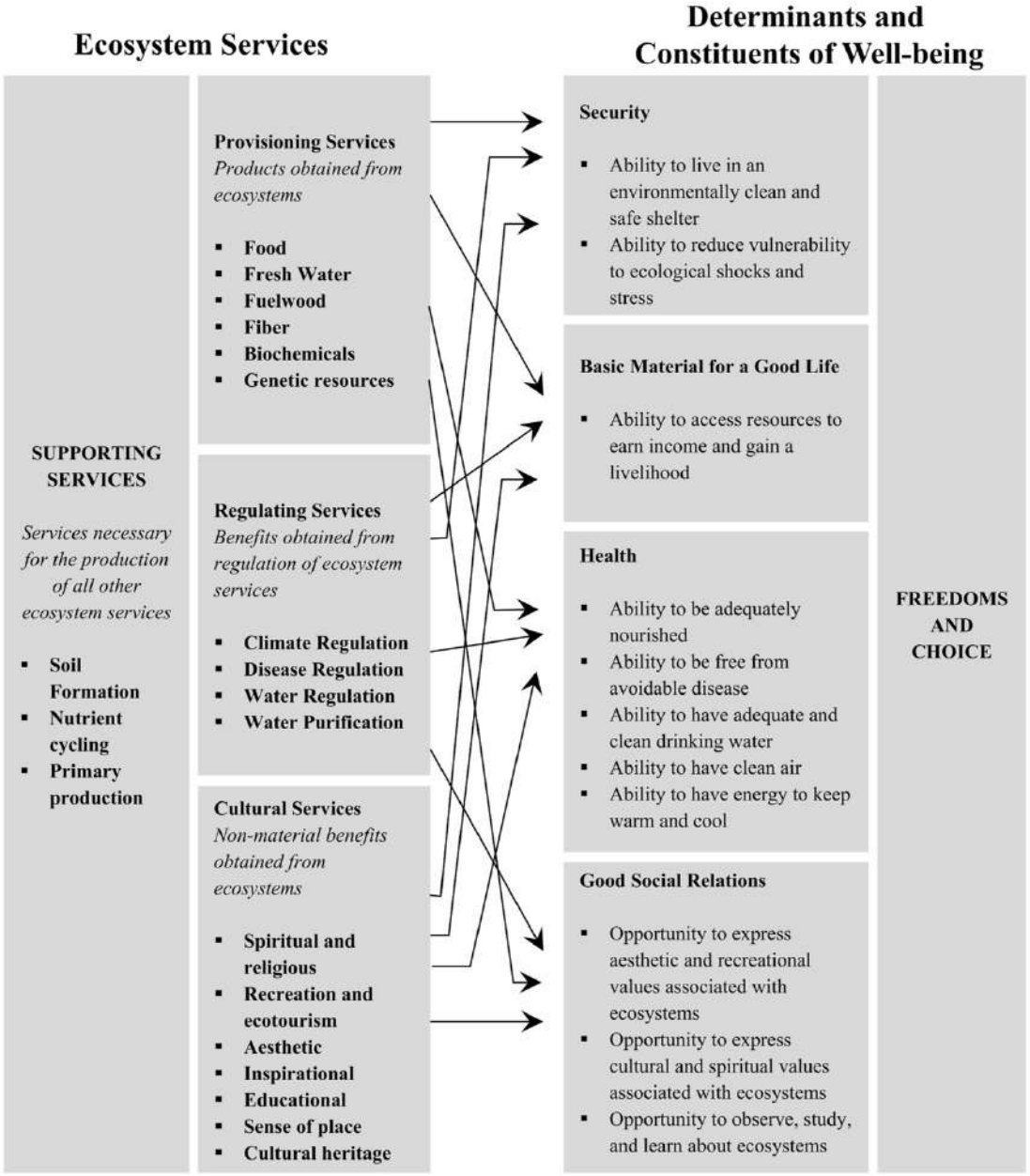


Figure 1. Ecosystem Services Classification (Millennium Ecosystem Assessment 2005)

In the Indian context, these ecosystem services are deeply embedded in the everyday lives of communities, especially those residing near forests and rivers. However, most planning

and development decisions do not explicitly account for them. This disconnect often leads to policies that degrade ecological health and increase long-term vulnerability, particularly in rapidly urbanizing regions where ecosystem thresholds are already under stress.

To address this, a growing body of work has focused on operationalizing ecosystem services within development planning. The Economics of Ecosystems and Biodiversity (TEEB) framework is among the most influential approaches in this regard. It emphasizes the need to make the value of ecosystem services visible and usable for decision-making. The GIZ-adapted version of the TEEB approach, widely used in Indian case studies, provides a stepwise methodology to identify priority services, assess their condition, and integrate these insights into local or regional policy (TEEB 2010).

A crucial aspect of this framework is understanding dependency: how different sectors and communities rely on healthy ecosystems to function. In river basins such as the Gurupura, this dependency spans both rural livelihoods and urban infrastructure. Agricultural activities, drinking water supply, tourism, and even cultural practices are closely tied to the functioning of forest and river systems. The degradation of these systems is not just an ecological issue but a socio-economic and planning concern.

Recent planning literature also advocates for spatializing ecosystem service assessments. Instead of treating ecosystems as background scenery, they are increasingly mapped as service-producing systems with specific spatial distributions, intensities, and vulnerabilities. These spatial patterns help reveal where high dependency overlaps with high ecological stress, critical insights for prioritizing interventions.

In parallel, there has been a call to integrate ecosystem service valuation within formal planning frameworks in India. The National Institute of Urban Affairs (NIUA), through its Urban River Management Plan (URMP) guidelines, has emphasized the inclusion of ecological value in city planning. While URMPs often focus on pollution control, drainage infrastructure, and regulatory compliance, few of them embed a spatially explicit understanding of how human populations depend on riverine or forest ecosystems (NIUA 2020). This gap limits the scope of management strategies and weakens their long-term resilience outcomes.

Together, these strands of literature indicate a shift in how we understand and plan for ecosystems. Traditionally, ecosystem studies were restricted to experts in the field of ecology. However, it is now being explored by experts from diverse domains. It is no longer static, giving way to multiple vocabulary- and systems-based approaches that emphasise service delivery, human dependency, and dynamic feedback. This study builds on that shift by applying a spatially grounded ecosystem service dependency analysis to the Gurupura River Basin, focusing specifically on the rural communities that rely on forest and river ecosystems. Rather than treating services as inventories, this research considers them as lived relationships that vary across space and time, relationships that must be understood if planning is to support both ecological integrity and human wellbeing genuinely.

3. Methodology

The methodology adopted for this study integrates spatial analysis, field-based survey data, and multi-criteria decision-making techniques to evaluate the dependency of rural communities on forest and river ecosystems for ecosystem services. The analysis is conducted in two parts: identification and scoring of ecosystem service indicators based on community-level primary data, followed by normalization and spatial analysis using buffer and watershed-based units.

The study area comprises the rural landscape of the Gurupura River Basin, including forested zones and riverine systems outside the Mangaluru urban planning boundary. The assessment focuses on two major ecosystem types: the forest ecosystem, which forms part of the Western Ghats ecologically sensitive zones, and the river ecosystem, which follows the 5th order stream in the rural areas of the Gurupura River. The services evaluated include provisioning, regulating, supporting, and cultural services, in line with the Millennium Ecosystem Assessment framework.

A primary household survey was conducted using questionnaires developed separately for forest and river ecosystems. These questionnaires collected both qualitative and quantitative data from communities residing within predefined spatial buffers. For the forest ecosystem, a buffer of up to 10 kilometres was created, segmented into 2 km, 5 km, 7 km, and 10 km zones. Villages in the inner 0-5 km core area were weighted more heavily due to their proximity to dense forest cover and greater ecological sensitivity. In the river ecosystem, micro-watersheds along the

rural river zone were considered using 2 km, 5 km, and 7 km buffers, with priority given to the transition zone at elevations between 20 and 80 meters, which supports intensive agricultural and domestic interaction with the river.

Indicators under each ecosystem service category were derived from both the literature and field observations. The dependency of each village on the identified services was scored on a scale of 1 to 10, with 1 indicating low dependency and 10 indicating high dependency. These raw scores were normalised to allow cross-comparison between spatial units. To assign relative weights to indicators, the Analytical Hierarchy Process (Saaty, Vargas and St. 2022) was employed. AHP allowed pairwise comparisons for weighting, followed by consistency checks to validate the judgments.

Spatial mapping was carried out using GIS. Village-wise scores were normalized and overlaid on spatial layers (village boundary and sub-watersheds) to generate thematic maps representing dependency patterns. These maps helped in identifying critical zones of dependency where planning interventions would be most needed. Separate composite maps were generated for each ecosystem service category (provisioning, regulating, supporting, and cultural), and a cumulative ecosystem service dependency map was prepared for both ecosystems. While the regulating ecosystem services benefit human societies beyond the delineated buffers, the study, has also assessed them within the buffers.

The idea of assessing ecosystem service flows based on the buffer technique was adapted from numerous papers, as well as the buffering of protected areas with core, buffer, and interim zones, and Eco-sensitive areas and zones. Whilst the first part was adopted from the paper "National Parks, buffer zones, and surrounding lands: Mapping ecosystem service flows" (Palomo et al 2013), the second phrase of Eco-sensitive zones was adapted from the guidelines for establishing ESZ, which also mentions its extent up to 10 km (Government of India 2011). By choosing these thresholds, the analysis is kept consistent with previous planning and assessing practice while taking into account the spatial gradient of ecosystem interdependence across regions of intimate interaction (2 km and 5 km) to buffer regions of peripheral influence (7 km and 10 km) primarily emerged from the direct and indirect dependence on the ecosystem services (Mallick et al. 2021) This was further supported by environmental observation and primary survey. Further, the buffer distance selections (2 km, 5 km, 7 km, and 10 km) were derived from general standards adopted in environmental appraisal and planning regulations in India. Environmental Impact Assessments (EIA) of industrial, infrastructure, and land-use proposals conventionally delimit study areas through concentric buffer zones, and 10 km (Government of India 2021) is often taken as the best estimate of the maximum ecological and socio-economic influence radius.

The weighting applied to the analysis (e.g., 3× and 2× multipliers) was chosen to reflect the diminishing strength of ecosystem interactions with increasing distance from the resource. Villages within the 0–5 km bracket are normally directly connected to forest resources or riverine services, obtaining provisioning resources on a day-by-day basis or taking advantage of regulating services for water supply and protection against floods. A higher weighting (3×) for these villages reflects their intense, frequent use. Those within the 5–7 km bracket remains dependent on these services but frequently indirectly, and therefore a moderate weighting (2×) is appropriate. Beyond 7 km, levels of dependency diminish and become more diffuse, as is the case with the lower weighting. Distance-decay thus follows ecological economics literature on resource access and service usage. The scores are normalized and mapped spatially.

The questionnaire was designed to capture demographic, socio–economic, ecological aspects, including resource dependency, cultural, and ecological memories. The emphasis on the questionnaire was on the identification of the typology of resources that the dwellers are dependent on, the degree of dependence on the mentioned ecosystem, their purpose of extraction, utilization, conservation, and regeneration of resources, the challenges they confront, and the changes they have witnessed over time, along with their perspective of 'development'.

There are certain limitations to this method. The dependency scores collected through surveys may be influenced by how well people remember information, their personal opinions, or seasonal changes in how they use ecosystem services. Moreover, the weightage constants used in the analysis were based on the interactions with local experts. Whilst this is not a foolproof method, it is one of the first to assess ecosystem service flows spatially. Such selections are suitable for preliminary spatial evaluation. However, future

research should be based on robust databases that can be aligned with the AHP (Analytical Hierarchy Process) for calculating weightings and the consistency ratio.

The forest ecosystem service dependency analysis and scoring outcomes were consolidated in Table 1, presenting the final normalized dependency values across all assessed villages. The spatial extent and categorization of the forest ecosystem and its associated villages are depicted in the map shown in Figure 2.

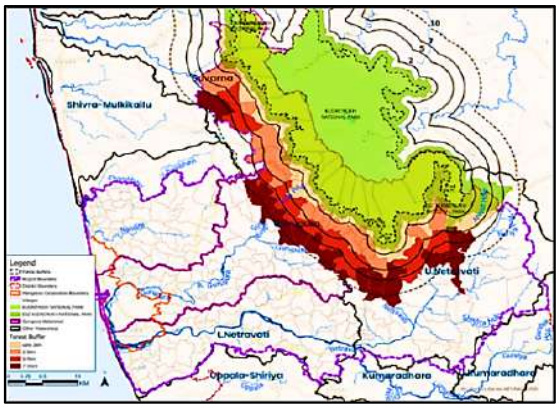


Figure 2. Map showing forest buffer and villages (Ananya 2025)



Figure 3. Map showing River Zones (Ananya 2025)

For the river ecosystem, the same methodological structure was applied. Micro-watersheds were used as the unit of analysis, and villages within them were assessed for their degree of dependency on river ecosystem services. Particular attention was given to regulating services, such as flood mitigation and groundwater recharge, given their importance in this low-lying coastal context.

The spatial context of river zones, comprising source, transition, and deposition regions, is presented in Table 2 and Figure 3, providing a geomorphological framework for understanding hydrological processes and human–river interactions. This zoning helps situate patterns of resource use, risk exposure, and ecosystem service provision along the river continuum.

Table 1. Normalized score for forest ecosystem services

Ecosystem Services		Score		Normalised Value		
		Research Observation (Out of 10)	Primary Survey	Research Observation	Primary Survey	Average
Provisioning	Freshwater	8	9	0.7	1	0.8
	Source of food	8	8	0.7	0.8	0.7
	Timber, Fiber	8	6	0.7	0.3	0.5
	Medicines	9	8	1	0.8	0.9
	Total					2.9
Regulating	Erosion regulation	6	5	0	0	0
	Micro-climate regulation	8	8	0.7	0.8	0.7
	Water quality	9	8	1	0.8	0.9
	Carbon sequestration	8	7	0.7	0.5	0.6
	Ground water recharge	8	7	0.7	0.5	0.6
	Flood mitigation	6	6	0	0.3	0.1
	Total					2.9
Supporting	Nutrient cycling & soil formation	8	7	0.7	0.5	0.6
	Habitat for species	9	8	1	0.8	0.9
	Employment generation	7	6	0.3	0.3	0.3
	Total					1.8
Cultural	Cultural & Religious importance	8	7	0.7	0.5	0.6
	Recreation & tourism	8	8	0.7	0.8	0.7
	Aesthetic value	8	7	0.7	0.5	0.6
	Total					1.9

Table 2. Normalized score for riverine ecosystem services

	Ecosystem Services	Score		Normalised Value		
		Research Observation (Out of 10)	Primary Survey	Research Observation	Primary Survey	Average
Provisioning	Freshwater	9	9	1	1	1
	Source of food	7	6	0.3	0.3	0.3
	Timber, Fiber	8	6	0.7	0.3	0.5
	Medicines	9	8	1	0.8	0.9
	Total					**2.6**
Regulating	Erosion regulation	6	5	0	0	0
	Micro-climate regulation	7	7	0.3	0.5	0.4
	Water quality	9	8	1	0.8	0.9
	Carbon sequestration	7	7	0.3	0.5	0.4
	Ground water recharge	9	8	1	0.8	0.9
	Flood mitigation	8	7	0.7	0.5	0.6
	Total					**3.2**
Supporting	Nutrient cycling & soil formation	8	7	0.7	0.5	0.6
	Habitat for species	9	8	1	0.8	0.9
	Employment generation	7	6	0.3	0.3	0.3
	Total					**1.8**
Cultural	Cultural & Religious importance	8	7	0.7	0.5	0.6
	Recreation & tourism	8	8	0.7	0.8	0.7
	Aesthetic value	8	7	0.7	0.5	0.6
	Total					1.9

The indicators and scores derived from the primary field survey are further supported by summary visuals that illustrate observed patterns of community dependency on river-based ecosystem services. Figures 4 and 5 synthesize these field findings across the four categories of ecosystem services, highlighting variations in provisioning, regulating, supporting, and cultural services across different river zones and settlement contexts.

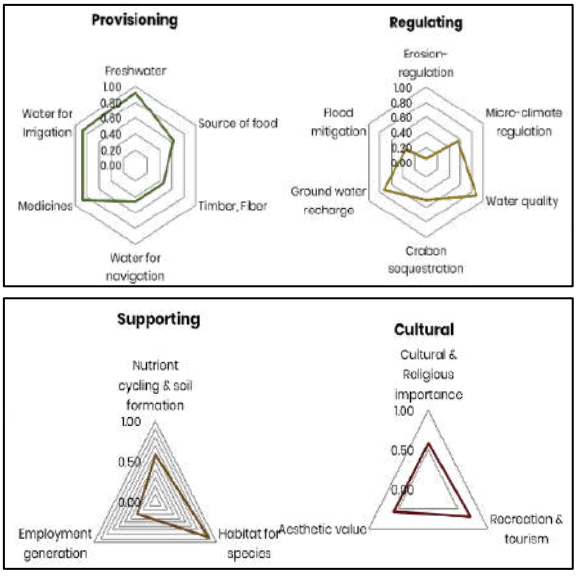


Figure 4. Score of Ecosystem Service indicators as per primary survey and research observations (Ananya 2025)

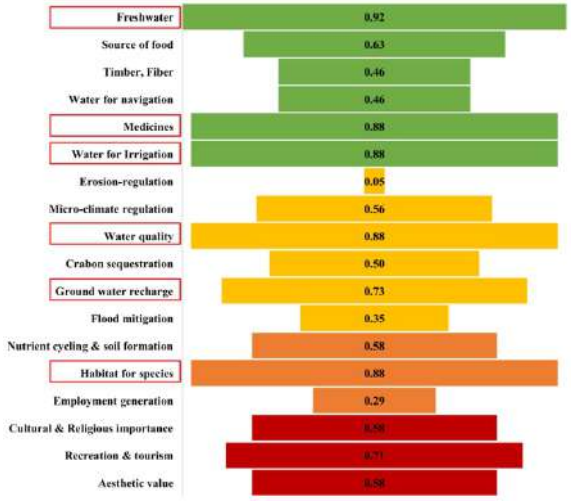


Figure 5. Chart depicting the ecosystem services with their scores (Ananya 2025)

4. Results

The results of the ecosystem service dependency analysis are presented separately for the forest and river ecosystems. Both systems were assessed using a spatially grounded approach that combined field survey data with normalized scoring and GIS-based analysis. The findings show variations in dependency patterns across both ecosystems and service categories, as well as settlement proximity to ecological resources.

4.1 Forest Ecosystem Service Dependency

For the forest ecosystem, the buffer is considered as per the guidelines to establish Eco-sensitive zones with a buffer of up to 10 kms. The villages within the 2 core areas, (Table 3) indicate that dependency on forest ecosystem services is consistently high in villages located within this core buffer, indicating direct dependency (Jain et al. 2016). Provisioning services such as fuelwood, medicinal plants, and minor forest produce showed the highest dependency scores. Villages farther from the forest edge demonstrated lower dependence across all categories. Each ecosystem service was scored on a scale of 1 to 3, where 1 denotes low dependency and 3 denotes high dependency.

These scores are then normalized, and provisioning, regulating, supporting, and cultural services reveal a sharp spatial gradient. Villages within the 0-2 km zone scored above 0.6 for provisioning and cultural services, while those beyond 7 km dropped below 0.1 in all categories. Supporting services such as soil quality and biodiversity functions were recognized by fewer respondents, reflecting lower direct visibility of these services. Spatial patterns of dependency align with forest proximity and administrative accessibility. Villages with better access to forest trails exhibited higher dependency on both provisioning and cultural services.

To understand the cumulative dependency across all service categories: provisioning, regulating, supporting, and cultural (Millennium Ecosystem Assessment (2005), a cumulative dependency map (Figure 6) was generated. This map integrates the normalized scores and reveals broader spatial trends in forest ecosystem reliance, highlighting zones with the highest composite dependency values.

Table 3. Normalized Score for Forest Ecosystem Services

Ecosystem Service	Service	Indicator	Scores				Average			
			Core Area up to 2 km buffer	2–5 km buffer	5–7 km buffer	>7–10 km buffer	Core Area up to 2 km buffer	2–5 km buffer	5–7 km buffer	> 7–10 km buffer
Provisioning	Water	Percentage population dependent on ground & surface water source	0.64	0.2	0.22	0.04	0.68	0.24	0.13	0.03
	Source of food	Proximity to forest	0.66	0.25	0.1	0.02				
	Timber, fibre, & fuel	% HH using wood for cooking + % houses made of wood	0.66	0.25	0.1	0.02				
	Medicines	Proximity to forest	0.66	0.26	0.1	0.02				
Regulating	Air quality	Proximity to forest	0.67	0.26	0.1	0.02	0.66	0.23	0.14	0.03
	Micro-climate	% waterbody area + forest	0.67	0.25	0.1	0.02				
	Groundwater rejuvenation	Ground water levels	0.64	0.2	0.22	0.04				
Supporting	Nutrient cycling & soil formation	% waterbody area + forest	0.57	0.23	0.21	0.07	0.57	0.23	0.23	0.07
	Habitat for species	% Forest area	0.66	0.26	0.27	0.02				
	Employment Generation	Number of workers	0.47	0.2	0.21	0.12				
Cultural	Cultural & Religious importance	Presence of pilgrim sites	0.28	0.14	0.22	0.03	0.57	0.14	0.14	0.02
	Recreation & tourism	Tourist locations & proximity to forest	0.66	0.26	0.1	0.02				
	Aesthetic value	Proximity to forest & waterbodies	0.66	0.08	0.1	0.02				
	Research & knowledge building	Proximity to forest	0.66	0.08	0.12	0.02				
Dependency Average			**0.61**	**0.21**	**0.16**	**0.03**	**0.61**	**0.21**	**0.16**	**0.04**

Table 4. Normalized Score for River Ecosystem Services

Ecosystem	Service	Indicator	Scores			Average		
			Core Area up to 2 km buffer	2–5 km buffer	5–7 km buffer	Core Area up to 2 km buffer	2–5 km buffer	5–7 km buffer
Provisioning	Freshwater	Percentage population dependent on ground & surface water sources	0.4	0.2	0.1	**0.47**	**0.23**	**0.3**
	Fishing	Proximity to river	0.6	0.3	0.1			
	Irrigation	Area under irrigation	0.4	0.2	0.7			
Regulating	Water quality & flooding regulation	% forest area + flooding extent	0.6	0.3	0.1	**0.65**	**0.25**	**0.065**
	Carbon sequestration	% waterbody area	0.7	0.2	0.03			
	Micro Climate Regulation	Proximity to waterbody	0.7	0.2	0.03			
	Ground water regulation	Ground water levels	0.6	0.3	0.1			
Supporting	Nutrient cycling & soil formation	% waterbody area + forest	0.7	0.1	0.03	**0.5**	**0.2**	**0.08**
	Habitat for species	% Forest area	0.4	0.3	0.1			
	Employment Generation	Number of Agricultural workers	0.4	0.2	0.1			
Cultural	Cultural and Religious importance	Temples and festivals along the river	0.5	0.1	0.1	**0.6**	**0.13**	**0.07**
	Recreation & tourism	Tourist locations & proximity to forest	0.5	0.1	0.1			
	Aesthetic value	Proximity to forest & waterbodies	0.7	0.1	0.03			
	Research & knowledge building	Presence of pilgrim sites and proximity to waterbody	0.7	0.2	0.03			
Dependency Average			**0.56**	**0.20**	**0.12**	**0.55**	**0.20**	**0.13**

(Ananya 2025)

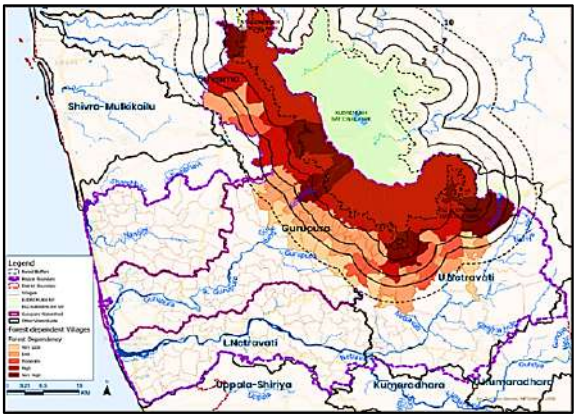


Figure 6. Cumulative Forest Ecosystem Service Dependency (Ananya 2025)

The category-wise spatial variation is illustrated through composite scoring across individual service types. Each map represents a distinct ecosystem service category derived from field data and normalized scores.

Dependency on provisioning services (Figure 7), such as fuelwood, medicinal plants, and minor forest produce, is highest in core forest villages with direct access to forest cover. Examples include villages such as Mala and Naravi, where daily subsistence needs like firewood collection and medicinal plant harvesting demonstrate strong provisioning dependence."

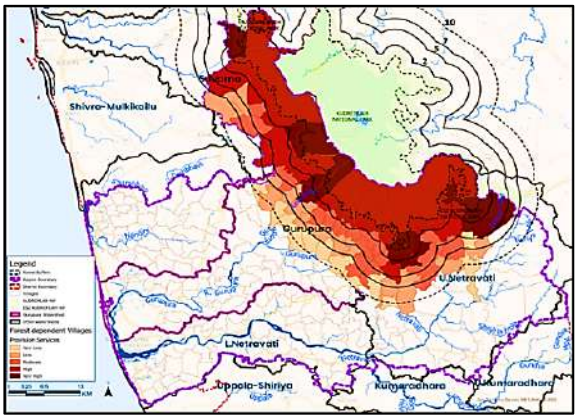


Figure 7. Forest – Provisioning Services (Ananya 2025)

Regulating services (Figure 8) show moderate dependency levels that taper outward from the forest core. Although the spatial analysis was carried out within the defined buffers, it is important to note that regulating functions, such as climate regulation, water flow moderation, and soil stability, extend beyond these zones and remain significant throughout the broader forested landscape.

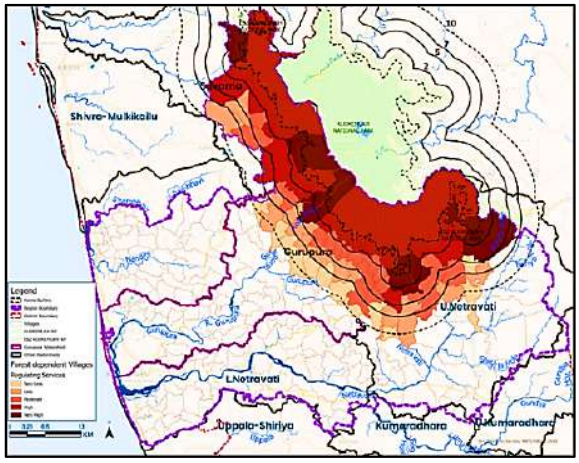


Figure 8. Forest – Regulating Services (Ananya 2025)

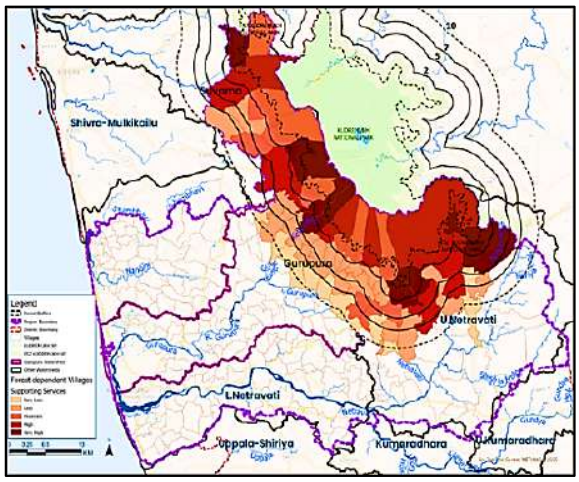


Figure 9. Forest – Supporting Services (Ananya 2025)

Supporting services (Figure 9) are critical for long-term ecological functioning and show higher mapped relevance in densely vegetated patches.

Cultural services (Figure 10) show highly localized dependency patterns, clustered around historically significant forest-linked settlements. This is particularly evident in villages like Nooralbettu, Eedu, Naravi, Sulkerimogru, and many others within the ESZ of the Kudremukh National Park, where traditional rituals, sacred groves, and forest-linked festivals continue to anchor local cultural identities.

4.2 River Ecosystem Service Dependency

In the Riverine ecosystem, villages are considered within the 2, 5, and 7 km buffers (Figure 11). Moreover, the same scoring pattern has been followed, focused on the rural reaches of the Gurupura River, particularly along its fifth-order stream segments. Survey responses revealed strong reliance on river-based provisioning services, including irrigation, drinking water for livestock, and household use. Regulating services such as flood mitigation and aquifer recharge were also recognized, especially in mid-elevation zones with sloping terrain.

Normalized scores (Table 4) highlight high dependency in the transition zone between 20- and 80-meter elevation. Smallholder agriculture and groundwater recharge form a mutually reinforcing relationship. Downstream villages show reduced dependence on provisioning but higher recognition of cultural and regulatory services. The cumulative map (Figure 11) of river ecosystem dependency shows the highest composite reliance in midstream and transition zones.

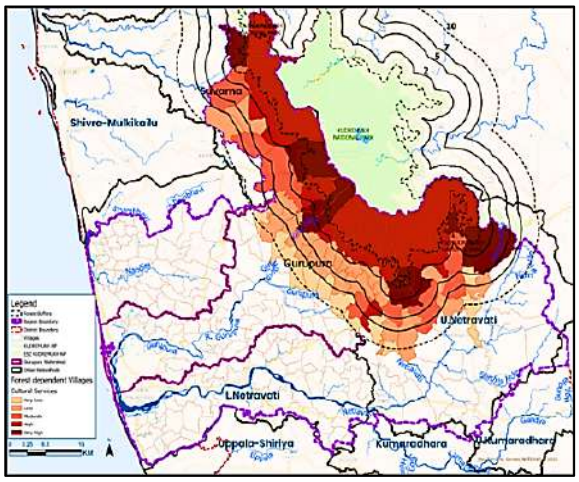


Figure 10. Forest – Cultural Services (Ananya 2025)

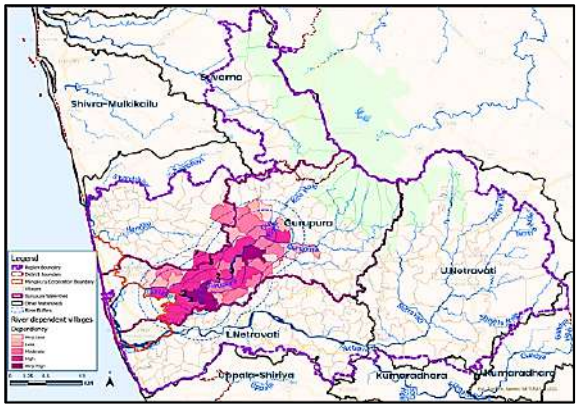


Figure 11. Cumulative River Ecosystem Service Dependency (Ananya 2025)

Dependency on provisioning services (Figure 12) such as irrigation, drinking water, and livestock use is concentrated in the transition zone, where direct river access supports household and agricultural needs. Census towns such as Karyangala and Addur Ulaibettu demonstrate particularly high dependence, relying on the river for irrigation and domestic water supply.

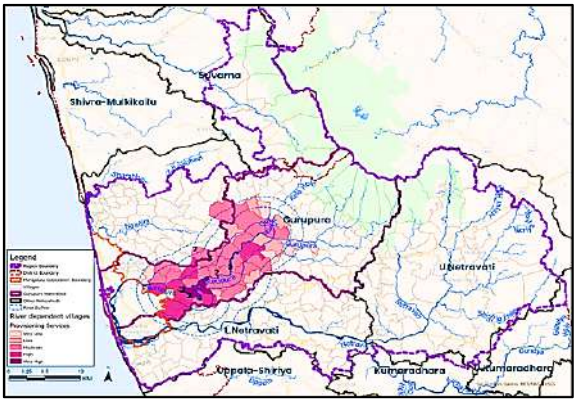


Figure 12. River – Provisioning Services (Ananya 2025)

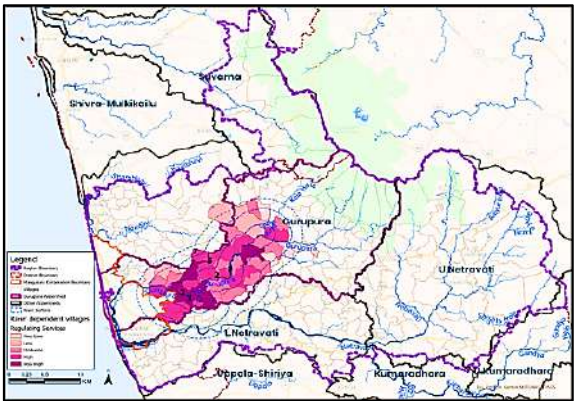


Figure 13. River – Regulating Services (Ananya 2025)

Regulating services (Figure 13), including flood attenuation and aquifer recharge, are more relevant in areas with sloping topography and moderate elevation, particularly in midstream watersheds. However, it is important to emphasize that many of these regulatory functions, such as flood attenuation, baseflow maintenance, aquifer recharge, and sediment transport, extend beyond the defined buffer zones. While their intensity and impact may vary across upstream, midstream, and downstream reaches, they continue to operate across the broader river basin, influencing areas well beyond the immediate proximity to the main channel.

Supporting services (Figure 14), such as nutrient cycling and sediment movement, although not directly cited in surveys, are functionally significant in the upper and transition zones due to their ecological roles in maintaining river health.

Cultural services (Figure 15) show spatial clustering in long-established riverbank villages with ritualistic and heritage-based connections to the river, especially in downstream segments. For example, towns like Gurupura and Venur host significant festivals, rituals, and community gatherings, along the riverbanks highlighting deep cultural ties.

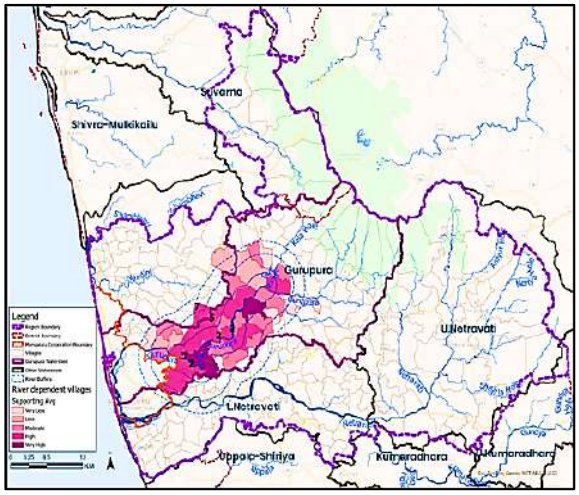


Figure 14. River – Supporting Services (Ananya 2025)

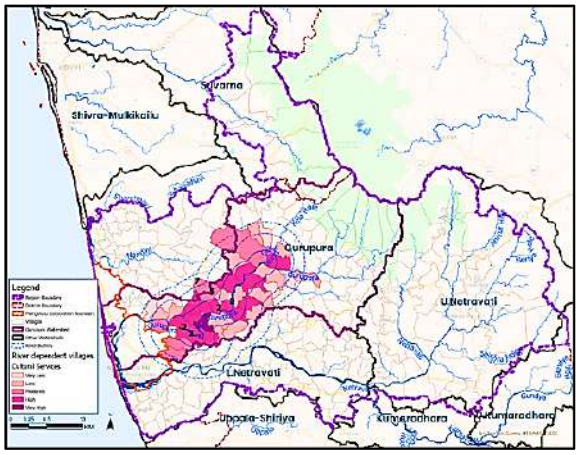


Figure 15. River – Cultural Services (Ananya 2025)

In contrast to the forest ecosystem, river dependency is more heterogeneous. Agricultural villages located on both banks showed different scores due to elevation, flood history, and groundwater recharge potential. Survey respondents in low-lying areas cited flood mitigation and sediment control as key regulatory functions, while those in the upper reaches emphasized drinking water and irrigation.

5. Discussion

The findings reveal that dependency on ecosystem services is shaped by both ecological conditions and patterns of human settlement (Mendako, Tian, and Matata 2022). Proximity, terrain, and land use determine how communities interact with forests and rivers, but so do cultural practices, economic needs, and institutional access. These dependencies are not uniform, and they cannot be explained by location alone.

In forested areas, the intensity of use and reliance on ecosystem services is often linked to traditional knowledge, resource availability, and accessibility (Nerfa, Rhemtulla, and Zerriffi 2020). In riverine contexts, dependency is more

dispersed and influenced by hydrology, agriculture, and vulnerability to water-related risks. Each landscape presents a distinct configuration of ecological function and community interaction.

This analysis highlights the importance of recognizing service- and place-specific relationships. Planning systems that treat ecosystems as uniform categories, forests as conservation zones, or rivers as drainage corridors, overlook the diversity of functions these systems perform for the people living alongside them. These systems must be integrated within the development framework (Ramachandra, Subash Chandran, and Joshi 2014). To maintain the ecological health of both the forest and the river, a watershed-based approach is also essential in addition to the buffer technique and both need to be aligned.

The study also suggests that vulnerability is not only ecological but also social. Communities with high dependency are often located in transition or edge zones, areas that face both ecological pressure and weak institutional coverage. These are also the spaces where planning interventions are most needed but least targeted.

Methodologically, basing spatial data on field insights enabled capturing dependencies that are difficult to quantify with secondary data alone. It also highlighted services, especially regulating and cultural, that are often under-represented in planning, yet crucial to the everyday resilience of rural communities.

The discussion points to a larger gap in environmental planning: the need to move beyond land cover categories and focus instead on the function's ecosystems perform, and the people who depend on them the most. It is not enough to protect natural areas in principle. What matters is sustaining the services they provide in practice.

Following this, future versions of the analysis can be strengthened by superimposing patterns of ecosystem service dependency with other spatial datasets that represent ecological stress and environmental hazard. Such might comprise land use and land cover (LULC) change detection maps (Figure 16) to identify zones of rapid land-use transformation, flood susceptibility (Figure 17) to determine zones of hydrological hazard, and Normalised Difference Vegetation Index (NDVI) (Figure 18) data to indicate vegetation health. Such integration will uncover "double vulnerability" zones: locations of communities that are heavily reliant on ecosystem services and which are also subject to degradation or hazard pressures.

Identifying such overlaps can help inform planning to prioritise the areas to be targeted for intervention, focusing on restoration, flood protection, and livelihood diversification across the locations of highest need.

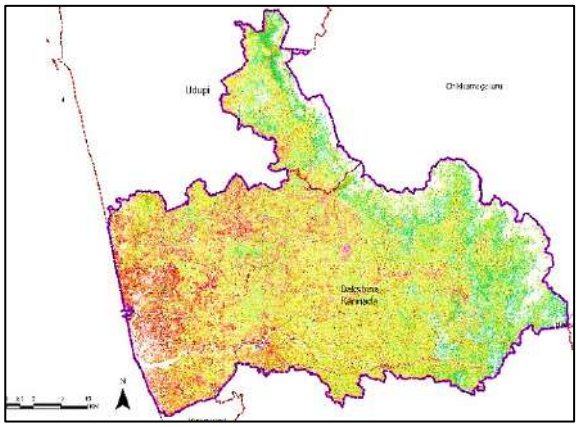


Figure 16. LULC Change 2015 - 2024 based on supervised classification of LULC 2015 and 2024 (Ananya 2025)

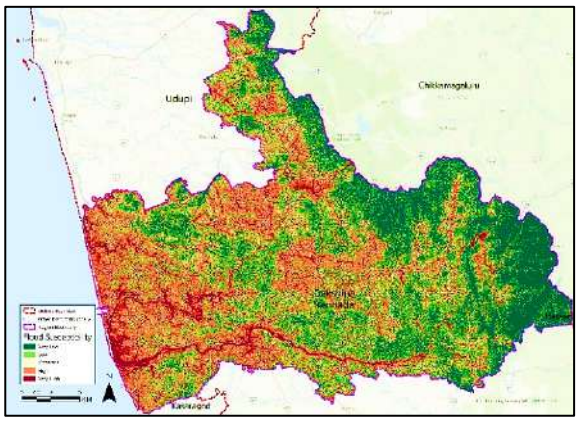


Figure 17. Flood susceptibility map (Ananya 2025)

The process will turn the practice of dependency mapping into a strategic planning tool that can to inform policy and investment choices.

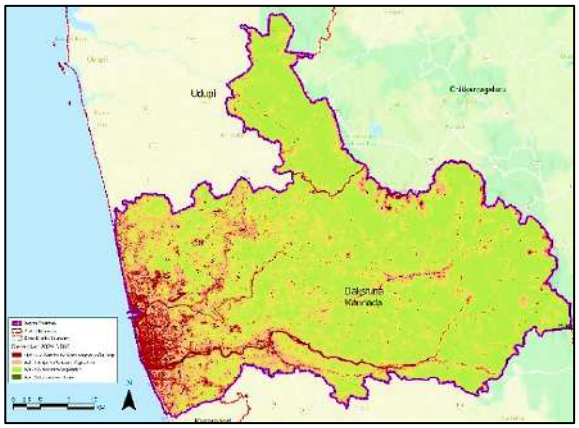


Figure 18. NDVI December 2024 (Ananya 2025)

To maximise the relevance of such mapping for applications in the planning field, it is important to situate the outputs within the wider policy and governance regimes. Ecosystem service dependence analysis can directly inform several Sustainable Development Goals (SDGs), namely SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land). While mapping the spatial structure of human dependence on ecosystem services, this approach is complementary to the aims of the Convention on Biological Diversity (CBD) and the Indian National Biodiversity Action Plan (NBAP), which place importance on integrating biodiversity concerns into planning regimes. In addition, platforms such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have encouraged methods that interconnect ecological functionality, human well-being, and governance, an ideal towards which the approach of the current study is complementary (United Nations 2021).

Integration of this analysis in formal planning tools is an essential follow-on step. Dependency maps can serve as evidence bases for zoning controls in master plans, allowing planners to create or define ecological buffers, green infrastructure corridors, and protected recharge areas. They could inform watershed development plans by identifying catchments with high dependence on provisioning service (IIT Roorkee and NMCG 2020), thereby informing priorities for soil conservation, afforestation, or water harvesting. Regional and developmental plans could be integrated with dependency data to direct urban growth away from ecologically sensitive areas and to promote low-impact land use in locations where communities remain dependent on natural resources for their livelihoods. This kind of evidence-based planning would also assist Strategic Environmental Assessments (SEA), which examine cumulative regional-level environmental effects and could incorporate dependency measures as part of their baseline analysis (Bons 2018).

From a governance perspective, institutional fragmentation is currently one of the biggest deterrents to operationalising the planning with an ecosystem services approach. Forest, water, agricultural, and rural development departments often operate in silos, leading to unchecked interventions that fail to account for the interdependence of ecosystem services. Establishing multi-stakeholder platforms, common geospatial data portals, and cross-sector planning committees is likely to link these dots. Such coordination is even more critical in the governance of river basins, which extend across multiple administrative boundaries and involve competing sectoral imperatives. Integrating dependency mapping into the administration of river basins may make resource allocation more efficient and ensure that interventions occur in locations where dependency and vulnerability converge most sharply (Sinha and Bimson 2021).

At the community level, participatory governance and co-management models can further enhance the effectiveness of ecosystem service planning. Many provisioning and cultural services, such as fuelwood collection, medicinal plant harvesting, or water harvesting, are closely tied to traditional knowledge systems. Integrating local knowledge into mapping exercises, participatory monitoring, and ecosystem restoration planning can increase the legitimacy, accuracy, and sustainability of interventions. Examples from river basin co-management initiatives in the Western Ghats and Nepal's community forestry programs demonstrate that combining scientific assessments with community stewardship significantly improves conservation outcomes and livelihood resilience (Sinha and Bimson 2021).

Financing mechanisms represent another critical aspect. Current plan budgets assign little value to ecosystem services as quantifiable assets, thereby limiting the intervention space. Linking dependency mapping with financing instruments such as the Compensatory Afforestation Fund Management and Planning Authority (CAMPA), MGNREGS watershed programs, or state-level adaptation funds for climate change could potentially help direct funds to areas where ecological investment would generate the highest social returns. Payment for Ecosystem Services (PES) programs, biodiversity offset programs, and corporate social responsibility (CSR) funds from basin-sited industries could also be used in favouring restoration and community-managed resource use in high-dependency areas (United Nations 2021).

Considering of climate change is another avenue for increasing the analytical value of ecosystem dependency mapping. Modelling in the future could explore how the variability of the climate such as rainfall changes, shifts in drought frequency, or increased intensity of flooding could alter dependency patterns or increase susceptibility. Scenario-modelling would permit

planners to experiment with the resilience of existing land-use plans under future climate conditions, in turn allowing for more adaptive and forward-planning interventions (Sinha and Bimson 2021).

Comparative observations from outside basins reinforce the potential for this approach. Analysis in the Ganga and Brahmaputra basins revealed how spatial assessments of ecosystem service may inform floodplain zoning, water allocation, and biodiversity corridors (Bons 2018, Sinha and Bimson 2021). Globally, the Australian Murray-Darling Basin Plan and the Rhine Basin's ecosystem restoration plan have both used similar analyses of dependency to mediate ecological health and socio-economic demand (Smith et al. 2025; CSIRO 2021; Fenten and Dieperink 2024; ICPR 2013; Waterloo 2019, Schmitt et al. 2019). These applications indicate that the method used herein may have broader applicability across multiple river systems with varying ecological, social, and institutional settings.

Finally, follow-on research should deepen the analytical thrust by relating data on ecosystem dependency to valuation studies, ecosystem accounts, and socio-economic modelling. Estimating of the economic value of ecosystem services could give additional impetus to their inclusion in public budgets and decision-making. The integration of statistics on dependencies into natural capital accounting systems, such as the UN's System of Environmental-Economic Accounting (SEEA), could yet cement ecosystem thinking in national and subnational planning settings (United Nations 2021).

In addition, mainstreaming ecosystem service dependency into land-use planning is also hampered by various feasibility issues that transcend technical capability. Institutional coordination across sectors remains inadequate, and local governments lack the human and financial resources to convert ecological analysis into a binding planning instrument. Financial resources also limit the use of ecosystem-based measures, particularly when other development considerations predominate in budget spreadsheets. Cross-departmental collaboration-enabled governance, ongoing capability building, and dedicated budget lines are hence critical if ecosystem dependency insights are to influence planning practice.

Another significant factor is the socio-economic and equity dimension of dependency. Observations in the field indicate that females, landless workers, and marginalised castes are more directly dependent on provisioning services such as fuelwood, medicinal plants, and small-scale fishing, as these livelihoods are part of subsistence. These groups seldom participate in formal decision-making, so their lack of involvement could deepen vulnerability should access to ecosystems be restricted or depleted. It is essential to recognise these differentiated dependencies and incorporate equity considerations into planning processes to design inclusive and equitable ecosystem management strategies.

To enhance policy and socio-economic involvement, integrating ecosystem service dependency analysis with a stakeholder participation framework into planning tools such as master plans, watershed management programs, and local development plans can be beneficial. This can be realised through the integration of dependency indicators into land-use zoning regulations, the creation of incentives for community-based stewardship programs, and the establishment of platforms for participatory governance that include local actors, including marginalised groups, directly in decision-making. Policies that combine livelihood diversification, ecosystem restoration, and social welfare measures create co-benefits that ensure planning interventions both protect the ecological system and enhance social resilience and economic opportunities.

6. Conclusion

This study highlights the importance of understanding how rural communities depend on forest and river ecosystems for a wide range of services. By mapping these dependencies spatially and categorizing them across provisioning, regulating, supporting, and cultural functions, the research reveals patterns that are often invisible in conventional planning frameworks. The analysis shows that dependency is not only a matter of geography, but of lived experience, ecological function, and socio-economic context. Communities interact with ecosystems in distinct and meaningful ways, and those relationships are critical to sustaining both livelihoods and landscape resilience.

Incorporating ecosystem service dependency into planning practice is not just about valuing nature; it is about recognizing where degradation would cause the greatest harm and where conservation would deliver the most benefit. This requires planning tools that go beyond static land classifications and account for the dynamic

interactions between people and their environment.

The approach used in this study demonstrates a scalable method for integrating local knowledge, field observation, and spatial analysis. It offers a framework for identifying areas of ecological importance based not just on biodiversity or risk, but on actual community reliance.

Ultimately, planning that acknowledges ecosystem service dependency is better positioned to support sustainable development, protect vulnerable communities, and ensure that ecological systems continue to perform the functions people depend on most.

But the research also has some limitations that must be considered. Household survey sample sizes, while enough to capture spatial trends, cannot be assumed to capture internal village-based dependency variation. The use of buffer distances that do not change, while a valuable methodological procedure, incorporates an element of generalisation that cannot capture subtle ecologically transitions. In addition, the research does not capture the urban–rural connectivity that shapes resource flows and patterns of dependency outside the buffer areas.

This work could be expanded by linking measures of dependency to the economic values of services provided by ecosystems, exploring how multiple scenarios of climate change would alter these dependencies, and incorporating outcomes into natural capital accounting processes. These would increase the usefulness of mapping ecosystem dependencies to long-term resource use and to policy purposes.

This developed methodological framework also has the potential to be replicated elsewhere in India's other river basins, were varying ecological and socio-economic settings shape dependency differently. By adjusting the indicators, weights, and spatial units to regional specifications, planners can use this framework to guide basin-based planning, improve ecological governance, and mainstream the consideration of ecosystem services into regional growth plans.

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Urban Heat, Water, and Livelihoods:
Climate Adaptation Planning for Jalgaon, Maharashtra

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Abstract: Jalgaon, a Tier-2 city of 460,000 people (Census 2011) in northern Maharashtra, faces intensifying heat, water stress, and infrastructure deficits that cluster in low-income wards. This paper advances a ward-scale climate adaptation framing for secondary Indian cities. Using 2014–2024 satellite products (Landsat NDVI; MODIS/Landsat LST) combined with ward-level infrastructure and housing indicators, it constructs a Composite Vulnerability Index (CVI) to rank hotspots and guide action. The paper finds multiple wards with persistent high LST and declining vegetation, coincident with service gaps (intermittent water supply, reliance on septic systems). Building on these diagnostics, it outlines replicable blue-green strategies, cool/green roofs, a green spine, and Mehrun Lake rejuvenation tied to feasible local instruments and schemes (AMRUT, PMKSY, CAMPA). This research adds a short implementation roadmap (priorities, indicative costs/funding, and stakeholder roles) and reflect on limitations (Census-2011 dependence; partial field verification) and future directions (routine ward dashboards; SDG alignment; scaling to peer Tier-2 cities). The contribution is twofold: (1) the first ward-level CVI for Jalgaon integrating heat, greenness, and services; and (2) a policy-linked, place-specific pathway that other secondary cities can adapt quickly.

Keywords: Urban Heat Island, Climate Risk, Tier 2 Cities, NDVI, LST, Spatial Planning, Blue-Green Infrastructure, Jalgaon, Urban Resilience, Remote Sensing.

सार: जलगाँव, उत्तरी महाराष्ट्र का एक स्तर -2 शहर है, जिसकी जनसंख्या 460,000 है (जनगणना 2011), और यह तीव्र तापमान वृद्धि, जल संकट और बुनियादी ढाँचे की कमियों का सामना कर रहा है, जो निम्न-आय वर्ग की वार्डों में केंद्रित हैं। यह शोधपत्र भारतीय द्वितीयक शहरों के लिए वार्ड-स्तरीय जलवायु अनुकूलन रूपरेखा प्रस्तुत करता है। 2014–2024 की उपग्रह उत्पादों का उपयोग करते हुए, जिन्हें वार्ड-स्तरीय बुनियादी ढाँचा और आवास सूचकों के साथ संयोजित किया गया है, अध्ययन एक समग्र संवेदनशीलता सूचकांक का निर्माण करता है, जो संकट-स्थलों को श्रेणीबद्ध करता है और कार्रवाई का मार्गदर्शन करता है। निष्कर्षों से कई ऐसी वार्डें सामने आती हैं, जिनमें उच्च भूमि सतह का तापमान और वनस्पति में गिरावट दीर्घकाल से बनी हुई है, जिसके साथ सेवा अंतराल भी संलग्न हैं (रुक-रुक कर जल-आपूर्ति, सेप्टिक निर्भरता)। इन निदानात्मक निष्कर्षों के आधार पर, अध्ययन प्रतिलिपि योग्य नील-हरित रणनीतियाँ प्रस्तुत करता है — ठंडी/हरी छतें, एक हरित मेरुदंड, और मेहरुन झील का पुनरुद्धार, जो व्यवहार्य स्थानीय उपकरणों और योजनाओं (ए. एम. आर. यू. टी., पीएमकेएसवाई, सीएएमपीए) से जुड़ी हुई हैं। अध्ययन में एक संक्षिप्त कार्यान्वयन का रोडमैप जोड़ा गया है — जिसमें प्राथमिकताएँ, संकेतात्मक लागत/निधि और हितधारकों की भूमिकाएँ शामिल हैं — साथ ही सीमाओं पर विचार (जनगणना-2011 पर निर्भरता; आंशिक क्षेत्र-सत्यापन) और भविष्य की दिशाएँ (नियमित वार्ड डैशबोर्ड; एसडीजी समन्वय; स्तर -2 शहरों के समकक्ष क्षेत्रों तक विस्तार)। यह योगदान दोहरा है: (1) जलगाँव के लिए पहला वार्ड-स्तरीय सी वी आई, जो तापमान, हरियाली और सेवाओं को एकीकृत करता है; और (2) एक नी नीति से जुड़े, स्थान-विशिष्ट पथ, जिसे अन्य द्वितीयक शहर शीघ्रता से अनुकूलित कर सकते हैं।

मुख्य शब्द: शहरी ऊष्मा द्वीप, जलवायु जोखिम, स्तर -2 शहर, एनडीवीआई, एलएसटी, स्थानिक योजना, ब्लू-ग्रीन इंफ्रास्ट्रक्चर, जलगाँव, शहरी लचीलापन, रिमोट सेंसिंग.

1. Introduction

Climate change has moved from projection to lived reality across India's cities, with fast-growing Tier-2 and Tier-3 centres experiencing the sharpest transitions. As farmland and open tracts give way to continuous built-up areas, heat loads intensify, rainfall becomes more erratic, and public health risks mount. Jalgaon, an agro-industrial hub in Khandesh, northern Maharashtra, illustrates this trajectory. Land use has shifted markedly over the last two decades, with built-up areas expanding and pressing into agricultural land, wetlands, and urban greens. The result is a persistent rise in urban temperatures, the emergence of pronounced heat-island pockets, and a measurable decline in vegetation. Peripheral and informal neighbourhoods face these pressures most acutely, alongside intermittent water supply, inadequate sanitation, and deteriorating housing conditions. Yet, like many Tier-2 cities, Jalgaon lacks a dedicated climate adaptation plan; investments tend to follow one-size-fits-all models that ignore the neighbourhood-scale nature of risk.

This paper responds to that gap by advancing a ward-level climate adaptation approach that links thermal exposure, water and infrastructure deficits, and livelihood vulnerability.

Climate-stress zones and diagnose service bottlenecks are mapped using remotely sensed indicators and ward–scale infrastructure and housing data. Building on these diagnostics, place-specific, blue–green strategies calibrated to Jalgaon's spatial form and institutional capacity are proposed.

The contribution is two-fold:

- An operational, ward-scale Composite Vulnerability Index (CVI) for Jalgaon that integrates heat, greenness, and basic services to priorities action; and

- A replicable adaptation toolkit including cool/green roofs, shaded corridors, and lake-system rejuvenation explicitly designed for secondary Indian cities to implement within existing policy instruments.

2. Literature Review

Urban settlements have become frontline arenas of climatic stress. Rising temperatures and increasingly variable rainfall amplify vulnerabilities in the Global South, where rapid population growth intersects with infrastructure deficits and constrained local capacity. These dynamics disproportionately burden informal and underserved neighbourhoods and foreground the need for place-specific adaptation rather than generic citywide responses. In this context, Climate Adaptation Plans (CAPs) have emerged as a practical vehicle for diagnosing local risks and designing context-sensitive strategies.

At the international scale, the Paris Agreement (UN 2015) established a clear mandate for adaptation alongside mitigation, while the IPCC's Sixth Assessment Report (2021) underscored intensifying extremes, prolonged heatwaves, erratic precipitation, and water scarcity across South Asia. These frameworks have pushed practice toward nature-based interventions and participatory governance, with attention to distributional equity so that resilience gains reach the most exposed groups. Transnational networks such as C40 Cities have equipped municipalities with heat-mapping tools, inventories, and equity-centred planning toolkits. Uptake, however, is uneven: megacities and large metros benefit most, whereas secondary cities frequently lack the data resolution, staffing, and budgeting mechanisms needed to translate guidance into ward-scale action.

Within India, the NAPCC and state-level SAPCCs define the strategic envelope for adaptation. Maharashtra's SAPCC flags recurring drought, groundwater decline, and land degradation as priority concerns (TERI 2014). Larger cities (e.g., Ahmedabad, Surat, Nagpur, Mumbai) have piloted targeted measures, such as heat action planning, riparian buffers, and cool-roof retrofits demonstrating that evidence-based, city-specific programs can reduce exposure when institutional commitment and financing align. Yet a persistent gap remains for Tier-2 cities like Jalgaon: disaggregated diagnostics (ward-level), climate-linked service baselines, and dedicated local governance structures are often missing, leaving these cities exposed to compound risks, surface heat spikes, vegetation loss, water stress, and service failures without clear prioritization mechanisms.

This study addresses the identified gap through a conceptual framework (Figure 1) that integrates three interlinked dimensions: climate vulnerability, assessed through indicators such as land surface temperature, green cover, and water availability; socio-economic exposure, reflected in patterns of informal housing, fragile livelihoods, and access to public services; and spatial planning mechanisms, including zoning, land-use regulation, and nature-based infrastructure. Because climate stress is spatially uneven and concentrates in informal and underserved wards, ward-level assessments are essential to targeting measures and sequencing investments.

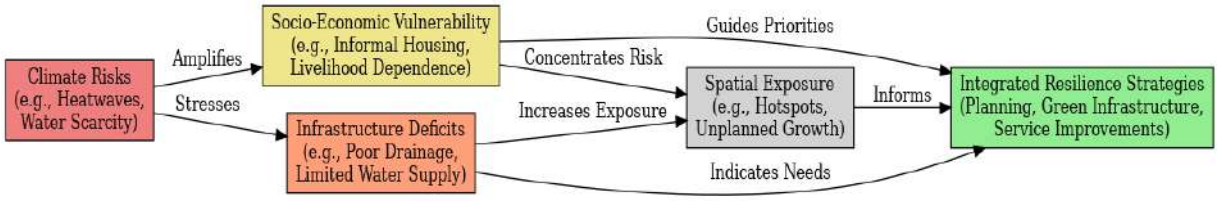


Figure 1. Conceptual Framework for Urban Climate Risk and Resilience. Methodology for Climate Adaptation Plan (Sethia 2025)

Recent scholarly evidence highlights three insights relevant to Jalgaon and similar secondary cities: urban heat is closely linked to loss of vegetation and increased impervious surfaces, with built form influencing micro-scale exposure; nature-based solutions such as tree belts, riparian buffers, pocket parks, and cool or green roofs can deliver measurable cooling when well targeted; and equity-focused interventions are most effective where heat stress overlaps with service deficits and fragile livelihoods. Building on this literature, the study develops a ward-scale Composite Vulnerability Index (CVI) that integrates heat, greenness, and basic services to prioritise action. It proposes a replicable blue–green adaptation package suited to the institutional context of secondary Indian cities. By situating Jalgaon within this scholarly and policy framework, the paper clarifies the rationale for its indicators, spatial scale, and intervention design while underscoring the relevance of ward-level climate adaptation.

3. Methodology and Analysis

All methods are organised around a single objective: enabling ward-level climate adaptation for Jalgaon, with heat risk as the primary driver and water and basic services as enabling capacities. Jalgaon, a Tier-2 city with a population of approximately 4.6 lakh (Census 2011), is experiencing increasing environmental stress but lacks ward-specific climate planning mechanisms. Accordingly, the methodology is structured around three core objectives: first, identifying key spatial and resilience parameters through a review of international, national, and state-level frameworks; second, assessing vulnerabilities and infrastructure stress at the ward scale using both primary and secondary data; and third, formulating targeted adaptation strategies based on geospatial analysis and institutional evaluation.

3.1 Literature and Policy Review

The study adopted a two-track scoping approach encompassing policy frameworks and recent scholarly literature. Policy sources included the UNFCCC Global Goal on Adaptation, the IPCC Sixth Assessment Report (AR6, 2021), India's National Action Plan on Climate Change and its associated missions—particularly the National Mission on Sustainable Habitat and the National Water Mission—the Maharashtra State Action Plan on Climate Change (2010; revised 2019), the Jalgaon District Disaster Management Plan, and selected Indian city case studies such as the Ahmedabad Heat Action Plan, Surat City Resilience initiatives, and Nagpur's green buffer strategies. To complement policy guidance with empirical evidence, the review also drew on recent peer-reviewed research addressing key themes: drivers of the Urban Heat Island (UHI) effect and micro-scale built form; the cooling performance of nature-based solutions (NbS); and equity-centred targeting in secondary cities of the Global South. Insights from this combined review informed the selection of indicators, the ward-level spatial resolution, and the emphasis on integrated blue–green adaptation interventions.

3.2 Baseline and Spatial Analysis

Municipal profile: Using records from the Jalgaon Municipal Corporation (JMC) and Census of India 2011, the study compiled data on built-up growth and urban sprawl, population density, household typologies, and the delineation of 69 municipal wards.

Environmental resources: Spatial datasets were developed to map slope, elevation, and geomorphology, as well as surface water bodies, drainage networks, potential groundwater recharge zones, and vegetation corridors, and urban green spaces.

Land use–land cover (LULC) dynamics (2014–2024): Multi-temporal Landsat and MODIS datasets were processed to derive land surface temperature (LST) patterns, including persistent heat bands and seasonal peaks; Normalized Difference Vegetation Index (NDVI) to assess vegetation condition and change; and trends in built-up expansion. Data processing involved cloud masking, seasonal compositing, emissivity-adjusted LST retrieval, NDVI normalization, and ward-level zonal statistical analysis.

3.3 Urban Form, Housing, and Heat Vulnerability

The built environment was characterised using indicators such as housing type (temporary, kutcha, or informal), roof materials, availability of shading and public spaces, and proximity to cooling infrastructure. These attributes were used to operationalise heat exposure and adaptive capacity at the ward scale, particularly in the absence of fine-grained household-level microclimatic data.

3.4 Infrastructure and Services Assessment

Ward-wise diagnostics were undertaken across five key sectors: (i) drainage systems, including the presence of open or covered drains and capacity mismatches; (ii) water supply, assessed in terms of coverage, reliability, and the absence of continuous 24×7 provision; (iii) sanitation and solid waste management, with emphasis on septic tank dependence and network gaps; (iv) energy, focusing on connection reliability and heat-period power outages; and (v) mobility, particularly the availability of shaded non-motorised transport (NMT) infrastructure and walkability. Wherever available, municipal updates from 2023–2024 were used to supplement Census of India 2011 data.

3.5 Ward-Level Composite Stress Mapping

To prioritise adaptation at the ward scale, a Composite Vulnerability Index (CVI) was developed that integrates heat exposure, ecological cooling capacity, and service constraints. The index combines six indicators: land surface temperature (LST) hotspots, NDVI decline, water supply reliability, sanitation risk, public green space deficit, and population density with housing condition proxies. All indicators were normalised using min–max scaling across 69 wards, with expert-judgement weights reflecting heat–health pathways (LST 0.25; NDVI 0.20; water 0.15; sanitation 0.15; green deficit 0.15; density/housing 0.10). The resulting CVI scores enabled ward-wise

ranking of vulnerability and identification of priority action zones.

3.6 Data Constraints and Supplements

The socio-economic baseline for this study is based on the Census of India 2011 data, acknowledging its temporal limitation. To address this, the analysis integrated Jalgaon Municipal Corporation records from 2023–2024 where available, used multi-year satellite datasets (2014–2024) to capture environmental dynamics, and conducted rapid field audits in selected hotspot wards to validate service gaps. Proxy indicators, such as ward-level access to public green spaces and OpenStreetMap facility data, were incorporated where official datasets were sparse. The study recommends establishing live ward-level dashboards to enable annual updates of NDVI and LST and to integrate routinely collected municipal service data for continuous monitoring.

3.7 SWOC Synthesis

A SWOC analysis was used to consolidate the preceding diagnostics and bridge evidence with action. Identified strengths include partial traction under AMRUT, an existing piped water network, and emerging institutional momentum. Key weaknesses include the prevalence of informal housing, significant gaps in sewerage infrastructure and weak data systems. Opportunities lie in initiatives such rejuvenating of Mehrun Lake, cool and green roof retrofits, and expanding of shaded non-motorised transport infrastructure. The primary challenges include limited ward-level awareness of climate action planning, constraints in operations and maintenance funding, and gaps in inter-departmental coordination.

3.8 Outputs

The results section and accompanying submission include high-resolution figures illustrating: (i) land surface temperature (LST) for March and December; (ii) NDVI change over the 2014–2024 period; (iii) ward-wise infrastructure and service gaps; and (iv) a CVI deciles map highlighting priority tiers. All maps use consistent symbology, ward labels, and scale bars to support clarity and replication.

4. Results and Discussion

The results of the ward-level analysis show that climate risks in Jalgaon are multidimensional, with rising heat exposure, vegetation loss, and service delivery gaps interacting to heighten overall vulnerability. These stressors are not evenly distributed; instead, they cluster in specific wards where socio-economic fragility and weak infrastructure overlap.

4.1 Heat Exposure and Vegetation Degradation

The Land Surface Temperature (LST) (Figures 2-a, b, c and d) analysis using MODIS and Landsat data between 2014 and 2024 revealed that more than 40% of Jalgaon's urban area now experiences UHI effects, with peak temperatures regularly exceeding 42.7°C in dense, built-up wards such as 56, 69, 15, and 7. This rise in surface temperatures correlates strongly with the loss of vegetation cover and the expansion of built-up surfaces. The reduction in vegetation from 0.33 in 2014 to 0.19 in 2024, particularly in highly urbanized areas such as Ward 69, along with the increase in impervious surfaces, has reduced the city's ability to mitigate heat through evapotranspiration, thereby directly intensifying UHI zones.

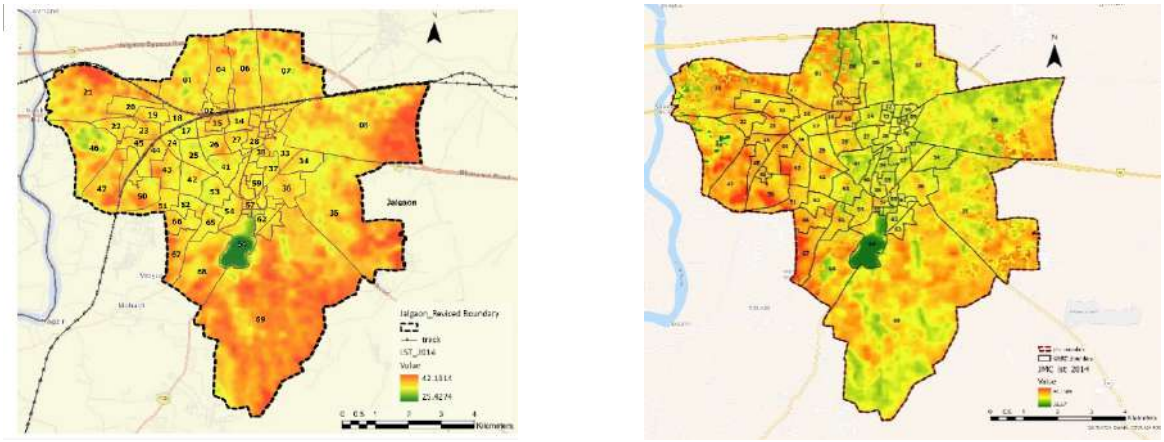
4.2 Water Supply and Infrastructure Deficiency

Although Jalgaon's piped water supply network reaches 98% of households, the city still fails to provide a continuous 24×7 supply to any of them. Field assessments confirmed that non-revenue water loss is approximately 25%, caused by outdated distribution lines and leakage (Figure 3-a). Further, only 25% of sewage generated is treated, while over 75% is discharged untreated into open drains or local water bodies. Most households rely on septic tanks (Figure 3-b) there is no underground sewerage network, particularly in Wards 7, 42, and 50.

4.3 Socio-Economic Vulnerability and Livelihood Stress

Jalgaon's economy remains heavily dependent on climate-sensitive occupations, particularly agriculture. Census 2011 data indicates that nearly 58% of the main workforce within Jalgaon Municipal Corporation is employed as agricultural labourers, while a further 12% are engaged as cultivators. This strong reliance on farm-based livelihoods exposes a large proportion of the population to climate disruptions, including erratic rainfall, extended dry spells, groundwater decline, and extreme heat. Such hazards directly undermine agricultural productivity, thereby threatening food security and income stability. The city's Work Participation Rate (WPR) is 40.5%, which is lower than the national average of 44.1% and the state average of 44.4%. When combined with a female literacy rate of only 70.6%, these figures highlight structural gender and livelihood vulnerabilities. In addition, the presence of 12% marginal workers and nearly 4% employed in household industries reflects the dominance of informal and unstable

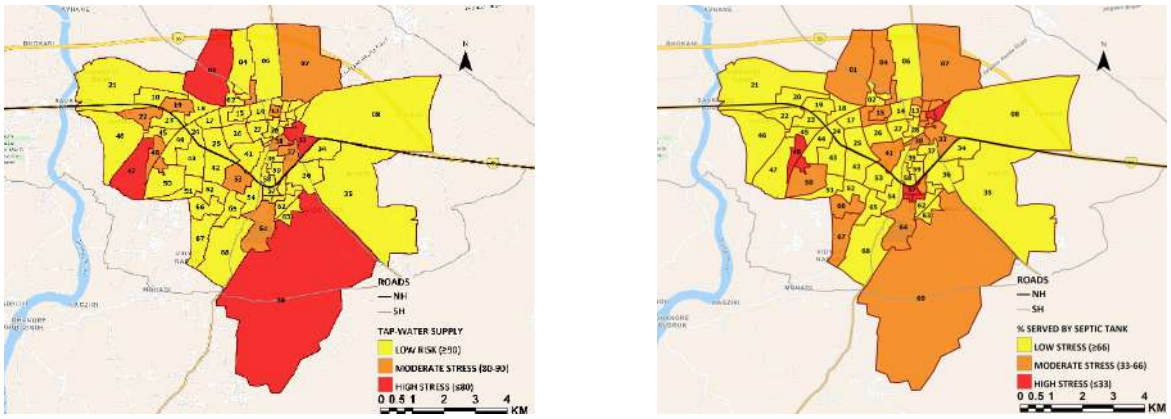
employment, particularly concentrated in slum settlements and peri-urban areas.



a) Land Surface Temperature for March 2014 **b)** Land Surface Temperature for March 2024

c) Land Surface Temperature for December 2014 **d)** Land Surface Temperature for December 2024

Figure 2. Land Surface Temperature and loss of vegetation cover, 2014 and 2024, Jalgaon, M.S.



a) Tap water supply and septic tank coverage **b)** septic tank coverage

Figure 3. Infrastructure stress mapping using Census 2011 indicators, Jalgaon City, M. S.

4.4 Ward-Level Composite Vulnerability Patterns

To integrate the multiple risks identified, a Composite Vulnerability Index (CVI) (Figure 4) was developed using six standardised indicators: land surface temperature (LST) hotspots, NDVI decline, water supply deficits, dependence on septic systems, green space shortages, and high population density, Table 1. The results indicate that Wards 56, 69, 7, and 50 consistently record the highest CVI scores, identifying them as priority areas for intervention.

These wards largely coincide with major informal housing clusters such as Samatha Nagar and Tambapura, where access to basic services is particularly limited. The findings underscore the need for place-specific adaptation strategies that

address environmental, physical, and socio-economic vulnerabilities simultaneously. Ward-level mapping of these intersecting stressors enables clearer identification of high-risk zones and supports more targeted and effective investment in climate adaptation.

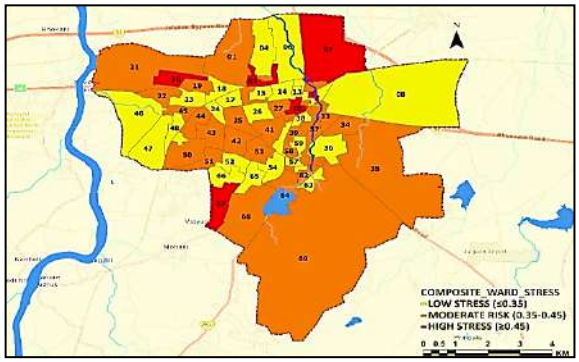


Figure 4. Composite Ward Stress Mapping for Jalgaon – based on ward-level indicators including LST, infrastructure, housing, and services (Sethia 2025)

Table 1: Composite Ward Stress Mapping for Jalgaon – based on ward-level indicators including LST, infrastructure, housing, and services (Sethia 2025).

Parameter	Description	Lowest Value	Highest Value
Population (Absolute)	Total number of people in the ward.	4,504 (Ward 24)	17,164 (Ward 69)
Tap Water Supply	% of households receiving a treated water supply.	52.1% (Ward 1)	100% (Multiple wards)
Electricity Connection	% of households with legal electricity connections.	84.5% (Ward 1)	100% (Multiple wards)
Population Served by Septic Tank	% of households relying on septic tanks (on-site sanitation).	0% (Ward 54)	94.4% (Ward 7)
Temporary Structures	% of structures identified as temporary (informal housing).	0% (Multiple wards)	9.1% (Ward 27)
Density (pers./ha)	Population per hectare indicates compactness.	10.56 (Ward 69)	792.38 (Ward 56)
Open Spaces	% of land available as open/public spaces (parks, greens).	0% (Multiple wards)	96.55% (Ward 8)
LST Hotspot (fraction)	Proportion of the ward that is a heat hotspot (high surface temperature zones > 40 °C).	0 (Multiple wards)	0.2365 (Ward 69)
Composite Index	Aggregated index of normalized indicators for vulnerability.	0.22 (Ward 1)	0.38 (Ward 69)

4.5 Response Strategies and Adaptation Planning

Based on the assessment of Jalgaon's vulnerabilities, this study proposes a set of integrated blue-green infrastructure measures and climate-sensitive policy actions designed to enhance resilience:

Green Spine Development: Establishing a continuous ecological corridor connecting Wards 47, 50, and 56 through shaded avenues, bio-swales, and public parks. This network would promote passive cooling, reduce surface runoff, and improve equitable access to green spaces.

Mehrun Lake Rejuvenation: Restoring the city's largest waterbody by introducing riparian buffers, aeration systems, and percolation tanks. These interventions would strengthen groundwater recharge, regulate the local microclimate, and create biodiversity-friendly habitats.

Cool and Green Roofs: Introducing mandatory and incentive-based retrofitting of reflective roofs in informal housing clusters and institutional campuses. Pilot projects for green roofs could be implemented in municipal schools and ward offices to demonstrate thermal regulation benefits.

Rooftop Gardens: Encouraging rooftop-based urban agriculture and thermal insulation, particularly in high-density neighbourhoods where open space is scarce. This measure would provide both cooling benefits and supplementary livelihoods.

Solar Farming and Renewable Energy Integration: Promoting peri-urban solar farms and agro-solar practices under schemes such as PM-KUSUM and related state initiatives. These would diversify farmer incomes while reducing dependence on conventional energy sources.

Collectively, these nature-based and energy-efficient strategies offer cost-effective, scalable, and context-appropriate solutions. They are designed to align with national and state climate missions such as AMRUT, PMKSY, and CAMPA, thereby ensuring both policy coherence and on-ground applicability.

5. Conclusions

This study shows that Jalgaon, a rapidly growing Tier-2 city in northern Maharashtra, faces an escalating climate-risk landscape marked by extreme heat, declining vegetation, overburdened infrastructure, and socio-economic vulnerabilities. Through an integrated spatial and environmental assessment, we found that land surface temperatures in key wards exceed 44.7°C and that

core zones have lost more than 40% of their urban greenery. These impacts concentrate in informal and underserved neighbourhoods where access to piped water, sanitation, and cooling infrastructure remains inadequate. The ward-level Composite Vulnerability Index (CVI) developed here provides a spatially granular picture of climate-stress zones, linking physical heat exposure to socio-economic fragility and service delivery gaps. This evidence reinforces the need for decentralised, ward-specific climate adaptation rather than one-size-fits-all models.

In response, the paper proposes actionable blue–green infrastructure measures such as cool roofs, urban forests, lake rejuvenation, and rooftop gardens that mitigate urban heat while enhancing ecological resilience and community well-being. These proposals are explicitly aligned with implementable national and state instruments (AMRUT 2015, PMKSY, CAMPA), providing a pathway for integrated, scalable, and locally relevant climate planning. The contribution is twofold: (i) the first ward-scale CVI for Jalgaon that operationalises prioritisation across heat, greenness, and basic services; and (ii) a replicable adaptation package tailored to secondary-city institutions and financing routes.

Limitations: Socio-economic baselines rely on Census 2011, and field verification was selective rather than longitudinal. Remote sensing captures surface conditions, not indoor thermal comfort or heat-health outcomes. Service data quality varies across wards, and some indicators required proxy layers where recent official statistics were unavailable. These constraints do not alter the priority pattern but should be addressed in implementation.

Future directions: Establish live ward dashboards (annual LST/NDVI updates, NRW, shaded-km, roof retrofits) and integrate SDG-linked indicators (e.g., 3.9, 6.1, 11.7, 13.1). Monitor pilot interventions (cool roofs, shaded corridors, lake buffers) with before–after thermal and usage data; incorporate gender-responsive metrics. Expand comparative analysis with peer Tier-2 cities (e.g., Nagpur, Surat, Guntur) to benchmark outcomes, refine cost and financing models (AMRUT micro-projects, CAMPA urban forestry, PMKSY recharge, CSR co-funding), and document O&M governance. Together, these steps can convert the Jalgaon framework into a scalable, ward-first adaptation playbook for India's secondary cities.

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City Resilience through Ecosystem Services, Bhubaneswar

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Abstract: City resilience is increasingly threatened by environmental and socio-economic pressures, which are intensified by rapid urbanisation. This growth causes habitat loss, ecological disruption, overuse of natural resources, and environmental degradation. Cities depend on healthy ecosystems for vital services such as climate regulation, clean air and water, food production, biodiversity support, and recreational spaces all crucial to human well-being and ecological sustainability. However, as ecosystems degrade, the supply of these services for current and future generations is at risk. This study examines how ecosystem services can strengthen resilience and help cities better cope with these challenges, focusing on Bhubaneswar city, an Indian coastal city prone to cyclone-induced urban flooding. It assesses the role of green infrastructure and ecological assets in reducing disaster vulnerability and supporting long-term environmental sustainability. The research highlights the need to incorporate ecosystem services into urban planning to minimise the negative impacts of rapid urbanisation while strengthening adaptive capacity. Drawing on existing literature, case studies, and policy interventions, the study examines the contribution of ecosystem services to strengthening urban resilience to urban flooding induced by cyclones and intense rainfall. It also highlights the opportunities of nature-based solutions towards managing urban flood risks and enhancing city resilience. This research aims to bridge the gap between ecosystem service theory and real-world urban resilience planning, providing insights into how cities like Bhubaneswar can prepare for and adapt to climate-induced hazards. The findings aim to inform context-specific planning strategies and policy interventions for disaster-resilient urban development.

Keywords: Resilience, Urban Ecosystems, Ecosystem Services, Urbanisation, Nature-Based Solutions

सार: शहरी लचीलापन पर्यावरणीय और सामाजिक-आर्थिक दबावों से तेज़ी से संकट का सामना कर रहा है, जो तीव्र शहरीकरण के कारण और गहरा हुआ है। यह वृद्धि आवास-क्षरण, पारिस्थितिक व्यवधान, प्राकृतिक संसाधनों के अत्यधिक उपयोग, और पर्यावरणीय क्षरण का कारण बनती है। शहर जलवायु विनियमन, स्वच्छ वायु और जल, खाद्य उत्पादन, जैव-विविधता समर्थन, और मानव कल्याण एवं पारिस्थितिक स्थायित्व के लिए आवश्यक मनोरंजन स्थलों जैसी महत्वपूर्ण सेवाओं के लिए स्वस्थ पारिस्थितिकी प्रणालियों पर निर्भर हैं। किंतु जैसे-जैसे पारिस्थितिकी प्रणालियाँ क्षरित होती हैं, वर्तमान और भविष्य की पीढ़ियों के लिए इन सेवाओं की आपूर्ति जोखिम में पड़ जाती है। यह अध्ययन यह परीक्षण करता है कि पारिस्थितिक तंत्र सेवाएँ शहरी लचीलापन को कैसे सुदृढ़ कर सकती हैं और शहरों को इन चुनौतियों का सामना करने में बेहतर सक्षम बना सकती हैं। अध्ययन का केंद्रबिंदु भुवनेश्वर शहर है, जो भारत का एक तटीय शहर है और चक्रवातजन्य शहरी बाढ़ के प्रति संवेदनशील है। यह अनुसंधान हरित बुनियादी ढाँचा और पारिस्थितिक संपत्तियों की आपदा-संवेदनशीलता को कम करने तथा दीर्घकालीन पर्यावरणीय स्थायित्व का समर्थन करने में भूमिका का मूल्यांकन करता है। शोध तीव्र शहरीकरण के नकारात्मक प्रभावों को कम करते हुए अनुकूलन क्षमता को सुदृढ़ करने के लिए शहरी नियोजन में पारिस्थितिकी सेवाओं को सम्मिलित करने की आवश्यकता को रेखांकित करता है। विद्यमान साहित्य, प्रकरण अध्ययनों और नीति-हस्तक्षेपों के माध्यम से, यह अध्ययन चक्रवात और तीव्र वर्षा से प्रेरित शहरी बाढ़ की चुनौतियों के विरुद्ध शहरी लचीलापन को सुदृढ़ करने में पारिस्थितिकी सेवाओं के योगदान की जांच करता है। यह शोध प्रकृति-आधारित समाधानों के माध्यम से शहरी बाढ़ जोखिम प्रबंधन और शहर के लचीलेपन को बढ़ाने की संभावनाओं को भी उजागर करता है। इस अनुसंधान का उद्देश्य पारिस्थितिकी सेवा सिद्धांत और वास्तविक-जगत के शहरी लचीलापन नियोजन के बीच अंतराल को पाटना है, साथ ही यह भी प्रदान करना है कि भुवनेश्वर जैसे शहर जलवायु-प्रेरित आपदाओं के लिए कैसे तैयारी कर सकते हैं और अनुकूलन कर सकते हैं। निष्कर्ष संदर्भ-विशिष्ट नियोजन रणनीतियों और आपदा-लचीले शहरी विकास के लिए नीति-हस्तक्षेपों को सूचित करने का लक्ष्य रखते हैं।

मुख्य शब्द: लचीलापन, शहरी पारिस्थितिकी तंत्र, पारिस्थितिकी तंत्र सेवाएँ, शहरीकरण, प्रकृति-आधारित समाधान

1. Introduction

Ecosystems in urban areas are crucial for sustaining city life by providing a range of essential services, including clean air and water, climate regulation, food production, recreation, and biodiversity conservation. (Bolund and Hunhammar 1999, Kumar 2010). These urban ecosystem services underpin human-nature interactions, improving the liveability of cities. However, rapid urbanisation has led to habitat loss, ecosystem degradation, and high resource consumption (McNeill 2000). As cities grow, ecosystems face significant disruption, degrading biodiversity and limiting the provision of critical services (Millennium Ecosystem Assessment 2005). This threatens both current and future generations (Kumar 2010).

Urban resilience depends on maintaining social and ecological functions, making ecosystem services vital in connecting ecological health with urban infrastructure (Alberti et al. 2003). By supporting adaptation to external challenges, including climate change, as well as internal shifts such as demographic changes, these services enable the building of resilient cities (Meerow et al. 2015). Recognising and incorporating ecosystem services into urban development is critical to building resilient cities that enhance human well-being and long-term ecological sustainability.

1.1 Need for the Study

Urban systems are increasingly vulnerable to social, ecological, and economic disturbances that threaten their resilience. Recently, there has been a growing emphasis on strengthening resilience (Carpenter et al. 2001), especially in vulnerable urban areas facing pressures from climate change and urbanisation. (Solecki et al. 2011, PlaNYC 2013).

Despite the recognised benefits of incorporating ecosystem services (ES) into urban development to mitigate these impacts, their effective implementation and management remain limited (Gómez-Baggethun and Barton 2013). Incorporating ecosystem services in urban planning can enhance resilience and improve urban social-ecological systems (Solecki and Marcotullio 2013).

Therefore, this study is needed to explore strategies for incorporating ecosystem services into urban planning to address the impacts of rapid urbanisation. By bridging gaps in the practical implementation of ecosystem services, it aims to provide insights into how cities can manage and adapt urban ecosystems to sustain service delivery, especially under global environmental change (Gómez-Baggethun et al. 2013).

1.2 Aim and Objectives

This paper examines the role of ecosystem services in strengthening urban resilience, with a particular focus on integrating ecosystem-based strategies into urban planning for reducing rainfall- and cyclone-induced urban flood risks. The objectives of the study are to identify key urban flood-regulating ecosystem services and assess their contribution to flood resilience; examine the impacts of urbanisation on these ecosystem services; evaluate urban flood vulnerability using a GIS-based framework; and develop planning-oriented recommendations for enhancing ecosystem-based city resilience.

1.3 Scope and Limitations

The scope of this research is confined to examining the role of ecosystem services within urban areas, with a specific focus on urban green spaces and regulatory and supporting ecosystem services. The study undertakes a multi-layered analysis that includes assessing the city's vulnerability and adaptive capacity to urban flooding caused by rainfall and cyclonic events, monitoring changes in land use and land cover (LULC), and evaluating vegetation health through NDVI analysis. It further involves mapping key ecosystem services provided by urban green spaces—such as flood regulation, carbon sequestration, and biodiversity conservation—and developing an ecosystem services hotspot map to identify high-value service zones. In addition, the study conducts an economic valuation of the ecosystem services provided by urban green spaces and forests. It identifies potential sites for interventions such as afforestation, wetland restoration, and the development of new urban green spaces. The research is subject to certain limitations: it is restricted to the municipal corporation limits of the study area, focuses exclusively on urban resilience to flooding, and considers only regulatory and supporting ecosystem services.

2. Literature Review

Ecosystem services refer to the benefits that humans derive from natural systems, including land, water, and vegetation, which together generate a continuous flow of goods and services essential for human well-being (Millennium Ecosystem Assessment, 2005; United Nations, 2005). These services are commonly classified into four broad categories. Provisioning services include tangible goods provided by ecosystems, such as food, fresh water, fibre, and raw materials. Regulating services encompass functions that regulate environmental conditions, including climate regulation, air and water purification, maintenance of soil quality, flood control, and carbon sequestration. Supporting services sustain the underlying ecological processes that deliver all other services, such as habitat provision, nutrient cycling, and biodiversity maintenance. Cultural services represent the non-material benefits derived from ecosystems, including recreation, aesthetic enjoyment, and spiritual and cultural values.



Figure 1. Ecosystem Services (WWF 2016)

The ecosystem services approach was internationally recognised with the United Nations Millennium Ecosystem Assessment (Reid et al 2005). Following up, the Economics of Ecosystems and Biodiversity (TEEB) studies advanced economic valuation of ecosystem

services. They contributed to the development of conceptual frameworks for systematically assessing ecosystem services and identifying social values (Figure 1).

Several interdisciplinary frameworks link ecosystem services with urban resilience. One such framework, demonstrated through the case of Barcelona, emphasises the application of blue-green infrastructure and ecosystem service policies guided by filters and principles. The filters, namely perceptions, institutions, and infrastructures, influence how ecosystem services are perceived, governed, and physically supported, thereby shaping their effectiveness in enhancing resilience. The Resilience Principles of Ecosystem Service, ranging from P1 to P7, further guide the adaptive capacity of urban ecosystems such as wetlands, rivers, and parks (Luca et al. 2021).

Another approach adopts a socio-ecological systems perspective, recognising the reciprocal relationship between ecosystems and human societies and highlighting the integration of ecosystem services into urban planning as essential for achieving disaster resilience, social stability, and long-term human well-being (McPhearson et al. 2015). Recent studies underscore the importance of integrating ecosystem-based approaches into disaster risk reduction (DRR), highlighting the role of provisioning and regulating services—such as food security and climate regulation—in reducing vulnerability to hazards (Walz et al. n.d.). The Social–Ecological–Technological Systems (SETS) framework further extends this perspective by incorporating technological dimensions to promote equitable distribution of ecosystem benefits and strengthen climate resilience (McPhearson et al. 2022). Complementing this, research on urban agglomerations indicates that regulating services have the strongest direct influence on resilience, while supporting services exert an indirect influence (Zhang et al. 2024). The ecosystem services cascade model provides an integrative lens by explaining how management, mobilisation, allocation, and appreciation shape the interaction between human systems and ecosystem service flows (Fedele et al. 2017).

City resilience measures and policies from the Global South show the value of ecosystem-based approaches. For example, in China and Thailand, flood-prone cities such as Jinhua and Bangkok have adopted natural measures for wetland restoration, including green roofs and detention ponds, to reduce waterlogging while enhancing biodiversity and public space. In the Philippines, mangrove rehabilitation and watershed management, supported through payment for ecosystem services, have helped improve cyclone-induced storm protection and community resilience. Lastly, Brazil's Itaipu program helped demonstrate how ecological corridors, as well as reforestation, safeguard hydropower and sequester carbon, thereby offering economic and environmental benefits.

These frameworks highlight the many ways ecosystem services contribute to building resilient cities and shaping sustainable urban growth. They emphasise the need for cross-disciplinary integration, participatory governance, and strategic planning to harness ecosystem services for sustainable, resilient urban development effectively.

3. Methodology

3.1 Overview of the study area

Bhubaneswar, known as the Temple City, is the capital and one of the largest cities in Odisha, India. Renowned for its numerous historic and culturally significant temples, it holds a prominent place in the state's heritage. According to the 2011 Census of India, the city's population was 8.37 lakh, which is projected to increase to 11.3 lakh by 2025. The Bhubaneswar Municipal Corporation covers 162 square kilometres. The Bhubaneswar Development Planning Area is 422 square kilometres. The city lies south of the Mahanadi Delta, supported by the Kuakhai River on the east and the Daya River on the south, and bounded by the Chandaka Wildlife Sanctuary and Nandankanan Zoological Park to the north and west (Bhubaneswar Development Planning Area 2024) (Figure 2).

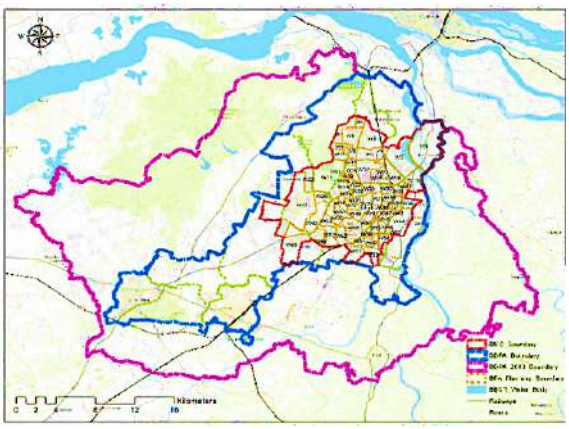


Figure 2. Administrative Map, Bhubaneswar

Bhubaneswar is highly vulnerable to urban flooding; Odisha's most frequent and damaging natural hazard. Nearly 80% of annual rainfall gets concentrated within only three monsoon months, leading to flash floods, siltation, and breaches in embankments (Government of

Odisha, 2019). Storm surges and river flooding intensity challenges across coastal and delta regions. Factors such as floodplain encroachment, rising population, and dependence on monsoon-driven agriculture further heighten vulnerability. Additionally, low socio-economic conditions amplify the impacts on affected communities (OSDMA 2019).

3.2 Data Collection

Both primary and secondary data sources have been utilised. Primary data were collected through surveys and household questionnaires to understand city residents' perceptions of ecosystem services for urban flood mitigation. Secondary data included satellite imagery, city development plans, the Census of India, Odisha Disaster Management Authority reports, and remote sensing sources such as USGS and Open Topo.

3.3 Method of Analysis

Based on a review of literature, the study adopts a mixed-methods approach combining household surveys and spatial analysis to assess urban flood management in Bhubaneswar. Resident surveys captured local perceptions and awareness, while spatial analysis included land-use, land-cover change, NDVI-based vegetation assessment, vulnerability mapping of flood-prone areas, and ecosystem service mapping to identify suitable zones for nature-based solutions. City resilience was further evaluated through resilience mapping, with the benefits of urban green spaces monetised using the i-Tree My Tree suite. The study concludes by proposing nature-based solutions at the city, ward, and slum levels, forming a multi-scalar strategy to enhance urban flood resilience.

4. Analysis and Key Findings

4.1 Urbanization Impact on Eco-sensitive Zones

EXTENT OF GREEN AND BLUE RESOURCES IN BDPA

The green cover of the Bhubaneswar development planning area covers 11,129.47 hectares, concentrated in the western region, including the Eco Sensitive Zone and Chandaka Sanctuary, which are connected to city-protected forest reserves (Figure 3). The study area's blue resources include surface water bodies with the Kuakhai River, a distributary of the Mahanadi that further branches into the Kushbhadra and Bhargavi rivers. Bhargavi gives rise to the culturally significant Daya River, which flows into Chilika Lake. The Daya River supports both urban and rural ecosystems, as well as a diverse range of flora and fauna (Bhubaneswar Development Planning Area 2024).

URBAN EXPANSION AND HABITAT DISRUPTION

The rapid urban sprawl in conurbations of Bhubaneswar, Cuttack and Khurda, driven by land sales near the sanctuary has led to an infrastructure boom at the expense of natural habitats. Road construction, footpath widening, and the development of bypasses on highways can lead to habitat fragmentation and increased interactions between wildlife and humans. In addition, mining in the buffer and peripheral zones of the sanctuary has severely degraded habitats, resulting in accidental wildlife deaths and minimal reclamation efforts. Urban expansion, habitat fragmentation, illegal logging, and forest degradation in Bhubaneswar have increasingly threatened eco-sensitive areas such as Nandankanan and Chandaka, particularly following the removal of the 1 km construction buffer in 2022. Although initiatives such as the National Afforestation Program and the Go Green Drive seek to restore forest cover and strengthen greenbelts, the findings underscore the continued need for stronger regulatory controls and sustainable planning. To understand these pressures, the study conducted a spatiotemporal analysis of land-use land-cover (LULC) changes in Bhubaneswar between 1995 and 2025 using multi-temporal Landsat imagery. Supervised classification of Landsat 5 and Landsat 9 data enabled the assessment of long-term land-cover transitions and the spatial patterns of urban expansion over time.

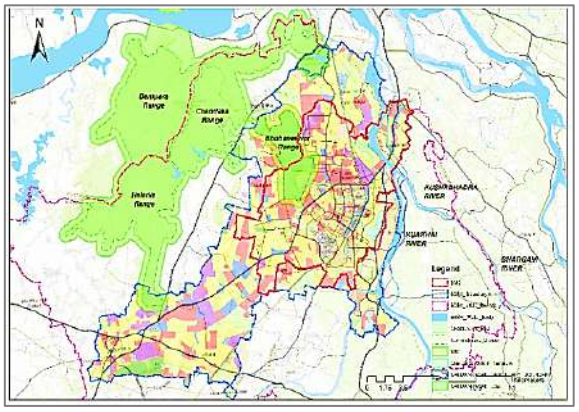


Figure 3. Regional Greens in BDPA, Chandaka Dampara Sanctuary

LULC DISTRIBUTION OVER TIME AND SPACE

Over the period 1995 to 2025, Bhubaneswar has experienced a steady 24.6 percent rise in built-up areas, reflecting rapid urbanisation in the city. This expansion has led to the degradation of dense vegetation, which initially declined, then recovered slightly and then decreased again. At

the same time, sparse vegetation has decreased for two decades, only to show a significant increase after 2015. The water body percentage also decreased consistently until 2015, with only a marginal increase afterward (Figure 4). Overall, this trend indicates rising urban pressure, leading to habitat loss and an imbalance in the ecosystem.

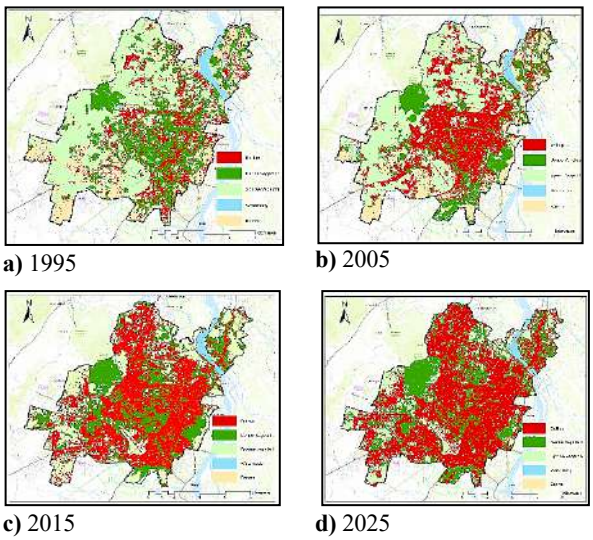


Figure 4. Land Use–Land Cover (LULC), Bhubaneswar

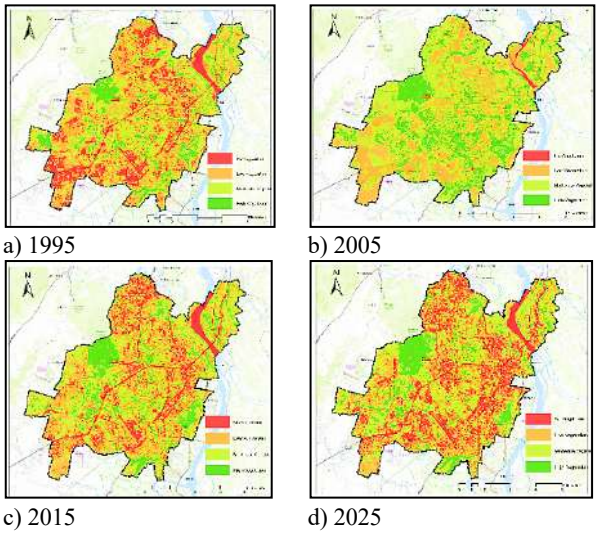


Figure 5. Normalised Difference Vegetation Index (NDVI)

The substantial growth in impervious built-up surfaces, accompanied by transportation infrastructure development, has disrupted natural infiltration processes. This has reduced the city's flood retention capacity by limiting groundwater recharge and increasing surface runoff, thereby exacerbating urban flood risks. The dynamic changes in vegetation and waterbody coverage further emphasise the degradation of ecological buffers critical for flood mitigation.

4.2 Vegetation Index

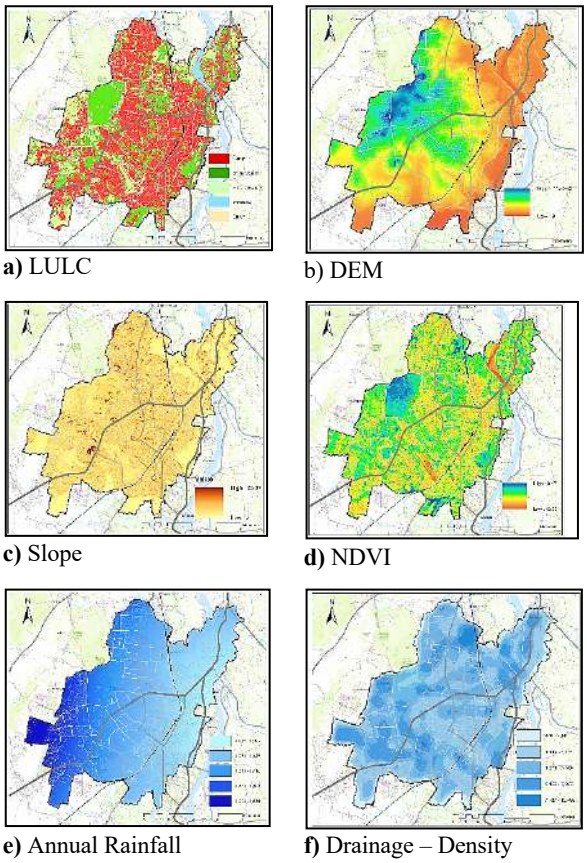
The Normalised Difference Vegetation Index (NDVI) is a quantitative measure ranging from −1 to +1 that uses visible and near-infrared remote sensing data to assess the presence and density of vegetation. In this study, NDVI was derived using Landsat 5 imagery for the period 1995–2011 and Landsat 9 imagery obtained from the USGS Earth Explorer for 2015–2025. NDVI was calculated using the standard near-infrared-to-red reflectance ratio, with appropriate band combinations for each sensor (Figure 5). The analysis reveals a notable decline in vegetation cover in Bhubaneswar from the mid-1990s to the early 2000s, particularly in areas such as Bharatpur Sanctuary, followed by a gradual recovery in green cover up to 2025, indicating partial ecological regeneration over time.

It has been observed that although vegetation cover decreased between 1995 and 2005, it gradually recovered from 2005 to 2025. This observed pattern reflects the positive impact of afforestation program, urban greening efforts, and environmental policies. However, the ongoing urban expansion, along with infrastructure development, continues to challenge the needed preservation of ecological balance.

4.3 Urban Flood Vulnerability under Rainfall and Cyclone Events Mapping

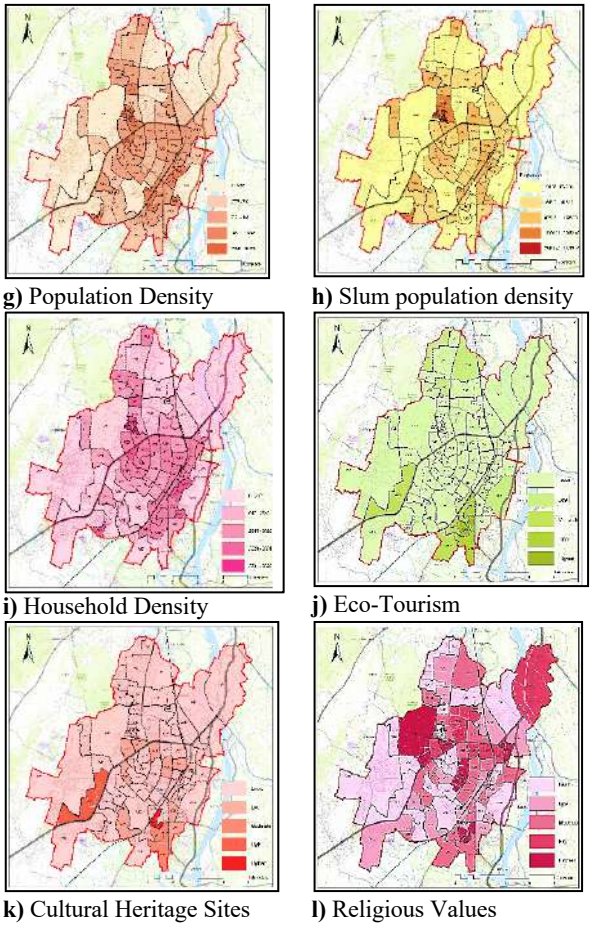
Urban flood vulnerability in Bhubaneswar was assessed using an integrated geospatial approach that combined biophysical, socio-economic, and cultural factors, with relative weights assigned using the Analytic Hierarchy Process (AHP). The analysis emphasizes the role of ecosystem services in mediating flood risk. Biophysical vulnerability was evaluated using key parameters: land use–land cover, slope, NDVI, elevation, drainage density, and rainfall, which together highlight that low-lying, gently sloping areas with sparse vegetation and inadequate drainage are most susceptible to flooding due to poor runoff and water accumulation (Figure 6).

The socio-economic vulnerability assessment was carried out using indicators such as slum population, household density, and city population density (Figure 7 a, b, c). Areas with a high concentration of slums and dense populations are more prone to urban flooding due to poor living conditions and limited access to essential services. Cultural vulnerability was assessed using various indicators, such as ecotourism, religious significance, and ward-wise cultural heritage site density (Figure 7 d, e, and f). Areas with a high density of temples, cultural landmarks, and heritage sites are particularly at risk of flood damage.



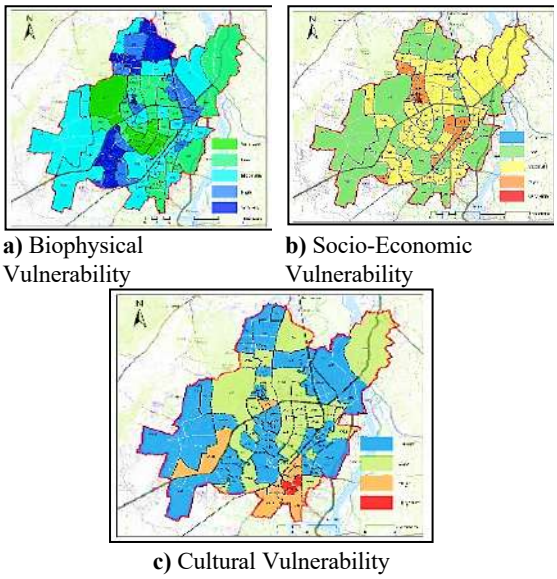
a) LULC b) DEM **c)** Slope **d)** NDVI **e)** Annual Rainfall **f)** Drainage – Density

Figure 6. Biophysical vulnerability of Bhubaneswar



g) Population Density **h)** Slum population density **i)** Household Density **j)** Eco-Tourism **k)** Cultural Heritage Sites **l)** Religious Values

Figure 7. Socio-economic vulnerability



a) Biophysical Vulnerability **b)** Socio-Economic Vulnerability **c)** Cultural Vulnerability

Figure 8. Composite maps of bio-physical, socio-economic and cultural vulnerability maps

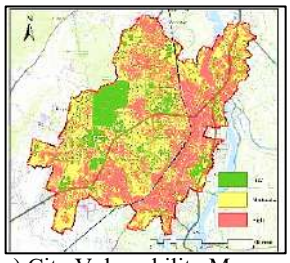
For each criterion, selections were made based on a review of the literature and their relevance to urban flood risk and resilience through ecosystem services. The relative importance of each criterion within its category was determined using the Analytic Hierarchy Process. Pairwise comparison matrices were created, and the resulting weights were validated using consistency ratio checks. Then, using calculated AHP weights and weighted overlay analysis in ArcGIS, composite bio-physical, socio-economic, and cultural vulnerability maps (Figure 8 a, b, and c) were prepared.

COMPOSITE VULNERABILITY ASSESSMENT

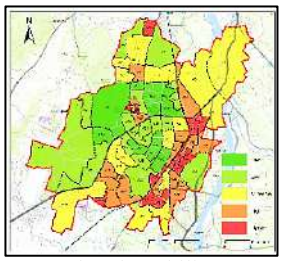
The composite vulnerability map integrates biophysical, socio-economic, and cultural factors using a weighted overlay approach at city, ward, and slum scales (Figures 9-a, b and c). The results show that central and eastern Bhubaneswar are the most vulnerable due to low elevation, dense impervious surfaces, high population, and sensitive cultural assets, while peripheral areas, especially in the northwest and southeast, face lower risk owing to less development, higher vegetation cover, and more favourable topography.

Biophysical, socio-economic, and cultural factors influence urban flood risk in the city. The central and eastern areas are the most vulnerable due to low elevation, rapid development, high population density, and concentrated cultural assets, while the northwest and southeast face lower risk because of favourable terrain and vegetation cover. These findings highlight the need for ecosystem-based flood mitigation

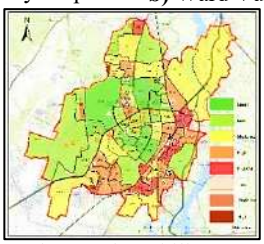
measures, including improved drainage, green infrastructure, and protection of cultural sites to enhance urban resilience.



a) City Vulnerability Map



b) Ward Vulnerability Map



c) Slum Vulnerability Map

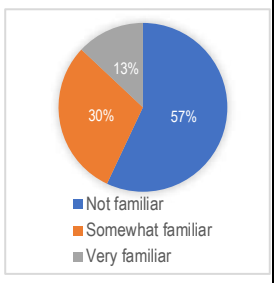
Figure 9. Composite vulnerability assessment**,** Bhubaneshwar**.**

4.4 Understanding Public Perception of the link between Ecosystem Services and Urban Flood Resilience

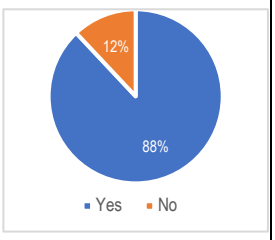
The survey was designed to capture public and stakeholder perspectives on the role of ecosystem services in strengthening disaster resilience, with a focus on urban flooding in Bhubaneswar. It examined citizens' awareness of the contribution of urban green spaces to flood resilience, stakeholder-identified vulnerabilities related to cyclone-induced flooding, and the adequacy of existing policies and planning responses. The survey covered two respondent groups: residents from the most flood-vulnerable wards (20, 21, 26, and 3) and key stakeholders, including urban planners, government officials, and disaster management authorities. A total sample size of 119 respondents was determined based on the projected 2025 population, using a 95% confidence level and a 9% margin of error.

PERCEPTIONS AND COMMUNITY INSIGHTS

The perception survey in Bhubaneswar indicates a high level of public and stakeholder recognition of the role of ecosystem services (ES) in enhancing urban flood resilience. While only 57% of respondents were familiar with the term "ecosystem services", a much larger share (88%) acknowledged their importance in mitigating urban flooding. Respondents reported noticeable environmental changes over the past decade, particularly vegetation loss (26%) and increased flooding (24%), with Cyclone Fani identified as the most significant flood-related event. Although over half of the respondents (52%) perceived the city to be reasonably well prepared, community participation in environmental initiatives remains low (16%). Nevertheless, there is strong public support (94%) for ecosystem-based policies and interventions, especially for wetland restoration and the expansion of urban green cover (Figure 10- a, b, c, d and e).

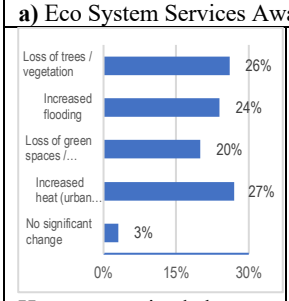


How familiar are you with the concept of Ecosystem services?

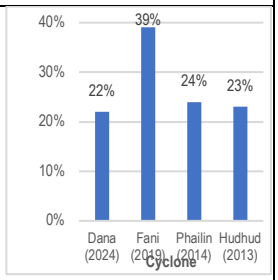


Are you aware that natural Ecosystems (Forests, Wetlands, urban Parks etc) help reduce cyclone impacts?

a) Eco System Services Awareness



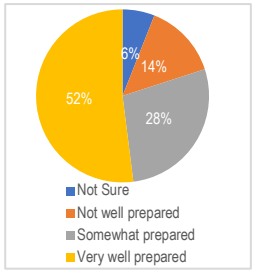
Have you noticed changes in Ecosystem in last 5-10 years in Bhubaneswar?



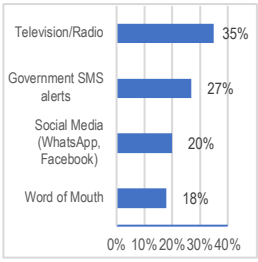
If yes, which cyclone (s) do you remember most?

b) Eco System Services change observation

c) Historic cyclone influence

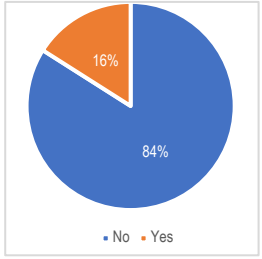


How prepared do you think Bhubaneswar is for cyclone?

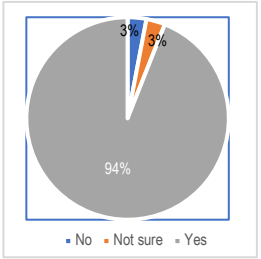


How do you receive cyclone warnings?

d) Preparedness on cyclone induced flooding



Are you involved in any community-led environmental initiatives?

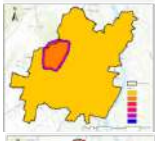
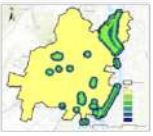


Would you support more Government policies to reduce cyclone-induced urban floods?

e) Support for Policies Enhancing Flood Resilience

Figure 10. Support for Policies Enhancing Flood Resilience

Table 1. Criteria for Mapping Ecosystem Services, which Regulate Urban Floods

Ecosystem Services	Overlay Criteria	Justification	Criteria	
Carbon Sequestration	NDVI > 0.4 = High Carbon Storage, 0.2-0.4 = Medium, <0.2 = Low	Higher NDVI areas (forests, wetlands) have better carbon sequestration potential. Built-up areas show negligible carbon storage	NDVI	
			Above Ground Biomass	
Flood Regulation	Low slope, permeable soil, and vegetation = High Flood Retention	Forests and wetlands in lower slopes show high retention. Built-up areas and steep slopes contribute to runoff.	Curve Number	
			Drainage Density	
			Slope	
Erosion Control	Low slope + Dense Vegetation + Productive soil + High Soil Depth = High Soil Erosion Control	Chandaka Forest and parks have high erosion control, whereas urban expansion areas show higher susceptibility.	Soil type	
			Soil depth	
			Soil productivity	
Biodiversity Hotspots	NDVI > 0.4, Proximity to water bodies, Within Protected Area	Chandaka-Dampara Sanctuary and riverbanks show high biodiversity importance, while urban areas are low in biodiversity.	ESZ Buffer	
			LULC	
			Water Bodies buffer	
Final Ecosystem Service Composite Mapping	Weighted Sum of Above Layers	It shows high potential in forested and wetland areas like Chandaka-Dampara. Moderate potential exists in agricultural and semi-vegetated zones. Low Potential in built up areas, Clayey soil, steep slope		

STAKEHOLDER PERSPECTIVES

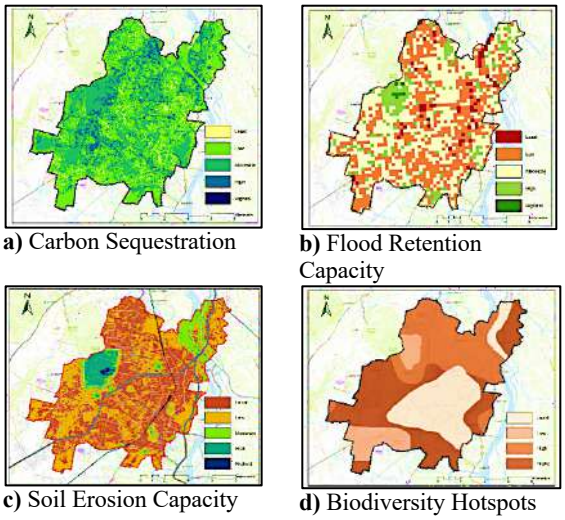
Interviews with officials highlighted long-standing coordination challenges in Bhubaneswar's flood management, dating back to the 1999 Super Cyclone. Representatives from IMD, OSDMA, BMC, and BDA emphasised the impacts of extreme rainfall on slums and critical infrastructure, prolonged urban flooding during cyclonic events, and vulnerabilities arising from rapid urban sprawl

and inadequate drainage systems. Collectively, these perspectives underscore the need for innovative resilience measures, including green infrastructure and Miyawaki forests, to address urban flood risk.

Overall, the analysis underscores the need for stronger policy action, improved stakeholder coordination, and sustained public engagement to translate awareness into effective, long-term flood mitigation strategies, particularly through the integration of ecosystem-based and spatial planning approaches.

4.5 Assessing Ecosystem Services that Regulate Urban Flooding

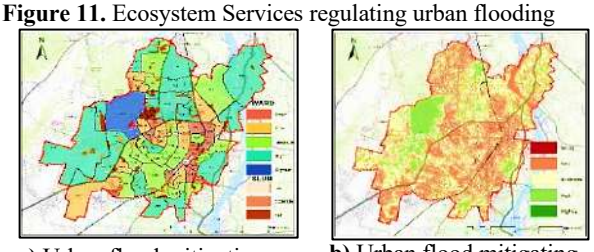
The assessment of ecosystem services for urban flood regulation in Bhubaneswar employed a GIS-based, multi-criteria approach (Table 1) to identify natural areas that enhance flood resilience through functions such as runoff regulation, soil stabilisation, carbon sequestration, and biodiversity conservation. Using geospatial datasets integrated with the Analytic Hierarchy Process (AHP), key biophysical and ecological criteria, including NDVI, slope, curve number, drainage, soil characteristics, and proximity to ecological assets, were selected and weighted based on expert judgment and literature (Figure 11-a, b, c, d). These standardised criteria were combined using a weighted overlay analysis to produce an ecosystem service map highlighting environmentally sensitive zones critical to urban flood control.



a) Carbon Sequestration **b)** Flood Retention Capacity

c) Soil Erosion Capacity **d)** Biodiversity Hotspots

Figure 11. Ecosystem Services regulating urban flooding



a) Urban flood mitigating ecosystem service Map **b)** Urban flood mitigating ecosystem service Map (Ward and Slum Scale)

Figure 12. Urban flood mitigating ecosystem service Maps

A GIS-based suitability analysis was conducted by classifying each criterion into low-to-high potential categories and applying AHP-derived weights through a weighted overlay method to generate a composite map of urban flood-regulating ecosystem services. Thematic layers representing carbon sequestration, flood regulation, soil erosion control, and biodiversity highlight that areas with dense vegetation, gentle slopes, lower runoff potential, and healthy soils, such as forest patches and zones near ecological assets, play a critical role in moderating runoff, enhancing infiltration, stabilising soils, and supporting biodiversity, thereby strengthening urban flood resilience in Bhubaneswar

4.6 Spatial Integration of Ecosystem Services for Urban Flood Mitigation

The final composite map combines all ecosystem service layers, weighted according to AHP-derived criteria, to highlight areas with the greatest potential for regulating urban floods at three scales: city scale (Figure 12-a) and ward and slum scale (Figure 12-b). This map serves as a valuable tool for guiding green infrastructure development, flood-resilient urban planning, and the designation of conservation zones. The potential for urban flood-regulating ecosystem services is highest in the northern and northwestern zones, including the Chandaka-Dampara Forest and surrounding wetlands. It is moderate in the semi-urban fringes and agricultural areas and lowest in the central city and densely populated neighbourhoods.

4.7 Assessing the Economic Value of Urban Green Areas

Rapidly growing cities such as Bhubaneswar rely on green infrastructure to replicate natural processes that deliver critical ecosystem services, including stormwater regulation, carbon sequestration, and flood risk mitigation. This study conducted a ward-wise economic valuation of ecosystem services using the i-Tree MyTree model, estimating the monetary benefits of urban trees from carbon storage, rainfall interception, and runoff reduction. Using species data for common urban trees and converting values to Indian Rupees, the analysis found that wards with higher green cover—particularly on the urban periphery and near greenbelts—generate the greatest ecosystem service benefits, underscoring the role of urban green spaces in strengthening flood resilience.

4.8 Trends in Historical Disaster Losses

Ward-level structural and economic losses from past flooding events and cyclones in Bhubaneswar were compiled from secondary data sources and mapped using GIS to capture spatial differences in vulnerability (Figure 13-a, b). The results showed that central and eastern wards suffered the highest economic losses, largely due to dense urbanisation, low soil permeability, and limited green spaces, all of which worsen runoff and increase flood severity. The disaster loss map, presented in crores (Cr.), clearly highlights zones with repeated high exposure and damage. This information was then compared with ecosystem service benefits, providing an important basis for evaluating resilience across the city.

4.9 Using BLR to Classify Economic Resilience

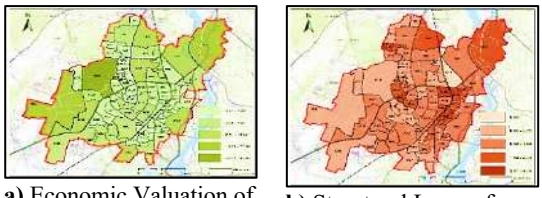
For every ward, the Benefit Loss Ratio (BLR) was determined by dividing the total economic value of ecosystem services by the corresponding disaster-related losses (Figure 14-a). Based on these BLR outcomes and the distribution of green infrastructure, the wards were grouped into three categories of economic resilience: high, moderate, and low (Figure 14-b).

4.10 Mapping Economic Resilience-Based Ward Zoning

Using a multi-criteria framework that incorporated (BLR), ecosystem service valuation, and vulnerability assessment, an integrated economic resilience map was generated. The analysis revealed three distinct resilience categories: high, moderate, and low. Areas on the western edge and peripheral wards generally demonstrated higher resilience, supported by strong BLR scores, lower vulnerability, and greater ecosystem service potential. In contrast, the city's core emerged as the most fragile, where dense urban development and limited green infrastructure have intensified disaster-related losses while reducing ecological benefits. These low-resilience pockets signal critical targets for green infrastructure investment and focused policy action.

4.11 Resilience Capacity of Urban Areas

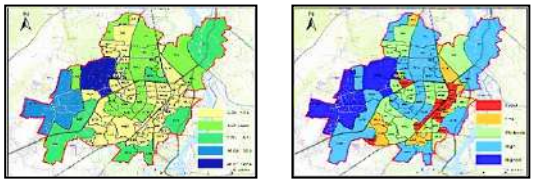
Urban flood resilience is the city's ability to absorb shocks, recover rapidly, and adapt to long-term climate stresses. This challenge is particularly acute in fast-growing cities such as Bhubaneswar. This study adopts a holistic framework that links ecosystem services with socio-infrastructural conditions to assess how cities prepare for, cope with, and recover from urban flooding. Resilience was evaluated using a City Resilience Capacity Index developed through GIS-based multi-criteria analysis combined with the Analytic Hierarchy Process (AHP). Eleven spatial indicators representing ecological capacity (Figure 15-a, b, c, and d), infrastructure adequacy (Figure 16-a, b, c, and d), and socio-economic sensitivity (Figure 17-a, b and c) were selected, standardized, and weighted based on literature and expert judgment to capture their relative contribution to urban flood resilience.



a) Economic Valuation of Ecosystem Services

b) Structural Losses from Disasters

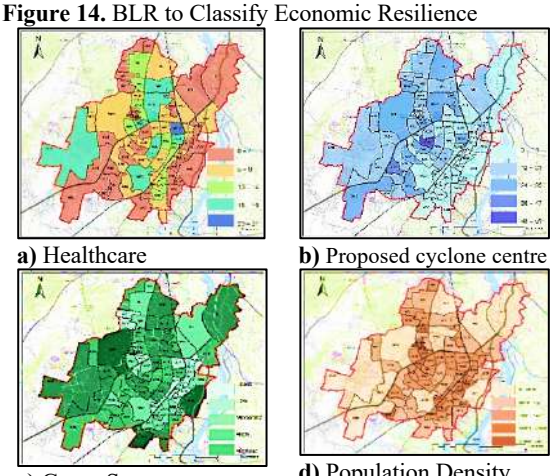
Figure 13. Ward-level structural and economic losses (in crores)



a) Ward Wise Benefit Cost Ratio Map

b) Ward Wise Economic Resilience

Figure 14. BLR to Classify Economic Resilience



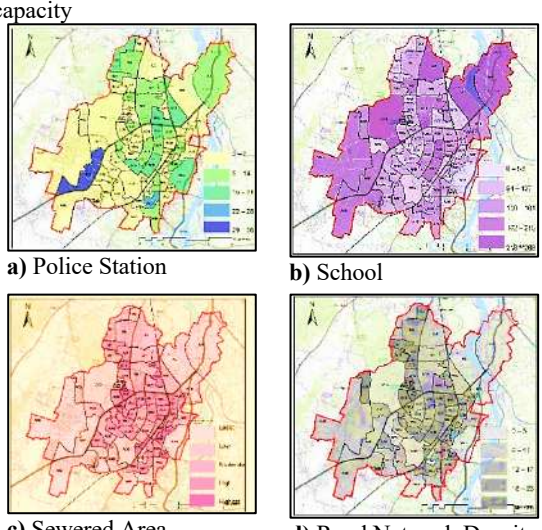
a) Healthcare

b) Proposed cyclone centre

c) Green Spaces

d) Population Density

Figure 15. Spatial indicators representing ecological capacity



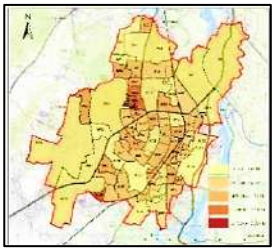
a) Police Station

b) School

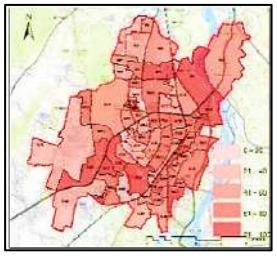
c) Sewered Area

d) Road Network Density

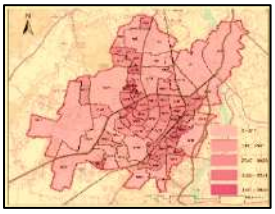
Figure 16. Spatial indicators representing infrastructure adequacy



a) Slum Population Density



b) Household with good conditions



c) Household Density

Figure 17. Spatial indicators representing socio-economic sensitivity

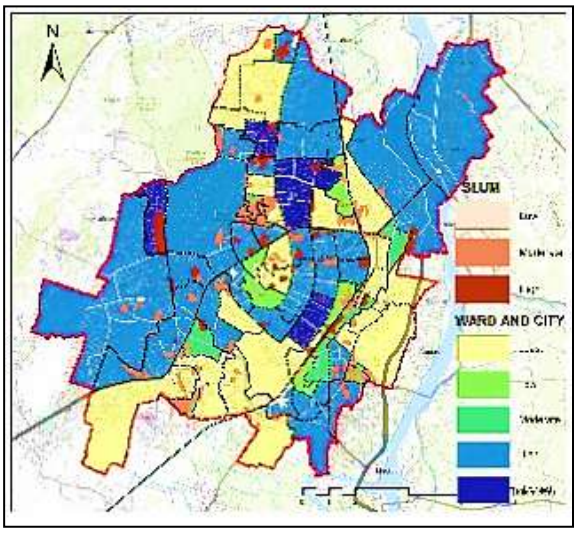


Figure 18. Resilience Index Map of Bhubaneswar City (city, ward, and slum scale) (Shweta 2025)

GIS-BASED COMPOSITE RESILIENCE INDEX MAPPING

The composite City Resilience Map identifies three resilience levels across Bhubaneswar (Figure 18). High-resilience zones are concentrated in central wards with better access to green spaces and services, while moderate- resilience areas are found in transitional zones with uneven infrastructure. Low-resilience zones are mainly peripheral and informal settlements, marked by high density, limited green cover, poor connectivity, and inadequate public infrastructure.

SPATIAL ANALYSIS OF RESILIENCE ZONES

The spatial distribution of resilience across Bhubaneswar reveals significant urban disparities in service availability and risk exposure. The city core shows higher adaptive capacity, supported by integrated infrastructure and abundant green cover. In contrast, peripheral wards are underserved and more vulnerable to climate-related hazards such as flooding. The resilience capacity map serves as a strategic tool for guiding investments in essential infrastructure and ecosystem restoration, thereby strengthening vulnerable areas. It also informs policies for equitable service distribution and promotes a more resilient urban structure.

5. Key Issues and Future Potential

5.1 Environmental Challenges

Urbanization in Bhubaneswar between 1995 and 2025 has led to significant environmental and ecological challenges. Key issues include rapid urban expansion and loss of green spaces, declining NDVI and vegetation cover, increased flood and soil erosion risks, biodiversity loss and habitat fragmentation, heightened physical and socio-economic vulnerabilities, limited public awareness of ecosystem services, uncontrolled development in eco-sensitive areas, and the cumulative effects of climate change on urban ecosystems. Together, these challenges weaken the city's resilience and its ability to manage both human-induced and climate-related risks sustainably.

5.2 Ecosystem Services and Urban Vulnerability Correlation

A Pearson correlation of -0.68 suggests a moderate to strong negative relationship between flood vulnerability and flood-regulating ecosystem services (Figure 19). This indicates that areas with higher flood risk are often those with lower levels of ecosystem services.

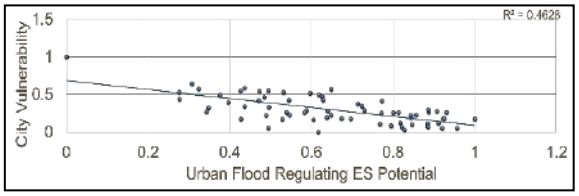


Figure 19. Ecosystem Services and Urban Vulnerability Correlation (Shweta 2025)

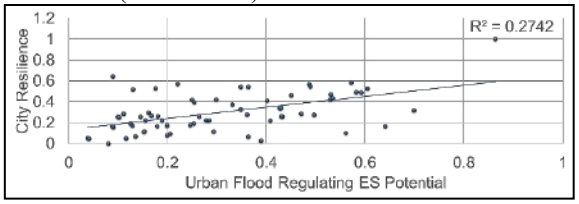


Figure 20. Urban Resilience and Urban Flood Regulating ES Potential Correlation (Shweta 2025)

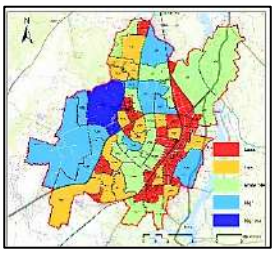
5.3 Ecosystem Services and Urban Flood Regulating ES Potential Correlation

In addition, the Pearson correlation of +0.52 indicates a moderate-to-high positive relationship between ecosystem service

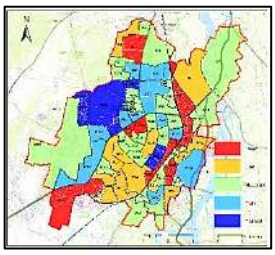
potential and city resilience at the ward level (Figure 20). This suggests a moderate positive relationship, indicating that while ecological assets contribute to urban resilience, there are still notable gaps at the ward level.

5.4 Spatial Classification of Priority Zones for Intervention

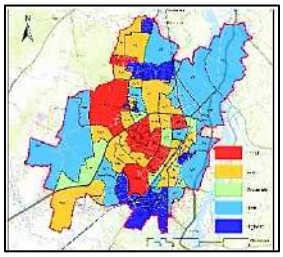
Overlaying the eco-sensitive potential and vulnerability maps allowed wards to be classified into priority categories. Wards with high ecosystem service potential but low resilience (Figure 21-a) were identified as critical intervention areas requiring urgent restoration and resilience-building measures. In contrast, zones with both high potential and high resilience (Figure 21-b) represent key ecological assets that effectively support the city's adaptive capacity and should be preserved. Areas with low ecosystem potential and low resilience (Figure 21-c) were flagged as priority zones for both ecological restoration and infrastructure enhancement.



a) Wards with High Ecosystem Service Potential and Low Vulnerability



b) Wards with Low Capacity and Low Ecosystem Service Potential



c) Wards with High Ecosystem Service Potential and High Vulnerability (Shweta 2025)

Figure 21. Spatial classification of priority zones for intervention.

The analyses highlight the crucial role of ecosystem services in enhancing urban resilience. Planning efforts should prioritise protecting areas with high ecosystem service potential, restoring vulnerable ecological zones, and integrating of nature-based solutions into broader urban development strategies.

6. Recommendations

6.1 Multi-Scale Implementation Framework

"Nature-based Solutions are actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Source: IUCN).

In Bhubaneswar, the adoption of Nature-Based Solutions (NBS) is proposed across three spatial scales: zonal, ward, and local area, with potential financing avenues including AMRUT 2.0, CAMPA, and the 15th Finance Commission grants (Table 2). Wards that demonstrate both high ecosystem service potential and elevated vulnerability (Figure 22) are priority sites for NBS deployment, as they locations offer the greatest scope for reducing risk while enhancing ecological benefits.

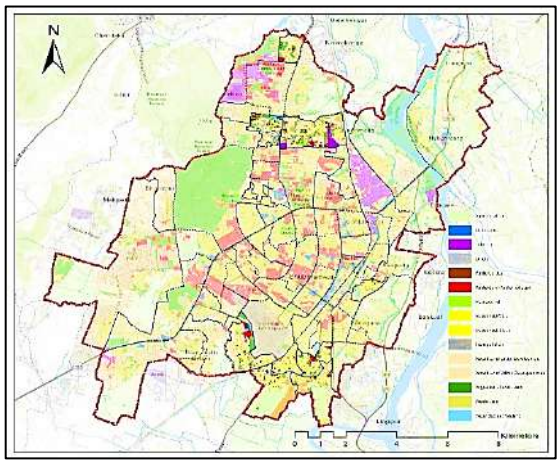
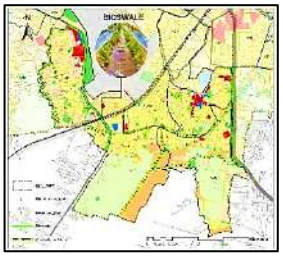
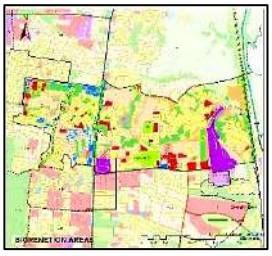


Figure 22. Areas of High Vulnerability and Strong Flood-Regulating Ecosystem Services (Shweta 2025)



a) South-East Zone



b) North Zone



c) Ward 43



d) Ward 2



e) Slum Level Proposal on Salia Sahi, Bhubaneswar

Figure 23. Multi-scale proposed NBS framework

6.2 Multi-Scale Interventions

At the zonal level, areas such as the South-East Zone (Wards 59, 60, 61, 62, and 67) (Figure 23-a) are recommended for interventions such as bioswales, bio-retention areas, and gravel filters to enhance carbon sequestration and reduce runoff. In the North Zone (Wards 8 and 9) (Figure 23-b), efforts focus on improving green infrastructure through stormwater filtration systems and the expansion of green spaces. Ward-specific measures include bio retention infrastructure in Ward 43 (Figure 23-c) and gravel-based detention systems in Ward 2 (Figure 23-d), providing both ecological and social benefits. In highly vulnerable areas such as Wards 21 and 26 (Figure 23-e) (for example, Salia Sahi), interventions emphasize integrated waste and water management, revitalization of open spaces, and community-based environmental education programs.

Table 2. Multi-scale proposed NBS benefit quantification

South-East Zone	**Bioretention Areas**	**Nos.**	**Area (sqm)**	**Carbon Sequestered (lbs)**	**CO_2 Equivalent (lbs)**	**Runoff Avoided (Gal)**	**Rainfall Intercepted (Gal)**
		14.00	809.20	2,754.68	10,449.81	2,222.81	39,425.39
	Bioswale	Length (m)	Area (Sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off (litres/year)
		5,355.00	16,065.00	1.49	0.15	3,595.35	3,595,347.00
	Gravel Filter Strips	Length (m)	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off available (litres/year)
		10938.00	16407.00	1.49	0.15	3,671.89	3,671,886.60
	Detention basin	Nos	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off available (cum/year)	Run off (litres/year)
		7.00	63,700.00	7.46	3.75	71,280.30	71,280,300.00
North Zone	**Bioretention Areas**	Nos	Area (sqm)	Carbon Sequestered (lbs)	CO_2 Equivalent (lbs)	Runoff Avoided (Gal)	Rainfall Intercepted (Gal)
		12.00	693.60	2361.15312	8956.977	1905.2637	33793.19078
	Bioswale	Length (m)	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off available (litres/year)
		2917.00	8751.00	1.49	0.15	3.49	4.49
	Gravel Filter Strip	Length (m)	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off (litres/year)
		1,936.00	2,904.00	1.49	0.15	649.92	649,915.20
	Detention basin	Nos	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off (litres/year)
		1.00	4,900.00	1.49	1.50	5,483.10	5,483,100.00
Ward 43	**Bioretention Areas**	Nos	Area (sqm)	Carbon Sequestered (lbs)	CO_2 Equivalent (lbs)	Runoff Avoided (Gal)	Rainfall Intercepted (Gal)
		3	173.40	590.2883	2239.244	476.3159	8448.297696
	Bioswale	Length (m)	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off (litres/year)
		3,303.81	9,911.42	1.49	0.15	2,218.18	2,218,175.35
	Gravel Filter Strips	Length (m)	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off (litres/year)
		977.00	1,465.50	1.49	0.15	327.98	327,978.90
	Detention basin	Nos	Area (sqm)	Rain fall (m)	Runoff Coefficient*	Run off (cum/year)	Run off (litres/year)
		1.00	4900.00	1.49	0.75	5,483.10	5,483,100.00
Ward 2	**Bioretention Areas**	Nos	Area (sq m)	Carbon Sequestered (lbs)	CO_2 Equivalent (lbs)	Runoff Avoided (Gal)	Rainfall Intercepted (Gal)
		11	635.80	2,164.39	8,210.56	1,746.49	30,977.09
	Bioswale	Length (m)	Area (sqm) (to be filled)	Rain fall (m) (to be filled)	Runoff Coefficient*	Quantum of Run off available (cum/year)	Quantum of Run off available (litres/year)
		1,182.00	3,546.00	1.49	0.15	793.59	793,594.80

6.3 Benefit Quantification of Proposed Nature-Based Solutions

Table 2 presents a zone-wise assessment of proposed Nature-Based Solutions (NBS) interventions, including bioswales, gravel filter strips, and detention basins, across three bioretention zones. It quantifies their potential benefits in terms reduced runoff, groundwater recharge, flood attenuation, and improved overall urban resilience. By comparing intervention types and spatial contexts, the assessment highlights how targeted NBS implementation can enhance flood regulation efficiency while supporting ecological restoration and sustainable urban water management.

In Bhubaneswar, the adoption of Nature-Based Solutions (NBS) is proposed across three spatial scales: zonal, ward, and local area, with potential financing avenues including AMRUT 2.0, CAMPA, and the 15th Finance Commission grants (Table 3). Wards that demonstrate both high ecosystem service potential and elevated vulnerability (Figure 22) are priority sites for NBS deployment, as they locations offer the greatest scope for reducing risk while enhancing ecological benefits.

Table 3. Multiscale NBS intervention proposal

Scale	Ward/Area	Key Actions/ Measures	Funding Source
South-East Zone	Wards 59, 60, 61, 62, 67	Bioretention areas, Bioswales, Runoff reduction, Carbon sequestration	AMRUT 2.0 (stormwater projects) CAMPA Fund (for green cover & carbon sink) 15th Finance Commission Grants
North Zone	Ward 8, 9	Green filters, Gutter strips, Enhance green space functionality	
Ward	Ward 43	Bioretention areas, Tree cover for social + ES benefit	
	Ward 2	Gravel filters, Detention basins, Stormwater storage	
Slum Area	Ward 21, 26 (Salia Sahi)	Improved waste and sewage management, Open space rejuvenation, Decentralized wastewater solutions, Community empowerment through training, climate awareness, and participatory tools to further build resilience.	

6.4 Policy Recommendations

To strengthen urban flood resilience in Bhubaneswar, ecosystem service-based strategies should be integrated into planning, infrastructure, and governance. Green infrastructure, such as rain gardens and bioswales, can be introduced in parks and along major drains as flood detention zones. Buffer zones of 5–9 meters should be mandated along drains and ponds and enforced through revised land-use regulations. Streets should adopt sponge-city features, such as permeable pavements and bioswales. Urban ponds and wetlands should be restored and safeguarded as natural flood-retention areas under a designated land-use category. Governance reforms include creating an Ecosystem Cell within BMC for eco-based disaster risk reduction. Incentives such as FAR bonuses and tax rebates should promote water-sensitive urban design in private developments. These strategies align with Bhubaneswar's CDP 2040 goals for compact growth and resilient blue-green infrastructure.

7. Conclusions

This study highlights the critical role of ecosystem services in building city resilience against urban floods. By systematically identifying, mapping, and integrating these services into city planning, they can serve as powerful tools to reduce risk and enhance ecological stability. The research focuses on the regulatory and supporting services that influence how floods are managed across Bhubaneswar, exploring how these natural assets contribute to the city's overall resilience. Central to the study is the concept of Ecosystem-based Disaster Risk Reduction (Eco-DRR), which shows how nature-based solutions can be thoughtfully applied using spatial analysis, ecological valuation, and effective institutional support.

Practical strategies are proposed to guide urban growth while preserving ecological integrity, aligning with long-term plans such as the CDP 2040 and Smart City initiatives Overall, this work provides a practical, evidence-based framework for incorporating ecosystem services into urban flood resilience strategies, offering guidance for climate-adapted development and emphasizing the importance of green spaces and nature-based interventions in shaping sustainable urban policy in India.

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