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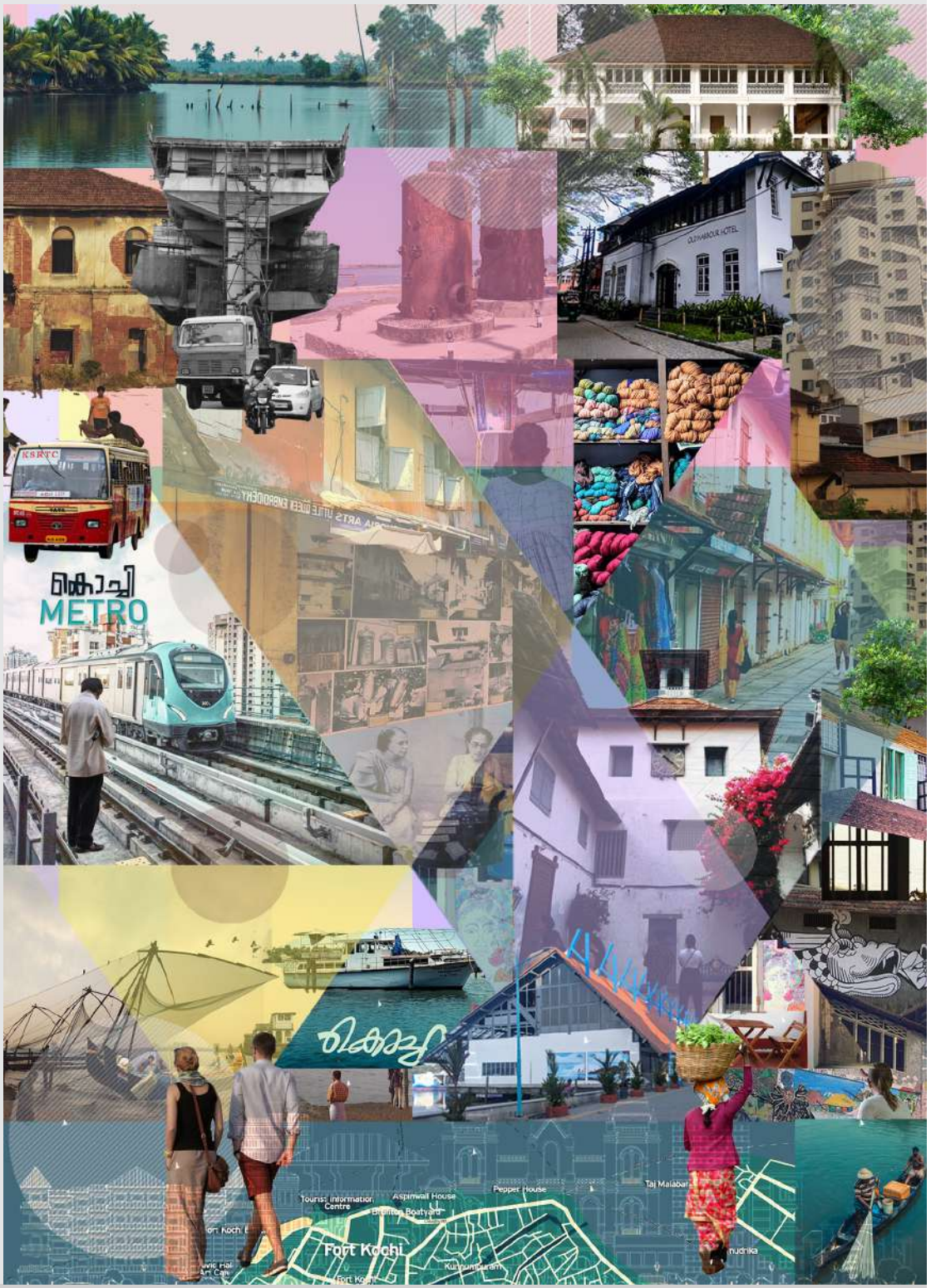
**योजना तथा वास्तुकला विद्यालय, नई दिल्ली**
संसद के अधिनियम के तहत "राष्ट्रीय महत्व का संस्थान" (शिक्षा मंत्रालय, भारत सरकार)

# SPACE

The SPA Journal of Planning and Architecture

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SPACE is a quarterly research journal of the School of Planning and Architecture, New Delhi. Papers published in this journal bring together cutting-edge knowledge and fresh insights in the fields of architecture, planning, design and technology. SPACE presents the scholarly works of academicians, researchers, professionals, and policymakers from India and abroad in the entire gamut of the built environments.

# SPACE, The SPA Journal of Planning and Architecture

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SPACE, the quarterly journal of SPA, New Delhi seeks to publish original research papers, shorter research notes and synopsis of dissertations and theses in all areas of planning, architecture, design and technology. Authors from the planning discipline may focus on environment planning, housing and habitat studies, infrastructure planning, transport planning, urban and regional planning and papers on any other aspect of planning such as urban governance and management. Authors from the fields of architecture, design and technology may delve into the broad areas of architectural conservation, landscape architecture, urban design, industrial design, building engineering and project management.



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# SPACE, The SPA Journal of Planning and Architecture

Volume 25, Number 3-4, July-September and October-December 2021

## Contents

# Departments of Studies at the School of Planning and Architecture, New Delhi

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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Each Department of Studies has a research centre capable of handling advanced research in respective areas of interest. Each Department of Studies also has a Departmental Research Committee (DRC) and the Head of the Department of Studies is its chairperson. Each department through their Advisory Committees, chaired by the Head of Departments, can propose changes to their departmental agenda for research, curriculum and pedagogy.

In addition to regular faculty, a large number of visiting professors, visiting faculty and contract faculty contribute to academic programs of School. School offers opportunity for interdepartmental/inter-university credits including those from foreign universities under Memorandum of Understanding (MoU) with School.

# Editorial

This issue of SPACE, the SPA Journal of Planning and Architecture, includes twelve research papers that offer insight into a wide spectrum of topics that aim to address waste waterscape inducing inequalities in informal areas (a case of the NCT of Delhi); socio-spatial disparities in the Indian megacities (a case of the Greater Mumbai); gender inclusivity in Kochi's tourism sector (challenges, opportunities, and strategic recommendations); the shift in women's mobility patterns post the launch of gender-targeted schemes in Delhi buses; net zero sustainable development planning for an institutional campus design; tribal museums (a vessel for conservation or misrepresentation of the 'cultural other'); ensuring long-term affordability in low-cost housing (the trade-off between cost compromises and service); crowdshipping in urban freight logistics (a systematic literature review); thermal comfort conditions in Rajbaris of Bengal (a case study of Bawali); planning for resilient development along a river (a case of the Guwahati Metropolitan area); the impact of economic growth on women's labour market in CNCR districts; and colonial land control and urban planning of Delhi between 1900 and 1940.

"Waste waterscape inducing inequalities in informal areas: a case of the NCT of Delhi" examines three long-standing informal settlements in Delhi's Barapullah sub-basin: Madrasi Camp, Indira Camp II, and Anna Nagar. This research paper proposes a practical pathway that combines simple water conveyance, small-scale decentralised water treatment, low-risk household water reuse and transparent local governance to reduce waste water discharge into the Yamuna and narrow WASH inequalities. "Socio-spatial disparities in the Indian megacities: a case of Greater Mumbai" evaluates social disparities using specific parameters or indicators, and scrutinises the spatial implications of these disparities. The paper recommends policy-level and development plan-level interventions to reduce social disparities. "Gender inclusivity in Kochi's tourism sector: challenges, opportunities, and strategic recommendations" employed both primary and secondary methods to assess gender diversity across employment, entrepreneurship, community participation, education, and leadership. The study emphasises the importance of developing comprehensive strategies to promote gender inclusivity within the tourism industry, including flexible work arrangements, enhanced safety measures, and targeted skill development. "The shift in women's mobility patterns post the launch of gender-targeted schemes in Delhi buses" found a 33 percent rise in the female ridership since the launch of the Pink Slip scheme in 2019. "Net Zero Sustainable Development Planning for an Institutional Campus Design" proposes a comprehensive framework for achieving net-zero energy, carbon, water, and waste, as well as sustainable development, of university campuses in India. The study emphasises the need for integrated solutions and moving beyond building-centric approaches. "Tribal Museums: a vessel for conservation or misrepresentation of the 'cultural other'?" paper presents examples from Madhya Pradesh, India and argues that such forms of museumification promote a fossilised, even misleading, vision of the community, popularising exoticism and creating a binary between the tribal and the non-tribal in the popular imagination of the audience for these displays. "Ensuring long-term affordability in low-cost housing: trade-off between cost compromises and service life," through a detailed analysis of case studies and building systems, the study reveals that material quality and design level have the greatest impact (over 60%) on the service life of structural systems, with inherent deficiencies arising from cost compromises CP) that reduce service life. These findings underscore the need to improve design practices and strategies for low-cost housing to balance service-life performance and lifecycle costs across building components. "Crowdshipping in Urban Freight Logistics: A Systematic Literature Review" is based on 61 peer-reviewed research papers and presents a stock of the evolution of crowdshipping from a niche idea to a visible strand of urban freight practice, built around digital platforms and gig-based delivery work. Thematically, the literature tends to cluster around six recurring concerns: how crowdshipping is organised as a business and operational model; how platforms and digital infrastructure are designed; the optimisation and simulation tools used to plan services; behavioural aspects of participation; environmental and sustainability claims; and emerging policy or regulatory debates. "Thermal comfort conditions in Rajbaris of Bengal: a case study of Bawali" has three sections: the historical context in which the Rajbaris took shape; the adaptive Reuse of Bawali Rajbari, highlighting passive design strategies; and the assessment of thermal comfort within the adapted Rajbari. "Planning for Resilient Development Along a River: A Case of Guwahati Metropolitan Area" analyses the spatial and environmental changes along the Brahmaputra River within the GMA and proposes strategies for resilient development of the GMA at the micro, meso, and macro levels through structural, behavioural, and institutional measures. "Impact of Economic Growth on Women's Labour Market in CNCR Districts" argues that women's labour market participation

contributes to economic growth and serves as a pivotal catalyst for fostering sustainable development and economic prosperity. Further, by promoting women's education, ensuring gender-responsive labour policies, creating supportive work environments, and addressing socio-cultural barriers, sustainable development strategies can empower women to actively participate in the labour force, thereby contributing to inclusive growth and economic development. "Colonial land control and urban planning: Delhi between 1900 and 1940" aims to decode two colonial official documents. The paper uses archival research to show how land acquisition became central to British colonial urban planning ideology and how Improvement Trust schemes and policies facilitated land control.

(CHITRAREKHA KABRE)

**Editor**

# संपादकीय

स्पेस, एसपीए योजना और वास्तुकला पत्रिका के इस अंक में बारह लेख शामिल हैं जो विविध शोध विषयों में अंतर्दृष्टि प्रदान करते हैं, जिनका उद्देश्य संबोधित करना है, अनौपचारिक क्षेत्रों में अपशिष्ट जल-परिदृश्य से उत्पन्न असमानताओं को (एनसीटी दिल्ली का एक मामला); भारतीय महानगरों में सामाजिक-स्थानिक असमानताएं (ग्रेटर मुंबई का एक मामला); कोच्चि के पर्यटन क्षेत्र में लैंगिक समावेशिता (चुनौतियां, अवसर और रणनीतिक सुझाव); दिल्ली की बसों में लैंगिक-लक्षित योजनाओं के शुरू होने के बाद महिलाओं की आवाजाही के तरीकों में आया बदलाव; किसी संस्थागत परिसर के डिज़ाइन के लिए 'नेट ज़ीरो' सतत विकास की योजना; जनजातीय संग्रहालय (संरक्षण का माध्यम या 'सांस्कृतिक रूप से भिन्न' लोगों का गलत चित्रण); कम लागत वाले आवासों में दीर्घकालिक सामर्थ्य सुनिश्चित करना (लागत में कटौती और सेवा अवधि के बीच का संतुलन); शहरी माल ढुलाई लॉजिस्टिक्स में 'क्राउडशिपिंग' (एक व्यवस्थित साहित्य समीक्षा); बंगाल के राजबाड़ियों में तापीय आराम की स्थितियां (बावली का एक वृत का अध्ययन); नदी के किनारे लचीले विकास की योजना बनाना (गुवाहाटी महानगरीय क्षेत्र का एक मामला); सीएनसीआर ज़िलों में महिलाओं के श्रम बाज़ार पर आर्थिक विकास का प्रभाव; और दिल्ली में औपनिवेशिक भूमि नियंत्रण तथा शहरी नियोजन (1900 से 1940 के बीच)।

"अनौपचारिक क्षेत्रों में अपशिष्ट जल-परिदृश्य से उत्पन्न असमानताएं: एनसीटी दिल्ली का एक मामला," दिल्ली के बारापुल्ला उप-बेसिन में स्थित तीन पुराने अनौपचारिक बस्तियों—मद्रासी कैंप, इंदिरा कैंप II और अन्ना नगर— का अध्ययन करता है। यह शोध-पत्र यमुना नदी में अपशिष्ट जल के बहाव को कम करने और WASH (जल, स्वच्छता और सफाई) से जुड़ी असमानताओं को दूर करने के लिए एक व्यावहारिक मार्ग का प्रस्ताव करता है, जिसमें, सरल जल परिवहन व्यवस्था, छोटे पैमाने पर विकेंद्रीकृत जल उपचार, घरों में कम जोखिम वाले जल-पुनर्चक्रण और को पारदर्शी स्थानीय शासन एकीकृत किया गया है। "भारतीय महानगरों में सामाजिक-स्थानिक असमानताएं: ग्रेटर मुंबई का एक केस स्टडी" विशिष्ट मापदंडों या संकेतकों का उपयोग करके सामाजिक असमानताओं का मूल्यांकन करता है, और इन असमानताओं के स्थानिक प्रभावों की गहन जाँच करता है। यह शोध-पत्र सामाजिक असमानताओं को कम करने के लिए नीति-स्तर और विकास योजना-स्तर पर हस्तक्षेपों का सुझाव करता है। "कोच्चि के पर्यटन क्षेत्र में लैंगिक समावेशिता: चुनौतियाँ, अवसर और रणनीतिक सुझाव" अध्ययन में रोज़गार, उद्यमिता, सामुदायिक भागीदारी, शिक्षा और नेतृत्व के क्षेत्रों में लैंगिक विविधता का आकलन करने के लिए प्राथमिक और द्वितीयक, दोनों ही शोध पद्धतियों का उपयोग किया गया है। । यह अध्ययन पर्यटन उद्योग में लैंगिक समावेशिता को बढ़ावा देने के लिए व्यापक रणनीतियाँ विकसित करने के महत्व पर ज़ोर देता है, जिसमें सुविधाजनक कार्य व्यवस्थाएँ, सुरक्षा के बेहतर उपाय और लक्षित कौशल विकास शामिल हैं। दिल्ली की बसों में लैंगिक-लक्षित योजनाओं के शुरू होने के बाद महिलाओं की आवाजाही के तरीकों में आया बदलाव पर किए गए अध्ययन में पाया गया कि 2019 में 'पिंक स्लिप योजना' शुरू होने के बाद से महिला यात्रियों की संख्या में 33 प्रतिशत की वृद्धि हुई है। "किसी संस्थागत परिसर के डिज़ाइन के लिए नेट-ज़ीरो सतत विकास की योजना" भारत में विश्वविद्यालय परिसरों में नेट-ज़ीरो ऊर्जा, कार्बन, जल और अपशिष्ट, तथा सतत विकास हासिल करने के लिए एक व्यापक रूपरेखा प्रस्तुत करती है। यह अध्ययन एकीकृत समाधानों की आवश्यकता और केवल भवन-केंद्रित दृष्टिकोणों से आगे बढ़ने पर ज़ोर देता है। जनजातीय संग्रहालय (संरक्षण के लिए एक पात्र या 'सांस्कृतिक रूप से भिन्न' लोगों का गलत चित्रण) शोध-पत्र भारत के मध्य प्रदेश से उदाहरण प्रस्तुत करता है तथा यह तर्क करता है कि संग्रहालयीकरण समुदाय की एक जीवाश्मवत, और यहाँ तक कि भ्रामक, दृष्टि को बढ़ावा देता है; ये 'विचित्रता' को लोकप्रिय बनाते हैं और इन प्रदर्शनियों को देखने वाले दर्शकों की आम सोच में आदिवासियों और गैर-आदिवासियों के बीच एक द्वंद्व पैदा करते हैं। कम लागत वाले आवासों में दीर्घकालिक सामर्थ्य सुनिश्चित करना : लागत में कटौती और सेवा अवधि के बीच का संतुलन"—केस स्टडीज़ और भवन प्रणालियों के विस्तृत विश्लेषण के माध्यम से, यह अध्ययन बताता है कि संरचनात्मक प्रणालियों की सेवा अवधि पर सामग्री की गुणवत्ता और डिज़ाइन के स्तर का सबसे अधिक (60% से अधिक) प्रभाव पड़ता है; साथ ही, लागत में कटौती (सी पी) के कारण उत्पन्न होने वाली अंतर्निहित कमियाँ सेवा अवधि को कम कर देती हैं। ये निष्कर्ष कम लागत वाले आवासों के लिए डिज़ाइन प्रथाओं और रणनीतियों में सुधार की आवश्यकता पर ज़ोर देते हैं, ताकि भवन के विभिन्न अवयव में सेवा अवधि प्रदर्शन और जीवनचक्र लागत के बीच संतुलन बनाया जा सके। "शहरी माल ढुलाई लॉजिस्टिक्स में 'क्राउडशिपिंग': एक व्यवस्थित साहित्य समीक्षा," 61 सहकर्मी-समीक्षित शोध पत्रों पर आधारित है और यह क्राउडशिपिंग के विकास का एक लेखा-जोखा प्रस्तुत करता है—कैसे यह एक विशिष्ट विचार से विकसित होकर शहरी माल ढुलाई के क्षेत्र में एक प्रमुख हिस्सा बन गया, जो डिजिटल प्लेटफ़ॉर्म और गिग-आधारित डिलीवरी कार्य पर आधारित है। विषयगत रूप से, यह साहित्य मुख्य रूप से छह बार-बार सामने आने वाले मुद्दों के इर्द-गिर्द केंद्रित है: क्राउडशिपिंग को एक व्यावसायिक और परिचालन मॉडल के रूप में कैसे व्यवस्थित किया जाता है; प्लेटफ़ॉर्म और डिजिटल बुनियादी ढांचे को कैसे डिज़ाइन किया जाता है; सेवाओं की योजना बनाने के लिए उपयोग किए जाने वाले अनुकूलन और सिमुलेशन उपकरण; इसमें भागीदारी के व्यवहारिक पहलू; पर्यावरणीय और स्थिरता संबंधी दावे; और उभरती हुई नीति या विनियामक बहसें। "बंगाल के राजबाड़ियों में तापीय आराम की स्थितियां: बावली का एक वृत का अध्ययन" में तीन खंड हैं: ऐतिहासिक संदर्भ जिसमें राजबाड़ियों का निर्माण हुआ; बावली राजबाड़ी का अनुकूली पुन: उपयोग, जिसमें निष्क्रिय डिजाइन रणनीतियों पर प्रकाश डाला गया है; और अनुकूलित राजबाड़ी के भीतर तापीय आराम का आकलन है। "नदी के किनारे लचीले विकास की योजना: गुवाहाटी महानगरीय क्षेत्र का एक मामला," यह GMA के भीतर ब्रह्मपुत्र नदी के किनारे होने वाले स्थानिक और पर्यावरणीय परिवर्तनों का विश्लेषण करता है, और संरचनात्मक, व्यवहारात्मक तथा संस्थागत

उपायों के माध्यम से सूक्ष्म, मध्यम और वृहद स्तरों पर GMA के सुदृढ़ विकास हेतु रणनीतियों का प्रस्ताव प्रस्तुत करता है। "सीएनसीआर ज़िलों में महिलाओं के श्रम बाज़ार पर आर्थिक विकास का प्रभाव" यह तर्क देता है कि महिलाओं की श्रम बाज़ार में भागीदारी आर्थिक विकास में योगदान देती है और सतत विकास तथा आर्थिक समृद्धि को बढ़ावा देने में एक अहम उत्प्रेरक की भूमिका निभाती है। इसके अतिरिक्त, महिलाओं की शिक्षा को बढ़ावा देकर, लैंगिक-संवेदनशील श्रम नीतियों को सुनिश्चित करके, काम के लिए सहायक माहौल बनाकर, और सामाजिक-सांस्कृतिक बाधाओं को दूर करके, सतत विकास की रणनीतियाँ महिलाओं को श्रम शक्ति में सक्रिय रूप से हिस्सा लेने के लिए सशक्त बना सकती हैं; जिससे समावेशी विकास और आर्थिक विकास में योगदान मिलेगा। "औपनिवेशिक भूमि नियंत्रण और शहरी नियोजन: 1900 से 1940 के बीच का दिल्ली" का उद्देश्य औपनिवेशिक काल के दो आधिकारिक दस्तावेजों की व्याख्या करना है। यह अभिलेखागार शोध का उपयोग करके दिखाता है कि कैसे भूमि अधिग्रहण ब्रिटिश औपनिवेशिक शहरी नियोजन की विचारधारा का केंद्र बन गया था, और कैसे सुधार न्यास 'इम्प्रूवमेंट ट्रस्ट' की योजनाओं और नीतियों ने भूमि नियंत्रण को सुगम बनाया।

(चित्ररेखा काबरे)

संपादक

# Waste waterscape inducing inequalities in Informal areas:
## A Case of the NCT of Delhi

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**Abstract:** Wastewater is both a by-product of urban life and a latent resource in cities facing tightening freshwater budgets. How used water is handled depends as much on institutions and local power as on pipes and treatment plants? This study examines three long-standing informal settlements in Delhi's Barapullah sub-basin: Madrasi Camp, Indira Camp II, and Anna Nagar. Using household interviews, narrative accounts, and field observation over two years, it traces household supply, end uses, reuse, and disposal to show how the local wastewaterscape produces unequal access to water, sanitation, and hygiene. Combined accounting indicates about 297 litres of household supply per day, roughly 49 to 59 litres per capita per day, which sits below national and city benchmarks. Only about 80% is reused even once. The remainder becomes wastewater that is mainly discharged untreated, with an estimated 92% flowing to open drains, nearby water bodies, or fields. Governance and social structure shape these outcomes. Pradhan-led fee collection for toilets and tanker water creates dependency and price exposure during emergencies. Gendered roles leave women with the heaviest burden of collection and storage, while open defecation persists at 20% to 60% across sites. Indira Camp II exhibits the most significant vulnerability, with approximately 70% effective water access and the highest share of income spent on water, at 10 to 20%. The paper proposes a practical pathway that combines simple conveyance, small-scale decentralized treatment, and low-risk household reuse with transparent local governance to reduce discharge into the Yamuna and narrow WASH inequalities.

**Keywords:** Waste waterscape, WASH, Informal Settlements, Governance, NCT of Delhi, Power Dynamics

**सार:** अपशिष्ट जल शहरी जीवन का एक उपोत्पाद और कड़े मीठे पानी के बजट का सामना कर रहे शहरों में एक गुप्त संसाधन दोनों है। इस्तेमाल किए गए पानी को कैसे प्रबंधित किया जाता है, यह पाइपों और उपचार संयंत्रों के साथ-साथ संस्थानों और स्थानीय बिजली पर भी निर्भर करता है। यह अध्ययन दिल्ली के बारापुला उप-बेसिन में तीन लंबे समय से चली आ रही अनौपचारिक बस्तियों की जांच करता है: मद्रासी कैंप, इंदिरा कैंप II और अन्ना नगर। दो वर्षों में घरेलू साक्षात्कार, वर्णनात्मक विवरण और क्षेत्र अवलोकन का उपयोग करते हुए, यह घरेलू आपूर्ति, अंतिम उपयोग, पुन: उपयोग और निपटान का पता लगाता है ताकि यह दिखाया जा सके कि स्थानीय अपशिष्ट जल परिदृश्य पानी, स्वच्छता और स्वास्थ्य की असमान पहुंच कैसे पैदा करता है। संयुक्त लेखांकन प्रति दिन लगभग 297 लीटर घरेलू आपूर्ति, लगभग 49 से 59 लीटर प्रति व्यक्ति प्रति दिन दर्शाता है, जो राष्ट्रीय और शहर के बेंचमार्क से नीचे है प्रधान के नेतृत्व में शौचालयों और टैंकर के पानी के लिए शुल्क वसूली आपात स्थितियों के दौरान निर्भरता और मूल्य जोखिम पैदा करती है। लैंगिक भूमिकाओं के कारण संग्रह और भंडारण का सबसे भारी बोझ महिलाओं पर पड़ता है, जबकि खुले में शौच सभी स्थलों पर 20 से 60% तक जारी है। इंदिरा कैंप II सबसे अधिक असुरक्षित है, जहाँ लगभग 70% लोगों को प्रभावी जल पहुँच प्राप्त है और आय का सबसे अधिक हिस्सा, 10 से 20%, पानी पर खर्च होता है। यह पत्र एक व्यावहारिक मार्ग प्रस्तावित करता है जो सरल परिवहन, छोटे पैमाने पर विकेन्द्रीकृत उपचार, और कम जोखिम वाले घरेलू पुन: उपयोग को पारदर्शी स्थानीय शासन के साथ जोड़ता है ताकि यमुना में अपशिष्ट जल का निर्वहन कम किया जा सके और वाश असमानताओं को कम किया जा सके।

**मुख्य शब्द:** अपशिष्ट जल परिदृश्य, वाश, अनौपचारिक बस्तियाँ, शासन, राष्ट्रीय राजधानी क्षेत्र दिल्ली, विद्युत गतिशीलता

## 1. Introduction

The waste waterscape lens is situated within urban political ecology, linking infrastructure with governance and everyday practice (Karpouzoglou 2016). It shifts attention from pipes alone to the rules, incentives, and social hierarchies that determine where water flows, who pays, and who bears the costs of disposal. In Delhi, the expansion of freshwater supply has progressed faster than investment in collection and treatment, particularly in informal areas outside the sewer grid. Figure 1 outlines the study frame, which follows the flows of used water and the institutions that govern them. Within this frame, political priorities, uneven economic resources, and social stratification generate distinct waste waterscapes across neighbourhoods. The study examines how these arrangements influence inequalities in water, sanitation, and hygiene, and explores feasible steps to narrow those gaps.

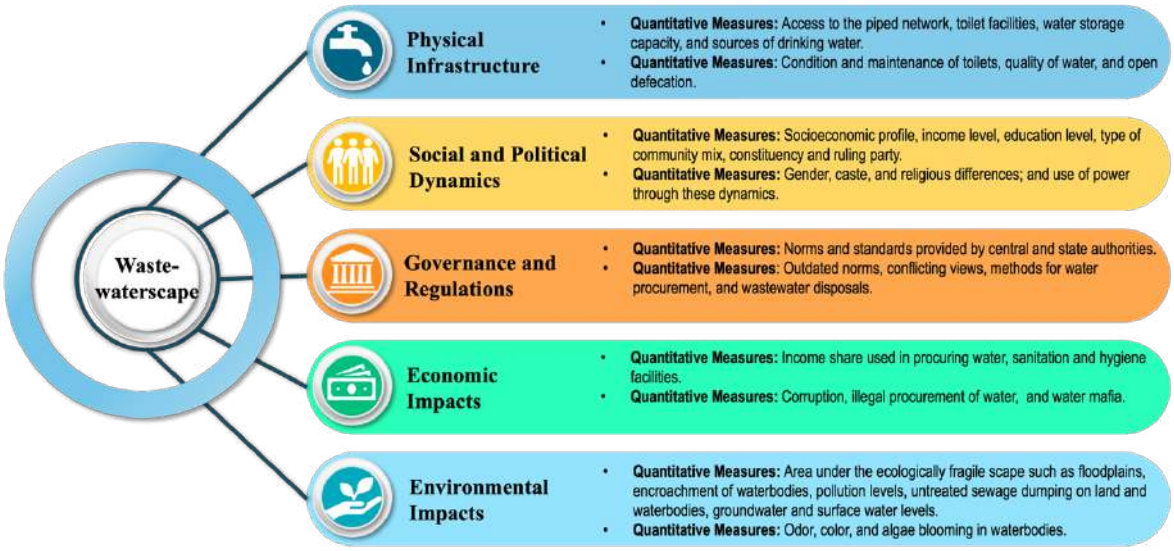


**Figure 1.** Concept of Waste waterscape
Source: Karpouzoglou T. 2016

The Water, Sanitation, and Hygiene (WASH) Performance Index 2015, developed by the Water Institute at the University of North Carolina, ranked India as a bottom performer, with a score of 93 (Prakash et al. 2022). Many initiatives, such as the Water, Sanitation, and Hygiene Institute (WASH Institute), provide technical assistance to Indian government ministries, including the Ministry of Jal Shakti and the Ministry of Housing and Urban Affairs (MoHUA), to implement projects like the Swachh Bharat Mission and the Jal Jeevan Mission. However, in the context of Delhi, non-notified slum settlements, which are deemed illegal occupations, are not entitled to formal water or sanitation services from the Delhi Jal Board (DJB) (Kumar et al. 2021). Yet, paradoxically, many of these settlements receive freshwater/clean/potable water through informal connections to trunk pipelines. While the provision of water is often driven by political motivations, such as securing votes from slum dwellers, basic services for wastewater treatment, reuse, and safe disposal are largely absent. Traditional practices, indigenous knowledge, and sustainable methods for wastewater management have been eroded, leaving residents dependent on ad hoc and inadequate solutions.

The field context in the National Capital Territory of Delhi shows an apparent mismatch: agencies extend freshwater supply while collection and treatment infrastructure lag behind. Open or poorly built drains, standing water, and persistent dampness allow disease vectors to thrive. Public taps mounted along lanes often run for extended periods, allowing clean water to spill into waterlogged streets. In narrow drains that are frequently blocked, this freshwater mixes with household wastewater. In many dwellings, toilets are absent, which limits blackwater generation; even so, the greywater produced, much of which is suitable for low-risk reuse, is discharged untreated into trunk drains that carry sewage from other parts of the city. These combined flows reach the Yamuna untreated and contribute to the environmental load.

Settlement populations commonly range from 5,000 to 10,000 residents, which keeps the daily demand for freshwater high. Meeting that demand depends on a web of actors that includes local political leaders, municipal staff, community representatives, private vendors, intermediaries, and gatekeepers. Access can hinge on payments or patronage, and the terms of service vary within and across lanes. The outcome is stratified access at the household level, accompanied by uneven practices in local governance.

These conditions underline the need to examine the waste waterscape of informal settlements, where need, entitlement, equity, and transparency intersect. The study analyzes how the waste waterscape in such areas shapes inequalities in water, sanitation, and hygiene, using selected informal settlements as case studies. The Research question is “How does the current waste waterscape of informal areas induce inequalities in water, sanitation, and hygiene?” the research objectives are:

i. To describe the waste waterscape of informal areas in the National Capital Territory of Delhi.

ii. To examine how the waste waterscape contributes to inequalities within the WASH system of an informal area.

iii. To assess the impact of the waste waterscape on overall WASH conditions in the selected informal areas.

iv. To recommend strategies to mitigate WASH inequalities linked to the waste waterscape.

## 2. Research Methods

The study began by stating the research question and objectives, which then guided subsequent design choices. A focused literature review clarified the concept of the waste waterscape, its components, and the indicators through which inequality manifests. The analytic framework places the waste waterscape at the center, serving as the continuum that links water uses to waste generation. It traces how material flows interact with social, economic, institutional, and ecological processes. Surrounding this core are five interdependent components (Figure 1): physical infrastructure, social and political dynamics, governance and regulation, economic impacts, and environmental impacts. Each element is operationalized through measurable indicators that, taken together, describe the complexity of urban water inequalities.

The study design began with a focused review to define the waste waterscape concept, specify components for analysis, and select indicators of inequality. A case study strategy was employed. Primary data were collected through structured and semi-structured interviews, supplemented by field observations and narrative accounts, over a period of two years. Flow accounting was used to trace household water use, reuse, and disposal, and discourse analysis was applied to interview material to document local governance, norms, and perceived risks. Findings from these streams were integrated into the discussion and used to develop actionable recommendations.

**Table 1.** List of component-wise indicators

| S. No. | Components | Indicators | Purpose / Description |
|---|---|---|---|
| 1 | Physical Infrastructure | Proportion of households connected to the piped water network (DJB piped water) | To assess the access and adequacy of physical water infrastructure<br>To evaluate the functionality and quality of sanitation facilities |
| | | Number of functional toilets and bath facilities per 100 households | |
| | | Quantity of access to potable water | |
| | | Water storage capacity per household (liters) | |
| | | Water supply LPCD | |
| | | Toilet Facility at the house | |
| 2 | Social and Political Dynamics | Frequency of open defecation incidents | To analyze social and economic diversity influencing water access, its inclusion, and power dynamics in water management |
| | | Average households' income | |
| | | Educational attainment level of household heads | |
| | | Type and mix of residential communities | |
| | | Representation of women and marginalized groups in water committees | |
| | | Influence of community or political leadership on water access | |
| 3 | Governance and Regulations | Degree of social conflict reported on water use | To assess the strength and clarity of regulatory frameworks and identify policy overlaps and governance inefficiencies |
| | | Existence of state/national standards-based water distribution | |
| | | Level of compliance with the DJB and CPCB standards for wastewater disposal | |
| | | Presence of monitoring and enforcement mechanisms for | |
| | | Number of outdated/conflicting regulations on wastewater disposal | |
| | | Number of institutions with overlapping responsibilities | |
| 4 | Economic Impacts | Frequency of regulatory audits or compliance checks | To quantify the financial burden of water and sanitation services and detect informal or exploitative systems in the water supply chain |
| | | Average household expenditure on water and sanitation per month | |
| | | Proportion of daily water comes from informal water sources (Tanker, Bottled water) | |
| | | Share of income spent on water procurement (%) | |
| | | Reported incidents of corruption or illegal water procurement | |
| | | Existence of 'water mafia' or informal distribution networks | |
| 5 | Environmental Impacts | Extent of area under ecologically sensitive or flood-prone zones | To measure environmental stress from wastewater and urban runoff and identify ecological degradation and pollution hotspots. |
| | | Volume of untreated sewage discharged to natural drains | |
| | | Drains having the presence of fecal matter or black water | |
| | | Frequency of visible pollution events (odor, color) | |
| | | Rate of encroachment on natural waterbodies (ha/year) | |

Source: Author, 2024

## 3. Analysis and Results

Three sites were purposively selected within the Barapullah sub-basin: Madrasi Camp (n = 18 households), Indira Camp II (n = 27), and Anna Nagar (n = 30). Each settlement is situated near a significant drain, enabling a comparable assessment of supply, use, reuse, and disposal. Combined accounting shows a total household supply of 297 litres per day sourced from Delhi Jal Board pipes, DJB tankers, shared community points, and bottled water. Approximately eight percent of this volume is reused at least once; the remainder becomes wastewater, which is predominantly discharged to open drains and adjacent water bodies. Cross-site comparisons indicate that Indira Camp II has the lowest effective access to water and the highest incidence of open defecation. At the same time, Anna Nagar performs better in terms of basic infrastructure, yet still lacks safe collection and treatment. Subsequent tables and the Sankey diagram report source shares, end uses, and disposal routes used for policy interpretation.

The field investigation for this study focuses on three informal settlements—Anna Nagar, Madrasi Camp, and Indira Camp II (Table 2). Each site presents distinct socio-economic and infrastructural characteristics, while sharing common challenges shaped by the prevailing waste-waterscape.

**Table 2:** Details of the selected Informal settlements.

| S. No. | Area Name | Anna Nagar | Madrasi Camp | Indira Camp II |
|---|---|---|---|---|
| 1 | Area (in sq m) | 21,035 | 4,633 | 13,500 |
| 2 | Population | 15,000 | 2,012 | 2,705 |
| 3 | Number of Households | 3,000 | 353 | 541 |
| 4 | Average Household | 5 | 5.7 | 5 |
| 5 | Sample survey | 30 | 18 | 27 |
| 6 | Adjacent Drain | Indraprastha Drain | Barapullah Drain | Maharani Bagh Drain |

Source: Author, 2025

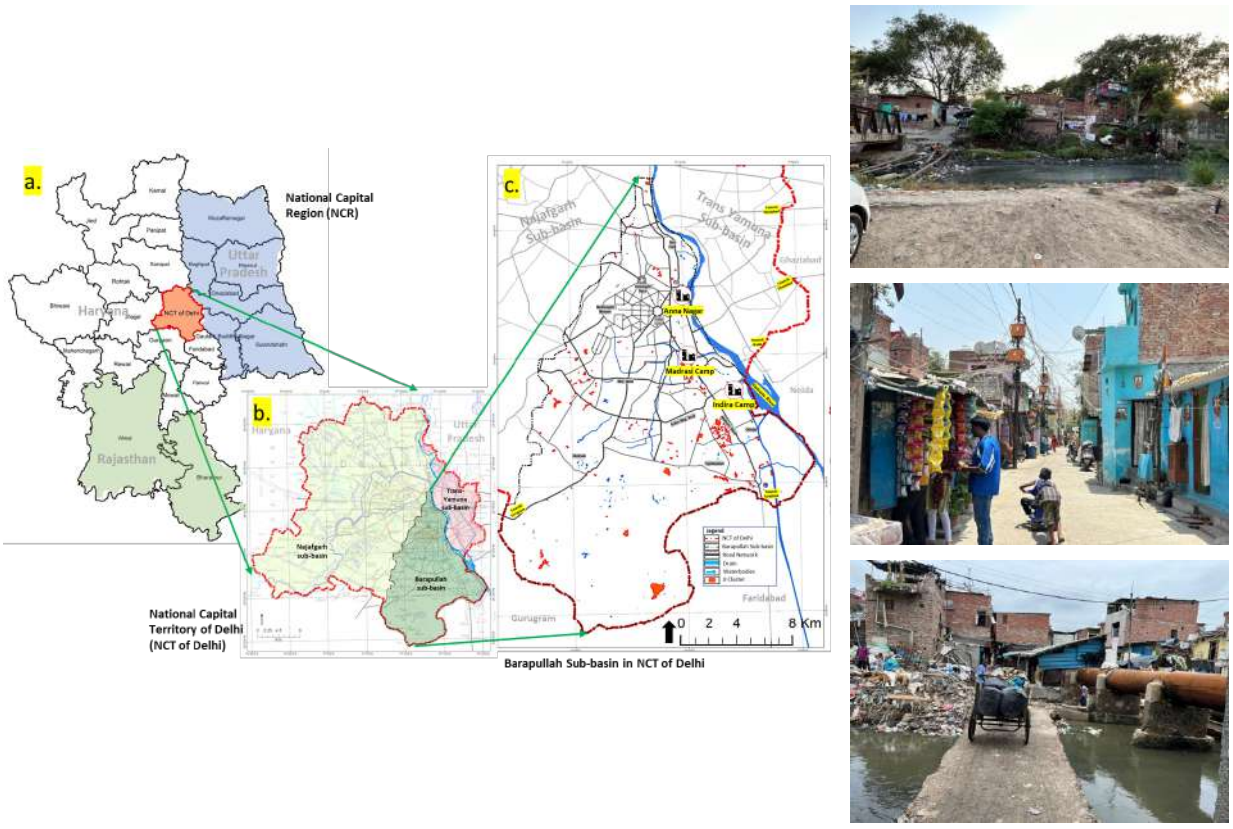


**Figure 2:** Location of the selected Informal settlements
Source: Author, 2025

Anna Nagar, with a history of around 60 years, is home to communities from Andhra Pradesh, Uttar Pradesh, and Punjab. Housing is permanent but suffers from dampness issues. The settlement has a mixed religious profile, comprising Hindus and Sikhs, with education levels generally at the

senior secondary stage. Both men and women are engaged in private jobs or small businesses. The water supply is relatively stable, with 100% connection to the DJB trunk line at 62 LPCD, and drinking water is obtained directly from the taps. Sanitation is limited to two community toilets, each equipped with two water closets and two baths. Approximately 30% of households have private bathrooms. Open defecation stands at 20%. Wastewater is discharged untreated into the Indraprastha Drain, and there is no practice of wastewater reuse.

Madrasi Camp, established around 50–60 years ago, is predominantly inhabited by residents of Tamil Nadu origin. Housing structures are generally permanent and well-maintained, with Hinduism as the predominant religion. Education levels are mostly elementary, and women are engaged as house helpers or homemakers, while men are employed in private jobs or run small businesses. Approximately 80% of the settlement is connected to the Delhi Jal Board (DJB) trunk line, with rooftop tanks of 500-liter capacity supplying water at a rate of around 62 liters per capita per day (LPCD). Drinking water is accessed directly from taps. Sanitation infrastructure consists of one community toilet block with two water closets and two bathing areas, though only 10% of households have private toilets. Open defecation remains at 40%, and wastewater is discharged untreated into the Barapullah Drain. Limited wastewater reuse is practiced, with only about 10% of the wastewater being recycled locally.

Indira Camp II, formed roughly 45 years ago, comprises residents from Bangladesh, West Bengal, and Bihar. Housing is temporary and in poor condition, with a predominantly Muslim population. Approximately 70% of households are connected to the DJB trunk line, while the remainder rely on tanker supplies stored in tanks ranging from 250 to 500 liters. Residents purchase drinking water in bottles, which cost ₹40–50 each. Education levels are significantly low, with nearly 70% of the population lacking formal education. Women primarily work as house helpers or homemakers, while men often engage in informal jobs, such as vending and construction. The settlement has one community toilet with 10 water closets and 10 bathing areas, though frequent flooding hampers usability. Open defecation is prevalent at 60%, and wastewater is discharged untreated into the Maharani Bagh Drain. No wastewater reuse is practiced.

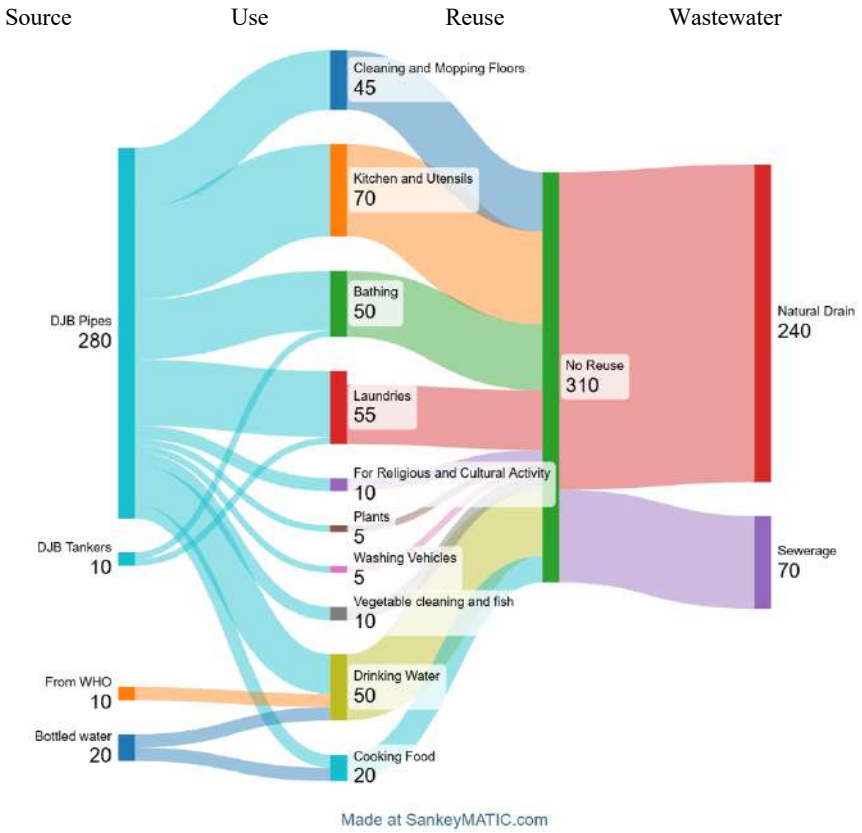


**Figure 3.** Flow of water through various usages and its quantity in Anna Nagar
Source: Primary Data compiled by the Author

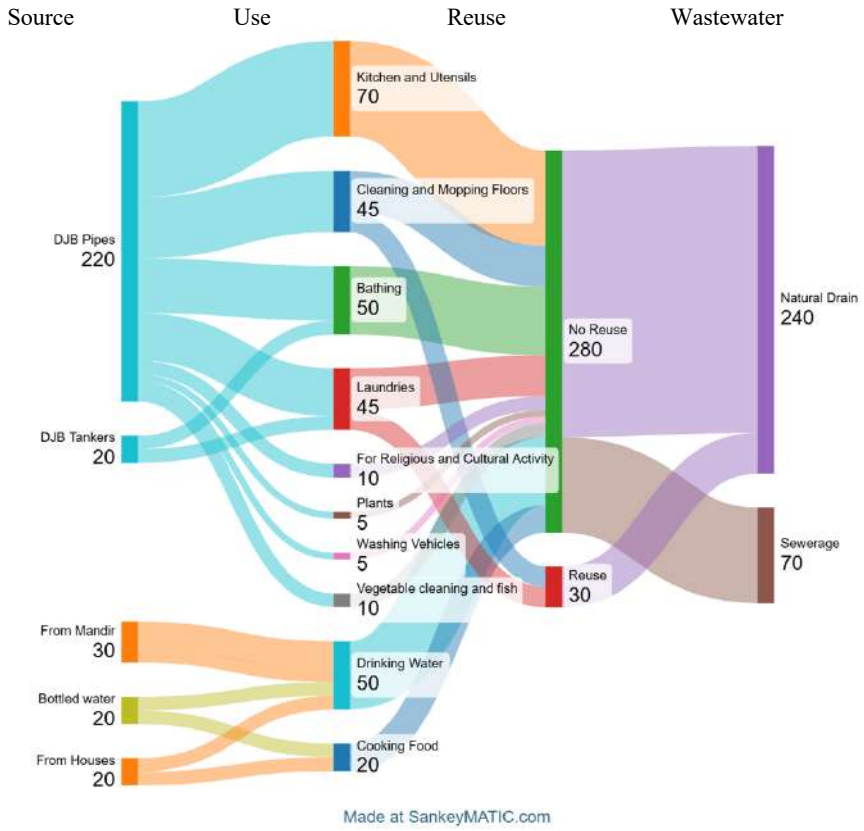


**Figure 4.** Flow of water through various usages and its quantity in Madarasi Camp
Source: Primary Data compiled by the Author

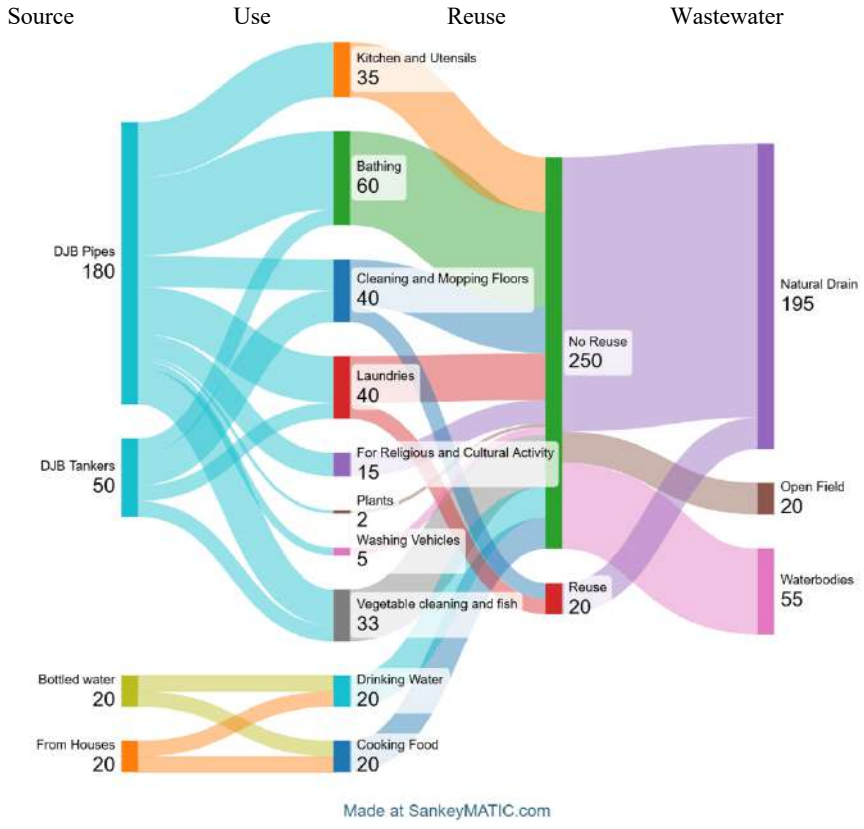


**Figure 5.** Flow of water through various usages and its quantity in Indira Camp II
Source: Primary Data compiled by the Author

## 4. Position of Settlement based on Indicators

A comparative table of settlement with status pertaining to the listed indicators. Based on the comparative analysis of the three settlements, Anna Nagar, Madrasi Camp, and Indira Camp II. It is evident that all face severe infrastructural, social, and environmental challenges, but with varying degrees of intensity. As shown in Table 3.

Anna Nagar performs relatively better in terms of water network coverage (100%), higher LPCD (62), and more effective management through political engagement and partial community representation. However, it still suffers from open defecation, limited toilet availability, and untreated wastewater discharge.

Madrasi Camp has moderate infrastructure; however, its reliance on local leadership and the absence of clear formal procedures indicate a weak accountability system. Indira Camp II is the most vulnerable of the three sites: water access is approximately 70 percent, household storage is minimal, education levels are lower on average, religious influence significantly shapes leadership, and open defecation is the highest at about 60 percent. The economic burden is also most significant here, with households spending roughly 10 to 20 percent of income on water, a clear signal of inequitable access and affordability stress.

Across all three settlements, wastewater is discharged untreated, and similar patterns of pollution and encroachment are visible. Anna Nagar performs relatively better due to its stronger basic infrastructure and some community participation; however, none of the sites demonstrate sustainable wastewater management or effective institutional performance.

**Table 3.** Comparison among settlements

| S. No. | Components | Indicators | Anna Nagar | Madrasi Camp | Indira Camp II |
|---|---|---|---|---|---|
| 1 | Physical Infrastructure | Proportion of households connected to the piped water network (DJB piped water) | 100% | 80% | 70% |
| | | Number of functional toilets and bath facilities per 100 households | 1 toilet per 150 and 1 Bath per 160 Households | 1 toilet per 175 and 1 Bath per 175 Households | 1 toilet per 55 and 1 Bath per 50 Households |
| | | Quantity of access to potable water | 93% | 76% | 84% |
| | | Water storage capacity per household (liters) | 500-600 liters | 500-600 liters | 200-300 liters |
| | | Water supply LPCD | 62 liters | 53 liters | 42 liters |
| | | Reuse of wastewater | No reuse | 8 % | 6 % |
| | | Toilet Facility at the house | 30% | 10% | 0% |
| | | Frequency of open defecation incidents | 20% | 40% | 60% |
| 2 | Social and Political Dynamics | Average households' income | Rs. 20000-25000 Monthly | Rs. 10000-15000 Monthly | Rs. 7500-10000 Monthly |
| | | Educational attainment level of household heads | Mostly Senior Secondary | Mostly Elementary Education | Approx. 70 % do not have a formal education |
| | | Type and mix of residential communities | Heterogeneous community | Homogenous community | Homogenous community |
| | | Representation of women and marginalized groups in water committees | In a group of management, there are 40 percent | Pradhan is a Woman. Most of the management is done by them. | No representation |
| | | Influence of community or political leadership on water access | Political Leaders to access water | Local Community help and local leader influence | Local leader influence based on religion preference. |
| | | Degree of social conflict reported on water use | Almost daily | Very few | Almost daily |
| 3 | Governance and Regulations | Existence of state/national standards-based water distribution | no | no | no |
| | | Level of compliance with the DJB and CPCB standards for wastewater disposal | Discharged untreated into the Barapullah Drain | Discharged untreated into the Maharani Bagh Drain | Discharged untreated into the Indraprastha Drain |

| S. No. | Components | Indicators | Anna Nagar | Madrasi Camp | Indira Camp II |
|---|---|---|---|---|---|
| | | Presence of monitoring and enforcement mechanisms for Wastewater | Not present | | |
| | | Number of outdated/conflicting regulations on wastewater disposal | People are depending on the Indian Railway yard for maintaining the Wastewater disposal | People are individually maintaining Wastewater disposal | People are not maintaining Wastewater disposal; it is going by gravity. |
| | | Number of institutions with overlapping responsibilities | Delhi Jal Board, Municipal Corporation of Delhi | | |
| | | Frequency of regulatory audits or compliance checks | Weekly for public toilets | Monthly for public toilets | Monthly for public toilets |
| 4 | Economic Impacts | Average household expenditure on water and sanitation per month | Rs. 500-800 monthly | Rs. 1000 Monthly | Rs. 1000-1500 Monthly |
| | | Proportion of daily water comes from informal water sources (Tanker, Bottled water) | 10 % | 21% | 14% |
| | | Share of income spent on water procurement (%) | 5-8 % | 6-10 % | 10-20 % |
| | | Reported incidents of corruption or illegal water procurement | a few | a few | several |
| | | Existence of 'water mafia' or informal distribution networks | Yes | Yes | Yes |
| 5 | Environmental Impacts | Extent of area under ecologically sensitive or flood-prone zones | 100% | 100% | 100% |
| | | Volume of untreated sewage discharged to natural drains | 77% | 77% | 71% |
| | | Drains having the presence of fecal matter or black water | Present | Present | Present |
| | | Frequency of visible pollution events (odor, color) | Foul odour and black in color presence of green water hyacinth | Foul odour and black in color presence of green water hyacinth | Foul odour and black in color presence of Solid waste dumping |
| | | Rate of encroachment on natural waterbodies | 100% encroachment | 100% encroachment | 100% encroachment |

Source: Primary Data compiled by the Author

## 5. Commonalities and Shared Challenges

Despite differences in social composition, housing quality, and supply arrangements, the WASH systems share structural gaps. None of the settlements is connected to a formal sewer network. As a result, untreated wastewater is routed to major drains that ultimately carry the load to the Yamuna. Open defecation persists at various levels, and community toilets are scarce, poorly maintained, or unusable during flooding.

Where reuse occurs, it is limited and does not change outcomes at scale. Prioritising freshwater supply without building accompanying disposal and treatment capacity leaves households exposed to repeated health risks and environmental decline, and it locks communities into arrangements that depend on uneven local governance.

## 6. Flow of water to wastewater

The Sankey diagram aggregates flow for Madrasi Camp, Indira Camp II, and Anna Nagar, showing sources, household uses, any reuse, and final disposal. The total household supply is 297 litres per day, equivalent to approximately 49 to 59 litres per capita per day. This is below the CPHEEO 1999 norm of 70 litres per capita per day for towns without sewerage and well below

the Master Plan for Delhi 2021 benchmark of 225 litres per capita per day.

Sources are distributed as follows: Delhi Jal Board pipes, 207 liters; DJB tankers, 35 liters; community points, 35 liters; and bottled water, 20 liters. Reported uses include bathing (62 litres), kitchen and utensils (51 litres), laundry (45 litres), floor cleaning (39 litres), cooking (22 litres), religious or cultural uses (16 litres), vegetable and fish cleaning (21 litres), drinking (33 litres), vehicle washing (5 litres), and plant watering (3 litres).

Only 24 litres, about 8 percent of total use, is reused at least once within households. The remaining 273 litres are not reused and enter the wastewater stream. Disposal is largely unmanaged: approximately 204 litres flow into natural drains, 40 litres enter sewers where connections exist for a small minority of households, 30 litres reach nearby water bodies, and 23 litres are discharged into open fields. This pattern shows a consistent imbalance. Supply is maintained through pipes, tankers, and shared points, while disposal remains mostly untreated and is released to the local environment. Limited sewer access and minimal reuse perpetuate WASH inequalities, reinforcing the case for decentralized treatment paired with everyday reuse practices.

Entrance of the Community as well as the Community toilet is shown in the red circle

Overflowing sewerage and drains water near the Entrance to the Indira Camp II

The state of the pre-fabricated toilets (provided by the govt.) in the settlement.

Wastewater entered in the house due to overflowing drain

DJB fresh water supply passing through Taimoor Nagar

The streets are lower than the Taimoor Nagar Drain flooded with back flows from the drain.

**Figure 6.** Condition of selected site.
Source: Author

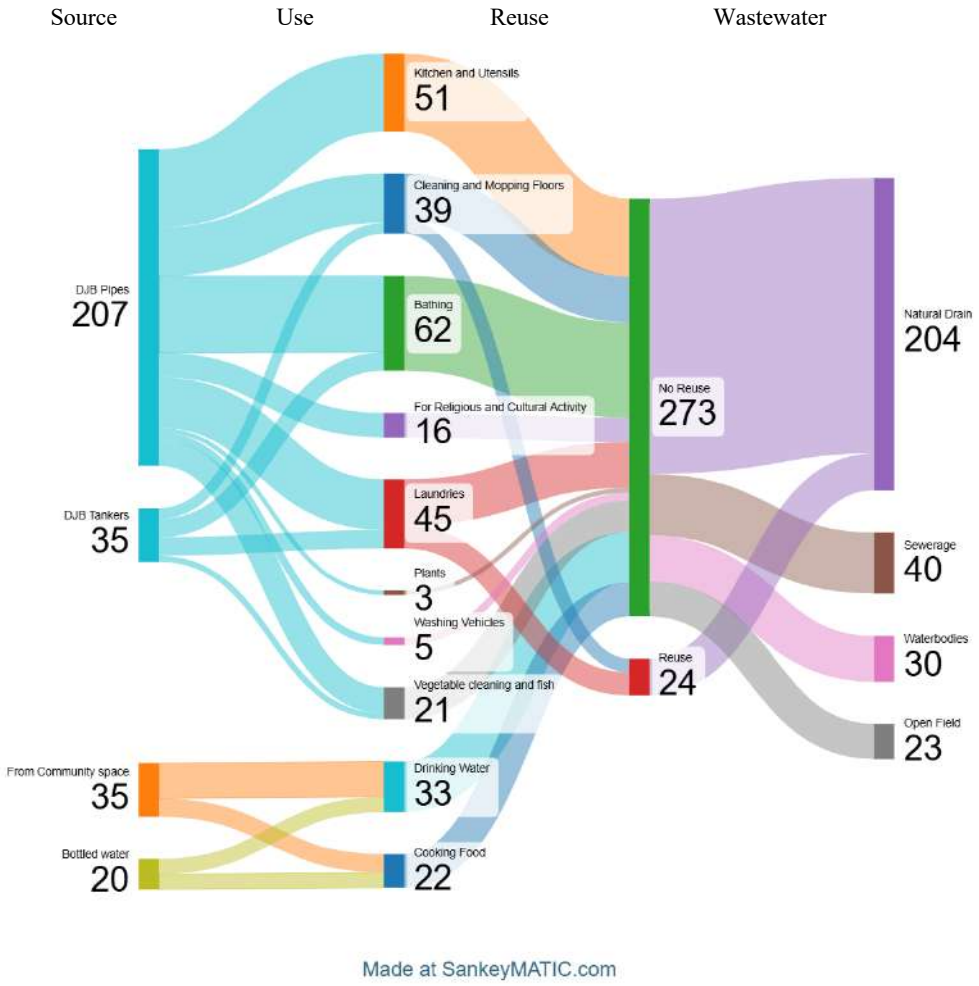


**Figure 7.** Flow of water through various usages and its quantity
Source: Primary Data compiled by the Author

## 7. Discussion

Access to water and sanitation in the study settlements reflects the overlap of local authority, social identity, site conditions, and incomplete infrastructure. In each settlement, residents recognise a Pradhan who mediates day-to-day dealings with municipal staff and vendors. Although the role is framed as representative, it often functions as a gatekeeper for basic services. Households across all three sites reported making routine payments of ₹100 per month for toilet upkeep and ₹50 for tanker supply, despite these services being part of government programs. About nine in ten respondents identified the pradhan as the first person they call in an emergency, a dependency that can translate into higher charges when services are most needed.

Religious composition shapes housing access. Madrasi Camp and Anna Nagar are mainly Hindu, and statements from the Pradhan's household in Madrasi Camp indicated a stated preference for Hindu tenants on grounds of perceived cleanliness, which in practice discourages Muslim and other non-Hindu applicants. Indira Camp is predominantly Muslim, producing internal cohesion but mirroring wider patterns of urban segregation. These filters determine who lives where and who receives informal priority when scarce services are allocated.

Gendered division of labour amplifies WASH disadvantages. Women are primarily responsible for collecting and storing water, tasks that are physically demanding and time sensitive. Where shared toilets are unhygienic or unsafe, an estimated four in five women resort to open defecation, with clear consequences for privacy and dignity. During pregnancy, these risks increase; poor ventilation and unreliable water in communal facilities lead some families to rent a nearby room for safer sanitation over several months. Together, these mechanisms show how authority, identity, and limited infrastructure combine to produce unequal exposure within the same neighbourhoods.

The role of local authorities shows an imbalance between water provision and

sanitation. While toilet infrastructure exists in limited form, none of the settlements are connected to a sewerage network, resulting in the illegal drainage of untreated wastewater into nearby water bodies or natural drains. Residents rarely lodge complaints about water quality or quantity, fearing retaliation, as government officials may reduce or cut the supply. The water supply—297 liters per household per day (49–59 LPCD)—is already below the CPHEEO (1999) standard of 70 LPCD for towns without sewerage and far below Delhi's standard of 225 LPCD in the Master Plan for Delhi, 2021.

It has been a long and challenging journey for urban areas to achieve Open Defecation Free (ODF) status, and one of the major hurdles has been extending sanitation coverage to slum settlements (Upadhyay 2020). Nearly a decade has passed since the launch of the Swachh Bharat Mission. Yet, a significant portion of the population living in slums continues to openly acknowledge that they are compelled to defecate in the open. Across all settlements, an average of 50 percent of the population still practices open defecation. There is an average of 1 toilet per 150 households and 1 Bath per 160 Households, which is the worst. The key issues include a lack of space to construct household toilets, irregular water supply, and the absence of proper sewage connectivity. Slum areas present multiple challenges to the large-scale toilet construction drive initiated under the *Swachh Bharat Abhiyan*, highlighting the persistent infrastructural and service delivery gaps in achieving inclusive urban sanitation.

The flow diagram translates these dynamics into material terms. Freshwater arrives through Delhi Jal Board connections, tankers, and shared taps, but wastewater receives slight organised handling. Site-level accounting indicates that roughly 92 percent of outflow leaves the settlements untreated through open drains, water bodies, or adjacent fields. This imbalance provides water while offloading the health and environmental costs of disposal onto the same communities. Reuse is rare, reflecting the decline of everyday conservation practices and the absence of small, decentralised treatment options. The result is a recurring pattern in which unequal governance, infrastructure gaps, and social marginalisation sustain WASH inequalities.

Location intensifies risk. Many sites are located on low-lying floodplains or beside natural channels, where dampness, waterlogging, and seasonal flooding are common during the monsoon season. Water may be available, but sanitation remains neglected, which deepens environmental damage and public health exposure. Taken together, the wastewaterscape is shaped by informal authority, social discrimination, gendered labour, geographic vulnerability, and weak infrastructure. The Sankey diagram indicates that supply exists, albeit below formal norms, while disposal is politically mediated and environmentally unsustainable, with untreated flows that perpetuate hazards and exacerbate WASH inequalities.

## 8. Conclusions and Way forward

Interviews and field observations conducted across Anna Nagar, Madrasi Camp, and Indira Camp II reveal a significant yet underutilized opportunity for greywater reuse. Because toilet connections are limited in many dwellings, a large share of household wastewater contains little fecal content; yet, most of it is discharged to open drains and then carried untreated to natural water bodies. The result is the waste of potential resources, along with local flooding, persistent dampness, and pollution. A basic drainage network linked to a decentralized wastewater treatment system can convert this problem into a workable solution. DEWATS requires modest operation and maintenance and can lift effluent quality enough to enable safe reuse.

Simple practices can begin immediately. Laundry and utensil rinse water can be redirected for cleaning, plant watering, or toilet flushing, thereby reducing the demand for freshwater. Culturally sensitive workshops, practical demonstrations, and community-led efforts can embed these routines in daily life. By combining small-scale treatment with behavior change, settlements can use water more efficiently, reduce reliance on politically mediated supply chains, and narrow WASH inequalities while improving environmental conditions.

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# Socio-spatial Disparities in the Indian Megacities

## A Case Study of Greater Mumbai

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**Abstract:** Megacities, with populations exceeding ten million, are vibrant economic centres that attract a diverse array of individuals seeking better employment opportunities, educational prospects, and an improved quality of life. These cities serve as magnets for talent and ambition, transforming into melting pots of cultures and ideas. However, the rapid and often unplanned expansion of these megacities brings with it a host of complex challenges. Among the most pressing issues are those stemming from social disparities, which manifest as inadequate infrastructure, congested transportation systems, and significant environmental degradation. These issues disproportionately affect marginalized communities, exacerbating social disparities. The paper examines the multifaceted nature of social disparities and how they manifest spatially to recommend urban planning interventions in order to reduce the disparities in Greater Mumbai. The study commences with a comprehensive literature review including definitions, concepts, methods and case studies as well as a background study on the city. It then evaluates social disparities in Greater Mumbai using specific parameters or indicators, first at the city and then ward level. Further, the study scrutinizes the spatial implications of these social disparities, examines the resulting issues and vulnerabilities and finally recommends policy level and development plan level interventions.

**Keywords:** Megacity, Disparity, Socio-spatial, Gentrification, Multidimensional poverty, spatial implications, multifaceted nature

**सार:** एक करोड़ से ज़्यादा आबादी वाले महानगर, जीवंत आर्थिक केंद्र होते हैं जो बेहतर रोज़गार के अवसरों, शिक्षा की संभावनाओं और जीवन की बेहतर गुणवत्ता की तलाश में अलग-अलग तरह के लोगों को आकर्षित करते हैं। ये शहर प्रतिभा और महत्वाकांक्षा के लिए चुम्बक के रूप काम करते हैं, और संस्कृतियों और विचारों के संगम स्थल बन जाते हैं। हालाँकि, इन महानगरो का तेज़ी से और अक्सर अनियोजित विस्तार अपने साथ कई जटिल चुनौतियाँ लाता है। सबसे ज़रूरी मुद्दों में से एक सामाजिक असमानताएँ हैं, जो अपर्याप्त बुनियादी ढाँचे, भीड़भाड़ वाले परिवहन प्रणाली और महत्वपूर्ण पर्यावरण के नुकसान के रूप में सामने आती हैं। ये मुद्दे हाशिए पर पड़े समुदायों को असमान रूप से प्रभावित करते हैं, जिससे सामाजिक असमानताएँ और बढ़ जाती हैं। यह लेख सामाजिक असमानताओं के बहुआयामी स्वरूप की जाँच करता है और वे स्थानिक रूप से कैसे प्रकट होती हैं, ताकि बृहन्मुंबई में असमानताओं को कम करने के लिए शहरी नियोजन हस्तक्षेपों की सिफारिश की जा सके। यह अध्ययन एक व्यापक साहित्य समीक्षा के साथ शुरू होता है जिसमें परिभाषाएँ, अवधारणाएँ, तरीके और व्यष्टि अध्ययन के साथ-साथ शहर पर एक पृष्ठभूमि अध्ययन शामिल है। इसके बाद यह विशिष्ट मापदंडों या संकेतकों का उपयोग करके बृहन्मुंबई में सामाजिक असमानताओं का मूल्यांकन करता है, पहले शहर और फिर वार्ड स्तर पर। इसके अलावा, यह अध्ययन इन सामाजिक असमानताओं के स्थानिक प्रभावों की जाँच करता है, परिणामस्वरूप होने वाले मुद्दों और कमजोरियों की जाँच करता है और अंत में नीति स्तर और विकास योजना स्तर के हस्तक्षेपों की सिफारिश करता है।

**मुख्य शब्द**: महानगर, असमानता, सामाजिक-स्थानिक, सम्भ्रान्तिकरण, बहुआयामी गरीबी, स्थानिक प्रभाव, बहुआयामी प्रकृति

## 1. Background

### *1.1 Megacity*

A megacity is typically an urban agglomeration with a population of 10 million or more, as per the United Nations Department of Economic and Social Affairs, 2011. Currently, there are 33 megacities in the world ('World Urbanization Prospects' 2019). Megacities exhibit distinctive features, including substantial population size, high population density, socio-economic heterogeneity, administrative centrality, resource accessibility, elevated service provision, enhanced connectivity, increased opportunities, high influx of population, and significant waste generation and disposal practices. These urban conglomerations are commonly perceived as drivers of national economic growth and contributing to Global Gross Domestic Product (GDP) ('The World Economic Forum' 2024).

Presently, India hosts six megacities: Delhi, serving as the political capital; Mumbai (Referred to as Greater Mumbai in the paper where municipal extents are considered), distinguished as the financial nucleus; Bengaluru, recognised as the epicentre of Information Technology (IT); Chennai, notable for housing the Indian motor industry; Kolkata, a prominent trading hub; and the most recent addition to this list, Hyderabad. Internationally, the urban agglomerations of Greater Tokyo, Jakarta Metropolitan Area, and Greater New York are the three most prominent megacities owing to their sizes and importance as urban centres worldwide (Table 1).

**Table 1.** International megacities

| City | Population 2023 | Area ($km^2$) |
|---|---|---|
| Greater Tokyo | 40,700,000 | 13,452 |
| Jakarta Metro | 34,500,000 | 6,802 |
| Greater New York | 18,937,000 | 12,093 |

('DEMOGRAPHIA: Demographics Development Impacts Market Research & Urban Policy', n.d.)

### *1.2 Social disparity*

'Disparity' originates from the Latin "dis," meaning "apart" or "non," indicating a form of "non-equality." This term is commonly used to describe unjust inequalities in social or economic conditions. Examples include racial disparities in hiring, health gaps between the rich and the poor, and income differences between men and women. Essentially, "disparity" is a word highlighting instances of perceived unfairness, prompting discussions about equity in various aspects of society ('Disparity Definition & Meaning | Britannica Dictionary', n.d.). Social disparity characterises a scenario or state where specific individuals or groups are granted unequal opportunities, rights, benefits, and incentives compared to others.

### *1.3 Need to study*

It is estimated that 1% of India's population owns more than 40% of the country's total wealth. In contrast, the bottom half of the population together shares just 3% of wealth ('Oxfam India | NGO Working for Child Education, Inequality, Women Empowerment', n.d.). On the other hand, approximately 64% of the total ₹14.83 lakh crore in Goods and Services Tax (GST) came from the bottom 50% of the population in 2021-22, with only 3% of GST coming from the top 10%. Moreover, India has had the fastest growth of millionaires in the world. Further, the Gini's Coefficient of Urban India, which is an indicator of Economic disparity, has risen consistently over the past years (Figure 1). Additionally, it is estimated that by 2050, over half of India's population will be residing in urban areas ('India 2024: An Urban India - CSEP', n.d.), and 1 in 5 megacities will be from India.

In Mumbai, 33% of all Indian Dollar Billionaires and Millionaires reside (Forbes, n.d.), making it a hub of wealth. South Mumbai's Tardeo stands out as India's most expensive residential area, with an average price of INR 56,000 per square foot, while Malabar Hills commands a staggering rate of INR 1,13,000 per square foot ('International Business, World News & Global Stock Market Analysis', n.d.). Mumbai boasts the highest GDP share (6%) of any city in India, reflecting its economic significance. However, Mumbai also faces stark contrasts, as it is home to Dharavi, India's largest slum and the second-largest in Asia ('The Thriving Economy of One of Asia's Biggest Slums' 2016), housing over a million people. 42% of the city's population resides in slums, covering nearly 12% of its total area, as shown in Table 2. This highlights the city's significant wealth gap, with almost 50% of its population unable to afford housing, despite its economic prowess ('Report on the Revised Draft Development Plan for Greater Mumbai' 2016).

Hence, it can be deduced that megacities serve as residences for both the affluent and the economically disadvantaged. An examination of social disparity within Indian megacities is crucial for fostering equitable development, serving as the cornerstone for well-informed policy formulations.

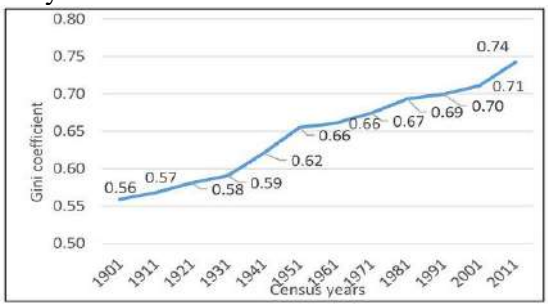


**Figure 1.** Rise in Gini's Coefficient (Shaban, Kourtit, and Nijkamp 2020)

Only 9% of the population of Greater Mumbai earns more than Rs. 60,000 per month, and 25% of the households earn less than Rs. 12,500 per month. The median household income is only INR 20,000 per month. At the same time, the lowest price for even a single-bedroom public housing unit starts from INR 14,00,000 ('Report on the Revised Draft Development Plan for Greater Mumbai' 2016). The wage/price index has also risen to an all-time high of 4.7 in the past decade. (Table 3).

Given that the cost of housing is much higher than the affordable range of 4-5 times a family's annual gross income, it is apparent that nearly half of the population is unable to afford to own a house, even of minimum standards. The Wage/Price Index further highlights this.

**Table 2.** Comparison of Indian Megacities (Yadav and Bhagat, n.d.), ('The World Economic Forum' 2024) ('Statista - The Statistics Portal', n.d.)

| City | Population 2023 | Area (sq Km) | % Area covered by slums | % slum population | Per capita GDP |
|---|---|---|---|---|---|
| Delhi | 32,941, 000 | 1483 | 10% | 25% | 6,44,700 |
| Mumbai | 25,370,000 | 6640 | 12% | 42% | 8,69,200 |
| Kolkata | 15,333,000 | 1899 | 14% | 30% | 4,23,200 |
| Chennai | 11,933,000 | 5904 | 9% | 11% | 5,81,300 |
| Bengaluru | 13,193,000 | 8005 | 4% | 9% | 6,21,500 |
| Hyderabad | 10,584,000 | 7257 | 17% | 61% | 2,98,400 |

**Table 3.** Wages/Prices/Index ratio ('Report on the Revised Draft Development Plan for Greater Mumbai' 2016)

| Wage/Prices/Index | 2003 | 2012 | 2023 |
|---|---|---|---|
| Per annum (INR) average annual wasges of factory workers | 71,778 | 1,03,000 | 1,44,024 |
| Index no. of wages | 100 | 143.5 | 200.6 |
| Per sqft (INR) Average prices of flats in Greater Mumbai (INR) | 3275 | 18,632 | 34,511 |
| Index number | 100 | 500.2 | 932.7 |
| Greater Mumbai price index-wage index ration (2001, 2010, and 2023) | - | 3.5 | 4.7 |

### *1.4 Aim and Objectives*

To examine the multifaceted nature of social disparities and how they manifest spatially, to recommend urban planning interventions to reduce the disparities in Greater Mumbai. The objectives of the study are as given hereinafter:

- To assess the social disparities in Greater Mumbai using the identified parameters or indicators
- To study the spatial implications of Social disparities and resulting issues and vulnerabilities in Greater Mumbai
- To identify the ward/area(s) in Greater Mumbai based on the issues for detailed analysis. To suggest key areas for urban planning interventions to reduce socio-spatial disparities

### *1.4 Scope*

The study area is defined as the Municipal Corporation of Greater Mumbai area, comprising the Island City, Eastern and Western Suburbs, divided into 24 municipal wards. The study focuses on the spatial manifestations of the social, economic, infrastructure, and environmental sectors. The study does not focus on the spatial manifestations of religious, gender-based, or caste-based social disparities

## 2. Research Design

The study begins with a comprehensive literature review to establish a background on social disparities in urban settings and how they manifest spatially, particularly in Greater Mumbai. This encompasses concepts, methods, case studies, and policies/guidelines addressing social disparity in Indian Megacities, along with a comprehensive background study of Greater Mumbai in these areas. This review sets the stage for formulating an aim, clear research objectives, defining the scope of the study, and outlining the specific aspects of socio-spatial disparities to be analysed in the context of Indian Megacities. The identified sectors include housing, health, education, environment, vulnerability to disasters, water supply, solid waste management, sanitation, accessibility to open spaces, transportation, income, and governance. The sectors are not studied in siloes, but the interrelations of the sectors are also taken into consideration to then identify the area (s)/ward(s) for detailed study.

The data collection is through both primary and secondary sources. Primary data collection includes parameter/indicator surveys and household surveys to gather information on the various dimensions. Secondary data sources, including aspect-wise data from agencies and reports/publications, complement the primary data collection efforts.

The data analysis phase focuses on conducting quantitative and qualitative assessments to analyse socio-spatial disparities in Greater Mumbai. Quantitative assessments are performed at city and area/ward levels to understand the distribution of resources and services. At the city level, following the analysis for individual sectors, a map of the city is prepared using the Analytical Hierarchy Process (AHP), which outlines which wards are better serviced, socially and physically, in terms of infrastructure.

Following this quantitative assessment, wards H/E and H/W are chosen for detailed analysis as the 'study area.'

A study is carried out for the housing sector of the study area, based on the Ready Reckoner rates for 2023-24, to estimate the economic standing and determining the housing typology of each plot into HIG-I (25L-5 Cr PA), HIG-II (5 Cr and above PA), MIG (10-25 LPA), LIG (5-15 LPA), EWS (3-15 LPA) and informal settlements or slums. The generated data is then superimposed with the provision of amenities and services to derive the access that each housing typology has, and thereby the people residing in them have. These assessments aid in identifying underlying factors contributing to social inequalities and disparities in access to essential services. To ascertain the statistical significance of the analysis, a Chi-squared test of significance is performed.

Based on the findings from data analysis, gaps and issues are identified, and planning policies and interventions to address the socio-spatial disparities are proposed. These involve formulating guidelines, policies, strategies, and projects to improve access to services and reduce social inequalities in urban areas at the city and study area level.

The conclusion summarises the key findings pertaining to socio-spatial disparities in Indian megacities, highlighting the implications for urban planning, policy-making, and social development. Recommendations for future research and policy interventions are provided to advance further the understanding and mitigation of social inequalities in urban settings.

## 3. Literature Review

In the context of Indian megacities, disparities become evident across economic, social, spatial, and environmental dimensions.

### *3.1 Economic Disparities*

Megacities exhibit profound income disparities, resulting in extreme impoverishment at one end of the spectrum and substantial resource wastage at the other ('Observer Research Foundation | ORF', n.d.). The economic landscape of megacities often manifests stark disparities in employment opportunities, exacerbating income inequalities and contributing to resource misallocation (Kumar 2014).

### *3.2 Social Disparities*

- Differences in Educational Opportunities: Social disparities within Indian megacities are notably reflected in differences in educational opportunities ('The National Council of Applied Economic Research (NCAER) Annual Report' 2017).
- Disparity in Health Access*:* Another significant social dimension is the disparity in health access (Suel et al. 2019).
- Social Exclusion and Discrimination: Social disparities further manifest through social exclusion and discrimination based on factors such as race, ethnicity, gender, and religion (Kumar 2014).
- Crime and Security: Marginalised communities in megacities often experience heightened levels of crime and violence, emphasising the social challenges that need to be addressed.

### *3.3 Spatial Disparities*

- Housing Disparities: Spatial inequalities are evident in housing disparities, ranging from luxurious apartments and gated communities to overcrowded and inadequate housing, including informal settlements and slums ('The Pathway to Affordable Housing in Urban India: A Case Study of Mumbai | Policy Commons', n.d.).
- Empty Luxury Housing Stock: The presence of unoccupied upscale housing adds a layer to spatial dynamics ('Draft of the Mumbai Metropolitan Regional Plan for 2016-2036', 2016).
- Lack of Per Capita Open Spaces: The pervasive lack of per capita amenities, encompassing open spaces, healthcare facilities, educational resources, and social amenities, constitutes a critical challenge within megacities ('Planning Committee Report for the Revised Draft Development Plan for Greater Mumbai' 2016).
- Access to Basic Services*:* Spatial dimensions of disparities include variations in access to basic services like clean water, sanitation, healthcare, education, and transportation.

### *3.4 Environmental Disparities*

- Pollution: Environmental manifestations of disparities include marginalised communities residing in areas with poor environmental conditions, such as pollution and inadequate waste disposal.

- Vulnerability to Natural Disasters: Another environmental aspect is the vulnerability of specific communities to natural disasters ('The National Council of Applied Economic Research (NCAER) Annual Report' 2017).

### *3.5 Manifestations of Socio-spatial Disparities*

- 'Gentrification' is commonly defined as the displacement of certain social classes within an area due to increased investment and the arrival of more affluent segments of society ('The Gentrification Debates: A Reader - Japonica Brown-Saracino - Google Books', n.d.). Gentrification encompasses several impacts, including escalating property values, alterations in housing stock, cultural and commercial transformations, displacement of lower-income residents, an influx of affluent residents, cultural preservation and conflict, and a widening gap in economic disparities (Observer Research Foundation | ORF, n.d., Kumar, 2014).
- 'Ghettoisation' is originating as a process of isolation or restriction faced by minority groups (Weinstein 2014). One of the primary consequences of ghettoisation in Indian megacities is the stark lack of access to basic services within informal settlements or *"bastis."* Clean water, sanitation facilities, and healthcare become elusive for residents in these areas (Jamil 2014), exposing them to heightened health risks and limiting their opportunities for upward social mobility.

**Table 4.** Measurement Indices for poverty and disparity ('National Multidimensional Poverty Index, A Progress Review' 2023) (Earnest et al. 2015)

| Index | About | Positive | Negative |
|---|---|---|---|
| NITI AAYOG Multidimensional Poverty Index (MPI) | Weighted index: The MPI seeks to measure Poverty across its multiple dimensions for health, education and standard of living | Considers poverty as a multi-dimensional phenomenon instead of purely economic | Does not consider the other end of the spectrum for abundance. No measure of disparity |
| **THE SOCIO-ECONOMIC ADVANTAGE AND DISADVANTAGE INDICES, SINGAPORE** | | | |
| The Socio-Economic Disadvantage Index (SEDI)<br>The Socio-Economic Advantage index (SAI) | Principal Component Analysis (PCA) was to create both the SEDI and SAI. PCA is a data reduction technique that is used to summarise a large number of variables into a smaller group, collectively known as a principal component. | Considers disparity for the index for multiple factors | The advantage and disadvantage indices are separated. |
| **THE SOCIO-ECONOMIC INDICES FOR AREAS (SEIFA), AUSTRALIAN BUREAU OF STATISTICS** | | | |
| Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD).<br>Index of Education and Occupation (IEO)<br>Index of Economic Resources (IER).<br>Index of Social Disadvantage (IND) | This index summarises information about the economic and social conditions, occupational and educational characteristics, of people and households within an area. It includes variables such as income education, employment. and occupation | Objective and accurate index for disparity in various sectors | Not comprehensive measure of social disparity |
| **ECONOMIC INDICES** | | | |
| Gini coefficient, S80/S20 ratio, P90/P10 ratio, P50/P10 ratio | The Gini coefficient is an indicator of income inequality that measures the extent to which income is distributed unevenly in a population. It ranges from 0 (perfect equality) to 1 (perfect inequality). S80/S20 is the ratio of the average income of the 20% richest to the 20% poorest in a population P90/P10 is the ratio compares the income at the $90^{th}$ percentile to the one at the $10^{th}$ percentile | Objective and accurate index for economic disparity | Does not aid in measuring any other disparity |
| **SUSTAINABLE DEVELOPMENT GOAL 11** | | | |
| Sustainable and Inclusive Cities | Sustainable Development Goal 11 aims to make cities and human settlements inclusive, safe, resilient and sustainable. There are 10 targets and 15 indications and uses weighted index method | Takes sustainability and inclusivity into account. Apt for studying urban areas | Does not and in measuring any other disparity |

**Table 5.** Parameter and indicators (Authors)

| PARAMETER | INDICATORS | PARAMETER | INDICATORS |
|---|---|---|---|
| **HEALTH** | • Access to affordable healthcare<br>• Per capita healthcare<br>• Maternal health<br>• Access to ambulance services<br>• Types of illness<br>• Expenditure on Healthcare | **HOUSING** | • Housing Typology<br>• Housing condition<br>• Tenement density<br>• Per-capita housing area<br>• Vulnerability to crime<br>• Net population density<br>• Home ownership |
| **EDUCATION** | • Access to quality, affordable education<br>• Per capita Edu. amenities<br>• Student-teacher ratio<br>• Student-classroom ratio<br>• Student-toilet ratio<br>• Infrastructure condition<br>• Teacher qualification<br>• % of EWS and Minority students<br>• Student dropout rate | **WATER SUPPLY** | • Availability of HH water connection<br>• Access to community taps<br>• Availability of 24/7 water supply<br>• Availability of sufficient water supply per person per day<br>• Quality of water<br>• Formal/ Informal water supply |
| **OPEN SPACES** | • Per capita open spaces<br>• Quality of open spaces<br>• Access to open spaces | **SOLID WASTE** | • Availability of the door to the collection<br>• Segregation of waste |
| **INCOME** | • Annual household income<br>• Formal/Informal employment | **SANITATION** | • Availability of the HH toilet<br>• Access to community toilets<br>• Formal/ Informal sewerage system |
| **GOVERNANCE** | • Receptiveness to formal Municipal complaints<br>• Turnaround time | **ENVIRONMENT AND HAZARD VULNERABILITY** | • Location of flood spots<br>• Flood water inundation time<br>• Vulnerability to fires, floods, and landslides |

### *3.6 Dynamic Nature of Poverty and Social Disparity*

Poverty and, consequently, social disparity possess a dynamic nature. Social disparity gives rise to spatial disparities, resulting in insecure housing and a lack of access to infrastructure, rendering individuals vulnerable to shocks. This vulnerability, in turn, hampers recovery efforts, perpetuating a cycle that leads back to poverty, subsequently contributing once again to social disparity (The National Council of Applied Economic Research (NCAER) Annual Report, n.d.).

### *3.7 Measuring Poverty and Socio-spatial Disparity*

NITI AYOG Multidimensional Poverty Index: Multi-dimensional poverty refers to a concept and measurement approach that goes beyond traditional income-based measures of poverty to assess the well-being of individuals and communities from a more holistic perspective ('National Multidimensional Poverty Index, A Progress Review' 2023). The MPI seeks to measure Poverty across its multiple dimensions and, in effect, complements existing poverty statistics based on per capita consumption expenditure and can be calculated as follows:

$$MPI = H \times A$$

where,

H = Headcount ratio, A = Intensity of poverty

The indicators are broadly categorised under Health, Education, and Standard of living, with one-third weightage to each, with a total of twelve sub-indicators, three for Health, two for Education, and seven for Standard of Living.

Based on the various measurement indices for poverty and disparity (Table 4) and the case studies for good practices across megacities and metropolises across the world, parameters and indicators for socio-spatial disparity have been derived, Table 5.

## 4. City evolution and history of disparity in Greater Mumbai

Greater Mumbai, formerly Bombay, is the capital of Maharashtra, India, and serves as the country's financial, commercial, and entertainment hub, contributing to 6.16% of the country's GDP. Located on the Konkan coast, Greater Mumbai boasts a naturally deep harbour. The evolution of Greater Mumbai spans centuries, beginning as a collection of fishing villages and trading outposts. The city's transformation started in 1661 when the seven islands that now form

Mumbai Island City were ceded to the British East India Company. Under British rule, Bombay flourished as a trading port, leading to rapid urbanization due to the setting up of industry and manufacturing, especially in textiles and shipping. Since its inception, Mumbai has attracted both the rich, in the form of the nobility and business people, and the poor, as migrant labourers on the port lands and the textile mills.

In 2024, Greater Mumbai has a population of 13.4 million (Projected from Census 2011, based on the growth rate in the 'Report on the Revised Draft Development Plan for Greater Mumbai' 2016) spread over an area of 458.28 square kilometres, resulting in a population density of 317 persons per hectare. The city is divided into 24 municipal wards and 88 census wards. Between 2001 and 2011, Mumbai experienced a decadal growth rate of 3.87%. The city has 7,06,595 households with an average household size of 4.4 persons. The decadal growth rate has drastically reduced over the past two decades, which can be attributed to both the unaffordability of the city and the relative affordability of housing in the Mumbai Metropolitan Region.

## 5. City-Level Socio-spatial Disparity

### *5.1 Housing*

Housing in Greater Mumbai is a complex and multifaceted issue, reflecting the city's diverse socio-economic landscape. The city's housing stock comprises various types of housing (Figure 2), each catering to different segments of the population. One of the prevalent forms of housing in Mumbai is *chawls*, which are multi-storeyed tenements that originated during the British colonial era to accommodate industrial workers. Chawls typically consist of small, cramped rooms arranged around a common courtyard or corridor, and continue to house a significant portion of the city's population, particularly in older parts of the city.

Another common form of housing in Mumbai is apartments or flats, which range from modest one-room dwellings to luxurious high-rise apartments with modern amenities. Apartments are prevalent in both public and private housing sectors, catering to a wide range of income groups. Informal settlements, or slums, are also a prominent feature of Mumbai's housing landscape, housing a substantial portion of the city's population. These settlements are characterized by poor construction quality, lack of basic services, and overcrowding, posing significant challenges in terms of sanitation, health, and safety. In Mumbai, slums comprise 42% of all housing typologies, followed by MIG (34%), HIG (17%), and LIG/EWS (7%).


**Figure 2.** Housing scenario of Mumbai ('Report on the Revised Draft Development Plan for Greater Mumbai', 2016)

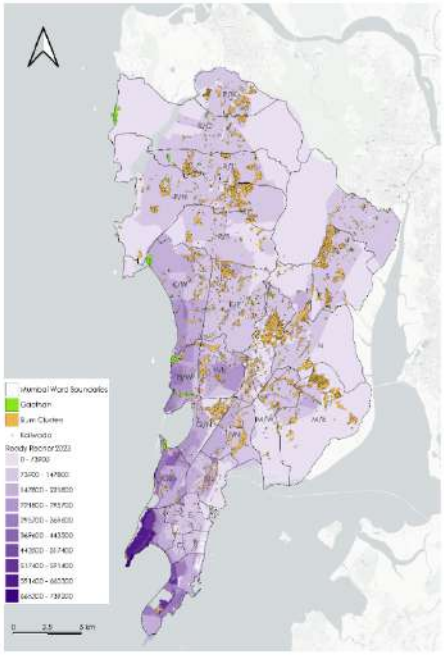

**Figure 3.** Slum clusters vis-à-vis Ready Reckoner Rates (Authors)

In recent years, Mumbai has also seen a rise in gated communities and high-end residential complexes, particularly in the suburbs and outskirts of the city. These developments offer a range of amenities such as security, recreational facilities, and green spaces, catering to the growing demand for upscale housing options. The housing scenario in Mumbai is characterized

by a mix of formal and informal housing types, reflecting the city's diverse population and the complex interplay of socio-economic factors shaping its urban landscape. Slums are more prolific in areas away from the west coast and the island city, which have exuberantly high prices, Figure 3.

Further, the tenement density calculation for the redevelopment of residential buildings versus the tenement density prescribed for rehabilitation and resettlement units varies vastly. For the former, a maximum tenement density of 500 is set. In contrast, for the latter, a minimum tenement density of 650 is set, leading to an appalling density of nearly 14.6 lakh people per square kilometer. This leads to cramped housing with minimal light and ventilation.

Unsanitary living conditions and lack of access to natural light and ventilation in Mumbai's housing have become breeding grounds for communicable diseases, particularly tuberculosis (TB). A recent study by MMR-IES found a direct correlation between diluted Development Control Rules (DCRs) and the incidence of TB.

### *5.2 Social Infrastructure*

The Municipal Corporation of Greater Mumbai (MCGM) operates 26 maternity homes, 161 dispensaries, 167 health posts, and 10 municipal hospitals ('Report on the Revised Draft Development Plan for Greater Mumbai' 2016). The average per capita availability of all medical amenities is 0.24 square meters per person (Figure 4). Wards A, D, E, F/S, F/N, H/W, and K/E have the highest per capita health amenities, while Wards M/E, M/W, L, and R/C have the lowest. Wards F/S, F/N, and E have significantly higher per capita medical amenities due to the presence of government hospitals such as King Edward Memorial Hospital, JJ Hospital, and Tata Memorial Hospital. Island City boasts the highest per capita health amenities.

Currently, the Municipal Corporation of Greater Mumbai (MCGM) operates 1255 primary schools, 109 secondary schools, and 430 private aided primary schools. The average per capita space available for education is 0.69 square meters per person (Figure 5). Wards A, D, H/E, F/N, P/S, S, and T have the highest per capita educational amenities, while Wards C, M/E, L, P/N, P/S, and R/C have the lowest. Wards S and T have significantly higher per capita educational amenities due to the presence of the IIT-Bombay Campus. However, since it is a National Institute and does not solely cater to the city, it has not been considered in the calculation.

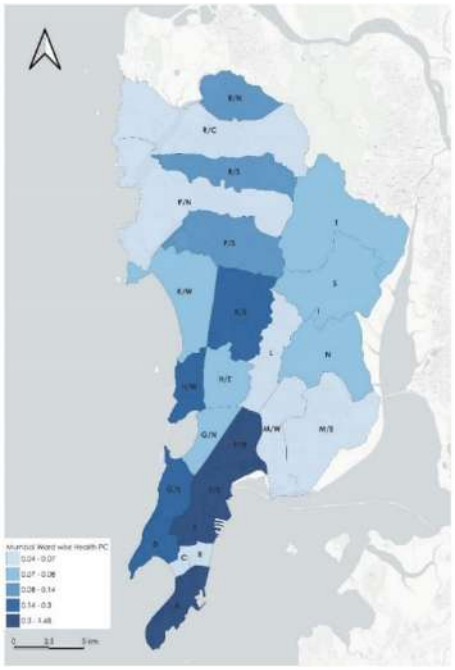

**Figure 4.** Ward-wise per capita health amenities (Authors)

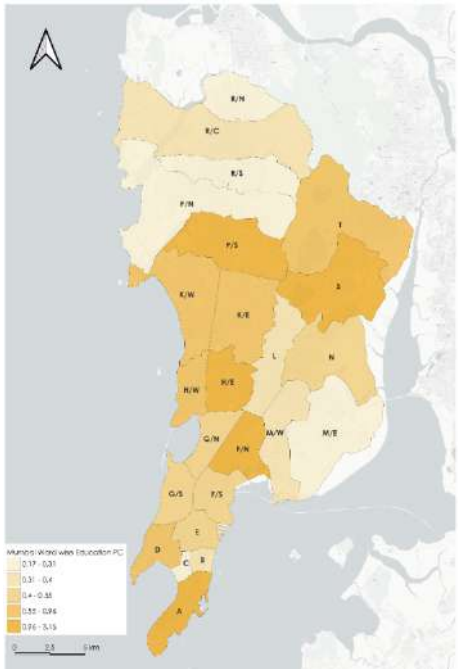

**Figure 5.** Ward-wise per capita educational amenities (Authors)

If all varieties of open spaces in the city are added, they make up a significant area of 128.41 sq. km or a per capita open space availability of 10.32 sq. m. However, a large part of these is publicly inaccessible. Open spaces accessible to all amount to only 15.37 sq. km or a per capita open space availability of 1.24 sq. m, which is ten times less than the URDPFI recommendation.

Wards A, D, G/S, K/W, M/W, T, P/N, R/S, and R/C have the highest per capita open space

amenities, while Wards B, M/E, H/E, and L have the lowest (Figure 6). The northern wards of R/C, R/S, and R/N in the Western Suburbs and the T and S wards in the Eastern Suburbs contain the Sanjay Gandhi National Park. Despite being a National Park, residents of Greater Mumbai benefit from it; hence, it has been included in the calculations. The Western Suburbs have the highest per capita open space.

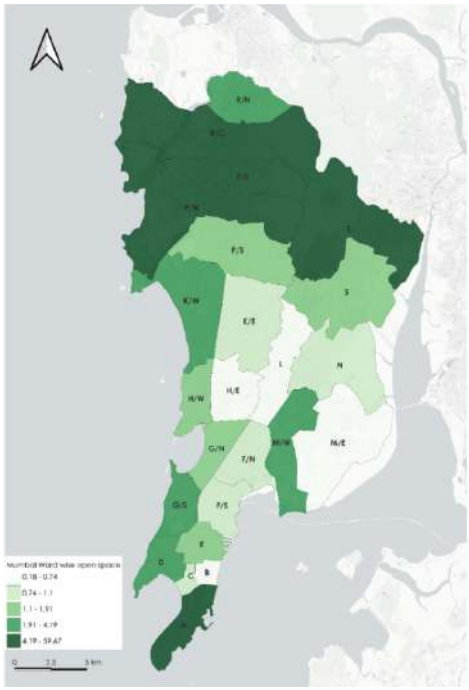

**Figure 6.** Ward-wise per capita open spaces (Authors)

### *5.3 Physical Infrastructure*

Wards A, B, C, D, E, F/S, G/S, G/N, H/W, K/E, and M/W have nearly 100% household water tap connections. In contrast, Wards S and L have less than 80% of households equipped with water connections, with both wards having a significantly high slum population (50 to 70%) due to slum clusters in Kurla, Bhandup, Nahur, Vikhroli, and Kanjurmarg. Island city has the highest percentage of households with tap water connections.

Island city has three outfalls, two sewage treatment plants, and nine pumping stations. The Western Suburbs have six outfalls, two sewage treatment plants, and six pumping stations. The Eastern Suburbs have 11 outfalls, two sewage treatment plants, and three pumping stations ('Report on the Revised Draft Development Plan for Greater Mumbai' 2016). In terms of sewage treatment amenities per capita, Island city has the highest, followed by the Western Suburbs and then the Eastern Suburbs.

Mumbai has three dumping grounds, located in Deonar, Bhandup, and Mulund, totaling 513 hectares. These wards also have a significantly high slum population (50 to 70%) and are situated in the Eastern Suburbs. The Deonar and Mulund Dumping Grounds are particularly problematic due to prevalent fires, leading to respiratory issues for a significant population. In contrast, Island City has three sanitary refuse sheds, and the Western Suburbs have a closed solid waste disposal site in Gorai, which has been transformed into a park near Gorai Beach.

Every day, approximately 4.5 million people enter Greater Mumbai, and 4.47 million people move out. The linkages between Greater Mumbai and MMR play a major role in retaining the primacy of Greater Mumbai. However, the city's public transport systems have not kept pace with the city's growth. Therefore, it is witnessing acute road congestion and overcrowding in trains and buses. Greater Mumbai has a distinct advantage of a high modal share of 76% (excluding pedestrians) in favour of public transport.

The Central and Western Suburban Rail Services carry an estimated 7 million passengers every day, while the public bus transport system handles 5.5 million passengers. Further, a higher percentage of the budget (36,856 Cr) is spent on the island city, with a lesser population, and a lower percentage rate on eastern suburbs (11,259 Cr) with a higher population. Additionally, the main transit lines are located away from Koliwadas and slum clusters, catering more to upscale areas.

A ward level comparison (Table 6) presents the summary of all per-capita amenities provision to be used as the basis for the Analytical Hierarchy Process.

## 6. Analytical Hierarchy Process

Based on the ward-level comparison, an analysis was done using the MCDM method, Analytical Hierarchy Process (AHP), and the weightages were allotted as displayed in Table 7.

Based on the criteria and respective weightages, the 24 wards were ranked, with the A ward in the island city ranking first and the M/E ward in the eastern suburbs ranking last (Table 8) (Figure 7).

Wards selected for further analysis are adjacent wards H/W and H/E based on a high RR rate, high percentage of slum, and a mix of various types of housing (MHADA, SRA, Slums, HIG and MIG, Gaothans, and Koliwadas). The combined area will be henceforth referred to as the 'study area.'

**Table 6.** Ward-level amenities comparison (Authors)

| Ward | Areas | Area (Ha) | Developed Area (Ha) | % area developed | Population in Lakh (2011) | Population in Lakh (2021) | Growth rate | Pop. density 2011 (pph) | Pop. density 2021 (pph) | Slum pop. 2011 | Open Spaces (Ha) | Open Spaces PC (sqm) 2021 | Medical Amenities (Ex.) | Medical Amenities (2034 Res.) | Existing Per capita Health | Ex. Edu. Amenities | Edu. Amenities (2034 Res.) | Existing Per capita Education | Highest Sqm Residential rate | % of slums |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Fort, Churchgate, Colaba, and Navy Nagar | 1,120.91 | 877.96 | 78.32 | 185,014 | 167,000 | - 0.097 | 165 | 149 | 63,400 | 74.86 | 4.48 | 24.00 | 0.24 | 1.44 | 25.53 | 0.43 | 1.53 | 576,300 | 34.27 |
| B | Masjid Bunder, Mohd. Ali Road, Dongri and Bhendi Bazar | 265.82 | 261.58 | 98.40 | 127,290 | 112,000 | - 0.120 | 478 | 421 | 14,400 | 2.03 | 0.18 | 0.53 | 0.68 | 0.05 | 3.66 | 0.17 | 0.33 | 158,900 | 11 |
| C | Pydhonie and Bhuleshwar | 191.30 | 190.21 | 99.43 | 166,161 | 152,000 | - 0.085 | 867 | 795 | 4,000 | 13.23 | 0.87 | 0.74 | 0.33 | 0.05 | 2.59 | 1.13 | 0.17 | 445,600 | 3 |
| D | Grant Road, Walkeshwar, Malabar Hill, Breach Candy to Haji Ali, Tardeo Road | 830.20 | 755.50 | 91.00 | 346,866 | 335,000 | - 0.034 | 239 | 404 | 33,000 | 87.95 | 2.63 | 10.19 | 0.22 | 0.30 | 20.64 | 1.35 | 0.62 | 1,140,500 | 9.51 |
| E | Byculla, Madanpura, Agripada, Nagpada, Dockyard Road, Reay Road, Chichpokli | 727.39 | 727.31 | 99.10 | 393,286 | 360,000 | - 0.085 | 520 | 495 | 77,800 | 42.41 | 1.18 | 40.07 | 5.26 | 1.11 | 18.76 | 3.16 | 0.52 | 469,900 | 19.78 |
| F/S | Parel | 987.24 | 904.00 | 91.56 | 360,972 | 351,000 | - 0.028 | 355 | 356 | 95,200 | 51.95 | 1.08 | 14.90 | 8.29 | 0.31 | 48.30 | 6.11 | 1.00 | 381,500 | 58.29 |
| F/N | Matunga, Sion, Wadala, Hindu Colony | 1,285.37 | 821.07 | 70.44 | 529,034 | 482,000 | - 0.089 | 412 | 375 | 308,400 | 26.57 | 0.76 | 51.84 | 2.77 | 1.48 | 15.51 | 8.50 | 0.44 | 255,000 | 26.37 |
| G/S | Worli and Prabhadevi | 974.11 | 817.85 | 83.96 | 377,749 | 344,000 | - 0.089 | 388 | 353 | 78,300 | 42.01 | 0.72 | 3.80 | 2.08 | 0.07 | 22.77 | 5.70 | 0.39 | 460,300 | 31.65 |
| G/N | Dharavi, Mahim and Dadar, parts of BKC | 831.54 | | 98.00 | 599,039 | 580,000 | - 0.032 | 721 | 698 | 189,600 | 125.15 | 3.64 | 9.69 | 1.11 | 0.28 | 11.72 | 4.89 | 0.34 | 300,900 | 20.73 |
| H/E | Bandra East, Khar East and Santacruz East, parts of Vile Parle, Mahim and Dharavi | 1,241.93 | | 97.14 | 563,445 | 556,000 | - 0.013 | 448 | 448 | 241,006 | 30.65 | 0.55 | 4.05 | 3.30 | 0.07 | 100.10 | 5.55 | 1.80 | 372,100 | 42.14 |
| H/W | Bandra West, Khar West, Santacruz West | 865.04 | 766.00 | | 301,375 | 287,000 | - 0.048 | 341 | 332 | 112,994 | 37.15 | 1.29 | 6.56 | 0.31 | 0.23 | 26.79 | 1.60 | 0.93 | 449,600 | 38.53 |
| K/E | Andheri East, Jogeshwari East, and Vile Parle East, Aarey | 2,400.00 | 1,543.00 | 92.06 | 823,885 | 834,000 | 0.012 | 343 | 348 | 403,800 | 64.46 | 0.77 | 16.56 | 9.60 | 0.20 | 46.56 | 16.63 | 0.56 | 372,100 | 49.01 |
| K/W | Andheri West, Jogeshwari West, and Vile Parle West, Oshiwara | 2,518.22 | 1,887.00 | 74.93 | 748,688 | 782,000 | 0.044 | 298 | 311 | 108,800 | 155.92 | 1.99 | 16.89 | 7.27 | 0.22 | 72.52 | 12.17 | 0.93 | 267,700 | 14.53 |
| P/S | Goregaon, parts of Malad and Oshiwara, Aarey Colony, Film City | 2,519.10 | 2,471.67 | 80.00 | 463,507 | 483,000 | 0.042 | 184 | 192 | 264,000 | 557.69 | 5.39 | 7.58 | 6.21 | 0.07 | 23.61 | 20.05 | 0.23 | 176,500 | 53.59 |
| P/N | Malad, Manori, Marve, Aksa, and Madh | 4,670.05 | 1,724.74 | 42.00 | 941,366 | 1,035,000 | 0.099 | 201 | 222 | 504,500 | 77.46 | 1.60 | 5.90 | 5.72 | 0.12 | 69.74 | 7.94 | 1.44 | 142,100 | 56.96 |
| R/S | Kandivali and Charkop, Lohandwala Complex, SGNP, Manori Cree | 1,831.31 | | 63.00 | 691,229 | 782,000 | 0.131 | 377 | 427 | 399,200 | 1,478.31 | 25.67 | 4.16 | 9.77 | 0.07 | 22.99 | 21.93 | 0.40 | 195,600 | 18.55 |
| R/C | Borivali, Sanay Gandhi National Park | 4,795.00 | 1,217.00 | | 562,162 | 576,000 | 0.025 | 117 | 120 | 104,300 | 203.61 | 3.99 | 5.20 | 7.46 | 0.10 | 14.68 | 13.32 | 0.29 | 177,200 | 51.35 |
| R/N | Dahisar | 1,417.67 | 702.02 | 49.51 | 431,368 | 510,000 | 0.182 | 304 | 360 | 221,500 | 489.53 | 6.26 | 7.60 | 7.28 | 0.10 | 16.13 | 18.17 | 0.21 | 132,400 | 57.75 |
| L | Sakinaka, Chandivali, Asalpha, and Kurla and parts of Powai, Parts of Dharavi | 1,562.54 | 1,275.99 | 90.69 | 902,225 | 981,000 | 0.087 | 580 | 628 | 490,400 | 61.91 | 0.63 | 4.40 | 11.67 | 0.04 | 39.04 | 12.57 | 0.40 | 296,300 | 54.35 |
| M/E | Mankhurd, Anushakti Nagar, Deonar, Cheetah Camp, Shivaji Nagar | 3,819.71 | 2,559.55 | 67.00 | 807,720 | 902,000 | 0.117 | 244 | 236 | 245,300 | 45.05 | 0.50 | 6.25 | 9.07 | 0.07 | 25.36 | 9.44 | 0.28 | 199,800 | 30.37 |
| M/W | Chembur, Sindhi Society, Suman Nagar, Chheda Nagar and Tilak Nagar | 1,762.02 | 1,360.91 | 77.23 | 411,893 | 413,000 | 0.003 | 234 | 234 | 217,200 | 96.53 | 2.34 | 1.54 | 2.86 | 0.04 | 16.55 | 12.23 | 0.40 | 199,800 | 52.73 |
| N | Ghatkopar, Vidyavihar and Pant Nagar | 2,968.38 | | 40.00 | 622,853 | 632,000 | 0.015 | 210 | 213 | 385,600 | 65.28 | 1.03 | 8.98 | 4.79 | 0.14 | 27.99 | 11.29 | 0.44 | 137,700 | 57.57 |
| S | Bhandup, Powai, IIT, Kanjurmarh, Vikhroli and Nahur | 3,255.45 | 1,927.40 | 59.00 | 743,783 | 779,000 | 0.047 | 228 | 239 | 537,900 | 111.39 | 1.43 | 7.60 | 14.01 | 0.10 | 245.25 | 18.86 | 3.15 | 277,800 | 72.32 |
| T | Mulund, SGNP, Salt Pans | 4,491.67 | | 24.06 | 341,463 | 347,000 | 0.016 | 76 | 77 | 111,800 | 2,070.62 | 59.67 | 11.26 | 7.17 | 0.32 | 26.37 | 8.61 | 0.76 | 135,000 | 32.73 |

**Table 7.** AHP Weightages (Authors)

| Criteria | Weightage |
|---|---|
| % slum population | 13.2% |
| Average RR rate | 12.5% |
| Health per capita | 8.1% |
| Open Spaces per capita | 9.1% |
| Education per capita | 7.2% |
| Water supply | 8.3% |
| Location of sewerage treatment amenities | 5.8% |
| Location of solid waste amenities | 6.9% |
| Per capita expenditure on transportation amenities | 9.4% |
| Location of water-logging spot | 10.1% |
| Location of landslide spots | 9.3% |

**Table 8.** Ranking of all 24 wards as per AHP (Authors)

| Rank | Ward Name | Areas |
|---|---|---|
| 1 | A | Fort, Churchgate, Colaba, and Navy Nagar |
| 2 | D | Grant Road, Walkeshwar, Malabar Hill, Breach Candy to Haji Ali, Tardeo Road |
| 3 | G/N | Dharavi, Mahim and Dadar, parts of BKC |
| 4 | K/W | Andheri West, Jogeshwari West, and Vile Parle West, Oshiwara |
| 5 | C | Pydhonie and Bhuleshwar |
| 6 | H/W | Bandra West, Khar West, Santacruz West |
| 7 | G/S | Worli and Prabhadevi |
| 8 | E | Byculla, Madanpura, Agripada, Nagpada, Dockyard Road, Reay Road, Chichpokli |
| 9 | F/N | Matunga, Sion, Wadala, Hindu Colony |
| 10 | F/S | Parel |
| 11 | K/E | Andheri East, Jogeshwari East, and Vile Parle East, Aarey |
| 12 | B | Masjid Bunder, Mohd. Ali Road, Dongri and Bhendi Bazar |
| 13 | H/E | Bandra East, Khar East and Santacruz East, parts of Vile Parle, Mahim and Dharavi |
| 14 | M/W | Chembur, Sindhi Society, Suman Nagar, Chheda Nagar and Tilak Nagar |
| 15 | R/C | Borivali, Sanay Gandhi National Park |
| 16 | S | Bhandup, Powai, IIT, Kanjurmarh, Vikhroli and Nahur |
| 17 | T | Mulund, SGNP, Salt Pans |
| 18 | P/S | Goregaon, parts of Malad and Oshiwara, Aarey Colony, Film City |
| 19 | P/N | Malad, Manori, Marve, Aksa, and Madh |
| 20 | R/N | Dahisar |
| 21 | R/S | Kandivali and Charkop, Lohandwala Complex, SGNP, Manori Cree |
| 22 | L | Sakinaka, Chandivali, Asalpha, and Kurla and parts of Powai, Parts of Dharavi |
| 23 | N | Ghatkopar, Vidyavihar and Pant Nagar |
| 24 | M/E | Mankhurd, Anushakti Nagar, Deonar, Cheetah Camp, Shivaji Nagar |

## 7. Area Level Analysis

The study area is primarily composed of Bandra, which was formerly a small fishing village inhabited by Kolis (fishermen) and salt farmers. The area was part of Portuguese Bombay territory extending from Damaon to Chaul, before its acquisition by the English East India Company. It has the Ranwar, Chimbai, Shirley, Chuim, Pali village, and the Khar Danda Koliwada.

### *7.1 Housing*

The study area has undergone significant changes in its housing scenario over the years. Once a predominantly residential area with old-world charm, it has transformed into a bustling locality with a mix of old and new developments. Bandra is known for its distinct neighbourhoods, such as Pali Hill, Bandra Reclamation, and Bandstand, each offering a unique housing landscape (Figure 8). The Mithi River demarcates the boundary on the east.

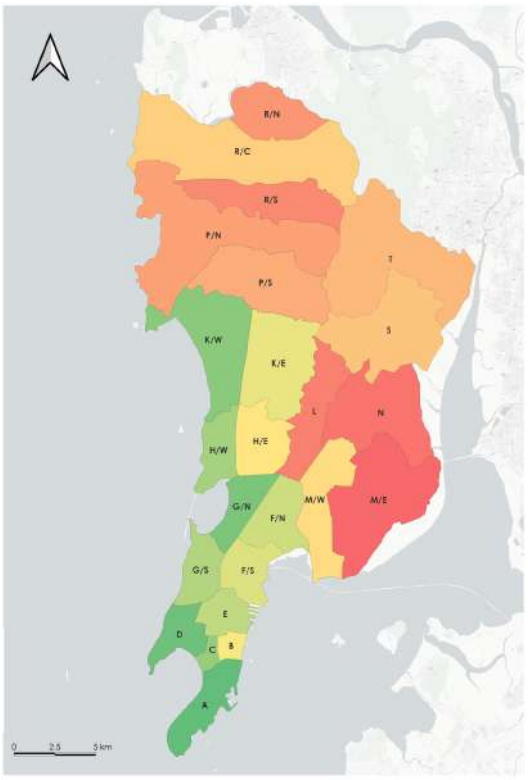


**Figure 7.** The most and least serviced areas of the city (Authors)

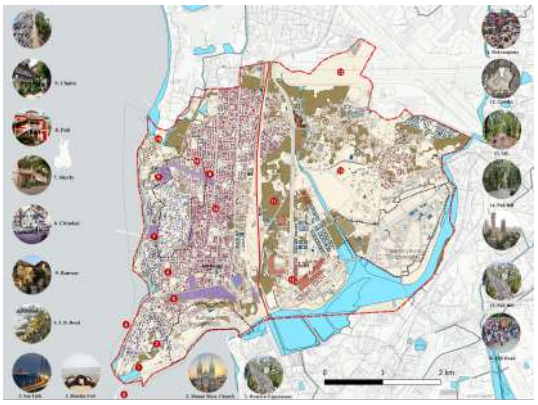

**Figure 8.** Housing Scenario (study area) (Authors)

A blend of old bungalows, high-rise apartments, and modern townships characterises the housing in Bandra. Pali Hill, once a quaint village, is now renowned for its luxurious bungalows and celebrity residences, reflecting the area's upscale living following gentrification. Bandra Reclamation, on the other hand, has seen the emergence of high-rise buildings and modern apartment complexes, catering to the growing housing demand.

However, the rapid development in Bandra has also led to challenges such as increased congestion, infrastructure strain, and ghettoization in slums of Behrampada owing to issues of affordability and contested land rights. The rising property prices have made it difficult for middle and lower-income groups to afford

housing in the area, leading to a demand for more affordable housing options.

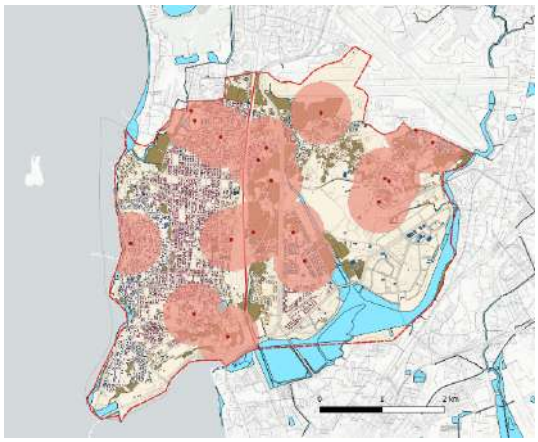

**Figure 9.** Schools with poor facilities (Authors)

### *7.2 Social Infrastructure*

EDUCATION

The schools in the study area were ranked based on facilities, using a rating scale from 0 to 24. A score of 0 to 10 indicated poor facilities, 10 to 20 represented average facilities, and a score of 20 to 24 indicated adequate facilities. This criterion was applied to 92 educational facilities in the area to assess the quality of their amenities. The result revealed that 19 schools had poor facilities, 48 schools had average facilities, and 25 schools had adequate facilities.

An 800 m buffer around the schools presented that the most predominant housing typology (41%) around schools with poor amenities was slums (Figure 9). Conversely, for schools with adequate facilities, the buffer included 55% HIG-I and HIG-II housing as the predominant housing typology.

Private schools and trust-funded schools typically have better student-teacher ratios, student-classroom ratios, infrastructure conditions, and teacher qualifications compared to government-aided schools. However, families living in slums often prefer government-aided schools due to affordability issues. Schools with poorer facilities are usually located closer to slum areas. Government-aided schools also tend to have higher dropout rates compared to private schools. Additionally, only 2% of people living in slums have a post-graduate degree, which significantly impacts their economic upward mobility.

HEALTH

The ambulance service covers a total area of 344 hectares and serves a population of 96,800, with over 50% belonging to the High-Income Group (HIG). Out of the 41 hospitals in the study area, 32 do not have ambulance services, while nine provide ambulance services.

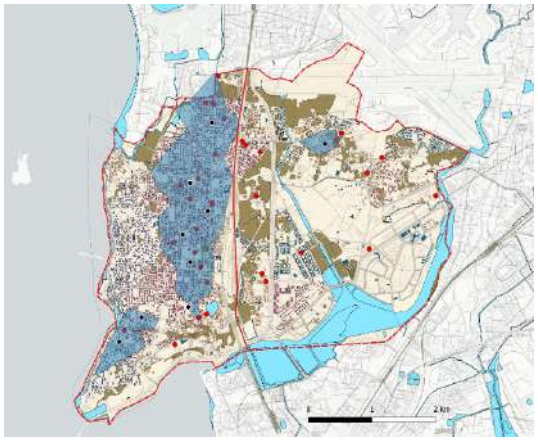

**Figure 10.** Isochrones of ambulance travel time in 10 min (Authors)

The isochrone of ambulance travel time of 10 minutes from its origin revealed that the predominant housing category catered to in this buffer is HIG (54%), with slums being only 6% (Figure 10).

There are a total of nine Urban Primary Health Centres (UPHCs) in the study area. UPHCs are intended to be established for every population of 50,000.

Families in Disadvantaged communities (slums and koliwada) prefer Government Healthcare to Private Healthcare for larger health concerns due to the unaffordability. Of the nine Urban Public Health Centres (UPHC), those located near slums are overcrowded, while those in HIG areas are underutilised (Figure 11).

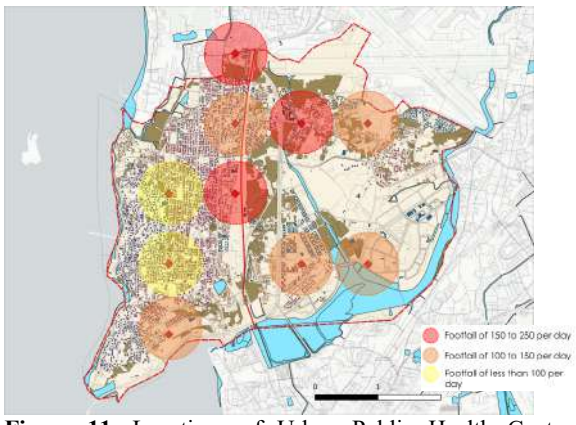


**Figure 11.** Locations of Urban Public Health Centres (UPHCs) (Authors)

70% of people living in slums prefer not to seek professional medical help, choosing to self-medicate for lesser issues. People living in slums are prone to vector-borne diseases such as typhoid, jaundice, malaria, and dengue, indicating polluted water supply and lack of

drainage. Poor health directly relates to economic losses due to absence from work, exacerbating existing socio-economic issues.

OPEN SPACES

Children, adults, and older people must have access to open spaces for healthy living; however, only 10% of slums have access to open spaces, based on a buffer of 150 m, while HIG-I and HIG-II collectively have 62% access (Figure 12).

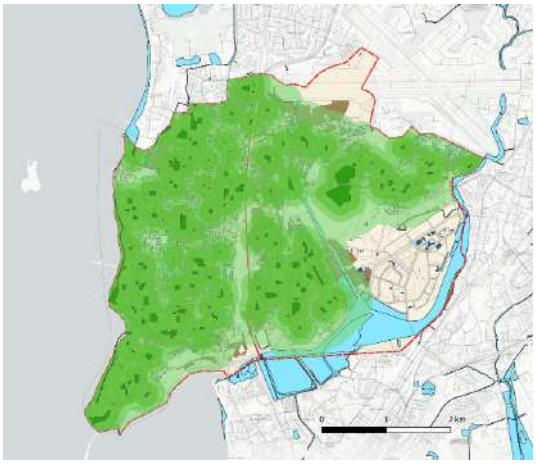

**Figure 12.** Distance from open spaces at 150, 250, 500 m (Authors)

This number further drastically reduces when taking into consideration that 87% of these open spaces are either inaccessible or poorly maintained due to garbage dumping or waterlogging

The lack of open spaces in a neighbourhood can have several negative effects, both physically and mentally, on its residents and the community as a whole. Furthermore, the lack of open spaces can impact social cohesion and community interaction. Open areas often serve as gathering places for residents, promoting social interaction and a sense of community. Without these spaces, neighbourhoods can feel isolated, and residents may experience a lack of connection with their neighbours.

Additionally, the absence of open spaces can have environmental consequences. Green spaces help to mitigate urban heat islands, improve air quality, and support biodiversity. Without these spaces, urban areas can become hotter, more polluted, and less resilient to climate change impacts.

65% of all water-logging spots within the study area are located within or near slums, making these areas particularly vulnerable to disaster-related damages and perpetuating a cycle of disaster-induced poverty (Figure 13).

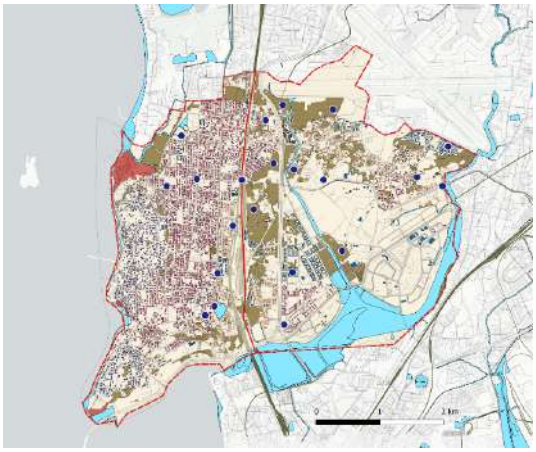

**Figure 13.** Location of flooding spots and vulnerable settlements (Authors)

### *3.4 Physical Infrastructure*

Slums in the area face significant challenges, including limited access to clean water and poor water quality. Solid waste is not segregated, and one in every four residents is unaware of its environmental impact. Sewage is frequently discharged directly into the sea or the Mithi River. The hazardous conditions of the land surrounding the Mithi, combined with flood vulnerability, have contributed to the proliferation of slum settlements along its banks. The situation is further worsened by the dumping of solid waste and industrial chemicals into the river.

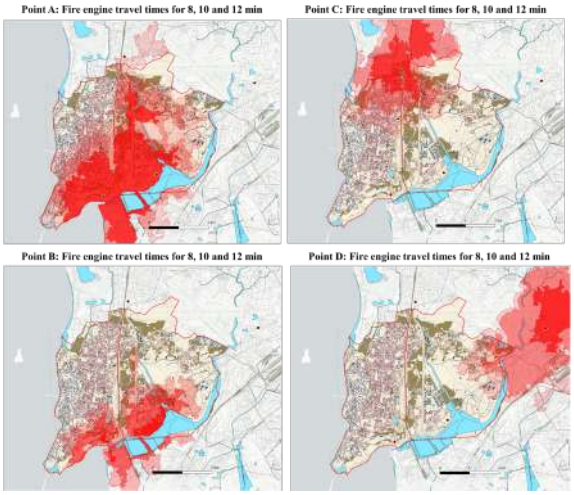


**Figure 14.** Response time for fire engines (Authors)

The road network within the study area is inconsistent in terms of quality and condition. While the optimal response time for a fire engine to reach the site of an incident is 5 minutes, the Municipal Corporation of Greater Mumbai (MCGM) Fire Brigade targets a response time of 8 minutes. Figure 14 presents the response time coverage of the four fire stations at 8, 10, and 12-minute intervals, along with the corresponding

spatial extent and housing typologies served within each timeframe.

The fire engine covers a total area of 924 hectares within an 8-minute response time. This service serves a population of 550, covering approximately only 11% of the slum areas. This is in vast contradiction to 63% covered by the HIG category. The difference in travel time can be attributed to both the location of the fire-engine parking locations and the condition and congestion on roads close to or leading up to the slums. The fire station receives an average of 75 to 100 calls per month.

The primary perception survey conducted in the study area revealed that the condition of roads was poor. It riddled with potholes in over 80% network of the slum's network, as opposed to 35% in other localities.

## 4 Issues

### *4.1 City Level Issues*

Disadvantaged communities and slums are often located away from transit lines and hotspots, leading to congestion and an abundance of empty luxury housing stock on road-fronting plots due to unaffordability. Housing typologies exhibit spatial segregation, neglecting inclusivity and the diverse needs of residents in a megacity. There is a significant lack of physical infrastructure, including household access to water supply, sewerage networks, drainage, solid waste disposal, and electricity. Resources such as water, human resources, and raw materials are distributed unequally. Urban slums suffer from congested living spaces and high density, resulting in poor living conditions. There is also a severe lack of capital for housing and infrastructure upgrades, as well as insufficient per capita amenities such as health, education, transport, and open spaces.

Specific areas such as Koliwadas, Gaothans, and Adivasipadas have been excluded from the Development Plan 2034, and there are currently no Development Control Regulations (DCRs) applicable to these regions. Formulating appropriate DCRs is essential to address these issues effectively.

### *4.2 Study Area Level Issues*

Slums face significant challenges, including inadequate physical and social infrastructure, which hampers residents' quality of life. Poor road infrastructure contributes to delays in service delivery, exacerbating these conditions. Urban Primary Health Centres (UPHCs) are often underutilised, limiting access to essential healthcare services. Additionally, a lack of open spaces restricts recreational opportunities and community interaction, further diminishing the living conditions in these areas. Addressing these issues is critical for enhancing the overall well-being of slum residents.

## 5 Recommendations

### *5.1 City Level Recommendations*

Issue: Location of Disadvantaged Communities/Slums:
To address the issue of disadvantaged communities and slums being located away from transit lines and hotspots, causing congestion and an abundance of empty luxury housing stock, Transit-Oriented Development (TOD) policies are recommended. Main building façades should directly face public streets without setbacks to promote visual surveillance. At least 50% of the building frontage, measured from the built-to-right-of-way (RoW) line, should have active frontage, except for RoW widths of 12 meters or less. Active frontages should include arcades, shop fronts, entrance doorways, access points, and transparent windows facing the main street. Ground-floor commercial frontages should maintain a minimum of 50% transparency. Vertical mixing of land use with mandatory commercial components on lower floors should be implemented to allow active frontage and "eyes on the street." Incentives for a mix of housing typologies (HIG, MIG, LIG, and EWS) should be provided. This model encourages a social mix, mixed-use spaces, walkability, and public transport usage, promoting inclusivity in redevelopment

Issue: Spatial Segregation in Housing Typologies:

To combat spatial segregation in housing typologies, policies inspired by Singapore's Housing and Development Board (HDB) are recommended. Singapore's system, which houses approximately 82% of its citizens in state-subsidised apartments, caters to various needs of the social mix, such as multi-generational families, the elderly and physically disabled, young couples, low-income families, singles, and affluent families, while promoting racial harmony.

Issue: Lack of Physical Infrastructure:

Addressing the lack of physical infrastructure requires prioritising the vulnerable through detailed mapping and upgrading of existing

infrastructure. Partnering with alternative service providers, such as NGOs and CSR funds, can enhance service provision. Utilising community capacities and resources can improve services, fostering self-reliance and encouraging organisational and self-representation.

Issue: Unequal Distribution of Resources:

To address the unequal distribution of resources, new Business Districts should be allocated in regions with suitable transportation and housing infrastructure. Modifying existing Development Control Regulations to moderate housing stock by limiting FSI and adding inclusive policies can lead to equitable and sustainable development with manageable densities.

Issue: Congested Living Spaces and High Density in Urban Slums:

Promoting transparency and integrated spatial planning through Urban Land Management can address the specific needs of congested and disadvantaged settlements. Integrated Urban Land Management can improve living conditions, ensuring optimum density, open spaces, and a healthy environment.

Issue: Lack of Capital for Housing and Infrastructure Upgradation:

To address the shortage of capital for housing and infrastructure upgrades, as well as the insufficient per capita amenities, financing and subsidies are recommended. Market corrections through subsidies and grants to address market failures, encouraging investment in socially beneficial development.

Issue: Indigenous Communities:

The inclusion of Koliwadas, Gaothans, and Adivasipadas in the Development Plan 2034 requires tailored Development Control Regulations (DCRs). Formulating different DCRs for heritage precincts, non-heritage precincts, and a Community and Land Reserve (CLR) model is essential.

### *5.2 Need for Appropriate DCRs*

- Type A: Heritage Precincts

For declared or proposed heritage precincts, including Gaothans, Koliwadas, and Adivasipadas, it is essential to maintain the original land use to avoid detriment to conservation efforts. The original road structure should be preserved, with relaxed parking norms to accommodate the traditional layouts. Any plot amalgamation or subdivision should require permission from the Mumbai Heritage Conservation Committee (MHCC) or the Municipal Corporation of Greater Mumbai (MCGM) to conserve the characteristic footprint of these areas. Additionally, architectural elements such as roof typology, road setbacks, floor heights, and balconies or verandas should be maintained in line with the original heritage fabric.

- Type B: Non-Heritage Precincts

For non-heritage precincts undergoing repair or reconstruction, the focus should be on maintaining the existing building footprint and heights. Basic improvements and structural repairs should be permitted, provided they do not extend beyond the existing building parameters. Stilt structures should not be allowed on road-facing façades, with the maximum stilt area limited to 50% of the building footprint.

- Type C: Community and Land Reserve (CLR) Structures

For the effective management and development of Koliwadas, Gaothans, and Adivasipadas, a Community Land Reserve (CLR) should own all the land and oversee the redevelopment, rehabilitation, promotion, and management processes. In contrast, individuals may own the buildings or tenements. The CLR should define the rights of all stakeholders, irrespective of ownership status and land use type, while retaining amenities.

### *5.3 DCRs for Slum Redevelopment*

For effective slum redevelopment, it is crucial to adhere to development norms consistent with the rest of the city, particularly regarding side open spaces, building heights, and density. Physical infrastructure should meet the standards set by the Central Public Health and Environmental Engineering Organisation (CPHEEO) for water supply, sewerage, and solid waste management. It is also essential to comply with per capita norms for suburbs, ensuring adequate health, educational amenities, and open spaces. Additionally, redevelopment must strictly follow Coastal Regulation Zone (CRZ) norms, including setbacks and protection of mangroves for slums along the coast or the Mithi River.

Government assistance in the form of low-interest loans should be provided to support self-redevelopment initiatives. A participatory development model, such as a Slum Land Trust, is vital for sustainable redevelopment. This model should include a committee comprising representatives from urban local bodies (ULB), ward officials, technical experts, relevant state

and central organizations, and both owners and tenants.

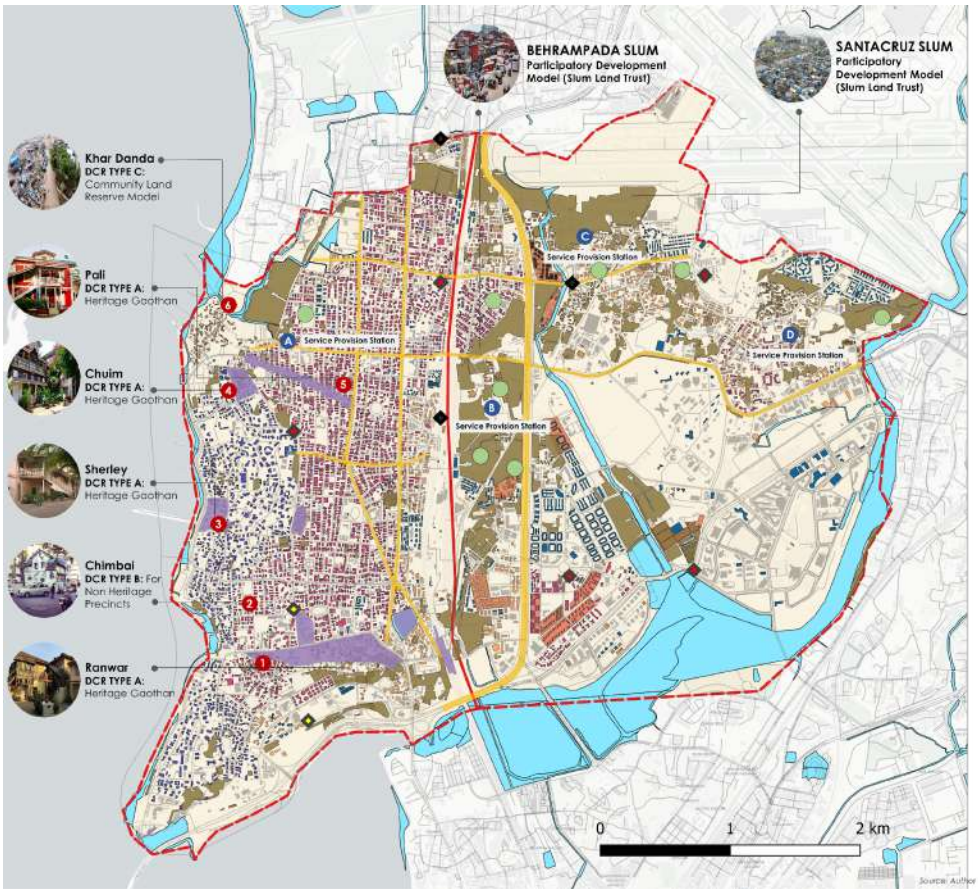


**Figure 15.** All recommendations at the study area level (Authors)

### *5.4 Area Level Recommendations*

- Strict adherence to CPHEEO standards for water supply, sewage, solid waste management, and drainage in slums is essential. This ensures equitable infrastructure development and environmental protection, leading to healthier lifestyles. Similarly, following city-wide benchmarks and providing subsidies for social infrastructure improvements can enhance opportunities, driving economic growth and upward social mobility.
- To improve service delivery in slums, establish service provision stations for ambulances and fire engines, and increase funding for road infrastructure. Addressing the under utilisation of UPHCs requires implementing a referral system to manage specialities and patient footfalls more effectively. For example, UPHCs near HIG-I and HIG-II housing can focus on geriatric specialities. At the same time, those near slums can be enhanced to handle higher footfalls and specialised maternal and child healthcare, including regular health drives. These measures will optimise the government healthcare system.
- Finally, to address the lack of open spaces, declutter existing ones, and provide additional areas such as playgrounds and gardens.

Figure 15 depicts all the interventions in the study area in terms of housing, education, health, open spaces, transportation, environment, and physical infrastructure, providing a holistic picture of development in a way that it bridges the socio-spatial disparities in the study area.

The recommendations complement one another and work in tandem towards a more inclusive and equitable development.

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# Gender Inclusivity in Kochi's Tourism Sector:
## Challenges, Opportunities, and Strategic Recommendations

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**Abstract:** The evolution of travel from a survival necessity to a vital component of human freedom has led to the global expansion of the tourism industry. This growth necessitates the industry's adaptation to societal challenges, particularly those related to inclusivity and diversity. Gender-inclusive planning is crucial for ensuring that tourism experiences and opportunities are accessible to all, regardless of age, gender identity, or disability status. The study mainly focuses on Kochi, a prime tourist destination in Kerala. The tourism industry in Kerala makes a significant contribution significantly to the state's economy. Kochi is a popular tourist destination; despite its popularity, concerns have been raised about the gender inclusivity of Kochi as a tourist destination. The research employed both primary and secondary methods to assess the gender diversity rate within in the tourism industry in Kochi, specifically in areas such as employment, entrepreneurship, community participation, education, and leadership. The study also evaluated the effectiveness of Kerala's tourism policies with in relation to international best practices. The key findings reveal that significant gender disparities exist across the tourism industry, particularly in leadership and employment. The study emphasizes the importance of developing comprehensive strategies to promote gender inclusivity within the tourism industry, including flexible work arrangements, enhanced safety measures, and targeted skill development. By industry addressing the gaps, Kochi's tourism industry can evolve into a more equitable and sustainable one, promoting greater representation and empowerment of women in all aspects of tourism. Based on the results, the same predictive analysis can be applied to any tourism industry across India. This approach has the potential to significantly strengthen the tourism sector, aligning with Sustainable Development Goals 5 (Gender Equality) and 8 (Decent Work and Economic Growth), driving the tourism industry towards its ultimate growth and development.

**Keywords:** Gender, Inclusivity, Tourism Industry, Tourists

**सार:** यात्रा के जीवनयापन की आवश्यकता से लेकर मानवीय स्वतंत्रता के एक महत्वपूर्ण घटक तक के विकास ने पर्यटन उद्योग के वैश्विक विस्तार को जन्म दिया है। इस वृद्धि के लिए उद्योग का सामाजिक चुनौतियों, विशेष रूप से समावेशिता और विविधता से संबंधित चुनौतियों के अनुकूल होना आवश्यक है। यह सुनिश्चित करने के लिए कि पर्यटन के अनुभव और अवसर सभी के लिए सुलभ हों, चाहे उनकी आयु, लैंगिक पहचान या विकलांगता की स्थिति कुछ भी हो, लैंगिक-समावेशी नियोजन अत्यंत महत्वपूर्ण है। यह अध्ययन मुख्य रूप से केरल के एक प्रमुख पर्यटन स्थल कोच्चि पर केंद्रित है। केरल का पर्यटन उद्योग राज्य की अर्थव्यवस्था में महत्वपूर्ण योगदान देता है। कोच्चि एक लोकप्रिय पर्यटन स्थल है; इसकी लोकप्रियता के बावजूद, एक पर्यटन स्थल के रूप में कोच्चि की लैंगिक समावेशिता को लेकर चिंताएँ व्यक्त की गई हैं। इस शोध में कोच्चि के पर्यटन उद्योग में, विशेष रूप से रोजगार, उद्यमिता, सामुदायिक भागीदारी, शिक्षा और नेतृत्व जैसे क्षेत्रों में, लैंगिक विविधता दर का आकलन करने के लिए प्राथमिक और द्वितीयक, दोनों विधियों का उपयोग किया गया। अध्ययन में अंतर्राष्ट्रीय सर्वोत्तम प्रथाओं के संदर्भ में केरल की पर्यटन नीतियों की प्रभावशीलता का भी मूल्यांकन किया गया। प्रमुख निष्कर्ष बताते हैं कि पर्यटन उद्योग में, विशेष रूप से नेतृत्व और रोजगार के क्षेत्र में, लैंगिक असमानताएँ महत्वपूर्ण हैं। यह अध्ययन पर्यटन उद्योग में लैंगिक समावेशिता को बढ़ावा देने के लिए व्यापक रणनीतियाँ विकसित करने के महत्व पर ज़ोर देता है, जिसमें लचीली कार्य व्यवस्थाएँ, बेहतर सुरक्षा उपाय और लक्षित कौशल विकास शामिल हैं। उद्योग द्वारा इन कमियों को दूर करके, कोच्चि का पर्यटन उद्योग अधिक समतामूलक और टिकाऊ बन सकता है, जिससे पर्यटन के सभी पहलुओं में महिलाओं का अधिक प्रतिनिधित्व और सशक्तिकरण हो सके। परिणामों के आधार पर, यही पूर्वानुमानात्मक विश्लेषण पूरे भारत में किसी भी पर्यटन उद्योग पर लागू किया जा सकता है। इस दृष्टिकोण में पर्यटन क्षेत्र को महत्वपूर्ण रूप से मज़बूत करने की क्षमता है, जो सतत विकास लक्ष्य 5 (लैंगिक समानता) और 8 (सभ्य कार्य और आर्थिक विकास) के साथ संरेखित होकर पर्यटन उद्योग को उसके अंतिम विकास और प्रगति की ओर अग्रसर करेगा।

**मुख्य शब्द:** लिंग, समावेशिता, पर्यटन उद्योग, पर्यटक

## 1. Introduction

Travel has always been a fundamental aspect of human life, with its origins rooted in the search for food, better living conditions, and survival. As societies evolved, so did the reasons for travel. People ventured to distant lands in search of education, work, adventure, and cultural exploration. Today, travel is not just a means of survival or discovery but an essential part of our freedom and quality of life, leading to the rapid growth of the global tourism industry. Tourism is a complex social, cultural, and economic phenomenon. It involves the movement of people beyond their usual environments for personal or professional purposes. According to the World Tourism Organization, these travellers – whether tourists or excursionists engage in activities that often contribute significantly to local economies through tourism expenditure (UNWTO). However, as the tourism industry expands, it could also evolve to address broader societal

issues, including inclusivity. Inclusivity, in its broadest sense, refers to ensuring that all individuals, regardless of their gender, background, or identity are treated fairly and equally according Cambridge dictionary. Gender-inclusive planning is crucial in the context of tourism. Gender inclusive planning involves designing and implementing policies and programs that actively consider gender as a key factor. It ensures that tourism experiences, opportunities, and benefits are accessible to everyone. The evolution of travel, the economic impact of tourism, and the need for inclusivity are interconnected. It becomes clear that gender-inclusive planning is not just a social responsibility but also a necessary step towards creating a more sustainable and equitable tourism industry.[1]

Gender-inclusive planning encompasses several essential components, including accessible and affordable infrastructure, women's participation in decision-making, thoughtful technology choices and pricing options, secure land and property ownership, employment opportunities in formal and informal labour markets, a clean environment, and safety for all citizens.[2]

In tourism, gender-inclusive planning focuses on both the industry and the tourist experience, recognizing the sector's potential to empower women and gender-diverse groups through employment and leadership roles. Given that tourism has one of the highest shares of women employees and entrepreneurs, it can serve as a powerful tool for fostering gender equity. Furthermore, gender inclusivity in tourism is vital as it creates economic opportunities for all, supports self-expression and personal growth, and caters to the diverse needs of travellers, regardless of gender, caste, age, or religion. By prioritizing inclusivity, the tourism sector can offer a more equitable and enriching experience for both workers and tourists[3].

In 2024, India's travel and tourism sector contributed approximately 9.1 percent to the nation's GDP, amounting to over 11.10 trillion U.S. dollars, reflecting a significant 12.1 percent increase from the previous year[4]. The Travel and Tourism Development Index (TTDI) 2024, published by the World Economic Forum (WEF), ranked India 39$^{th}$ among 119 countries, a notable improvement from its adjusted 38th place ranking in 2021. The TTDI report highlighted India's progress in areas such as the prioritizing of travel and tourism, safety and security, and health and hygiene. According to the UNWTO barometer for May 2024, global international tourist arrivals reached 975 million in 2022, with India recording 14.3 million, representing 1.47 percent of the international inbound tourism market share. In the Asia-Pacific region, India's share was 15.66 percent. In terms of Foreign Tourist Arrivals (FTAs) in 2022, 57.99 percent were male, 42 percent female, and 0.01 percent identified as third-gender, showing a slight shift from the male-female ratio of 59.7 percent to 40.3 percent in 2021.

Kerala, a state that has garnered significant international recognition as a prime tourist destination, serves as the focal point of this study due to its vital contribution to the state's economy, accounting for 10% of GDP and 23.5% of total employment. Kochi, in particular, stands out as a world-class tourist destination, attracting millions of both domestic and international visitors[5]. It has earned multiple accolades, such as being the first Indian city to join the World Tourism Cities Federation (WTCF) Council and being listed by Lonely Planet as one of the top cities to visit worldwide. In recent years, Kerala has been featured by CNN Travel as one of the '19 best places to visit in 2019,' selected by The New York Times as one of the 52 must-see destinations globally in 2023, and described by Travel and Leisure as 'One of the 100 great trips for the 21$^{st}$ century.' Time magazine further highlighted Kerala in 2022 as one of the 50 'extraordinary destinations' worldwide. Kerala is ranked ninth in the 'World's Greatest Places' to visit and is praised as an 'eco-tourism hot spot'. Most recently, in November 2023, Conde' Nast Traveler rated Kochi as one of the best places to visit in Asia in 2024.

Despite these accolades, concerns persist about whether Kochi adequately meets the needs of all tourists, particularly regarding age and gender inclusivity, underscoring the need for focused research on gender inclusivity within Kochi's tourism sector (Figure 1).

[1] European Institute for Gender Equality

[2] Gender-Inclusive Approaches in Urban Development, Asian Development bank

[3] World Tourism Organization a United Nations Specialized Agency (UNWTO)

[4] Statista Research Department, Jul 9, 2024

[5] District wise tourist arrival 2019


**Figure 1.** Newspaper clippings highlighting the lack of infrastructure and inclusive measures in Kochi for both residents and tourists Source: Media

This study examines gender inclusivity in Kochi's tourism industry employing a comprehensive and multifaceted methodology that combines primary and secondary research methods. Primary research involves conducting gender-disaggregated surveys among various stakeholders, including tourists, tourism workers, business owners, and local community members, to explore employment experiences, entrepreneurship opportunities, safety concerns, and overall experiences within the tourism sector. Secondary data collection focuses on gathering information about Kochi's land use, connectivity, demographics, population density, education levels, literacy rates, workforce participation, and crime data specific to the tourism industry. The study also evaluates gender diversity in employment, leadership, and entrepreneurship within the tourism sector, conducts policy analysis by comparing Kerala's tourism policies with international standards and Indian national guidelines, and assesses city-level issues such as stakeholder involvement and infrastructure gaps. While this methodology offers a detailed understanding of gender inclusivity in Kochi's tourism industry, it is limited by its exclusive focus on the tourism sector. This factor that should be taken into account when interpreting the results and formulating recommendations.

## 2. Overview of Kochi: Demography, Land Use, and Connectivity

As of 2024, Kochi City has a population of approximately 670,000 residents. It is characterized by a diverse demographic profile comprising a mix of various ethnicities, ages, and socioeconomic backgrounds, which contributes to its vibrant cultural and economic landscape. Kochi, a major urban agglomeration in Kerala, is renowned for its vibrant tourism sector, with Fort Kochi being one of the state's most popular destinations. Although there are no specific tourist circuits within Kochi itself, the city is linked to several regional tourism circuits that span the Ernakulam district and neighboring areas. These include the Perumbavoor Tourism Circuit, the Kalady-Malayattoor-Athirappally-Chalakudy-Mala-Azhikode Circuit, the Thrissur-Ernakulam Nature Tourism Circuit, a Spiritual Circuit covering 133 religious sites across 14 districts, and the Puthuvype-Munambam Beach Corridor[6].

Kochi's transportation infrastructure is diverse, featuring connectivity by air, road, rail, metro, and water (Figure 2). Cochin International Airport (CIAL), located 28 km north in Nedumbassery, is the largest and busiest airport in Kerala. The city benefits from extensive road connectivity via National and State Highways, which positions it as a key node in the North-South Corridor of the National Highway system. Rail transport is facilitated by Ernakulam Junction and Ernakulam Town stations, with additional connections through Cochin Harbor Terminus. The Kochi Metro Rail system enhances intra-city travel, with Phase 1 featuring 21 stations, including 12 within the city limits. Expansion plans are also in place. Water transport is supported by multiple passenger boat jetties and the Water Metro project, which aims to connect 10 islands across 78 km with 38 jetties.

In terms of land use, Kochi Corporation is predominantly residential comprising 36.53% of the land. Commercial uses account for 4.35%, while industrial uses cover 1.35%. Heritage and religious sites constitute 1.07% of the total land use. Despite these robust transportation options, there is a lack of integration among different transport modes, which can complicate navigation for tourists[7].

[6] Tourism Department

[7] Master plan for Kochi Municipal Corporation Area-2040

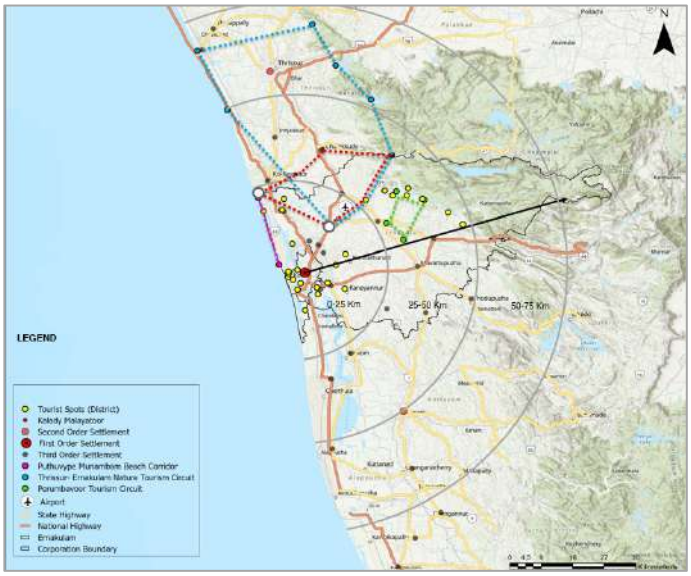


**Figure 2.** Regional Setting of Kochi City and Ernakulam District Tourism Map
Source: Tourism Department

## 3. Status of Gender Inclusivity in Kochi's Tourism Industry Sector

The gender-based tourism industry is grounded in four key principles: Awareness, Equity, Empowerment, and Representation. To assess gender inclusivity in Kochi's tourism sector, this study focuses on five key indicators: entrepreneurship, participation in community and civil society, employment, education and training, and leadership and decision-making. The evaluation encompasses an analysis of gender diversity in employment, leadership, and entrepreneurship within the tourism sector, as well as a policy review that compares Kerala's tourism policies with international standards and national guidelines in India. Additionally, the study examines city-level issues, including stakeholder involvement and infrastructure gaps, to provide a comprehensive understanding of the current status of gender inclusivity in Kochi's tourism industry.


**Figure 3.** Empowering Women in Kochi's Tourism Sector
Source: Author

**A.** Entrepreneurship: Gender-sensitive policies and frameworks are vital for empowering women in Kochi's tourism sector (Figure 3). Policies from 1988 to 2023 show progress in supporting women entrepreneurs, though with mixed outcomes. The ASHA Scheme, despite achieving a 67% gender diversity rate, struggled with awareness and access issues, whereas the Entrepreneur Support Scheme saw moderate success with 57% female participation [8]. Women are well-represented in industries such as food and beverages but remain underrepresented in male-dominated fields like photography and construction, highlighting ongoing challenges in accessing technology and expanding businesses.

[8] Industries Department, Ernakulam

**B.** Participating in Community and Civil Society: Community-based programs, such as Kudumbashree have been crucial in empowering women in Kochi through training, loans, and business support; however, gaps persist in tribal and coastal areas. Initiatives such as the Snehitha Calling Bell Weekly Celebration and the Sthreepaksha Navakeralam campaign have seen high female participation, contributing to both economic and psychological empowerment. However, broader outreach is needed to include underrepresented groups. Gender diversity in these programs is substantial, with Snehitha Calling Bell and DDU GKY classes achieving diversity rates of 66% and 61%, respectively, demonstrating effective gender inclusion in community engagement[9].

**C.** Employment: Kochi's tourism sector shows significant gender disparities in employment, with women notably underrepresented in various areas (Figure 4). Male dominance is evident in transport services, such as taxis and auto-rickshaws, while female participation remains minimal[10]. The Kochi Metro Rail Limited (KMRL) is an exception, with an 80% female workforce, in stark contrast to sectors like KSRTC, where women's participation is much lower [11] . Women are also underrepresented as hosts in accommodation, mainly due to societal and safety concerns. While KMRL shows good gender diversity, with an 80% diversity rate, other sectors, such as auto drivers, Tour Operators, and Women Bartenders have poor representation, with some having 0% diversity, highlighting the need for greater efforts to achieve gender parity in tourism employment [12].

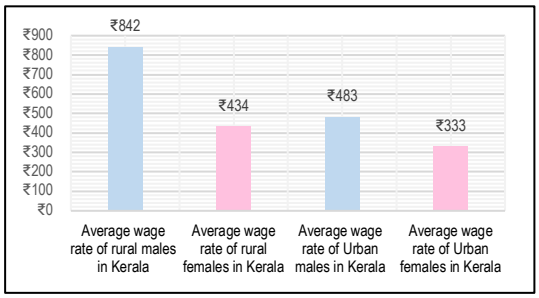


**Figure 4.** Gender Pay Gap in Kerala 2023 (Author)

**D.** Education and Training: Kerala's tourism sector benefits from strong educational institutions, such as the Kerala Institute of Tourism and Travel Studies (KITTS) and Food Craft Institutes (FCIs), which offer specialized training and skill development. However, programs like the Yuve Weave Training Scheme reveal a significant gender imbalance, with predominantly female participants. This trend of high female enrollment underscores the need to address gender imbalances in training and promote diverse representation in skill development programs, thereby forstering a more inclusive tourism workforce (Figure 5). While training and education opportunities are available, the ownership distribution index in industries based on the PMEGP Scheme shows moderate gender diversity at 48%, indicating some female ownership but also highlighting a gap in translating these skills into ownership roles, leaving room for more balanced distribution.

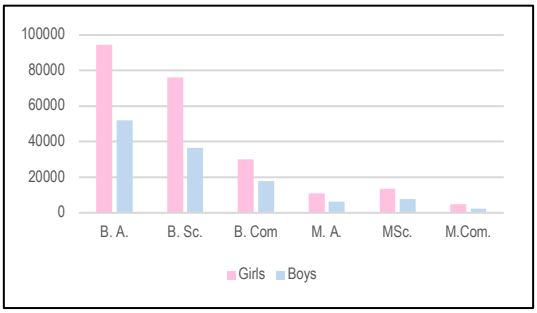


**Figure 5.** Enrollment of students in Arts and Science Colleges in Numbers
Source: Directorate of Collegiate Education

**E.** Leadership, Policy, and Decision-Making: Gender representation in leadership roles within Kochi's tourism sector is significantly low. Historical data reveal that no women have held ministerial positions related to tourism in Kerala over the past 50 years[13]. Current representation is minimal, with women comprising only 17% of the Kerala Tourism Infrastructure Limited Board and just 4% in the Association of Approved and Classified Hotels of Kerala [14] . This stark underrepresentation underscores systemic barriers and gender discrimination, emphasizing the need for policies that promote greater female leadership and decision-making in the sector [15] . The Association of Approved and Classified

[9] Kudumbashree, Ernakulam
[10] Census, 2011
[11] DTPC Ernakulam
[12] Gender-Sensitive Reforms in Public Transport, A Case of Kerala, 2021
[13] Information and Public Relations Department
[14] Website of Kerala Tourism Infrastructure Limited
[15] Website of Travel Operators Association Kerala

Hotels of Kerala has 4% representation of women in its committee members (2021-2022)[16]. Gender diversity in leadership roles remains poor, with only 16% of women on the KTIL Board of Directors and 9% on the Kerala Travel Mart Society's Managing Committee, indicating substantial gender disparity in decision-making positions (Table 1 and Figure 6).

The analysis reveals significant disparities in gender diversity across Kerala's tourism and related sectors. While specific entrepreneurship schemes and community engagement programs show promising gender diversity, leadership representation remains notably low, with women severely underrepresented in key decision-making roles. Employment representation is highly variable, ranging from complete absence in some subsectors to near-total female participation in others, highlighting an inconsistent approach to gender inclusivity across the industry.

**Table 1.** Gender Diversity Rates Across Various Sectors in Kerala's Tourism and Related Industries

| | | | | GENDER DIVERSITY RATE (Out of 100) | | |
|---|---|---|---|---|---|---|
| | | | | Percentage | Gender Component | Gradation as per range |
| Entrepreneurship | Entrepreneurship Equality Index | Schemes supporting Entrepreneurs | Entrepreneurship Support Scheme | 57% | | Moderate |
| | | | Assistance Scheme for Handicrafts Artisans (ASHA) | 67% | | Good |
| Leadership, Policy, and Decision-Making | Leadership Representation Index | Organisations under the Government of Kerala | Board of Directors (KTIL) | 16% | | Poor |
| | | | Managing Committee - Kerala Travel Mart Society | 9% | | Poor |
| Employment | Representation Index | Travel and Transportation | Auto Drivers | 0% | | Poor |
| | | | KSRTC Employees | 7% | | Poor |
| | | | KMRL Employees | 80% | | Good |
| | | Accommodation and Food Services | Homestays | 21% | | Poor |
| | | Handloom Weavers | Employees of Paravoor Cooperative Society | 98% | | Good |
| | | Tour Operators | Tour Operators in Kochi | 0% | | Poor |
| | | Tour Guides | Tour Guides in Kochi | 5% | | Poor |
| | | Safety and Security | Women Police Personnel | 6% | | Poor |
| | | Hospitality Industry | Women Bartenders | 0% | | Poor |
| Community Engagement | Community Engagement Index | Gender Programs by Kudumbashree | Snehitha Calling Bell Weekly celebration | 66% | | Good |
| | | | Class for DDU GKY beneficiaries | 61% | | Good |
| Economic participation | Ownership Distribution Index | Industries | Based on the PMEGP Scheme | 48% | | Moderate |

*Index:*

| | *Female* | | *Male* | | *Good (>66%)* | | *Moderate (34 -66%)* | | *Poor (<33%)* |
|---|---|---|---|---|---|---|---|---|---|

Source: By Author

[16] Website of Association of Approved and Classified hotels of Kerala

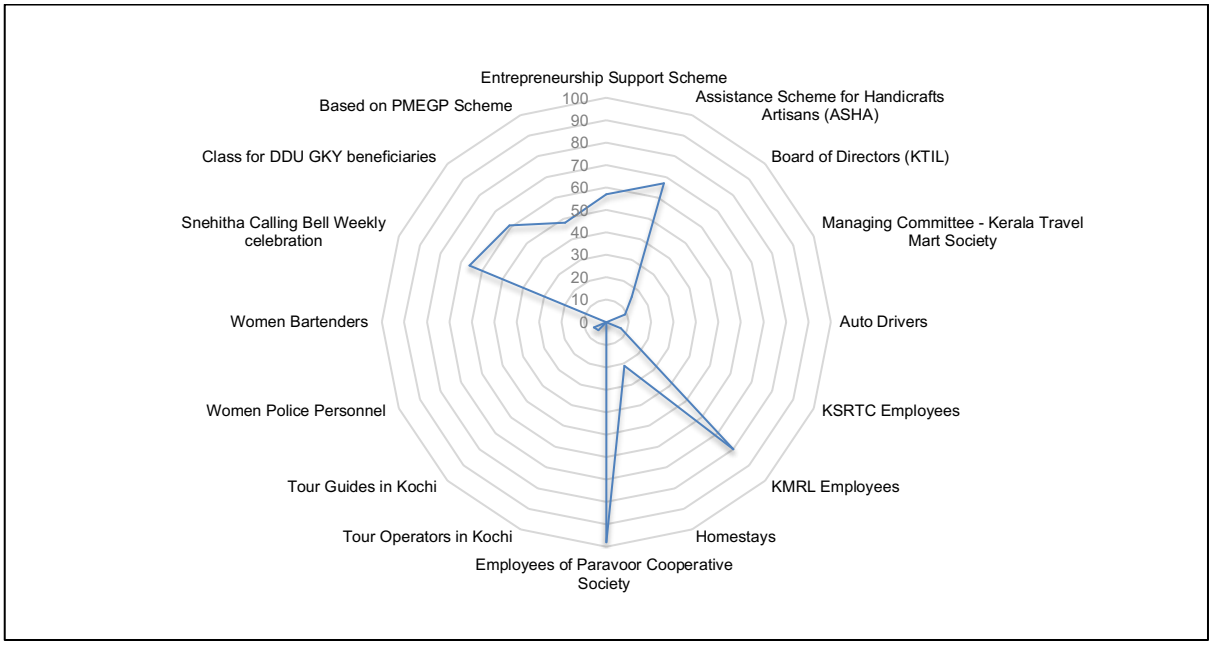


**Figure 6.** Women in the Tourism Industry in Kochi – Current Scenario
Source: Author

## 4. Case Studies: Best Practices in the Tourism Industry

The international and Indian case studies analyzed reveal a variety of strategies and initiatives aimed at promoting gender equality and empowering women in the tourism sector (Table 2). Each case study highlights different aspects of gender empowerment, including leadership and decision-making, entrepreneurship, education, and community engagement. The initiatives range from comprehensive policy frameworks to localized community-driven efforts. It reflects the diverse approaches required to tackle gender disparities in different contexts.

I. Leadership and Decision-Making

- Leadership Task Force for Women's Empowerment in African Tourism focuses on integrating gender issues into African tourism strategies, improving career opportunities for women in the sector, and promoting female role models.
- Peak DMC, India, has implemented a robust mentoring system, a zero-tolerance policy on sexual misconduct, and flexible scheduling, resulting in a significant increase in female tour leaders in the tourism sector.

II. Entrepreneurship

- Ride 4 a Woman, Uganda, is an NGO that empowers local women through skills development and income-generating activities, including sewing, basket weaving, and homestays. Despite several challenges, it has made significant strides in boosting women's economic independence.
- The European Union has Policies, including the European Union's Small Business Act and the Entrepreneurship 2020 Action Plan, which focus on improving access to finance for women, promoting work-life balance, expanding entrepreneurial networks, and supporting women-led enterprises in the tourism sector.

III. Education and Training

- Gender Equality in Tourism Plan, Valencia, Spain, is an innovative training program for public sector tourism workers that integrates gender perspectives into tourism policy. It exemplifies a collaborative approach to gender equality in tourism.

IV. Community Engagement

- Ride 4 a Woman, Uganda, is an NGO that focuses on community development beyond entrepreneurship by addressing gender-based violence and providing microloans, despite facing resistance from some community members.

These best practices demonstrate that fostering gender equality in the tourism industry requires a multifaceted approach. Effective leadership, access to education and training, supportive policies, and community engagement are all crucial components. However, there are challenges at times, such as resistance within communities, gender imbalances in specific sectors and the need for more inclusive outreach, which must be addressed to achieve true gender parity. The above matrix highlights successful strategies that can be adapted and implemented in other contexts to promote gender inclusivity and empowerment in the tourism industry.

**Table 2.** International and National Best Practices

| Aspect | Best Practice | Key Elements | Impact |
|---|---|---|---|
| Leadership & Decision-Making | Leadership Task Force for Women's Empowerment in African Tourism | Integration of<br>• gender issues,<br>• role models,<br>• career opportunities | • Promoted women's leadership in African tourism strategies<br>  |
| | Peak DMC, India | • Mentoring system,<br>• flexible scheduling,<br>• zero-tolerance policy on harassment | • A 700% increase in female tour leaders, leading to an increase in female representation<br>  |
| Entrepreneurship | Ride 4 a Woman, Uganda | • Skills training,<br>• income-generating activities,<br>• micro-loans | • Empowered 300 women, improved economic independence<br>  |
| | EU Policies (Small Business Act, Entrepreneurship 2020 Action Plan) | • Access to finance,<br>• entrepreneurial networks,<br>• work-life balance | • Supported women-led enterprises, improved work-life balance<br>  |
| Education & Training | Gender Equality in Tourism Plan, Valencia | • Training for public sector workers,<br>• gender-focused curriculum | • Advanced gender equality in tourism, despite challenges with LGBT integration<br>  |
| Community Engagement | Ride 4 a Woman, Uganda | • Domestic violence shelter,<br>• gender-based violence training,<br>• cultural activities | • Enhanced women's self-confidence, addressed community-specific challenges<br>  |

Source: UNWTO Global Report on Women in Tourism (SECOND EDITION)

## 5. Key Strategies and Recommendations

Gender-inclusive planning in the tourism industry is important, as the increased representation of women in the industry not only promotes gender equality. Instead, it also contributes to a more diverse and empathetic workforce, enhancing the inclusivity and safety of tourist destinations and their various components. The conceptual framework (Figure

7) for a gender-inclusive tourism industry in Kochi is built on four key principles. They are Awareness, Equity, Empowerment, and Representation. The key strategies and recommendations to enhance women's participation and representation across various aspects of the tourism industry are listed below.

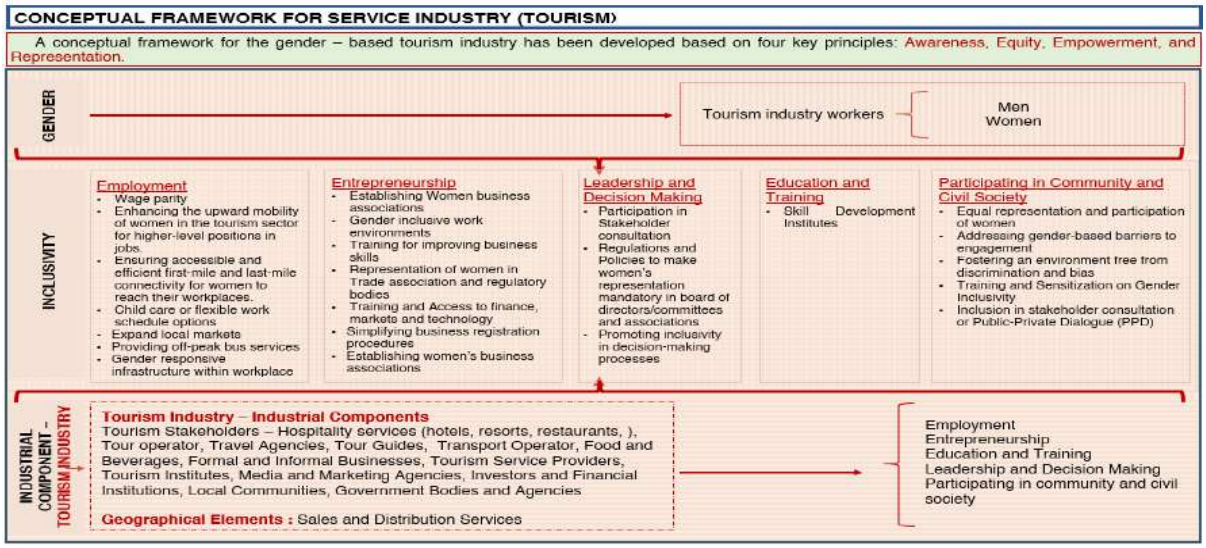


**Figure 7.** Conceptual framework for the service industry (Tourism)
Source: Author

**A.** Employment and Workplace Environment

- Flexible Work Arrangements can be achieved by implementing workplace flexibility to help women balance work and home responsibilities.
- To address sexual harassment, internal committees must be established to address the issue and conduct regular awareness programs to promote a safe working environment.
- To address the gender pay gap, enact policies to eliminate gender pay disparities, particularly in the casual labour sector.
- To achieve Skill Development for women in tourism, provide regular training programs to help women adapt to technological advancements and advance to higher employment levels.
- Safe Commuting can be implemented by improving transportation with last-mile connectivity and integrating of different modes to ensure safe commuting for women.
- Gender-Responsive Infrastructure at workplaces, including adequate sanitation facilities.
- Implement public safety measures such as street lighting, well-maintained footpaths, surveillance, and visible police presence.

**B.** Entrepreneurship

- Provide access to finance through credit, subsidies, loans, and financial incentives for women-owned tourism businesses.
- Focus on leadership qualities, soft skills, and networking to empower women entrepreneurs through capacity building and skill development.
- Develop purchase preference policies that favour women-led tourism enterprises and partner with e-commerce platforms to enhance marketing efforts.
- Raise awareness about entrepreneurship schemes and ensure their effective implementation through proper monitoring by relevant departments.

**C.** Community and Civil Society Participation

- Conduct education and awareness campaigns to challenge gender stereotypes and promote women's rights.
- Strengthen local government participation by mandating women's inclusion in decision-making processes and actively reaching out to marginalized women.
- Enhance economic empowerment through skill development programs, microfinance initiatives, and support for tourism-related businesses.
- Partner with existing women's groups and NGOs to extend outreach efforts and establish regular monitoring and feedback mechanisms.

**D.** Leadership and Decision-Making

- Actively increase the number of women in tourism boards, associations, and ministerial positions through targeted recruitment and mentorship programs.
- Implement initiatives to develop women's managerial and technical skills, leadership abilities, and confidence.

- Establish and enforce policies that promote equal opportunities for women in leadership and decision-making roles.
- Challenge and change prevailing gender norms and stereotypes through awareness campaigns and cultural sensitivity training.
- Launch initiatives to encourage women to pursue technical and higher-paying roles within the sector, supported by scholarships and targeted skills development programs.
- Regularly monitor and report on gender diversity in leadership positions and hold organizations accountable for failing to make progress.

**E.** Education and Training

- Offer training in diverse tourism sectors beyond traditional roles, incorporating technology skills, and developing soft skills and networking abilities.
- Facilitate job placement and support entrepreneurship initiatives for women post-training through partnerships with tourism businesses and mentorship programs.
- Ensure the training programs cover a wide range of topics, including hospitality management, eco-tourism, adventure tourism, and cultural tourism, with a focus on using digital tools and platforms relevant to the industry.

Proposed Scenario for Women in Tourism in Kochi

Implementing the above strategies will create a more inclusive and supportive environment for women in Kochi's tourism industry, leading to enhanced representation across various sectors, including employment, entrepreneurship, community participation, leadership, and education (Figure 8). The ultimate goal is to foster a tourism industry where women are equally represented, empowered, and actively contributing to the growth and development

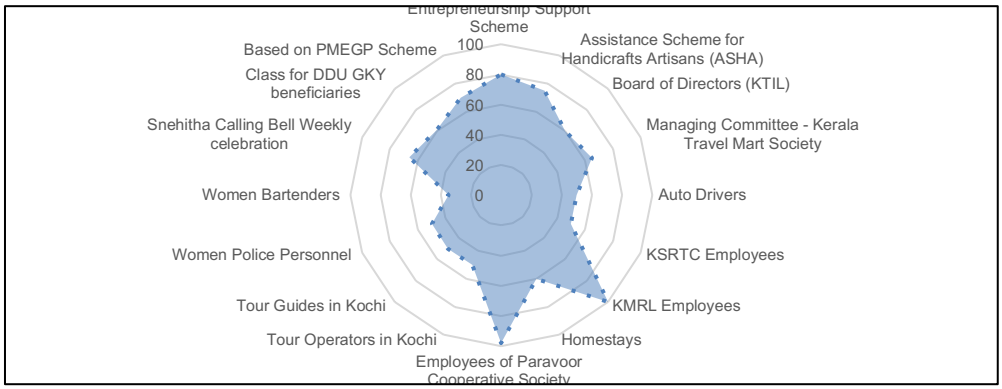


**Figure 8.** Women in the Tourism industry in Kochi - Proposed Scenario (Source: Author)

## 6. Conclusion

This study on gender inclusivity in Kochi's tourism sector reveals significant disparities while also highlighting key opportunities to enhance women's participation across various dimensions of the industry. Although specific initiatives, like the Entrepreneur Support Scheme, show commendable female engagement, others, such as the ASHA Scheme, expose alarming levels of underrepresentation. This inconsistency highlights the passing need to enhance awareness, accessibility, and the effective implementation of entrepreneurship support programs designed specifically for women. The employment landscape within Kochi's tourism sector reveals stark gender gaps, particularly in transportation services, where no female-registered taxis or autos currently operate. Conversely, the Kochi Metro Rail Limited sets a positive example of gender-inclusive practices, boasting an 80% female workforce. The absence of women in leadership roles, particularly the lack of female tourism ministers in Kerala, over the past 50 years, further underscores the critical need for policy reforms aimed at promoting gender equity in decision-making positions. Despite high female enrolment rates in tourism-related educational programs, this progress has not translated into proportional representation within the industry, especially in leadership roles. Additionally, persistent safety concerns, as indicated by stagnant crime rates against women in Kochi over the past decade, call for a reassessment of existing safety initiatives.

To address these challenges, comprehensive policy reforms are essential. Revising existing regulations to explicitly promote gender inclusivity and establishing measurable targets for women's participation in leadership and entrepreneurship are crucial step in achieving this goal. Developing targeted support programs to

empower women in underrepresented sectors, particularly in transportation and tour operations, is equally important. Enhancing safety measures, such as increasing Pink Police patrols and improving safety apps, is vital for ensuring a secure environment for women. Bridging the gap between education and employment through targeted skills training and mentorship programs will facilitate women's entry into the tourism sector. Cultural change initiatives aimed at challenging gender stereotypes are necessary to foster acceptance of women in non-traditional roles. Establishing robust monitoring and evaluation systems will ensure accountability and continuous improvement of gender inclusivity initiatives. Ultimately, facilitating collaborative partnerships among government bodies, private sector entities, and community organizations will create a supportive environment for women's participation in tourism. Addressing these multifaceted issues will enable Kochi to progress towards a more equitable, safe, and inclusive tourism industry. This gender-inclusive approach enhances the overall quality and appeal of Kochi's tourism offerings, positioning the region as a model for sustainable and equitable tourism development that aligns with global best practices and the broader goals of gender equality and economic empowerment.

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# The Shift in Women's Mobility Patterns Post the Launch of Gender-targeted Schemes in Delhi Buses

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**Abstract:** Women's mobility needs are different from those of men; this has been proven in a lot of studies. It is a well-established fact that many researchers have found that there are differences in the travel patterns of men and women. However, the differences in the results vary with the research papers and with the area where the research is conducted. According to a study conducted by the World Bank in 2020, women combine multiple destinations within one trip and are more dependent on public transport. The paper tries to understand the impact of the gender-targeted public transport schemes on women's mobility patterns. The travel patterns have been observed with respect to women's demographic and socio-economic characteristics. Women's travel patterns were observed to have shifted post the implementation of gender-targeted public transport schemes in Delhi buses. The study was conducted in the context of the Delhi buses, and surveys were conducted along two selected bus routes to find out the shifts in the travel patterns of women commuters of Delhi buses. There has been a 33 percent rise in the female ridership since the launch of the Pink slip scheme in 2019.

**Keywords**: mobility patterns, gender-targeted public transport schemes, travel patterns pre- and post-schemes, shift in travel characteristics

**सार:** महिलाओं की गतिशीलता की ज़रूरतें पुरुषों से अलग हैं; यह कई अध्ययनों में साबित हुआ है। यह एक अच्छी तरह से स्थापित तथ्य है कि कई शोधकर्ताओं ने पाया है कि पुरुषों और महिलाओं के यात्रा स्वरूप में अंतर हैं। हालाँकि, परिणामों में अंतर शोध पत्रों और उस क्षेत्र के साथ भिन्न होता है जहाँ शोध किया जाता है। विश्व बैंक द्वारा 2020 में किए गए एक अध्ययन के अनुसार, महिलाएं एक यात्रा में कई गंतव्यों को जोड़ती हैं और सार्वजनिक परिवहन पर अधिक निर्भर होती हैं। यह शोध पत्र महिलाओं की गतिशीलता स्वरूप पर लिंग-लक्षित सार्वजनिक परिवहन योजनाओं के प्रभाव को समझने का प्रयास करता है। महिलाओं की जनसांख्यिकीय और सामाजिक-आर्थिक विशेषताओं के संबंध में यात्रा स्वरूप देखे गए हैं। दिल्ली की बसों में लिंग-लक्षित सार्वजनिक परिवहन योजनाओं के कार्यान्वयन के बाद महिलाओं के यात्रा पैटर्न में बदलाव देखा गया। अध्ययन दिल्ली की बसों के संदर्भ में किया गया था, और दिल्ली की बसों की महिला यात्रियों की यात्रा स्वरूप में बदलाव का पता लगाने के लिए दो चयनित बस मार्गों पर सर्वेक्षण किए गए थे। 2019 में पिंक स्लिप योजना शुरू होने के बाद से महिला यात्रियों की संख्या में 33 प्रतिशत की बढ़ोतरी हुई है।

**मुख्य शब्द:** गतिशीलता प्रतिरूप, लिंग-लक्षित सार्वजनिक परिवहन योजनाएँ, योजना से पहले और बाद में यात्रा प्रतिरूप, यात्रा विशेषताओं में बदलाव

## 1. Introduction

It is a well-established fact that many researchers have found that there are differences in the travel patterns of men and women. However, the results on travel pattern differences vary across research papers and the areas where the research is conducted. According to a study conducted by the World Bank in 2020, there are differences in the travel patterns of men and women. Women combine multiple destinations within one trip (pick up children, shop, or other family obligations). Their travel becomes costlier due to the purchase of numerous single-fare tickets. Women are more dependent on public transport; 34 percent of women commuted to work by bus compared to 25 percent of men in Delhi (Alam and Dappe 2021). In India, women prefer travelling in the off-peak hours, and their travel is limited to a certain area. In Delhi's Sanjay Camp, 75 percent of women worked within a 5 km radius and 75 percent of men worked within a 12 km radius. Women are overrepresented as informal workers. Women are affected more when access to employment, education, or basic services is located away from their residences (Annette, 2018).

A study in Minneapolis, USA reveals that women tend to take trips with shorter travel distances and are more dependent on private vehicles than men. Further, when the trips were taken up for the purpose of household duties, the likelihood of a woman taking up the trip when compared to a man was found to be higher. Activities like escorting children from school or taking old parents to health care facilities affect women's mobility in a way where women leave out their leisure or fun activities in order to compensate for the 'extra time' they have to devote to the household responsibilities. Subsequently, women choose jobs and schools which are closer to their homes in order to reduce their travel time (Zhang and Song 2024).

A study conducted in Australia found that men tend to travel more frequently for business and work-related purposes compared to women. In contrast, women travel more often for leisure. Despite the differences in the frequencies for travel, women's trips were found to peak earlier than men's trips (Collins and Tisdell 2002).

A study in Andalusia, Spain claims that women perform more trips than men, regardless of the reason. The difference in the number of trips by gender is greater when the reason for the trip is related to household responsibilities. Men and women both travel greater distances due to work. Employed women travel considerably shorter distances to work than do men, even though they spend similar commute time. This suggests that the journey to work may reflect the magnitude of immobility that women face in their everyday lives (Sánchez et al. 2014).

## 2. Key Concepts in Women's Mobility

Apart from the differences in the mobility patterns of men and women, there are certain key concepts in women's mobility, which are concepts pertaining to women's travel patterns.

MOBILITY OF CARE: Care trips are often chained and shorter, and cover a smaller geographical area as compared to education or employment trips. Women are active participants in care trips. This was observed even in the primary survey conducted, which has been discussed further.

TIME POVERTY: Women often have to face a lack of time for leisure and rest after long hours spent at work, performing domestic tasks, and other activities. Women tend to use slower and less expensive modes of transport, especially when they are from lower-income backgrounds.

FORCED IMMOBILITY: Forced mobility occurs due to constraints in movement, which might be a consequence of insecurity in transport. Women often have to face forced immobility in which the perception of women's security, in public transport is a factor that influences their immobility.

FORCED MOBILITY: Functions that are taken for granted in some places are missing in others, leading to forced mobility in women. For example, inadequate access to water and sanitation in low-income communities forces women to travel in search of water irrespective of their wishes. (Thiberge and Brixi 2023)

## 3. Can Schemes Bring about a Shift in Travel Patterns?

Tallinn Estonia, Europe has a population of over 420,000 people. It is one of the first European capitals and the world's biggest city to provide free public transport services to all residents. After a year of its implementation, the scheme led to a rise in the PT usage by a total percentage of 14. Increased usage of public transport led to an increase in the market share of public transport by as high as 20 percent. More than 15 percent of respondents reported that the policy influenced both their travel choices and their destination. Average trip length for shopping and leisure purposes has increased, and the trend of travel to distant shopping centers has decreased, making local shopping centers the prevailing choice. PT satisfaction levels went up. The average satisfaction level improved to 3.35 from 3.20 post the scheme. The free rides and an increase in the supply of the services led to an increase in customer satisfaction. (Panjwani 2018)

## 4. Gender-Targeted Public Transport Schemes

Women often have to face many barriers in their mobility, as discussed in the previous sections. To reduce women's barriers to mobility, the government has launched gender-targeted public transport schemes.

As shown in Figure 1, the schemes were launched in the order of the Bus Marshal and universalization of the women helpline scheme in the year 2015, followed by the scheme for security of women in public road transport, and ultimately the Pink slip scheme being launched in the year 2019.


**Figure 1.** Timeline for launch of gender-targeted public transport schemes
(Source: The Indian Express, 2019)

BUS MARSHALS SCHEME: The bus marshals' scheme was launched in 2015. Civil defense volunteers and home guards were deployed in buses in Delhi. The scheme had to deploy 13,000 bus marshals. However, only 3,465 bus marshals were deputed.

UNIVERSALIZATION OF WOMEN HELPLINE SCHEME: The universalization of the women helpline scheme was launched in 2015. Under this scheme, a 24/7 helpline is available for women, and a telecom service number 181 is offered to the victims to reach out in case of any distress. The scheme also provides immediate assistance to women in distress and connects them with relevant services and authorities. (Aggarwal 2021)

SCHEME FOR SECURITY OF WOMEN IN PUBLIC ROAD TRANSPORT: The scheme for security of women in public road transport under the Nirbhaya Fund. In the first phase, 32 cities of 13 states with a population of 1 million or more were covered. The scheme includes provisions for vehicular location devices, as well as the installation of one or more panic buttons in public transport vehicles.

PINK SLIP SCHEME: The DTC (Delhi Transport Corporation) and cluster buses offer free rides to the women riders under the scheme. Operators are reimbursed based on the number of pink tickets issued. The reimbursement is done for an amount of INR 10 per ticket by the Delhi Government. The scheme was launched in September 2019 and implemented from October 29th, 2019. Some key shifts were observed post the launch of the scheme. 4.77 lakh female commuters of DTC buses availed of the benefits on the day of the launch of the scheme. On the day of implementation of the scheme, 3.2 lakh female commuters were issued pink tickets in the morning shift of 8 hours.

Following the launch of the Pink slip scheme in Delhi, several states also introduced of similar schemes offering women free bus rides. The scheme was launched in Punjab on 1st April, 2021 and in Tamil Nadu on 7th May, 2021 (Telangana Nava Nirmana Sena 2023).

## 5. Case Study Profile and Survey Design

Primary surveys were conducted across two bus routes in the city of Delhi. One of the routes is operated by DTC, while DIMTS operates the other route. The criteria for route selection were deployment of women bus employees along the routes, bus routes passing through industrial, low- and high-income areas, as well as different bus operators.

The data collected under this survey were the women users' perception of theirjourney and behavior patterns. The total daily female ridership in Delhi buses is 23.5 lakhs, according to an article by Hindustan Times in 2022. Taking a confidence level of 90 percent and a margin of error of 5 percent, the total sample size comes to around 270 women users-formula for sample size calculations (Source: Ase 1999).

$$\frac{z2 * p(1-p)] / e2}{1 + [z^2 * p(1-p)] / e^2 * N}$$

where z = z score calculated according to the confidence level
p = standard deviation
e = margin of error
N = population size

ROUTE 1 – 623: The first route ranges from Shahdara Terminal to Vasant Vihar and has a route length of 29km. There are 65 bus stops along the bus route, and the bus operator is DTC. The total number of samples collected was 160, with 68 on-board samples.

ROUTE 2 – 543: The second route ranges from Anand Vihar to Safdarjung Terminal and has a route length of 20km. There are 29 bus stops along the bus route, and the bus operator is DIMTS. The total number of samples collected was 110 with 42 on-board samples.

The data collected was regarding the travel patterns of 30 women users.

The data collected was regarding the boarding and deboarding count of women to check with the female ridership data collected. The sample was collected for two days.

Office visits were made to the DTC and DIMTS offices to collect data on ridership, bus routes, and fleet size. Furthermore, data regarding the ratio of male to female employees in the bus and the installation of safety equipment was also collected. The data collected was further cross-checked by conducting a safety equipment and behavioural survey.

## 6. Analysis

Data was collected from both the operators' offices, namely DTC and DIMTS. The offices shared the details about the buses' fleet size, bus

routes, and ridership data. The supply side characteristics include fleet size and operations on bus routes, while the demand side characteristics include ridership of Delhi buses.

The total fleet size is owned by two major owners, namely DTC and DIMTS. DTC owns fifty-four percent of the buses in operation, while only 46 percent of the buses, which are cluster buses, are owned by DIMTS. In the year 2022-23, the total fleet size was described as 7230.

The bus routes are operated by DTC only, DIMTS only, or by DTC and DIMTS both. The distribution of the bus routes is shown in Table 5. Forty-three percent of the bus routes are operational by DTC only. 34.5 percent of the routes are operated by DIMTS only. Both DTC and DIMTS operate 22.5 percent of the bus routes.

**Table 5.** Operators of bus routes in Delhi

| | Bus routes |
|---|---|
| **DTC** | 259 |
| **DIMTS** | 209 |
| **Both** | 138 |
| **Total** | 606 |

(Source: DTC; DIMTS, 2024)

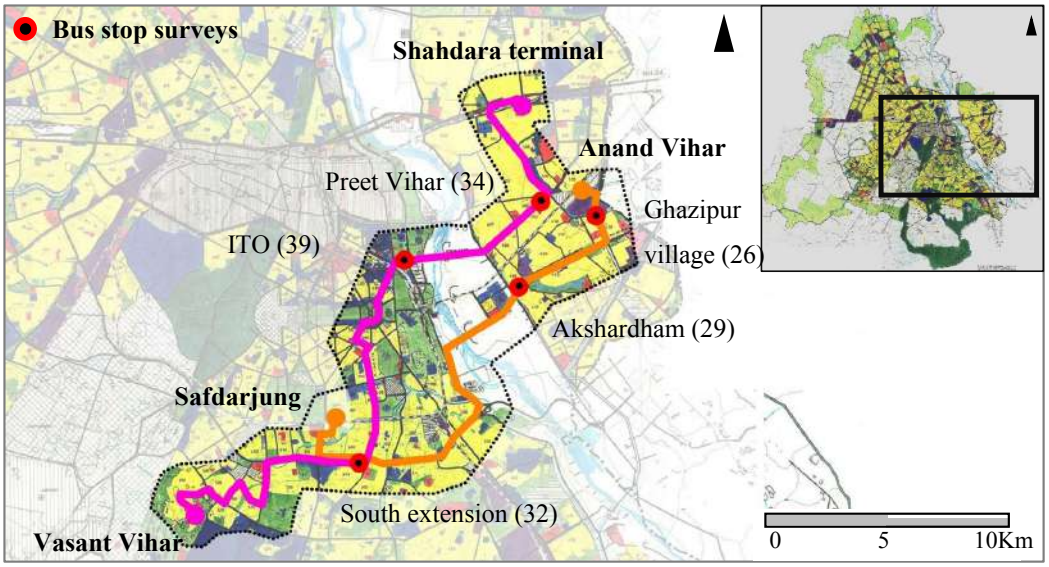


**Figure 2.** The selected bus routes for the case study

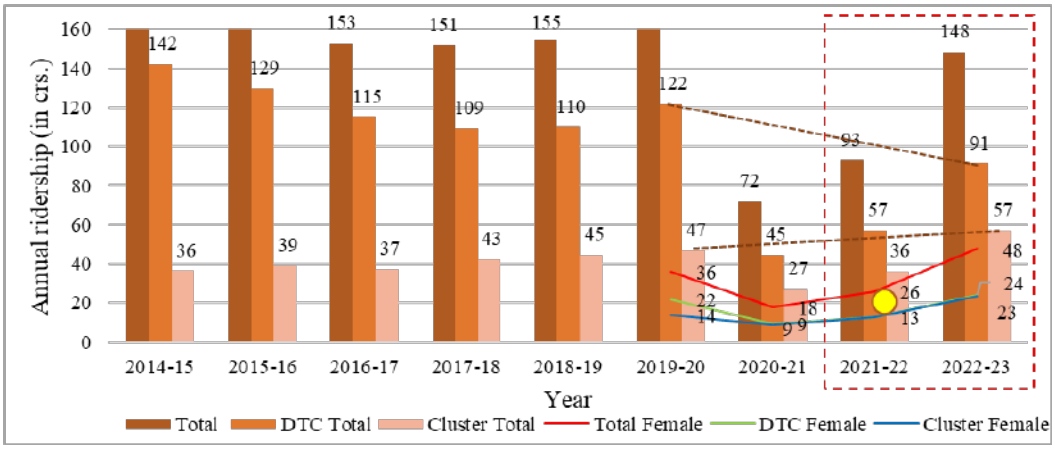


**Figure 3.** Annual female and total ridership
(Source: DTC; DIMTS, 2024)

## *6.1 Demand Characteristics*

There were changes observed in the ridership of women commuters of buses post the launch of the pink slip scheme in 2019. Due to the arrival of COVID 2019, the total ridership observed a dip. However, despite the arrival of COVID 2019, post the implementation of the Pink slip scheme in 2019, the female ridership saw a rise. These changes have been discussed in detail below.

The annual ridership saw a decline due to the arrival of COVID-19. However, even though DTC in the year 2022-23 reached to 75 percent of the ridership in the year 2019-20, the cluster buses have exceeded their ridership in the year 2022-23 compared to the ridership in the year 2019-20.

RIDERSHIP SHIFT FROM 2019-20 TO 2022-23: A shift was observed in the total as well as female ridership from 2019-20 to 2022-23 in Delhi buses. This shift has been observed since the Pink slip scheme was implemented in 2019. As evident in Tables 2 and 3, despite a dip in the total ridership from 2019 to 2022, there has been an increase of 33 percent in the female ridership. The Pink slip scheme was implemented in 2019. Since the data was collected from October 2019 (only 6 months), the count has been doubled to get an estimate for the whole year 2019.

**Table 2.** Shift of ridership from the year 2019-20 to the year 2022-23

| From 2019-20 to 2022-23 | Total |
|---|---|
| Shift in total ridership | -7.5 % |
| Shift in female ridership | 33 % |

(Source: DTC; DIMTS, 2024)

RIDERSHIP SHIFT FROM 2021-22 TO 2022-23: In the year 2021-22, female ridership for both DTC and cluster buses was 13crs. From the year 2021-22 to 2022-23, the increase in total ridership was 59 percent for both.

**Table 3**. Shift of ridership from the year 2021-22 to the year 2022-23

| From 2021-22 to 2022-23 | DTC | Cluster |
|---|---|---|
| Increase in total ridership | 59% | 59% |
| Increase in female ridership | 85% | 76% |

(Source: DTC; DIMTS, 2024)

## 7. Travel Patterns of Women Users

There were some common patterns observed in the women commuters of Delhi buses based on their age, occupation, and education level. Apart from the standard travel patterns, certain shifts were also observed in their travel pattern post the implementation of the gender-targeted public transport schemes in the buses of Delhi.

OCCUPATION AND TRAVEL FREQUENCY: Certain common traits were observed in the women with the same occupation. Their travel frequency was seen to be vary with their occupation. Women who were students, service workers, or industrial workers were found to be using Delhi buses more often for their travel. Women who were involved in business, the informal sector, or were self-employed, homemakers, or unemployed, were found to be travelling less frequently by bus.

Women of all occupations except the unemployed, were found to have used the bus daily; the unemployed women who are looking for employment travel rarely. School students were the only users who travelled more than twice by bus within a day, as shown in Figure 4.

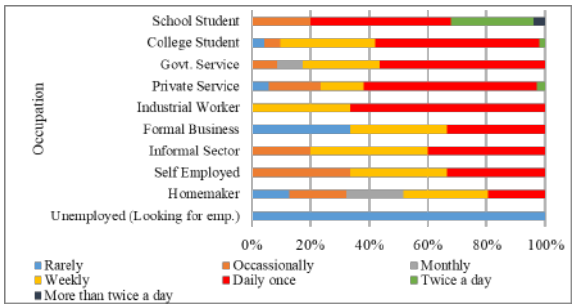


**Figure 4.** Variation of travel frequency with respect to the occupation of the women users
(Source: Primary survey, 2024)

OCCUPATION AND TRAVEL TIME: Women with a lower source of income, for example, women who were unemployed or those who were industrial workers, were found to travel for a greater number of hours for their trips. This was likely because these women preferred taking longer bus trips to reduce their travel expenditure. They opted for bus travel alone to minimize their travel time, rather than using mixed modes.

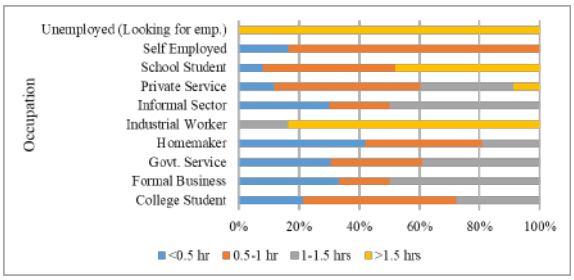


**Figure 5.** Variation in the travel time with respect to the occupation of the women users
(Source: Primary survey, 2024)

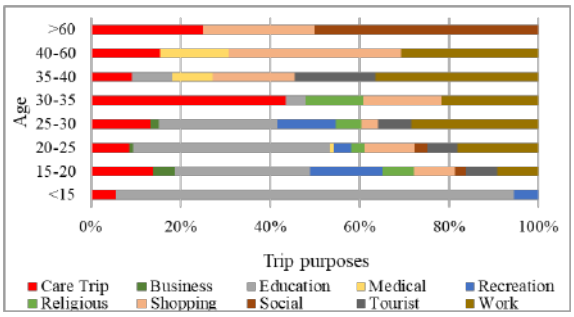


**Figure 6.** Variation of trip purposes with respect to the age of the women users
(Source: Primary survey, 2024)

The unemployed women looking for employment have a travel time of more than 1.5 hours. Women who are industrial workers travel for more than 1 hour shown in Figure 5.

AGE AND TRIP PURPOSE: The majority of women who uses buses for their mode of travel are those going for education and work, followed by those going for care trips. It was observed that

women up to the age of 40 years were taking trips for education and using buses for their travel. For recreational purposes, women of up to only 30 years of ages were found to be using buses for their travel. However, women of all age above 15 years were using the bus for shopping, whether for household purposes or personal needs. It was observed that women of all age groups were found to be carrying out care trips, as shown in Figure 6.

AGE AND TRIP DISTANCE: Women between the ages of 15 and 40 years were found to be travelling for a distance of less than 5 km up to a distance greater than 20 km. The maximum number of trips for any distance was found to be carried out by women between the ages of 20 and 25. Women users aged 40 or above were found to be travelling only up to a distance of 15 km, as observed in Figure 7.

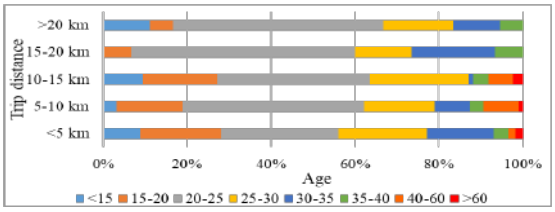


**Figure 7.** Variation of trip distance with the age of women users (Source: Primary survey, 2024)

## 8. Shift in Travel Characteristics Post-Schemes

Post the implementation of the schemes, several shifts have occurred in the travel, social, and economic characteristics of women's travel in Delhi buses. These characteristics have been discussed in detail below.

**Table 4.** Shift in PCTR and ATL of the women users' post-schemes

| Parameter A | Pre-scheme | Post-scheme |
|---|---|---|
| Overall PCTR | 0.7 | 0.75 |
| PCTR by bus | 0.5 | 0.63 |
| Mode share of bus trips | 68% | 84% |
| ATL | 8.4 km | 9.8 km |

(Source: Primary survey, 2024)

PCTR and ATL: Post the implementation of schemes, the overall PCTR (for all modes) has increased from 0.7 pre-schemes to 0.75 post-schemes. The mode share of bus trips has also increased from a percentage of 68 pre-schemes to 84 post-schemes, as shown in Table 4. The Pink slip scheme was the reason for the shift in mode for 95 percent of women users. The average trip length has increased from 8.4 km pre-schemes to 9.8 km post-schemes.

TRIP LENGTH: Post the implementation of gender-targeted public transport schemes in Delhi's buses, the travel distances of women commuters were found to have increased.

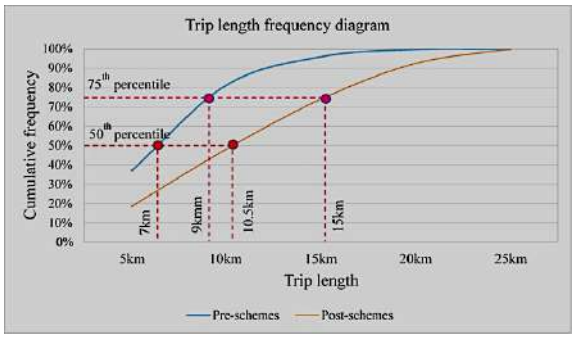


Figure 8. Trip length of the women users pre- and post-schemes (Source: Primary survey, 2024)

Fifty percent of the trips have a trip length of up to 7 km pre-schemes while post schemes trip length increases to up to 10.5 km. The 75 percent percentile of trips has a trip length of 9 km pre-schemes, while post-schemes, the trip length increases to up to 15 km, as shown in Figure 8.

TRIP LENGTH WITH RESPECT TO OCCUPATION: Pre-schemes, 50 percent of the industrial workers traveled beyond 15km for work trips.

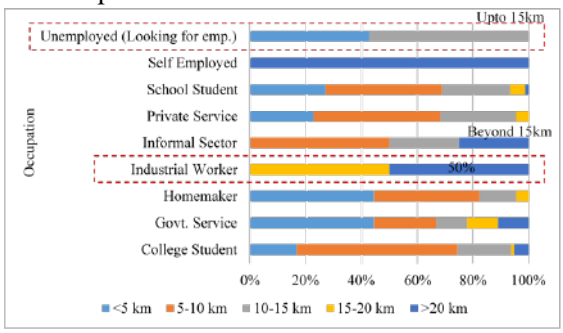


**Figure 9.** Trip length of women users' pre-schemes (Source: Primary survey, 2024)

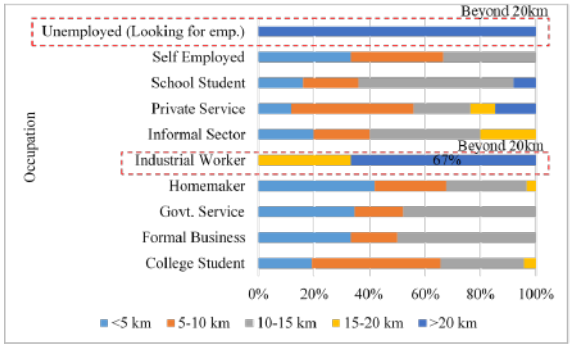


**Figure 10.** Trip length of women users' post-schemes (Source: Primary survey, 2024)

As shown in Figure 9, pre-schemes the unemployed women travelled only up to a distance of 15 km. Among the pre-schemes unemployed women, 24 percent secured employment post-schemes.

As shown in Figure 10, post-schemes, the unemployed women travelled up to a distance of beyond 20 km. Sixty five percent of the industrial workers travelled beyond 20 km for work trips post-schemes.

SHIFT IN MODES WITH RESPECT TO PREVIOUS MODE: Some women claimed that they no longer had to "be dependent on anyone else for traveling" and felt the freedom of not feeling the necessity of "taking permission every time before leaving home". These are some of the major changes women claimed to observe after they shifted their modes of travel from other modes like auto, metro, and e-rickshaw to buses post the implementation of the gender-targeted public transport schemes in the buses of Delhi.

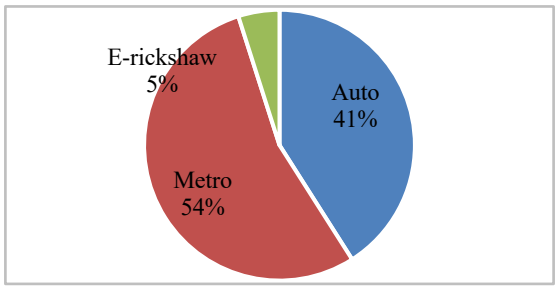


**Figure 11.** Shift in modes of women users
(Source: Primary survey, 2024)

Twenty one percent of the women users had shifted their mode to bus. Among the women who had shifted their modes to bus, 54 percent had shifted from metro, 41 percent from auto, and 5 percent from e-rickshaw as seen in Figure 11 shown above.

MODES WITH RESPECT TO TRAVEL FREQUENCY BY BUS: Among the women who had shifted their modes from other modes to buses, women who travelled daily once by bus post the implementation of the schemes were the maximum ones to have shifted their modes.

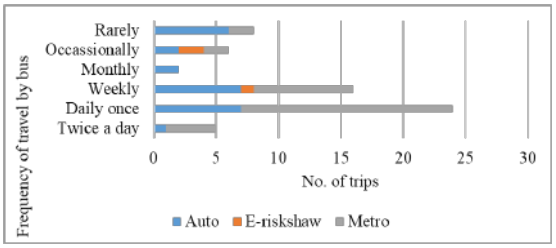


**Figure 12.** Shift in modes w.r.t. travel frequency by bus
(Source: Primary survey, 2024)

Most of the women who were daily travellers by bus were observed to have shifted their modes from the metro. In contrast, women who were occasional travellers by bus had shifted their modes from auto, followed by the least number of women who had shifted from e-rickshaws, as shown in Figure 12.

SHIFT IN MODES WITH RESPECT TO TRIP PURPOSE: Only 6 percent of the women users had access to a personal vehicle. For 95 percent of the women who shifted modes, a pink slip was the deciding factor. Although the schemes have successfully captured women from other modes, they have not captured women from private vehicles. Women who travelled daily were dropped off by someone in the first half of the day.

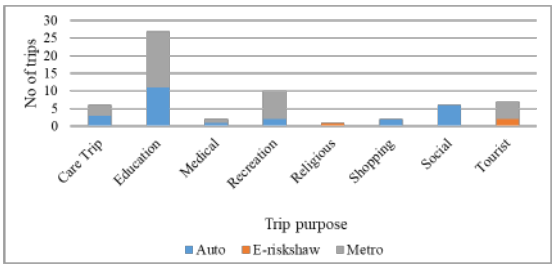


**Figure 13.** Shift in modes with respect to trip purpose
(Source: Primary survey, 2024)

Most of the modal shift that occurred was for educational trip purposes, which had majorly shifted from other modes, followed by recreation, and then by tourist purpose trips, as shown in Figure 13. Another important observation to be made here is that for educational trips, 60 percent of the modal shifts were from the metro, while the remaining 40 percent shifts were from the mode of auto rickshaw. All religious purpose trips that had observed a modal shift had shifted from e-rickshaw, indicating a reduction in trip distance for religious trips.

TRIP DISTANCE VS WAITING TIME: The waiting time for the bus was found to be directly proportional to the travel distance. Post the schemes, the longer the travel time of the women commuters on buses, the greater their waiting time for the bus. This, on one hand, shows the low reliability of the buses. On the other hand, this also shows women's willingness to wait for the buses for a longer duration for more extended trip, showing that women opt for buses for longer routes to cut down their travel expenses despite their longer waiting time.

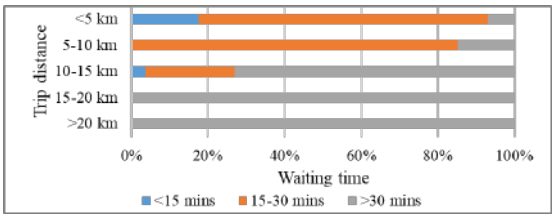


**Figure 14.** Trip distance vs waiting time of the women users
(Source: Primary survey, 2024)

For all the women who had a trip distance of more than 15 km post-schemes, their waiting time was observed to be above 30 minutes. For women

with a trip distance of 10 km to 15 km, 70 percent of them experienced a waiting time exceeding 30 minutes, as shown in Figure 14.

AGE VS WAITING TIME: The waiting time for the Delhi buses post-schemes was found to be directly proportional to the age of the women commuters.

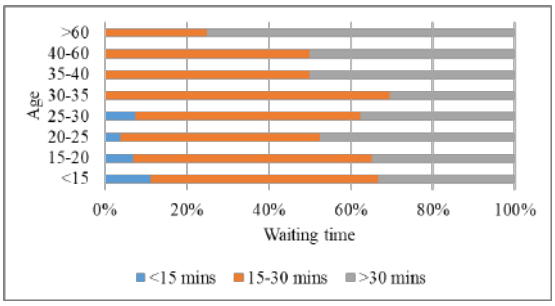


**Figure 15.** Age vs waiting time of the women users (Source: Primary survey, 2024)

As shown in Figure 15, among the women aged below 15 years, 67 percent of the women had a waiting time of less than 30 minutes. In contrast, for women aged 60 years and above, only 25 percent had a waiting time below 30 minutes. Only women users up to 30 years of age were willing to wait for less than 15 minutes before moving onto some other mode of travel.

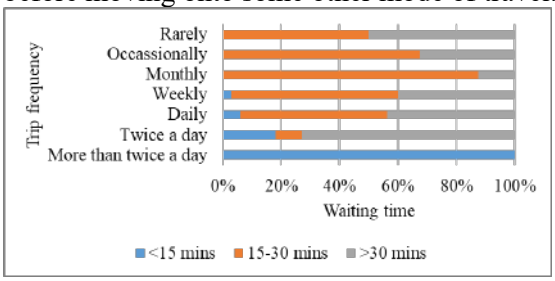


**Figure 16.** Trip frequency vs waiting time of the women users (Source: Primary survey, 2024)

WAITING TIME WITH RESPECT TO TRIP FREQUENCY: The waiting time for the buses is inversely proportional to the travel frequency of the women bus users' post-schemes. The greater the trip frequency of the women commuters, the greater their waiting time.

According to the users' survey, 62 percent of the women, reported an increase in waiting time post-schemes. For women users travelling more than twice a day, the waiting time is less than 15 minutes for all users.

## 9. Key Findings

There has been a 33 percent rise in the female ridership since the launch of the pink slip scheme in 2019.

The total PCTR of all modes has shifted from 0.7 pre-schemes to 0.75 post-schemes. The average trip length of the women bus users has increased from 8.4 km to 9.8 km.

Modal share of the bus trips among total trips of the women commuters has shifted from 68 percent pre-schemes to 84 percent post-schemes. For 95 percent of the shifted trips, a pink slip was the reason for a shift in the modes. Women reported feeling more financially independent after transitioning to the bust, as they no longer needed to seek permission before leaving home and could travel more freely.

Waiting time for buses in Delhi has increased since the introduction of schemes, which is also reflected in the change in behaviour of bus drivers toward women users.

Women feel secure enough to travel alone on buses, particularly during later hours of the day, post-schemes.

## 10. Conclusion

The study shows that there has been a significant shift in the travel patterns of women users of Delhi buses. The shift in the travel characteristics has been measured with respect to changes in the PCTR, trip lengths and mode trip lengths. These aspects have then been combined with the demographic characteristics of the women users of Delhi buses. The implementation of the schemes has brought about a significant shift in the travel patterns of women users by bus in Delhi. However, further research can explore the aspects with respect to the degree of influence of each scheme. The gaps identified can then be used to initiate strategies that increase the efficacy of the schemes.

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# Net-Zero Sustainable Development Planning for an Institutional Campus Design

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**Abstract:** In the context of urgent environmental issues and the need for sustainable development, this study offers a comprehensive framework for negotiating the complexities of attaining net-zero sustainability on university campuses in India. The study emphasizes the necessity of moving beyond building-centric techniques and adopting net-zero principles at the community level. It highlights the need for integrated solutions to address the challenges of energy, carbon, water, waste, and sustainable development, as well as the major gaps in present building-centric policies. An assessment of current methods was undertaken and a comprehensive approach for developing net zero sustainable campuses in India was proposed through a research process that included expert interviews, case studies, and a review of the literature. This process emphasized the integration of policy and technology, stakeholder collaboration, and continuous performance monitoring. Furthermore, an assessment of the status of net-zero strategy adoption on existing institutional campuses in India is necessary. The case studies selected were of campuses that are actively pursuing net-zero objectives, comprising both older and newer campuses, as well as those with limited spatial constraints and those with more expansive areas. This revealed prevalent barriers and the potential for transformative change through concerted efforts. The proposed approach has then been validated and improved by incorporating the recommendations of a pool of experts in the domain of energy, sustainability, and design. Overall, by offering a thorough road map for attaining net-zero sustainability on Indian university campuses, this research advances the conversation on sustainable urban development while promoting social cohesion, economic feasibility, and environmental resilience.

**Keywords:** Campus planning, Carbon, Energy, Environmental impact, Net zero, Sustainable development, Waste, Water

**सार:** ज़रूरी पर्यावरणीय मुद्दों और सस्टेनेबल डेवलपमेंट की ज़रूरत को देखते हुए, यह स्टडी भारतीय यूनिवर्सिटी कैंपस में नेट-ज़ीरो सस्टेनेबिलिटी हासिल करने की मुश्किलों को समझने के लिए एक व्यापक फ्रेमवर्क पेश करती है। यह स्टडी बिल्डिंग-केंद्रित तकनीकों से आगे बढ़कर कम्युनिटी लेवल पर नेट-ज़ीरो सिद्धांतों को अपनाने की ज़रूरत पर ज़ोर देती है। यह एनर्जी, कार्बन, पानी, कचरा और सस्टेनेबल डेवलपमेंट की चुनौतियों से निपटने के लिए इंटीग्रेटेड समाधानों की ज़रूरत पर ज़ोर देती है, साथ ही मौजूदा बिल्डिंग-केंद्रित नीतियों में बड़ी कमियों को भी उजागर करती है। मौजूदा तरीकों का आकलन किया गया और भारत में नेट ज़ीरो सस्टेनेबल कैंपस विकसित करने के लिए एक व्यापक दृष्टिकोण प्रस्तावित किया गया, जिसमें विशेषज्ञ इंटरव्यू, केस स्टडी और साहित्य की समीक्षा शामिल थी। इस प्रक्रिया में नीति और टेक्नोलॉजी के इंटीग्रेशन, स्टेकहोल्डर सहयोग और लगातार परफॉर्मेंस मॉनिटरिंग पर ज़ोर दिया गया। इसके अलावा, भारत में मौजूदा संस्थानों के कैंपस में नेट-ज़ीरो रणनीति अपनाने की स्थिति का आकलन करना भी ज़रूरी है। चुनी गई केस स्टडी उन कैंपस की थीं जो सक्रिय रूप से नेट-ज़ीरो उद्देश्यों को पूरा कर रहे हैं, जिनमें पुराने और नए कैंपस, साथ ही सीमित जगह वाले और ज़्यादा बड़े एरिया वाले कैंपस शामिल हैं। इससे प्रचलित बाधाओं और मिलकर किए गए प्रयासों से बड़े बदलाव की संभावना का पता चला। प्रस्तावित दृष्टिकोण को एनर्जी, सस्टेनेबिलिटी और डिज़ाइन के क्षेत्र के विशेषज्ञों के सुझावों को शामिल करके मान्य और बेहतर बनाया गया है। कुल मिलाकर, भारतीय यूनिवर्सिटी कैंपस में नेट-ज़ीरो सस्टेनेबिलिटी हासिल करने के लिए एक विस्तृत रोड मैप पेश करके, यह रिसर्च सस्टेनेबल शहरी विकास पर बातचीत को आगे बढ़ाती है, साथ ही सामाजिक एकता, आर्थिक व्यवहार्यता और पर्यावरणीय लचीलेपन को बढ़ावा देती है।

**मुख्य शब्द:** कैंपस प्लानिंग, कार्बन, ऊर्जा, पर्यावरणीय प्रभाव, नेट ज़ीरो, सतत विकास, कचरा, पानी

## 1. Introduction

The growing concerns about limited energy supplies, depleting energy resources, rising energy costs, and the increasing influence of greenhouse emissions on global warming have led to a surge in interest in the concept of net zero in recent years (Aelenei et al., 2013; Fankhauser et al., 2022). Urban areas consume up to 76% of global energy and generate three-quarters of global carbon emissions. Buildings alone use over 40% of all energy used, making them a key energy-consuming component of the world's structure (Jaysawal et al. 2022; Kushwah & Channi 2022; Mukherjee 2011; Saini et al. 2021; Zhou 2019).

Considering net-zero at the community level is essential for achieving overall net-zero energy goals for several key reasons. Firstly, not all buildings can feasibly achieve net-zero status due to varying levels of difficulty dictated by building type, site conditions, and operational requirements. Secondly, multi-building systems offer opportunities for energy sharing and load diversity, leading to reduced energy

consumption. For example, energy-intensive facilities like data centers and labs may benefit from shared energy resources in net-zero communities. Thirdly, focusing on net-zero communities allows for diverse electrical and thermal load profiles over different time scales, resulting in optimized energy generation and distribution. Moreover, incorporating mixed land uses within communities further enhances load diversity, reducing the overall capacity required for electricity generation. Lastly, expanding the boundaries of net-zero communities to include neighbouring open spaces enables the integration of nearby renewable energy sources, fostering a sustainable mix of buildings and urban densities (Deng et al. 2014; Griffith et al. 2007; Kallushi et al. 2012; Mavrigiannaki et al. 2021; Scognamiglio et al. 2014; Torcellini 2006). Ultimately, we may explore more energy-saving options in transportation, wastewater treatment, water supply, and other areas by looking past a building's exterior and footprint (Kallushi et al. 2012; Komninos 2022).

This paper examines the methodology and level of implementation of net-zero initiatives in India. It identifies gaps and challenges in their application, and proposes an integrated approach to planning sustainable institutional campuses with a focus on achieving net-zero status. The proposal takes into account India's regional context as a country dominated by cooling needs.

## 2. Literature Review

In this study, we explore the status of net-zero implementation in India and critically review the approaches being adopted to provide an integrated solution that caters to the holistic planning of net-zero sustainable institutional campuses.

### *2.1 Net- zero definition and types*

Net Zero in terms of the built environment encompasses various types. Buildings classified as Net Zero Energy Buildings (NZEBs) have zero net energy consumption, meaning that the entire amount of energy consumed by the building each year is roughly equal to the total amount of renewable energy generated on the site (Bureau of Energy Efficiency 2021; Fokaides 2012; Jaysawal et al. 2022; Khurshid et al. 2020; Kushwah and Channi 2022; Mukherjee 2011; Neto et al. 2022; Repuriya and Bano 2021).

It is not possible to have a true ZEB, which would imply zero flows (Torcellini 2006). The idea behind net zero is basically that the total energy generated and used in the building balances each other out (Fokaides 2012).

Net zero buildings are categorized into four types: net zero source, net zero site, net zero energy cost, and net zero energy emissions. A net-zero source building produces as much energy as it uses compared to the energy content of the energy source. Source energy refers to the primary energy consumed to generate, process, and export energy to the site (Aelenei et al. 2013; Repuriya & Bano 2021; Saini et al. 2021; Torcellini 2006). A net-zero site produces at least as much energy on-site as it consumes annually or throughout the year (Aelenei et al., 2013; Repuriya & Bano, 2021; Torcellini, 2006). A net-zero energy cost building is one where the grid payment to the building owner for renewable energy export should equate to the amount paid by the building owner to the grid for energy services throughout the year (Aelenei et al. 2013; Repuriya & Bano 2021; Torcellini 2006). Net zero energy emissions occur when a building produces net zero emissions that are produced by the energy needs of the building (Repuriya & Bano 2021; Torcellini 2006). Designers need to define a net-zero definition to determine the approach they need to adopt (Torcellini 2006).

Net-zero buildings and campuses can also be classified by the type of grid connection adopted, specifically off-grid and on-grid connections. Off-grid zero-energy buildings operate independently, disconnected from external energy utilities, requiring them to store energy throughout the year, particularly in winter, considering solar radiation fluctuations. On-grid zero energy buildings, prevalent worldwide and in India, connect to the grid, borrowing and subsequently returning a significant portion (half or more) of energy over the course of the year (Repuriya and Bano 2021).

Depending on the level of net zero balance achieved by a building or campus, they can also be classified as: nearly zero buildings, net zero, and net plus or net positive. Almost zero is one connected to the grid, which has almost zero energy balance. This indicates that there is a small difference between the amount of energy produced and consumed. Net-zero energy buildings, on a particular occasion, have an equal amount of energy produced as is consumed. Net positive buildings feed extra energy back into the grid by using less energy than the site generates (Bureau of Energy Efficiency 2021; Garde et al. 2014; Kushwah and Channi 2022; Repuriya and Bano 2021).

Zero-carbon building involves balancing greenhouse gas emissions with their active removal, but to address the accumulated gases and the depleting carbon budget, emission reduction efforts are essential (Rebecca Powell et al. 2022). An annual reduction in energy use by employing renewable energy sources leads to savings in greenhouse emissions. However, this process does not account for carbon emissions associated with building materials, the construction process, demolition, and disposal. Therefore, over its lifetime, a so-called NZEB might not produce net zero emissions (Jain and Rawal 2022).

Calculation metrics of Net Zero carbon involve (Kilkis 2007):

i. C = carbon content of energy source, kg $CO_2$/kW·h
ii. $CO_2$ = direct carbon emission, kg $CO_2$ for unit load
iii. $\Delta CO_2$ = avoidable carbon emission, kg $CO_2$ for unit load
iv. $\Sigma CO_2$ = compound carbon emission, kg $CO_2$ for unit load

Figure 1 illustrates a net-zero carbon building's whole life cycle.

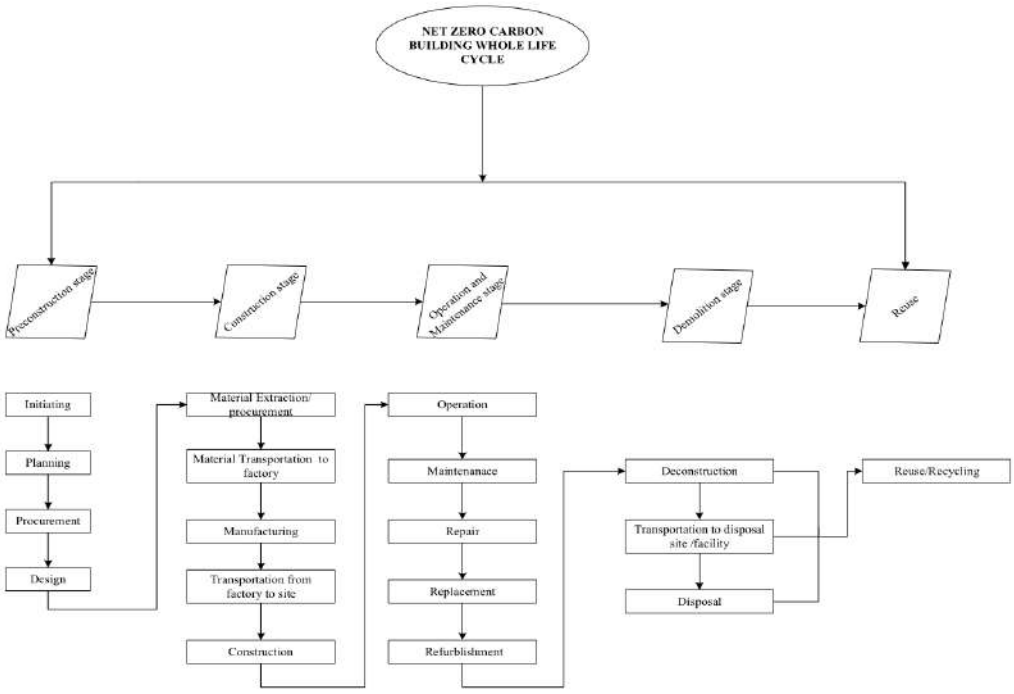


**Figure 1.** Net-zero carbon building whole lifecycle stages (source: Falana et al. 2024)

Sustainable design promotes conservation efforts to reduce overall water consumption. Techniques like water reuse and recycling, which emulate natural processes, further diminish the reliance on drinkable water sources. To achieve zero-water compliance, the building water cycle must function separately from municipal water and wastewater systems (Joustra & Yeh, 2015).

A zero-waste approach focuses on using all resources through responsible production, consumption, reuse, and recovery methods. This approach aims to redesign resource life cycles to prevent waste generation and eliminate any environmental or health threats from land, water, or air discharges (Hussain et al. 2022).

When it comes to the built environment, net zero can mean zero energy, water, waste, as well as zero carbon, all of which entail different strategies of implementation.

### *2.2 Fundamentals of net-zero energy building*

To reach a NZEB goal, necessary steps must be conducted at the design stage (Aelenei et al. 2013; Garde et al. 2014; Mavrigiannaki et al. 2021; Neto et al. 2022; Saini et al. 2021; Scognamiglio et al. 2014):

i) Reduce building energy demand using passive solutions and energy-efficient systems;

ii) Generate sufficient electricity by renewable energy systems to achieve the desired energy balance.

Achieving NZEB involves diverse technologies and systems, their complexity varying based on location and environmental conditions, with lighting being the predominant load followed by heating, cooling, ventilation, and plug loads (Mukherjee 2011).

### *2.3 Net-zero rating systems in India*

There are three prevalent net-zero rating systems in India, although they are focused primarily on net-zero energy, except for the LEED Zero program. The three rating systems have been described below:

i) IGBC Net Zero Energy Buildings Rating System: The rating is devised for both new and existing buildings, and the certificate is awarded when a project meets all mandatory requirements and can demonstrate that the net annual energy consumption is zero. It considers energy performance, thermal comfort, indoor temperature, and RH (IGBC, 2018).

ii) BEE Shunya Labelling Programme: The programme targets the Net Zero Energy Buildings (NZEB) and Net Positive Energy Buildings (NPEB). Here, the Energy Performance Index (EPI) in kWh/m$^2$/year is considered for rating the building to be between $10 \leq EPI \leq 0$ for net zero energy and $EPI < 0$ for Shunya + net positive rating (BEE 2021).

iii) LEED Zero Program: The certification recognizes LEED Zero carbon, energy, water, and waste balance to qualify.

There is a need for an integrated net-zero approach that encompasses energy, carbon, water, and waste, as well as sustainable development, which establishes metrics and procedures integral to achieving net-zero certification.

### *2.4 Challenges in implementing a net-zero strategy at a building level*

There are many challenges associated with implementing net-zero principles at a building level; they have been listed below:

i. Forecasting energy consumption during design is challenging due to uncertainties in occupancy, impacting optimal Energy Use Index (EUI) goals (Garde et al. 2014; Wismadi et al. 2022).
ii. Rising energy demands in the future due to climate change might not be met by the technologies currently in use today (Saini et al. 2021).
iii. Building type suitability affects NZEB accomplishment, with high-rise urban structures facing more challenges (Hachem-Vermette et al. 2019; Kallushi et al. 2012; Mavrigiannaki et al. 2021; Scognamiglio et al. 2014; Torcellini 2006).
iv. High capital costs and lack of financing deter stakeholders, and cost-optimal solutions may compromise energy performance. Cost considerations depend on climate, impacting renewable energy potential and building performance. Life-time costs and benefits need to account for non-financial gains like community health and climate resilience, enhancing stakeholder support (Kallushi et al. 2012; Mavrigiannaki et al. 2021; Rebecca Powell et al. 2022; Saini et al. 2021).
v. Limited data and expertise slow down net zero adoption in the industry (Rebecca Powell et al. 2022; Saini et al. 2021).
vi. User preferences shape net-zero energy buildings, with challenges in gaining acceptance as occupant behavior and physiological dimensions are influenced by it (Saini et al. 2021).

These barriers have prompted professionals to seek solutions that address the gaps in the building-focused net-zero approach. Thus, net-zero communities and districts are now being explored due to the benefit of scale, space, and diversity of use.

### *2.5 Designing a net-zero sustainable community*

Sustainability is a global process that aims to create an enduring future by considering environmental and social factors alongside economic factors (Chouksey et al. 2022). Neighbourhood performance is found to be highly influenced by a range of factors and design parameters. These include building design, density, occupant behaviour, system efficiency, urban geometry and layout design, and others (Hachem-Vermette et al. 2019). Rebecca Powel et al (2022) have devised a Net Zero action plan for university campuses involving the following action areas:

i. Energy
ii. Mobility
iii. Facilities
iv. Waste and recycling
v. Value chain
vi. Beyond campus operations

Achieving low and net-zero energy performance involves prioritizing integrated design and comprehensive community-level systems analysis over individual technologies, where treating the entire community as an integrated system is essential (Kallushi et al. 2012).

There aren't any specific standards or codes for net zero energy, carbon, waste, and water for large developments or institutional campuses. There are specific Indian and International codes and references that outline sustainability-related

requirements, while also addressing specific net-zero components such as LEED for Cities and Communities, Living Community Challenge, GRIHA Large Development, WELL Community Standard, LEED Neighbourhood Development and ClimateSmart Cities Assessment Framework 2.0.


**Figure 2.** Essential aspects of designing a net-zero sustainable campus (source: author)

Figure 2 outlines the key aspects of designing a net-zero sustainable campus, drawing on various standards for sustainable campus development, expert interviews, and thematic analysis. This categorization establishes the baseline to formulate the approach for a net-zero sustainable campus proposed in later sections.

### *2.6 Challenges of net-zero communities*

Particular challenges are associated with creating a net-zero community, such as:

i. Dependence on users: Community cohesion and user buy-in—that is, owners and tenants who are aware of and supportive of the net-zero goal—are necessary for the success of net-zero communities.

ii. Scale and type of building: Smaller clusters benefit from low-energy buildings but lack system scale and load diversity. Limited space hinders renewable energy installation. Larger groups face challenges in reducing energy across diverse buildings due to scale, yet they have strategic power generation opportunities in larger sites.

iii. Financial constraints: NZE communities may have higher initial development costs due to efficiency measures and infrastructure investment. Still, they offer long-term value by lowering operating costs, but finding buyers and lenders willing to attribute full value may be challenging.

iv. Ownership: Single ownership of the community's buildings and infrastructure enhances the feasibility of a development by facilitating synchronized construction schedules and efficient energy load allocation. However, challenges arise when buildings are sold or leased post-construction, potentially compromising unified decision-making.

v. Retrofitting existing campuses: Attaining Net Zero Energy status is typically more feasible in newly developed communities, where planners have the flexibility to implement energy-efficient solutions from the beginning. Conversely, upgrading current neighbourhoods poses a greater challenge because there are limited opportunities to optimize energy efficiency within pre-existing structures significantly.

The above challenges and limitations should be considered by professionals when planning net-zero campuses to ensure holistic development (Hachem-Vermette et al. 2019; Kallushi et al. 2012).

### *2.7 Review of the status of net-zero implementation in India*

A study was undertaken to review the status of existing net-zero certified buildings and campuses in India, as per the requirements of a successful net-zero implementation studied earlier.

The first step was to formulate a preliminary checklist according to the various criteria of net zero as found in the literature. The criteria were categorized into energy, carbon, water, and waste. However, sustainability requirements were only applicable to large developments, which will be studied later on.

A comparative review was undertaken of six net-zero buildings in India in Table 1. The minimum performance criteria were established from available codes or rating systems to assess the performance of the projects.

The projects selected for this study are prominent net-zero energy certified buildings and campuses in India. They all belong to cooling-dominated regions of the Indian subcontinent. All the cases have high energy demands as they are commercial or institutional buildings and are mechanically ventilated.

**Table 1.** Comparative analysis of existing net-zero buildings and campuses in India

| | | | IIT Jodhpur | CEPT | Godrej Plant 13 | Akshay Urja Bhawan | Jaquar Head Quarters | Paryavaran Bhawan |
|---|---|---|---|---|---|---|---|---|
| | **Project Details** | Minimum criteria | | | | | | |
| **Building Information** | Building location | - | Jodhpur, Rajasthan | Ahmedabad, Gujarat | Mumbai, Maharashtra | New Delhi, Delhi | Manesar, Haryana | New Delhi, Delhi |
| | Climate | | Hot-dry | Hot-dry | Warm-humid | Composite | Composite | Composite |
| | Building Type | | Institutional | Institutional | Commercial | Commercial | Commercial | Commercial |
| | Net Zero Energy building Type | | Positive | Positive | Net zero | Positive | Positive | Net zero |
| | Grid connection | | Connected | Connected | Connected | Connected | Connected | Connected |
| | Site area (sqm) | | 34,39,950 | - | - | 10,927 | 48,562 | - |
| | BUA (sqm) | | 8,07,518 | 498 | 24,443 | 5,100 | 48,000 | 9,565 |
| | No. of blocks | | - | 1 | 1 | 1 | 2 | 1 |
| | Max. no. of floors | | - | 3 | 6 | 13 | 4 | 11 |
| | Annual energy consumption (kWh) | | - | 32,500 | - | 62,415 | 5,63,482 | 14,00,000 |
| | EPI (kWh/m$^2$/yr) | EPI < 10 | 45 | 58 | 75 | 30 | - | 44 |
| | **Net Zero Energy Criteria** | | | | | | | |
| **Passive Design Strategy Adopted** | Site and Internal Planning | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Optimized building form | - | ✓ | ✓ | - | ✓ | ✓ | ✓ |
| | Advanced envelope | - | - | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Advanced glazing | - | - | ✓ | ✓ | × | ✓ | ✓ |
| | Thermal mass | - | ✓ | ✓ | ✓ | ✓ | × | ✓ |
| | Solar shading | - | ✓ | ✓ | ✓ | ✓ | × | ✓ |
| | Site vegetation | - | ✓ | × | ✓ | ✓ | ✓ | ✓ |
| | Natural ventilation | - | ✓ | ✓ | × | ✓ | ✓ | ✓ |
| | Skylights | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Blinds for glare control | - | - | - | ✓ | ✓ | ✓ | - |
| | Thermal Insulation | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | WWR (%) | - | - | 20 | 36 | - | - | - |
| | Daylighting | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Active Energy Efficient Systems** | Energy efficient lighting | - | × | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Advanced lighting control | - | × | ✓ | ✓ | - | ✓ | ✓ |
| | Efficient appliances | - | - | - | ✓ | - | ✓ | ✓ |
| | Load management | - | × | ✓ | ✓ | ✓ | ✓ | - |
| | Mechanical ventilation | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Radiant cooling | - | × | ✓ | × | × | ✓ | × |
| | Ceiling fans, evaporative cooling | - | ✓ | ✓ | × | - | × | ✓ |
| | HVAC (COP or Performance Index in kWh/m$^2$/yr) | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Energy storage system | - | × | × | × | × | × | × |
| **Renewable Energy Systems** | Energy demand met (%) | 100% | >100% | 120% | 100% | 107% | 122% | 100% |
| | Units generated/year (kWh) | - | 22.5 MWe | 39000 | 148487 | 67343 | 687448 | 14,00,000 |
| | Onsite renewable energy | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Offsite renewable energy | - | × | × | ✓ | × | × | × |
| | Net Surplus Energy (kWh) | - | - | 6500 | × | 4928 | 123966 | × |
| | Type of RE employed: | | | | | | | |
| | Solar | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Wind turbines | - | × | × | × | × | × | × |
| | Biomass | - | × | × | × | × | × | × |
| | Geothermal | - | × | × | × | × | × | ✓ |
| | Hydropower | - | × | × | × | × | × | × |
| | Other | - | × | × | × | × | × | × |

| | | | IIT Jodhpur | CEPT | Godrej Plant 13 | Akshay Urja Bhawan | Jaquar Head Quarters | Paryavaran Bhawan |
|---|---|---|---|---|---|---|---|---|
| | **Project Details** | Minimum criteria | | | | | | |
| | **Net Zero Carbon Criteria** | | | | | | | |
| | Zero emissions achieved in every lifecycle stage: | | | | | | | |
| Pre-construction | Raw material extraction | - | - | - | - | - | - | - |
| Pre-construction | Material transportation to factory | - | - | - | - | - | - | - |
| Pre-construction | Manufacturing | - | - | - | - | - | - | - |
| Construction | Transportation from factory to site | - | - | - | - | - | - | - |
| Construction | On-site installation | - | - | - | - | - | - | - |
| Operation | Operation | - | - | - | - | - | - | - |
| Operation | Maintenance | - | - | - | - | - | - | - |
| Operation | Repair | - | - | - | - | - | - | - |
| Operation | Replacement | - | - | - | - | - | - | - |
| Operation | Refurbishment | - | - | - | - | - | - | - |
| Operation | Operational water | - | - | - | - | - | - | - |
| Operation | Operational energy | - | - | - | - | - | - | - |
| End of life | Deconstruction or demolition | - | - | - | - | - | - | - |
| End of life | Transportation to disposal site | - | - | - | - | - | - | - |
| End of life | Waste processing | - | - | - | - | - | - | - |
| Beyond lifecycle | Reuse | - | - | - | - | - | - | - |
| Beyond lifecycle | Recycling | - | - | - | - | - | - | - |
| Beyond lifecycle | Recovery | - | - | - | - | - | - | - |
| Beyond lifecycle | Onsite generated electricity exported to grid | - | - | - | - | - | - | - |
| Beyond lifecycle | Offsite renewable energy added to grid | - | - | - | - | - | - | - |
| | (a) Total carbon caused (kg $CO_2e$) | - | - | - | - | - | - | - |
| | (b) Total carbon avoided (kg $CO_2e$) | - | - | - | - | - | - | - |
| | Total Carbon Balance (a-b) | ≤ 0 | - | - | - | - | - | - |
| | **Net Zero Water Criteria** | | | | | | | |
| | (a) Potable water consumed by the project (kLD) | - | - | - | - | - | - | - |
| Water reuse | Off-site water sources (use of reclaimed water) | - | × | - | - | - | - | - |
| Water reuse | On-site water sources: | | | | | | | |
| Water reuse | Captured rainwater (roof) | - | ✓ | - | - | - | - | - |
| Water reuse | Captured storm water runoff (site) | - | ✓ | - | - | - | - | - |
| Water reuse | Captured storm water overflow | - | × | - | - | - | - | - |
| Water reuse | AHU Condensate | - | × | - | - | - | - | - |
| Water reuse | Steam recovery | - | × | - | - | - | - | - |
| Water reuse | Greywater reuse | - | ✓ | - | - | - | - | - |
| Water reuse | Water returned to source | - | × | - | - | - | - | - |
| Water reuse | (b) Total alternative water sources + returned water | - | - | - | - | - | - | - |
| Water reuse | Total Water Balance (a-b) | ≤ 0 | - | - | - | - | - | - |
| | **Net Zero Waste Criteria** | | | | | | | |
| | Waste produced in a year | - | - | - | - | - | - | - |
| | Waste diverted from landfill, incineration and environment | ≥ 90 % | ✓ | - | - | - | - | - |

Note: "-" data not available

Net zero energy, as found in literature, has been divided into three main components: the passive design strategy, the application of active energy-efficient systems to reduce loads, and the adoption of renewable energy systems to meet the demand of the campus. Each of the three components has been subdivided to list the defined strategies that lead to net zero energy.

Net zero carbon, although greatly dependent on energy, enlists the various stages of a building's lifecycle, which contribute to the total carbon footprint of the built environment. Ranging from production, construction, to end of life, and beyond the lifecycle.

Net zero water criteria comprise the water demand of the project and its water reduction and reuse strategies to achieve self-sufficiency.

Net zero waste is described as the balance between the waste produced in a year and the percentage diverted from landfill, incineration environment.

The following inferences were drawn from the comparative study of existing net-zero buildings and campuses in India (Table 1):

- The majority of case studies adopt passive design techniques to reduce energy demand, but commercial buildings still have high energy requirements to maintain optimal comfort levels.
- The most common form of renewable energy in use is solar energy. Other forms of energy are yet to be explored widely in India.
- Cooling dominated countries need to incorporate passive design strategies in combination with energy efficient measures to bring down energy load in order to reduce the size and cost of renewable energy infrastructure.
- This approach lacks to account for emissions, water usage and waste.
- The financial implications of implementing net zero strategies have not been provided and evaluated in this study.
- The study revealed that the majority of net zero buildings in India are currently commercial or institutional, showcasing a need to study diverse building typologies and demands.
- The buildings and campuses selected for this study were included based on their certification under various net zero standards in India, reflecting their commitment to achieving net zero goals. However, due to the absence of a standardized framework across these certifications, many did not fully meet the core principles of net zero as outlined in the literature review, on the basis of which the checklist in Table 1 was prepared and used to benchmark the case studies. Specifically, these buildings did not comply with the Shunya Label's EPI requirement of <10 kWh, revealing inconsistencies in the current certification systems. Therefore, even if you are certified as net zero under IGBC Net Zero Energy Buildings Rating System, you might fail under the BEE Shunya Labelling Programme.

### *2.8 Research Gap and Need for Research*

The architectural scale of buildings, especially tall ones, is insufficient for net-zero design due to limited space for renewable energy systems on facades or roofs (Scognamiglio et al. 2014; Torcellini 2006). While much of the recent attention to net-zero energy neighbourhoods or communities has focused on residential single-family development, a larger potential lies with mixed-use communities such as military bases, universities, or health care campuses (Kallushi et al. 2012). Since a campus is a place with different types of buildings, such as academic, residential, recreational, and assembly. So, energy consumption in such areas is considerable (Kriti Jain & Sumedha Dua, 2023). By consuming less energy, Net Zero communities may protect the environment, advance national security, cut greenhouse gas emissions, increase employment opportunities, and lessen the effects of rising and unstable energy prices (Kallushi et al. 2012; Khurshid et al. Transportation 2011).

The literature emphasizes the need for a widely accepted net-zero definition that considers different local factors. There is a gap in addressing the lack of global standardization, as established in the previously undertaken comparative study of existing net-zero buildings and campuses in India (Table 1). Research is needed to develop standard criteria, metrics, and boundaries that can be universally applied to define net zero, accommodating regional variations, standard calculation processes, and corresponding indicators for net zero evaluation (Aelenei et al. 2013; Deng et al. 2014; Mavrigiannaki et al. 2021).

The study proposes an approach to achieving net-zero sustainability in institutional campus design, considering environmental, technical, and economic factors. The objectives to realize the aim were as follows:

i. To review the existing method of planning and implementing a net-zero strategy in India.
ii. To evaluate various approaches to designing a net-zero campus in India.
iii. To develop an integrated approach to achieving net zero sustainability in campus design, addressing energy, water, waste, and emissions.
iv. To verify the feasibility and effectiveness of the proposed approach compared to existing net-zero methods in India.

## 3. Methodology

The methodology adopted for this research draws on journal articles, books, standards, conference papers, and reports to assess the methods for planning and implementing net-zero principles in India, using case studies of net-zero buildings and campuses. Interviews with experts in architecture, engineering, energy, and sustainability provided the necessary insights due to the lack of existing standards for large institutional campuses. Data from interviews and the literature review have been applied to develop

an integrated checklist covering net-zero energy, carbon, water, waste, and sustainable development. This encompasses design, technological, policy-level, and performance requirements. Subsequently, the checklist is applied to existing campuses attempting net-zero sustainability and rated using a weighted matrix. Validation of the approach involved expert surveys, case studies, and feasibility analyses.

### *3.1 Evaluation of approaches to planning a net-zero sustainable campus*

The experts consulted in this study included three professionals with diverse expertise: an engineer, an architect, and a sustainability consultant with 5 to 25 years of experience. The projects undertaken by them were selected for further analysis.

Twelve preliminary open-ended questions were developed with follow-up questions tailored to each expert's domain. The questions focused on their approach to designing net-zero campuses, solutions for energy, carbon, water, and waste management; challenges faced in India; and reference standards for designing net-zero campuses. The study aimed to gain insights into different approaches to net-zero campus design and implementation, assess current practices, and identify sustainable solutions for the future. The following case studies were studied, and the inferences derived from them were as follows:

i. IIT Kanpur
ii. Reva University, Bengaluru
iii. IIT Jodhpur

These projects were selected for the study because they are among the very few examples of campuses in India where a net-zero application is being implemented. These projects are actively pursuing net zero through technology adoption and infrastructure development, and have set goals to achieve net zero in the next five to ten years.

The preliminary analysis of the collected data indicates that net-zero sustainability has not yet been successfully implemented on institutional campuses. Still, it is being implemented in existing as well as proposed institutes. The following insights were drawn from the case studies:

- Net-zero sustainability can be approached in the design stage. Still, it may take sufficient time after the beginning of operations to achieve a net-zero balance at a site level.
- Every campus project must be designed with consideration of the unique challenges and opportunities presented by its existing conditions.
- Campuses offer many advantages (space, infrastructure, and diverse use) over individual buildings, which can lead to the successful implementation of the net-zero goal. Still, they require an intricate understanding of underlying design, technological, performance, and policy-level efforts to make it possible.

The case studies are further discussed in the benchmarking study of the proposed framework in the following sections.

### *3.2 Development of an integrated approach to planning a net-zero sustainable campus*

Based on the strategies obtained from the expert interviews, the next step was to develop an approach to sub-categorize the strategies, map relationships, and create requirements for each category: Design and Technological/ Performance values (minimum criteria) / Policy-level recommendations.

The type of analysis performed was qualitative - thematic analysis and concept mapping to create the checklist for designing and implementing net zero at a campus level. After the approach was formulated, it was illustrated using case studies of earlier institutional campuses. The process flowchart illustrated in Figure 3 lays out the basis for the proposed approach, and, with the help of standards, codes, and data collected from expert interviews, it branches out further to describe the intricate requirements of a net-zero sustainable campus.

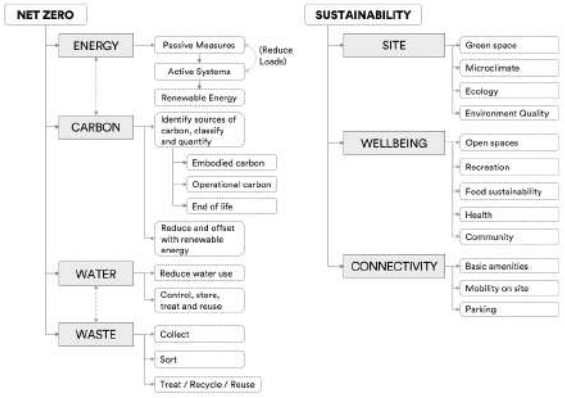


**Figure 3.** Net zero and sustainability measures of planning a campus (source: author)

The flowchart (Figure 3) enforces that there are two interrelated aspects: net zero and sustainability, which demand different requirements. Net zero is concerned with

achieving a balance of the resources used (energy, carbon, water, waste) by a campus and the sustainability of the inhabitants within its surroundings.

### *3.3 Net-Zero Sustainable Campus Criteria Checklist Formulation and Application to Case Studies*

Tables 2, 3, 4, 5, and 6 illustrate the proposed approach to achieving net-zero sustainability on a campus. The checklist comprises five major components: net-zero energy, carbon, water, waste, and sustainable development. It details various sub-criteria in five domains: design/technological, policy level, and performance requirements.

The three case studies have been scored and ranked according to their level of compliance: 3 – fully compliant, 2 – partially compliant, and 1 – not compliant. The mandatory requirements in each category must be met to achieve net zero status; failing which, the project does not qualify as a net zero sustainable campus.

The proposed net zero checklist (Tables 2, 3, 4, 5, and 6) details the requirements that lead to the successful planning and implementation of a net zero sustainable campus. The scores on a scale of 1 to 3 were awarded based on the level of compliance. For example, in the energy section, in site and internal planning, IIT Jodhpur fully complies with the design and technological requirements for orientation, as it orients its longer facades towards N-S relative to the prevailing wind direction. In contrast, IIT Kanpur and REVA University follow the guidelines for certain buildings but not all. So IIT Kanpur scores 3 (fully compliant) and the others 2 (partially compliant) for that particular optional requirement. But for the mandatory requirement for Energy in the Renewable Energy System section, all three case studies score 1 (not compliant) as they are yet to meet 100% energy demand through renewable energy sources. As a fundamental rule of the approach, a project must meet the mandatory criteria to achieve net-zero status successfully. This shows that all case studies fail in the energy segment due to this requirement (Table 4).

Following the ranking, a weighted matrix is used to score and rank each case study's performance according to the developed net zero checklist in Table 7. The five net zero and sustainability components have been weighed at: Energy (51%), Carbon (23%), Water (9%), Waste (7%), and Sustainable development (10%) after applying Analytical Hierarchy Process (AHP) for the level of significance/impact of the respective criteria as inferred from literature review and expert survey.

**Table 2.** Net zero checklist and benchmarking of case studies – Net Zero Energy

| | Criteria | Design / Technological Requirement | Policy Recommendations | Min. Performance criteria/ requirement | IIT Jodhpur | IIT Kanpur | REVA university |
|---|---|---|---|---|---|---|---|
| | | | | Optional/ Mandatory | Ranking | Ranking | Ranking |
| Building Information | Building location | - | - | - | Jodhpur, Rajasthan | Kanpur, Uttar Pradesh | Bengaluru, Karnataka |
| | Climate | | | | Hot and dry | Composite | Temperate |
| | Building Type | | | | Institutional | Institutional | Institutional |
| | Net zero campus type | | | | Near zero | Near zero | Near zero |
| | Grid connection | | | | Connected | Connected | Connected |
| | Site area (acres) | | | | 852 | 1055 | 45 |
| | BUA (sqm) | | | | 8,07,518 | 4,98,927 | 1,46,548 |
| | No. of blocks | | | | 250 | - | 12 |
| | Max. no. of floors | | | | G+3 | G+5 | G+9 |
| | No. of occupants | | | | 14,880 | 15,881 | 12,000 |
| | Annual energy consumption (kWh) | | | | 27 MW | 9.2 MW | 2.5 MW |
| | EPI (kWh/m$^2$/yr) | | | EPI < 10 M | 1 | 1 | 1 |
| | **Net Zero Energy Criteria/Strategy** | | | | | | |
| Passive Design Strategy Adopted | Site and Internal Planning | Orientation of buildings | Hot regions: Align long facades N-S (0° to 30°) with prevailing winds. Cold regions: Orient slightly east of south (15°) with longer axes N-S. | O | 3 | 2 | 2 |
| | | Massing | Building placement: Arrange buildings by height to align with wind flow, and use staggered layouts to | O | 3 | 2 | 1 |

| Criteria | Design / Technological Requirement | Policy Recommendations | Min. Performance criteria/ requirement | IIT Jodhpur | IIT Kanpur | REVA university |
|---|---|---|---|---|---|---|
| | | | Optional/ Mandatory | Ranking | Ranking | Ranking |
| | | enhance it.<br>In hot climates, compact forms (e.g., square plans) reduce heat gain.<br>In cold climates, buildings with a higher perimeter-to-area ratio for higher heat gain. | | | | |
| | Proximity to nearby buildings | Setbacks: Proper distance for natural light and ventilation.<br>Shading: Maximize mutual shading through building forms.<br>Height-to-width ratio: The building height minimal relative to the street width. | O | 3 | 2 | 2 |
| | Per capita green cover | Ensure optimal green space in large-scale developments. | 9 sqm/capita<br>M | 3 | 3 | 1 |
| Optimized building form | Plan depth (in m) | Design depth and fenestrations to maximize useful daylight illuminance (UDI). | O | 2 | 2 | 1 |
| | Aspect ratio of buildings (S.A./V) | Use compact form with a low S/V ratio to minimize heat gain/ loss. | O | 3 | 2 | 1 |
| | Compactness ratio of buildings (W/H) | Compact form is recommended to avoid excess heat gain/loss. | O | 3 | 3 | 2 |
| Advanced envelope | Wall (U value in $W/m^2.k$) | Max. U-factor for opaque external wall to be compliant. | 0.22<br>O | 1 | 1 | 1 |
| | Roof (U value in $W/m^2.k$) | Max assembly U-factors, with insulation integrated into the structural slab, not a false ceiling. | 0.20<br>O | 1 | 1 | 1 |
| | Glazing (U value in $W/m^2.k$ and SHGC) | Vertical fenestration to comply with max. U-factors. | 2.20 (all except cold) 1.80 (cold) 3 (temperate)<br>O | 3 | 1 | 1 |
| | | Vertical fenestration to comply with max. SHGC. | Non-north (0.25 for all) Non-north (0.62 for cold)<br>O | 3 | 1 | 1 |
| Thermal mass | Material used (specific heat capacity J/(kg °C)) | Thermal mass: Use in areas with significant diurnal temperature fluctuations.<br>Passive solar design: Strategically place and disperse thermal mass for effectiveness. | O | 2 | 2 | 2 |
| Solar shading | Vertical shading | East/west windows: Shade with vertical devices.<br>North side: Use vertical shades or internal blinds to block low evening summer sun. | O | 3 | 1 | 1 |
| | Horizontal shading | Use fixed horizontal overhangs on south-facing windows. | O | 3 | 3 | 3 |
| | Length of overhang | - | ≤ 1 m<br>O | 2 | 2 | 2 |
| | Balconies | Semi-outdoor spaces such as balconies can provide shade and protect interior spaces from overheating and climatic variations. | 2.5 - 3 m<br>O | 1 | 2 | 1 |

| Criteria | Design / Technological Requirement | Policy Recommendations | Min. Performance criteria/ requirement | IIT Jodhpur | IIT Kanpur | REVA university |
|---|---|---|---|---|---|---|
| | | | Optional/ Mandatory | Ranking | Ranking | Ranking |
| | Use of landscaping on the east and west facades | Lower buildings: Position deciduous trees on east/west to reduce summer heat and allow winter sunlight. | O | 3 | 3 | 3 |
| Natural Ventilation | Positioning of fenestrations | Windows: Optimize placement, size, and glazing to reduce cooling load.<br>Openings: Place in opposite pressure zones. | O | 3 | 3 | 3 |
| | WWR (%) | Optimize WWR to control heat gain/loss, ensure daylight, and adequate ventilation. | ≤ 40 %<br>O | 1 | 1 | 1 |
| | Operable windows | - | O | 3 | 3 | 3 |
| | Stack effect | - | O | 3 | 1 | 1 |
| | Wind tower | - | O | 1 | 1 | 1 |
| | Earth air tunnel | - | O | 2 | 1 | 1 |
| Thermal Insulation | Insulation in walls | Insulation: Place on the outer side for cooling, and on the inner side for heating.<br>Hot climates: Combine thermal insulation with adequate nighttime ventilation to reduce heat gain | O | 2 | 1 | 2 |
| | Insulation in the roof | | O | 2 | 1 | 2 |
| | Material used | PUF (Polyurethane Foam), XPS (Extruded Polystyrene), EPS (Expanded Polystyrene), Rockwool, and glass wool are commonly used as insulation materials. | O | 1 | 1 | 1 |
| | R-value | Higher R-values signify greater insulation effectiveness. | O | 1 | 1 | 1 |
| | Thickness (in mm) | The first 25 mm offers the highest energy savings; decreases as insulation increases up to 100 mm. | < 100 mm<br>O | 1 | 1 | 1 |
| **Daylighting** | Building orientation and form | East-west axis: Longer buildings improve daylighting and comfort.<br>Exposure: Maximize southern and optimize northern exposure. | O | 3 | 2 | 2 |
| | Window placement and size | Window sizing/ location: Ensure effective daylight penetration.<br>Deeper penetration: placing windows high on walls or in the roof. | O | 3 | 3 | 3 |
| | Floorplate depth | Floor plan depth: Ensure maximum daylight illuminance for above-grade areas.<br>Central courtyards/ atria: bring light into additional areas of large buildings. | O | 2 | 2 | 2 |
| | Floor area receiving daylight requirement | Achieve 100–2,000 lux for at least 90% of the floor area during 90% of daylight hours. | 40-60%<br>O | 1 | 1 | 1 |
| | Visual Light Transmittance (VLT) | Glazing materials used in the building envelope must have a min. VLT value. | 0.27<br>O | 1 | 1 | 1 |
| | Blinds for glare control | Strike a balance between daylight harvesting and glare protection. | O | 3 | 3 | 3 |

| | Criteria | Design / Technological Requirement | Policy Recommendations | Min. Performance criteria/ requirement | IIT Jodhpur | IIT Kanpur | REVA university |
|---|---|---|---|---|---|---|---|
| | | | | Optional/ Mandatory | Ranking | Ranking | Ranking |
| | | Skylights | In locations without windows, use roof monitors and skylights. | O | 1 | 1 | 1 |
| Active Energy Efficient Strategies | **Energy-efficient lighting** | Choice of lighting source and luminaire | Estimate lighting needs based on lux requirements, and choose lamps with optimal life-cycle cost and energy savings. | O | 1 | 1 | 1 |
| | | Lighting power density (W/m$^2$) | Designers should target an LPD reduction of at least 50% of the ECBC value. | 6 - 11.2<br>O | 1 | 1 | 1 |
| | **Advanced lighting control** | Standalone systems | | | | | |
| | | Occupancy control | - | O | 1 | 1 | 1 |
| | | Lighting control | - | O | 1 | 1 | 1 |
| | | Shading control | - | O | 3 | 1 | 1 |
| | | Network control system | - | O | 1 | 1 | 1 |
| | **Efficient appliances** | Solar off-grid appliances | | | | | |
| | | Solar internal lighting | - | O | 1 | 1 | 1 |
| | | Solar street lighting | - | O | 1 | 1 | 1 |
| | | Solar cookers | - | O | 1 | 1 | 1 |
| | | Solar water heaters | - | O | 3 | 3 | 3 |
| | | Star-rated refrigerators | - | O | 1 | 1 | 1 |
| | | High EER Room air conditioners | - | O | 1 | 1 | 1 |
| | | Star-rated Distribution Transformer | - | O | 1 | 1 | 1 |
| | | Star-rated Tubular Fluorescent Lamps | - | O | 1 | 1 | 1 |
| | | Star-rated ceiling fans | - | O | 1 | 1 | 1 |
| | | Star-rated electric geysers | - | O | 1 | 1 | 1 |
| | | Star-rated television | - | O | 1 | 1 | 1 |
| | **Load management** | Demand response program | - | O | 3 | 1 | 1 |
| | | Energy storage system | - | O | 2 | 1 | 1 |
| | | Building automation system | - | O | 1 | 1 | 1 |
| | | Peak Shaving | - | O | 1 | 1 | 1 |
| | **Mechanical ventilation** | HVAC Performance Index in kWh/m$^2$/yr | - | - | - | - | - |
| | | Radiant cooling | - | O | 1 | 2 | 1 |
| | | Ceiling fans | - | O | 3 | 3 | 3 |
| | | Evaporative cooling | - | O | 1 | 1 | 1 |
| | | Tri-Generation | - | O | 1 | 1 | 1 |
| | | BMS integration | - | O | 2 | 1 | 1 |
| | **Energy storage system** | Battery Energy Storage System | - | O | 2 | 1 | 1 |
| | | Thermal Energy Storage System | - | O | 1 | 1 | 1 |
| | | Solar PV + Battery Micro grids | - | O | 3 | 2 | 2 |

| | Criteria | Design / Technological Requirement | Policy Recommendations | Min. Performance criteria/ requirement | IIT Jodhpur | IIT Kanpur | REVA university |
|---|---|---|---|---|---|---|---|
| | | | | Optional/ Mandatory | Ranking | Ranking | Ranking |
| Renewable Energy Systems | **Energy demand met (%)** | - | - | 100% M | 1 | 1 | 1 |
| | **Units generated/ year (kWh)** | - | - | - | - | - | - |
| | **On-site renewable energy (%)** | - | - | M | 3 | 3 | 3 |
| | **Offsite renewable energy (%)** | - | - | O | 3 | 3 | 1 |
| | **Net Surplus Energy (kWh)** | - | - | O | 1 | 1 | 1 |
| | **Type of RE employed:** | | | | | | |
| | **Solar Photovoltaics** | Solar power plant | - | M | 3 | 3 | 1 |
| | | Grid connected | - | | 3 | 3 | 3 |
| | | Standalone systems | - | | 3 | 1 | 1 |
| | **Wind turbines** | Wind energy generation system | - | O | 3 | 1 | 1 |
| | **Biomass** | Biogas | - | O | 3 | 3 | 3 |
| | **Hydropower** | Pumped storage | - | O | 1 | 1 | 1 |
| | | Impoundment (dams) and diversion (river) | - | O | 1 | 1 | 1 |
| | **Other** | Geothermal | - | O | 1 | 1 | 1 |
| | | | | **TOTAL SCORE** | 144 | 118 | 108 |

**Table 3.** Net zero checklist and benchmarking of case studies – Net Zero Carbon

| | Net Zero Carbon Criteria/Strategy: | | | | | | |
|---|---|---|---|---|---|---|---|
| | Zero emissions achieved in every lifecycle stage | | | | | | |
| Preconstruction | Raw material extraction | Create a framework for carbon footprint assessment and create a carbon inventory for each phase. | SCOPE 1 & 2<br>• Maximizing energy efficiency through passive architecture elements and the latest Technologies<br>• Maximizing deployment of on-site renewables and use of off-site green power<br>• Maximizing water conservation through the use of efficient plumbing fixtures & systems<br>• Reduction in specific waste generation<br>SCOPE 3<br>• Promoting low carbon building materials & construction technologies<br>• Embracing clean, safe and connected mobility (e.g., E-vehicles)<br>• Reducing emissions due to travel – Work from home, Virtual event<br>After reducing the emission intensity, the projects shall adopt measures to abate 100% of the carbon emissions through:<br>• Building carbon sinks and carbon capture storage systems<br>e.g., Mass plantation - A fully grown tree captures ~20 kg of $CO_2$ / year<br>• Investments in off-site | M | 3 | 3 | 3 |
| | Material transportation to factory | | | | | | |
| | Manufacturing | | | | | | |
| Construction | Transportation from factory to site | | | | | | |
| | On-site installation | | | | | | |
| Operation | Operation | | | | | | |
| | Maintenance | | | | | | |
| | Repair | | | | | | |
| | Replacement | | | | | | |
| | Refurbishment | | | | | | |
| | Operational water | | | | | | |
| | Operational energy | | | | | | |
| End of life | Deconstruction or demolition | | | | | | |
| | Transportation to disposal site | | | | | | |
| | Waste processing | | | | | | |
| Beyond lifecycle | Reuse | | | | | | |
| | Recycling | | | | | | |
| | Recovery | | | | | | |
| | Onsite generated electricity exported to grid | | | | | | |
| | Offsite renewable energy added to grid | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | renewables<br>• Purchase of carbon credits, green bonds, energy saving certificates | | | | |
| | Scope 1 emissions ($tCO_2$) | - | - | - | - | - | - |
| | Scope 2 emissions ($tCO_2$) | - | - | - | - | - | - |
| | Scope 3 emissions ($tCO_2$) | - | - | - | - | - | - |
| | Emissions / sqm | - | - | 200-300 kg $CO_2$/sqm.<br>O | 1 | 1 | 3 |
| | Per capita $CO_2$ emissions p.a. | - | - | < 1.18 tons<br>O | 1 | 1 | 3 |
| | (a) Total carbon caused (kg $CO_2e$) | - | - | - | - | - | - |
| | (b) Total carbon avoided (kg $CO_2e$) | - | - | - | - | - | - |
| | TOTAL CARBON BALANCE (a-b) | - | - | ≤ 0<br>M | 1 | 1 | 1 |
| | | | | **TOTAL SCORE** | 6 | 6 | 10 |

**Table 4.** Net zero checklist and benchmarking of case studies – Net Zero Water

| | Net Zero Water Criteria | | | | | | |
|---|---|---|---|---|---|---|---|
| **Water consumed** | (a) Potable water consumed by the project (kLD) | Municipal water, bore well water (even if quality is not potable), tanker water purchased | - | - | - | - | - |
| | Water use reduction strategies employed | Use of water efficient technologies | - | -<br>O | 3 | 3 | 3 |
| **Water reuse** | Off-site water sources (use of reclaimed water) | Treated Greywater | - | -<br>O | 1 | 1 | 1 |
| | On-site water sources: | Captured rainwater (roof) | - | ≥ 90 %<br>O | 3 | 3 | 3 |
| | | Captured storm water runoff (site) | - | ≥ 90 %<br>O | 3 | 3 | 3 |
| | | AHU Condensate | - | -<br>O | 1 | 1 | 1 |
| | | Steam recovery | - | -<br>O | 1 | 1 | 1 |
| | | Treated Greywater | - | -<br>O | 3 | 3 | 3 |
| | Water returned to source | Recharge the local aquifer by capturing rainwater from roof and non-roof | - | -<br>O | 1 | 1 | 1 |
| | (b) Total alternative water sources + returned water | | - | - | - | - | - |
| | Near Net Zero Water | Water Performance Ratio > 0.75 & < 1.0 | - | > 0.75 & < 1.0<br>O | - | - | - |
| | Net Zero Water | Ratio of Water Back to Source (WBS) for Use = 1.0 | - | 1<br>M | 1 | 1 | 1 |
| | Water Positive (Platinum) | Ratio of Water Back to Source (WBS) for Use > 1.10s | - | > 1.1<br>O | - | - | - |
| | TOTAL WATER BALANCE (a-b) | | | ≤ 0<br>M | 1 | 1 | 1 |
| | | | | TOTAL SCORE | 18 | 18 | 18 |

**Table 5.** Net zero checklist and benchmarking of case studies – Net Zero Waste

| | Net Zero Waste Criteria | | | | | |
|---|---|---|---|---|---|---|
| Waste processing (operation phase) | Green procurement policy | Implement a green procurement policy at organizational level for procuring green products and materials during O&M phases | - O | 1 | 1 | 2 |
| | Solid waste | Sort and recycle - paper, soft plastic, glass bottles, aluminum cans | - O | 3 | 3 | 3 |
| | Organic waste | Organic waste composting at site | - O | 3 | 3 | 3 |
| | | Organic waste converted into biogas | - O | 3 | 3 | 3 |
| | Horticulture waste | Composted and reused / sold (wood) | - O | 3 | 3 | 3 |
| | E-waste and hazardous waste | Auctioned / Recycled | - O | 3 | 3 | 3 |
| | Chemical waste | Sort and recycle | - O | 3 | 3 | 3 |
| | Centralized sorting facility | Allocate centralized facility to store, segregate and handover collected waste to the identified recycle vendors. | - O | 3 | 3 | 3 |
| Waste management strategy (construction phase) | Use of green materials for construction | Eco-labelled Products, C&D waste, rapidly renewable materials, salvaged materials, recycled materials, alternative materials, bio based materials (% of total material cost) | 10 % O | 2 | 1 | 2 |
| | Segregation of Construction Waste | Facilitate segregation of C&D at source to encourage reuse or recycling of materials. | - O | 1 | 1 | 1 |
| | Incorporation of modularity and recyclability by design | Use Modular and/ or Prefabricated structure and Recycled content & Recyclable Materials | - O | 1 | 1 | 1 |
| | Sustainable demolition plan | For existing structures | - O | 1 | 1 | 1 |
| | Reduction of waste generation | Practices that reduce waste generation during construction | - O | 1 | 1 | 1 |
| | Reuse | Promote recycling of the waste products produced throughout the project | - O | 3 | 3 | 3 |
| | Recycle | Facilitate recycling of waste | - O | 3 | 3 | 3 |
| | Awareness | Initiate a sense of awareness amongst stakeholders | - O | 3 | 3 | 3 |
| | Waste produced | | - | - | - | - |
| | Quantity of waste sent to landfill | Qty of waste - (Qty. of waste reused + Qty of waste recycled) | - | - | - | - |
| | Waste diverted from landfill, incineration and environment (%) | Qty of waste diverted / Total qty of waste generated | | | | |
| | Near Net Zero Waste | - | 75 - 84 O | - | - | - |
| | Net Zero Waste | - | 85 - 94 M | 1 | 1 | 1 |
| | Net Zero Waste Platinum | -s | ≥ 95 O | - | - | - |
| | | | TOTAL SCORE | 38 | 37 | 39 |

**Table 6.** Net zero checklist and benchmarking of case studies – Development Quality

| | Development Quality | | | | | |
|---|---|---|---|---|---|---|
| Site Planning | Storm Water Management | Post development run-off rate and quantity from 5-year 24-hour design should not exceed the pre-development peak run-off rate and quantity. | M | 1 | 1 | 1 |
| | | > 90% of storm water quantity on site should be managed using sustainable urban drainage systems. | M | 3 | 1 | 3 |
| | Maintain existing site features | Ensure that 25-75% of the site area under existing natural features on site like water bodies, dense, mix-species tree clusters and contours are preserved. | M | 2 | 2 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Manage construction activities to reduce environmental damage | During construction, preserve and protect all the natural drainage channels on site. | M | 1 | 1 | 1 |
| | | Confine construction activities to pre-designated areas (staging) and adopt soil erosion and sedimentation control strategies (during construction) on site. | M | 1 | 1 | 1 |
| | Preserve and protect landscape on site | Increase existing vegetation cover on site by more than 25% by ensuring plantation of native trees and shrubs. | M | 3 | 3 | 3 |
| | | Reapply top soil in more than 75% of the landscape areas. | M | 1 | 1 | 1 |
| Energy | Smart mini-grids | Integration of various energy sources with prioritization to Renewable Energy Sources (RES) and dynamic balancing of energy supply and varying energy efficient loads of the Smart Mini-Grids | M | 2 | 1 | 1 |
| | | Automatic load control and demand-side management employed for shared services. | O | 1 | 1 | 1 |
| | Passive urban design for outdoor thermal comfort | Adopt passive design strategies so that the outdoor temperature is reduced | O | 3 | 3 | 3 |
| | | Street layouts and buildings have been designed to provide minimum obstruction to local wind flow | O | 3 | 3 | 3 |
| | Operation and maintenance | Metering and Sub metering of energy systems | O | 2 | 1 | 1 |
| Water and wastewater | Quality of water | Ensure quality of potable water / non potable water as per relevant standards | M | 3 | 3 | 3 |
| | | Ensure quality of captured rainwater for storage and recharge as well as recycled water for use comply with relevant standards | M | 3 | 3 | 3 |
| | STP/waste water treatment | Facility to comply with CPCB norms | M | 3 | 3 | 3 |
| | Rainwater recharge | Rainwater falling on site is recharged through appropriate filtration measures | M | 1 | 3 | 3 |
| | Fixtures | All fixtures on site - in all buildings - (WCs, urinals, showers and kitchen and lavatory faucets) should be low-flow fixtures | O | 3 | 3 | 3 |
| | Operation and maintenance | Metering and sub metering of the plumbing network | O | 2 | 1 | 1 |
| | | Install a remote control and monitoring system throughout the plumbing network. | O | 1 | 1 | 1 |
| Solid waste management | Use of sustainable construction materials | Use of at least 5% recycled waste (plastic waste) in road construction for at least 50-90% of the roads on site | O | 1 | 1 | 1 |
| | Construction and demolition waste management | Develop a construction waste management plan, for safe handling and segregated storage of construction waste | M | 1 | 1 | 1 |
| | | Adopt strategies to recycle and reuse construction and demolition waste on site | M | 1 | 1 | 1 |
| Transport | Provision of footpaths and/ or bicycling tracks and for safe interaction of NMT traffic with motorized traffic | All roads should have footpaths/sidewalks and cycle tracks. | M | 3 | 3 | 3 |
| | | Continuous, wide, and easily accessible pathways should be provided for bicycles, pedestrians, and walkways. | M | 3 | 3 | 3 |
| | Road network planning | Street network planning to be done in a manner to promote safety, community living, efficiency, walking and cycling. | M | 3 | 3 | 3 |
| | | Measures to control speed of vehicular traffic should be implemented on site. | M | 3 | 3 | 3 |
| | Parking for cars and two wheelers | Total parking area allocated for cars and two wheelers should not exceed the area required by the local bye laws/local authority norms. | M | 3 | 3 | 3 |
| | | Dedicated parking space for physically disabled people | M | 3 | 3 | 3 |
| | Collective transport services | Running collective transport services (route, stops, frequency, and capacity) for intra-site movement. | M | 3 | 3 | 3 |
| | | Providing connectivity to closest transportation nodes. | M | 3 | 3 | 3 |
| | Electric charging infrastructure for vehicles | Electric charging infrastructure provided for at least 10% of cars and bikes parked on site. | O | 1 | 1 | 1 |
| Socio-economic | Facilities for construction workers | NBC 2005's safety regulations must be followed on the construction site. | M | 1 | 1 | 1 |
| | | Clean drinking water and sanitary restrooms must be available to all construction workers on the job site. | M | 1 | 1 | 1 |
| | | Clean and hygienic lodging options are required for construction personnel. | M | 1 | 1 | 1 |
| | Social infrastructure in | Design of the development should be done according to guidelines on universal accessibility, including provision of disable-friendly public toilets. | M | 1 | 1 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| development | Create environmental awareness through imparting information like display boards. | M | 1 | 1 | 1 |
| | Dedicated resting areas and toilets for service staff must be provided. | M | 3 | 3 | 3 |
| Food production on site | Plan food production for more than 5-10 % of the total landscape area or equivalent (vertical farming etc.) | M | 3 | 1 | 3 |
| | | **TOTAL SCORE** | 78 | 73 | 77 |
| | | **GRAND TOTAL** | 284 | 252 | 252 |
| Note: "-" data not available | | | | | |

**Table 7.** Net zero approach: evaluation of case studies

| | | | IIT JODHPUR | | IIT KANPUR | | REVA UNIVERSITY | | DUMMY (IDEAL) | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **S. No.** | **Net Zero Criteria** | **Weightage** | **Score** | **Weighted Score** | **Score** | **Weighted Score** | **Score** | **Weighted Score** | **Score** | **Weighted Score** | |
| **1** | **ENERGY** | **51%** | | | | | | | | | |
| 1.1 | Passive design | 33 | 77 | 2541 | 62 | 2046 | 57 | 1881 | 108 | 3564 | Failing in mandatory criteria |
| 1.2 | Active measures | 14 | 42 | 588 | 35 | 490 | 34 | 476 | 87 | 1218 | |
| 1.3 | Renewable energy generation | 4 | 26 | 104 | 22 | 88 | 18 | 72 | 36 | 144 | Failing in mandatory criteria |
| 2 | CARBON | 23% | | | | | | | | | |
| 2.1 | Carbon footprint reduction | 19 | 5 | 95 | 5 | 95 | 9 | 171 | 9 | 171 | |
| 2.2 | Carbon balance | 4 | 1 | 4 | 1 | 4 | 1 | 4 | 3 | 12 | Failing in mandatory criteria |
| **3** | **WATER** | **9%** | | | | | | | | | |
| 3.1 | Water use reduction | 7.5 | 17 | 128 | 17 | 128 | 17 | 128 | 27 | 203 | Failing in mandatory criteria |
| 3.2 | Water balance | 1.5 | 1 | 2 | 1 | 2 | 1 | 2 | 3 | 5 | Failing in mandatory criteria |
| **4** | **WASTE** | **7%** | | | | | | | | | |
| 4.1 | Waste management | 6 | 37 | 222 | 36 | 216 | 38 | 228 | 48 | 288 | |
| 4.2 | Waste avoided | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | Failing in mandatory criteria |
| **5** | **SUSTAINABLE DEVELOPMENT** | **10%** | | | | | | | | | |
| 5.1 | Site planning | 0.5 | 12 | 5 | 10 | 5 | 12 | 5 | 21 | 9 | |
| 5.2 | Energy | 2.0 | 11 | 22 | 9 | 18 | 9 | 18 | 15 | 30 | |
| 5.3 | Water and wastewater | 0.9 | 16 | 15 | 17 | 16 | 17 | 16 | 21 | 19 | |
| 5.4 | Solid waste management | 1.0 | 3 | 3 | 3 | 3 | 3 | 3 | 9 | 9 | |
| 5.5 | Transport | 2.2 | 25 | 55 | 25 | 55 | 25 | 55 | 27 | 60 | |
| 5.6 | Socio-economic | 3.4 | 11 | 37 | 10 | 34 | 12 | 41 | 21 | 71 | |
| | TOTAL WEIGHTAGE | 100% | 285 | 3821 | 254 | 3199 | 254 | 3100 | 438 | 5805 | 100% |
| | Ranks | | 66 | R1 | 55 | R2 | 53 | R 3 | 100 | | |
| | PASS/FAIL | | FAIL | | FAIL | | FAIL | | PASS | | All case studies are failing in achieving mandatory net zero criteria |
| | RANKING | | | | | | | | | | |
| | 3 | Fully compliant | | | | | | | | | |
| | 2 | Partially compliant | | | | | | | | | |
| | 1 | Not compliant | | | | | | | | | |

Table 7 shows that all three case studies failed to meet the requirements of the proposed approach, especially in the mandatory net-zero requirements. This indicates a significant gap in the extent of net zero integration currently being adopted in India.

The following inferences have been drawn from the analysis of existing net zero campuses in India after applying the net zero sustainable campus's proposed approach:

- The case studies assessed here do not meet the mandatory requirements of the proposed framework, highlighting a significant gap in the current efforts to implement net zero in India to fulfill the strategy.
- As all three case studies are still in the process of implementing net-zero principles, their current metrics do not meet the criteria, but once the infrastructure is fully developed, they might successfully achieve net zero.

Table 7 shows that there is no successful example of implementing the net-zero strategy holistically on a campus in India. This warrants in-depth research into the barriers that lead to the above-mentioned challenges and the proposal of solutions to mitigate them.

## 4. Results

The evaluation of case studies against the proposed net-zero sustainable campus approach in India reveals a significant gap in compliance with mandatory requirements, particularly in achieving net-zero principles. Despite ongoing efforts to implement net-zero strategies, the current metrics for the assessed campuses fall short, underscoring the need for comprehensive solutions to address key challenges across energy, carbon, water, waste, and sustainable development. The criteria where the case studies failed are given in Table 8.

Researchers and professionals alike must take special care to address these challenges when planning a net-zero, sustainable campus to propose feasible solutions for the successful implementation of net-zero objectives. Many underlying causes, such as design and planning, technological, financial, and regulatory barriers, cause these challenges. Decisions made in the process have direct or indirect implications for the cost of projects (Saini et al. 2021).

## 5. Conclusion

In light of urgent environmental issues and the need for sustainable growth, this research has clarified the necessity of adopting net-zero sustainability on Indian institutional campuses. A thorough methodology that included expert interviews, case studies, and a literature review resulted in a comprehensive framework for navigating the challenges of achieving net-zero sustainability. This research sheds light on the adoption of the net-zero strategy in India today, highlighting the major obstacles to overcome and the possibility of revolutionary progress with determined efforts. Analyzing several strategies for creating net-zero, sustainable campuses shows that integration is feasible, though it requires effort and a thorough understanding of many variables.

The suggested method for creating net-zero, sustainable campuses emphasize stakeholder collaboration, ongoing performance monitoring, and the integration of technology and policy. Nevertheless, comparing the case studies to the suggested methodology reveals a significant compliance gap, highlighting the need for further investigation and validation. All things considered, this study advances the conversation on sustainable urban development in India by providing a roadmap for achieving net-zero sustainability on college campuses and promoting social cohesion, environmental resilience, and economic viability.

**Table 8.** Challenges in achieving net zero in case studies

| | |
|---|---|
| Energy | Achieving epi of 10 kwh/m$^2$/yr. |
| | Adopting advanced lighting control as an active energy-efficient measure |
| | Use of efficient appliances |
| | Lack of load management systems |
| | Implementing efficient mechanical ventilation systems |
| | Lack of energy storage systems |
| | Use of diverse renewable energy generation systems |
| | 100% energy demand met with renewable sources (net zero) |
| | Generating surplus renewable energy to offset carbon |
| Carbon | The carbon footprint framework omits scope three emissions. |
| | Reducing emissions/sqm and per capita emissions |
| | Reaching zero carbon balance by offsetting carbon (net zero principle) |
| Water | Achieving net zero through alternative water sources and reuse. |
| Waste | Use of green products and materials during construction and operation |
| | Implementing waste management strategies during the construction phase |
| | Greater than 85% waste diverted from landfill, incineration, and the environment (net zero principle) |
| Sustainable Development | Management of construction activities to reduce environmental impact |
| | Demand side Management and automatic control of loads for standard services |
| | Metering and sub-metering of energy and plumbing systems |

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# Tribal Museums:
## A Vessel for Conservation or Misrepresentation of the 'Cultural Other?'

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**Abstract:** Exploring the veracity of misrepresentation of tribal culture through ethnographic exhibits that, in effect, construct a 'cultural other', this article discusses the critical role of tribal museums in negotiating marginalisation of these communities. By questioning the purported role of cultural institutes in promoting and conserving culture and tradition, this research focuses on the representation of the dwellings of the Sahariyas, a Particularly Vulnerable Tribal Group in Madhya Pradesh, India. A comparative analysis based on visits to three tribal museums in Madhya Pradesh and ethnographic work on the Sahariya Tribe in Agraa, Sheopur, reveals a disconnect between the representations of their culture in the exhibits and the community's lived experiences on the ground. The findings provide a basis for a critical examination of claims to the authenticity of tribal-built heritage through displays of their lifeworlds and expose the construction of an identity that negates their lived reality. This paper argues that such forms of museumification promote a fossilized, even misleading, vision of the community that popularizes exoticism, creating a binary between the tribal and the non-tribal in the popular imagination of the audience for these displays. The inaccurate visual construction of tribal identity leads to a further marginalisation of these social groups and hinders their seamless integration with mainstream society.

**Keywords:** Sahariya Tribe, Tribal Museums, Ethnographic Displays, Marginalisation, Cultural Other

**सार:** नृवंशविज्ञान प्रदर्शनों के माध्यम से आदिवासी संस्कृति के गलत प्रतिनिधित्व की सत्यता की खोज करते हुए, जो वास्तव में एक 'सांस्कृतिक अन्य' का निर्माण करते हैं, यह लेख इन समुदायों के हाशिए पर जाने की स्थिति से निपटने में आदिवासी संग्रहालयों की महत्वपूर्ण भूमिका पर चर्चा करता है। संस्कृति और परंपरा को बढ़ावा देने और संरक्षित करने में सांस्कृतिक संस्थानों की कथित भूमिका पर सवाल उठाते हुए, यह शोध भारत के मध्य प्रदेश के विशेष रूप से कमजोर आदिवासी समूह के रूप में नामित सहरिया के आवासों के प्रतिनिधित्व पर केंद्रित है। मध्य प्रदेश के तीन आदिवासी संग्रहालयों की यात्राओं और श्योपुर के आगरा में स्थित सहरिया जनजाति पर नृवंशविज्ञान संबंधी कार्यों पर आधारित एक तुलनात्मक विश्लेषण से पता चलता है कि प्रदर्शनों में उनकी संस्कृति के प्रतिनिधित्व और जमीन पर समुदाय के जीवित अनुभवों के बीच एक अलगाव है। निष्कर्ष उनके जीवन की दुनिया के प्रदर्शनों के माध्यम से आदिवासी निर्मित विरासत की प्रामाणिकता का दावा करने के लिए एक महत्वपूर्ण नज़र का आधार प्रदान करते हैं और एक ऐसी पहचान के निर्माण को उजागर करते हैं जो उनकी जीवित वास्तविकता को नकारती है। इस शोधपत्र में तर्क दिया गया है कि संग्रहालयीकरण के ऐसे रूप समुदाय की एक जीवाश्म, यहां तक कि भ्रामक, दृष्टि को बढ़ावा देते हैं जो विदेशीपन को लोकप्रिय बनाता है, जिससे लोकप्रिय कल्पना में आदिवासी और गैर-आदिवासी की द्विआधारी छवि बनती है। आदिवासी पहचान के गलत दृश्य निर्माण से इन सामाजिक समूहों को और अधिक हाशिए पर धकेला जाता है और मुख्यधारा के समाज के साथ उनके सहज एकीकरण में बाधा उत्पन्न होती है।

**मुख्य शब्द:** सहरिया जनजाति, जनजातीय संग्रहालय, नृवंशविज्ञान प्रदर्शन, हाशियाकरण, सांस्कृतिक अन्य

## 1. Tribal Museums: Shaping the Narrative

Tribal museums were conceptualised as repositories of Adivasi communities' cultural heritage, aiming to represent their vulnerable voices and diverse socio-cultural and socio-economic dimensions. As multidimensional institutions dedicated to preserving and promoting tribal lifeworlds, conserving their identities and enhancing cultural integration, tribal museums play an essential role in safeguarding these cultures by keeping their history and the cultural ethos alive. They have also become platforms for disseminating knowledge, encouraging interactions, and harmoniously connecting diverse worlds.

However, in recent times, there has been an overwhelming focus on showcasing the tribal lifeworld in the country to capture the public's imagination and introduce tribal culture. Interestingly, no other ethnic group has been given such importance despite the diverse and culturally rich ethnic groups in India. Notwithstanding the significant role played by the tribal museums, questions of accurate representation of tribal cultures need to be raised in the light of "museumification," a term coined by American Sociologist F. Schurmann (Oxford English Dictionary, n.d.), of the tribes and the concept of "cultural other" promoting further marginalisation (Karnik 1998, Sebastian 2015). The concept of tribe and its image as primitive were laid during the rise of colonial ethnography, leading to their representation in ethnographic displays. Bates and Ikegame (2024, 2) point out that dioramas were a common method of representation of Indian people in colonial times. They further state how Indians were considered a different species of humanity, and observing

these primitive people in their traditional setting was "regarded as the gold standard of authenticity when it came to the representation of the other." Discussing the conceptualisation of the category "tribal" and the impulse to construct the narrative of the "collected Other," Karnik (1998, 276) states:

> The phrase 'museumising' indicates the presence of a range of problems implicated in the category, tribal: it emerges from the politics of viewing and from a contradiction at the heart of ethnic museums; that ethnic cultures lack the potential for transformation and therefore need to be preserved; and that the irresistible forces of modernity have radically altered tribal cultures. The paradox requires both historicising and unpacking in museum discourses so that tribal museums remain aware of the paradox and display or narrate it at all times. Another long-standing paradox or self-reflexivity, which is inherent in post-colonial ethnographic writing, informs the contouring of this problematic: how does one speak of the Other, without essentialising, appropriating, or falling between representation and appropriation?

Galla and Paulo (2016) further elaborate on the phenomenon of museumisation in the production of stereotypical construction of the Other through representation of indigenous peoples "in the old anthropological time frames." In the context of the construction of cultural other, Sebastian (2015, 40) also comments that "the anthropological gaze is intimately linked to the notion of the exotic."

Focusing on ethnographic displays, this article argues that the phenomenon of museumification holds in the present Indian context and that tribal museums participate in the process of othering by misrepresenting tribal cultures. It further reflects on this inauthentic representation of these displays in shaping the narrative of the Other. The research primarily employs a qualitative, interpretive methodology to draw specific inferences and conclusions. Through a comparative analysis of dwellings, this research explores the representation of the Sahariya Tribe's built environment in museums and the current sites of its dwelling spaces in Agraa, Sheopur, Madhya Pradesh. To develop a better understanding of the spatial dimension, I visited three tribal museums in Madhya Pradesh in December 2019 as the first source of information to observe and collect data on the dwellings:

A. Indira Gandhi Rashtriya Manav Sangrahalaya, Bhopal
B. Tribal Museum, Bhopal, and
C. Sahariya Museum, Sheopur Fort, Sheopur

Exploring the role of museums in constructing identities, photographs of museum exhibits are used as a research tool to understand the built environment of the Sahariya Tribe. Photographs have been an important source of ethnographic data gathering. Kharel (2015, 149) comments on the recognition of such images as "true in the sense that it holds a visual trace of a reality the camera was pointed at." Collected data, in the form of printed photographs, of dwellings was shared with 80 participants of the tribe. The research also employed on-site focus group discussions and unstructured interviews with tribal people, forest officers, and NGOs to validate the authenticity of the displays.

## 2. Museums as Sites of Learning: Understanding the Spatial Construct

The museums mentioned above have departed from the collection of objects. They are also focusing on the built environment and its intricate relation to the everyday lives of the tribes. The connection of the spatial dimension to rituals, festivals, occupation, and other everyday activities introduces the complexity and richness of the tribal legacy. It contributes to the creation of new knowledge by holistically understanding these communities.

**A.** Indira Gandhi Rashtriya Manav Sangrahalaya, Bhopal - The website of Indira Gandhi Rashtriya Manav Sangrahalaya (IGRMS n.d.) states that it is one of the largest and leading anthropological museums in India and 'the IGRMS, through its exhibitions and salvage activities, demonstrates the aesthetic qualities of India's traditional life styles." IGRMS, also known as the Museum of Man, presents an integration of India's diverse cultures. The indoor museum comprises 12 galleries that highlight bio-cultural evolution, ethnic art, rituals, and more. The open-air exhibition, Tribal Habitat, features full-scale prototypes of original dwellings from different ethnic groups in India. The collection showcases two tribes of Madhya Pradesh, the Agaria and the Bhil. The dwellings narrate the lives of these various tribes through displays of household objects, everyday activities, and rituals. The museum provides a broader context of tribal culture in India; however, there was a dearth of specific information about Sahariya dwellings or any aspect of their cultural lives.

**B.** Tribal Museum, Bhopal - It focuses on artifacts of seven tribes of Madhya Pradesh,

namely Baiga, Bhariya, Bhil, Gond, Kol, Korku, and Sahariya. The Tribal Life Gallery showcases realistic full-sized models of the tribes' dwellings. Another gallery focuses on stories of rituals and worship through art installations. Everyday life is presented through artefacts and cultural symbols that convey generational wisdom and meanings. It showcases the art, traditions, daily life, and customs of these indigenous groups through immersive, interactive displays. The museum allows visitors to carry their cameras for a fee. The museum has exhibition galleries and an Open-Air Theatre, and showcases tribal art, life, mythology, and prototypes of original dwellings of tribes. It also has an auditorium that regularly showcases cultural performances by tribal artists. There is an attempt to create a participatory experience that engages visitors through well-curated spaces. Despite the focus on Sahariyas, there is no documentation of the data-collection process for built-environment displays. An informal discussion with museum staff revealed that other tribe members helped build these dwellings; however, no concrete evidence was provided to verify the claim.

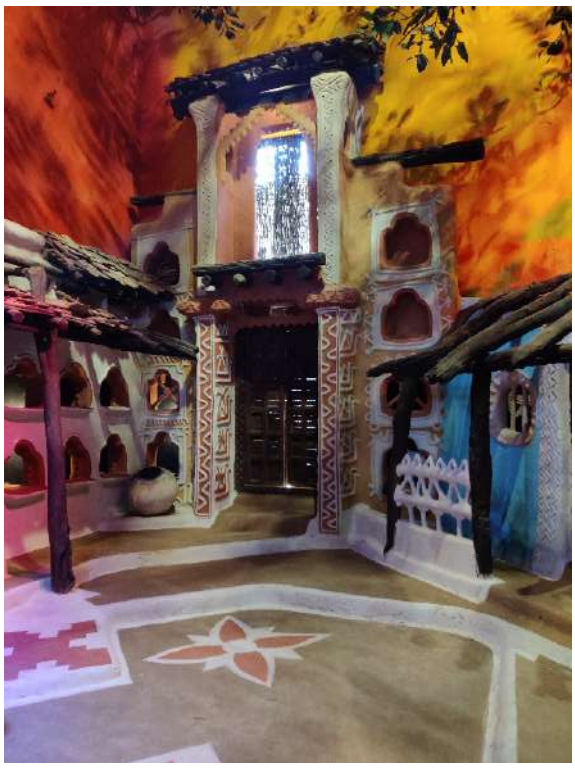

**Figure 1.** Life-sized exhibit of a Sahariya courtyard, Tribal Museum, Bhopal (own photo).

Unlike other houses shown in the museum, this exhibit focuses on the courtyard surrounded by four different exteriors, creating an image of house-like structures displaying intricate artwork. Figure 1 shows the level changes in the courtyard leading to the doors of three houses. The façades are depicted as single- and double-storeyed structures; the roofs are made of wooden logs serving as structural elements, with stone pieces as a top layer. The wooden doors are intricately carved and decorated. One of the dwellings is shown with circular windows, and the side wall serves as a support for the wooden log beam (Figure 2). Decorated niches for holding pots and other objects are also visible. There is an abundance of white, blue, earthy red (gerua), and brown colours. However, the internal spatial details of the dwellings are not part of the exhibit. In another gallery, information about the Sahariya worship area is provided, and a tree with a diya (oil lamp) is shown, representing their belief in not praying in temples (Figure 3).

**Figure 2.** Details of artwork on the side wall, Tribal Museum, Bhopal (own photo).

**Figure 3.** Detail of Worship Area, Tribal Museum, Bhopal (own photo).

Bates and Ikegame (2024, 13-14) argue that the Tribal Museum in Bhopal is taking a new direction that many state governments are keen to follow. They further comment:

> Although some critics have described the museum as 'Disneyeque', it clearly marks a turning point—ethnographic museums can now cease to be places for observation as an outsider and instead become spaces in which one can immerse oneself in tribal culture from the inside. However, this does not immediately mean that tribal cultures have been integrated into the 'national' culture. It is arguably more an indication that the tribal 'exotic' has gained a much broader audience by being made easier to consume.

The display of material culture, the set decoration, and lighting at Tribal Museum, Bhopal, engulf you in a world where the exhibits are used as props for selfies and invoke a feeling of a bygone era, of people frozen in the past. The (mis)representation of lived realities aims to fill the gap between the unknown and the known; unfortunately, it further marginalises the tribal world.

**C.** Sahariya Museum, Sheopur Fort – Itwas set up as a research center for the Sahariya tribe and "to protect the culture of the extremely backward Sahariya Tribe" (Sahariya Museum, n.d.), enabling images of people still rooted in primitive times. The Sahariya museum is a large space, with rooms on three sides and an open area showcasing life-sized dioramas of the everyday activities of the tribal people.

**Figure 4.** Details of artwork on the wall, Sahariya Museum, Sheopur (own photo).

The walls on all three sides are painted in white and an earthy red (gerua) colour, and show different ways of decorating doors. Massively decorated entrances featuring mirrors (kaanch) and thin bamboo mats, with horses on both sides (Figures 4 and 5), are part of the displays. Each wall facing the central hall features images of animals and plants that illustrate the Sahariya tribe's bond with nature. The mirror work on the wall may be influenced by the Sahariyas living in the neighbouring state of Rajasthan, where mirrors are used for decoration.

**Figure 5.** Details of artwork on the wall, Sahariya Museum, Sheopur (own photo).

**Figure 6.** Life-sized diorama depicting Sahariya men fishing at the Sahariya Museum, Sheopur (own photo).

The center of the hall showcases different aspects of Sahariya life through dioramas. These displays (Fig. 6) show activities like fishing, marriage ceremony, woman grinding grain inside a hut and so on using life-sized statues of dark-skinned men and women dressed in dhoti (a loose piece of clothing wrapped around the lower half of the body), kurta (a loose long shirt), pagdi (turban) and ghargra choli (skirt and blouse for women). Among other items on display are wooden toys, cooking utensils, and exercise equipment made by Sahariyas. These fossilised dioramas seem to project tribal culture as living in the past.

## 3. Learning from Fieldwork: Context of Authenticity

Sahariyas are one of the 75 tribal communities recognized by the Government of India as Particularly Vulnerable Tribal Groups (PVTGs) and mainly inhabit the state of Madhya Pradesh. A minor population is also found in the adjoining states of Uttar Pradesh and Rajasthan. According to the 2011 Census of India, the total population of the Sahariya Tribe in Madhya Pradesh is

6,14,958. The Sahariya call themselves the companions of Sher (tiger or lion), and, according to their legend, they were blessed by Lord Shiva to have access to the jungle and consider themselves the original inhabitants of the forest. They were a nomadic, forest-dwelling tribe before their displacement from Kuno National Park around 2000 to prepare the park for the arrival of Asiatic Lions from the Gir Forest, Gujarat. The promised relocation of Asiatic Lions has not occurred to date. However, 22 villages, amounting to 1545 families, were displaced and resettled in Agraa, Sheopur, near Kuno National Park. Finally, two decades after being displaced to conserve wildlife, on September 17, 2022, cheetahs from Namibia were released in Kuno National Park.

**Figure 7.** Traditional Sahariya Dwelling, Agraa, Sheopur (own photo).

**Figure 8.** Traditional Sahariya Dwelling, Agraa, Sheopur (own photo).

During the multiple visits over the years (2019 – 2025) to the resettlement site, most of the photographs of the tribal museum exhibits shown to the participants were rejected as incorrect representations of their dwellings. Photographs showing the colour blue, the courtyard, walls serving as support for roofs, and the tree with a diya representing their space of worship were considered authentic. Participants agreed that they draw flowers for wall decoration purposes, but drawings of birds and animals are rare. The visits also indicate that, unlike museum displays, traditional Sahariya dwellings are single-storeyed. They are constructed of stone with a mud plaster on the front wall and do not have windows (Figures 7 and 8). The doors are made up of plain wooden panels and lack intricate carvings. The roof is constructed from wooden logs, and traditionally, leaves were used as the top layer to provide shelter from the weather. Also, there is usually a gap between the top of the wall and the roof for ventilation and to support the wooden logs that serve as the base of the hut (Figure 2).

Sahariya indigenous knowledge lies in the exceptional understanding of their natural habitat. Their everyday lives are enacted through an intimate connection with nature, and this deep association is clearly visible in their dwellings. Despite displacement from their original habitat, current construction and spatial planning practices have not changed from their generational ways of living. However, their contact with the Kuno National Park, their original habitat, has decreased significantly due to wildlife conservation measures in place. Now, various construction materials, such as tarpaulin sheets, are being used to avoid seasonal roof repairs because forest products are unavailable.

**Figure 9.** Wall Decoration, Sahariya Dwelling, Agraa, Sheopur (own photo).

The empirical research, conducted through interviews, observations, and photographic data, further shows that the Sahariya tribe does not engage in elaborate decoration of their dwellings. The decorations (Figures 9 and 10) primarily feature images of the region's flora, highlighting the tribe's harmonious coexistence with nature. They also do not use mirror work, elaborate images of animals or birds on the walls. The Forest Officials at Kuno National Park also confirmed that Sahariyas prefer spending time in

the forest searching for medicinal plants, collecting resin and other forest produce, reiterating their connection to their habitat; however, they are not keen on decorating their huts as depicted in museum exhibits. The courtyard setting at the Tribal Museum, Bhopal, speaks of a culture passionate about art and fond of decorating their houses and surrounding spaces, which is not true of the Sahariya Tribe, as seen in their current dwellings. Also, the saharana (cluster of huts) used to engage and educate people about tribal culture lacks contextual information, which is crucial for understanding the cultural value that Sahariyas assign to their built environment.

**Figure 10.** Wall Decoration, Sahariya Dwelling, Agraa, Sheopur (own photo).

The paper argues that, with the intent to promote and conserve the tribal world, the vibrant exhibits fall short of showcasing reality and, in this case, unintentionally create a static, fossilised version of tribal life. Anshu and Firdausi (2018) mention that 'all knowledge is subjective and situated'. Therefore, it is imperative to understand the dynamic context that shapes the spatial construction of the Sahariya culture and its transformations in their lifeworld. After displacement, children born in resettlement villages are unaware of their generational ways of living. They may be on the verge of losing their cultural heritage, including crucial indigenous medicinal knowledge essential to their survival in remote areas with limited access to modern healthcare.

## 4. Conclusion - Marginalisation or Integration?

Tribal museums were initially established as repositories of material culture to promote and preserve the 'authentic' tribal past. To depict everyday tribal life, scenographic installations featuring life-size dioramas were created to introduce the specificities of diverse cultures and raise awareness among the general public. However, my study has shown a vast disconnect between 'ethnographic displays' and the 'lived experience' of the Sahariya tribe. Furthermore, the static dioramas have compounded the 'cultural other' stereotype due to a lack of clarity regarding the intent of such representations. Kanungo (2014, 490) rightly points out that such collections ignore the fact that the "collectors were more interested in the objects than in the culture of the people to whom they belonged."

Critically, my research process also demonstrates the necessity of an ethical framework for authentic representations of the tribal built environment. It reveals a need for rigorous research on the discourse of conservation and preservation, the intent of displays, and the essence of cultural heritage for each tribal group in India. To conserve any culture, the essence of culture and what constitutes a group's cultural heritage need to be thoroughly investigated to understand the cultural landscape and to valorise their generational wisdom. For an unbiased representation and holistic conservation of any culture, cross-disciplinary research is of utmost importance in the present situation. Cross-disciplinary research enables engagement with a wider audience and opens new avenues for collaborative research across varying expertise. Tribal museums should engage in research that integrates diverse disciplinary perspectives and methods, drawing on dimensions beyond discipline-specific approaches. Tribal cultures are mines of complexity, and a single anthropological lens no longer captures the intricacies of their lives.

Outreach activities involving different tribal groups and mainstream society can offer better development measures and serve as a platform to share the struggles of Adivasi communities, such as the impact of displacement on the Sahariya tribe. To strengthen pedagogical impact and build the competence of museum personnel, interaction with tribal communities and their participation in identifying, documenting, and representing their cultural heritage are paramount. Integration of tribal people into the research approach and process, and timely reconstruction of ongoing transformations in constructing tribal lifeworld exhibits, will help improve the interpretation of their cultural processes and negotiations with displacement and current realities. In this sense, it becomes urgent that ownership of culture must be placed with the tribal community, who are the foremost stakeholders in how they are represented. Tribal museums, as cultural

institutions, rather than acting as intermediaries between indigenous populations and their audiences, should act as the facilitators to conserve and disseminate knowledge in more dynamic ways. It must be remembered, tribal cultures need to be conserved and valorised by museums, not caricatured.

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# Ensuring Long-term Affordability in Low-cost Housing:
## The Trade-off between Cost Compromises and Service Life

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**Abstract:** This study investigates the impact of strategies adopted in terms of materials, design, and/or technology, and their cost compromises (CP), on the design life of low-cost housing buildings in Delhi NCR, focusing on inaccessible structural components, major replaceable components, and building services. Through a detailed analysis of case studies and building systems, the study identifies the key parameters affecting the service life of these components and their respective cost compromises. The findings reveal that material quality and design level have the highest impact (of more than 60%) on the service life of structural systems, with inherent deficiencies arising due to cost compromises leading to reduced service life, most impacted by reduced material consumption of a costlier item of a component (CP5) and Use of deteriorated material (CP15). The study also highlights the critical roles of work execution at the field level and maintenance in building services. At the same time, building services components are predominantly affected by inadequate work execution level and infrequent maintenance (having an impact of more than 70%), with plumbing jointing issues being a significant concern. The study emphasises the critical role of in-use conditions in exacerbating these issues, as evidenced by the Bawana housing project's MEP systems. These findings underscore the need to improve design practices and strategies for low-cost housing to balance service-life performance and lifecycle costs across components.

**Keywords:** Low-cost housing, Affordability, Alternate Strategies, Cost compromises, Conditional Assessment, Factor Rating, Service Life estimation

**सार:** यह अध्ययन दिल्ली NCR में कम लागत वाले हाउसिंग बिल्डिंग की डिज़ाइन लाइफ़ पर मटीरियल, डिज़ाइन, और/या टेक्नोलॉजी के मामले में अपनाई गई रणनीतियों और उनके कॉस्ट कॉम्प्रोमाइज़ (CP) के असर की जांच करती है, जिसमें दुर्गम स्ट्रक्चरल कंपोनेंट्स, मुख्य बदलने योग्य कंपोनेंट्स, और बिल्डिंग सर्विसेज़ पर ध्यान केंद्रित किया गया है। केस स्टडीज़ और बिल्डिंग सिस्टम के विस्तृत विश्लेषण के माध्यम से, यह स्टडी इन कंपोनेंट्स की सर्विस लाइफ़ और उनके संबंधित कॉस्ट कॉम्प्रोमाइज़ को प्रभावित करने वाले मुख्य मापदंडों की पहचान करती है। निष्कर्षों से पता चलता है कि मटीरियल की गुणवत्ता और डिज़ाइन स्तर का स्ट्रक्चरल सिस्टम की सर्विस लाइफ़ पर सबसे अधिक प्रभाव (60% से अधिक) पड़ता है, जिसमें कॉस्ट कॉम्प्रोमाइज़ के कारण होने वाली आंतरिक कमियों से सर्विस लाइफ़ कम हो जाती है, जो एक कंपोनेंट की महंगी चीज़ की कम मटीरियल खपत (CP5) और खराब मटीरियल के उपयोग (CP15) से सबसे अधिक प्रभावित होती है। यह स्टडी फील्ड स्तर पर काम के निष्पादन और बिल्डिंग सर्विसेज़ में रखरखाव की महत्वपूर्ण भूमिकाओं पर भी प्रकाश डालती है। साथ ही, बिल्डिंग सर्विसेज़ कंपोनेंट्स मुख्य रूप से अपर्याप्त कार्य निष्पादन स्तर और अनियमित रखरखाव (70% से अधिक प्रभाव) से प्रभावित होते हैं, जिसमें प्लंबिंग जॉइंटिंग की समस्याएं एक महत्वपूर्ण चिंता का विषय हैं। यह स्टडी इन समस्याओं को बढ़ाने में उपयोग की स्थितियों की महत्वपूर्ण भूमिका पर जोर देती है, जैसा कि बवाना हाउसिंग प्रोजेक्ट के MEP सिस्टम से पता चलता है। ये निष्कर्ष कंपोनेंट्स में सर्विस-लाइफ़ प्रदर्शन और लाइफ़साइकिल लागत को संतुलित करने के लिए कम लागत वाले आवास के लिए डिज़ाइन प्रथाओं और रणनीतियों में सुधार की आवश्यकता पर जोर देते हैं।

**मुख्य शब्द:** कम लागत वाले आवास, सामर्थ्य, वैकल्पिक रणनीतियाँ, लागत में समझौता, सशर्त मूल्यांकन, फैक्टर रेटिंग, सेवा जीवन का अनुमान

## 1. Introduction

Affordable housing is often misunderstood as simply low-cost housing. In reality, LCH (Low House Housing) has been rebranded as 'Affordable Housing', which some may argue is a more accurate term. Affordable housing is shelter that can be obtained without unreasonable financial difficulty, allowing individuals or families to maintain a decent standard of living. This includes having enough income left after paying for housing to cover other necessities such as utilities, insurance, and taxes. In the USA and Canada, affordable housing is commonly defined as housing that costs no more than 30% of a household's income.

On the other hand, low-cost housing requires effective budgeting and resource management to reduce costs without compromising the structure's strength, performance, or lifespan. This distinction is crucial in understanding the nuances of providing adequate housing for different income groups (Barot 2021). Additionally, the total cost of housing affordability encompasses not only the initial purchase costs but also ongoing expenses such as routine maintenance, property taxes, utilities, and transaction costs, such as stamp duty. These costs can pose a significant burden for low-income groups moving into affordable housing, particularly apartments in redevelopment

projects. (Gopalan and Venkataraman 2015) highlight that while affordability is often presented as a single, static figure, it fails to account for variations in land prices, income levels, and expenditures across cities and populations. This oversight leads to an incomplete understanding of true affordability and the challenges faced by those seeking affordable housing.

New construction technologies such as EPS and sandwich panels, monolithic RCC, tunnel formwork, precast RCC, waffle-Crete blocks, SLIP formwork, fly-ash-based hollow blocks, 3D volumetric technology, precast steel structure, structural stay-in-place formwork system, light gauge steel frame structure (LGSF), and glass fibre reinforced gypsum (GFRG) panel are being adopted in low-cost housing under the Technologies Sub-Mission of PMAY-U, according to (PIB Delhi 2022) These technologies offer innovative solutions to enhance the efficiency and affordability of housing projects, contributing to the government's goal of providing affordable housing for all. However, their universal application is limited by location and climatic zones. The Delhi NCR region has adopted monolithic RCC using aluminium formwork and precast RCC technology (PIB Delhi 2022) due to their efficiency, construction speed, and cost-effectiveness, which cater to the region's construction needs and requirements. Despite promising benefits such as cost savings, reduced construction time, and environmental sustainability, operational issues compromise these advantages throughout the structures' operational life. These issues, including seepage, plaster undulations, cracking of monolithic walls, alignment problems with doors and windows, common area maintenance challenges, and unoccupied units due to location and transit issues, are compounded by common water challenges, drainage problems, cracks, spalling, water dampness in exterior elements, wear and tear, uneven slabs, gaps, rusting, leaks in doors and windows, uneven floors, mould growth, water leaks, rusting, and foul smell in pipes. Maintenance approaches vary, with DDA housing projects typically employing corrective and predetermined maintenance, while developers like Signature Global and Supertech prefer preventive and condition-based strategies (Sruti Pulupula 2023). It is imperative to research to ensure that housing remains affordable throughout its Design Service Life (DSL).

This research aims to optimise cost-effective strategies in low-cost housing construction while maintaining the intended design service life and durability of its building components. It focuses on identifying strategies for design, materials, or technology to economise on building components for low-cost housing and on assessing the current condition and defects through visual inspections. The research intends to map deficiencies in service-life parameters, classify issues as due to cost compromises or general issues, and forecast service life based on conditional assessments to determine the actual contribution of parameter impacts to service life.

Acknowledging the role of materials and location in influencing construction costs for low-cost housing for economically weaker sections (EWS) and low-income groups (LIG), the research focuses on planning and design interventions at both macro and micro levels, particularly in Delhi NCR, with a specific emphasis on climatic considerations for composite types. The primary intent is to analyse and chart how intended affordability and design service life are ensured post-occupancy of low-cost housing. The framework is based on a service life forecast using a factored method, based on the present condition of building components, visual inspections, and maintenance levels. The overall research intends to enhance current design processes in low-cost housing rather than proposing new strategies.

## 2. Theoretical background and hypotheses

This study examines the potential deficiencies and inherent issues in low-cost housing construction due to cost compromises (CPs) made in materials, design and/or technology. While these cost-saving measures reduce upfront expenses, they can shorten service life, leading to higher repair, maintenance, and renovation costs in the future.

### *2.1 Comparing Conventional and Low-Cost Housing*

This delves into the strategies, exploring how compromises are made in material, design, or technology to achieve Low-cost housing and compromises translate into cost savings, for example, as (Rastogi 2022) states, the ability to reduce costs while maintaining quality in building materials specified for construction, ensuring cost-effectiveness in material selection, whether through:

i. Economies of scale and repetition: Utilising

standardised designs and materials to streamline production and reduce costs.

ii. Strategic elimination: Eliminating non-essential elements to create functional yet efficient living spaces.

iii. Embracing alternative materials: Employing lower-cost, readily available materials that meet basic structural and durability requirements.

Through this exploration, the areas where the compromises precisely achieve the intended low cost will be uncovered.

A comprehensive list of cost compromises (CP) was identified from the above study namely Cost-effective material (CP1), Low-grade material (CP2), Reduced material consumption (CP3), Substitution of a costlier item of a component (CP4), Reduced material consumption of a costlier item of a component (CP5), Simple construction (CP6), Low-cost construction processes (CP7), Minimal finishes (Utilitarian) (CP8), Size efficiency (CP9), Modular design (CP10), Economy of repetition (CP11), Mass scaling (CP12), Cost-effective lightweight solution (CP13), Elimination of an item (CP14), Use of deteriorated material (CP15).

**Table 1.** Low-cost housing compromises

| S. No. | Conventional housing | Low-cost housing | Description |
|---|---|---|---|
| | **Material Compromise** | | |
| 1 | 18 mm Plastering | 12 mm plastering | Economy of material thickness |
| 2 | 1:4 cement-sand plastering | 1:6 cement-sand plastering | Reduced cement consumption |
| 3 | 600 x 600 floor tiles | 300 x 300 floor tiles | Reduced tile costs - tile slab size |
| 4 | Conventional cast-in-situ RCC floor or roof | Filler slab - Reinforced Brick Concrete (RBC) Slabs | Reduced consumption of concrete and cheap cost of bricks |
| 5 | 230 mm Brick masonry wall | 200mm thick Fly ash hollow brick wall | reduced consumption of mortar for jointing due to large blocks<br>faster and economical construction due to large blocks<br>economical structural members and reduced loads on foundations - due to low density of about 600 to 1100 kg/cum against 2200 to 2400 solid walls |
| 6 | 230 mm Brick masonry wall | 200mm thick Aerated concrete block wall | reduced loads on foundations - due to low density<br>less mortar for jointing of blocks |
| 7 | 230 mm Brick masonry wall | 300mm thick CSEB block work | CSEB are cheaper than fired bricks, an economy of approximately 20%. |
| 8 | 115 mm the Brick wall masonry for internal walls | Prefabricated Sandwich panels - 75mm the EPS concrete sandwich panels for internal walls<br>Cost of the actual panel is Rs. 1440/10 sqm and that of bricks is 7455/10sqm; mortar costs are 120/10sqm for EPS wall system, while labour charges are high – 1900/10sqm | Economy of wall thickness<br>reduced built-up area<br>Reduced dead loads<br>No plastering costs - ready-to-use panels<br>No finishing costs - ready to use panels<br>reduced indirect costs - fast pace construction |
| 9 | 230mm the brick wall system | 150 mm the Precast EPS wall panel system | reduced indirect cost - fast construction<br>economy of wall thickness<br>reduced built-up area<br>Easy to install - reduced labour charges<br>no plastering costs<br>Reduced dead loads - economy of foundations and RCC structure |
| 10 | burnt clay brick masonry | cellular light weight concrete masonry | reduced dead loads - savings in foundation |
| | **Design Compromise** | | |
| 1 | RCC frame structure (G+3 | Load bearing Brick masonry structure (G+3) | no columns, no beams - reduced consumption of concert and steel<br>proportional layout - reduced dead space<br>reduced load on foundation<br>reduced floor to floor height<br>cheap cost of bricks compared to concrete den steel |
| 2 | RC column foundation | Under Reamed pile foundation | reduced concrete and still consumption - 20 to 25%<br>economical over RC column foundation |
| 3 | cast -in-situ RC foundation, beam, column, floor/roof (G+3) | Confined masonry (G+3) - brunt solid –clay or concrete block units, RC Tie-beams, | reduced steel and concrete consumption up to 30% cost reduction<br>reduced built up area - 230x230 columns than conventional |

| S. No. | Conventional housing | Low-cost housing | Description |
|---|---|---|---|
| | | bands- plinth beam, sill band, lintel band, Roof band | 300 x 300mm<br>well-proportioned building layout - reduce dead space<br>economy of small sections - smaller sections of RC tie-beams and tie-columns at every 4 m |
| 4 | Conventional RCC beam | Speed floor construction system | reduced dead loads of up to 30%<br>Reduced indirect costs by 20 to 30%, reduced construction time as work can be done in parallel on more than one floor at a time<br>no need of propping - tempo array plywood held in place using lock bars<br>No need of columns - spanning up to 10 m<br>No need of ceiling plaster - due to good finish achieved through plywood formwork<br>reduced floor to floor height-with 200mm depth steel joists |
| 5 | two pipe system | one pipe system | less shaft space<br>less consumption of pipes |
| 6 | layouts designed with respect to user specific requirement, climate, other considerations | repetitive unit planning (identical clustering, identical floor plans vertically) | economy of identical units - reduced efforts<br>reduced shaft space<br>reduced cost of jointing in MEP |
| 7 | traditional layout | Deep plan layout with band active | cheap central part<br>reduced frontage - reduced road lengths<br>reduced façade area |
| 8 | 4-unit clustering | 6-to-8-unit clustering | increased density of units<br>efficiency of space utilization - reduced land costs<br>cheap central part |
| 9 | G+12 or G+13 | G+3, G+4 | no need of lifts<br>no need of shear walls<br>reduced cost of extra cost of works above 6th story<br>reduced steel consumption |
| 10 | G+3, G+4 | G+12 or G+13 | increased density of units |
| 11 | Individual housing units | narrow block residences | reduced setbacks - reduced land area<br>increased density of units<br>shared common side walls<br>reduced frontage - reduced road lengths<br>No fenestrations on the side<br>reduced faced area due to narrow plan |
| 12 | Adequate carpet area<br>living area - 9.5 sqm<br>bedroom - 9.5 sqm<br>kitchen - 5 sqm<br>Bath - 1.8 sqm<br>W.C. - 1.1 sqm | compromised carpet area<br>living area - 9.072 sqm<br>bedroom - 6.6 sqm<br>kitchen - 3.3 sqm<br>Bath - 1.2 sqm<br>W.C. - 0.96 sqm | reduced building foot print<br>reduced land costs |
| 13 | Adequate fenestration area<br>living area - 1.134 sqm<br>bedroom - 0.825 sqm<br>kitchen - 0.515 sqm<br>Bath - 0.3 sqm<br>W.C. - 0.3 sqm | compromised fenestration area<br>living area - 0.9sqm<br>bedroom - 0.9sqm<br>kitchen - 0.54sqm<br>Bath - 0.405sqm<br>W.C. - 0.405 sqm | reduced fenestration area - reduced glazing costs |
| 14 | Location within the city | Location outskirts of the city - townhouses | reduced land costs |
| | **Material / Technology** | | |
| 1 | Conventional cast-in-situ RCC floor or roof | Precast R.C. Plank and partially precast joist system | no need of shuttering<br>consumption of cement of about 25%<br>reduced consumption of steel of about 10% reduced<br>reduced indirect costs - with reduced construction time<br>economy of slab thickness - 75mm slab<br>reduced floor to floor height |
| 2 | Conventional cast-in-situ RCC floor or roof | Precast Brick Panel and Partially Precast Joist System | reduced self-load<br>reduced concrete consumption of 25 to 30%<br>economy of slab thickness - 75mm slab<br>reduced floor to floor height |
| | **Material/Design** | | |
| 3 | Conventional wall and roof system (G+3) | Load bearing Light Gauge framed structural system (G+3) | reduced indirect, wastage costs - typical four storied building constructed in one month<br>reduction in dead load - reduced foundation costs - due to light superstructure<br>reduced consumption of cement |

| S. No. | Conventional housing | Low-cost housing | Description |
|---|---|---|---|
| | | | No columns and beams<br>reduced built-up area |
| | **Design / Technology** | | |
| 4 | cast-in-situ RC framed structure | Precast large concrete panel system | reduced indirect and wastage cost - fast pace construction<br>well-proportioned layout - reduced dead space<br>economy of wall sections: Flexibility in design - can bed design to nearly any size of 120mm<br>economy of scale - mass housing, repetitive units<br>50mm slab - reduced cost of construction of slabs of about 23.22% cheaper<br>200 x 400 beam sections, 900 x 350mm column - reduced cost of construction of columns of about 21.4% cheaper<br>reduced floor to floor height |
| 5 | RCC frame structure | Load bearing Precast RCC wall structure | economy of thinner wall sections<br>Fast construction- reduced indirect costs<br>design flexibility - reduced dead space<br>reduced built-up area - space taken by columns, space taken up by conventional 230mm brick walls<br>Economy of mass scaling, modular, repetitive unit plans<br>reduced floor height - reduction of space taken up by beams |
| 6 | cast-in-situ RC framed structure | Monolithic concrete construction system with Aluminum formwork - Monolithic RC wall designed as shear wall | economy of wall thickness - 100mm |
| | | As per Detailed cost calculations applied on DDA Lokanayakapuram - it was found to have higher costs of about 50% | no need of plastering due to high quality, uniform finish<br>reduced indirect costs - unsurpassed construction speed and less manpower<br>Economy of scale - with number of repetitions of formwork (at least 100 repetitions), mass housing of more than 500 units<br>Economy of modular design |
| | **Design / Material / Technology** | | |
| 7 | conventional wall & roof system | Load bearing GFRG Panel system with RC infill for typical floor structures | reduced consumption of concrete and steel - 50% reduction in cost |
| | | Cost of the actual panel is high Rs.1323 / sqm | reduced dead weights - savings in foundation<br>economy of panel thickness - 124mm panel thickness<br>reduced indirect costs - fast pace construction<br>No columns and beams<br>reduced built-up area<br>better planned proportional plan - reduced dead spaces<br>reduced floor to floor height<br>no need of wall plastering<br>no need of ceiling plastering |

Source: (Bhoir, 2023; Ganga Warrier et al., 2019; Garg & Sharma, 2022; Habieb et al., 2023; Hernández et al., 2023; Khan et al., 2023; Lu et al., 2020; Madhushan et al., 2023; Murtyas et al., 2023; Olaiya et al., 2023; Ortiz et al., 2023; Rahim et al., 2020; Rastogi et al., 2019; Romero Quidel et al., 2023; Salzer et al., 2017; Sruti Pulupula, 2023; Tofiluk, 2023; Zhou & Su, 2023) & Unpublished thesis books.

### *2.2 Deficiencies in Low-cost Housing due to cost compromises*

The sustainability and longevity of low-cost housing require considering not only initial construction costs but also long-term operational and maintenance aspects. These compromises can lead to deficiencies impacting the service life of housing units. This research identifies potential deficiencies arising from cost-saving compromises, based on secondary case studies and literature reviews.

Table 2 discusses the shortcomings in low-cost housing construction, highlighting the need to consider long-term operational and maintenance aspects alongside initial construction costs for sustainability. It identifies potential or inherent deficiencies in material, design, and technological cost compromises. Material compromises can cause chipping, erosion, and structural problems, while design compromises can result in inadequate space. Technological compromises can make alterations or expansions difficult. Addressing these deficiencies is crucial for the longevity of affordable housing projects.

**Table 2.** Related Issues or defects in Low-cost housing – materials

| S. No. | Low-cost housing description | Defects / issues identified Case studies, Literatures on possible deficiency issues that may arise |
|---|---|---|
| 1 | 12 mm plastering | Chipping of plaster |
| 2 | 1:6 cement-sand plastering | erosion of surface |
| 3 | 300 x 300 floor tiles | Displacement of flooring tiles |
| 4 | Filler slab – Reinforced Brick Concrete (RBC) Slabs | Deflection values are slightly higher in filler slabs, exhibiting a slight increase (12-15.4%) compared to conventional ones.<br>Bricks being porous material absorbs moisture from air, may lead to corrosion of reinforcement bars if not encased properly in concrete<br>quality of bricks affects the durability of slab<br>brick being heterogenous material may causes quality issues<br>absorbs water which causes dampness and efflorescence with time |
| 5 | 200 mm thick Fly ash hollow brick wall | crack when increased stresses due to non-load bearing capacity<br>water seepage through these blocks is often more than through burnt clay bricks |
| 6 | 200 mm thick Aerated Concrete block wall | poor plastering – high water absorption up to 50% through porous surface<br>drying shrinkage cracks, stress concentration cracks due to non-load bearing capacity |
| 7 | 300mm thick CSEB block work | Under-stabilization resulting in low quality products.<br>Proper soil identification is required – affects the quality of bricks<br>Low technical performances compared to concrete |
| 8 | Prefabricated Sandwich panels – 75 mm the EPS concrete sandwich panels for internal walls | Difficulties in alterations to plumbing, electrical, fittings, etc.<br>Joinery defects in monolithic joints – causing leaks |
| 9 | 150 mm Precast EPS wall panel system | Joinery defects in monolithic joints – causing leaks |
| 10 | cellular light weight concrete masonry | cracks due to low compressive strength |
| 1 | Load bearing Brick masonry structure (G+3) | cracks in brick masonry due to stresses<br>Weathering, Moisture damage, Mold and mildew growth, Dampness<br>Variations in soil composition, curing conditions, and the manufacturing process may lead to inconsistencies in block strength and durability |
| 2 | Under Reamed pile foundation | water bearing ground or unstable ground causes problems |
| 3 | Confined masonry (G+3) - brunt solid – clay or concrete<br>block units, RC Tie-beams, bands- plinth beam, sill band, lintel band, Roof band | as confined masonry walls are load bearing and RC tie columns don't sustain significant gravity loads, quality of bricks affects the load carrying capacity |
| 4 | Speed floor construction system | services accommodated through pre-punched holes |
| 5 | one pipe system | problem of back flow, clogging and choking |
| 6 | repetitive unit planning (identical clustering, identical floor plans vertically) | - |
| 12 | compromised carpet area | no adequate functional space |
| 13 | compromised fenestration area | no adequate ventilation |
| 14 | outskirts of the city - townhouses | increased travelling costs |
| 1 | Precast R.C. Plank and partially precast joist system | Damage due aggressive environments<br>Water Leaks & damage, Cracking, spalling, mold and mildew growth<br>Visible Precast planks & joints, Cracks, Wear & Tear, Skirting Cracks<br>Reduced cover increases susceptibility to wear and tear, durability issues |
| 2 | Precast Brick Panel and Partially Precast Joist System | Bricks being porous material absorbs moisture from air, may lead to corrosion of reinforcement bars if not encased properly in concrete<br>quality of bricks affects the durability of slab |
| 3 | Load bearing Light Gauge framed structural system (G+3) | - |
| 4 | Precast large concrete panel system | Joinery defects – leaks, Displacements |
| 5 | Load bearing Precast RCC wall structure | Joinery defects, leaks |
| 6 | Monolithic concrete construction system with Aluminum formwork - Monolithic RC wall designed as shear wall | Problem of making alterations to electrical or plumbing fittings as the fittings should go through cavities |
| 7 | Load bearing GFRG Panel system with RC infill for typical floor structures | Proper sealing and waterproofing of joints between prefabricated components for preventing water infiltration. If not addressed during the manufacturing and assembly stages, water damage could affect the structure's long-term durability.<br>The connections between prefabricated elements critical in the overall structural integrity. Over time, wear and tear on these connection points could lead to stability issues if not designed and executed properly.<br>challenges in terms of modifications, expansions, or renovations, as these processes might be more intricate compared to traditional construction |

Source: (Bhoir 2023; Ganga Warrier et al. 2019; Garg and Sharma 2022; Habieb et al. 2023; Hernández et al. 2023; Khan et al. 2023; Madhushan et al. 2023; Murtyas et al. 2023; Olaiya et al. 2023; Ortiz et al. 2023; Rahim et al. 2020; Romero Quidel et al. 2023; Salzer et al. 2017; Sruti Pulupula 2023; Tofiluk 2023; Zhou and Su 2023) & Unpublished thesis books.

Therefore, hypothesis 1 reads: *"The various cost compromises (CP) (refer section 2.1) made in Low-cost housing are crucial in reducing the cost of construction but certain cost compromises (CP) are found to have inherent issues and cause deficiencies and defects post occupancy and reduce the service life of its building components and therefore causing the need for special repairs and increase the life cycle cost eventually".*

However, the deficiencies can be even due to general issues caused due to poorly execution of work in site or lack of cyclic maintenance, as (Ganisen et al. 2015) suggests there is a notable absence of specific details regarding the particular maintenance requirements for the Low-cost housing projects, including necessary repairs, inspections, and potential issues that might arise (Sinha et al. 2020). There is a necessity to apply risk factors to analyse the probabilistic maintenance (Park et al. 2019). The ease of maintenance of the technologies adopted for structural components of low-cost housing is crucial to consider, along with occupant behavioural influences and engagement in O & M (Nägeli et al. 2019; Sunikka-Blank et al. 2019). Conditions of in-use, such as puncturing through the monolithic structural walls to add more switchboards (Sruti Pulupula 2023) or other similar in-use modifications, can also lead to deficiencies in the building components. Therefore, the research attempts to determine whether the deficiencies are due to general concerns or cost compromises, and which cost compromises are acceptable for balancing the intended designs for each individual's life and which might actually result in deficiencies.

## 3. Methods

### *3.1 Introduction*

The research process begins with a critical review of post-occupation service life issues in low-cost housing. To achieve the first objective, the literature is thoroughly reviewed to identify the strategies and cost compromises adopted in low-cost housing, including materials, design, and technology. This list will be used in the second objective to map the root causes of deficiencies identified in the current building condition of the case studies, along with the potential cost compromises that may have caused these defects. The second objective also involves assessing the severity of the various defects identified in the building components through a "conditional grading scale." The conditional assessment of building components of low-cost housing from the second objective will be used to forecast their service life using the "factor rating method" in the third objective, substantiating how cost compromises affect the intended design service life. These cost compromises will be validated to determine which are acceptable, and problematic cost compromises will be identified.

### *3.2 Service Life estimation using "Conditional Assessment"*

Omoare et al. (2022) State service life as the duration a building can perform without major repairs or deterioration, while durability is its ability to withstand environmental attacks without performance decline. Duling et al. (2008) highlights those various factors, including material quality, design level, work execution level, indoor and outdoor environment, in-use condition, and maintenance level, influence the durability and degradation of building materials and components. While life cycle cost (LCC) calculations are crucial for understanding (Varun Raj et al. 2020) the financial implications of low-cost housing, assumptions made in these studies are often oversimplified and fail to capture the intricate cost dynamics, operational dynamics and market fluctuations due to lack of accurate real-time data and real time maintenance data (Kim and Lim 2019; Pinky Devi and Palaniappan 2019; Srivastava and Kumar 2018), the factor method, on the other hand, uses predetermined factors or coefficients to estimate and is less detailed and requires less effort and data compared to the detailed method. This method allows quick comparisons of different strategies for low-cost housing by providing a structured approach to incorporating the impact of service life, which will ultimately affect the life-cycle cost; therefore, the cost implications are inferred and adopted in the study.

The Factor Method estimates service life by applying seven parameters to a reference service life (Expected service life or Design Service life) and the inherent lifespan of the component under ideal conditions, whereas other methods, such as deterministic models, use fixed parameters, and stochastic models incorporate statistical analysis. The Factor Method simplifies estimation with limited input, making it practical for the application, but it doesn't quantify changes in condition over time.

The study conducted an expert survey based on a 5-point Likert scale. It utilised Cochran's equation to calculate a sample size of 35 from a population of 200 facility management

professionals in Delhi NCR, with a precision level of 10% and a confidence level of 80%.

The survey received responses from 36 participants with varying levels of experience in facility management, providing insights into the factors influencing durability and degradation in low-cost housing, Figure 1. The survey results showed excellent reliability (Cronbach's alpha = 0.955383805) among these factors. Material durability had the highest weightage (0.90), indicating its significant role, followed by design level (0.73), in-use condition (0.66), maintenance level (0.64), and work execution level (0.63). Factors such as outdoor environment (0.51) and indoor environment (0.44) also contributed significantly. The experts suggested that ensuring the durability of building components involves selecting materials that resist deterioration, considering construction dimensions, anticipating wear and tear, designing protective systems, and implementing cost-effective maintenance management. Balancing these parameters can enhance the durability and longevity of building components in low-cost housing projects.

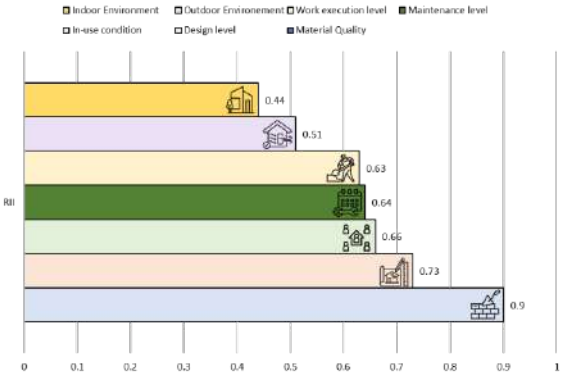


**Figure 1.** RII of Parameters Affecting the Service Life of Building components of Low-cost housing: expert survey results (Author)

The method is systematic, offering an objective evaluation and accounting for multiple criteria (Duling et al. 2008; Omoare et al. 2022). A 10-point grading system (Figure 1) is incorporated into the Factor Method to assess the condition of the building components of the selected low-cost housing projects, which will be discussed in detail later, and from which the factored value is calculated. These are numerical modifiers that adjust the RSL based on factors such as environment, design, and maintenance. CPWD Maintenance Manual (2019) suggests a 75-year service life for RCC structures and a 55-year service life for load-bearing structures. Based on this, the expected service life of different building components is extrapolated from the minimum design lives for components (DLC) suggested in (ISO 15686-1:2000 (E) 2000).

To collect data on defects in low-cost housing, visual inspections (Arya and Agarwal 2007) will be conducted on selected case studies. To ensure consistency, we will use a checklist developed from a literature review that identifies various types of defects, through which observations are recorded in a structured, systematic way based on the current conditions of the housing projects.

The various types of defects in a building, includes foundation settlement (D1), structural cracks (D2), air cracks / Non-structural cracks (D3), corrosion and spalling of concrete (D4), buckling of elements (D5), structural deformation (D6), bulging and falling of patches with exposed reinforcement (D7), surface irregularities (D8), missing elements (D9), moisture ingress (D10), microbial infestation (D11), damaged or deteriorated elements (D12), Deformation of elements (D13), inadequate sealing (D14), Faulty hardware (D15), warping of elements (D16), delamination of elements (D17), biological decay of elements (D18), rusting of components (D19), peeling off of layer (D20), weeping (D21), leakage at joints (D22), leaking elements / T&D loss (D23), malfunction & water clogging (D24), total failure of the system (D25), and patterned cracking (D26).

The information below outlines signs and characteristics of various types of defects that can occur in building structures, along with their associated signs and characteristics. These defects range from foundation settlement and structural cracks to moisture ingress and biological decay. Each defect is described in detail, specifying the signs or indicators to look for during visual inspections. This comprehensive list serves as a valuable reference for conducting visual inspections to accurately identify and document defects in building structures.

Foundation settlement refers to uneven floors or sloping, cracks in walls or floors, misaligned doors and windows, visible gaps around windows and doors, wall and floor damage, drywall cracks, slab deterioration, and structural instability. Structural cracks are wider than 1/4 inch or horizontal cracks, diagonal, and run in definite directions with greater magnitudes. Air cracks or non-structural cracks are shallow, random, and do not extend through the entire thickness of the concrete. Corrosion and spalling of concrete characterised by circular or elliptical depressions in the concrete surfaces 20 mm or more, Chunks

of concrete crumbling and breaking off, Rust stains on concrete surfaces, Visible damage to concrete structures. Patterned cracking is characterised by cracks forming geometric shapes (e.g., grids, diagonals), Cracks radiating from a central point, regularly spaced cracks, and cracks resembling a honeycomb pattern. Patterned cracks may indicate underlying structural issues or material weaknesses. Surface irregularities include bumps, depressions, undulating surfaces, uneven plaster or paint finishes, surface cracks or spalling, missing elements, moisture ingress, mold growth, fungi, rusting of components, peeling off of layers, weeping, leakage at joints, leaking elements and total failure of the system (Allotey 2014; Anamika 2023; Arya and Agarwal 2007; Ayininuola and Olalusi 2005; Forcada et al. 2016; Georgiou 2010; International Labour Organization Better Work Jordan Programme Enhancing the Structural Integrity of Dormitory Buildings in Jordan's Garment Sector-Phase II Guidance for Assessment and Repair of Typical Defects Report 2021; Konior and Rejment 2021; Neha V Bagdiya and Wadalkar 2015; US Army Corps of Engineers 1991).

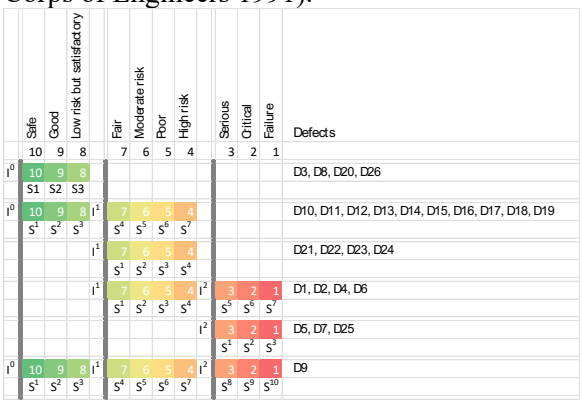


**Figure 2.** Conditional Grading Range (based on Impact & Severity) defined by experts for the various defects identified, Post Occupancy
Key: I - Impact, S – Severity (Author)

The defect-based condition assessment model is a structured approach to building inspection that employs a grading scale from 1 to 10 to evaluate the severity of building defects (Kumar Verma et al. 2013). The scale is categorised into Low Risk to Satisfactory (10-7), Moderate Risk to High Risk (6-4), and Serious to Failure (3-1), for the ease of expert survey. Expert surveys are used to determine the range of conditions for each defect using a condition grading scale, ensuring that the severity and impact of each defect are accurately captured (Figure 2). This approach allows for a more nuanced assessment, considering the cumulative effect of all observed defects on the overall structural integrity. By selecting the exact condition from the range of scale values, more precise evaluations can be made, leading to more accurate service life predictions. The model aims to reduce subjectivity and human errors in the assessment process. The individual defect severity assessments are combined to calculate the overall condition assessment of the building (Faqih and Zayed 2021). The sample size for the survey was calculated using Cochran's equation, with a precision level of 10%, a confidence level of 80%, and a population level of 200. The appropriate sample size, given the population size and specified combination of precision, confidence, and variability, is 35. Cronbach's alpha ($\alpha = 0.793341$), a measure of a scale or test's internal consistency or reliability, was found to be highly reliable. The survey results indicate that among the 41 respondents, a significant portion has varying levels of experience in facility management. The majority, 70.7%, are Facility managers, while 12.2% are contractors, and 17.1% are civil engineers. The expert opinions on post-occupancy defect severity use a scale from 1 to 10, with lower numbers indicating more critical issues.

This scale range identified through expert survey, for various post-occupancy defects with respect to their impact level ($I^0$, $I^1$, $I^2$) with a range of 0-3 (Low to High) on the service life of building components, this will be used to conduct the conditional assessment of the defects and their severity level, identified through visual inspection of the selected case studies.

Structural defects such as foundation settlement, structural cracks, buckling, and deformation are graded harshly, starting from 4 or lower, indicating high risk and the need for immediate action to ensure building safety. Cosmetic issues like surface irregularities, air cracks, and warping have a wider range, starting at seven or higher, suggesting they are less urgent but still require attention. Moisture-related defects, such as ingress, leaking elements, and weeping, are taken seriously, with ratings starting at six or lower, as they can lead to further problems if left unaddressed. Missing elements and system failures receive the most critical ratings, with ratings ranging from 3 or lower, indicating high risk and requiring immediate rectification. Expert judgment plays a crucial role in assigning a specific grade within the range based on the defect. This approach improves the accuracy of service-life predictions for building components in low-cost housing.

### *3.3 Root cause analysis of factors contributing to the reduction of design service life*

Root Cause Analysis (RCA) is a systematic method used to identify the root causes of defects in building components(Aljassmi & Han, 2013; Al-Zwainy et al., 2018). It is used in the study to analyse why certain cost compromises (check section 2.1) lead to defects post-occupancy of Low-cost housing projects. RCA intends to identify contributing service-life parameters (see section 3.2) and cost compromises.

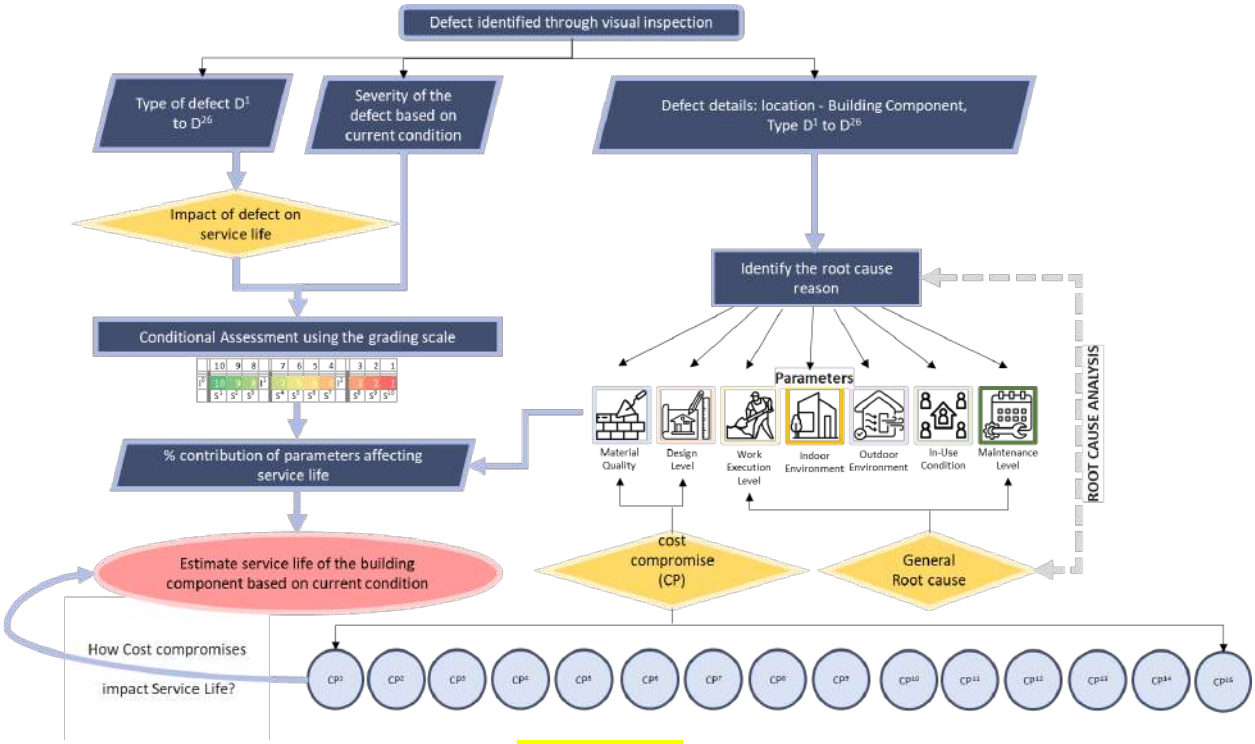


**Figure 3.** Process adopted to analyse the hypothesis (check section 2.2)
Source: Author

Overall, the flowchart (Figure 3) provides a general framework for investigating defects in selected case studies, emphasising the importance of considering how defects impact service life and how and which cost compromises (CP) made in low-cost housing might influence these parameters affecting service life.

The intent for evaluating case studies and gathering information on different aspects of low-cost housing includes assessing and evaluating the parameters discussed in (section 3.2). The case studies (check annexure 1 for case studies selection criteria) were selected in such a way that it provides insights into different distinct technologies adopted in low-cost housing in Delhi NCR, used various compromises and cost reduction strategies implemented in low-cost housing projects, including material, technology, and design aspects as identified in (section 2.1) and majorly revolve around parameters such as technological compromises socio-economic focus on EWS & LIG, location and demographic representation in Delhi NCR, design and material innovation, and maintenance practices adopted by RWA. These criteria aim to understand and address key challenges in low-cost housing initiatives for the EWS and LIG segments in Delhi NCR, focusing on innovative strategies while maintaining structural integrity and region-specific liveability standards.

## 4. Results

The selected case studies were analysed building component wise and were mainly categorised as Inaccessible structural components (comprising structure(s)) and Major replaceable components (comprising Internal walls (W), Fenestration (F), Tiling / Dado / Flooring (T), Railing). Building services (comprises MEP). A reduction in service life relative to the expected design service life was observed for all building components in the conditional assessment of present conditions for selected case studies. The parameters' impact on the expected service life of building components was analysed, and their % contributions were determined relative to the root causes of the identified defects. Further, the contributing cost compromises (CP) were identified.

The results suggests that the material quality and design level have the highest impact (of more than 60%) on the service life of all four structural systems analyzed from case studies, suggesting

deficiencies or inherent issues in the cost compromises adopted in these strategies; Reduced material consumption of a costlier item of a component (CP5), Use of deteriorated material (CP15) having the most severe impact on reduction of intended design service life. The other cost compromises, though not significant, that affect the service life of structural components are reduced material consumption (CP3), Economy of Repetition (CP11), Elimination of an item (CP14), and low-cost construction processes (CP7).

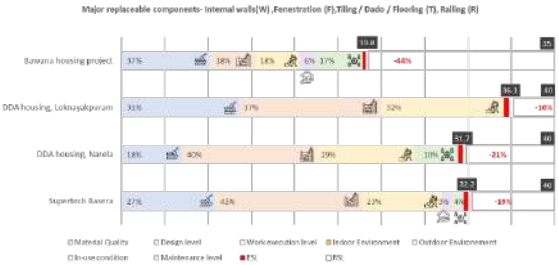


**Figure 4** Case study-wise: Service life predictions of major replaceable components and the % contribution of impact of parameters
Source: Author

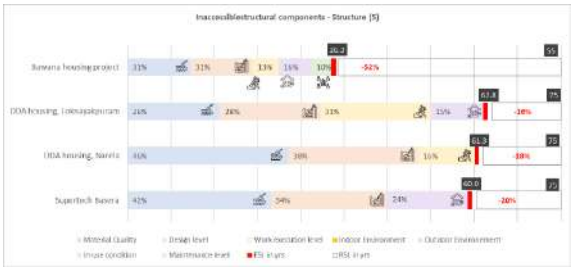


**Figure 5.** Case study-wise: Service life predictions of Inaccessible structural components and the % contribution of impact of parameters
Source: Author

The majorly replaceable components of low-cost housing (internal walls, fenestration, finishes, Figure 4) are also found to be majorly impacted by the cost compromise (CP) -Reduced material consumption of a costlier item of a component (CP5) and Use of deteriorated material (CP15) along with Low grade material (CP2), Substitution of a more expensive item of a component (CP4), Reduced material consumption (CP3) & Elimination of an item (CP14). Inaccessible structural and major replaceable building components are mainly found to be impacted (impact of more than 60%) by the parameters material quality and design level, suggesting the need for improving the current design practices or strategies adopted in Low-cost housing to strike a balance between the service life performance and costs over the life cycle, Figure 5.

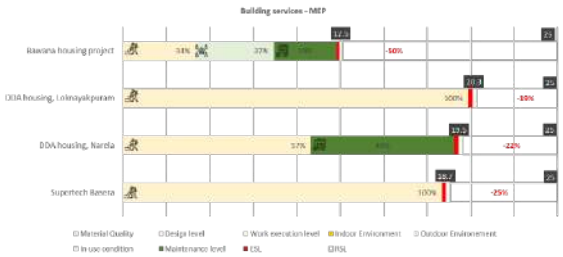


**Figure 6.** Case study-wise: Service life predictions of building services components and the % contribution of the impact of parameters
**Source**: Author

The conditional assessment of building components of low-cost housing from the second objective will be used to forecast their service life using the "factor rating method" in the third objective, substantiating how cost compromises affect the intended design service life, Figure 6. These cost compromises will be validated to determine which are acceptable, and problematic cost compromises will be identified.

Issues are mostly found to stem from inadequate work execution and infrequent maintenance, with an influence of more than 70% on the building services component of low-cost housing projects. Improper jointing in plumbing is a major general issue impacting the service life of these components. The results also highlighted the critical role of in-use conditions in exacerbating these issues. Illegal expansions and poor community care have led to a staggering 37% reduction in the efficiency of Mechanical, Electrical, and Plumbing (MEP) systems in the Bawana housing project. This revelation underscores the urgent need for improved maintenance practices and stricter enforcement of building regulations. Without addressing these underlying issues, the sustainability and livability of low-cost housing projects like Bawana remain in danger of failure.

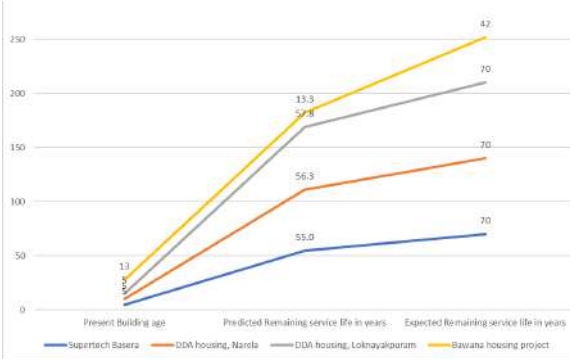


**Figure 6.** Expected Vs Predicted service life of selected Low-cost housing case studies based on current condition assessment (Source: Author)

## 5. Discussion

As the design life of buildings is primarily affected by inaccessible structural building components, the research focused on identifying the root causes, particularly those related to cost comprises (CP) and general issues, across four major low-cost housing technologies adopted in the Delhi NCR region.

This section examines the balance between cost and performance in low-cost housing projects. It analyses compromises across four building systems, categorising them as acceptable compromises (✓) or defects leading to defects (✗). The analysis helps construction professionals make informed decisions about cost-effective construction methods while ensuring building longevity and safety.

**Table 3.** Acceptable vs. Problematic Cost Compromises in Monolithic Construction

| **Monolithic Structure** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CODE** | **COMPROMISE** | **Actual Cost Compromises** | **Problematic Areas** | **Cost Compromises that can be made without Durability loss** | **Parameter in concern** | **Monolithic Structure - Defects caused by compromise** | **Root causes** |
| CP1 | Cost-effective material | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP2 | Low-grade material | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP3 | Reduced material consumption | ✓ | ✓ | ✗ | Design level | Structural cracks | insufficient cover - Reduced concrete volume |
| CP4 | Substitution of a costlier item of a component | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP5 | Reduced the material consumption of a costlier component | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP6 | Simple construction | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP7 | Low-cost construction processes | ✗ | ✓ | ✗ | Work execution level | Structural cracks | Difficulty in hardening the thickness of the hardening mass, accompanied by heat |
| CP8 | Minimal Finishes (Utilitarian) | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP9 | Size efficiency | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP10 | Modular design | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP11 | Economy of Repetition | ✓ | ✓ | ✗ | Design level | Air cracks / Non-structural cracks, Surface irregularities | Destruction of bushings and fastening - Repetition of formwork - Economy of scale, Deterioration of shield of shields - Repetition of formwork - Economy of scale, Destruction of protective coating of the shield frames, Destruction of castle joints |
| CP12 | Mass scaling | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP13 | Cost-Effective Lightweight Solution | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP14 | Elimination of an item | ✓ | ✓ | ✗ | Design level | Moisture ingress, Patterned cracking, Inadequate sealing | Lack of plaster, lack of a protective barrier - Lack of plaster, Not covered by protective layer further enhances the cracks, poor joinery detail |
| CP15 | Use of deteriorated material | ✓ | ✓ | ✗ | Material Quality | Air cracks / Non-structural cracks, Moisture ingress, Patterned cracking | poor concrete mixes - reduce the cement content, poor quality control of concrete batches leading to material not resistant to climatic actions, Sand containing an excessive amount of dust - cheap cost of sand |

Source: Author

Acceptable Compromises (✓):

i. Reduced material consumption (CP3): This can be acceptable if achieved through design optimization, not by skimping on concrete cover (which is crucial for durability).
ii. Minimal finishes (CP8): Opting for utilitarian finishes can save costs without compromising structural integrity.
iii. Size efficiency (CP9): Designing structures with optimal size utilization reduces material usage without sacrificing strength.
iv. Modular design (CP10): Modular elements can streamline construction and potentially reduce costs.
v. Economy of repetition (CP11): Repetitive use of standardized components can be cost-effective as long as it doesn't lead to issues like formwork damage.
vi. Mass scaling (CP12): Optimizing the mass of structural elements can be a good cost-saving approach.
vii. Cost-effective lightweight solutions (CP13): Lightweight materials can be cost-effective as long as they meet structural requirements.
viii. Elimination of non-critical items (CP14): Removing unnecessary elements can save costs, but proper sealing and detailing are essential to prevent moisture ingress and cracking.

**Table 4.** Acceptable vs. Problematic Cost Compromises in Pre-fabricated panel structure

| Pre-fabricated panels for slabs and shear walls | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CODE** | **COMPROMISE** | **Actual Cost Compromises** | **Problematic Areas** | **Cost Compromises that can be made without Durability loss** | **Parameter in concern** | **Monolithic Structure - Defects caused due to compromise** | **Root causes** |
| CP1 | Cost effective material | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP2 | Low grade material | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP3 | Reduced material consumption | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP4 | Substitution of a costlier item of a component | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP5 | Reduced material consumption of a costlier item of a component | ✓ | ✓ | ✗ | Work execution level, Maintenance level | Air cracks / Non-structural cracks, Microbial infestation | Poor concrete Mix, Lack of Maintenance |
| CP6 | Simple construction | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP7 | Low-cost construction processes | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP8 | Minimal Finishes (Utilitarian) | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP9 | Size efficiency | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP10 | Modular design | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP11 | Economy of Repetition | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP12 | Mass scaling | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP13 | Cost-Effective Lightweight Solution | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP14 | Elimination of an item | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP15 | Use of deteriorated material | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |

**Source:** author

Acceptable Compromises (✓):

i. Reduced material consumption (CP3): This can be acceptable if achieved through optimized panel design, not by compromising on material quality.
ii. Simple construction (CP6): Straightforward construction methods can be cost-effective as long as they meet quality standards.
iii. Low-cost construction processes (CP7): Affordable construction techniques can be viable if they ensure proper curing and quality control.
iv. Minimal finishes (CP8): Utilitarian finishes can save costs without affecting structural performance.
v. Size efficiency (CP9): Designing panels with optimal size utilization reduces material usage without sacrificing strength.
vi. Modular design (CP10): Modular pre-fabricated elements can streamline construction and potentially reduce costs.
vii. Economy of repetition (CP11): Repetitive use of standardized panels can be cost-effective.
viii. Mass scaling (CP12): Optimizing the mass of pre-fabricated elements can be a good cost-saving approach.
ix. Cost-effective lightweight solutions (CP13): Lightweight materials can be cost-effective as long as they meet structural requirements.

Elimination of non-critical items (CP14): Removing unnecessary features from the panels can save costs.

**Table 5.** Acceptable vs. Problematic Cost Compromises in RCC frame structure with AAC blocks infill

| RCC frame structure with AAC blocks infill | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CODE** | **COMPROMISE** | **Actual Cost Compromises** | **Problematic Areas** | **Cost Compromises that can be made without Durability loss** | **Parameter in concern** | **Monolithic Structure - Defects caused due to compromise** | **Root causes** |
| CP1 | Cost effective material | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP2 | Low grade material | ✗ | ✓ | ✗ | Material Quality | Damaged or deteriorated elements | Sulphate attack |
| CP3 | Reduced material consumption | ✓ | ✓ | ✗ | Material Quality | Moisture ingress | very weak plaster: unable to resist impacts, reduced resistance to water absorption |
| CP4 | Substitution of a costlier item of a component | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP5 | Reduced material consumption of a costlier item of a component | ✓ | ✓ | ✗ | Material Quality | Air cracks / Non-structural cracks, Structural cracks | Poor concrete Mix, mortar ratio of 1:6 has the least tensile bond strength |
| CP6 | Simple construction | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP7 | Low-cost construction processes | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP8 | Minimal Finishes (Utilitarian) | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP9 | Size efficiency | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP10 | Modular design | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP11 | Economy of Repetition | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP12 | Mass scaling | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP13 | Cost-Effective Lightweight Solution | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP14 | Elimination of an item | ✓ | ✓ | ✗ | Design level | Moisture ingress, Structural cracks | lack of a protective barrier - Lack of plaster, no cement slurry coating |
| CP15 | Use of deteriorated material | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |

**Source:** author

Acceptable Compromises (✓):

i. Reduced material consumption (CP3): This can be acceptable if achieved through efficient design, not by compromising on material quality (like weak plaster).
ii. Substitution of components (CP4): Replacing expensive elements with suitable alternatives can save costs.
iii. Simple construction methods (CP6): Straightforward construction techniques can be cost-effective as long as they meet quality standards.
iv. Low-cost construction processes (CP7): Affordable construction methods can be viable if they ensure proper curing and quality control.
v. Cost-effective lightweight solutions (CP13): Lightweight materials can be cost-effective as long as they meet structural requirements.
vi. Elimination of non-critical items (CP14): Removing unnecessary elements can save costs, but proper detailing is essential to prevent moisture ingress and cracking.

Acceptable Compromises (✓):

i. Cost-effective materials (CP1): Using economical materials for brick infill can be acceptable if they meet quality standards.
ii. Reduced material consumption (CP3): Optimizing design to minimize material usage for precast elements and brick infill is possible without compromising durability, but maintaining adequate concrete cover is crucial.
iii. Substitution of expensive components (CP4): Replacing some components with cost-effective alternatives can be viable if they meet performance requirements.
iv. Simple construction (CP6): Straightforward construction methods can be cost-effective as long as they meet quality standards.
v. Low-cost construction processes (CP7): Affordable construction techniques can be viable if they ensure proper curing and quality control.
vi. Minimal finishes (CP8): Utilitarian finishes can save costs, but proper detailing is needed to prevent moisture ingress.
vii. Cost-effective lightweight solutions (CP13):

Lightweight materials can be cost-effective for brick infill as long as they meet structural requirements.

viii. Elimination of non-critical items (CP14): Removing unnecessary features like waterproofing coatings can save costs, but proper design is essential to prevent moisture ingress and cracking.

**Table 6.** Acceptable vs. Problematic Cost Compromises in Load bearing structure

| Load bearing structure with brick infill walls with Precast RC Joists & Precast RC Planks | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CODE** | **COMPROMISE** | **Actual Cost Compromises** | **Problematic Areas** | **Cost Compromises that can be made** | **Parameter in concern** | **Monolithic Structure - Defects caused due to compromise** | **Root causes** |
| CP1 | Cost effective material | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP2 | Low grade material | ✓ | ✓ | ✗ | Material Quality | Structural cracks, Damaged or deteriorated elements | cracks in brick masonry due to stresses, being heterogenous material, quality of bricks affect the durability |
| CP3 | Reduced material consumption | ✓ | ✓ | ✗ | Design level | Corrosion and spalling of concrete, Moisture ingress | reduced cover increases susceptibility to wear and tear, durability issues, reduced cover susceptible to infiltration - Reduced concrete consumption |
| CP4 | Substitution of a costlier item of a component | ✓ | ✓ | ✗ | Material Quality | Damaged or deteriorated elements, Deformation of elements | Poor grade of plaster - moisture infiltration, the mortar ratio of 1:6 has the least tensile bond strength |
| CP5 | Reduced material consumption of a costlier component | ✓ | ✓ | ✗ | Material Quality, Design level, Work execution level | Air cracks / Non-structural cracks, Moisture ingress, Bulging, falling of patches with exposed reinforcement, Surface irregularities, Missing elements, Patterned cracking | poor concrete mix, Inadequate joinery details - No steel reinforcement bars, poor concrete mix - damage due aggressive environments, poor handling of thin sections, Poor strength of casted ferrocement steps - reduced cement consumption, mortar ratio of 1:6 has the least tensile bond strength |
| CP6 | Simple construction | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP7 | Low-cost construction processes | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP8 | Minimal Finishes (Utilitarian) | ✓ | ✓ | ✗ | Design level | Moisture ingress | poor resistance to impacts, reduced resistance to water absorption - Lack of plaster |
| CP9 | Size efficiency | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP10 | Modular design | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP11 | Economy of Repetition | ✗ | ✓ | ✗ | Design level | Surface irregularities | Use of deformed formworks |
| CP12 | Mass scaling | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| CP13 | Cost-Effective Lightweight Solution | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| CP14 | Elimination of an item | ✓ | ✓ | ✗ | Design | Patterned | no cement slurry |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | level | cracking, Moisture ingress | coating, water near the ground or unstable ground causes issues - lack of Waterproofing coatings |
| CP15 | Use of deteriorated material | ✓ | ✓ | X | Material Quality, Design level | Surface irregularities, Moisture ingress, biological decay of elements | Use of damaged bricks, absorbs water which causes dampness and efflorescence with time, weathering |

**Source:** Author

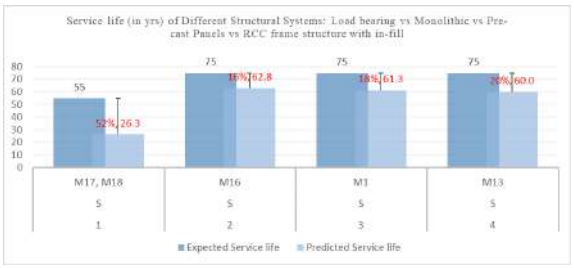


**Figure 7.** Comparison between Predicted service life of different Structural Systems
**Source:** Author

The load-bearing structural systems found in low-cost housing in the Delhi NCR region are seen to have adopted many unacceptable cost compromises and can prove to be expensive over the structural systems' life cycle, despite having a lower initial cost of construction compared to other structural systems. In contrast, the recently adopted alternative technologies, such as monolithic, precast, and RCC frame with AAC blocks structural systems, are said to perform better over the service life compared to load-bearing structures. RCC frame with AAC blocks and precast structural systems are recommended for wide adoption in low-cost housing units for the Delhi-NCR region, taking into account both the initial cost of construction and the service life performance. This is especially important given the high initial costs associated with monolithic structural systems.

## 6. Conclusion

The study explores the interplay between cost compromises (CPs) and their impact on the performance of four common building systems used in the NCR region: monolithic structures, precast panels, RCC frames with AAC infill, and load-bearing brick infill with precast RC elements. The analysis reveals that several cost-saving compromises can be implemented across these systems without sacrificing structural integrity or durability. These include:

- Utilizing optimized designs that minimize material consumption.
- Selecting cost-effective but high-quality materials.
- Employing simple and efficient construction methods.
- Considering alternative, affordable components that meet performance requirements.

The study also highlights the importance of caution when implementing certain cost-cutting compromises. Practices such as using low-grade materials, exceeding recommended material consumption limits, or neglecting proper construction techniques can lead to significant problems. These issues can manifest as structural cracks, moisture ingress, reduced durability, and even safety hazards.

In conclusion, achieving cost-effective construction requires a thoughtful and balanced approach. By carefully evaluating CPs and understanding their potential consequences, construction professionals can make informed decisions that optimize project budgets while ensuring the building's long-term performance and safety. This knowledge empowers them to deliver high-quality structures that are both economical and sustainable.

Further Considerations: By estimating a building's expected lifespan based on material quality, construction practices, and environmental factors, professionals can gain crucial insights for maintenance planning and budgeting throughout the building's life cycle. Staying up to date on advances in cost-effective methods and critically evaluating their impact on building performance remains crucial as the construction industry evolves.

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**Annexure 1 Chosen case studies and their selection criteria aligned with specific parameters**

**Table 7.** Criteria met: case study selection

| Low-cost housing | Bawana housing project | DDA housing, Lokanayakapuram | DDA housing, Narela | Supertech Basera |
|---|---|---|---|---|
| Material Compromises | | | | |
| 200mm thick Aerated concrete block wall | | P | P | P |
| 12mm plastering | P | P | P | P |
| 1:6 cement-sand plastering | P | P | P | P |
| small tile size of 300 x 300 floor tiles | P | P | P | P |
| ferrocement RCC tank | P | | | |
| Technology / Design / Material Compromises | | | | |
| Precast R.C. Plank and partially precast joist system | P | | | |
| Precast Brick Panel and Partially Precast Joist System | | | P | |
| Under Reamed pile foundation | P | | | |
| Precast extensive concrete panel system | | | P | |
| Monolithic concrete construction system with Aluminum formwork - Monolithic RC wall designed as shear wall | | P | | |
| Load bearing Brick masonry structure (G+3) | P | | | |
| Load bearing Precast RCC wall structure | | | P | |
| Design Compromises | | | | |
| repetitive unit planning (identical clustering, identical floor plans vertically) | P | P | P | P |
| 6-to-8-unit clustering | | P | | P |
| Deep plan layout | | | P | P |
| G+3, G+4 with no lifts | P | | P | |
| G+12 or G+13 | | P | | P |
| Compromised carpet area | | P | P | |
| Compromised Fenestration area | | P | P | |
| Thinner wall elements | | | P | |
| No sunshade drops in balconies | | | | P |
| insufficient sunshade of 50mm width / no sunshade | | | P | P |
| no plastering on wall surfaces, ceiling surfaces | | | P | |
| Neglected terrace or unfinished terrace area | | | | P |
| insufficient tile drops | | | P | |
| Inadequate electrical fixtures | P | P | P | P |
| one pipe system | P | | | |
| Lack of commercial spaces in design | | P | P | P |
| Lack of garbage chutes | | P | P | P |
| outskirts of the city | P | P | P | |

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# Crowdshipping in Urban Freight Logistics:
## A Systematic Literature Review

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**Abstract:** Over the past decade, crowdshipping has moved from a niche idea to a visible strand of urban freight practice, built around digital platforms and gig-based delivery work. This paper takes stock of that evolution through a systematic review of 61 peer-reviewed studies. A small bibliometric exercise, combined with a thematic reading of the material, is used to trace how research on crowdshipping has grown, where it is being produced, which methods are commonly applied, and which questions receive most attention. The bibliometric results indicate a clear rise in publications from around 2015 onward, with much of the early work originating in the United States and several European countries. Keyword patterns and journal outlets indicate that the subject spans logistics, sustainability studies, behavioural research, and urban planning. Thematically, the literature tends to cluster around six recurring concerns: how crowdshipping is organised as a business and operational model; how platforms and digital infrastructure are designed; the optimisation and simulation tools used to plan services; behavioural aspects of participation; environmental and sustainability claims; and emerging policy or regulatory debates. Technical and operational issues are examined in considerable detail, whereas other elements appear less developed. Questions of governance, labour rights, and the everyday conditions of crowdshippers are only partially addressed, particularly in work on developing and middle-income contexts. Evidence on integration with public transport systems and on realised environmental outcomes is also limited. On this basis, the paper outlines directions for further research that give greater weight to policy engagement, interdisciplinary collaboration, and empirical validation in real urban settings. The review is intended as a reference point for scholars, practitioners, and public authorities who are considering how crowdshipping might be incorporated into broader strategies for sustainable urban mobility and freight.

**Keywords:** Crowdshipping, Urban freight, Last mile logistics, urban mobility

**सार:** पिछले एक दशक में, क्राउडशिपिंग एक खास आइडिया से शहरी माल ढुलाई के काम का एक अहम हिस्सा बन गया है, जो डिजिटल प्लेटफॉर्म और गिग-बेस्ड डिलीवरी काम पर आधारित है। यह पेपर 61 पीयर-रिव्यूड स्टडीज़ की सिस्टमैटिक समीक्षा के ज़रिए इस बदलाव का जायज़ा लेता है। एक छोटी बिब्लियोमेट्रिक एक्सरसाइज़, जिसे मटेरियल की थीमेटिक रीडिंग के साथ जोड़ा गया है, का इस्तेमाल यह पता लगाने के लिए किया गया है कि क्राउडशिपिंग पर रिसर्च कैसे बढ़ी है, यह कहाँ हो रही है, कौन से तरीके आमतौर पर इस्तेमाल किए जाते हैं, और किन सवालों पर सबसे ज़्यादा ध्यान दिया जाता है। बिब्लियोमेट्रिक नतीजों से पता चलता है कि 2015 के आसपास से पब्लिकेशन में साफ बढ़ोतरी हुई है, जिसमें ज़्यादातर शुरुआती काम यूनाइटेड स्टेट्स और कई यूरोपीय देशों में हुआ है। कीवर्ड पैटर्न और जर्नल आउटलेट बताते हैं कि यह विषय लॉजिस्टिक्स, सस्टेनेबिलिटी स्टडीज़, बिहेवियरल रिसर्च और शहरी प्लानिंग तक फैला हुआ है। थीमेटिक रूप से, लिटरेचर छह बार-बार आने वाली चिंताओं के इर्द-गिर्द इकट्ठा होता है: क्राउडशिपिंग को एक बिज़नेस और ऑपरेशनल मॉडल के रूप में कैसे ऑर्गनाइज़ किया जाता है; प्लेटफॉर्म और डिजिटल इंफ्रास्ट्रक्चर कैसे डिज़ाइन किए जाते हैं; सेवाओं की योजना बनाने के लिए इस्तेमाल किए जाने वाले ऑप्टिमाइज़ेशन और सिमुलेशन टूल; भागीदारी के बिहेवियरल पहलू; पर्यावरणीय और सस्टेनेबिलिटी के दावे; और उभरती हुई पॉलिसी या रेगुलेटरी बहसें। तकनीकी और ऑपरेशनल मुद्दों की काफी डिटेल में जांच की गई है, जबकि दूसरे एलिमेंट कम विकसित लगते हैं। गवर्नेंस, लेबर राइट्स और क्राउडशिपर की रोज़मर्रा की स्थितियों के सवाल सिर्फ़ आंशिक रूप से हल किए गए हैं, खासकर विकासशील और मध्यम आय वाले देशों में किए गए काम में। पब्लिक ट्रांसपोर्ट सिस्टम के साथ इंटीग्रेशन और हासिल किए गए पर्यावरणीय नतीजों पर भी सबूत सीमित हैं। इस आधार पर, यह पेपर आगे की रिसर्च के लिए दिशा-निर्देश बताता है जो पॉलिसी जुड़ाव, इंटरडिसिप्लिनरी सहयोग और असली शहरी माहौल में अनुभवजन्य सत्यापन को ज़्यादा महत्व देते हैं। इस समीक्षा का मकसद विद्वानों, प्रैक्टिशनर्स और पब्लिक अथॉरिटीज़ के लिए एक संदर्भ बिंदु के रूप में काम करना है जो इस बात पर विचार कर रहे हैं कि क्राउडशिपिंग को स्थायी शहरी गतिशीलता और माल ढुलाई के लिए व्यापक रणनीतियों में कैसे शामिल किया जा सकता है।

**मुख्य शब्द:** क्राउडशिपिंग, शहरी माल ढुलाई, लास्ट माइल लॉजिस्टिक्स, शहरी गतिशीलता

## 1. Introduction

Urban freight activity has drawn growing attention as cities cope with the combined effects of expanding e-commerce, rapid urban growth, and rising expectations for fast, reliable delivery services. Increasing volumes of goods moving through dense urban areas place additional strain on road networks and logistics facilities, which in turn contribute to congestion, deteriorating air quality, and operational inefficiencies in delivery systems (Fessler et al. 2024; Le & Ukkusuri 2019). Traditional approaches to the last mile, built around large distribution centers and dedicated fleets of commercial vehicles, are therefore being questioned as appropriate solutions for compact, densely populated cities (Zhang & Zhang 2024). These pressures have encouraged both researchers and practitioners to experiment with alternative models that promise improvement in environmental performance, scalability, and cost for urban goods movement.

Crowdshipping has emerged as one such alternative. In this arrangement, ordinary

residents use their regular trips through the city to carry parcels matched to them via a digital platform. Often described as crowdsourced delivery, the model relies on individuals with access to personal or shared transport, such as two-wheelers, bicycles, or public transport, who are willing to combine these trips with small-scale delivery tasks (De Oliveira Leite Nascimento et al. 2023). Rather than introducing additional vehicles into the system, crowdshipping builds on existing travel patterns, which can reduce redundant vehicle kilometres and lower emissions compared with conventional courier operations (Ermagun & Stathopoulos 2021). By turning regular commuters into occasional delivery agents, crowdshipping connects directly with broader trends in platform-based gig work and collaborative consumption, where underused capacities are reoriented toward new commercial and service functions (Buldeo Rai et al. 2017)

Crowdshipping has been operationalized worldwide. Such giants as Amazon and Walmart have integrated into their logistics systems as Amazon Flex and Spark Delivery, which involve freelance driver enrolment in the delivery of parcels on the same day (Buldeo Rai et al. 2018; Ishfaq and Bajwa 2019; Nguyen et al. 2018). In the same manner, a variety of startups across countries, such as Piggybaggy in Finland, Trunkrs in the Netherlands, and Postmates in the United States, have shown that digital platforms can quickly and flexibly organize distributed delivery networks. Dunzo, Shadowfax, and other platforms/companies are modifying the crowdshipping model to meet the needs of India's urban regions, characterized by high supply chain disintegration, an informal labour market, and high population density (Kumar and Chidambara 2024). These developments underscore the potential of crowdshipping to address long-standing inefficiencies in urban freight delivery systems, especially in cities facing space constraints and rising environmental concerns.

Although crowdshipping is already being tested and deployed in many contexts, academic work on it remains scattered across different fields. Individual studies have tended to focus on specific questions, such as the environmental implications of these services (Le et al. 2019), pricing and tariff design (Behrend et al. 2019), or users' and couriers' willingness to participate in such schemes (Boysen et al. 2022). What is still missing is a synthesis that draws these strands together and considers how they relate to one another. Existing reviews either adopt a broader lens on crowd logistics or approach crowdshipping mainly through an operations research or optimisation perspective, leaving policy, behavioural, and sustainability aspects only partially covered (Macrina et al. 2020). As a result, the field lacks an overview that connects conceptual work, empirical evidence, and practice across regions.

This review addresses this gap by examining the academic literature on crowdshipping within the broader context of urban freight. It organises the identified studies into major thematic groups, traces how research has developed across different parts of the world, and highlights the main methodological approaches used. A brief bibliometric component maps publication trends and leading contributors to the field. Taken together, these elements are intended to provide a structured point of reference for researchers, practitioners, and public authorities interested in the future of sustainable urban logistics and the role that innovative delivery models such as crowdshipping may play in its development.

## 2. Methodology

The review is based on a structured reading of academic work on crowdshipping in urban freight. The aim was to follow a procedure that other researchers could trace and repeat. First, relevant search terms and databases were chosen, and an initial pool of publications was collected. Second, explicit inclusion and exclusion criteria were applied to remove studies that were off-topic or did not meet basic quality requirements. In the final step, the remaining papers were read in detail and grouped into broad themes, which then formed the basis for the analysis presented in the following sections.

### *2.1 Literature Search and Data Sources*

The review draws on studies located through Scopus, Web of Science, ScienceDirect, and SpringerLink. Searches used terms such as crowdshipping, crowdsourced delivery, crowd logistics, last-mile logistics, and urban freight, combined in different ways to capture various wordings. The period from 2010 to 2024 was considered, as crowdshipping began to appear in the literature around 2010 and gained prominence thereafter. Only peer-reviewed journal articles, conference papers, and scholarly book chapters were included, while reports, white papers, and other non-reviewed sources were excluded.

### *2.2 Inclusion and Exclusion Criteria*

Studies were included if they explicitly addressed crowdshipping or its related sub-domains (e.g., peer-to-peer delivery, gig-based last-mile logistics), particularly within urban or last-mile freight contexts. Eligible papers employed conceptual, empirical, simulation, or optimization-based frameworks. Conversely, studies that focused solely on conventional freight transport without a crowdsourcing component, or those centered on personal ride-sharing without goods movement, were excluded. Papers not available in English or lacking full-text access were also removed. Following de-duplication, 145 studies were initially identified. Based on title and abstract screening, 89 articles were shortlisted for full-text review. A final pool of 61 publications met all inclusion criteria and were selected for detailed analysis. The overall review process is illustrated in Figure 1.

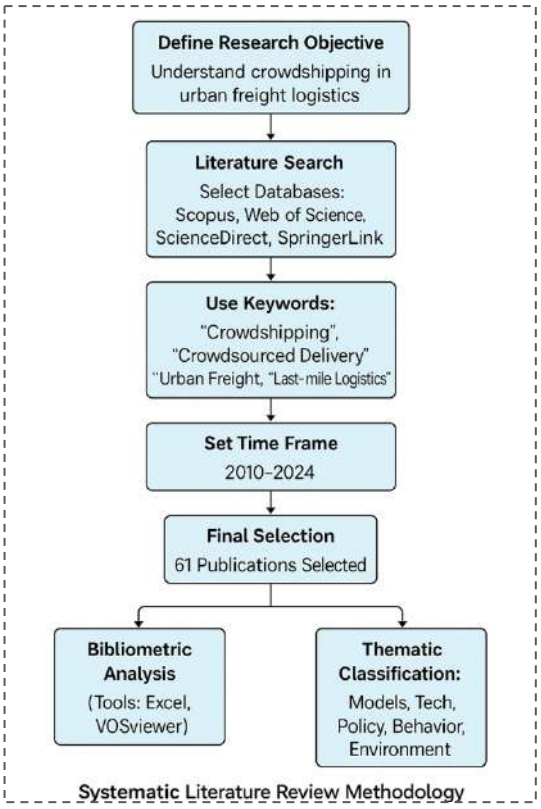


**Figure 1** Methodological framework for the systematic literature review on crowdshipping

### *2.3 Analytical Strategy*

The analysis was carried out in two main steps, combining numerical description with close reading of the texts. In the first step, a simple bibliometric scan was used to sketch the broad contours of the field. Publication counts over time, the main contributing countries, and the journals that most frequently published on crowdshipping were identified. These indicators were compiled and tabulated in spreadsheet software (Microsoft Excel) to visualise trends and geographical concentration.

The second step involved a more interpretative review of the selected studies. Each paper was read and then placed into one or more thematic groups according to its primary focus and methods. The themes covered operational models, platform and technology design, optimisation approaches, behavioural responses, environmental impacts, and policy and regulatory questions. Studies were allowed to sit in several themes when their scope was broader. Taken together, this mix of quantitative description and thematic coding offered both a general picture of how the literature has evolved and a clearer view of the main clusters of ideas that currently define research on crowdshipping.

## 3. Bibliometric Analysis

A descriptive bibliometric scan was conducted alongside the qualitative review to examine how work on crowdshipping has developed over time and across regions. The focus was on fundamental indicators, including publication growth, country contributions, recurrent keywords, and the journals that most often publish on the topic. Data were taken from Scopus and Web of Science using the same keyword set as in the main review, covering the period 2010–2024.

### *3.1 Publication Trends Over Time*

Research output on crowdshipping was very limited in the early 2010s. Only a few papers appeared between 2010 and 2014, after which the number of studies began to increase. From around 2016, publication activity rises steadily, reflecting growing interest in last-mile logistics, the gig economy, and urban sustainability. Figure 2 plots these trends for the period 2010–2024. The curve climbs from 2016 and reaches its highest levels between 2021 and 2023. By the end of the review window, 61 publications had been identified.

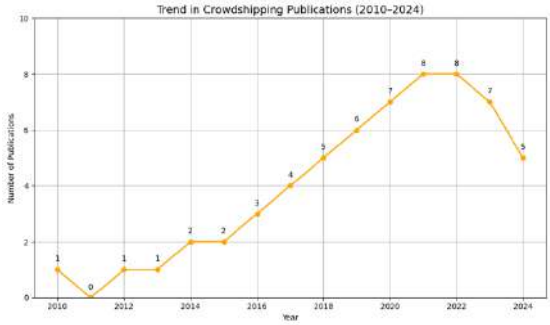


**Figure 2.** Annual trend of crowdshipping-related publications from 2010 to 2024.

### *3.2 Geographic Distribution of Research*

The spatial pattern of contributions is uneven. Most of the early and most frequent publications come from research groups in the United States, Germany, the Netherlands, and the United Kingdom, often focusing on operational pilots, platform design, and regulatory questions in well-developed logistics markets. More recently, work from Asia has become more visible. Studies from Singapore, China, and India, for example, examine crowd shipping in the context of smart mobility initiatives and public transport systems.

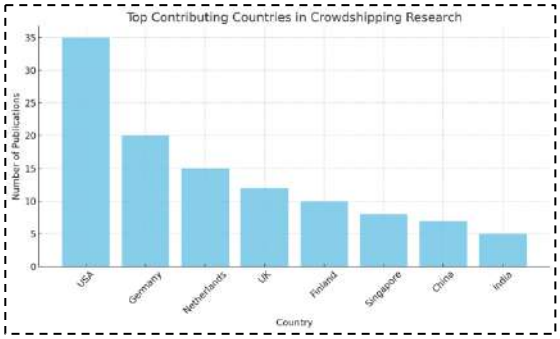


**Figure 3.** Top contributing countries in crowdshipping research output

Figure 3 presents a horizontal bar chart of publications by country. The United States appears as the most significant contributor with 35 papers, followed by Germany, the Netherlands, and the United Kingdom. The emergence of studies from Asian cities suggests a gradual shift toward a more geographically diverse research landscape.

### *3.3 Keyword Analysis and Conceptual Focus*

The keyword scan shows that most work on crowdshipping is anchored in a familiar set of ideas around urban goods movement. Terms such as "crowdshipping," "urban freight," "last mile delivery," "sustainability," and "platform economy" appear most often across the 61 papers.

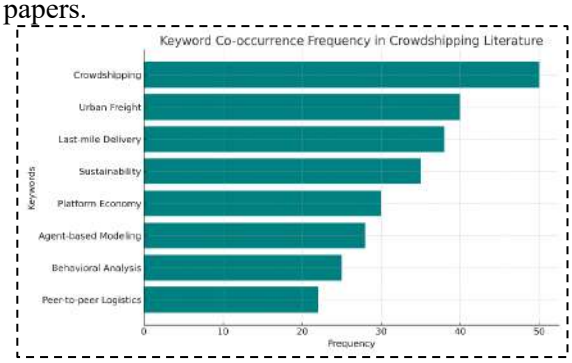


**Figure 4.** Most frequent keywords in crowdshipping literature

Alongside these, expressions like "behavioural analysis", "peer to peer logistics", and "sharing economy" point to a growing interest in how people use and experience these services, as well as in the digital systems that support them. Figure 4 summarises the most frequently used keywords in the reviewed studies. Crowdshipping, urban freight, last-mile delivery, and sustainability stand out clearly, indicating that the field is framed simultaneously as a logistics, environmental, and socio-technical problem.

### *3.4 Thematic Categories of Research*

The publications were grouped into seven broad themes after detailed reading. Work on operational arrangements and business models accounts for the largest share, followed by studies that use optimisation or other modelling approaches to design or test crowdshipping schemes. Other themes include platform and interface design, participation and behavioural aspects, environmental impacts, policy and regulation, and a small set of papers that cut across several of these areas. Figure 5 presents the number of research papers in each thematic group. The spread of topics confirms that crowdshipping has developed as an interdisciplinary field, but also shows where attention has been most concentrated so far.

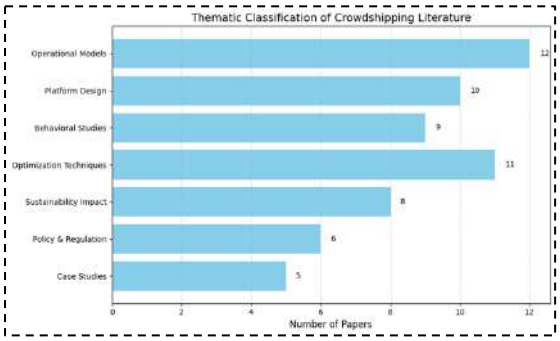


**Figure 5.** Thematic classification of reviewed crowdshipping studies

### *3.5 Methodological Approaches in Crowdshipping Research*

The reviewed studies use a mix of methods rather than a single dominant approach. Early contributions are mainly conceptual or review-based, proposing definitions, classifying models, or outlining potential applications. Over time, more empirical work appears in the form of user and courier surveys, stated preference experiments, and case studies of specific pilots. In parallel, there is a substantial body of research that relies on optimisation techniques and simulation models to examine routing, task allocation, and system performance.

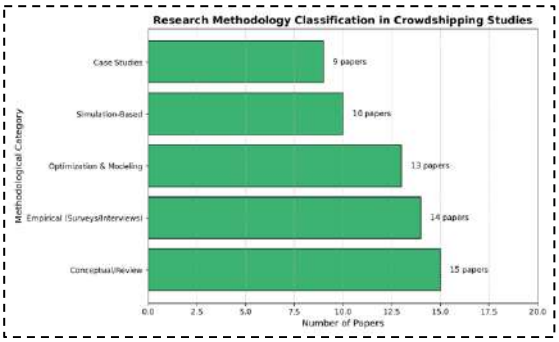


**Figure 6.** Classification of reviewed papers by research

Figure 6 groups the 61 research papers by method. Conceptual and empirical studies make up a large share, with optimisation and simulation approaches forming another significant block. A smaller number of contributions use detailed case-based analysis or mixed methods designs, reflecting the practical and theoretical complexity of the topic.

### *3.6 Journal-wise Distribution of Crowdshipping Research*

Crowdshipping research is dispersed across a range of journals rather than concentrated in a single outlet. Many papers appear in transport and logistics journals, while others are published in journals focused on sustainability, supply chain management, or urban studies. Within the sample, Transportation Research Part E has the highest number of publications, followed by Sustainability, the International Journal of Physical Distribution and Logistics Management (IJPDLM) and Research in Transportation Economics as shown in Figure 7. This distribution underlines the interdisciplinary character of the field: crowdshipping is treated at once as a logistics innovation, a component of urban mobility systems and a potential contributor to environmental and social objectives.

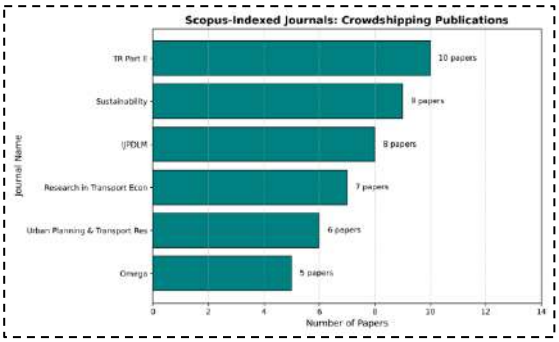


**Figure 7** Crowdshipping publications across journals

## 4. Thematic Analysis of Literature

Crowdshipping research has advanced through an interdisciplinary blend of logistics, digital platforms, urban sustainability, and behavioral studies. This section presents a comprehensive thematic mapping of the literature based on conceptual convergence and empirical focus. The discussion elaborates on six core themes derived from the systematic review, each contributing distinctively to the evolving understanding of crowdshipping systems.

### *4.1 Operational and Business Models*

A large group of studies concentrates on how crowdshipping is organised as a delivery service and business model. Most of this work distinguishes three main arrangements: customer-to-customer (C2C), business-to-customer (B2C), and mixed or hybrid formats. In all three cases, delivery activities are outsourced to a digitally coordinated pool of individuals, and performance is usually discussed in terms of scalability, reliability of service, and the ease with which these schemes can be linked to existing freight systems in the city.

Ahamed et al. (2021) and Akeb et al. (2018) noted that C2C arrangements tend to work better in settings with strong social networks and informal ties, though these schemes may suffer from weaker traceability and less predictable service quality. B2C models, in contrast, allow firms to exercise greater control over operations and are often seen as more commercially robust. Recent contributions also draw attention to micro depots, modular logistics units, and similar spatial configurations that can cut down unnecessary vehicle kilometres and make better use of limited urban space. (Tapia et al., 2023) Describe decentralised arrangements in which tasks are assigned dynamically, central warehousing is reduced, and routes can be adjusted with greater flexibility. Across these studies, a common idea is that crowdshipping leverages latent or idle capacity already present in urban travel patterns, connecting the discussion directly to broader debates on smart city freight planning.

### *4.2 Platform Design and Digital Infrastructure*

A second body of work treats digital platforms and their infrastructure as the core of the crowdshipping system. Here, the primary focus is on how requests and available couriers are matched, how tasks are allocated, and how information is shared in real time. Typical elements include tracking functions, route and task optimisation, and incentive or pricing schemes that can be adjusted while the system is operating. (Akbar et al. 2024) emphasise the role of adaptive assignment algorithms and

geofencing tools in reducing failed deliveries and making platforms more responsive to short-term fluctuations in demand.

There is also growing reference to blockchain applications and the use of Internet of Things (IoT) devices along the delivery chain. (Comi and Hriekova 2024) explains that platforms powered by blockchain can improve transaction security and establish clearer dispute-resolution procedures, thereby strengthening trust between users and crowdshippers. At the same time, the literature points out that these advances raise unresolved questions. Data protection, ownership of information, and the ability of different devices and systems to work together are recurring concerns, especially in large cities where technologies, operators, and user groups are highly diverse.

### *4.3 Optimization and Simulation Techniques*

This part of the literature on crowdshipping is dominated by techniques of quantitative optimization. A substantial body of literature has used vehicle routing algorithms, agent-based simulation models, and dynamic dispatch systems to optimize performance in the last-mile delivery problem. (Allahviranloo and Baghestani 2019; Behrend et al. 2021) developed a real-time task allocation model for dynamic routing in high-density areas, showing improvements in delivery success rates and system efficiency (Xu 2024). The agent-based simulation is often used to assess the behaviours of system agents in the context of differences in logistical and market conditions (Di Giacobbe et al. 2021; Dötterl et al. 2020; Xu 2024). Use a hybrid optimization approach that incorporates delivery time windows, platform constraints, and crowd participation dynamics to design robust dispatch policies for volatile demand scenarios (Harada & Yamauchi 2018). These models provide a theoretical basis for building adaptive, reactive crowdshipping designs that enable scaling in uncertain metropolitan environments.

### *4.4 Behavioral and Participation Insights*

The decision of individuals to participate in crowdshipping, whether as couriers (crowdshippers) or customers, is influenced by a complex array of behavioral factors. The relevant literature on this theme draws on transport psychology, behavioral economics, and choice modeling to identify the factors motivating people to become crowdshippers or customers. Bajec & Tuljak-Suban (2022) stated-preference methods are used to investigate the effects of route deviation tolerance, compensation level, and environmental concern on the willingness to work (WTW) in crowdshipping systems. Savelsbergh & Ulmer (2024) analyzed the influence of trust in digital platforms, prior experience, and perceived platform reliability on participation rates (Xie et al. 2023). Based on the findings, it can be concluded that monetary compensation is not an adequate motivator for maintaining engagement, as overall system transparency and task predictability are also important factors. This area of research is especially valuable to platform designers interested in building user-retention strategies and maximizing the user experience.

### *4.5 Environmental and Sustainability Impacts*

Crowdshipping is frequently sold as a sustainable substitute to the traditional models of delivery because it has the potential to optimize deliveries by prioritizing multiple stops and minimizing unutilized miles (Xiao et al. 2023). A study (Punel et al. 2018) compares traditional logistics functions with crowd-based ones using simulation data. It concludes that incorporating delivery activities into regular commuter journeys reduces vehicle kilometers travelled (VKT) by 25%. However, sustainability outcomes vary significantly based on modal choice, trip chaining behavior, and urban density. (Aronshtam et al. 2024) caution that if crowdshippers use private vehicles solely for deliveries, emission levels may not be significantly lower than conventional systems (Marcucci et al. 2018). The empirical literature on life-cycle assessment (LCA) or long-term environmental trade-offs is limited, with very few studies that have conducted an extensive life-cycle assessment to support further empirical validation.

### *4.6 Policy and Regulatory Perspectives*

Regulatory issues constitute a relatively underexplored but critical area in crowdshipping research. This has resulted in significant ambiguity due to the lack of standardized legal frameworks for labour classification, insurance, liability, and taxation. Sina Mohri et al. (2023) argue that the lack of regulation may lead to exploitative labour conditions and inconsistent service standards unless formal policies are developed to safeguard gig workers' rights. Buldeo Rai (2019) calls for a multi-stakeholder governance model that includes regulators, platform operators, and civil society groups to ensure accountability and ethical implementation. Moreover, zoning regulations, public right-of-way rules, and data privacy laws

are seldom considered in academic discussions, even though they play a crucial role in real-world feasibility.

## 5. Global Practices and Indian Context

Crowdshipping has emerged as a transformative approach in urban logistics, leveraging the gig economy and digital platforms to optimize last-mile delivery. This section examines global implementations of crowdshipping and explores its current state and potential within the Indian context.

### *5.1 Global Practices in Crowdshipping*

#### *5.1.1 North America and Europe*

In North America, crowdshipping has grown mainly through large private platforms rather than public initiatives. Services such as Amazon Flex and Uber Eats rely on independent couriers for the last mile, expanding or shrinking their active workforce in line with demand. Comparative studies suggest that these schemes can cut delivery times and reduce operating costs compared with conventional fleets, but they also point to unresolved questions about working conditions and compliance with labour and transport regulations (Patier & Routhier 2020; Simoni et al. 2020; Yang 2018).

In Europe, similar ideas are often framed within broader goals of sustainable mobility and urban planning. Several cities have experimented with models in which parcels are shifted onto walking, cycling, or public transport legs of commuter trips. Copenhagen is a frequently cited case in which parcel flows have been integrated into everyday journeys to reduce empty vehicle kilometres and congestion. The available evidence indicates that using existing commuter routes for small parcel deliveries can lower emissions and traffic pressure while keeping service performance at an acceptable level.

#### *5.1.2 Asia-Pacific and Emerging Economies*

In the Asia Pacific region, most of the documented experiments with crowdshipping are found in large, dense cities with strong digital networks and good public transport. Singapore is a common reference point: pilot schemes there have asked ordinary commuters, as well as existing bus and metro services, to carry small parcels alongside their regular trips to ease last-mile delivery pressures (Karakikes & Nathanail, 2022; Qiu et al., 2021; Wali et al., 2022). The results are generally encouraging, but they also make it clear that such schemes only work well when rules on safety, liability, and service standards are clearly set out. Similar ideas are now being tested in several emerging economies. Studies from Ukraine, for instance, examine how potential users view crowdshipping and whether they are willing to pay for it (Montuori et al., 2023; Rossolov & Susilo, 2024). These investigations report broadly positive attitudes, particularly among younger respondents, and suggest that adoption is feasible when basic conditions are met. In countries where logistics networks are patchy or conventional courier services do not reach all areas, this evidence points to crowdshipping as a possible way to fill delivery gaps, provided there is adequate institutional backing and appropriate technical support.

### *5.2 Crowdshipping in the Indian Context*

India presents a unique landscape for crowdshipping, characterized by rapid urbanization, a burgeoning e-commerce sector, and diverse logistical challenges.

#### *5.2.1 Current State and Initiatives*

Crowdshipping is still in its early stages in India, but some efforts are already being made to implement the scheme into the logistics system. Studies (Carannante et al. 2025; Hwang et al. 2025; Mittal et al. 2022; Sawik 2024; Upadhyay et al. 2021) have explored the potential of crowdshipping in reverse logistics, suggesting that leveraging the existing commuter network can enhance efficiency in returning goods, particularly in rural areas. Moreover, when it comes to tier-1 cities, studies have already suggested the possibility of synchronisation of crowdshipping with public transportation to streamline last-mile shipments, and this is only attainable with sound planning and cooperation among the parties involved (Alharbi et al., 2022; Ram & Acharyulu, 2024; Upadhyay et al., 2020).

#### *5.2.2 Challenges and Opportunities*

Using crowdshipping in India brings together a mix of practical and structural difficulties closely linked to the way Indian cities function. Many urban areas still struggle with fundamental infrastructure problems: road surfaces are often poor, congestion is frequent, and there is very limited space formally set aside for loading and unloading. These conditions make it challenging to run reliable and time-sensitive delivery services, especially in large metropolitan regions with dense populations and constantly changing traffic patterns (Awasthi et al. 2025; Upadhyay et al. 2021).

Unclear regulation adds another layer of complexity. At present, there is no dedicated legal framework that governs how digital logistics platforms and crowdshippers should operate. It is often uncertain whether a crowdshipper should be treated as an employee or self-employed, and this ambiguity affects access to social protection, tax rules, and the responsibilities of platform operators (Kalbalia and Koushik 2025; Patnaik et al. 2025). In the absence of precise regulation and formal recognition, long-term policy support, investment, and standard-setting remain hesitant (Devari et al. 2017).

Digital and technological issues are also visible. India has seen rapid growth in mobile and internet penetration, but this progress is uneven. Differences in income, education, and location mean that many potential workers, especially in peri-urban and semi-rural areas, do not have regular access to suitable smartphones or lack the digital literacy needed to use app-based systems with confidence (Elmay et al. 2025; Ruiz et al. 2017). This digital divide can reduce the size and diversity of the pool of possible crowdshippers.

At the same time, several conditions make India a promising setting for crowdshipping innovations. The country has a large and relatively young population that is familiar with digital platforms and comfortable with flexible work arrangements. E-commerce activity has expanded rapidly in both major cities and smaller towns, increasing demand for low-cost, adaptable last-mile delivery solutions. Government programmes that aim to improve digital infrastructure, support start-ups, and encourage shared or platform-based mobility can also create room for crowdshipping models to be tested and scaled within the wider logistics system (Devkar et al. 2009; Manmadhan et al. 2024).

For crowdshipping to develop as a durable and inclusive part of the logistics industry in India, responses will need to be organised on several fronts. Regulations around crowdshipping need to be made more explicit so that the roles of platforms, clients, and delivery workers are clearly set out, and so that people working through these apps receive fair pay and basic protections. Once crowdshipping is recognised in policy as a legitimate part of urban freight, it becomes easier to introduce rules on safety, service quality, and simple procedures for handling complaints or disputes. On the technological side, platform and application design should focus on ease of use and wide access (Devkar et al. 2009; Joshi & Achuthan 2016). Lightweight apps that can run on older phones, offer several language options, and function reasonably well with limited connectivity are more likely to reach users across different income groups. Simple layouts and interfaces that do not demand high levels of digital literacy can further reduce entry barriers.

Coordinated action is needed if crowdshipping is to move beyond a handful of pilot projects. Public authorities, logistics firms, and civil society organisations all have a role to play in that process (Sinha 2018). In practical terms, this may involve formal public–private arrangements that finance small trials, share operational data, and offer limited incentives for early adopters. Alongside these measures, outreach and basic training sessions can help prospective crowdshippers understand how the platforms work, which is especially important for people with little experience of app-based or digital work.

Where such support exists, crowdshipping can sit alongside established courier and freight operators rather than replace them, and can help cover areas where rapid growth, urban expansion, or weak infrastructure make conventional delivery difficult. If these institutional efforts are paired with clear rules and sensible technology choices, crowdshipping has a reasonable chance of becoming a locally responsive, relatively low-impact way to meet last-mile delivery needs in Indian cities.

## 6. Discussion

The studies examined in this review indicate that crowdshipping has not developed within a clearly bounded discipline. Instead, it sits across several conversations: urban freight operations, digital labour, and sustainability all feature in different parts of the literature. The sixty-one papers included here differ in method, case study context, and theoretical emphasis, yet together they allow a reasonably clear picture to be drawn of how the idea has been framed and tested so far. When publication trends are read alongside the thematic analysis, it becomes easier to see both the field's main strengths and the areas that remain thin or uneven.

Most contributions still deal with operational questions. Much attention is given to how parcels are routed through the network, how tasks are assigned to available couriers, and how fluctuations in demand are handled using algorithms and optimisation models. Simulation exercises are common, and performance is usually assessed in terms of efficiency or service

quality. A related group of studies focuses on the functioning of the platforms themselves, examining features such as real-time tracking, interface design, and rating or reputation mechanisms that build trust between users and delivery agents.

Other aspects are far less developed. Regulatory issues appear only sporadically, even though national and local rules shape how platforms are allowed to operate and how responsibilities are distributed between firms and workers. The day-to-day realities of people doing delivery work through these platforms are also addressed in only a limited way, despite widespread public discussion about gig work and precarious employment. Environmental impacts are often mentioned but are rarely placed at the centre of the analysis, and are frequently treated as side effects rather than core outcomes.

Taken together, these patterns suggest that future research needs to engage more directly with the social and institutional contexts in which crowdshipping systems operate. Without this, it is difficult to judge whether crowdshipping can move from small-scale pilots and experiments to a stable role within urban freight strategies. The field is still in a formative stage, and its longer-term contribution will depend on how well insights from operational modelling are linked with questions of regulation, labour, urban space, and sustainability.

### *6.1 Research Gaps Identified*

The growth of crowdshipping literature has not removed some critical blind spots. A first gap concerns regulation. Only a small number of studies examine in detail how rules on liability, tax treatment, insurance cover, or minimum standards for platform conduct should apply, or how different regulatory choices might support or constrain these services in practice.

A second gap relates to the people doing the delivery work. Most crowdshippers are treated as gig workers, yet there is limited systematic analysis of income stability, risk exposure, working hours, or access to social protection. Work on how crowdshipping might be linked with public transport or wider urban mobility systems is also relatively thin. Although some authors point to potential synergies with cycling, walking, and mass transit, there is little empirical evidence on how such arrangements actually perform in real cities.

Environmental effects form another weakly covered area. The idea that crowdshipping can cut emissions or reduce energy use is often mentioned. Still, only a few studies provide robust comparative assessments that would allow these claims to be tested. Questions of trust, data use, and platform governance are similarly underexplored, even though they strongly influence whether people are willing to use or work through these platforms.

Finally, the geographical spread of research is narrow. Most empirical work still comes from North America and Western Europe. Conditions in cities in Asia, Africa, and Latin America, where digital platforms are expanding quickly and logistics constraints are quite different, receive far less attention. This imbalance limits understanding of how crowdshipping operates across varied social, institutional, and infrastructural contexts.

## 7. Conclusion

Crowdshipping has become an important option in urban freight logistics, particularly for managing last-mile deliveries in growing e-commerce markets. It allows firms and platforms to draw on flexible pools of couriers and to scale services up or down with demand. This model fits naturally with the spread of app-based platforms, shared mobility, and more responsive logistics systems. The research carried out so far has helped to explain how these platforms are structured, how information flows through them, and how their operations can be organised in dense urban areas.

Even with this progress, current knowledge is still partial. Many studies focus on technology and operations, while social, institutional, and spatial aspects receive less attention. Crowdshipping is not only a technical solution; it is also part of wider patterns of urban work, use of public space, and local regulation. A more coherent research agenda would therefore link digital platform design with user behaviour, labour conditions, urban form, and long-term sustainability goals. Insights from transport planning, labour studies, urban geography, environmental analysis, and data governance can jointly support this task.

Questions of equity and worker well-being are critical. Most crowdshippers are treated as independent contractors, which raises concerns about income stability, working hours, exposure to risk, and access to social security. If crowdshipping is to be promoted as part of sustainable urban logistics, these concerns cannot be separated from debates on access,

affordability, and the distribution of benefits and burdens across different social groups. Policy design, platform rules, and local enforcement will all influence whether these services widen or reduce existing inequalities.

A further challenge lies in connecting crowdshipping to other elements of the urban mobility system. There is considerable potential to align parcel movements with public transport corridors and facilities, for example, by using metro stations, city bus routes, or regional rapid transit systems as transfer points or micro hubs. These kinds of arrangements should not be treated as automatically successful just because they seem attractive in theory. They need to be tried out in real settings and evaluated carefully, for example, by looking at how reliable the services are, what happens to overall travel times, whether safety is affected, and how users and couriers actually respond to them. Claims about environmental gains also need firmer evidence. Comparative studies that measure emissions, energy consumption, or changes in land use across different delivery setups would help clarify whether the supposed benefits are actually realised in practice.

For municipal administrations and transport planners, crowdshipping is better seen as one option in a broader toolbox of urban freight measures rather than as a complete solution in itself. Decisions about support or regulation will depend very much on local conditions: the strength of digital infrastructure, the role of informal logistics, the way local government is organised, and so on. In the longer run, the value of crowdshipping is likely to hinge less on any particular app or technical feature and more on steady work on regulation, inclusive design of services, and the capacity of both public institutions and platforms to adapt to changing patterns of demand and urban growth.

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# Thermal Comfort conditions in *Rajbaris* of Bengal:
## A case study of the Bawali *Rajbari*

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**Abstract:** This research paper explores the *'Rajbari'* typology and its extensive conversion into heritage hotels, a current trend in West Bengal. In particular, it examines the level of thermal comfort achieved within the *Rajbaris* adapted as Heritage Hotels. To understand the architectural development of the typology and its extensive presence within the region, we explore the historical background of the Bengal Presidency. The Bengal Presidency was witness to great social, political, and historical turmoil during the period known as the 'Bengal Renaissance', when most of the beautiful, grand pre- and post-British era palaces, *Zamindar baris,* and *Rajbaris* were constructed. With this context, a study was undertaken to evaluate the architectural style, passive design strategies and most importantly, assess the thermal comfort conditions of one of the prominent *Rajbaris* – the Bawali *Rajbari* - a heritage property repurposed as a heritage hotel. The paper has three sections: the study of the historical context in which the *Rajbaris* took shape; adaptive Reuse of Bawali *Rajbari,* highlighting passive design strategies; and the evaluation of thermal comfort within the adapted *Rajbari.* As India reflects on its colonial history in new ways, more than 75 years after Independence, this research addresses an urgent, overlooked dimension of adaptive reuse: thermal comfort. It points to thermal comfort in heritage buildings, especially given the exceedingly limited research in this field. Therefore, this study seeks to further the academic discussion on thermal and heritage perceptions of heritage buildings.

**Keywords:** Rajbaris, Zamindari system, Thermal Comfort, Adaptive Reuse, Heritage Hotels.

**सार:** यह शोध पत्र 'राजबाड़ी' वर्गीकरण और उसके विरासत होटलों में बड़े पैमाने पर बदलाव की पड़ताल करता है, जो पश्चिम बंगाल में एक मौजूदा रुझान है। विशेष रूप से, यह विरासत होटलों के तौर पर बदले गए राजबाड़ियों में हासिल ऊष्मीय आराम के स्तर की जांच करता है। इस वर्गीकरण के वास्तुशिल्प विकास और इस क्षेत्र में इसकी बड़ी मौजूदगी को समझने के लिए, हम बंगाल प्रेसीडेंसी के ऐतिहासिक पृष्ठभूमि को देखते हैं। बंगाल प्रेसीडेंसी 'बंगाल पुनर्जागरण' के नाम से जाने जाने वाले समय के दौरान बड़े सामाजिक, राजनीतिक और ऐतिहासिक उथल-पुथल का गवाह था, जब ब्रिटिश काल से पहले और बाद के ज़्यादातर खूबसूरत, शानदार महल, ज़मींदार बाड़ी और राजबाड़ी बनाए गए थे। इसी संदर्भ में, एक प्रमुख राजबाड़ी - बावाली राजबाड़ी - जो एक विरासत संपत्ति है जिसे विरासत होटल के रूप में फिर से इस्तेमाल किया गया है, उसकी स्थापत्य शैली, अप्रतिरोधी रचना रणनीतियों का अध्ययन जिसमें राजबाड़ियों ने आकार लिया; बावाली राजबाड़ी का अनुकूली पुन: उपयोग, जिसमें अप्रतिरोधी रचना रणनीतियों पर ज़ोर दिया गया है; और बदली हुई राजबाड़ी में ऊष्मीय आराम का मूल्यांकन। जैसा कि भारत आज़ादी के 75 साल से ज़्यादा समय बाद अपने औपनिवेशिक इतिहास पर नए तरीकों से सोच रहा है, यह शोध अनुकूली पुन: उपयोग के एक ज़रूरी, अनदेखे पहलू: ऊष्मीय आराम पर ध्यान देता है। यह विरासत इमारतों में ऊष्मीय आराम की ओर इशारा करता है, खासकर इस क्षेत्र में बहुत सीमित शोध को देखते हुए। इसलिए, यह अध्ययन विरासत इमारतों की ऊष्मीय आराम और विरासत धारणाओं पर वैज्ञानिक चर्चा को आगे बढ़ाने का प्रयास करता है।

**मुख्य शब्द:** राजबाड़ी, ज़मींदारी व्यवस्था, ऊष्मीय आराम, अनुकूली पुन: उपयोग, विरासत होटल।

## 1. Introduction

'The decaying mansions of the babus, who were the rich, British-influenced Indian gentry, were built in a medley of architectural styles that V.S. Naipaul calls 'Calcutta Corinthian' and are unique.' (Dutta 2003)

During the 18th and 19th centuries, the chief interests of the aristocratic feudal lords of the land – familiarly known as zamindars, who often held courtesy titles of 'Rajas' and 'Maharajas' – were not only in European dress, wine, horses and such external glamours of life but also in architectural forms and embellishments avidly emulating the west for their pretentious country houses or palaces (Ahmed and Sanday 1986). These picturesque palaces combined elements of European Renaissance and Mughal architecture. The eastern region, or the erstwhile Bengal Presidency (Undivided Bengal, Orissa, Bihar, Jharkhand, and Assam), is strewn with numerous such neglected palaces, devoid of their valuable furnishings, fittings, and artworks. This collection of buildings, which clearly reflects the influence of the European Renaissance, represents a significant development of an architectural style in this region and makes for a critical case in architecture emerging from transcultural encounters.

The British provided significant support to Kolkata's landowning and revenue-collecting elite class from the 1750s until 1900, with powerful backing during the latter half of the eighteenth century. The increasing ambitions of the socially mobile landowners became more apparent during the nineteenth century, with the

construction of the *Rajbaris/Zamindar baris* belonging to the landowning elite families. Today, the examples that remain in their original state are scarce, with most structures in an advanced state of deterioration, while others have entirely vanished (Chaudhuri (ed) 1990).

> The country house in British colonial Bengal may be seen as a culmination of capital's processes and fortunes, the emblem of a modernized agricultural system and "improvement." The Bengal country house was indeed a modern building type, and yet it is difficult to sustain the image of the country house as a tool and manifestation of "improvement." In fact, the term "country house" was rarely used to refer to this building type in Bengal. In popular parlance it was the "garden house." Garden houses came to be seen as haunts of a city-based elite who were completely estranged from the culture and social life of the countryside, even as these spaces continued to be used by the nationalist elite as "rural" retreats. (Chattopadhyay 2007)

Alongside Bengal's renowned British architecture, the local land-owning elite who amassed wealth through their association with the British constructed hybrid mansions and palaces that were evidently influenced by British architectural styles and the colonial experiences of these indigenous landowners. These residential edifices/ structures epitomise a distinctive era in the architectural and cultural development of the region. They serve as tangible markers of the experiences and achievements of a populace that aspired, adjusted, and thrived under colonial governance. Although the British colonial architecture in Bengal has been extensively documented, the residential mansions and palaces of the city's landowning elite remain largely obscure. Some comprehensive research on Rajbaris is presented by authors such as Mahua Chakrabarti, Sangita Kar, Murchana Madhury, Joanne Taylor, Shyam Chand Mukerji, and Nibedita Das. Their works form an important intellectual context for the field of this study. (Chakrabarti 2020), (Kar 2023), (Murchana Madhury* and Labanya Sarker 2023), (Mukerji 1991). However, this study aims to address a significant knowledge gap in the study of Zamindar mansions in West Bengal. The aspect of Re-Use is an emerging area of research, and this study builds upon it, specifically focusing on the thermal comfort aspect of the Rajbari typology prevalent in the region, which is a novel and under-researched area.

Among all the traditional building typologies in West Bengal, the *Rajbari* is most representative of the state's large-scale residential architecture. There is ambiguity in the literature and general discourse about the appropriate term for these heritage buildings, which are variously called mansions, palaces, the great houses, zamindar baris, Rajbaris, etc. Regardless of the term used, these heritage structures, a standing testament to the Zamindari era, are dilapidated, unkept and in a state of disrepair requiring urgent conservation of the remains.

The state of West Bengal, in the light of conserving the Rajbari, has propagated its willingness to promote the conversion of Rajbaris into heritage hotels, following in the footsteps of the state of Rajasthan, like Umaid Bhawan Palace - Jodhpur, Jag Niwas Udaipur, The City Palace – Jaipur, Neemrana Fort Palace, etc. (Sharma 2022), (Nandwani 2019). This led to many Rajbaris being put to adaptive reuse as heritage hotels by the various private owners in West Bengal. The adaptive reuse of a large number of Rajbaris and the dilapidated, neglected state of an equally large number of Rajbaris led this study to inquire into the current state of the Rajbari typology by examining its reuse methodology, passive design strategies, and thermal comfort conditions within.

Thermal comfort is a fundamental human necessity. One of the basic and essential roles of any built structure is to offer protection from external adversities. Traditional architecture is recognised for its responsiveness and adaptation to local climatic conditions, thereby providing comfortable interiors through the use of varied passive design features. Research on thermal comfort in heritage buildings is very limited in India. Hence, the study aims to foster scholarly discourse on thermal and heritage perception.
This would help us understand the relationship among the conservation of heritage structures, energy-efficient solutions, and thermal comfort conditions.

## 2. The Genesis of the Zamindari System

Before the British acquisition of the 'Dewani' of Bengal in 1765, the peasant typically remitted a third of the total yield from his property as a tax portion to the zamindar. The system originated from the Mughal period. Murshid Quli Khan, then Nawab of Bengal, partitioned the entire territory in Bengal into thirteen 'chaklas' (circles) and designated twenty-five regions as 'khalsa' land (crown land). Thirteen 'chaklas' were divided into thirteen sections, which were assigned to state officers as 'jaigir' rather than salary. At the same time, the crown lands were leased to 'ijaradars' or contractors to collect land

tax. The individuals responsible for collecting land tax under the 'ijaradari' system later came to be known as 'zamindars'. They were even granted titles such as 'Raja' and 'Maharaja', despite not being of noble descent. (Ahmed and Sanday 1986)

The zamindari system was a conventional framework in the socio-political and socio-economic history of Bengal. This system was created during the Mughal, or pre-colonial, era of Bengal's history and subsequently restructured under the British, or colonial, period. The zamindari system, which was restructured and formalised during British rule in Bengal, significantly influenced socio-economic and socio-political conditions, thereby facilitating long-term economic and political advantages for the British administration. The colonial authorities endorsed this system and utilised it to exploit Bengal. (Baden-Powell 1896), (Guha 1963). The zamindars were established or diminished as agents of the British revenue administration to collect taxes for the British Government. The enactment of the 'Permanent Settlement' by Lord Cornwallis in 1793 restructured the zamindari system, negatively impacting the traditional zamindari system and the peasantry in Bengal. The 'Permanent Settlement' conferred landlord rights on zamindars and established them as landowners, while peasants were converted into tenant farmers. (Ratnalekha Ray 1975) The immediate effect of this arrangement was the dislodgment of many old zamindars from their estates. It also adversely affected the peasants' customary rights and interests. They were stripped of land rights and title, as well as other rights and privileges they had enjoyed during the pre-colonial era in Bengal. The defaulting estates were sold up, their palaces taken up by new moneyed men, and a new aristocracy of absentee landlords emerged. These newly created feudal aristocrats owned vast tracts of land, built exotic mansions, and lived their lives in great splendour and thoughtless emulation of Western society. This accumulation of wealth led to a phenomenal rise in the construction of large *Rajbaris* across various parts of Bengal, mainly after 1793.

## 3. The *Rajbaris* of Bengal Presidency

The late 18th and early 19th centuries witnessed the emergence of 'Babu Culture,' a phenomenon unique to Bengal. The babus were members of prominent Bonedi (aristocratic) families of the former undivided Bengal. The Babu culture that thrived in Bengal resulted from the amalgamation of English liberalism, Mughal conservatism, and indigenous revivalism, incorporating elements of socio-cultural moral values. The zamindari system nurtured this culture. The Babus, having inherited their fortune from their forebearers, indulged in a lavish lifestyle characterised by avarice, affluence, and moral decay. (Sreemany n.d.)

Among the prominent old zamindaris that survived are the Birbhum zamindari, founded by Asadullah Khan, and the Bishnupur Zamindari, established by the Malla Hambir Rajas. New Zamindars who rose to prominence as trusted aides or advisers included Ramjivan, who founded Natore Raj; Raghunandan, who founded Dighapatia Raj; and Chaudhary of Mymensingh pargana, who founded Muktagacha Raj, to name a few. And then there were the ‘absentee landlords’ who built Rajbaris in their rural land holdings along with lavish palaces at the nearby urban centres, too. Some of these ‘great families’ which survived to carry on the lineage are the Thakurs of Jorasanko, Nabakrishna Deb of Shobhabazaar, Lahas of Lahabari, Mullicks of Mullickbari, Nandlal Basu of Basubati, etc. (Joanne Taylor 2008)

**Figure 1.** Prominent Rajbaris of West Bengal

The socio-political and intellectual life in Bengal during the period generally referred to as the ‘Bengal Renaissance’ was at its peak. (Gangopadhyay 2000) Those 20 years (1825 - 1845) ushered in a new era in the history of Bengal. Bengal Presidency was one of the three key presidencies of the East India Company (the British government), along with Madras and Bombay. The Bengal Presidency extended from Assam in the northeast to parts of Burma (Myanmar) and the Strait of Malacca in the southeast. It included the current states of Orissa, Bihar, Jharkhand, West Bengal, and Bangladesh (then East Bengal) during the 18th and 19th centuries. It is within this Bengal Presidency that the Zamindars, or the new landed gentry, post the

permanent settlement, began rampantly building aristocratic, lavish homes, which came to be called '*Rajbaris*' mainly due to the titles of 'Raja' conferred on them by their British rulers.

Out of the 200-odd *Rajbaris* in the region, this paper has identified and mapped 55 prominent *Rajbaris* across West Bengal, Odisha, Bihar, Assam, and Bangladesh. East Bengal (Current Bangladesh) peasants were forced to grow indigo, replacing rice. It was in this region that rice and indigo plantations were established. Many Zamindaris emerged here to keep peasants growing indigo and rice under check and control. For this reason, a large dispersal of Rajbaris is found across current Bangladesh today.

These heritage structures, in recent times a standing testament to the Zamindari era, are dilapidated, unkempt, and in a state of disrepair, requiring urgent conservation of the remains.

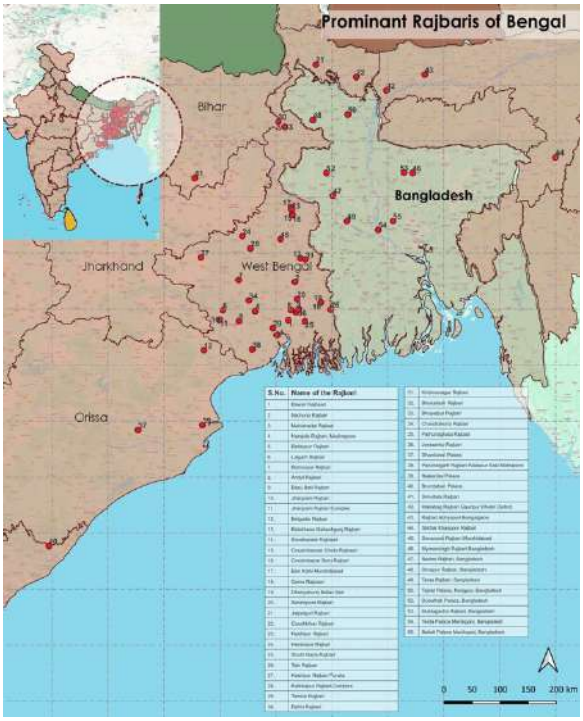


**Figure 2**. Dispersal of Rajbaris in the Bengal Presidency, overlaid on a present-day map of eastern India.

## 4. Heritage Hospitality in West Bengal

The Rajbaris that stand today are shorn of their original opulence. The multiroom properties have very few residents today. The 'naach ghar' is empty except for the massive chandeliers, which only seem to accentuate the desolation. The reception room, once famous for its magnificent furnishings, is locked and inaccessible, and so is the 'thakur dalan'. Yet what visibly startles one with is the scale and grandeur – gigantic mirrors, imposing mahogany tables, lofty ceilings, etc. The recognisable signs of affluence of a Rajbari – large verandahs, a thakur dalan and an open courtyard (Chakrabarti 2020).

'*Rajbaris*' require sound financial investment for their upkeep, maintenance and proper conservation. In most cases, the ownership or guardianship lacks financial stability. Given these background trends, owners look to maintain these buildings by converting them to uses that yield the highest financial returns. 'Hotel' is one such use which shows promising financial returns to the owners.

Hence, the current trend of converting palaces, *Rajbaris*, *havēlīs* (Indian mansions), and large residences into hotels is seen as a viable economic model for sustaining otherwise unprotected heritage structures. Heritage tourism has also become a popular trendsetter, as many tourists (national and international) seem interested in experiencing the architecture and historical aspects of a heritage site. This is further augmented by providing opportunities to experience staying in heritage hotels.

**Table 1.** List of Prominent Rajbaris in W. Bengal that have been adapted as Heritage Hotels (source: Author).

| Rajbari Name | Year Constructed | Location | Year Adapted |
|---|---|---|---|
| Bawali Rajbari | 1725 AD | Budge Budge South Parganas | 2015 |
| Itachuna Rajbari | 1766 AD | Khanyan Hoogly | 2012 |
| Jhargram Rajbari | 1836 AD | Jhargram W. Midnapore | 2018 |
| Belgadia Palace | 1804 AD | Baripada Mayurbhanj | 2019 |
| Cossimbazar Rajbari | 1735 AD | Behrampur Murshidabad | 2016 |
| Mahishadal Rajbari | 1837 AD | Mahishadal E. Midnapore | 2018 |
| Amadpur Rajbari | 1730 AD | Amadpur Bardhman | 2017 |

In India, adaptive reuse gained prominence following the post-independence abolition of the privy purse of former princely rulers. In 1971, the Indian government abolished royal titles and privy purses, converting the "rajas" into ordinary citizens of India. Consequently, the royal families were obligated to pay taxes on their property, complicating the maintenance of their holdings. Physical assets, such as palaces, forts, and jewellery, were transformed into liabilities that required ongoing investment for maintenance. Consequently, converting these monumental structures into heritage hotels appeared to be a feasible strategy for preserving their legacy via a sustainable business model (Nandwani 2019).

The Indian state of Rājasthān was a pioneer in recognising the potential to repurpose significant heritage structures into hotels, exemplified by the early 1960s transformation of the Jag Niwas

summer palace into the Taj Lake Palace Hotel. The success of these initial efforts led to additional adaptive reuse projects, including the Falaknuma Palace in Hyderabad, Rajakkad Estate in Travancore, Jehanuma Palace in Bhopal, and Mehrangarh Fort in Jodhpur, among others. Neemrana Fort Palace was one of the initial fort palaces to be converted into a hotel in 1980 by Aman and Francis, the Founders of Neemrana Hotels (Sharma 2022). The heritage hospitality sector has since experienced significant growth, with havelis, palaces, mansions, coffee estates, and colonial residences being transformed into hotels.

The tourism policies of Rajasthan supported the heritage hotel movement by creating special provisions and incentives for repurposing heritage buildings. This was supported by a series of policy instruments, including the Rajasthan Tourism Policy, Guidelines for granting certificates of heritage for operating Heritage Hotels and Heritage Properties, the Rajasthan Tourism Trade Act, and the Heritage Certificate Guidelines.

Following Rājasthān's lead in adapting fort palaces and havelis into hotels, the West Bengal state government began promoting the adaptive reuse of *Rājbāris* as heritage hotels as a sustainable, commercially viable model. Efforts are presently underway to convert many historic properties across the state into heritage hotels, a trend accepted by the property owners. The government of West Bengal intended to save these heritage buildings, as a result of which the practice of rehabilitating old buildings for new use became widespread. *'The state government has decided to use a cluster of 100 palatial properties across the state to convert them into heritage hotels, a trend accepted by the property owners.*' (Tamaghna Banerjee & Udit Prasanna Mukherji 2022).

## 5. The *Rajbari* Typology

The *Rajbaris* symbolise the socio-cultural lifestyle of Zamindar families prevalent in society at the time. These houses bear witness to the rise of a group of economically advantaged Bengalis, thanks to their genius for language and business. The British favoured this class to form an intermediate group of natives who could execute their orders and facilitate communication between the rest of the natives and the colonisers. These houses also bear witness to the development of this "intermediate" class from early mediators who were greedy for making quick money to the genesis of an intellectually evolved second generation of Babus who were Western-educated and brought the Renaissance to Bengal, and generated many radical social, cultural and political reforms

In Bengal, two primary types of Rajbari configurations exist: first, the residences constructed by Marwari merchants, who, upon arriving in the city, replicated their ancestral homes to acclimatise to the new environment; second, the *Rajbari*, erected by affluent Bengali babus, who, influenced by Western architectural styles and British aesthetics, designed these mansions with elegant furnishings and sculptures while preserving the traditional inward courtyard layout and puja room. "The courtyard houses of Calcutta exhibit eclectic combinations of Western-style facades, marble statues, imported tiles, and traditional design elements" (Randhawa 1999).

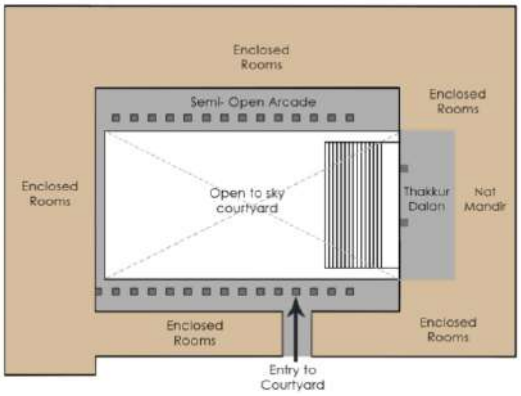


**Figure 3.** A typical single courtyard Rajbari plan

The Rajbari is an inward courtyard typology with single or multiple courtyards. It is a simple plan with rooms laid around a central courtyard. (Figure 3) The traditional plan appears symmetrical. In most of the larger Rajbaris, there is more than a single courtyard – the outer courtyard being for public use or '*bahirmahal*', while the inner courtyard is for more intimate use within the family or '*andarmahal*'. The rooms are arranged around the courtyard according to their functions. The unique feature of the Rajbaris is the existence of '*thakurdalan*' (puja room) and '*natmandir*' (stage for cultural performances). The Bengali reverence for culture and performing arts is evident in the construction of these *Rajbaris*, with a raised platform adjacent to the main courtyard that served as a stage for music, dance, and theatre. A *puja mandap* or *thakur dalan* (worship room) is often situated on one side of the courtyard and serves as the location for the family's daily worship rituals. (Das, n.d.)

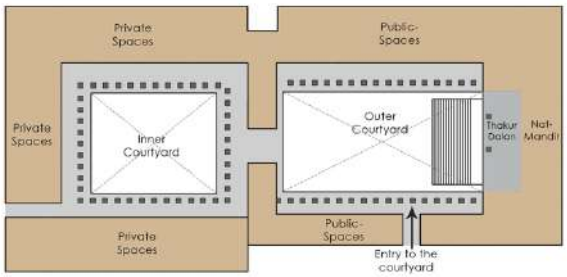


**Figure 4.** A typical double courtyard Rajbari plan

Entry to the *Rajbari* is usually through the central courtyard, which is used for festivals and celebrations. The inner courtyard has a more restricted entry. Circulation within the *Rajbari* is mostly through deep arcaded *verandahs* along the central courtyard (Figure 4). Most rooms open onto the arcaded corridor. Some common characteristics of Rajbaris are single or multiple courtyards surrounded by rooms, deep arcaded verandahs, high internal ceiling, massive walls and wooden slated doors & windows. The architectural style of most Rajbaris is seen as an amalgamation of Western exteriors and traditional interiors. The traditional *puja mandap* is seen supported by Doric columns. In contrast, a western façade is seen at the guardroom entrance, crowned with a *bangladar* roof, embodying the architectural aesthetics of Bengal.

To understand the architectural characteristics, its passive design features in response to the climate and thermal comfort conditions, we undertake a case study of a single-courtyard typology, Rajbari – Bawali Rajbari.

## 6. Bawali *Rajbari* – The Case Study

### *6.1 Case Study Description*

Bawali Rajbari is located in Budge Budge, a small town in South 24 Parganas, on the Hooghly River, approximately 25 km from Kolkata.

The history of the Mondal dynasty of Bawali dates back to the late 18th century. Shoba Ram Rai, the Zamindar of Bawāli, was awarded 121405.693 hectares (300,000 acres) of land in the 24 Parganas area in a strategic location on the Hooghly River as recompense for suppressing a peasant insurrection. The Rājbāri exemplifies a typical single-courtyard typology, constructed 250 years ago. It endured nearly 150 years of uninterrupted habitation until the family squandered the majority of their fortune, leading to the deterioration of the enormous residence. The Rajbari was rediscovered, repaired, and repurposed as a heritage hotel in 2017, showcasing the magnificence of Bengal's Zamindars.

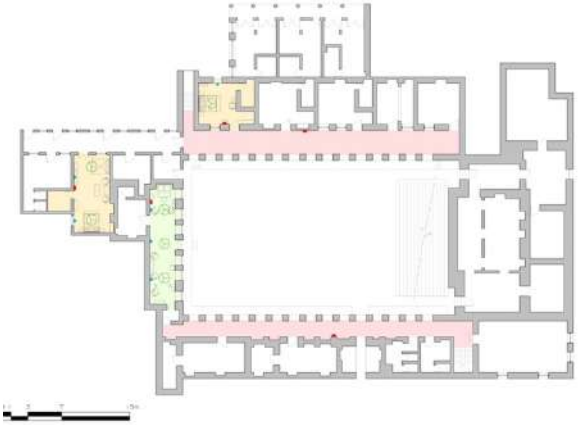

**Figure 5.** Layout plan of Bawali Rajbari

The original style of the two-story building features a central courtyard structure surrounded by collonaded corridors, which serve as a buffer to the series of rooms located behind it. The original Rajbari was constructed in brick masonry, lime mortar, and lime plaster. Load-bearing walls with thicknesses ranging from 600 mm to 750 mm are seen to support the structural system. This substantial wall structure incorporates a sequence of doors and windows adjacent to the arcaded corridor on the ground level and the collonaded corridor on the upper level. The original doors are wooden-panel doors, while the windows feature double shutters with external timber louvres and internal glass-pane shutters. These moveable louvred windows, locally referred to as 'khorkhori,' admit light and provide ventilation while preventing rain ingress.

**Figure 6.** A view of the central courtyard of Bawali Rajbari

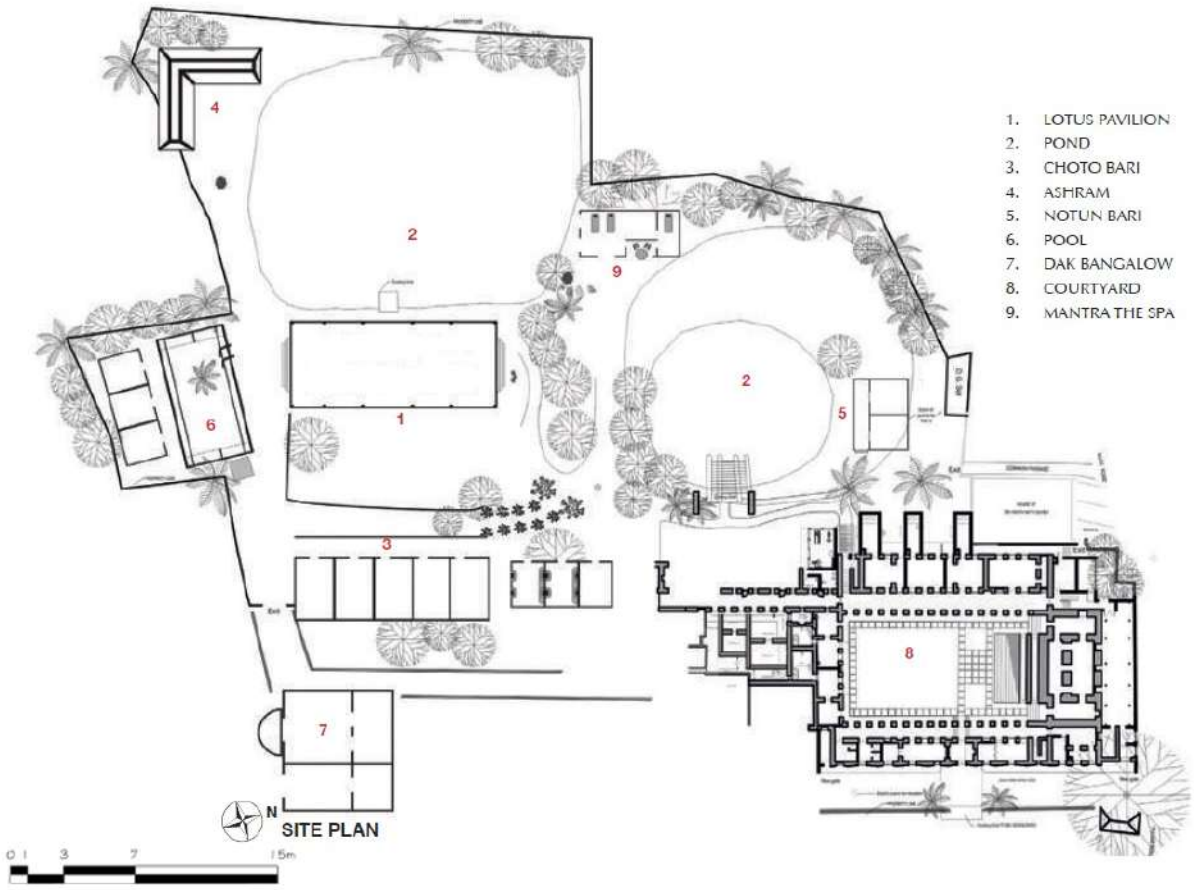


**Figure 7**. The Rajbari Site Plan

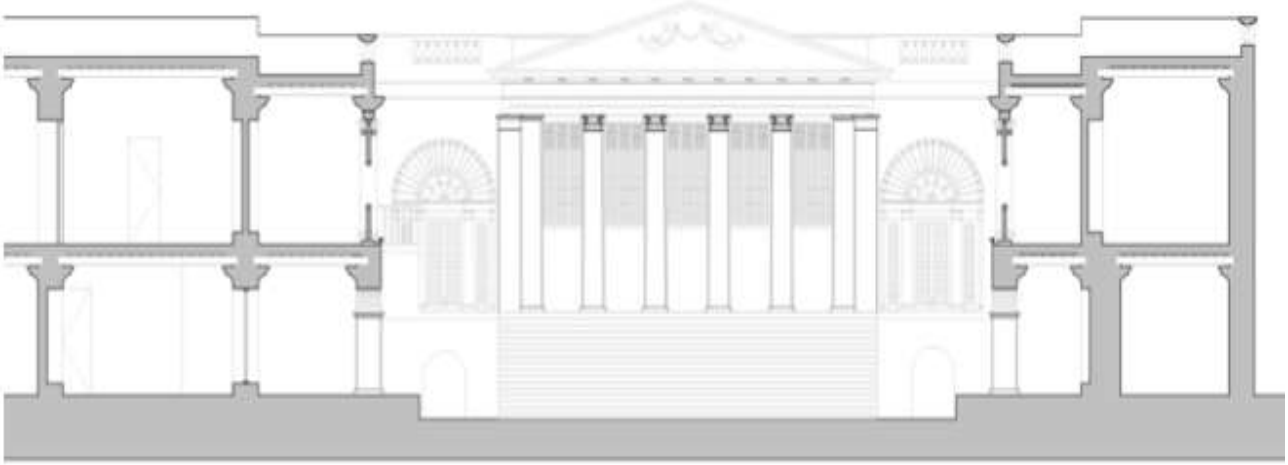

**Figure 8.** Sectional Elevation of the Rajbari facing North, showing the Doric columns of the Puja Mandap

### *5.2 Passive Design Strategies*

ORIENTATION

Solar radiation and the movement of the sun in the sky impact major design decisions**,** such as site selection, building orientation, building shape, and the location of openings and sun control devices. The Rajbari is oriented along the N-S axis. The Puja mandap is located in the north**,** and the lounging spaces are seen in the south. The rooms are oriented along the East-West axis. The east corridor rooms are cooler than the west corridor rooms**,** though the west corridor rooms are well shaded by landscape and tree foliage at the back (Figure 7).

The central courtyard is 30.06 m long and 16.09 m wide, with a surrounding building height of 9.8 m. The courtyard is sunken 0.75m below the interior ground-floor level. The courtyard's aspect ratio is 1.63. The aspect ratio of the courtyard is moderate, neither too high nor too low and hence does not allow much sunlight into

the building. The most important criterion for a courtyard in a warm, humid climate is to tame the sun and channel the wind.

## THERMAL MASS (TM)

The building is constructed in brick masonry with lime mortar and lime plaster, with thickness varying from 600 to 800 mm. The use of TM can be effective in reducing total energy consumption and maintaining thermal comfort. The design avoids heat storage and promotes ventilation to dissipate humidity through the use of massive walls and louvred windows.

## EVAPORATIVE COOLING

The Rajbari is located near two natural ponds on the site (Figure 7). The presence of the ponds (*pukur* in Bengali) and the surrounding landscape and vegetation help lower the temperature in the vicinity. Evaporative cooling allows the surroundings of the Rajbari to cool during the hot summer months.

**Figure 9**. The birds-eye view of Bawali Rajbari

## VENTILATION STRATEGIES

The Rajbari typology, through its design, provides efficient ventilation by dissipating heat through high ventilators. The windows of the Rajbari are louvred, with a high wall-to-window ratio, allowing sufficient sunlight and appropriate ventilation during the warm, humid months. The strategic location of doors and windows allows for short cross-ventilation paths, creating pleasant thermal comfort.

## BUILDING ENVELOPE CHARACTERISTICS

The Rajbari's external building envelope consists of masonry walls with appropriate window openings. The inner building envelope is surrounded by collonaded corridors that protect from the sun during overheated months through the use of shaded *verandahs* and wooden latticework. This produces a homogeneous climatic response through self- or internal shading and protects against heavy rain.

Bawali Rajbari was purchased by a Marwari businessman, Ajay Rawla, from Kolkata in 2010 and restored and adapted into a heritage hotel in 2017. The concept of adaptive reuse was executed to restore as many authentic existing historic parts of the building as possible (Figures 10, 11). As far as possible, original building materials were retained, and new additions were made with compatible materials sourced locally. Post-adaptive reuse, this traditional, naturally ventilated typology displays the following prominent architectural characteristics, showcasing its passive design features and climate responsiveness. (Dasgupta et al. 2024)

- The central courtyard acts as an air sink, ventilating the surroundings.
- Strategic positioning of large doors and windows to help achieve cross ventilation.
- Thermal mass to dampen temperatures.
- The deep verandahs and arcaded corridors around the central courtyard on the ground and first floors act as buffer spaces, providing filtered daylight, solar shading, and ventilation.
- Strategic building orientation helps provide shade to the internal facades, which reduces heat gain.
- The use of wooden slats between the corridor columns acts as a screen to prevent heat gain.
- Proximity to a water body adds to the microclimatic effect and cools the surroundings.

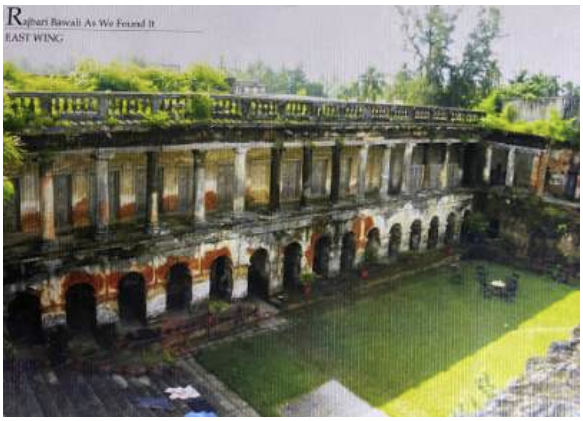


**Figure 10.** Bawali Rajbari East Wing before restoration

**Figure 11.** Bawali Rajbari East Wing post restoration


**Figure 12.** average daily air temperature (Ta) (top) and relative humidity (RH) (bottom) for the entire building over the course of a year

**Table 1.** List of Instruments used for Logging

| | Parameter | Range | | Accuracy | |
|---|---|---|---|---|---|
| | | Instrument | Standard | Instrument | Standard |
| Extech HT30 | Globe temperature | 0 - 80° C | 10 - 40° C | ± 2° C | ± 2° C |
| TSI 9545-A | Air Velocity | 0 – 30 m/s | 0.05 -1m/s | ± 0.015 m/s | ± 0.05 m/s |
| | Air temperature | -10° - 60° | 10 - 40° C | ± 0.3°C | ± 0.5° C |
| | RH | 0 - 90% | - | ± 3% | - |
| HOBO | Air temperature | 20° to 70° C | 10 - 40° C | ± 0.35°C | ± 0.5° C |
| | RH | 5% to 95% RH | - | ± 2.5% | - |
| HTC EasyLog | Air temperature | 40° to 70° C | 10 - 40° C | ± 1.0°C | ± 0.5° C |
| | RH | 0% to 100% RH | - | ± 3.0 % | - |

This study identifies the building's warmest and coolest typical days by assessing air temperature and relative humidity. Daily air temperature data indicates a variance of 20-24 ºC in the average temperature for January, February, and December. January 29th records the lowest average temperature. Between April and early July, the average temperature ranges from 25 ºC to 30 ºC, with the peak temperature recorded on May 24th (Figure 12). Nonetheless, relative humidity remains elevated throughout the year, with lower averages in warmer months and higher averages in wetter months.

### *5.3 Thermal Comfort Mapping*

The Rajbari, as an adapted hotel comprising public and private spaces. 13 data loggers were placed at strategic locations within public and private spaces for monitoring and continuous data logging of environmental parameters, including temperature (ta) and Relative Humidity (RH). The spaces within the Rajbari were partly naturally ventilated and partly fully air-conditioned, making it a mixed-mode building.

Analysis of monthly average relative humidity within the building reveals a significant increase during the summer season. The period of lowest average relative humidity, generally around 50%, occurs predominantly in March and April, notably between noon and approximately 16:00. From June to October, it occurs especially in the morning hours. Between around 07:00 and 11:00, relative humidity significantly rises, averaging over 90%, coinciding with the rainy season. The architectural envelope reverses the environmental conditions (i.e., being drier in winter months). This is evident from Figure 13.


**Figure 13.** average daily air temperature (Ta) and relative humidity (RH) each month across the entire building. The data was acquired through placed sensors, the warmer air temperatures represented by red and the colder air temperatures represented by blue

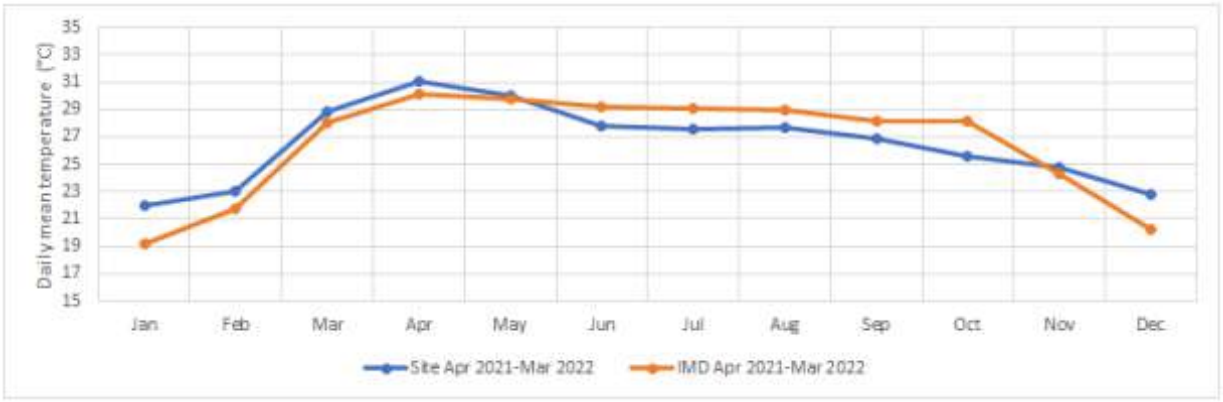


**Figure 14.** The plot shows IMD temperature data for each month's daily mean temperature, compared with the daily mean temperature by month recorded at the building site using data loggers located in unconditioned spaces throughout the building's corridors.

The analysed seasons pertain to the specific periods of summer, winter, and the rainy season. The temperature disparity between the Indian Meteorological Department (IMD) and the local site averages a divergence of roughly 0.2 °C colder in summer, 1.1°C cooler in the rainy season, and 2.1 °C warmer in winter (Figure 14) The Rajbari's typical winter outdoor temperatures are 1.6°C higher than the nearby weather station's temperature of 22.7°C, while in summer, they are 0.9°C lower than the local weather station's average of 29.4°C, resulting in an overall average difference of 1.2°C between summer and winter. This study investigates the mixed-mode operations of a heritage Rajbari, emphasising the reduction of mechanical system usage throughout the year. Mixed-mode buildings are quickly becoming the norm in India, particularly with heritage structures where passive design elements are present and can be appropriately converted for new purposes. The internal climate of such buildings can be engineered to promote the use of existing passive design elements while minimising reliance on traditional air-conditioning methods.

## 7. Conclusions

This paper elucidates the intricate factors influencing the architectural design and thermal comfort of the Rajbaris in Bengal. Their affluence exemplifies the region's historical essence and the considerable riches and grandeur of the Bengali magnates who established the Great Houses.

This research underscores the complex interaction among climate, heritage building design incorporating passive design characteristics, and operational strategies, as reflected in regional, spatial, and temporal variability. These observations emphasise the need for customised environmental control

strategies to enhance thermal comfort and humidity regulation across diverse geographical settings. This study has delineated the emergence of the Rajbaris and analysed the architectural style that evolved in their wake. The study demonstrates that a large number of Rajbaris lie abandoned, dilapidated and in a state of neglect, exemplifying the destruction of the legacy. Their survival is threatened unless they receive timely intervention in the right direction.

The preliminary results indicate the need to propose appropriate design solutions for environmental & thermal adaptation within heritage buildings being put to new use. The study reveals there are comfort standards for new buildings, but none for heritage buildings. Mixed-mode buildings are increasingly becoming the norm in India, especially in heritage buildings where passive design features exist and can be suitably adapted to new uses. The indoor environment in such buildings can be designed to encourage the use of existing passive design features and reduce reliance on conventional air conditioning. (Dasgupta et al. 2024)

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# Planning for Resilient Development Along a River:

## A Case of the Guwahati Metropolitan Area

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**Abstract:** The rapid urban growth accompanied by economic profit motive to acquire lucrative land parcels has led to destruction of forest cover, affected the natural streams, encroachment along river belts. The increasing population in the city core and associated infrastructural needs to sustain the population has disrupted balance in the natural system. Consequently, exceeding the developmental threshold increases the susceptibility of the region to various risk. The city regions which had developed along the river are more vulnerable to risk in the preceding context. This highlights the necessity for incorporating resilient planning strategies for such river sensitive regions beyond generalist master plans. Against this backdrop the Guwahati Metropolitan Areas forms an interesting case being developed on the either side of main Brahmaputra River course. The research explores the areas of assessment in regional scale resilience for such river sensitive regions. The central question is how resilient planning can be incorporated in river specific city region? Several plans and policies exist for the protection of river sensitive areas but however, the hydro physiological spatial assessment of resources and connectedness to development have been underscored. Thus, hydrological modelling and temporal land utilization assessment can give guidance for future course of planning. The juxtaposition of institutional and the spatial factor is significant for connecting citizen with the river and maintain threshold for incorporating resilience in river specific metropolitan areas.

**Keywords:** Metropolitan; Urbanization; Resilient; River; Governance

**सार:** आकर्षक भूमि भूखंडों को हासिल करने के लिए आर्थिक लाभ की मंशा के साथ तेजी से शहरी विकास ने वन क्षेत्र को नष्ट कर दिया है, प्राकृतिक जलधाराओं को प्रभावित किया है, नदी के किनारों पर अतिक्रमण किया है। शहर के केंद्र में बढ़ती आबादी और आबादी को बनाए रखने के लिए संबंधित बुनियादी ढांचे की जरूरतों ने प्राकृतिक प्रणाली में संतुलन को बाधित कर दिया है। नतीजतन, विकास की सीमा को पार करने से क्षेत्र में विभिन्न जोखिमों की संवेदनशीलता बढ़ जाती है। नदी के किनारे विकसित हुए शहरी क्षेत्र पिछले संदर्भ में जोखिम के प्रति अधिक संवेदनशील हैं। यह सामान्य मास्टर प्लान से परे ऐसे नदी संवेदनशील क्षेत्रों के लिए लचीली योजना रणनीतियों को शामिल करने की आवश्यकता को उजागर करता है। इस पृष्ठभूमि के खिलाफ गुवाहाटी महानगर क्षेत्र मुख्य ब्रह्मपुत्र नदी के दोनों ओर विकसित किया जा रहा एक दिलचस्प मामला है। शोध ऐसे नदी संवेदनशील क्षेत्रों के लिए क्षेत्रीय स्तर पर लचीलेपन के आकलन के क्षेत्रों का पता लगाता है। केंद्रीय प्रश्न यह है कि नदी विशिष्ट शहरी क्षेत्र में लचीली योजना कैसे शामिल की जा सकती है? नदी के प्रति संवेदनशील क्षेत्रों की सुरक्षा के लिए कई योजनाएँ और नीतियाँ मौजूद हैं, लेकिन संसाधनों के हाइड्रोफिजियोलॉजिकल स्थानिक मूल्यांकन और विकास से जुड़ाव को रेखांकित किया गया है। संस्थागत और स्थानिक कारक का मेल नागरिकों को नदी से जोड़ने और नदी विशिष्ट महानगरीय क्षेत्रों में लचीलेपन को शामिल करने की सीमा बनाए रखने के लिए महत्वपूर्ण है।

**मुख्य शब्द:** महानगरीय; शहरीकरण; प्रतिरोधक्षम्तापूर्ण; नदी; शासन

## 1. Introduction

The history of ancient civilization has witnessed the sprawl of settlements along the river due to the availability of fertile lands and ease of accessibility to water. This preludes a symbiotic relationship between the river and growth of the cities. According to the census of India 2011 among 4041 statutory towns approximately, 200 towns are located along rivers. The activities in these settlements directly or indirectly affect the streams which joins the main river. Thus, in the absence of consideration of the developmental threshold and integrating the river in the planning mechanism it depletes the water resource. It is necessary that the major rivers, its tributaries, basins and the sub basins are considered while planning for activities within metropolitan areas. This shall enable to restrict deforestation and denudation, resource overuse, pollution overload, under replenishment of water, river mutilation and geologic disruption. Thus, future densification of urban settlements along the river should incorporate existing drainage plans, identification of watershed and sub-watershed of main rivers within the city, existing network of streams and water resource potential to maintain ecological value, prevent flood hazards, loss of biodiversity for balanced development within threshold in such environmentally fragile metropolitan regions.

Sustainable and integrated river management planning in these settlements is therefore necessary for resilient development. This can be achieved through optimal utilisation of land and water resources, integration of drainage network plans and disaster plans within the master plans, mapping and protection of ecological resources and inter sectoral involvement of stakeholders in a bottom-up approach from local to national level organization.

In this context the study focuses on aspects to be assessed for resilient development of a

metropolitan region along the river. This involves assessing the transformation of land utilization in the process of urbanization, examining the hydrological aspects and the existing water governance structure within the metropolitan region for holistic development of the region as well as prevent the pressure on the river ecology.

## 2. Methodology

The study area is constituted by the Guwahati Metropolitan Area (GMA) boundary. The GMA encompasses parts of two districts which are Kamrup Rural and Kamrup Metro. It is surrounded by Nalbari district in the North, Marigaon and Darrang district in the east, Goalpara and Barpeta district in the west and borders of Meghalaya in the south eastern side. Administratively, the GMA comprises of 8 blocks which are Chandrapur, Chayan Barbour, Rani rural, Rani Metro, Bezara Rural, Bezara Metro, Sualkuchi and Dimoria (Figure 1) (Kamrup Rural, District Census Handbook, 2011; Kamrup Metro, District Census Handbook, 2011). The study carries out an inter-block analysis of the consequences of urbanization along the Brahmaputra River in the GMA. An attempt has been made to highlight the challenges both, in the urban core and the rural counterpart.

The paper has been divided into five sub-sections. First section details out the concept of resilient development and water governance. The next section draws upon the case studies of Wuhan, Dhaka and Pune Metropolitan Region to reiterate the findings of the literature review. The third section analyses the spatial and environmental changes along the Brahmaputra River within the GMA. This has been done by studying the master plans, land utilization changes, changes in vegetation cover, watershed analysis, hazards and disaster occurrence, infrastructure expansion projects, agriculture and industrial scenario, and demographic analysis. Several tools have been made use of for these studies such as the, Digital Elevation Model (DEM), hydrological model, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), satellite image analysis and secondary data analysis using Census of India 2011. The fourth section undertakes stakeholder analysis for understanding water governance of the GMA. Lastly, in the fifth section, strategies have been proposed for resilient development of the GMA at the micro, meso and macro level through structural, behavioural and institutional measure.

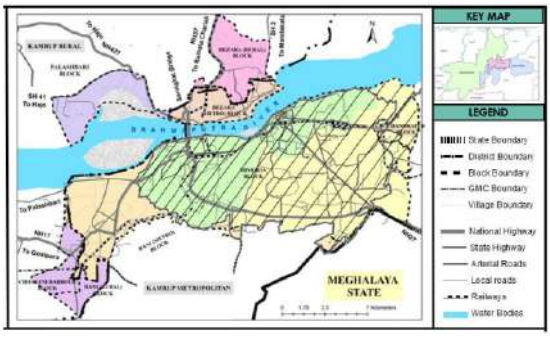


**Figure 1**. Administrative Boundary of the GMA (Guwahati Master Plan 2045)

## 3. Literature Review

The major river system in India constitutes the Ganga-Brahmaputra-Meghna River system. Brahmaputra forms a lifeline for the entire northeast India. The Brahmaputra River has total length of 2900 km which flows through four countries which are China, India, Bhutan, Bangladesh before draining into Bangladesh. The average discharge from the river is 19,820 cumec which is highest among the major Indian river system and constitutes 33.6 % of its area in India (Sharma 2014). The second highest area drained by the major river is in Assam which 70,634 sq.km. In this context alike Ganga River system, it is also essential to assess the land utilization patterns surrounding the Brahmaputra basin. As the physical spaces are altered it leads to loss of ecological value, flood management problem, changes in the natural drainage pattern, waste water management issues, loss of biodiversity, loss of the quality of open spaces (Strategic Guidelines for River Sensitive Master Plans, 2021). These rivers within the city as a result of their interaction with the influencing factors within the city extent have sharply contributed to the rising ecological footprints and the declining biocapacity (Mainstreaming Urban River Management into Master Plans Strategic Guidelines for River Towns, 2023). The major concerns with the rivers in India as a cause of urbanization are that there is almost 60percent reduction in per capita fresh water availability from 2001 levels by 2050, 80% untreated sewage flowing directly into rivers, 4.8 billion litres sewage flowing into rivers, 53898 MLD sewage generated and 10.8 million people dependent on riverine fishes in India (Mainstreaming Urban River Management into Master Plans Strategic Guidelines for River Towns, 2023; Strategic Guidelines for River Sensitive Master Plans, 2021). In this purview it is essential for long term conservation and preservation of river and also to leverage economic, social and environmental value of water. It is crucial that

the development activities are undertaken with due consideration of the river sensitive guidelines respecting the threshold of development or its ability to function. The importance of integrating the river within the 'planning' mechanism of the city is, therefore, of paramount importance. (Strategic Guidelines for River Sensitive Master Plans 2021). The unregulated and the unplanned urbanization process along the Brahmaputra in the GMA (gateway to the north east) is critical to the health of the river and the associated streams draining into the river raising concerns for future growth.

Guwahati is blessed with rivers, waterbodies and a number of hillocks. In the case of Guwahati, the rapid, unplanned and organic urban has changed the land use pattern of the city. Uncontrolled development activities have done a lot of harm to the ecology and environment of the city. One of the wetlands in the city is Deepor Beel, Ramsar Wetland, which is under threat due to the encroachment and unplanned urban development of the city. With a significant population growth, the city also faces floods and landslides due to several anthropogenic activities. Integrating the environment in regional perspective can help in efficient management of the city. There is a need of bringing a balance in the development process between conserving ecological resources with emphasis on the sensitivity of the Brahmaputra River so that it supports varying requirements of the city. This can be assessed by incorporating resilience within the system of spatial planning for maintaining stability, as well as resilience within the institutional mechanism wherein the stakeholders in water management are involved.

### *3.1 Resilience in Spatial Planning*

The idea of resilience can be explained as the capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing in order to reach and maintain an acceptable level of functioning and structure (Sellberg et al. 2018; Ayyoob and Yamagata 2014; Marchese et al. 2017). Resilience is the ability of the system not only to bounce back but also to adapt and transform. (Rega and Bonifazi 2020**)**. Regional Resilience which deals with the stability, the ability to anticipate, prepare for, respond to and recovery when a region is confronted with external interference or impact (Ming et al. 2016). The different scales of assessment of resilience includes self- recovery, innovation, disaster resilient infrastructure system (Rozenblat et al. 2018). Self- Recovery is the ability to deliver a timely, effective, fair and reasonable response to emergencies, so as to ensure a faster, better, safer and fairer recovery. Innovation refers to a feature that a region restores its original status without changing its system structure and function or enters a new state. Thirdly, Disaster Resilient Infrastructure System wherein resilience is seen as a process that involves social systems, built environment and natural systems simultaneously, so social capital and place depend on each other. Thus, for water sensitive regions where main rivers are an integral part of the system it is important that vulnerable factors on the land directly affecting the water bodies are precisely assessed. In such regions strategic importance of institutions involved in water governance shall be identified and incorporated within the planning mechanism for building resilience.

### *3.2 Water Governance for Resilient Planning*

Limitations of laws and regulations on the national level, led cities to establish local regulations to meet the needs of local river management. However, a considerable number of cities lack river management policies, and the relevant laws and regulations. Thus, planning of urban river management lags behind the actual river development, leading to disorderly occupation of river land and severe water pollution in the process of urban construction. (Zhao et al. 2020). With urbanization and industrialization, as people's irrational activities exceed the regional resources and environmental carrying capacity problems related to food security and destruction of the ecological environment may exerts 'pressure' on the limited resources. Whenever the development exceeds the threshold, the governance plays a crucial role to enforce measures so as to restrict development within the carrying capacity limits of the region (Bao et al. 2020). In this context firstly, at the organizational level, the authority for steering the water agenda is lacking. Consequently, diversity of frameworks, ideas, interests, and values at various scales increases complexity (Moore 2013). Secondly, CBWM (Community based Water Management) are to increase people's participation in decision-making regarding their water resources and to strengthen capacities to coherently manage these resources (Shunglu et al. 2022). Thirdly, economic activities have become increasingly dependent on water resources thus making stakeholder engagement all the more crucial. Stakeholder engagement involves consideration of civil society and end users, to reach out to other groups of actors with

an influence on water-related planning, decision-making, implementation, monitoring, evaluation. The major components include drivers, type of stakeholders, obstacles, mechanisms, assessment, cost and benefit (Akhmouch and Clavreul 2016**)**. The OECD framework involves primarily these three major aspects in water management.

### *3.3 Importance of the Study of the Guwahati Metropolitan Area (GMA)*

There are several case studies across the world wherein the above discussed issues have been spatially experienced like that of the Wuhan Metropolitan region which has grown along the Yangtze River, the Dhaka metropolitan region (Abrar et al. 2022) which has grown along the Buriganga River and the Pune Metropolitan Region which has grown along Mula Mathu River (Kantakumar et al. 2016). The GMA unlike the other metro regions along the river is the Gateway to the North eastern India which has undergone rapid urbanisation and economic transformation. The GMA assumes a significant location in the north east by being a city on the banks of the part of the vast Brahmaputra River basin lying within India. The direct consequences of the activities within the GMA negatively affects the Brahmaputra River and the associated tributaries. The Brahmaputra has a total catchment area of 580,000 sq.km. The major part of the basin lies in China and Assam. The GMA occupies 328 sq. km. in the basin. And is endowed with bountiful natural resource, rich heritage and culture. The population growth and accelerated economic development due to its strategic position has led to the overuse and abuse of the natural resources including the river. The existing issues within the GMA includes rapid unplanned and organic urban growth, change in the land use pattern of the city due to the uncontrolled developmental activities affecting the ecology and the environment of the city, incompatible land use/land cover around Ramsar Notified Wetland, namely, the Deepor beel. This, puts it under threat due to encroachment and unplanned development in its vicinity. The GMA is prone to flood and landslides and is located in the earthquake zone five which further increases its vulnerability. The Guwahati water front on the banks of the Brahmaputra is one of the spectacular water fronts but is threatened by the existence of growth of squatter settlements and presence of unorganized and unsafe river transport. All such factors which requires a comprehensive solution to make such river sensitive metropolitan regions resilient are detailed in the subsequent sections. The other aspects like clear roles and the responsibilities, sub-basin scale of management, planning and regulation, policy coherence, community participation and consultations, monitoring and evaluation of inter sectoral data which are necessary in an institutional realm are also explained subsequently.

## 4. The GMA and its Development along Brahmaputra River

The census of India 2011 identifies six urban agglomerations in Assam, which are Guwahati, Silchar, Dibrugarh, Jorhat, Tinsukia and Tezpur. And out of which Guwahati, Tezpur and Dibrugarh lies on the banks of Brahmaputra River. Guwahati has the highest population among these urban centers, which is 968549 (Census of India 2011) and has the highest growth rate of 91.12 % among the three urban centers location on the banks of the river. This explains the increasing demand for land leads to the transformation of the topographical landscape to accommodate the population and accelerate the economic prosperity of the region. Guwahati in this backdrop assumes a strategic position being the 'Gateway to the North-East India,' which serves as a reason for the high rate of urbanization as well as large scale spatial transformation of the land at the cost of agricultural land, forest cover and shrinking water channels joining the main river (Dev et al. 2017). Several master plans of Greater Guwahati since the beginning of 1969 have led to haphazard urban densification without planned physical infrastructure like water supply, storm water drainage, sewerage. Besides, encroachment on the river banks lead to direct sewage disposal, siltation, polluted water channels, which ultimately affects the main river system (Dev et al. 2017; Zhao 2020). However, the increasing built-up areas along the hill slopes in violation to the building bye laws, increasing imperviousness due to infrastructural additions all makes the region susceptible to hazards like flood and landslides blocking the flow of natural streams. This necessitates integrated planning strategies to conserve the habitat for biodiversity, conserve the water supply channels for people industries, commerce and livestock, preserve the aesthetic quality of the landscape at the same time foster leverage economic growth by attracting investments and foster social cohesion (Strategic Guidelines for River Sensitive Master Plans 2021; Sharifi 2014).

### *4.1 Spatial Expansion of the boundary of the GMA*

The Guwahati Metropolitan Development Authority (GMDA) was formed in 1992 under the GMDA Act 1985 which replaced the erstwhile Guwahati Development Authority constituted in 1962 under the Town and Country Planning Act, 1959 (Kakoty and Gogoi 2019). The boundaries of the Guwahati Metropolitan Area therefore underwent a change throughout the planning period to the present. According to the present proposed plan of 2045 The Guwahati Metropolitan Area has 3.66percent of the population of Assam and covers nearly 1percent of the total area of Assam. It constitutes 8 revenue circles and 8 blocks and 2 districts. Throughout the planning period the spatial extension of the Guwahati has gone areal extension to accommodate for the increasing demand for the land. The spatial expansion of the GMA in the various master plans from 1965 to 2045 has been mapped (Figure 2). It is observed that the general growth direction was towards the south western part of the GMA. In the present period the general growth direction is towards the north and the north western part of the GMA. The southward extension mainly comprises of the blocks of Chayani Barbour and Rani Rural while the northern extension constitutes Bezara Rural and the in the north western part includes the Sualkuchi part. Further if we analyse the areal limits, it is assessed that in the year 1965 the total area was 265.24sq.km and subsequently it increased to 283.31 sq.km., 285.08 sq.km, 293.77 sq.km and 328.74 sq.km in the years 1986, 2009, 2025 and 2045 respectively. This explains the increasing demand for land for the population for GMA being the hub of economic activities for the entire north-east India. It was only during the proposal for the 2025 master plan that the conservation of sensitive natural environment, integrated intra-urban transport system, well distributed physical and social infrastructure, provide space for functional economic activities, affordable housing, effective land development process and the implementation strategy were included in study. These areas of focus persisted in the master plan of 2045 also. However, it lacked emphasis on the protection of the river ecology in the process of development. Critically, the GMA constitutes several water bodies such as the Ramsar wetland site which is the Deepor Beel, along with others such as the Salsiko Beel, Borsola Beel and the Sarusola Beel, presence of major forest areas such as the in the hills of Lankeshwar, Fatasil, Gotanagr, Kamakhaya, Kalapahar, Narakashur, Kharguli, Nabagraha, Noonmati, Sunsali, Narangi, Hengrabari and Saraia. Apart from these the major sub-basins of the Brahmaputra include the Foreshore basin, the Salsiko basin, Borsola Basin, Bharalu Basin, North Guwahati Basin. This explains that hydrologically the region is one distinct from other metropolitan areas. This necessitates integration of land development plans with due consideration of the hydrological characters of the region.

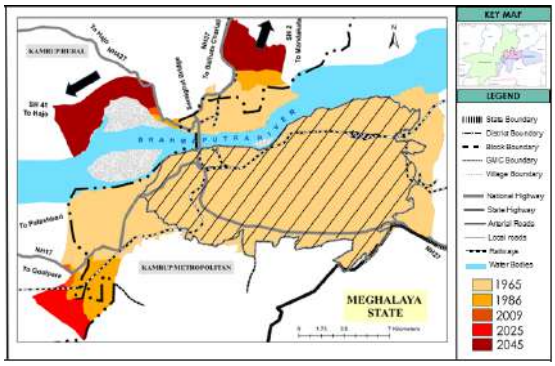


**Figure 2.** Spatial Extension of the GMA 1965-2045 (Prepared by the Author from Master Plan of GMA)

### *4.2 Demographic Scenario in the GMA*

The earlier analysis shows that the spread of built up footprint from the core of Dimoria block to the south eastern and in the successive period in the south western part as well as towards the northern part. This has been explained through the graph The peak growth has occurred in 1991 in the GMC area and it substantially decreased in 2001 and 2011 in the core (Figure 3). This decrease is in complete contrast to the area excluding the GMC in the peripheral parts which further substantiates the earlier analysis that in the peripheral areas the agricultural land and the forest area have been affected as a consequence of increased population pressure. The differences in the block density have also been mapped.

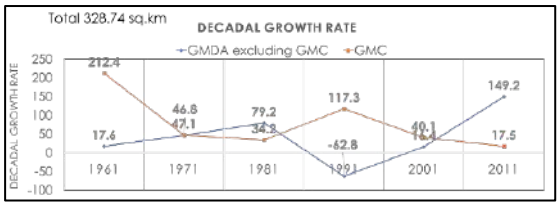


**Figure 3.** Population Growth Scenario in the GMA 1961-2011 (Master Plan of Guwahati 2045)

The block density map of the GMA (Figure 4) shows that highest density of more than 2100 person per sq.km in Dimoria block and Sualkuchi block. This followed by medium density between 1100 to 2100 persons per sq.km in the Rani Metro and Bezara Metro block and the least density below 1100 sq.km in the south western part in Rani Rural and Chndrapur block in the eastern

part and in Bezara Rural. Since Dimoria is the largest block within the GMA and also constitutes the GMC area a further ward wise analysis of the population is represented along with the distribution of the slum population.

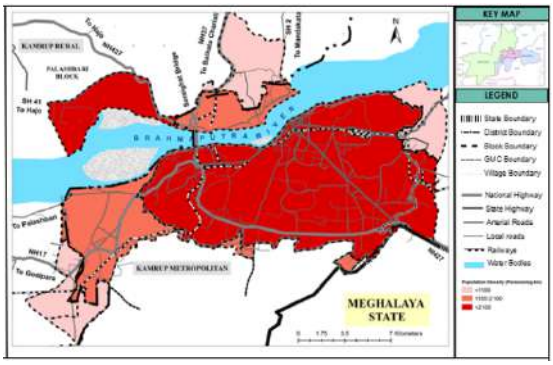


**Figure 4.** Variation in Block Density of the GMA, 2011 (Census of India, 2011)

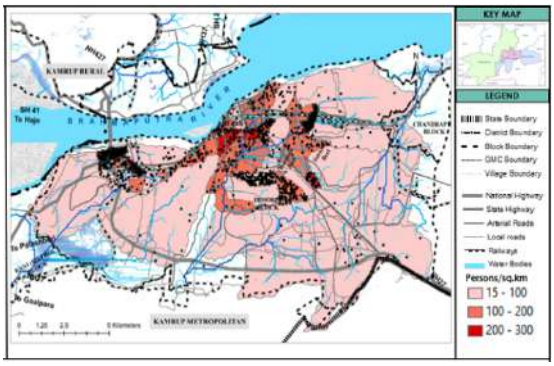


**Figure 5**. Location of Slums and Population Density,2011 (Census 2011 and Master Plan of Guwahati 2045)

The spatial distribution of the slum population (Figure 5) shows that slums are concentrated within the Dimoria block mostly adjacent to the river. This explains that in the situation of the occurrence of the flood and the water associated hazard it is these population who are most vulnerable.

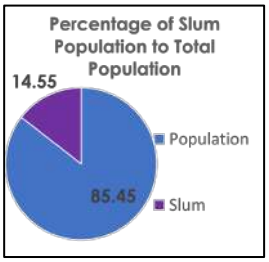


**Figure 6.** Percentage of Slum Population (Census of India 2011)

The slum constitutes 14.55 percentage of the total population (Figure 6). The presence of several such non-notified slums results in unmonitored wastes going directly into the river and other water bodies. In the state of Assam, highest in-migration is being experienced by Kamrup Metropolitan District, i.e., 89.32 percent (Figure 7). A large part of this population gets concentrated in the slums. This is mainly due to the job opportunities available in the GMA, which is the economic hub of North-Eastern India.

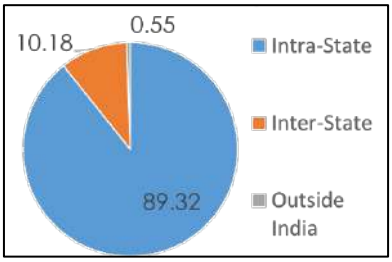


**Figure 7.** Migration Status in the GMA (Census of India 2011, Master Plan of Guwahati 2045)

### *4.3 Spatio-Temporal Variation in Land Utilization Categories in the GMA 1965-2022*

The land utilization pattern for the GMA has been assessed for the year 1976, 1989, 2010 and 2022 to show the spatial change of the area and how the increasing built-up has taken place at the cost of natural environment. It is observed that the built-up has increased by 19.21%, 26.08 %, 31.69 %, 66.56 % during the years 1976, 1989, 2010 and 2022 respectively (Figure 8). The variation in the spatial rate of increase and decrease in different land utilization categories is calculated (Table 1).

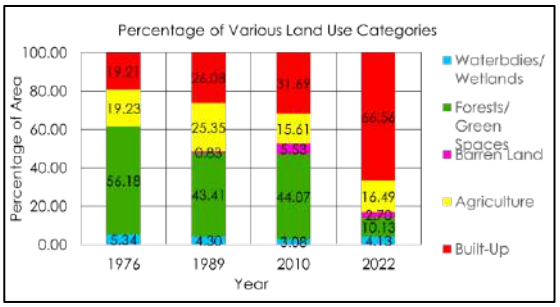


**Figure 8.** Temporal Variation in Land Utilization Pattern 1976-2022, (Landsat and Sentinal Image Analysis)

**Table 1.** Net Variations in land utilization 1976-2022 (Landsat Series Satellite Images)

| Built up | Barren land | Forests/ Green Spaces | Waterbodies/ Wetlands | Agriculture |
|---|---|---|---|---|
| 51.88 | 2.95 | -50.46 | -1.32 | -3.00 |

| Land Utilization | 1976-1989 | 1989-2010 | 2010-2022 |
|---|---|---|---|
| Built-up | 22.58 | 18.46 | 114.61 |
| Barren Land | 2.73 | 15.44 | -9.31 |
| Forests/ Green Spaces | -41.96 | 2.14 | -111.57 |
| Waterbodies/ Wetlands | -3.43 | -4.01 | 3.48 |
| Agriculture | 20.12 | -32.01 | 2.88 |

In the first period the major spatial expansion of the built-up area is at the cost of the green spaces or forest cover and water bodies. During the second period the yearly rate of increase of built-up area and the barren land was

accompanied by the decrease of the agricultural area. In the third period there has been the largest increase in the built-up. It is also during this period that the largest decrease in the spatial extent of the forest cover occurred. The average spatial variation explains that the built-up area during the three periods has increased at 51.88 sq.km per year and the barren land increased by 2.95 sq.km per year while that of the natural features such as the forest, waterbodies and agriculture decreased by 50.46 sq.km per year, 1.32 sq.km per year and 3.00 sq.km per year respectively. The spatial distribution of the land utilization categories has been mapped (Figure 9) shows that the initial process of growth of the settlement started along the river from the Dimoria block. Consequently, the growth direction was towards the south direction along the major national highways.

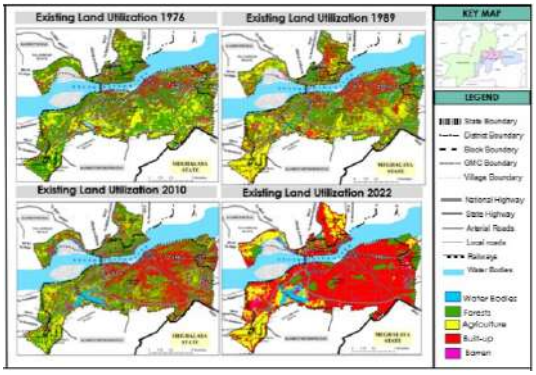


**Figure 9.** Pattern of Land Utilization in the GMA 1976-2022 (Landsat and Sentinal Satellite Image Analysis)

The drastic densification of the built-up is evident in the 2022 land utilization map. Further, it is notable that initially the existence of the forest cover has also been rapidly reduced. The rate of reduction has been highest near the core area (Dimoria block) within the municipal boundary than in the periphery. It is observed that with increase in the distance from the center the peripheral part of the GMA mostly constitutes the agricultural land. In the due course of time increasing built-up has reduced the agricultural land. In the land utilization map of 1976, there has been existence of several small water bodies which has been affected by the increased built-up as evident from the land utilization map of 2022. It is also seen that the concretization on the either side of the Brahmaputra River. This explains that the floodplains of the river which were earlier under the forest cover has been replaced by built-up. It is prominent in the 2022 utilization map in the North Guwahati Bezara rural and Bezara Metro block which were earlier under the forest cover has been replaced by the built-up which expanded further towards the agricultural land.

## 5. Assessment Aspects for Resilient Development in the GMA

Topographically the GMA stands diverse from other metropolitan regions in India in the presence of various hills and wetland and *beels* (small water bodies) and major river network in the central part of the city. It is within the same core as analyzed from the above discussion that the greatest concentration of economic activities and human settlement has taken place. The following aspects represents the issues which require planning intervention for a resilient riverside development.

### *5.1 Urbanization and its Influence on Hydro-Physical Landscape*

To assess the topographical variation (Figure 10) and its interaction with other natural and man-made developments a cross sectional transect chart analysis has been done. The transect chart (Figure 11) shows an overlay of both the physical and infrastructural attributes along the section to develop correlation among elevation, river network, forest, transport and settlement. The analysis shows that along the section AB from west to east the eastern part has several hills namely the Nilachal Hill, Fatasil Hill with the highest elevation, Kalapahar Hill and the Khannapara Hill. The streams passing down the hills are the Kalmoni River, Bharalu River and Basistha River. It is also observed the major roads network and railway network cut across the hills to provide connectivity to the entire region. The major road networks in this context cuts across the Nilachal Hill and the Fatasil Hill. The settlement pattern analysis also shows that it is around this network that the settlements have grown encroaching the hillslopes and the forested areas. Further, it is also observed that in the western part of the section lies the Brahmaputra plain. The built-up area is developed adjacent to the Brahmaputra plain. According to the River Regulation Zoning there are several buffer zones that has been identified which are 500m identified as prohibited zone followed by 1 km buffer and 3 km buffer with several restrictions in the developments. The percentage of encroachments in various hill is explained. Further, to analyze how the urbanization has affected the densification of the vegetation and water bodies the (Normalized Difference Vegetation Index) NDVI and (Normalized Difference Water Index) NDWI has been mapped. The NDVI analysis (Figure 12) shows the yearly variation in vegetation density in GMA. The values of NDVI ranges between 0.2 to 0.6. The higher value indicates that the GMA

has higher vegetation density. It is observed that the high value of NDVI is present for a small portion of area within the GMA. Throughout the GMA the vegetation mostly range between 0.2-0.4 mostly for the eastern part of the GMA which includes the Chandrapur block and in the western part which includes the Rani Metro block and Rani Rural Block. A certain portion of high index is also present in the northern part which includes the Bezara rural and Bezara metro block.

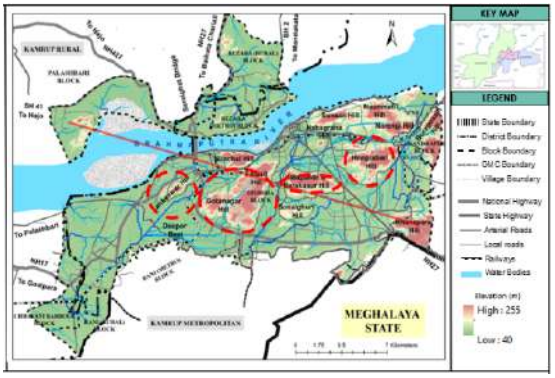


**Figure 10**. Topographic Variation GMA 2024(SRTM DEM data Analysis)

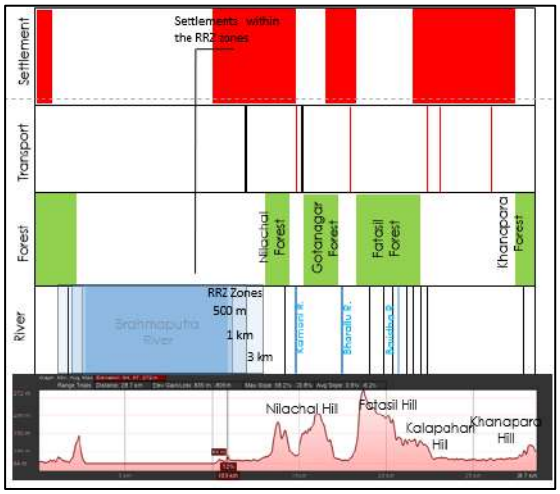


**Figure 11**. Transect Chart Analysis 2024

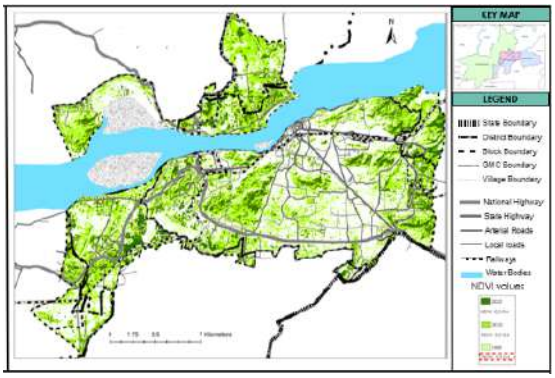


**Figure 12.** NDVI Analysis 2024 (Landsat Satellite Image Analysis)

The NDWI analysis (Figure 13) shows the yearly variation in water density in lakes and streams in GMA. The values of NDWI ranges between 0.1 to 0.6. The higher value indicates that the GMA has higher water density. The higher NDVI and NDWI values in the year 1989 represents the higher density of the vegetation and the water bodies during the previous period. As a consequence of urbanisation the densification has been affected along with a real change. Thus, the index values show negative relation with the built-up expansion. to 0.6. The higher value indicates that the GMA has higher water density.

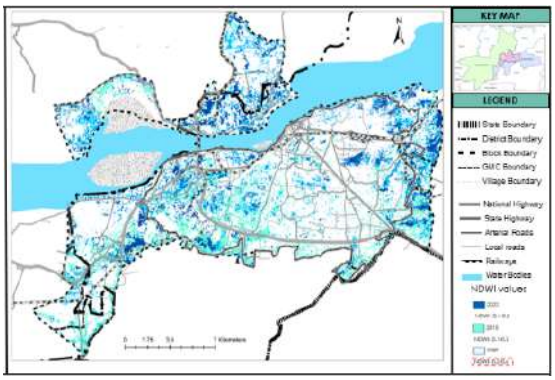


**Figure 13**. NDWI Analysis 2024 (Landsat Satellite Image Analysis)

### *5.2 Developmental Impacts on Existing Natural Water Bodies*

The increased rate of urbanization consequently leads to increased anthropogenic activities leading to the generation of wastes from various domestic, industrial and commercial purposes directly into the water bodies. The major polluted stretches along the Sarusola Beel and the Borsola Beel (Figure 14). The major drains crossing through the core area of the GMA has been identified to have the BOD level more than 30 which signifies the highly polluted stretches. These drains ultimately join beels in GMA like the Bharalu River, Borsola Beel, Silsako Beel, Sorusola Beel and the Deepor Beel which gets further connected to the main Brahmaputra River and pollutes it. Bharalu River being centrally located in the city is the most polluted with the major drains connecting it. In the absence of the Sewage Treatment Plant in the city the entire sewage is drained into the main river. It is observed (Figure 15) that that the major concentration of industries irrespective of the residential concentration is also within the central core area which has added to the pollution of the Bharalu River. The GMA in the last five years has witnessed unprecedented growth of micro and small industries which is again concentrated within the main GMC area. In the absence of efficient monitoring of the industries the chemical waste from the industries is directly discharged into the river. Among the two districts which constitutes the GMA Kamrup (rural) has

57.40 % of orange industries and 4.69 % of red industries while that Kamrup (metro) consists of 64.66 % of orange industries and 21.02 % of red industries.

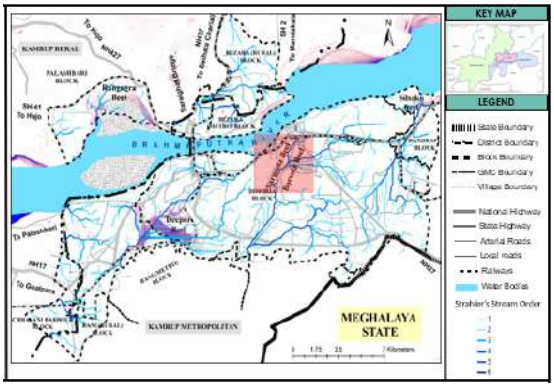


**Figure 14.** Polluted Stretch 2024 (CPCB Guwahati Unpublished source)

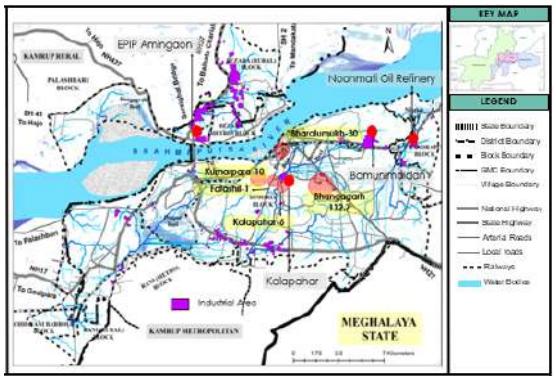


**Figure 15.** Distribution of industries in Guwahati 2024 (Guwahati Master Plan 2045)

### *5.3 Water Infrastructure Issues in the GMA*

The GMA being a part of the major Brahmaputra Basin also constitutes of several sub-basin which are the Deepor Basin, Bharalu Basin, Sikaso basin, Foreshore Basin, North Guwahati Basin, Kalmoni Basin. The volume of water in these basins have also been mapped (Figure 16). It is observed that spatially the areas under built-up shows low volume of water in the respective sub-basins. As in the case of Dimoria block which shows the highest level of urbanization has the least volume of water. Similar cases are observed for Bezara metro block, Sualkuchi block and their respective sub-basins. The GMA is primarily served with two sources of water which is surface water and the groundwater. The surface constitutes 97.25 % of the water supply while the rest is the groundwater from the total supply of 54.6MLD. In lieu of the growing population the present water demand is 177.2 MLD which is met through unmonitored borehole extraction. This explains the negative relation between urbanization and low volume of water in the corresponding sub-basins. Morevever, the rapid rate of urbanization in such blocks like Dimoria, Sualkuchi and Bezara in the absence of consideration of stream orders blocks the natural flow of water. This further leads to the low volume of water.

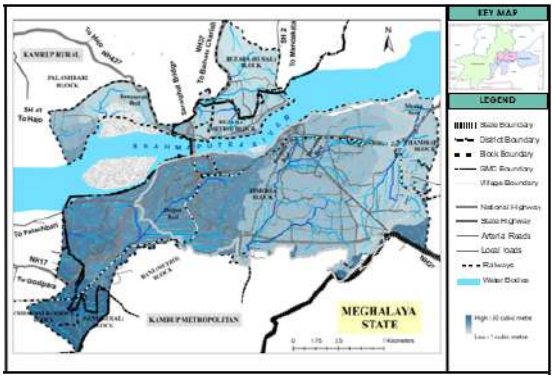


**Figure 16**. Variation Water Volume in Sub-basins in Guwahati, 2024 (SRTM DEM Analysis, 2024)

### *5.4. Physiographic Alternation and Hazard Susceptibility of the GMA.*

In the due course of urbanization, the flood plains of the Brahmaputra have been encroached. The construction of the buildings has taken place along the slopes of the hills which has obstructed the natural flow of water, the areas considered as natural sinks has been encroached as a consequence of which waterlogging leading to flood is a yearly recurrent phenomenon. The poorly designed drains, inadequate de-siltation initiatives have further caused deterioration of the sub-basins hydrological flow. Furthermore, the hills have been cut along with massive destruction of the forest cover which has led to losing of the soil strength and as a consequence has made the region vulnerable to landslides too. The areas under flood and landslides have been demarcated for the GMA (Figure 17).

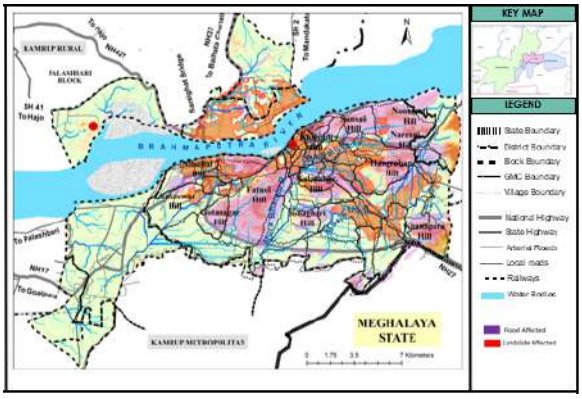


**Figure 17.** Hazard Zone in Guwahati, 2024 (Compilation from Assam State Disaster Management Report)

The areas susceptible to flood and landslide in GMA has also been identified. It is observed that there are several areas within the GMA which are affected by both flood and landslides. In the year 2022 almost 42 % of the area was affected by flood while 61% of the area was affected by

landslide and 6 % is affected by both landslide and flood. At least, 23.73 % of the population is vulnerable to flood and 7.06 % is affected by landslide. The reason for such larger percentage affected by flood is that a large concentration of unauthorized slum population is located along the Brahmaputra River. The above sections therefore, reflects the various social, economic, spatial and environmental issues that are presently requires planning intervention. The spatial issues in this regard highlights the expansion of boundaries in the absence of strategized river sensitive planning and management, the rapid expansion of the built-up along the river. Environmentally, there has been a rapid degradation of the forest cover and cutting of the hills for construction affects the natural balance in the river sensitive regime. Economically, the agricultural activities with large scale use of fertilizers and the growth of industries mostly red and orange categories have affected the overall river health and associated streams. Socially, the rapid encroachments along the river in the due course of migration has also affected the natural health of the river. It is for such issues that certain resilient strategies shall be proposed such that the river health can be maintained in the due process of urbanization.

## 6. Water Institutions in the GMA and their Role in Resilient Planning

There exist different governing bodies within the GMA for the management and the supply of water from the source to the distribution of water Throughout the GMA the water supply is managed by Public Health and Engineering Department (PHED) and Water Users Association for the rural parts while GMDWSB for the urban areas beyond municipal corporation. The GMC manages water supply only for wards under its jurisdiction within Dimoria block. The rural blocks include Chayan Barbour, Chandrapur, Bezara Rural and Rani Rural while urban blocks are Dimoria, Sualkuchi, Bezara Metro and Rani Metro (Figure 18). There are several authorities that manage the distribution of water, flow of water from the storm water drains and the management of sewerage system in GMA. The multiplicity of institutions in the water sector is another challenge in the absence of well-defined roles. It is therefore necessary to analyze the roles and the functions of different governing institutions in the management of water bodies. There are several authorities that manage the distribution of water, flow of water from the storm water drains and the management of sewerage system in GMA. The multiplicity of institutions in the water sector is another challenge in the absence of well-defined roles. It is therefore necessary to analyze the roles and the functions of different governing institutions in the management of water bodies.

The flow chart (Figure 19) explains that there lags a well-coordinated hierarchical involvement of stakeholders from various sectors within the water management scenario. This forms a crucial factor in building resilience within the system where developmental threshold should be taken into consideration along the river belt.

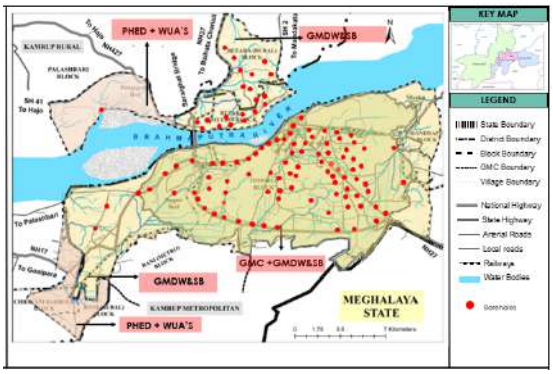


**Figure 18.** Water Institutions in Assam 2024 (prepared by the Author from Primary Survey)

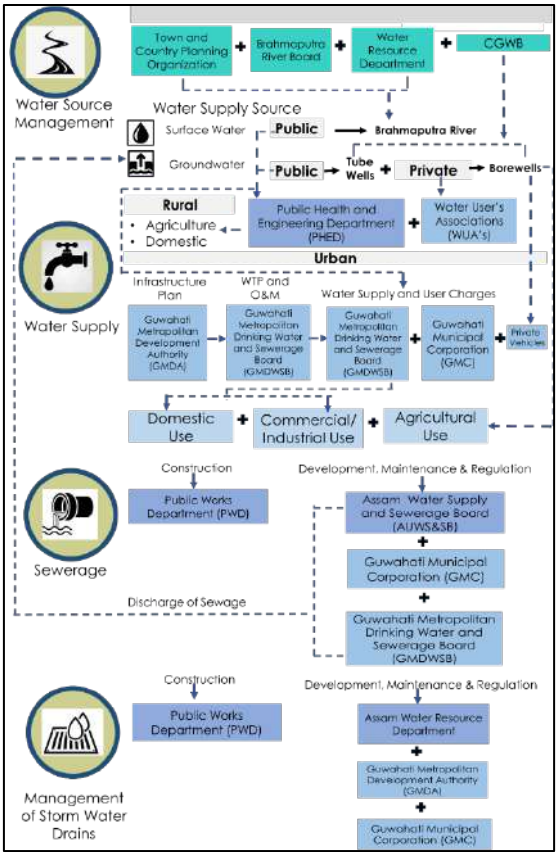


**Figure 19**. Present Scenario of Water management in Guwahati, 2024 (Primary Survey)

### 6.1. *Performance of Institutions in Urban and Rural Scenario*

A metropolitan region being a crucial boundary for planning consists of both rural and urban population. Since both the population, economic activities and the environmental conditions vary much between the rural and the urban spectrum therefore the situations pertaining to water demand and supply also vary. Hence, it is also necessary to understand the indicators performance separately in the rural and the urban scenario. A subjective analysis has been performed in this regard (Table 2). It can be interpreted that active institutional involvement is absent in the case of industrial and the agricultural sector. In the rural scenario the GMC lacks any active involvement in any of the parameters of analysis. The GMDWSB is only concerned with the assessment and monitoring and dealing with domestic and water demand. The GMDA involvement in rural areas is similar to that of the urban scenario. The PHED has an active involvement in agriculture, industries and domestic water demand in the rural area. The absence of any planned involvement of institution in dealing with the industries and the agriculture in the urban scenario affects the waste generated from these sectors into the river.

**Table 2.** Urban and Rural Water Institutions Involvement in Guwahati, 2024 (Primary Survey)

| Urban Scenario | | | | | | |
|---|---|---|---|---|---|---|
| Institutions | Funding | Plan Formulation | Assessment & Monitoring | Role in Industrial Water Demand | Role in Agricultural Water Demand | Role in Domestic Water Demand |
| GMC | | | | | | |
| GMDWSB | | | | | | |
| GMDA | | | | | | |
| PHED | | | | | | |
| **Rural Scenario** | | | | | | |
| Institutions | Funding | Plan Formulation | Assessment & Monitoring | Role in Industrial Water Demand | Role in Agricultural Water Demand | Role in Domestic Water Demand |
| GMC | | | | | | |
| GMDWSB | | | | | | |
| GMDA | | | | | | |
| PHED | | | | | | |

### 6.2. *Comparative Analysis of Indicators in Water Management*

The indicators as derived from the OECD framework (OECD 2015) has been compared with different segments of water i. e. the storm water drainage, sewerage and water supply (Figure 20). This further enhances our understanding about the drawbacks that exists in different indicators and needs to be strengthened.

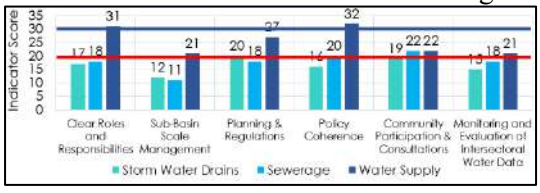


**Figure 20.** Score Analysis of Water Institutions in Guwahati, 2024 (Stakeholders Survey)

The present condition in GMA reflects that despite the presence of several institutions it lacks a coordinated approaches for integrating the local communities with the management of water. Therefore, integration of water in institutions for the indicators (Figure 21) are required for protection of water resource and holistic resilience along the river.

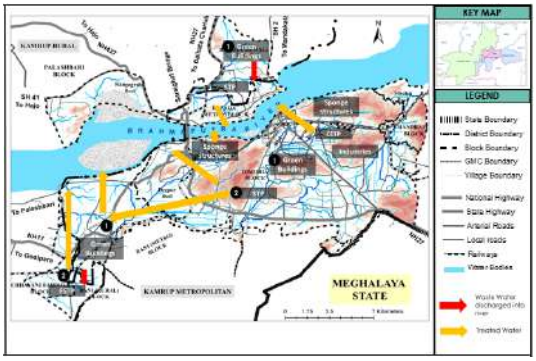


**Figure 21.** Integrated Rural and Urban Resilient Water Management Strategy, 2024 (Prepared by the Authors)

## 7. Conclusion and Way Forward

GMA is situated in ecologically fragile area. It also has been experiencing rapid urbanization which has disregarded river sensitivity and hydrological condition of the sub-basins. Also, GMA's economy is transforming towards secondary and tertiary sector further leading to built-up expansion at the cost of agricultural land. This adds to the exploitation of water resource and neglects river management. To address the existing issues in GMA interventions would be required at the micro, meso as well as macro level. Micro level strategies being those taken at

local level along the river including structural measure, buffers and behavioural strategies. Meso level strategies emphasizes on inter-block management of water Macro strategies identifies the hierarchical involvement of governing bodies within the institutional framework for undertaking projects in river sensitive regions.

At the micro level resilience strategies that can be undertaken for the management of river and the surrounding area includes planned river regulation zonation through implementation of RRZ (River Regulation Zoning Guidelines) and conservation zones as emphasized in Assam Disaster Management Plan, creation of detention ponds within the residential areas which acts as natural sponge structures as outlined in River Centric Urban Planning Guidelines 2021. The strategies for economic resilience can be creation of river museums, use of floral wastes for making essence, incense sticks, colours, biogas, bioethanol, vermicomposting, creation of non-permanent structures for markets along the river for selling traditional materials of Assam. Thematic parks like flower parks and butterfly parks serves as eco-friendly way of generating revenue at the same time preserve the river frontier. The strategies to involve the local people through Youth Heritage Walks along the river, use of print and social media to educate citizens about river, yearly river festivals to inculcate the traditional value of river shall enable to maintain the river health and connect local citizen to the river through bottom-up approach can be implemented by promoting hierarchical involvement of multiple stakeholders from different sectors.

At the meso scale the resilient strategies should incorporate use of treated waste water from the treatment plants into the agricultural farmlands of Rani rural, Rani metro block and Chayani Barbour block, creation of network of bamboo structures in river, biodiversity parks to maintain the river ecosystem which together can improve the river health as highlighted in report of Eco-Friendly Intervention for Riverfront Development, 2022. There is an urgent need for functioning of STPs for each of North Guwahati and South Guwahati along with CETPs for industries and FSTPs for rural areas for treating of grey water. Preparation of solid waste management plan, implementation Jal Jeevan Mission guidelines, BOD level monitoring by the Assam state pollution control board, in situ upgradation of slums, integration of town planning schemes within GMA, implementation of strategies under Paramghat Krishi Vikas Yojna for sustainable agriculture, biomedical waste management strategy for management of industrial and agricultural waste polluting the water are some other meso scale initiatives that can be undertaken.

There are also several guidelines at the national (macro) level like the River Regulation Zoning, National Water policy, National Forest Policy, Hill Town Building Byelaws, incorporation of the green building code for urban and peri-urban areas to enable long-term resilience for river sensitive regions.

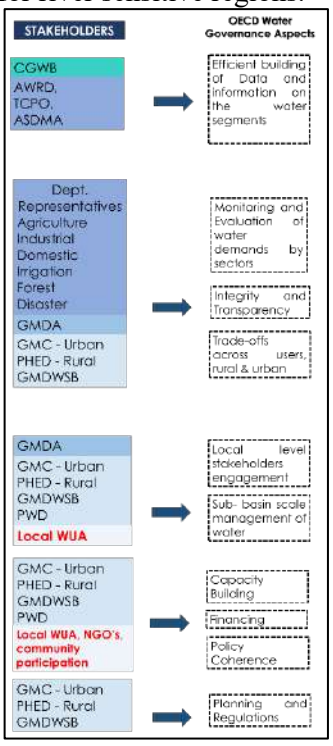


**Figure 22.** Proposed Coordinated Hierarchy of Involvement of Water Institutions in Guwahati, 2024

Further, at the macro scale, strategies for integration of service providing institutions (Figure 22) during the initiation of any project in river sensitive regions can promote resilience through better coordinated governance. It is necessary that involvement of all the institutions takes place from the national to the local level including the active participation of local citizens. The first stage involves stake holders for identifying the objectives and defining them. The second stage involves institution at the state level like the representatives from agriculture, industrial, domestic irrigation, forest and disaster, the GMDA, the GMC for urban issues, PHED-rural and GMDWSB. The third stage includes identification of alternative strategies for river management in the presence of local bodies and WUA's. The fourth stage involves investments for the projects, feasibility study and the environmental impact assessment with active

community participation. The final stage involves monitoring and implementation of the project under the service delivering authorities. Thus, resilient planning of infrastructure, environment and institutional structure is essential for management of river sensitive regions as it integrates the river with rural and urban activities sustainably in due course of urbanization. This shall enable to protect river health. It also develops a bottom-up approach in water management through involvement of multi-sectoral institutions and citizens for efficient and resilient planning of river sensitive regions.

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# The Impact of Economic Growth on Women's Labour Market in CNCR Districts

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**Abstract:** Women's engagement in labour contributes to economic growth and is a pivotal catalyst for fostering sustainable development and economic prosperity. In India, however, while the female labour force participation rate has been gradually increasing, it still falls below the global average. Furthermore, in North and South India, significant disparities exist in women's workforce participation, shaped by various socioeconomic factors that impede their access to quality employment opportunities. As a focal point for economic activities and infrastructure development in India, Delhi continues to attract a significant influx of migrants from neighbouring states. While this population growth presents economic opportunities, it also poses challenges in terms of employment creation and labour market participation. Additionally, the Central National Capital Region (CNCR), comprising Delhi and its adjacent towns, grapples with dynamic changes driven by core-periphery relationships, industrial diversification, and demographic shifts, which pose challenges to inclusive growth, particularly impacting women. Despite overall economic growth, female workforce participation in Delhi and the CNCR region remains stagnant or even declining in certain sectors. This trend highlights significant barriers that hinder women's active participation in the workforce. Addressing these challenges requires a comprehensive approach that combines policy interventions, social initiatives, and economic incentives. The study on the impact of economic growth on the women's labour market in the CNCR region aims to address these complex challenges. By promoting women's education, ensuring gender-responsive labour policies, creating supportive work environments, and addressing socio-cultural barriers, sustainable development strategies can empower women to actively participate in the labour force, thereby contributing to inclusive growth and economic development

**Keywords:** Economic growth, labour force participation rate, work force participation rate, unemployment rate, barriers and enablers.

**सार:** श्रम में महिलाओं की भागीदारी सतत विकास और आर्थिक समृद्धि को बढ़ावा देने के लिए एक महत्वपूर्ण उत्प्रेरक है। हालाँकि, भारत में महिला श्रम बल की भागीदारी दर धीरे-धीरे बढ़ रही है, फिर भी यह वैश्विक औसत से नीचे आती है। इसके अलावा, उत्तर और दक्षिण भारत में, महिलाओं की कार्यबल भागीदारी में महत्वपूर्ण असमानताएं मौजूद हैं, जो विभिन्न सामाजिक आर्थिक कारकों से आकार लेती हैं जो गुणवत्तापूर्ण रोजगार के अवसरों तक उनकी पहुंच को बाधित करते हैं। भारत में आर्थिक गतिविधियों और बुनियादी ढांचे के विकास के लिए एक केंद्र बिंदु होने के नाते, दिल्ली पड़ोसी राज्यों से प्रवासियों की एक महत्वपूर्ण आमद को आकर्षित करना जारी रखती है; हालाँकि यह जनसंख्या वृद्धि आर्थिक अवसर प्रस्तुत करती है, लेकिन यह रोजगार सृजन और श्रम बाजार में भागीदारी के मामले में भी चुनौतियां पेश करती है। इसके अतिरिक्त, दिल्ली और उसके आस-पास के शहरों को शामिल करने वाला केंद्रीय राष्ट्रीय राजधानी क्षेत्र (सीएनसीआर) मुख्य-परिधीय संबंधों, औद्योगिक विविधीकरण और जनसांख्यिकीय बदलावों द्वारा संचालित गतिशील परिवर्तनों से जूझ रहा है, जो समावेशी विकास के लिए चुनौतियां पेश करते हैं, विशेष रूप से महिलाओं को प्रभावित करते हैं। समग्र आर्थिक विकास के बावजूद, दिल्ली और सी. एन. सी. आर. क्षेत्र में महिला कार्यबल की भागीदारी कुछ क्षेत्रों में स्थिर या यहां तक कि घटती जा रही है। यह प्रवृत्ति कार्यबल में महिलाओं की सक्रिय भागीदारी में बाधा डालने वाली महत्वपूर्ण बाधाओं को रेखांकित करती हैइन चुनौतियों से निपटने के लिए एक व्यापक दृष्टिकोण की आवश्यकता होती है जो नीतिगत हस्तक्षेपों, सामाजिक पहलों और आर्थिक प्रोत्साहनों को जोड़ता है। सीएनसीआर क्षेत्र में महिलाओं के श्रम बाजार पर आर्थिक विकास के प्रभाव पर अध्ययन का उद्देश्य इन जटिल चुनौतियों का समाधान करना है। महिलाओं की शिक्षा को बढ़ावा देकर, लैंगिक-उत्तरदायी श्रम नीतियों को सुनिश्चित करके, सहायक कार्य वातावरण का निर्माण करके और सामाजिक-सांस्कृतिक बाधाओं को दूर करके, सतत विकास रणनीतियाँ महिलाओं को श्रम बल में सक्रिय रूप से भाग लेने के लिए सशक्त बना सकती हैं, जिससे समावेशी विकास और आर्थिक विकास में योगदान मिल सकता है।

**मुख्य शब्द:** आर्थिक विकास, श्रम बल भागीदारी दर, कार्य बल भागीदारी दर, बेरोजगारी दर, बाधाएं और समर्थकारी।

## 1. Introduction

The Indian economy has undergone significant transformation in recent years, positioning itself as the 12th largest economy globally and the third largest in Asia, trailing behind only China and Japan. This transformation is driven not only by internal reforms but also by the powerful forces of globalization, which are reshaping the global economic landscape. In this evolving economic scenario, there is a notable shift in focus towards the development of urban centers, which now contribute over 60 percent of the country's total gross domestic product (GDP).

Female participation in the labour force and access to decent work is crucial for inclusive and sustainable economic development in any country. India's female labour force participation rate has shown a noticeable upward trend despite

being below the global average. However, this growth is not uniform across the country. Various socio-economic factors contribute to significant regional differences in female labour force participation, particularly between Northern and Southern India. States like Delhi, Haryana, and Uttar Pradesh are still below 17 percent despite Delhi being one of the fastest-growing economies with various job opportunities that attract a large number of migrants from all over India.

The Central National Capital Region (CNCR), formerly known as the Delhi Metropolitan Area, as delineated in the Regional Plan – 2021, encompasses the notified and controlled development areas of neighboring towns such as Ghaziabad–Loni and Noida in Uttar Pradesh and Gurugram-Manesar, Faridabad-Ballabhgarh, Jhajjar, and Sonipat-Kundli in Haryana, Figure 1. The region experiences dynamic shifts in its core-periphery relationships, industrial landscape, and demographics. While job opportunities are expanding in the peripheries, gender disparities persist, with a notably low female workforce participation rate.

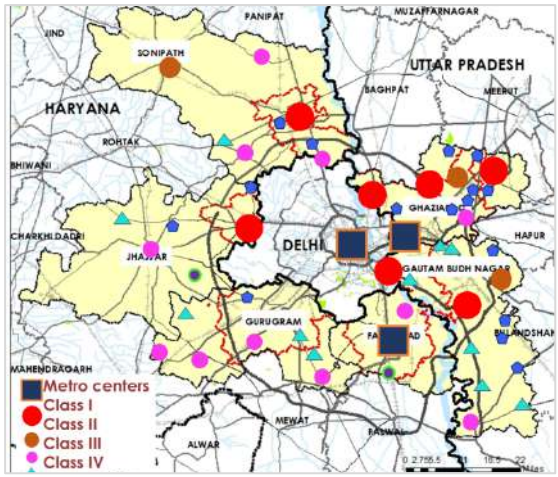


**Figure 1.** Settlement Hierarchy (Source: Primary Census Abstract 2011)

The demographic composition reveals distinct patterns, with areas like Ghaziabad exhibiting higher female representation, likely due to economic opportunities and accessibility. In comparison, Jhajjar reports lower representation, which may be attributed to traditional gender roles and socio-economic factors. Major urban centers like Gurugram, Faridabad, and Ghaziabad are crucial for attracting investments and offering employment opportunities, shaping the labour market dynamics. This trend highlights significant barriers that hinder women's active participation in the workforce. Addressing these challenges requires a comprehensive approach that combines policy interventions, social initiatives, and economic incentives. This study aims to examine the impact of the sectoral economic growth of the CNCR region on women's labour market through the following four objectives:

i) To identify and analyse the economic growth trends in the CNCR Region.
ii) To assess the current status of women in the labour market across various economic sectors
iii) To investigate challenges and barriers that impact women's participation in the workforce amidst economic growth
iv) To develop recommendations and strategies to enhance women's labour market participation to promote inclusivity.

## 2. Methodology

This research employs a mixed-method approach, integrating both qualitative and quantitative methodologies. It draws upon primary and secondary data collected from diverse sources, including research papers, books, articles, documentaries, and official reports. The study is primarily based on the analysis and findings of the "Study of Economic Profile of NCR" conducted by the NCR Planning Board, supplemented by data and information published by the Ministry of Statistics and Programme Implementation (MOSPI), Central Statistical Organization (CSO), Periodic Labour Force Survey (PLFS), District Statistical Handbooks, State-Level Economic Surveys, and participating State Governments, as well as inputs from various industry associations.

The research unfolds in four stages:

i) Identification of sectoral economic growth and historical trends using indicators such as GDP, PCGVA, and sectoral contributions to GDP.
ii) Analysis of sectoral labour and workforce disaggregated by sex, focusing on labour force participation rate (LFPR), workforce participation rate (WFPR), unemployment rate (UR), and sectoral female employment trends since 2011.
iii) Identification of enablers and barriers to female employment, classified under categories like gender norms, violence against women, access to amenities, education, government policies, and work culture.
iv) Identification of strategies to increase women's participation in the workforce based on a women empowerment framework designed to address the identified challenges.

## 3. Economic growth

Economic growth refers to the increase in the production of economic goods and services over time. It is commonly measured using indicators such as Gross Domestic Product (GDP), Per Capita Income (PCI), and trends in employment and unemployment. Economic growth has various impacts, including increased in job opportunities, higher income levels, and a reduction in poverty and inequality.

In the context of the CNCR districts, this growth is more than just a figure for the country's overall growth. It represents an evolving economy with significant implications for the workforce, particularly for women. To understand the impact on the labour market, which comprises of both employed and unemployed women, the following indicators have been used: labour force participation rate (LFPR), working force participation rate (WFPR), and unemployment rates.

### *3.1 Economic Growth Trends in CNCR*

The National Capital Region (NCR) of India is rapidly emerging as a world-class economic region and is one of the fastest-growing regions in the country.

The CNCR districts have experienced significant economic growth, with the gross domestic product (GDP) increasing from INR 2.9 trillion in 2011-12 to INR 5.4 trillion in 2022-23, representing a growth rate of 86.2 percent in the fiscal year 2007-08, the NCR's economy was predominantly driven by the service sector, which accounted for 66 percent of its GDP. The total GDP increased from 2011 to 2023 in CNCR, Table 1. Gurugram, followed by Faridabad, is the largest GDP contributor, indicating high economic growth and development. In contrast, Sonipat and Jhajjar (Bahadurgarh) appear to lag due to challenges such as slower industrial growth and infrastructure deficits.

The per capita Gross Value Added (PCGVA) in the CNCR districts has also witnessed a substantial increase, rising from INR 1.3 lakh in 2011-12 to INR 2.1 lakh in 2022-23, indicating a growth of 61.5 percent, Figure 2.

In the Haryana sub-region, Gurugram had the highest PCGVA at INR 489,000 in 2022-23, followed by Faridabad at INR 293,000 and Jhajjar at INR 259,000. Sonipat had the lowest PCGVA at INR 250,000.

In the Uttar Pradesh sub-region, Gautam Buddh Nagar (Noida) had a higher PCGVA compared to Ghaziabad, indicating challenges in industrial diversification and job opportunities in Ghaziabad.

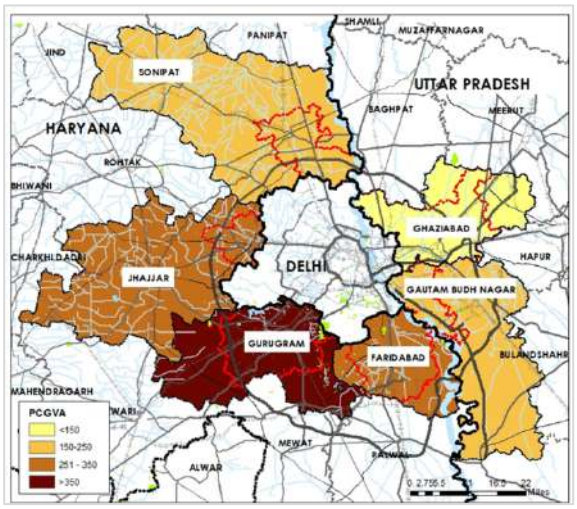


**Figure 2.** Per Capita Gross Value Added (PCGVA) in CNCR (2021-22) Source: Department of Economic & Statistical Analysis, Haryana and Uttar Pradesh; IHD Estimates

**Table 1.** Sectoral GDP Contribution

| CNCR ZONES | Primary | | | Secondary | | | Tertiary | | |
|---|---|---|---|---|---|---|---|---|---|
| | GDP (Crore) | Share (%) | Change since 2011 | GDP (Crore) | Share (%) | Change since 2011 | GDP (Crore) | Share (%) | Change since 2011 |
| Ghaziabad | 0.7 | 3 | -1.2 | 10.2 | 42 | -1.8 | 13.5 | 55.3 | 6.9 |
| Noida | 0.01 | 0 | 0.02 | 3.6 | 14 | -11 | 22.3 | 86 | 15.2 |
| Sonipat | 1.6 | 15 | -5.8 | 4.6 | 43 | 15.7 | 4.5 | 41.8 | 3.2 |
| Bahadurgarh | 0.5 | 8 | -4.8 | 1.8 | 29 | 1.5 | 3.9 | 63.6 | 2.1 |
| Gurugram | 0 | 0 | 0 | 42.1 | 41 | -5.1 | 59.7 | 58.6 | 45.7 |
| Faridabad | 0.6 | 1 | 0 | 21.3 | 37 | -1.6 | 35.2 | 61.5 | 21.7 |

(Source: Department of Economic & Statistical Analysis, Haryana and Uttar Pradesh; IHD Estimates).

In the Uttar Pradesh sub-region, Noida had a significantly higher per capita income compared to Ghaziabad. This disparity is due to Noida's strategic positioning as an economic hub. In the Haryana sub-region, Gurugram again stood out with the highest per capita income of INR 741,000 thousand, driven by its diverse and robust economic sectors. Faridabad also showed notable per capita income at Rs. 364 thousand, reflecting its strong industrial base.

Gurugram and Noida have the highest per capita income (PCI), while Ghaziabad has the lowest, despite making a significant contribution to the GDP, Figure 3. The presence of labour-intensive industries and informal sectors can depress average income levels. Economic disparities within the district can lead to uneven distribution of economic gains.

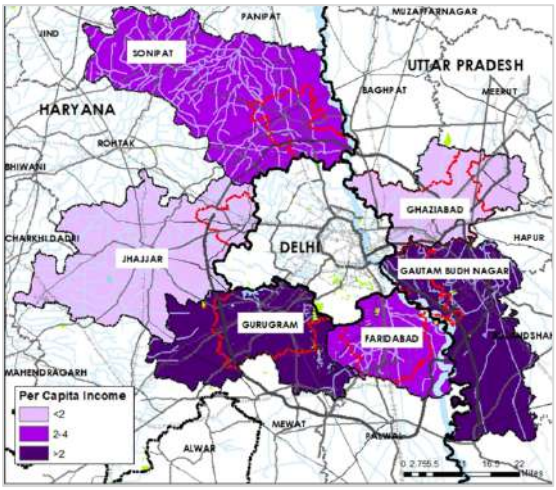


**Figure 3.** Per Capita income in CNCR (2021-22)
Source: Department of Economic & Statistical Analysis, Haryana and Uttar Pradesh; IHD Estimates

### *3.2 Economic Growth and Disparities*

From 2011-12 to 2022-23, the GDP of the Central National Capital Region (CNCR) increased from INR 76,000 crore to Rs. 132,000 crore, reflecting an average annual growth rate of 10.5%. However, disparities exist between sub-regions, with Haryana's GDP approximately 2.7 times higher than that of Uttar Pradesh. Economic growth in Haryana, particularly in Gurugram and Faridabad, has significantly outpaced that in Uttar Pradesh's districts such as Ghaziabad and Gautam Buddh Nagar (Noida). In Uttar Pradesh, Noida has experienced growth, whereas Ghaziabad has declined due to population increases that have not been accompanied by corresponding economic activity. In Haryana, Gurugram leads in GDP contributions, while Sonipat lags behind.

### *3.3 Sectoral Contributions*

The sectoral contribution to GDP has undergone a notable shift, with the tertiary sector (services) emerging as the dominant contributor, accounting for 63.4 percent of the total GDP in 2022-23, followed by the secondary sector (industry) at 32.6 percent and the primary sector (agriculture) at 4 percent.

i) Primary Sector: The primary sector's contribution to the GDP of CNCR cities has been steadily declining. This decline is attributed to rapid urbanization and the subsequent reduction in rural and cultivable land. Gurugram and Faridabad have negligible contributions from the primary sector, highlighting their transition to urban and industrial economies.
ii) Secondary Sector: The share of the secondary sector's GDP for CNCR cities has seen a slight decline over the last decade. The manufacturing sector within the secondary sector has shown growth, increasing its share from 24.3 % to 26.3 % over the same period. Gurugram stands out with a substantial 29.9 percent contribution to its GDP from the secondary sector, driven by diverse industries, including automobile and electronics manufacturing.
iii) Tertiary Sector: The service sector remains the major contributor to the GDP of CNCR cities. The service sector experienced an average annual growth rate of 12.6 % during this period. In the Uttar Pradesh sub-region, cities like Ghaziabad and Noida exhibit significant contributions from the tertiary sector, with Noida particularly standing out due to its thriving IT sector and planned urban development. Meanwhile, Gurugram's service sector contributes a dominant 59.7 percent to its GDP, driven by industries such as finance, IT, and real estate.

The economic landscape of CNCR exhibits significant growth, driven primarily by the tertiary sector, with substantial contributions also coming from the secondary sector. However, there are notable disparities between the Haryana and Uttar Pradesh sub-regions, with Haryana generally showing higher economic performance. Gurugram and Faridabad in Haryana, as well as Noida in Uttar Pradesh are major economic centers driven by industrialization, infrastructure development, and the presence of multinational corporations. In contrast, cities like Sonipat, Jhajjar, and Ghaziabad face challenges that hinder their economic growth, highlighting the need for targeted economic policies to address these disparities

## 4. Labour Market Indicators and Gender Disparities

This section delineates the present employment landscape encompassing both organized and unorganized sectors across CNCR cities. The section is bifurcated into two main segments. The initial part delves into the existing employment scenario within CNCR cities. The subsequent part scrutinizes the evolution of trends and

sectors since 2011, along with an in-depth analysis of gender disparities across various employment sectors within CNCR cities.

### *4.1 Labour Participation Rate (LPR)*

The Labour Participation Rate (LPR) for adults aged 15 and above in CNCR cities has seen a significant decline over the past decade, Table 2. It dropped from 57.2% in 2011-12 to 45.5% in 2022-23. This decrease was more pronounced between 2011-12 and 2017-16, when it fell by 10.2 percentage points, compared to a smaller decline of 1.5 percentage points between 2017-16 and 2022-23. The initial period's decline was primarily due to a significant drop in male LPR, while the latter period's decline was driven by a fall in female LPR. The male LPR, at 74.5%, is more than four times higher than the female LPR, which stands at 18.2%, mirroring patterns seen across India and in NCT Delhi.

At the sub-regional level, the Uttar Pradesh Sub Region experienced a more substantial decline in LPR, dropping by 18.4 percentage points, compared to a 3.5 percentage point decline in the Haryana Sub Region over the last decade and a half. Within the U.P sub-region, the Ghaziabad-Loni Complex and Noida have notable LPRs of 43.4% and 48.6%, respectively. Similarly, in the Haryana sub-region, the Sonipat-Kundli Complex, Bahadurgarh, Gurgram-Manesar Complex, and Faridabad-Ballabgarh Complex show LPRs ranging from 43.5% to 50.3%.

**Table 2.** Change in share of labour force and work force

| | LFPR | | WFPR | |
|---|---|---|---|---|
| **CNCR zones** | **Total Labour** | **Change in share since 2011** | **Female Labour** | **Change in share since 2011** |
| Ghaziabad-Loni Complex | 49 | 2.4 | 5.5 | -5.8 |
| Noida | 55.8 | 4.1 | 20.8 | -6.8 |
| Sonipat-Kundli Complex | 41.35 | -1.05 | 23.2 | 1.4 |
| Bahadurgarh | 35 | -2.7 | 16 | 5.6 |
| Gurgram-Manesar Complex | 52.4 | 2.1 | 9.8 | -6.6 |
| Faridabad-Ballavgarh Complex | 46 | 0.8 | 0.4 | -13.8 |

(Source: NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2011-22)

**Table 3.** Change in share of female labour force and work force

| | LFPR | | WFPR | |
|---|---|---|---|---|
| **CNCR zones** | **Female Labour** | **Change in share since 2011** | **Female WFPR** | **Change in share since 2011** |
| Ghaziabad-Loni Complex | 5.5 | -5.8 | 6.3 | -5 |
| Noida | 20.8 | -6.8 | 28 | 1.6 |
| Sonipat-Kundli Complex | 23.2 | 1.4 | 18 | -3.8 |
| Bahadurgarh | 16 | 5.6 | 2.8 | -7 |
| Gurgram-Manesar Complex | 9.8 | -6.6 | 8.8 | 3 |
| Faridabad-Ballavgarh Complex | 0.4 | -13.8 | 8 | -5.5 |

(Source: NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2011-22)

**Table 4.** Sectoral Change in share of Employment

| | Sector | Total Employment in Lakhs | change in share since 2011 |
|---|---|---|---|
| Primary | Agriculture, etc. | 1 | -1.1 |
| | Mining & Quarrying | 0.1 | -0.3 |
| Secondary | Manufacturing | 8.6 | 8.5 |
| | Electricity, Gas & Water supply | 0.7 | 1.9 |
| | Construction | 8.2 | -2.3 |
| Tertiary | Trade, Hotel & restaurants | 6.1 | 4.75 |
| | Transport, Storage & Communication | 3.1 | 1.95 |
| | Finance, Business, Real Estate, etc. | 2.7 | 0.83 |
| | Public Admin, Health, education | 3.2 | 1 |

Source: NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2011-22

### *4.2 Work Participation Rate (WPR)*

The Work Participation Rate (WPR) for adults aged 15 and above in CNCR cities also shows a declining trend, falling from 56.6% in 2011-12 to 41.2% in 2022-23. This decline was steeper between 2011-12 and 2017-16, when it dropped by 10.6 percentage points, compared to a 4.8 percentage point decrease from 2017-16 to 2022-23. There is a significant gender disparity in WPR, with the male WPR consistently declining while the female WPR has seen a marginal increase over a longer period.

In the U.P sub-region, the Ghaziabad-Loni Complex and Noida exhibit total WPRs of 38.3% and 44%, respectively. These rates reflect the proportion of the working-age population actively engaged in economic activities within these zones. Noida's slightly higher total WPR compared to Ghaziabad-Loni Complex suggests relatively better overall employment opportunities or conditions in Noida. Similarly, the Haryana sub-region exhibits diverse levels of total WPRs, ranging from 40.2% to 47.1% across the Sonipat-Kundli Complex, Bahadurgarh, the Gurugram-Manesar Complex, and the Faridabad-Ballabgarh Complex. These figures indicate varying degrees of workforce engagement across different economic activities and regions within Haryana, influenced by factors such as economic development, industrialization, urbanization, education levels, and access to employment opportunities.

### *4.3 Female Labour Force Participation Rate (FLFPR)*

Female Labour Force Participation Rates (FLFPR) vary significantly across regions within the CNCR. In the U.P sub-region, the Ghaziabad-Loni Complex and Noida exhibit FLFPRs of 8.4% and 24.2%, respectively. Noida's significantly higher FLFPR compared to the Ghaziabad-Loni Complex suggests relatively better opportunities or conditions for women's participation in the workforce in Noida. Factors influencing these rates include industry composition, employment policies, educational attainment, and social norms. In the Haryana sub-region, FLFPRs range from 7.3% to 22.5% across various complexes, reflecting varying degrees of female workforce engagement across different economic activities and regions.

### *4.4 Female Workforce Participation Rate (FWFPR)*

The Female Workforce Participation Rate (FWFPR) measures the proportion of women in the workforce, either employed or actively seeking employment, Table 3. In the U.P sub-region, the Ghaziabad-Loni Complex and Noida have FWFPRs of 6.8% and 21.1%, respectively. Noida's notably higher FWFPR compared to the Ghaziabad-Loni Complex suggests relatively better opportunities or conditions for women's employment in Noida. In the Haryana sub-region, the Sonipat-Kundli Complex, Bahadurgarh, Gurgaon-Manesar Complex, and Faridabad-Ballabgarh Complex exhibit diverse levels of FWFPR, ranging from 7% to 22.5%.

These figures reflect varying degrees of female workforce engagement across different economic activities and regions, influenced by socio-cultural norms, access to education and skill development, availability of suitable job opportunities, and support for work-life balance.

The gender gap analysis reveals contrasting trends in the participation rates of male and female workforces over time. Both male and female participation rates have increased, indicating overall growth in workforce engagement. However, female participation rates have consistently surpassed those of males, indicating a narrowing gender gap in workforce participation.

In Uttar Pradesh, there has been a decline in the gender gap over the specified period, suggesting progress towards greater gender equality in workforce participation within the sub-region. Conversely, Haryana has seen an increase in the gender gap during the same period, indicating a widening disparity between the participation rates of males and females in the workforce. Notable regions such as Gautam Buddh Nagar (Noida) and Gurugram show decreases in the share of female labour force participation rates, reflecting improvements in female workforce participation. However, the Faridabad-Ballabgarh Complex shows a significant decline in female participation, suggesting the presence of barriers or challenges hindering female workforce engagement in that specific area.

### *4.5 Unemployment Rate (UR)*

The Unemployment Rate in CNCR has surged from 1.0% in 2011-12 to 9.6% in 2022-23, highlighting significant challenges within the labour market. The female unemployment rate has consistently been higher than the male unemployment rate, although the male unemployment rate has increased more rapidly in recent years.

Sub-regions show similar patterns in unemployment rates, with cities in the U.P sub-region having higher unemployment rates than those in the Haryana sub-region in 2022-23. The sharp increase in female unemployment, particularly in the Haryana sub-region, suggests a decline in traditional agriculture-related jobs for women, which are being replaced by jobs in the male-dominated manufacturing and service sectors

## 5. Sectoral Distribution and Employment Trends

The industrial distribution across cities in the CNCR (Central National Capital Region) displays significant variations between the sub-regions of Uttar Pradesh and Haryana. In 2017-18, Haryana had a higher share of employment in manufacturing at 35.2%, compared to 28.0% in Uttar Pradesh. Conversely, Uttar Pradesh had a larger share of employment in the trade, hotel, and restaurant sectors, accounting for one-fourth of total employment, compared to only one-sixth in Haryana. The tertiary sector holds the largest share of employment across all regions, while Haryana leads in secondary sector employment, indicating a stronger industrial base.

In 2022-23, employment in CNCR was concentrated in four key sectors: manufacturing (31.8%), trade, hotels, and restaurants (21.8%), public administration, education, health, and other services (11.6%), and transport, storage, and communications (10.6%). Haryana continued to dominate in manufacturing, while Uttar Pradesh showed strength in trade and hospitality, highlighting regional differences in employment structures. Notable changes since 2011 include an 8.1% increase in manufacturing employment, a 1.9% rise in the trade and hospitality sectors, and a 5.2% decline in the public administration, education, and health sectors.

### *5.1 Changes in Sectoral Employment Share Since 2011*

Since 2011, the manufacturing sector has experienced the most notable increase in employment, rising by 8.1%. This growth was followed by the trade, hotel, and restaurant industries, which saw a 1.9% increase, and the electricity, gas, and water supply sectors, which grew by 1.2%. In contrast, the public administration, health, and education sectors declined by 5.2%, while the construction sector dropped by 5.3%. The manufacturing sector has shown resilience, experiencing significant fluctuations, including a 19.4 percentage point decline between 2005 and 2012 before rebounding.

Gautam Buddh Nagar (Noida) and Gurugram have emerged as key commercial hubs, excelling in trade, hotels, finance, and real estate. Meanwhile, Sonipat-Kundli remains more agriculture-dependent, and Jhajjar (Bahadurgarh) plays a significant role in trade.

In the primary sector, Gautam Buddh Nagar (Noida) leads in agricultural establishments, while Gurugram excels in non-agricultural establishments, highlighting the region's economic diversity.

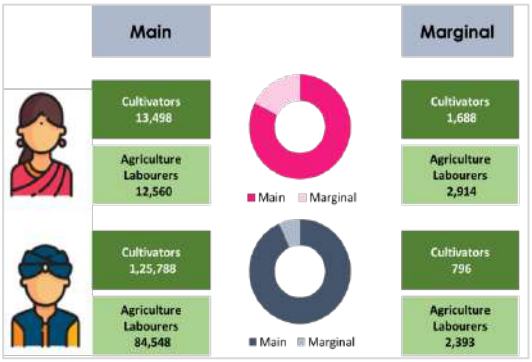


**Figure 4.** Employment share in Primary Sector (Source: NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2017-22)

The analysis of female employment in the manufacturing, construction, and utilities sectors reveals disparities. Ghaziabad and Gautam Buddh Nagar (Noida) exhibit lower employment rates in manufacturing, while higher rates are observed in Gurugram and Faridabad. Faridabad maintains the highest percentage of manufacturing employment but also the highest gender gap. Gender gaps in manufacturing range from 7.3% to 11.3%, with an average of 9.8%. Gurugram exhibits a decreasing gender gap, indicating efforts to promote gender equality.

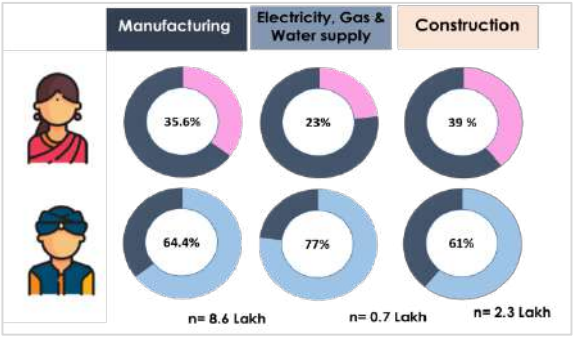


**Figure 5.** Employment share in the Secondary Sector Source: NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2017-22

The electricity, gas, and water supply sector employs a relatively small workforce. Faridabad

stands out with the highest total employment percentages in this sector, while Jhajjar (Bahadurgarh) reports no employment. Gender gaps are increasing in Ghaziabad, Gautam Buddh Nagar (Noida), Sonipat-Kundli, and Gurugram, though improvements are noted in some regions. Female employment in the construction sector has increased notably from 2011 to 2021, especially in Ghaziabad, Gautam Buddh Nagar (Noida), and Faridabad. The gender gap has decreased significantly, particularly in Ghaziabad, where it reduced from 12.0% in 2011 to 0.2% in 2021.

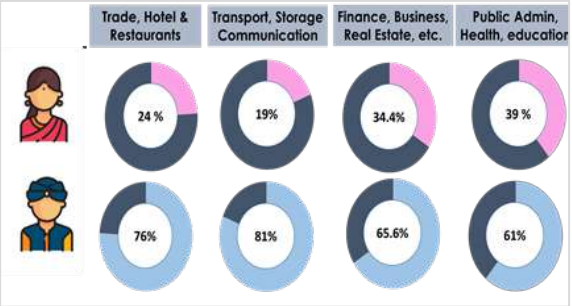


**Figure 6.** Employment share in Tertiary Sector (Source: NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2017-22)

Female employment trends in trade, restaurants, hotels, transportation, communication, finance, business, real estate, public administration, health, and education sectors show significant shifts. From 2011 to 2021, female employment increased in these sectors, particularly in Ghaziabad, Gautam Buddh Nagar (Noida), and Gurugram. Despite overall growth, some regions experienced a decline in female employment, indicating varying employment dynamics. Gender gaps in these sectors have generally decreased, suggesting progress towards gender equality.

### *5.2 Mapping of economic growth sectors with a share of employment*

Based on the literature review, district-level analysis of economic growth and its impact on sectoral female employment trends as well as overall labour force participation rates and workforce participation rates, identified the issues, and potential of CNCR districts. Further analysis categorized these districts under three scenarios based on similar economic characteristics, employment trends, and issues:

a) In scenario 1, where there is a decline in the Female Labour Force Participation Rate (FLFPR) alongside an increase in the Female Workforce Participation Rate (FWFPR), multiple factors contribute to this phenomenon. Women are shifting towards industries experiencing growth, pursuing education in job-growing sectors, engaging in informal sector activities, experiencing underemployment, or facing challenges re-entering the workforce. Districts like Noida and Gurugram exhibit declines in female employment across various sectors, attributed to barriers such as high crime rates, maternal mortality ratios, and a prevalence of unskilled labour. Despite these challenges, these districts also boast positive attributes, including good access to resources, high levels of education, and low gender gaps in literacy and adolescent marriage rates.

b) Scenario 2 presents a scenario where there is an increase in FLFPR but a decline in FWFPR. Factors contributing to this shift include population growth, economic downturns, delayed entry into the workforce, skill-job mismatches, seasonal employment, automation, and low per capita income. Districts like Sonipat and Jhajjar reflect declines in female employment across various sectors, including electricity, gas and water supply, as well as finance, business, and real estate, among others. These declines are attributed to factors such as high gender gaps in literacy, adolescent marriage rates, and casual labour. However, positive attributes include low workplace crime rates, increased regular employment, and high levels of skilled labour in certain sectors.

c) Scenario 3 depicts a decline in both FLFPR and FWFPR, driven by factors such as low per capita income, unequal resource distribution, limited opportunities for low-skilled and informal work, high population growth, and unemployment. Districts like Ghaziabad and Faridabad exhibit declines in female employment across various sectors, with barriers such as high crime rates, school dropout rates, and maternal mortality ratios. Nonetheless, these districts also possess positive attributes, such as large working-age population, high levels of education, and low middle school dropout rates.

Addressing structural inequalities, improving access to education and training, promoting inclusive economic growth, and tackling systemic barriers are essential for supporting women's workforce participation and achieving gender equality.

## 6. Barriers and Enablers to Women's Workforce Participation

In light of the second-stage analysis, an extensive literature review, identified and classified barriers and enablers to female employment under various categories, including gender norms and stereotypes, violence against women, access to basic amenities, education and skilling, government policies, and work culture. These barriers perpetuate economic inequality and hinder the realization of women's full potential in the labour force.

### *6.1 Gender Norms and Stereotypes*

a. Adolescent marriage: Early marriage significantly restricts women's educational and career prospects. Data from NFHS-4 and NFHS-5 reveal that Gurugram has the highest proportion of women aged 20-24 who were married before 18, whereas Bahadurgarh showed the lowest percentage in NFHS-4, and Ghaziabad showed improvements in NFHS-5.

b. Adolescent pregnancy: Early pregnancies disrupt education and limit workforce entry. NFHS-5 data show a marked increase in adolescent pregnancies in Gurugram, rising from 1.3% (NFHS-4) to 6.9% (NFHS-5). In contrast, Ghaziabad and Bahadurgarh reported significant declines, indicating positive trends.

c. Decision-making participation**:** Women's limited participation in decision-making processes at familial and societal levels constrains their ability and diminishes their opportunities to access higher education. This further reduces their chances of securing employment or developing business enterprises to advocate for educational and employment opportunities. NFHS-5 data illustrate low female participation in decision-making roles across CNCR districts.

d. Unpaid work**:** Women disproportionately bear unpaid domestic and care responsibilities, limiting their economic participation. The Time Use Survey 2019 indicates that women in Uttar Pradesh and Haryana allocate a significant portion of their time to unpaid domestic services, with lower time spent on employment-related activities.

### *6.2 Education and Skilling*

a. Female illiteracy rates**:** High female illiteracy in CNCR districts is a major barrier. NFHS-5 data show that Sonipat-Kundli and Bahadurgarh have the highest female literacy rates at 87.3% and 88.2%, respectively. Gurugram and Faridabad also exhibit high literacy rates, while Ghaziabad and Noida lag slightly behind.

b. Educational attainment**:** NFHS-5 indicates a rise in women with 10+ years of schooling across all districts. Bahadurgarh shows the highest increased from 53.2% (NFHS-4) to 62.7% (NFHS-5), followed by Gurugram, which increased from 51% to 59.6%. These trends suggest improved access to education.

c. Enrollment and drop-out rates**:** Disparities in enrollment and high drop-out rates among girls hinder their entry into workforce. UDISE reports (2017-18) reveal that Noida has the highest gross enrollment rate at 104.2% for middle school, while Sonipat shows a strong senior secondary enrollment rate of 94.5%. Female drop-out rates are significant, with a rate of 8.21% in Ghaziabad for senior secondary education.

d. Skilled and unskilled labour**:** A significant portion of the female workforce in CNCR districts remains unskilled due to limited access to education and training. The Ministry of Skill Development and Entrepreneurship data highlight Ghaziabad and Noida as having high concentrations of skilled workers in manufacturing and public administration, respectively. Conversely, unskilled labour is predominantly in the construction and trade sectors.

### *6.3 Employment status of workers*

Data from the NSS 61$^{st}$ and 68$^{th}$ rounds indicate that in 2017-18, 44.5% of workers in CNCR were regularly employed, 42% were self-employed, and 13.5% were casual labourers. Trends from 2004-05 to 2017-18 indicate a decline in self-employment from 49.3% to 42% and an increase in regular employment from 40.1% to 44.5%. Noida and Ghaziabad exhibit high self-employment rates of 44.5% and 43.2%, respectively, while Faridabad and Gurugram have high regular employment rates of 65% and 62.7%, respectively.

### *6.4 Unsupportive work culture*

a. Discrimination at work: Gender-based discrimination is pervasive in workplaces within CNCR districts, manifesting in various forms such as wage disparities, limited job security, and harassment. This section delves into these discriminatory practices and their impact on women's workforce participation, drawing on specific data to illustrate these challenges and identify potential solutions.

b. Wage gap: Women often face lower wages and limited job security compared to men. According to data from the Ministry of Labour and Employment, the highest monthly income sectors for women include Security, Management, and Power, with average monthly earnings of approximately INR 35,000, INR 40,000, and INR 45,000, respectively. Conversely, men's highest income sectors are Security, Iron and Steel, and Management, with average monthly earnings of INR 40,000, INR 50,000, and INR 45,000, respectively. Sectors like Textiles and Handlooms, Leather, and Electronics and Hardware exhibit significant gender pay gaps, with women earning 20-30% less than their male counterparts for similar roles and expertise.

c. Odd working schedules: Irregular working hours pose significant challenges for women, particularly those with caregiving responsibilities. Data from a survey conducted by the Ministry of Women and Child Development indicate that 35% of women in CNCR districts struggle with balancing work and family commitments due to non-traditional working hours, leading to higher dropout rates from the workforce.

d. Limited job opportunities: Structural barriers, including geographic isolation, underdeveloped infrastructure, and economic disparities limit job opportunities for women in CNCR districts. According to the Census (2011), areas like Jhajjar and Bahadurgarh have lower employment rates for women (20-25%) compared to more developed areas like Gurugram and Noida (40-45%).

e. Lack of maternity leave and childcare policies: Inadequate maternity leave and childcare policies further exacerbate the challenges women face. Data from the National Family Health Survey (NFHS-5) reveal that only 40% of women in CNCR districts have access to paid maternity leave, and just 30% have access to affordable childcare facilities, resulting in many women prematurely leaving the workforce.

f. Access to jobs: Women face additional hurdles in accessing employment due to geographic, educational, and discriminatory barriers. NFHS-5 data indicate that 60% of women in CNCR districts lack access to reliable transportation and 50% face educational barriers that limit their job prospects. Social norms restricting women's mobility further marginalize them, perpetuating economic inequality.

### *6.5 Lack of Amenities*

a. Basic amenities such as clean water, electricity, and public infrastructure are crucial for sustaining employment. According to the Census (2011), Noida has the highest percentage of households with access to clean water (87.42%), followed by Sonipat-Kundli (87.11%) and Gurugram (86.28%). However, Faridabad and Bahadurgarh lag with lower access rates of 73.56% and 82.23% respectively.

b. Lack of childcare facilities: The absence of affordable childcare facilities in CNCR districts forces women to choose between caregiving and employment. Data from NFHS-5 indicate that only 25% of women in CNCR districts have access to affordable childcare, significantly limiting their workforce participation.

c. Access to technology: Limited access to technology, such as computers, smartphones, and the internet, hinders women's ability to participate in the digital economy. NFHS-5 data indicate that 70% of women in Haryana have access to mobile phones, compared to 60% in Uttar Pradesh, highlighting regional disparities in access to technology.

d. Access to bank accounts: Access to formal financial services is crucial for women's economic empowerment. NFHS-5 data reveal that 80% of women in Uttar Pradesh have bank accounts compared to 70% in Haryana. Financial inclusion is vital for women's participation in the workforce and entrepreneurship.

e. Sanitation and health: Inadequate sanitation and healthcare services pose significant barriers to women's participation in workforce. According to the Census (2011), Sonipat has the highest number of healthcare facilities, including 3 district hospitals and 7 Community Health Centers (CHCs), while Jhajjar has the least, with only 3 CHCs and 5 Primary Health Centers (PHCs).

### *6.6 Violence Against Women*

Violence against women is a significant barrier to their workforce participation. Data on crime incidents from NCRPB indicate high rates of violence in cities like Gurugram and Faridabad, with rape cases recorded at 186 and 95, respectively. Addressing violence against women requires comprehensive measures to ensure their

safety and empowerment. Further, a correlation coefficient matrix is utilized to establish interrelationships and rank barriers.

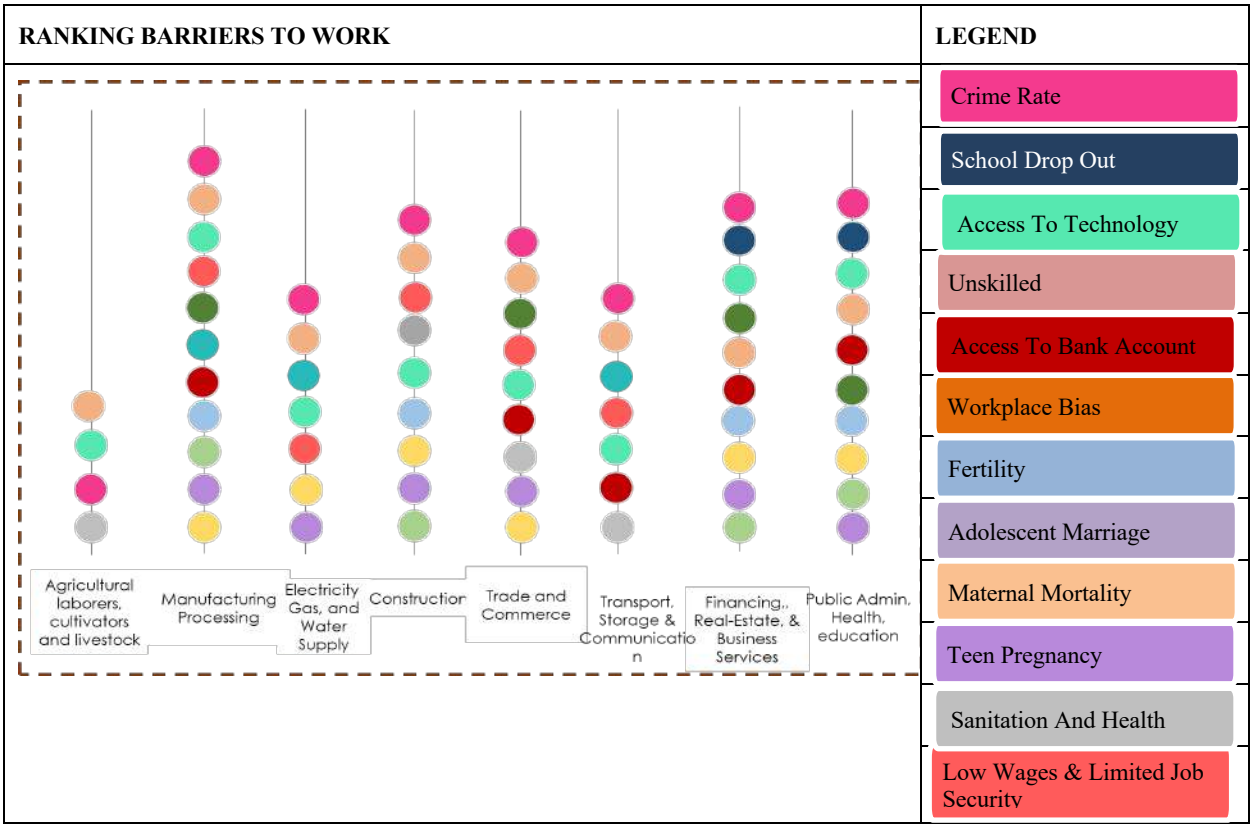


**Figure 7.** Ranking Sectoral Barriers to work

Source: Author's correlation coefficient analysis, NSS 61st Round, 68th Round and Periodic Labour Force Survey, 2017-18, National Family Health Survey (NFHS-5 & 4) NCRPB, Crime Record Data (2019-22), Census (2011), Ministry of Skill Development and Entrepreneurship

## 7. Interrelationship between barriers and employment

To identify the interrelationship between barriers to work and sectoral employment trends in CNCR a correlation coefficient analysis is conducted to rank the barriers according to their level of correlation with female employment in the sector. To identify the issues and challenges faced by women in accessing and participating in the labour market, the districts were further categorized.

The correlation analysis of sectoral employment trends and barriers in CNCR highlights distinct interrelationships. In agriculture, higher employment rates correlate with lower crime rates but also pose more socio-economic challenges for women.

Manufacturing benefits from higher education and skill development, showing strong negative correlations with crime and early marriages. The electricity, gas, and water supply sectors face barriers from crime and unskilled labour, but can benefit from educational improvements. Similar patterns are observed in the construction and transport sectors.

The trade, finance, and public sectors also underscore the importance of education and socio-economic stability for employment growth. Reducing crime and enhancing education are key to boosting sectoral employment in CNCR Based on the district-level analysis, several issues affecting female employment trends have been identified across CNCR districts.

In Scenario 1, exemplified by Noida and Gurugram, there is a noted decline in the Female Labour Force Participation Rate (FLFPR) alongside an increase in the Female Workforce Participation Rate (FWFPR). This shift is influenced by factors such as women concentrating in growing industries while leaving stagnant sectors, pursuing education aligned with job-growing fields, engaging in informal sector activities, experiencing underemployment, and facing challenges re-entering the workforce.

Scenario 2, represented by Sonipat and Jhajjar, exhibits an increase in FLFPR but a decline in FWFPR, primarily due to factors such

as population growth, economic downturns, skills-job mismatches, seasonal employment, technological changes, and agricultural shifts.

In Scenario 3, observed in districts such as Ghaziabad and Faridabad, both FLFPR and FWFPR decline due to low economic growth, unequal resource distribution, reliance on low-skilled work, and structural barriers that hinder women's employment. To address these issues, recommendations include policy reforms to reduce the obstacles, enhance education and training opportunities, and promote inclusive economic growth across CNCR districts thereby improving women's workforce participation and economic empowerment.

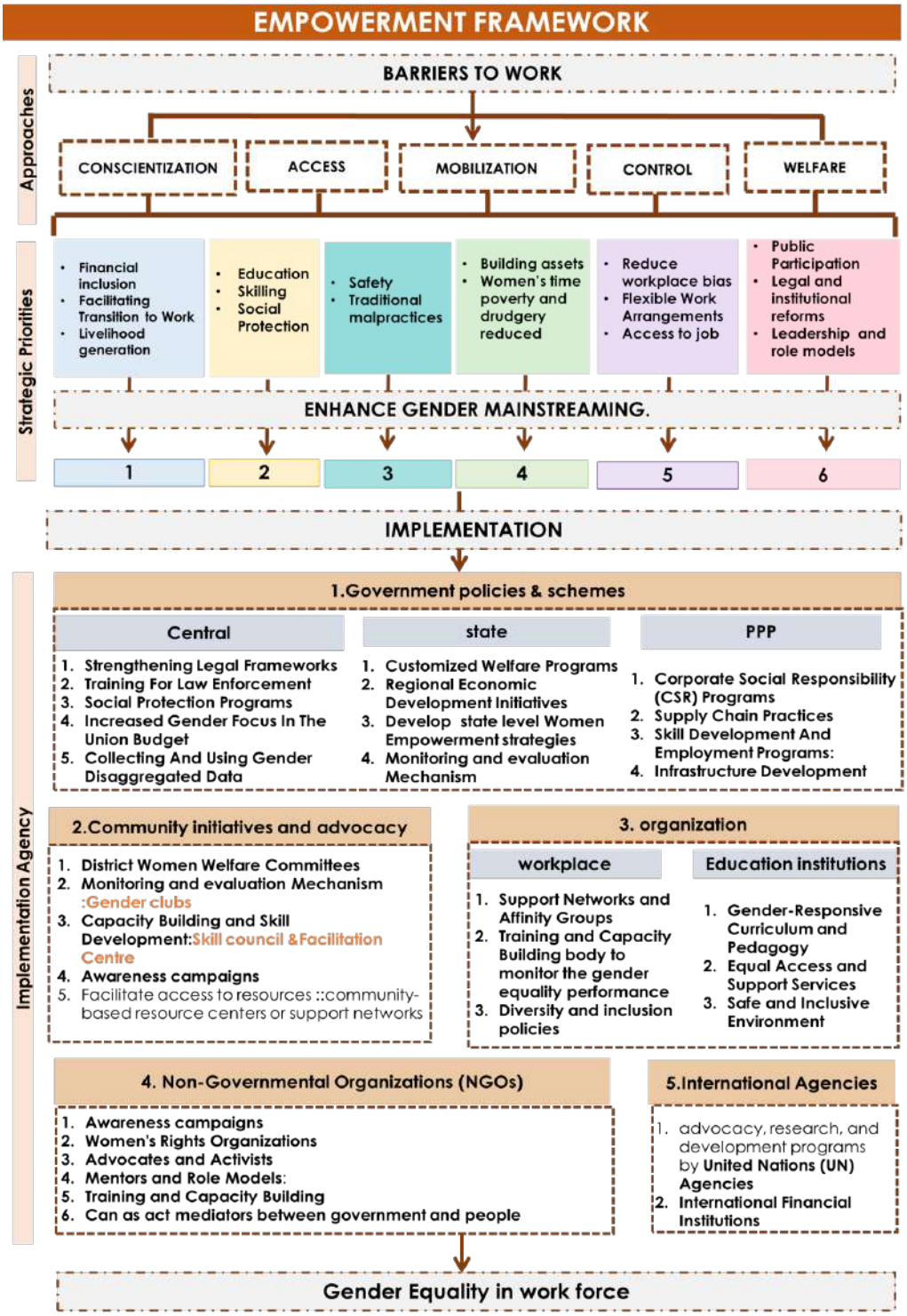


**Figure 8.** Woman Economic Empowerment Framework
*Source: Implementation Guide, Tamil Nadu women empowerment policy, ADB Operational Priority 2: Accelerating Progress in Gender* (Framed by the authors, 2024)

## 8. Recommendation

By examining these barriers and enablers within the context of CNCR districts. The following planning strategies and recommendations are formulated to reduce the obstacles to women's workforce participation in CNCR. Additionally, site-specific strategies and policy-level recommendations were formulated to eliminate the overall obstacles that prevent women from entering the workforce and to support them. The recommendations are based on the following six key strategic and operational priorities.

i) Women's Economic Empowerment

Women's economic empowerment is about enhancing women's ability to participate in and benefit from economic activities on an equal basis with men. This includes improving access to employment, financial resources, education, and entrepreneurship opportunities. Key strategies include:

- Financial inclusion and support for entrepreneurship: Providing financial incentives, assistance with business registration processes, and allocating loans or credit to women or women-owned businesses.
- Facilitating transition to work: Implementing supplier diversity and inclusion policies, offering career counseling for girls, and facilitating peer-to-peer learning.
- Livelihood generation: Linking existing livelihood projects with women's self-help groups, supporting women in non-traditional livelihoods, promoting community-based income-generating activities, and planning for street vending.

ii) Gender equality and development

Gender equality and development involve ensuring equal rights, opportunities, and treatment for all individuals, regardless of their genders. Strategies include:

- Education: Promoting gender parity in STEM education, providing financial incentives for women in gender-stereotyped categories, and supporting women researchers through IT and knowledge platforms.
- Skilling: Offering high-end skilling in emerging sectors, providing skill training for fresh graduates and women returning to work, and initiating apprenticeship programs.
- Social Protection: Exploring innovative training and outreach programs for women, building industry-academia partnerships, and offering online classes and digital messaging for pregnant women.

iii) Access to Amenities

Ensuring women have access to essential amenities is crucial for achieving gender equality and promoting overall well-being. Strategies include:

- Community-Based Resource Centers: Establishing centers with health services, toilets, and support networks.
- Internet and Technology Access: Implementing initiatives to improve women's access to and proficiency in using the internet and technology.
- Infrastructure Investments: Investing in childcare and eldercare infrastructure to reduce unpaid work burdens.
- Family-Friendly Policies: Adopting policies that promote equitable distribution of caregiving duties within families.

iv) Decision-making and leadership

Promoting women's roles in decision-making and leadership involves:

- Public Participation and Representation: Building inclusive leadership capabilities and implementing quota systems.
- Legal and Institutional Reforms: Developing leadership programs and training at local and national levels.
- Leadership and Role Models: Increasing the number of women in management and technical roles and encouraging women in leadership positions like help-mates under MNREGA.

v) Reducing Workplace Bias

Reducing workplace bias and gender disparity is crucial for empowering women in the workforce. Strategies include:

- Monitoring Mechanisms: Implementing joint monitoring to ensure compliance with laws protecting women at work.
  Flexible Work Arrangements: Offering incentives, leaves, succession planning programs, and flexible working options.
- Access to Jobs: Providing transit hostels, safe commuting, last-mile connectivity, and supporting small-scale women farmers.

vi) Reducing Violence Against Women

Reducing gender-based violence is essential for women's full participation in socioeconomic activities. Strategies include:

- Safety: Planning for psychological safety in public spaces, supporting women in distress, integrating support mechanisms, raising alcohol and drug awareness in education, and protecting victims/witnesses.

- Cultural Practices: Offering incentives to promote child marriage-free communities and creating community platforms for advocacy and engagement.

Five key strategic and operational priorities have been identified through engagement with multiple stakeholders: the empowerment of local communities, the implementation of bottom-up decision-making, the integration of alternative sustainable livelihood practices, the promotion of participatory management, the provision of legal support, and the fostering collaboration among international and national agencies, NGOs and private companies.

Establishing clear metrics for success is crucial to effectively implementing the aforementioned strategies aimed at improving women's labour market participation. These metrics offer a structured approach to evaluating progress, identifying gaps, and adjusting interventions as needed. For economic empowerment, key metrics include a 10% annual increase in women's access to financial services and a 15% rise in the number of registered women-owned businesses. Similarly, for education and skill development, a 20% increase in female enrolment in STEM fields within five years and an 80% completion rate of vocational training programs are essential indicators of progress.

In terms of access to amenities, success can be measured by a 30% annual growth in the use of community resource centers and the establishment of at least one childcare facility per district, with 70% utilization by working mothers. For leadership and decision-making, achieving 40% women's representation in senior management roles within 10 years and ensuring that 60% of participants in leadership programs move into decision-making roles are key metrics.

In reducing workplace bias, success is gauged by a 50% decrease in gender discrimination cases over five years, and 75% of companies adopt flexible work policies. Finally, reducing violence against women includes a 30% reduction in reported cases and a 50% increase in women's satisfaction with safety in public spaces. These metrics serve as benchmarks for measuring progress and success.

## 9. Conclusion

In conclusion, women's participation in the labour force is crucial for sustainable development and economic growth. However, the challenges faced by women in the CNCR region, including lack of access to decent work, workplace discrimination, and socio-cultural barriers, hinder their ability to participate in the labour force.

The impact of the economy on women's participation in the labour market necessitates a comprehensive and concerted effort to overcome barriers and foster gender equality. Addressing these challenges requires a multifaceted sector approach as well as the involvement of multiple stakeholders including the government, private sector, and civil society. By investing in infrastructure and amenities, providing education and skill development opportunities, and promoting inclusive growth, one can create an enabling environment that supports women's participation in the labour force and promotes inclusive and sustainable development.

The recommendations outlined across five strategic operational priorities offer a roadmap toward creating an inclusive environment where women can access economic opportunities and contribute meaningfully to societal progress. By empowering women economically, promoting gender equality in education and skill development, ensuring access to essential amenities, enhancing women's representation in decision-making and leadership roles, and reducing workplace bias and gender-based violence, societies can unlock the full potential of their female workforce. However, the successful implementation of these recommendations requires collaboration among diverse stakeholders, including governments, nongovernment organizations (NGOs), private companies, communities, and international agencies. Together, by prioritizing women's empowerment and fostering inclusive policies and practices, India can build a more equitable and prosperous future for all.

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# Colonial land control and urban planning:
## Delhi between 1900 and 1940

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**Abstract:** Planned at the same time as the Imperial Capital of 'New' Delhi, the extensions of 'old' Delhi were also started in response to overcrowding and the expansion of the city of Delhi during the early 1900s. However, the 'planning' of the old city area tells a story quite contrary to the making of the grand Imperial Delhi, which reveals a focus on land acquisition and control through planning techniques and institutions. The need for land for the new capital city of the Empire coincided with a growing escalation of land value in urban areas. Between the land acquisition requirements for the new capital and the framework created for the Delhi Improvement Trust, instituted specifically to expand the existing city, this paper examines how colonial policies and institutional frameworks brought urban land under the British Indian government's direct control. Decoding two colonial official documents, the paper uses archival research to show how land acquisition became central to British colonial urban planning ideology and how Improvement Trust schemes and policies facilitated land control. Urban planning and land control became inextricably linked with the pursuit of profits for the colonial government, and at the same time, resulted in the spatial production of colonial 'difference' and inequality in urban spaces.
**Keywords**: Urban History, Delhi, Colonial Ideology, Improvement, Colonial Planning, Western Extension Area

**सार:** 'नई' दिल्ली की शाही राजधानी के साथ ही नियोजित, 'पुरानी' दिल्ली का विस्तार भी 1900 के दशक की शुरुआत में दिल्ली शहर की भीड़भाड़ और विस्तार के जवाब में शुरू किया गया था। हालाँकि पुराने शहर के क्षेत्र की 'योजना' भव्य शाही दिल्ली के निर्माण के बिल्कुल विपरीत कहानी कहती है जो नियोजन तकनीकों और संस्थानों के माध्यम से भूमि अधिग्रहण और नियंत्रण पर ध्यान केंद्रित करती है। ब्रिटिश साम्राज्य के नए राजधानी शहर के लिए भूमि की आवश्यकता, शहरी क्षेत्रों में भूमि के मूल्य में वृद्धि के साथ मेल खाती थी। नई राजधानी के लिए भूमि अधिग्रहण आवश्यकताओं और मौजूदा शहर के विस्तार के लिए विशेष रूप से स्थापित दिल्ली सुधार ट्रस्ट के लिए बनाए गए ढांचे के बीच, अंग्रेजों ने ऐसी नीतियाँ बनाईं और संस्थागत उपकरण बनाए जो शहरी भूमि को उनके सीधे नियंत्रण में लाए। दो औपनिवेशिक आधिकारिक दस्तावेजों को डिकोड करते हुए, यह पत्र अभिलेखीय शोध का उपयोग करके यह दिखाता है कि कैसे भूमि अधिग्रहण ब्रिटिश औपनिवेशिक शहरी नियोजन विचारधारा का केंद्र बन गया और कैसे सुधार ट्रस्ट की योजनाओं और नीतियों ने भूमि नियंत्रण को सुविधाजनक बनाया। शहरी नियोजन और भूमि पर नियंत्रण औपनिवेशिक सरकार के लिए लाभ कमाने में अभिन्न रूप से जुड़ गए और साथ ही शहरी क्षेत्र में औपनिवेशिक 'अंतर' और असमानता का स्थानिक उत्पादन हुआ।

**मुख्य शब्द:** शहरी इतिहास, दिल्ली, औपनिवेशिक विचारधारा, सुधार, औपनिवेशिक योजना, पश्चिमी विस्तार का क्षेत्र

## 1. Introduction

The period following the relocation of the British Imperial capital from Calcutta to Delhi between 1911-1931 was marked by intense building activity and rapid urban growth. This was driven by Delhi's new political significance and, a few decades earlier, its strategic location as a railway junction. While much has been written about the creation of the imperial capital at Delhi, its design based on 'modern' planning principles and garden city ideas, its wide avenues, and grand imperial scale, what is often overlooked is the urban growth and planning offered to the native city during the same time period. When the British annexed Delhi in 1803, they took over the seat of the Mughal Empire, with its last capital city—Shahjahanabad—a walled medieval city built by Shah Jahan in 1648. This continued to be the city of Delhi through the 19th century, with some settlements growing around the walls—particularly the Civil Lines in the north of the city and the suburbs with a native population towards the west. The south was primarily agricultural land with several ruined remains of past towns, forts, and structures dating back at least a millennium, and the River Yamuna flows along its eastern edge. The British eventually built the new capital in the south of Shahjahanbad, calling it 'New Delhi', which was inaugurated in 1931. After this, Shahjahanbad was referred to as 'Old Delhi'.

The influx of migrants to build and work in this new city led to its population almost doubling in the first four decades of the century—from 1,80,000 in 1890 to 350,000 in 1931. Preceded by the city becoming an important commercial centre with a network of railway lines—positioned Delhi strategically—connecting to the important port cities of Calcutta and Bombay, as well as regions inland like the North Western Province, Punjab, and Rajputana. However, over

the years of colonial rule, the city's growth was not supported by any urban planning or provision for planned areas for housing for its growing native population. Unlike the systematic and elaborate planning of the new capital city, which was primarily meant for Europeans, the native parts of the city experienced urban growth, resulting in ad hoc, unplanned expansion of the city onto its western peripheries. The civil lines, mainly occupied by Europeans, on the other hand, developed into a suburban area with large bungalows on sprawling lots of land, serviced by roads, gardens, water, and electricity.

First, along the railway lines that spread across the western suburbs, the city developed its commercial areas, particularly around the existing settlements of Sadar Bazaar, Sabzi Mandi, and Paharganj. Later, with the removal of several villages to make the new capital, its displaced people and migrant labour for building the new city also gravitated to these three existing settlements. While a new extension was proposed in Karol Bagh for the growing native population and was meant to be part of the overall planning of the new city, it was an incomplete project for the first 25 years, with only marginal efforts in planning and no provision of urban services, attributed to a fund shortage (Mehta and Dasgupta 2024)

Against this backdrop, this paper raises the following questions. How was the grand building of New Delhi, with lavish grand avenues, leisure gardens, and sprawling bungalows, justified for Europeans, while stringency and negligence were doled out towards the native city? Was there a connection between government ownership of land and policies of urban planning in this period? This paper aims to examine the relationship between land control and urban planning, and how these two concepts emerged in Delhi during the early twentieth century. It critically examines how, through the outright annexation of land, its re-categorization in land titles and tenures, and the enactment of land acquisition laws favorable to colonizers, land control becomes a central focus of colonial governance and urban planning, and how its impact affects the social geography of the city.

## 2. Methodology

This paper uses historical archival research as its primary source of data, critically examining two specific official documents to understand the British colonial authority, narrative, and policies on land control around Delhi. These two documents are, ‘The Report on the Administration of the Crown Lands of Delhi (1909) by an Indian Civil Services officer specialised in ‘Settlements’, R. B. Whitehead, and the ‘Report on the Acquisition of Land for the Imperial Capital in Delhi’ (1912) by Major H. C. Beadon, appointed as a special officer for land acquisition for Imperial Delhi. These two documents were written in the time period selected for study, from 1900 to 1940. While the documents are written in the early part of this time period, the 1930s and 1940s are included, as it was during this period that significant urban development work was undertaken for the native areas. During this time period, I utilize several other documents related to the establishment of the Delhi Improvement Trust, with a focus on land-related aspects of urban expansion and development.

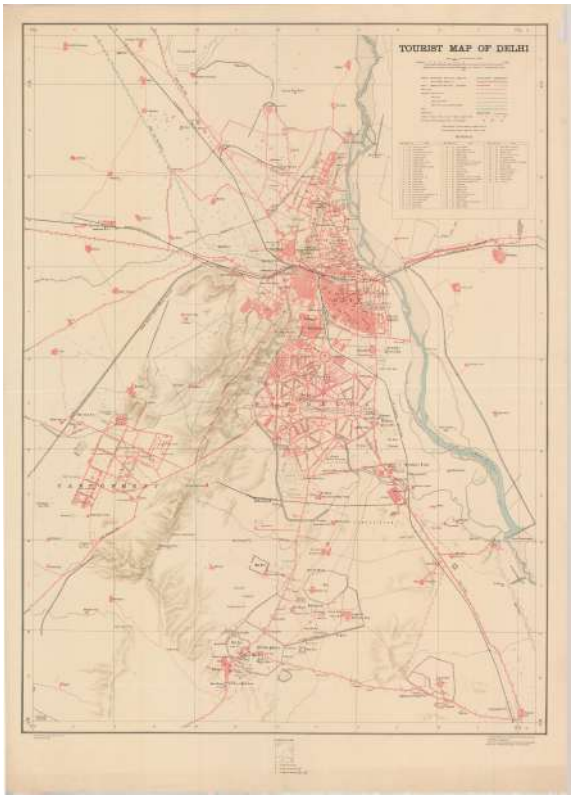


**Figure 2.** Tourist map of Delhi from 1927, showing the extent of the city's expansion and the density differences between the existing walled city of Shahjahanabad and New Delhi. Source: Maps Section, University of Chicago Archives.

## 3. Re-categorizing and Claiming Land

‘The Report on the Administration of the Crown Lands of Delhi’, published in 1909, marks a crucial transition in the assertion of colonial authoritative knowledge. This report laid the groundwork that later became part of the institutional instruments of planning and urban governance in Delhi’s suburban land. Unlike previous assertions on land revenue and raw

material production in agricultural lands, the British government's colonial policies in urban areas began to focus on claiming and controlling urban, and particularly suburban, land. The lands on the outskirts of urban centres had been growing significantly in value as urban work and finance gained importance.

Since the annexation of Delhi in 1803, and after the British were victorious in quashing the Mutiny of 1857 (also referred to as the Revolt of 1857 or the First War of Independence, 'Mutiny' used here for consistency with the word used in the colonial archives) by a 'general proclamation' large areas of land that had been considered the property of the last Mughal King of Delhi, were annexed as 'Crown' lands. These Crown lands had, however, been ignored when they were a burden to manage in the years between 1857 and 1908, until this report was commissioned, when land values had shown an exponential increase. This report was the first to consolidate Crown lands, *nazul* (royal land), and *taiul* (private property of kings) lands, all under the title of *nazul* lands, to re-categorise and consolidate land owned by the British government. Although the government annexed a significant amount of land in both urban and rural areas, this report focuses specifically on the peripheral land within a 6-mile radius around Delhi. Before staking claim on these lands, the report first summarises the histories, internal conflicts, and legal discrepancies to encompass its authoritative assertions on this land.

Even though the claim on the land by the British administration after the Mutiny was sweeping, it was mired by inconsistencies in the ground reality of land ownership. The King did not own all the land that the British government presumed he did, which they declared would be taken over by the Crown. Nonetheless, it was an authoritative colonial order established after the Mutiny, with a vengeance, also serving as a lesson for the mutineers, including the King (who was exiled and his son executed). The report states that, "It has been *generally assumed* [*emphasis mine]* that the lands of Jahan Numa and Khandrat Kalan were amongst those assigned to the King of Delhi in 1803 and after the Mutiny they were *summarily confiscated [emphasis mine]* as being *taiul*, but that this is by no means certain will appear later on…The Crown property of the King of Delhi was confiscated by a *general proclamation* [*emphasis mine*], and it was not ascertained what the property actually was…

Meanwhile came the settlement of 1864, the papers of which show the government to be the owner of the entire areas of Jahan Numa and Khandrat Kalan." (Whitehead 1909, 16). Jahan Numah and Khandrat Kalan, although not specific villages, were the largest *mauzas* (village areas) surrounding the then-city of Delhi, which was being transferred from the King to the Crown as escheat.

In 1909, this Report was commissioned for organising the misplaced and incomplete land records of all 'Crown' land that had been taken over as escheat since 1857. Of the 810 villages in the district (Gazetteer, 1883-4), 198 had been annexed on this count (Table 1).

**Table 1**. Villages escheated by the British government after the Mutiny; source: Whitehead, 1909, p.182

| | | Description |
|---|---|---|
| Sonepat (3) | 3 | Misc. Jagirdars |
| Delhi (61) | 11 | King of Delhi |
| | 5 | King of Oudh |
| | 7 | Nawab of Jhajjar |
| | 13 | Mirza Mughal Beg |
| | 3 | Raja Jai Sukh Ram |
| | 8 | Rao Paligri |
| | 4 | Nawab Bahadur Jang Khan |
| | 10 | Misc. Jagirdars |
| Ballabhgarh | 8 | King of Delhi |
| | 126 | Raja of Ballabhgarh |
| **Total villages** | **198** | |

The report highlights the inconsistencies and problems that arose between 1857 and 1909, the years in which it was compiled. It states that "the State has become proprietor of many villages and plots of land close to Delhi and the Ballabhgarh Tahsil, which are known as Crown lands, difficulties of administration have arisen, so government has already sold a good[ly] portion of this property retaining only areas which, being within six miles of Delhi, may be required for public [emphasis mine] purpose or for which sale may not be immediately possible or advisable" (Whitehead 1909, 179).

Post-Mutiny, the British confiscated land in 34 villages from the Raja of Ballabhgarh and imposed a 10% surcharge on the revenue with the Zamindar. However, after 15 years, when Mohammad Ali Shah of Sardhana petitioned to buy rights over these villages in 1872, it was revealed by an inquiry case that the British Government, in fact, did not have rights to all the land in these 34 villages. Government rights were only on land owned directly by the Ballabhgarh Raja. Cases in which land had been in continuous occupation for over 12 years before would have gained the right to occupancy and could not be annexed. Eventually, only eight of the 34 villages

belonged to the Government, and in the remaining villages, they had merely shared rights with the Zamindars. In another case, the village lands of Chandrawal, in the north of the walled city of Delhi, were confiscated from the rebellious Gujjars after the Mutiny. However, these government lands had been sold or auctioned over time, resulting in the area becoming the Civil Lines during this period. Since the owners had been paying one rupee monthly as rent to the nazul fund, they were 'inferior owners' even if not full proprietors, with rights to lease in perpetuity.

Narrowing its focus to the immediate suburbs of the city of Delhi, the Report continues to detail the exact villages within the Municipal limits of Delhi. "The lands of 14 villages were included in the Delhi Municipality… The Municipal area has now been made a separate estate for revenue purposes. The riverine ones: Firozabad Khadar, Jatwara Kalan, Chandrawal, Andhaoli, Khaitwara, Salimpur, Ghondli, Mubarikpur Reti; then there was Firozabad Bangar, Khandrat Kalan, Banskauli, Jahan Numa, Raipur Chhaoni, and Sadhaura Kalan" (Whitehead 1909, 7).

Of these 14 villages, two are of importance but also rife with conflicts and land contestation—Khandrat Kalan and Jahan Numa — and were hence dealt with in the greatest detail in Whitehead's Report (1909). These two also constituted the largest area occupied around the city, and post-Mutiny, had been annexed with the sweeping assumption that the King owned them. This was not entirely true, and the Report reveals the various discrepancies. The first discrepancy was due to grants (*maufi*) of land made by both the Mughals and post-Mutiny British, as well as by the British as rewards to loyalists during the Mutiny. The Report shows how "the greater part of the land outside the abadi in *mauzas* Khandrat and Jahan Numa was held in *muafi* tenures. Of the 152 arable, pasture, and garden land recorded by an Assistant Commissioner's attempts at recording land tenures in these two villages (*mauza*), 142 related to *muafi* tenure."

The government had recorded itself as the owner of land in 137 of the 143 land holdings in Jahan Numa in the 1880 Settlement record. As seen in Table 2, Whitehead's assessment, however, revealed that only 21 were found to be clearly owned by the government, and four were disputable; the rest were incontestably owned as grants held by '*muafidars'* under various tenure heads. Whitehead's recommendation, in consultation with the Settlement Officer, was to rectify this and record them as owners.

**Table 2.** Validity of the Lands claimed by the government in the Crown Land Report. Source: compiled by the Author from (Whitehead 1909, 22-23)

| **No. of *Khatas*** | **Tenure (*khata*)** | **Government as owner** | |
|---|---|---|---|
| | | recorded in 1880 | in the 1909 Report |
| **28** | *Makbuza* (ancestral) | Yes | NO |
| **16** | *sardarakhti muafi* | Yes | NO |
| **4** | Non-occupancy | Yes | Dispute |
| **19** | *Nazul* land | Yes | Yes |
| **2** | *Abadi* | NO | NO |
| **1** | Railway land | Yes | Yes |
| **1** | Canal land | Yes | Yes |
| **8** | *Nisf-ret* | Yes | NO |
| **60** | Perpetual *muafi* | Yes | NO |
| **4** | Propriety | NO | NO |
| **143** | TOTAL | | |

The inconsistency revealed in land records and claims continued. The report goes on to state, "…Khandrat Kalan was also entered as State Property, encumbered only by *muafi* grants. Its area extends south of the city". Khandrat[1] Kalan was constantly referred to as a site of the ruins of the past, imagined as a dry landscape of only ruins. However, the descriptions found in the Delhi Town Planning Committee's (DTPC 1913, 3) final report also show that this was a fertile site with good soil and drainage for building the new city. Revenue data in the Gazetteers also reveal that this area of Khandrat Kalan generated one of the highest revenue rates from agriculture.

The Report also reveals other historical land ownership contradictions in this area that, over time, were obscured by the authoritative claim that the British Imperial government asserted regarding ownership of these lands. Some of the contradictions that arose over time were officially instigated decisions that were nonetheless overlooked. Two of these are particularly curious. A brief overview of the intervention that dates back to 1830, when an area in the west of the city was colonised by Charles Trevelyan[2] , who was

[1] The root word of Khandrat is *khandar* which means ruins.

[2] C E Trevelyan, later became the Governor of Madras. An Evangelist and reformer, he also wrote on several issues. Quoting his words from David Scott, *Colonial Governmentality* , 2005, p. 64: "The only means at our disposal for preventing [revolution] and securing [reform]," he said, "is to

then the Secretary to the Resident in Delhi. The Report states, "The lands of Jahan Numa, as well as those of Khandrat Kalan, from the year 1803 till Trevelyan's attempt at colonisation in 1831, were nothing but rocky waste covered with the ruins of ancient Delhi. Trevelyan received the permission of the government to dispose of 200 bighas at Rs 30 per bigha." The report justifies this project initiated by an officer lauding his effort, saying that he "greatly interested himself in colonising the State wastelands outside the city for beautifying and improving the suburbs." Incidentally, it was discovered a decade later that the officer had sold 570 bighas instead of the 200 bighas he was authorised to sell. Two hundred bighas were sold to Diwan Kishen Lal and came to be known as Kisenganj, while the remaining bighas were sold to others. Primarily considered a failure except for two additions—a bridge and a road (the Sadar Bazaar Road), the grant holders of what came to be known (even today) as Trevelyanganj became owners and *muafidars* in perpetuity; however, the exact records of this were destroyed in the Mutiny. (Whitehead 1909 15)

The second case occurred a couple of decades later, with another Trevelyan—Major Trevelyan, who came to Delhi as a Cantonment Magistrate with his troops and was stationed at the old Idgah in Jahan Numa, to oversee the surveillance of the western suburbs post-Mutiny in 1858. He invited shopkeepers to set up in the vicinity, to provide supplies for his troops, and also resettle some merchants displaced by the government's demolitions to create a glacis around the Fort area in the city. The land chosen was government-owned wastelands east of Pahari Dhiraj. While it is unclear how the government came to own this land, (it could have been taken over under Pastureland Act or the Wastelands Claims Act' that claimed common lands that were pasturelands as 'wastelands'[3]), 7896.75 sq. m. (85,000 sq. ft.) of shops and plots were sold to 67 individuals, which kick-started what is one of the busiest wholesale markets in Delhi even today. While Major Trevelyan predicted that the colony would remain here forever, he made a clause that no compensation would be paid if it had to be removed, and that the sale of the shop to anyone else would not be permitted. Fifty years later, Whitehead's Report on the Administration of the Crown Lands in 1909 refers to these people who had been officially allotted land and had paid rents for 50 years supporting the British Troops, referred to as 'Major Trevelyan's squatters', taking away their right on land with the title of a 'squatter'. At the same time, this 'colony' laid the seeds for the largest commercial area outside the city that flourished with its proximity to the railway lines, stations, and yards that came up in this larger area after the military moved from this location.

The area known as Qarol Bagh came under government ownership. In 1874, with an outbreak of cholera in the city, the rangers of Pahari Dhiraj were relocated to this suburb, which at the time was considered quite far from the city center. It was found desirable to remove the work of skin-dressing and dyeing to a less populated area in Banskauli. The Government land is now nazul. The State land in Banskauli is that occupied by the PWD and the Canal departments, and a large area of grazing and cultivable land is still under direct management. Between the 1870s and the 1890s, the Land Acquisition Act was used to acquire large parcels of land for various Railway lines, including the Rajputana-Malwa line, the Central India Railway, and the Delhi-Umballa-Kalka Railway. Rs 28,955 compensation was paid to owners who had full property rights. (Whitehead 1909, 23) This also confirmed the irregularity of the sweeping claim by the government of owning the land around Delhi.

Finally, Clarkgunj was proposed as a city extension project by Robert Clark, Deputy Commissioner of Delhi. This development was started but never completed[4]. Some plots in this area were sold to individuals and for shops, but the larger chunk of land was instead sold to the Delhi-Agra Chord line to connect Delhi to Mathura (Whitehead 1909, 31).

Land grants, official transformations, sales, and transfers of land during the 50 years following the Mutiny in the lands around the city are hence very evident in the histories related in the report. Even though some officers between 1858 and 1908 reported on the complex ownerships of land that the government had claimed, no action was taken, either due to a lack of personnel or funds, as these suburban lands held significantly less importance. It had been

set the natives on a process of European improvement, to which they are already sufficiently inclined. They will then cease to desire and aim at independence on the old Indian footing.''—gives an insight to his work in Delhi to 'improve' land.

[3] See work of Minoti Chakrobarti-Kaul on Commons and V K Gidwani, 1992 on wastelands

[4] For more details on Clarkgunj, see 'Indigenous Modernities' by Jyoti Hosagrahar, 2005

recognised that the titles of land were missing, inadequate, and inaccurate, leading to several lapses and incorrect claims over the 100 years of British control. This neglect also led to petty encroachments by the people on rightful claims, making property titles and land ownership a very messy affair.

However, after 25 years, when the Settlement Report for the Delhi District of Punjab Province was published in 1882, all 10,502 Bighas of land, except for 50 Bighas, were still recorded as government-owned (Maconachie 1882). The 1909 report by Whitehead found that, of this, only 6,372 belonged to the government. (Whitehead 1909, 28). Furthermore, it also concluded that the proprietary right of the occupiers in Khandrat Kalan and Jahan Numa needed to be recognized. Eventually, even though the Report recorded detailed histories of the government's lapses and its erroneous authoritative claim on land in Delhi, it finally lays the onus. It demeans the native people as 'squatters', stating that, "A large amount of landed property in this neighbourhood was sold by the Deputy Commissioner after the Mutiny, but many purchasers had subsequently added enormously to their holdings by encroachment. The occupants of Khandrat were mostly squatters and had no good title to land." (Whitehead 1909 17). It notes that 30% of the land was never owned by the King (190 acres in Jahan Numa, 50 in Chandrawal, 226 in Khandrat Kalan, 55 in Andhaoli, and 433 in Kaithwara) (Whitehead 1909, p. 2) and had already been annexed earlier. While there is no clear evidence of how these were taken over by the government, as Nazul.

Nonetheless, despite these discrepancies in the government's administration of lands for over a hundred years, the Report continues to assert its authority, and in conclusion, lays the blame for mismanagement back on the Municipality, which was a semi-local representative body with control of nazul lands since 1874. It overlooked that, without adequate funds and an inadequate staff, and despite some attempts at inquiries that were not supported from above, the scapegoating of the Municipality was incorrect; more importantly, it served as a smokescreen to justify the transfer of control and ownership of suburban land directly to the government.

Not surprising then that, just a few years before commissioning this report, the land values had been recorded in 1902 with suburban lands escalating by 700% in Sadar Bazaar, 400% in Paharganj and 300% in Sabzi Mandi (Whitehead 1909, 32), exposing the profitability of suburban land that was the hidden agenda of the government's claim and eventual control of nazul lands. At the same time, the 1912 Gazetteer despite this detailed study of 'Crown' land continued to assert that "there are considerable areas of agricultural and urban land of which the State is full owner…such areas have become Crown property almost entirely through escheat, and that after the Mutiny… the nazul lands which now remain are: Outside the six mile radius 4,395 acres, inside the six mile radius 10,078 acres." (Gazetteer 1912, 189).

With the government's authoritative claim to ownership of this increasingly profitable suburban land in Delhi, this report from 1909 is followed in a few years by the announcement of the shift of the imperial capital of British India from Calcutta to Delhi. Taken as an opportunity to showcase their imperial superiority, as well as Western science and technology, art, and culture, New Delhi became a grand exercise in establishing British Imperial power and permanence in comparison to the previous Mughal city, now Old Delhi. However, most research on the creation of New Delhi focuses on aesthetics, architecture, town planning, and historical studies of design discussions and decisions. These have largely overlooked how land was acquired for the construction of this capital city and extended beyond what was required for the city itself. The following section examines the role of land acquisition and control in colonial urban planning and development, highlighting their connection to profit-making.

## 4. Land Acquisition for the making of New Delhi

Major H.C. Beadon was brought in as a special land acquisition officer for the new capital project. During his earlier tenure as Deputy Commissioner, he proposed city extensions, improvements, and outlined the need for town planning in Delhi. Beadon's 1912, 'Report on the Acquisition of Land for the Imperial Capital in Delhi', details the areas in Delhi that were recommended for acquisition for the new capital city and the larger Delhi area. Based on the Land Acquisition Act of 1894, this report advanced ideas for acquiring land for the new city. Like other ventures of this Act, which were created to gain control over resources in the colonies, particularly land, to facilitate colonial infrastructural projects such as railways (Shankar, 2018) and canals (Whitcombe, 1983), without encumbrance. Its legal frameworks justified eminent domain, claiming lands that

were previously commons or private land and appropriating them for 'public' use. This Report reveals how the planning of New Delhi used this Act with a focus on urban expansion.

The Act was enforced in Delhi with amendments for acquiring land for the development of New Delhi and the expansion of Old Delhi. The amendment permitted compensation to be fixed for land rates in its existing use, which would be much cheaper, as much of the surrounding land was agricultural or 'waste' land. This would later give the government high returns when sold as city land. This report enabled the government to determine the value of the land in detail, based on various indicators such as proximity to the city, land use, and market value in the area. Based on the final use of the land as part of the city, the Report also estimated the returns possible from the land, and an overall financial outlook of profit to be made from this land acquisition is finally presented in the document.

As President of the New Delhi Municipal Committee, Beadon had noted in 1912, "The people of Delhi have been huddled into a totally insufficient area so that the streets have been encroached upon (and) slums have been built."[5] Hence, his recommended expansion and land acquisition plan would justify the city's vision for future growth. His report proposed 17477.2 hectares (43187 acres) of land for acquisition around Delhi (Figure 1). Even with a grand plan for the new city, it needed only a fifth of this at 3106.4 hectares (7676 acres). Planned on the southern side of the existing city for a small population of only 35,000, it was more than twice the area of the existing city that carried a population of 3,50,000 in an area of 1543.5 hectares (3814 acres) (Census of India, 1931)

The Map created to envision the land acquisition exercise shows two separate tracts. (Figure 1). The pink colour was for the "Imperial Tract", and the green for the "Delhi City Expansion Tract". The imperial area was almost five times greater 17477.2 hectares (43187 acres) than the Delhi City Expansion Tract 3792.3 hectares (9371 acres) for the existing city (Beadon 1912). Further, the map also highlights a large grey area, which is recommended for purchase or 'firm control'. The area to be acquired included 19 villages (Singh and Islamuddin 2017). This land was divided into five blocks based on the final use to which they would be put, with a broad idea of the circle of land (value) from which they were being acquired.

The financial outlook and justification for all projects undertaken by the colonial government were key factors in approving any project that would involve financial outlays. This report was created to project an estimate of the expenditure involved and to predict the probable returns on it from the proposed land acquisition exercise. Categorisation of land as private or government, included its agricultural productivity—irrigated and unirrigated, and waste—used in estimating the cost of land (derived from 20-year market value of current rents), it also weighed the loss of revenue from the land that the government would have incurred earlier. Irrigated land was priced at double that of un-irrigated land, and soil type was also considered, as it was crucial in assessing revenues. All non-agricultural land was categorised as 'waste' land—culturable and unculturable—valued at Rs 50 and Rs 37.5 per hectare (Rs 20 and Rs 15 per acre), respectively, and that near the city was valued at Rs. 100 per hectare (Rs 40 per acre). Compensation was also provided for building materials in settlements where the land was categorised as 'waste'. Although this detailed analysis and categorization with a weighted price index seems fair, it is essential to note that at the time, land values had increased by up to 700% in some areas close to the city, as stated earlier.

Next, the report creates a framework for the final use of land to estimate its potential return on investment. For this, the proposed acquired land is divided into four classifications of final use:

"Class I, was the financially unproductive land (for cantonment and official buildings, which would not give any returns); Class II, the ones producing low rent (official bungalows with annual rent of Rs 24 per bungalow in 1.62 hectares (4 acres) of land); Class III, those producing high rents (private bungalows for a premium of Rs 1250 per hectare (Rs 500 per acre) and annual ground rent of Rs 100 per hectare (Rs 25 per acre) and finally; Class IV, those producing very high rents (bazaars)" (Beadon 1912).

As shown in Table 3, the extensive acquisition of 17477.2 hectares (43,187 acres) of land cost a large sum of almost 5 million rupees. Given the constant stringency on funds and outlays for the city improvement, development, and extension

[5] Quoted in Slums of old Delhi, Bharat Sevak Samaj, 1958, p215

works, this was a very large area of land. The stated objective of colonial benevolence towards the colonised people and the need for the city to expand had been ignored for at least 50 years or more, and no housing or urban amenities were provided despite repeated demands from both officers in post and native people. (Mehta &and Dasgupta 2024). However, this massive acquisition project was undertaken for a purpose larger than space for the city. This becomes evident when the report reveals that the thumb rule for justifying the viability of this large acquisition project was that 2.5 times the land revenue must be made in sale/rents from the two largest Blocks - B and D. And given the current rise in market price of land Beadon was well aware that despite no returns from Cantonment which would not pay any rents or costs and was 22% of the entire land, and very low returns from much of the imperial Tract which would be 'public' offices also paying minimal rents.

**Table 3.** Distribution of land type to be acquired in the 5 Blocks demarcated around the city.

| Block/ use | Total (acres) | Cost of acquisition |
|---|---|---|
| A: Cantonment | 9,405 (22%) | 10,37,310 |
| B: Imperial tract (excluding Paharganj) | 13,338 (31%) | 14,86,845 |
| C: City Expansion | 2,542 (6%) | 1,03,325 |
| D: City Expansion | 13,184 (30%) | 1194625 |
| E: City Expansion | 4,628 (11%) | 762420 |
| **TOTAL** | **43,187** | **45,84,525** |

Source: Author, derived from Beadon's Report on the Acquisition of Land for the Imperial Capital in Delhi, 1912

Of the 43,187 acres of land to be acquired, it must be noted that the imperial tract—Block B — is shown as 13,338 acres, of which only 7,676 acres (57%) were needed for the new city planned. However, almost no land was to be allocated to poor people, who formed the majority of the population, but were a class that would not be remunerative and would not add to the profitability of the land. They were even cleared out of their slum dwellings and left to find other places to 'squat' (Mehta, forthcoming).

The large scale of the acquisition reflected a futuristic vision that would also capture the existing rate of land and reap the exponentially increasing rate of land value in the future. For this, the acquisition would be notified, but staggered, allowing the zamindars of the area to continue cultivation till the land was required. At this time, the profits from increasing land value could also be retained as government revenue. Quoting Beadon, "in considering outlays I think we are justified in omitting from consideration the 'subsequent outlays' on village sites: for when the time for such expenditure is ripe, there will be an expansion which give rise to returns more than commensurate with the expenditure." He adds, "the non-garden portion of the Delhi City Expansion Tracts must be abnormally profitable" (Beadon 1912, pp105-109). To reduce liability and losses, he recommends removing the garden portions and Paharganj due to higher compensation expenditure. He shows that with a gross outlay of Rs. 37,89,027 (excluding the garden area), the developed returns would be Rs. 81,36,879 despite half the area of Imperial tracts being non-remunerative, thus achieving 2.5 times increase in returns (profit).

The focus on increasing profit—through expanding the area to acquire, amending the Act to acquire land at the least possible cost, and as it had become evident the economics of increasing land value in the time that the land was held—all reveal how land acquisition was not a move to acquire land in the interest of the 'public', but was used as an instrument of increasing and creating more avenues for making profit. Extending this idea forward, the following section shows how land acquisition also soon became an instrument of urban planning and improvements.

## 5. Land Control and Urban Planning/ Improvement

The inclusion of the Land Acquisition Act in the Delhi Improvement Trust (in 1937) was a crucial amendment brought into the Improvement Trust Act for Delhi. Improvement Trusts, first introduced in India in 1898 (Legg, 2008), had previously proven to be a loss-making burden, as seen in Calcutta, Bombay, Lucknow, and several other cities. (Ranganathan, 2018). Several earlier calls in Delhi for the introduction of the improvement trust had been declined (see Ali, 1922). The modified 'Acquisition' of land by the 'Schedule to the Trust Act', brought the necessary amendment that allowed the assessment of market value to be determined by the use the land was being put to when the relevant notification was issued, which would be much lower than market rates. Those evicted under the Land Acquisition Act were forced to accept a price of ordinary agricultural land from the Trust. While devaluing the owner's compensation, this amendment made it possible for the government to generate a considerable

increase in potential profit. Additionally, the provision of roads and basic urban infrastructure under 'improvement' schemes would attract very high premium payments for plots of land leased to middle- and higher-income groups.

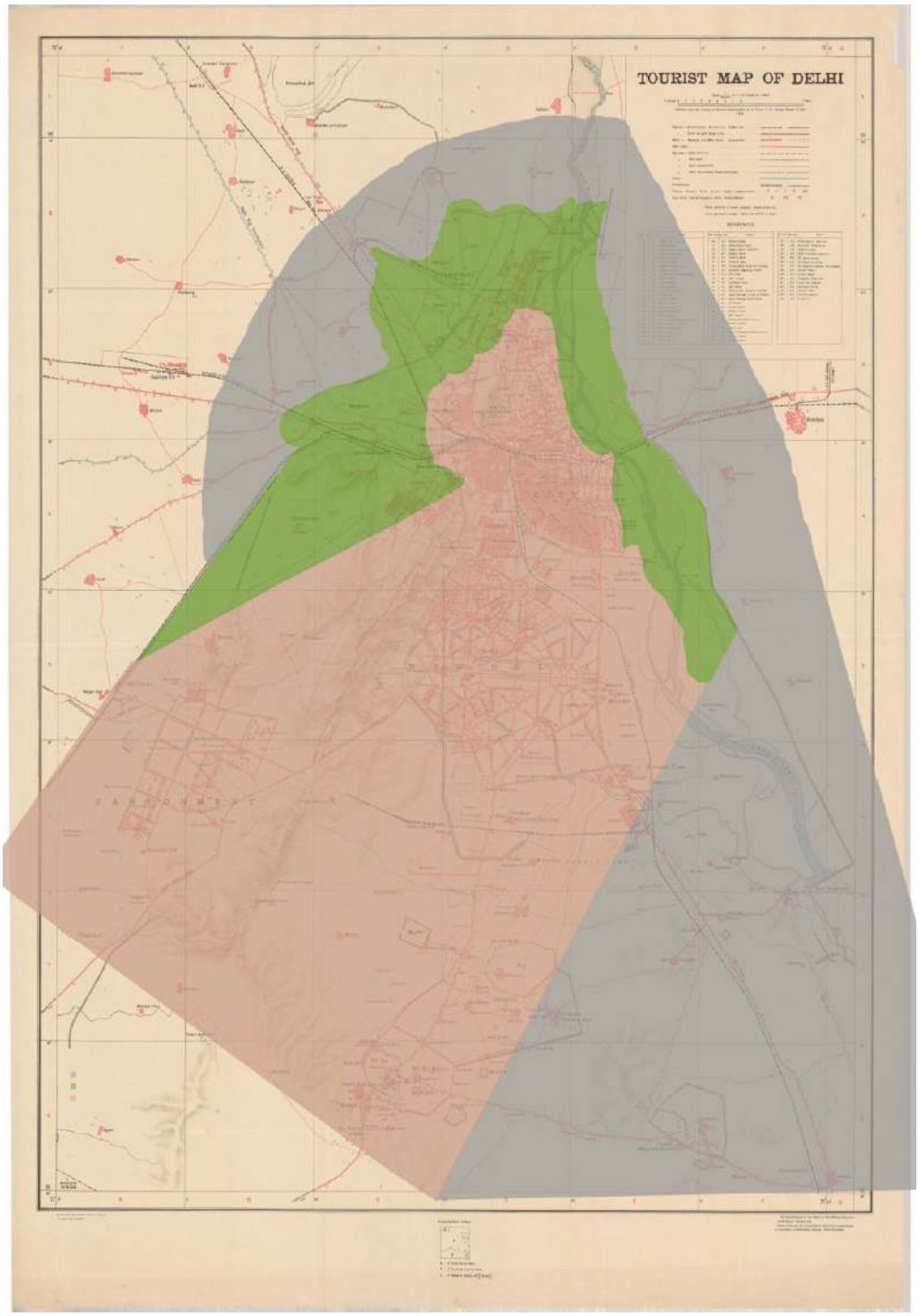


**Figure 1**. Extents of Beadon's land acquisition proposals 1912 [Pink: Imperial Tract, Green: Delhi expansion tract, Grey: area of 'firm control'; overlaid on basemap 'Tourist map of Delhi, 1927; source: Author, drawn with UChicago Archives basemap and colour zones derived from Beadon's 1912. Report on the acquisition of land for the Imperial Capital at Delhi.

Between 1936 and 1940, urban improvement activities developed at an enthusiastic pace, and it became evident that the land acquisition component of the DIT became increasingly significant. The Trust took control of the 'valuable Nazul estate', which had been consolidated with the 1909 Report by Whitehead. With an increased inclusion of agricultural areas and a focus on slum clearance followed by land acquisition, it was estimated that government estate (nazul land) would yield a profit of Rs 6,600,000. (Legg 2008 171). Furthermore, the Trust was established as a separate legal and

administrative entity, citing the Municipal administration's inadequate performance in urban improvements as justification. However, in fact, this helped to facilitate the financial separation, as the income and profit generated by the Trust were not reinvested in Trust activities for the poorer sections of society and the improvement of urban conditions, but were instead diverted to the colonial government's treasury. It stated that estates were 'held by the Trust on an agreement with the Secretary of State of India in Council, to be managed and developed by the Trust subject to a fixed annual payment of 2 lakh, and to the right of the government to any profit that might ultimately accrue. The arrangement implies a distinction between "nazul development" and development on acquired land, which may be referred to as "Trust development".[6]

These nomenclatures were also based on land ownership. While this paper's focus is not on the details of the improvement scheme (Hosagrahar 2005; Legg 2007; Mehta and Dasgupta 2024), it reveals how urban development/ improvement projects under DIT became focused on slum clearance and land acquisition, making them a profit-making exercise. Further lease of land plots (instead of outright sale) to middle- and higher-income groups made this an even more lucrative exercise, while people experiencing poverty were displaced without any accountability or re-housing.

In his study of Delhi's colonial growth, Legg also argues that, "with common sense, the government could reap a rich profit from the improvement of Delhi, while also benefiting the city. It was upon this assumption that the Viceroy reordered the whole of the Delhi Administration, with the Trust at its heart." (Legg, 2008, 169). As the first Chairman and proposer of the Trust, who had crafted the amendments to make the Trust financially viable, was also frustrated by the changes Hume was forced to make, which excluded the slum dwellers and the poorest from any improvement in their living conditions and access to affordable housing options. Hume recorded his disapproval of the diversion of funds meant for relieving the congestion of Delhi mentioning in the draft report that it would hamper the progress of the work of the Trust, adding that 'It would be unfortunate if the work of improvement for which old Delhi city has so long waited should once again miscarry, because the development agency has thrust upon its extraneous municipal activities greater than it can bear' (Legg 2008, 170-2).

## 6. Conclusion

The land and settlements outside of Delhi are curiously absent in most official documents until the early 20th century, when they were first addressed in the report on Crown (nazul) lands of Delhi in 1909—the first document studied in this paper. This document is specifically commissioned for the purpose of taking control of the lands surrounding the city. Later, the need for land acquisition for the new capital city, announced in 1912, led to a larger vision for land acquisition around Delhi—the second document studied here. Analysis of these two reports reveals how the rising land values since the beginning of the 20th century have brought a new focus towards land and its value, particularly around the city. This understanding becomes deeply entrenched in the colonial planning of the city in subsequent years. Framed with a vision to alleviate the terrible living conditions of an increasingly congested city and its urgent need for expansion, the DIT proposal uses 'improvements' under an amended Improvement Trust Act to subsequently also enable land acquisition as its core premise for urban development. These two official colonial documents reveal the colonial intentions of profit, which lay at the heart of their interest in expanding control over land.

The administrative segregation of urban lands in Delhi was formalized by 1909 under the category of nazul lands (government-owned lands). The focus on Nazul land was mainly in the suburbs, where land was still predominantly agricultural, pastureland, or forested, and other common lands, particularly within a six-mile radius of the city, where the increase in land values would be the most profitable. The control of land was systematically transferred from local to the Imperial government through instruments of law, such as amendments to the Land Acquisition Act and later the Improvement Trust Act. The claim on land within a six-mile radius around the city also meant acquiring (and displacing) 110 villages in the area for the construction of the new capital. The scale of misappropriation of land and dispossession of native people and communities was achieved by creating colonial authoritative knowledge that amounted to misrepresentation of land tenures, records that continue even today. Triggered by the growing city and its escalating land market, with increased land values, such a scale of land acquisition was promoted—not only for the planned city but also for securing access to future profit.

The categorization and eventual control of suburban land helped construct an imagined reality of

[6] Annual Administration Report of the Delhi Province for 1937-38, Chief Commissioner E M Jenkins, Published by GOI 1939: NAI 31/24/39, pp 25-28

the benevolent basis for colonial rule under the idiom of 'improvement'. The suburban land of Delhi eventually became a valuable resource that could be capitalised through the urban property market using town planning and improvement policies. This study examined the relationship between land control and planning in the early 20th century under colonial rule. However, examining its details and revealing the colonial focus on profit-making makes this study a historiography that may shed light on many issues related to urban land and its influence on urban planning policies post-independence, which have continued as a colonial mindset of dispossession of owners and appropriation of commons.

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