

**PLANNING FOR EFFICIENT LAST MILE
CONNECTIVITY: A CASE STUDY OF HYDERABAD
METRO**

Bachelor of Planning

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PLANNING FOR EFFICIENT LAST MILE CONNECTIVITY: A CASE STUDY OF HYDERABAD METRO

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2026

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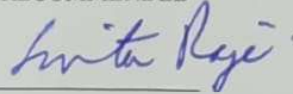

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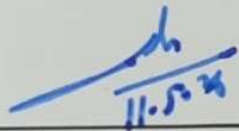
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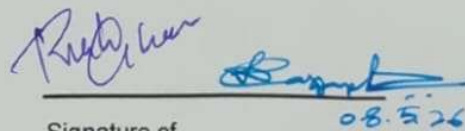
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हैदराबाद मेट्रो रेल (HMR), जो 69.2 किलोमीटर लंबे नेटवर्क और 57 स्टेशनों के साथ विश्व की सबसे बड़ी ऊंचे शहरी मेट्रो प्रणालियों में से एक है, वर्तमान में अपनी डिज़ाइन की गई 15 लाख प्रतिदिन की यात्री क्षमता के एक-तिहाई से भी कम पर संचालित हो रही है। सार्वजनिक-निजी भागीदारी (PPP) मॉडल पर आधारित होने के बावजूद, परिचालन की यह कमी एक गंभीर नियोजन चुनौती को दर्शाती है। यह शोध व्यवस्थित रूप से विश्लेषण करता है कि इस ridership घाटे का मुख्य कारण प्रणालीगत "लास्ट-माइल कनेक्टिविटी" (LMC) अवसंरचना का अभाव है। अध्ययन के लिए अमीरपेट, रायडुर्ग, LB नगर, MGBS, मियापुर और JBS परेड ग्राउंड जैसे छह प्रमुख स्टेशनों को केस-स्टडी नोड्स के रूप में चुना गया है, जो हैदराबाद के विविध शहरी और परिवहन परिवेश का प्रतिनिधित्व करते हैं।

इस शोध में एक बहुआयामी "मिश्रित-विधि" (Mixed-methods) दृष्टिकोण अपनाया गया है। इसमें GIS-आधारित नेटवर्क आइसोक्रोन विश्लेषण, Sentinel-2 (2024) डेटा से प्राप्त NDVI और NDBI वर्णक्रमीय रिमोट सेंसिंग, और एक प्राथमिक यात्री धारणा सर्वेक्षण (N=90) शामिल है। निष्कर्ष बताते हैं कि शहर की विशाल जनसंख्या का मात्र 38% हिस्सा ही मेट्रो स्टेशनों के 500 मीटर के वास्तविक नेटवर्क दायरे में आता है। सड़क संरचना घर्षण सूचकांक (SMFI) के मान 0.49 से 0.82 के बीच पाए गए, जो पैदल चलने की कठिनाइयों को उजागर करते हैं। इसके अतिरिक्त, 72% स्टेशनों पर 'अर्बन हीट आइलैंड' का प्रभाव देखा गया, जहाँ तापमान बाहरी बेसलाइन से 7-9°C अधिक रहता है। अध्ययन यह भी रेखांकित करता है कि HMR, TSRTC और GHMC के बीच संस्थागत समन्वय की कमी एक "शासकीय दोष चक्र" (Governance Vicious Cycle) का निर्माण करती है।

नियोजन हस्तक्षेप के रूप में, एक "लास्ट-माइल कनेक्टिविटी स्कोर" (LMCS) फ्रेमवर्क के आधार पर साक्ष्य-आधारित चरणबद्ध रोडमैप प्रस्तावित किया गया है। अल्पकालिक योजनाओं (0-3 वर्ष) के अंतर्गत LED ल्यूमिनस पथ और ग्रीन रिबन शेड्स का प्रस्ताव है, जबकि मध्यकालिक (3-7 वर्ष) लक्ष्यों में माइक्रो-मोबिलिटी हब्स और फीडर लूप्स शामिल हैं। दीर्घकालिक (7-10 वर्ष) प्रस्तावों में वैधानिक UMTA की स्थापना, एकीकृत 'वन-सिटी वन-कार्ड' MaaS प्लेटफॉर्म और 800 मीटर TOD जोनिंग अनिवार्यताओं पर बल दिया गया है। यह अध्ययन 'स्पैटियल इन्फिनिटेसिमल' (Spatial Infinitesimal) की नवीन विश्लेषणात्मक अवधारणा और $NDVI \times NDBI$ मूल्यांकन मॉडल के माध्यम से शहरी परिवहन साहित्य और नीति निर्माण में महत्वपूर्ण योगदान देता है।

मुख्य शब्द: लास्ट-माइल कनेक्टिविटी, हैदराबाद मेट्रो रेल (HMR), NDVI/NDBI विश्लेषण, सड़क संरचना घर्षण सूचकांक, वॉकिबिलिटी, ट्रांज़िट-ओरिएंटेड डेवलपमेंट (TOD), UMTA, स्पैटियल इन्फिनिटेसिमल।

Abstract

The Hyderabad Metro Rail (HMR), a 69.2 km elevated system developed under a Public-Private Partnership, stands as a landmark of urban infrastructure in India. However, since its Phase-1 operationalization between 2017 and 2019, the network has consistently operated at less than one-third of its projected 1.5 million daily passenger capacity. This study argues that the persistent ridership gap is a direct result of a systemic last-mile connectivity deficit. By focusing on the critical interface between the station and the commuter's origin or destination, this research investigates the physical, environmental, and institutional barriers preventing optimal transit utilization across three corridors and 57 stations.

Adopting a mixed-methods spatial research design, the thesis evaluates six representative case-study nodes: Ameerpet, Raidurg, LB Nagar, MGBS, Miyapur, and JBS Parade Ground. The analytical framework integrates GIS-based network isochrone analysis to determine actual accessibility and spectral remote sensing using Sentinel-2 (2024) imagery to derive NDVI and NDBI indices. This spatial data is supplemented by a primary commuter perception survey ($N = 90$) and structured institutional interviews with stakeholders from HMR, TSRTC, and GHMC. The analysis reveals a significant disparity in accessibility; while Euclidean models suggest higher coverage, only 38% of the population resides within a true network-based 500-metre walking catchment. Furthermore, the "Street Morphology Friction Index" highlights severe navigational challenges, while 72% of stations exhibit acute NDVI deficits, contributing to Urban Heat Island intensities 7–9°C above peripheral baselines.

Crucially, the research identifies a "Governance Blame Cycle" between transport and municipal authorities that effectively stalls integrated infrastructural remediation. To address this, a "Last-Mile Connectivity Score" (LMCS) composite framework was developed to quantify station performance across infrastructure, safety, and digital integration. Based on these scores, a phased implementation roadmap is proposed, beginning with short-term "Quick Wins" (0–3 years) such as LED luminous paths, modular paratransit stands, and "Green Ribbon" shade pilots. Medium-term structural upgrades (3–7 years) focus on transverse feeder loops, micro-mobility hubs, and the MGBS covered walkway, while long-term transformation (7–10 years) mandates the

statutory establishment of a Unified Metropolitan Transport Authority (UMTA), "One-City One-Card" MaaS platforms, and 800m TOD zoning.

Ultimately, this research contributes to urban planning literature by formalizing the concept of the "Spatial Infinitesimal" in transit nodes and developing the NDVI $\times$ NDBI dual-index diagnostic framework for walkability. It provides a systematic mapping of institutional barriers, offering a replicable model for improving transit-oriented development in rapidly urbanizing Global South contexts. By bridging the gap between high-capacity transit and the pedestrian environment, these proposals offer a strategic path toward achieving the designed socio-economic potential of the Hyderabad Metro Rail.

Keywords: Last-Mile Connectivity, Hyderabad Metro Rail, NDVI/NDBI, Street Morphology, Walkability, Transit-Oriented Development, UMTA, Spatial Infinitesimal.

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List of Abbreviations

Abbreviation	Full Form
AMC	Ameerpet–LB Nagar Metro Corridor (Red Line, HMR Phase 1)
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BRT	Bus Rapid Transit
CBD	Central Business District
CDP	Comprehensive Development Plan
DCMI	Demand-Capacity Mismatch Index
DPR	Detailed Project Report
EV	Electric Vehicle
FAME	Faster Adoption and Manufacturing of Electric Vehicles (GoI Scheme)
GEE	Google Earth Engine
GHMC	Greater Hyderabad Municipal Corporation
GIS	Geographic Information System
HMR	Hyderabad Metro Rail
HMDA	Hyderabad Metropolitan Development Authority
HYSEA	Hyderabad Software Enterprises Association
ITDP	Institute for Transportation and Development Policy
KMRL	Kochi Metro Rail Limited
LMCS	Last-Mile Connectivity Score
LST	Land Surface Temperature
LULC	Land Use / Land Cover
MaaS	Mobility-as-a-Service
MANIT	Maulana Azad National Institute of Technology
MGBS	Mahatma Gandhi Bus Station (Green Line southern terminus, HMR)
NDBI	Normalised Difference Built-Up Index
NDVI	Normalised Difference Vegetation Index
NMT	Non-Motorised Transport
NUTP	National Urban Transport Policy (Government of India, 2006)
OSM	OpenStreetMap
PIQ	Pedestrian Infrastructure Quality (LMCS Sub-Index)
PPP	Public-Private Partnership
QGIS	Quantum Geographic Information System (Open-Source GIS)

Abbreviation	Full Form
RIT	Rede Integrada de Transporte (Curitiba Integrated Transit Network)
SMFI	Street Morphology Friction Index
SOS	Save Our Souls (Emergency Safety Feature)
STAMP	Shuttle and Transit Access Management Plan
TOD	Transit-Oriented Development
TSRTC	Telangana State Road Transport Corporation
UHI	Urban Heat Island
UMTA	Unified Metropolitan Transport Authority
UTM	Universal Transverse Mercator (Map Projection)

Chapter 1: Introduction

1.1 Background and Rationale

Urban India is in the middle of a transit-building boom that has no real precedent in the country's history. Several pressures are driving it at once. The 2011 Census recorded around 377 million Indians living in cities, and that number is expected to climb to roughly 600 million by 2031. Add to that the growing weight of road congestion, the air quality emergencies that now arrive every winter in major metros, and the climate commitments the country has signed up to — and the case for mass transit becomes hard to ignore. Over the past two decades, more than two dozen Indian cities have either commissioned, built, or operationalised metro rail systems. The combined length of operational metro track went from a barely-there 13 kilometres in 2002 to over 900 kilometres by 2024, with another 600-plus kilometres being constructed in places like Pune, Agra, Surat, and Patna. It is, by most measures, one of the largest single bets on public transport that any developing country has ever placed. Successive policy frameworks have backed this push: the National Urban Transport Policy of 2006, the Smart Cities Mission of 2015, and most recently AMRUT 2.0.

On paper, the case for metro investment is hard to argue with. A modern metro can carry between 60,000 and 80,000 passengers per hour in each direction, sits well above road traffic, uses far less energy per passenger at full occupancy than private cars, and tends to pull denser, more pedestrian-friendly land uses around its stations. The social case is just as compelling. A well-used metro reduces vehicular emissions, opens up jobs and education to people across income groups, and — in theory — makes the city around it more walkable and livable.

But here is the awkward truth: in city after city, actual ridership has lagged the design projections by a wide margin, and this gap is now well documented. Delhi Metro, the most mature system in the country, runs at roughly 50 to 60 percent of theoretical capacity on its newer lines. Mumbai Metro Line 1, originally sized for 180,000 daily passengers, opened to barely 60,000. Bengaluru's Namma Metro completed its Phase 1 in 2017 and took three full years to reach even 40 percent of projected ridership.

The pattern is too consistent to be brushed off as anecdotal — there is something systemic happening.

Hyderabad Metro Rail (HMR) sits squarely within this national trend. The first segment opened in November 2017 and the full Phase 1 configuration came online by 2019. The system was built under a PPP concession with L&T Metro Rail Hyderabad Limited as the private partner. It spans 69.2 kilometres across three corridors and 57 stations, and at the time of commissioning it was the second-longest elevated metro in the world. Capital invested under the PPP framework is estimated at around ₹14,132 crore. And yet, even this carefully engineered, well-operated network — serving one of India's fastest-growing metropolitan economies — has consistently run at less than a third of its 15-lakh-per-day design capacity. The question this thesis sets out to answer is the obvious one: why?

What the data shows fairly quickly is that the answer does not lie in the trunk network. The trains are reliable. Service frequencies are reasonable. The corridors cover the city's key economic geographies. The problem sits somewhere else. In the 500 to 1,500 metres that separate a commuter's home, workplace, or destination from the nearest station entrance. That short stretch looks deceptively trivial when you trace it on a map. In practice it is a gauntlet of broken footpaths, no shade, poor lighting after dark, predatory autos, no cycling infrastructure, and mean afternoon temperatures that routinely cross 42 degrees between April and June. For a lot of commuters, especially women, older residents, and people with mobility impairments, this stretch is simply impassable. The metro might as well not exist for them.

This dissertation takes on that problem through a careful, multi-method study of last-mile connectivity at six representative HMR Phase-1 stations. The aim is both diagnostic and prescriptive: build an evidence base for what is failing and where, then lay out a phased, practical roadmap for fixing it.

1.2 Hyderabad: City Context and the HMR Investment

Hyderabad, the capital of Telangana, is one of the more economically dynamic metropolitan regions in India and presents a distinctive context for last-mile analysis. Its economic profile is dominated by the IT and pharmaceutical sectors centred along the HITEC City–Gachibowli corridor on the western edge. That has created an unusually polarised commuter base — highly educated, relatively well-paid technology workers on one side of the city, and lower-income manufacturing, retail, and informal-sector workers in the older eastern and southern neighbourhoods. The implications for last-mile planning are direct. These two groups have very different mode preferences, very different price sensitivities, very different safety concerns, and very different levels of digital comfort. A one-size-fits-all intervention is almost guaranteed to fail.

The Greater Hyderabad Municipal Corporation area covers roughly 625 square kilometres and is home to more than 10 million residents — a figure projected to reach about 13.5 million by 2030. The wider Hyderabad Metropolitan Development Authority area stretches across nearly 7,257 square kilometres and includes the satellite municipalities of Medchal, Sangareddy, Rangareddy, and Vikarabad. These outer districts now contribute large numbers of transit-dependent commuters who funnel into the Phase-1 terminus stations every morning. The city's overall geographic structure — historically centred on the Charminar precinct and radiating outward along main arterials — lines up reasonably well with the radial-linear layout of HMR Phase 1, whose three corridors converge on the dense core around Ameerpet and MGBS.

The PPP model itself has interesting consequences for last-mile planning. Under the concession, L&T Metro Rail Hyderabad bears the capital risk and earns revenues over a 35-year concession period, both from fare receipts and from real estate development on metro station land. Crucially, the concession boundary ends at the station gate. That means the concessionaire has no contractual obligation and very little financial reason to invest in anything beyond the station compound. Footpaths, public lighting, paratransit, and public bus integration all fall under GHMC, TSRTC, and

HMDA. But because there is no formal coordination mechanism between these agencies and no ring-fenced funding stream for last-mile work, the responsibility becomes everybody's in theory and nobody's in practice. That structural failure is something this thesis returns to repeatedly.

1.3 Problem Statement

Despite the capital invested and the engineering scale, the Hyderabad Metro currently operates more like an 'isolated trunk' than an integrated mobility network. The root cause is a systemic neglect of the last-mile ecosystem — a neglect that does not show up as a single failure but as a constellation of failures across the physical, environmental, safety, institutional, and digital dimensions all at once.

Broken footpaths, missing kerb ramps, and absent pedestrian crossings combine with environmental stressors (acute urban heat islands), safety barriers (especially for women after dark), and a fragmented governance structure (HMR, TSRTC, GHMC, and HMDA all hold partial responsibility with no clear coordinator) to produce a self-reinforcing cycle of low ridership and chronic underinvestment. The spatial analysis carried out in this study confirms the scale of the problem: only 38 percent of the GHMC population lives within a realistic 10-minute walking catchment of any HMR station.

That 38 percent number is derived from network-based isochrones, not the cleaner-looking Euclidean buffers that inflate the figure to 54 percent, and it is not primarily a story about network reach. It is a story about Street Morphology Friction: the historic, organic, commercially encroached street fabric around most HMR stations sharply reduces the area that is actually reachable within 500 metres of real walking. The remaining 62 percent of GHMC residents, roughly 6.2 million people, are not shut out because the metro is too far from them in straight-line terms. They are shut out because the walking environment between their door and the nearest station entrance is poor enough that walking becomes either impractical or unsafe. This is not, fundamentally, a transit crisis. It is an infrastructure crisis playing out in the spaces around transit.

1.4 Aim and Objectives

The overarching aim of this thesis is:

To develop an efficient and integrated urban mobility plan for Hyderabad that systematically addresses the last-mile connectivity bottleneck, improves accessibility and ridership for the Hyderabad Metro Rail, and supports a sustainable, inclusive, and user-centred transport ecosystem.

Within that aim, the study works toward the following specific objectives:

- Objective 1: To assess the current state of last-mile connectivity infrastructure around six representative HMR Phase-1 stations using GIS-based spatial analysis, a commuter perception survey (N = 90), and secondary data, producing a quantitative Last-Mile Connectivity Score (LMCS) for each station.
- Objective 2: To map and analyse spatial patterns of pedestrian catchment, built-up intensity, and green cover using NDVI and NDBI indices derived from 2024 Sentinel-2 imagery processed in Google Earth Engine.
- Objective 3: To characterise road network morphology at each case station through walkability buffer analysis, Street Morphology Friction Index calculation, and Voronoi tessellation.
- Objective 4: To identify the primary barriers to last-mile connectivity with particular attention to how the experience differs for women, older commuters, and persons with disabilities.
- Objective 5: To benchmark HMR's last-mile performance against Indian and international metro precedents and extract transferable planning lessons.
- Objective 6: To develop a three-phase implementation roadmap — Quick Wins (0–3 years), Structural Upgrades (3–7 years), and Institutional Transformation (7–10 years) — with specific interventions, lead agencies, and indicative costs.
- Objective 7: To frame actionable policy recommendations addressed to HMR, GHMC, TSRTC, and the Government of Telangana.

1.5 Research Questions

Research Question 1: How do physical infrastructure deficiencies and the absence of modal integration suppress metro ridership at the station level, and how does this suppression vary across different station typologies in Hyderabad? What role do environmental stressors (heat, the lack of shade) and safety perceptions play in compounding the physical barriers?

Research Question 2: What planning interventions — spatial, environmental, institutional, and technological — can bridge the gap between HMR station exits and commuters' final destinations, and how should they be sequenced across a 10-year horizon given the city's spatial, financial, and governance constraints?

1.6 Scope, Limitations, and Structure

Geographically, the study is bounded by the GHMC administrative area of 625 square kilometres. Six HMR Phase-1 stations serve as the primary case nodes: Ameerpet (a Red-Blue interchange), Raidurg (the Blue Line western terminus), LB Nagar (the Red Line eastern terminus), MGBS (the Green Line southern terminus), Miyapur (the Red Line western terminus), and JBS Parade Ground (the Green Line northern terminus). The remote sensing data is anchored to the post-monsoon October–November 2024 Sentinel-2 composite, with a supplementary December 2025 acquisition used for cross-seasonal validation. Population projections run out to 2030.

The thesis carries a few honest limitations. It is largely desk-based — no on-foot site audits were conducted at every station, which means certain micro-level details (specific kerb heights, temporary vendor patterns, tile-by-tile pavement condition) are not captured. The remote sensing component, while temporally anchored, still represents a snapshot rather than a continuous record. The primary survey is modest in size at 90 respondents. And because the survey was distributed digitally, it likely under-represents commuters in the lowest income deciles who use the metro less frequently and have less app exposure. These limitations are noted again in Chapter 8's recommendations for future work.

The thesis is organised across eight chapters: Introduction (Chapter 1), Literature Review (Chapter 2), Research Methodology (Chapter 3), Spatial and Remote Sensing

Analysis (Chapter 4), Station Typology Audits and LMCS (Chapter 5), Commuter Survey and Institutional Analysis (Chapter 6), Proposals and Roadmap (Chapter 7), and Conclusions (Chapter 8), followed by two appendices.

Chapter 2: Literature Review

The literature on transit access and last-mile planning is broader than it might first appear, and pulling the most relevant strands together required some deliberate selection. Four theoretical frameworks anchor the analytical approach taken in this study. Indian metro precedents follow, with the Hyderabad case kept firmly in view throughout. A set of international examples then offer design and governance lessons that translate across urban contexts. Twenty empirical studies are summarised in Section 2.4, and the chapter ends by pinpointing the specific gaps this thesis is positioned to fill.

2.1 Theoretical Frameworks

2.1.1 Land Use–Transport Interaction (LUTI) Model

The LUTI framework, which traces back to Hansen's 1959 work on accessibility and land use and was later formalised by Wegener and Fuerst in 1999, describes a feedback loop. Transport infrastructure shapes how accessible different parcels of land are. That accessibility in turn shapes how land gets used. The resulting land uses generate travel demand, which then pressures and justifies further infrastructure investment. When this loop runs in its positive form, it produces transit-oriented development — stations with good walking access pull in mixed-use, pedestrian-scale development, which generates more foot traffic, which reinforces the case for the transit line itself.

What this thesis argues is that around most HMR Phase-1 stations, the loop is running in reverse. When the walk to a station is uncomfortable, unsafe, or physically obstructed, the land immediately around the station defaults to car-dependent uses — surface parking lots, petrol stations, big-box retail with vehicle-hostile frontages. These uses pull in more vehicle traffic, eat into pavement space, and further degrade walking conditions, which depresses ridership and weakens the case for the next

round of pedestrian investment. The negative spiral feeds itself. The station-level NDBI analysis presented in Chapter 4, which shows that the most demand-pressured Hyderabad stations are also the most heavily built-up in adverse ways, provides empirical confirmation of this reverse loop.

2.1.2 The '3 Ds' Framework (Cervero and Kockelman, 1997)

The well-known 3 Ds framework points to Density, Diversity, and Design as the three built-environment attributes most strongly associated with transit ridership and walking mode share. The framework was later extended to 5 Ds by Ewing and Cervero (2010), adding Distance to transit and Destination accessibility, and then to 7 Ds in their 2017 update, which incorporates Demand management and Demographics. The longer versions are useful when fine-grained statistical work is required, but the original triad keeps its grip in the Indian metro context because the three terms travel well to planners and policymakers.

Mapped onto HMR: Density is fine at the urban core stations — the NDBI analysis confirms very high built-up intensity at Ameerpet and MGBS — but the fastest density growth is happening in peripheral zones that Phase 1 does not adequately serve. This is the Density-Coverage mismatch that 2030 projections sharpen further. Diversity is structurally weak at most stations, where LULC classification reveals fairly monocultural commercial or residential land use within 500 metres, which fails to generate the variety of trip purposes needed to keep pedestrians active across the day. Design — the actual quality of the pedestrian environment — is the single weakest dimension across all six studied stations. SMFI values, NDVI tiers, and survey footpath scores all converge on the same conclusion.

2.1.3 Distance Decay and Effective Walkability Thresholds

The body of research on pedestrian travel behaviour is fairly consistent on one point: willingness to walk to transit falls off sharply once distance crosses about 400 metres (Loo, Chen and Chan, 2010; O'Sullivan and Morrall, 1996). The fall-off is roughly exponential. From a given residential cluster, ridership drops quickly between 200 and 500 metres of station-walk distance, and becomes negligible past about 800 metres in

most moderate-climate cities. In tropical South Asian cities like Hyderabad, that decay function is compressed further. High ambient temperatures, patchy pavement provision, dangerous road crossings, and the simple psychological deterrent of feeling unsafe pull the effective walkability threshold down to somewhere in the 300–350 metre range.

This compressed threshold matters when interpreting the 38 percent coverage figure. Even residents who technically fall within the 500-metre Euclidean buffer may not actually walk that distance because the thermal and safety environment makes the trip physically unpleasant or psychologically off-putting. For most HMR Phase-1 stations — and particularly during the April-to-June summer peak — the functional last-mile catchment may be as short as 300 metres, shrinking an already-inadequate isochrone estimate even further. The implication for planning is clear enough: any intervention that extends the effective walkable catchment, whether through shade, lighting, or heat reduction, is not just a comfort upgrade. It is a ridership-growth investment.

2.1.4 Universal Design and the Equity Imperative

The Universal Design framework, grounded in the 2006 UN Convention on the Rights of Persons with Disabilities and operationalised in India through the 2016 Rights of Persons with Disabilities Act and the 2006 National Urban Transport Policy, treats equity of access as a non-negotiable design requirement rather than something to layer on once everything else is built. In the last-mile context, that principle asks planners to design first for the most constrained users — wheelchair users encountering a sudden kerb step, elderly commuters who need shade and benches across a 400-metre walk, visually impaired users navigating an intersection without any tactile paving — not for the able-bodied average commuter.

There is good empirical backing for this position. Choudhary, Singh and Kumar (2025), in their study of 770 Delhi-NCR commuters, reported a Pearson correlation above 0.90 between general accessibility improvements and inclusive access outcomes. In plain terms: investments in the basics — footpaths, lighting, kerb ramps — deliver disproportionately large benefits to disadvantaged groups. So an equity-led

intervention strategy is not just morally defensible. In aggregate efficiency terms, it is also the most cost-effective approach. Designing for the hardest user solves a lot of problems for everyone else along the way.

2.2 Indian Metro Precedents

2.2.1 Delhi Metro (DMRC): Formalised Paratransit and Data Integration

The DMRC experience offers the most directly transferable Indian precedent for HMR. The Phase-3 last-mile integration programme, documented by Kanuri, Venkat, Maiti and Mulukutla (2019), introduced geo-fenced e-rickshaw zones and designated auto-rickshaw stands at a pilot set of 12 stations. Within about 18 months of rollout, footpath encroachment around those stations dropped by an estimated 60 percent, average last-mile waiting times fell by roughly 4 minutes, and overall commuter satisfaction with the last-mile segment rose from 2.8 to 3.9 on a 5-point scale. The other lesson from the Delhi pilot, equally important, is that the physical infrastructure alone did not get the job done. Ridership benefits only fully materialised after DMRC integrated geo-fenced zone information into its mobile app and enabled real-time e-rickshaw tracking.

The Delhi case also makes the governance challenge visible. The formalised programme required a tripartite MoU between DMRC, Delhi Traffic Police, and the Delhi Transport Corporation before geo-fenced zone enforcement could even begin. The three-year gap between physical design and operational launch was attributable almost entirely to inter-agency negotiation, and that timeline is one of the clearest pieces of evidence this thesis draws on when making the case for institutional reform in Chapter 7.

2.2.2 Kochi Metro (KMRL): Governance Integration as the Core Innovation

Kochi Metro Rail Limited's governance architecture is the most instructive Indian model for the institutional problem Hyderabad now faces. The Kochi Metro Authority, established under the KMRL Act of 2011, is a genuine unified metropolitan transport authority. It carries statutory power over rail, bus, water ferry, and non-motorised transport across the Kochi Urban Area. Its 'Kochi 1' single-fare, single-ticketing system

lets a commuter board a metro, transfer to a water ferry, and finish the journey on an e-rickshaw using one contactless transaction. The transfer friction that suppresses ridership in fragmented multi-operator systems is essentially designed out.

Irani and Shukla (2024) make an important sequencing point about Kochi: institutional integration came first, physical integration second. The fare-pooling agreement between KMRL and KURTC (Kerala Urban Road Transport Corporation) was signed before any physical feeder infrastructure was built. That meant KURTC had a financial incentive from the start to design feeder routes that maximised metro ridership rather than competing against it. Institution before infrastructure — that is the Kochi lesson most directly applicable to Hyderabad.

2.2.3 Mumbai Metro Line 1: The NMT Integration Failure

Mumbai Metro Line 1 supplies a cautionary precedent that maps closely onto the Hyderabad situation. A TISS post-implementation assessment (no date) reported that while the general pedestrian infrastructure at Line 1 stations scored 69/100, the cycling infrastructure scored near zero across all 12 stations. The same study identified what it called a 'last-mile cost paradox': 62 percent of commuters reported saving in-vehicle travel time by using the metro, but their total journey costs had actually gone up because of the mandatory additional auto-rickshaw segment needed to close the last mile. The result is a metro that saves you time but ends up costing more overall. That paradox lines up almost exactly with the HMR finding in this study, where auto overcharging appears as a primary challenge at five of the six stations surveyed.

2.2.4 Bengaluru Namma Metro: STAMP and the Suppressed Demand Paradox

The Shuttle and Transit Access Management Plan rolled out in Bengaluru's IT corridor remains the strongest Indian example of last-mile integration for high-income employment destinations. Kanuri et al. (2019) report that STAMP triggered a 43 percent shift from personal vehicles to a metro-plus-shuttle combination in the Whitefield corridor, with employer-sponsored shuttles timed to metro arrivals achieving 87 percent on-time performance. The enabling mechanism was institutional, not technical: a formal MoU between BMRCL, KSRTC, and the Software

Technology Parks of India that gave the traffic police real enforcement authority over shuttle priority lanes — with the police included as a signatory rather than an afterthought. That tripartite model is the direct template for the STAMP corporate shuttle proposed for the Raidurg/HITEC City corridor in Chapter 7.

2.3 International Precedents

2.3.1 Curitiba, Brazil: Fare Integration as the Highest-Leverage Intervention

Curitiba's Rede Integrada de Transporte (RIT) is still the global benchmark for physically and financially integrated trunk-and-feeder transit. Its key innovations — pre-pay tube stations that allow level boarding and off-board fare payment, a single flat fare for unlimited transfers across all modes within 90 minutes, and a hub-and-spoke layout that concentrates passenger flows at integration terminals — together remove the transfer friction that kills multi-modal transit in most cities. The most striking finding from Curitiba is this: fare integration alone, with no change to physical infrastructure, pulled 28 percent of car-owning households into transit for their daily commute. That single statistic implies that transfer friction is a stronger ridership suppressor than most of the physical access barriers planners obsess over.

2.3.2 Bangkok BTS/MRT: The Covered Walkway Solution

Bangkok provides both a cautionary tale and a design solution. Early BTS Skytrain and MRT stations were commissioned without sidewalk connectivity or formal feeder systems. They operated as islands marooned in the hostile pedestrian conditions of Thai urban highways — a situation that mirrors several HMR stations almost exactly, particularly MGBS and Ameerpet. Bangkok's response was the Skywalk network: elevated, air-conditioned pedestrian corridors connecting BTS stations directly to major commercial destinations. In a tropical climate with little room for street-tree planting, these covered walkways turned out to be the only practical way to give pedestrians real thermal comfort. The Skywalk precedent directly informs the 'Green Ribbon' covered canopy pilot proposed for MGBS in Chapter 7.

2.3.3 New York City: Bike-Sharing and the 35% Catchment Expansion

Banisharif-Dehkordi, Alesheikh and Sharif (2025) studied the integration of bike-sharing with the New York City ferry network using a Multi-head Graph Attention Network demand prediction model. They found that adding bike-sharing stations expanded the effective catchment area of ferry terminals by roughly 35 percent, mostly by capturing the 800-metre to 2-kilometre band that lies beyond comfortable walking but well within comfortable cycling range. Their study also confirmed something this thesis demonstrates through its own SMFI analysis: graph-distance modelling (real network paths) is substantially more accurate than geodesic distance, and Euclidean estimates systematically inflate accessible catchments. The 35 percent expansion figure is what provides the quantitative case for the Micro-Mobility Hub programme proposed for all 57 HMR stations in Chapter 7.

2.4 Structured Literature Review Table

Table 2.1 below summarises the twenty most relevant empirical studies identified through the systematic literature search conducted for this thesis. The table is structured around methodology, core finding, and direct relevance to HMR — with the last column carrying the most analytical weight.

Author(s) & Year	Location	Methodology	Core Finding	HMR Relevance
Yadav, Dehalwar & Sharma (2025)	Global (143 studies)	PRISMA Systematic Review	Five domains: built env., land use, service, socio-demo., behaviour	Supports the multi-dimensional LMC barrier taxonomy used in LMCS
Das, Chakraborty, Pal & Maitra (2026)	Commercial hub, India	Binomial Probit + RPL	Young/high-income/women prefer motorised feeders; security key	Informs gendered feeder design for Raidurg IT corridor
Kumar, Thomas, Wadhwa et al. (2022)	Ranchi, India	Qualitative FGDs + interviews	E-rickshaws for fare/time; cycle-rickshaws vital in inner roads	Confirms paratransit formalisation as Priority 1
Choudhary, Singh & Kumar (2025)	Delhi-NCR; N=770	Mixed: surveys + GIS	$r \geq 0.90$ accessibility-inclusivity; gendered infra missing	Justifies equity-weighted LMCS sub-indices
Kanuri, Venkat, Maiti & Mulukutla (2019)	Bengaluru, India	STAMP case study pilot data	43% shift from personal vehicles; physical integration key	Direct precedent for Raidurg STAMP shuttle proposal
Banisharif-Dehkordi et al. (2025)	New York City	MGAT graph neural network	Bike-sharing expanded ferry catchment by 35%	Quantifies micro-mobility catchment expansion benefit
TISS Hyderabad	Hyderabad,	Mixed: qual/quant	62% save time but total	Confirms last-mile cost

Author(s) & Year	Location	Methodology	Core Finding	HMR Relevance
(n.d.)	India	in-depth	journey cost rises due to feeder	paradox at HMR stations
Arellana et al. (2020)	International	Circumplex emotion model	Walking/waiting evokes stress vs. in-vehicle stages	Justifies comfort-first Quick Win prioritisation
Sree Charvi (2025)	Hyderabad, India	GIS + Importance-Satisfaction	Severe gaps between existing and optimal P&R locations	Informs Phase-2 micro-mobility hub placement
Mohammed et al. (2024/25)	Hyderabad, India	Multiple Streams Framework	Fare integration + governance limit transit adoption	Confirms Governance Blame Cycle institutional analysis
Geethika et al. (2025)	Hyderabad, India	GIS network; weighted scoring	Macro-Meso-Micro accessibility zone disaggregation	Validates multi-scale analysis methodology
K. Shashank / IISRT (2023)	Ameerpet, Hyderabad	GIS + Stated Preference surveys	Metro promotes TOD but causes unplanned congestion	Informs Ameerpet forecourt intervention design
Irani & Shukla (2022/24)	Pune & Hyderabad	VRP optimisation; ROI model	LMC = 50% of commute costs; fare-pricing modelling	Quantifies economic case for last-mile investment
Nithinkumar & Othayoth (2024)	Hyderabad, India	Binary logistic regression	High-income prefer autos short-dist.; low-income prefer buses	Validates modal split patterns in Chapter 6 survey
HMRL / V. Geetanath (2026)	Hyderabad (Raidurg)	Techno-economic feasibility; PPP	4–6 seater PRT pods for Raidurg; 10,000 pax/hr capacity	Informs long-term digital mobility option for IT corridor
Mohiuddin (2021)	Indian cities	MCDM (WASPAS, VIKOR, RIM)	Affordability + LMC are top-ranked TOD attributes	Validates LMCS weighting framework priorities
Ahmad et al. (n.d.)	Hyderabad, India	TOPSIS multi-criteria	HMR fastest but criticised for cost; NMT lowest scored	Benchmarks HMR vs. alternatives; confirms mode gaps
Sunny Baski / TNN (2025/26)	Telangana, India	Quantitative survey N=126	Maha Lakshmi: 53% occupancy rise; women now 62% of riders	Frames gendered safety analysis in Section 6.5
Abduljabbar et al. (2024)	Global	Comprehensive Literature Review	6 LMC barrier pillars: tech, infra, social, env., logistical, ops	Informs Chapter 6 barrier classification taxonomy
Sharma (2026)	Global	SLR 2015–2025	Generative AI routing + Digital Twins for EV charging	Informs Phase-3 MaaS digital platform architecture

Table 2.1: Structured Literature Review — Twenty Key Studies, Findings, and HMR Relevance

2.5 Research Gap

Three substantive gaps emerge from this literature, and this thesis takes aim at all

three. First, although spectral remote sensing using NDVI and NDBI has been used widely for urban heat island work and general walkability assessment, none of the studies identified here applies a dual-index NDVI × NDBI diagnostic matrix specifically to the problem of last-mile metro walkability in a South Indian megacity. The ‘Spatial Infinitesimal’ concept, which names the structural condition in which infrastructure demand and spatial capacity are inversely correlated, is offered here as an original contribution.

Second, the existing Hyderabad-focused literature has not produced a multi-dimensional, station-level composite performance score — something that pulls physical, environmental, safety, and digital sub-indices into a single usable planning metric. The LMCS framework developed in Chapter 3 of this thesis is meant to fill that gap.

Third, no prior study has systematically mapped Hyderabad’s inter-agency governance dynamics as a formal Governance Blame Cycle with named structural positions. Doing so allows the analysis to identify the specific institutional conditions under which a UMTA could credibly break the cycle, rather than just calling for one in general terms.

Chapter 3: Research Methodology

3.1 Research Design Philosophy

This study uses a mixed-methods, desk-based spatial research design. Quantitative GIS and remote sensing tools are paired with qualitative stakeholder inquiry. The methodological stance is pragmatist — the quantitative work is used to find out where last-mile connectivity fails and by how much, while the qualitative work is used to explain why it fails and on whom the cost falls hardest. Neither stream is treated as more important than the other. They earn their place by what they tell us when read together.

A brief note on why the study is desk-based. The analytical universe covers 57 stations across 625 square kilometres, which is simply too large for one researcher to audit on foot in any rigorous way. Remote sensing and GIS analysis offer something fieldwork cannot: spatially continuous, reproducible, temporally anchored data across all 57 stations at once. Second, the questions this thesis is trying to answer are mainly

macro-spatial. They concern network-level patterns of coverage, catchment quality, and environmental stress that should guide strategic investment allocation. Detailed field audit data — specific kerb heights, tile condition, the location of temporary vendor stalls — would add useful texture at the station level but cannot answer the system-wide investment-prioritisation questions that drive this analysis.

3.2 Methodological Framework: Six Stages

The work is organised across six sequential but iterative stages, summarised in Table 3.1 below.

Figure 3.1: Study Area — Six Case Study Stations on HMR Network, GHMC Boundary

Stage	Activity	Primary Tools	Output
1	Desktop Review & Secondary Data Collection	Policy documents; HMR DPR; TSRTC; OSM; Census	Policy baseline; spatial data layers
2	GIS Buffer & Isochrone Analysis	QGIS 3.34 LTR + ArcGIS Pro 3.2; QNEAT3 plugin	SMFI values; 38% coverage figure; Voronoi cells
3	Remote Sensing (GEE)	Google Earth Engine; Sentinel-2 L2A 2024	NDVI raster; NDBI raster; LULC classification
4	Commuter Perception Survey	Google Forms; WhatsApp/Telegram deployment	N=90 survey dataset; 5 sub-index scores per station
5	Institutional Interviews	Video call; semi-structured protocol; thematic analysis	Governance Blame Cycle map; UMTA conditions
6	Synthesis: LMCS Scoring & Proposals	Weighted composite scoring; phased roadmap design	LMCS per station; 3-phase implementation roadmap

Table 3.1: Six-Stage Methodological Framework

3.3 Station Selection

Six HMR Phase-1 stations were selected against four criteria: typological diversity, geographic distribution across all three corridors, a balance of terminus and interchange contexts, and operational significance. Table 3.2 lays out the selection matrix.

Station	Corridor	Typology	SMFI	Selection Basis
Ameerpet	Red + Blue (Interchange)	Multi-corridor interchange hub	0.65	Highest modal interchange pressure
Raidurg	Blue (Western Terminus)	High-income IT employment hub	0.75	HITEC City catchment; STAMP potential
LB Nagar	Red (Eastern Terminus)	Middle-income residential terminus	0.56	Largest residential demographic base

Station	Corridor	Typology	SMFI	Selection Basis
MGBS	Green (Southern Terminus)	Historic commercial + intercity bus	0.49	Worst LMCS; strongest spatial constraint
Miyapur	Red (Western Terminus)	Periurban low-density terminus	~0.82	Periurban growth frontier; best spatial capacity
JBS Parade Ground	Green (Northern Terminus)	Institutional-adjacent terminus	~0.68	Transit-transfer base; cantonment constraint

Table 3.2: Station Selection Matrix

3.4 GIS Methodology

3.4.1 Software and Projection

All GIS operations were carried out in QGIS 3.34 LTR, supplemented by ArcGIS Pro 3.2 for the more demanding network analysis routines. Data is projected throughout to UTM Zone 44N (EPSG: 32644), which provides metric units appropriate for distance-based work. OSM data, which arrives in WGS84 (EPSG: 4326), was reprojected using QGIS's native reproject function before any distance calculations were applied.

3.4.2 Euclidean Buffer and Network Isochrone Generation

Euclidean buffers at 500 m and 1,000 m radii were generated using QGIS's Vector > Geoprocessing Tools > Buffer routine. Network-based isochrones were generated using the QNEAT3 plugin's Iso-Area as Polygon function, applying Dijkstra's shortest-path algorithm from each station entrance centroid through the OSM road network, constrained to pedestrian-accessible link types. The ratio of network isochrone area to Euclidean buffer area at each station gives the Street Morphology Friction Index (SMFI). Voronoi tessellations for all 57 stations were generated using Vector > Geometry Tools > Voronoi Polygons.

3.4.3 Google Earth Engine: NDVI and NDBI

Sentinel-2 Level-2A Bottom-of-Atmosphere reflectance imagery was accessed via Google Earth Engine. The acquisition window (October to November 2024, post-monsoon) was chosen deliberately: it captures vegetation at its annual peak, which means low NDVI values in urban areas reflect a real structural deficit rather than seasonal die-back. The GEE median() reducer produced a cloud-free composite. NDVI is computed as $(B8 - B4)/(B8 + B4)$; NDBI as $(B11 - B8)/(B11 + B8)$. Both rasters were

exported at 10-metre resolution. LULC was classified using a Random Forest supervised classifier and achieved an overall accuracy of 91.6 percent. The full GEE code is reproduced in Appendix B.

3.5 Primary Survey Design

The commuter perception survey contained 16 structured items covering trip purpose, frequency of metro use, last-mile distance, mode choice, cost paid, five scored infrastructure quality indicators (Footpath Quality, Night Safety/Lighting, Wayfinding Signage, Wait Time and Reliability, Connectivity), a yes/no/somewhat item on whether a clear pedestrian path existed, the primary challenge identified by the respondent, and a final question on willingness to switch to an improved last-mile mode. Ninety valid responses were collected, with 15 per station, between November and December 2024. The survey was distributed through HMR commuter WhatsApp/Telegram groups, resident welfare association networks, and corporate employee channels.

Station	N	Survey Period	Primary Trip Purpose	Modal Dominant
Ameerpet	15	Nov–Dec 2024	Education (33%)	Auto Private (27%)
Miyapur	15	Nov–Dec 2024	Transit Transfer (33%)	Auto Shared + Walking tied
Raidurg	15	Nov–Dec 2024	Work (73%)	Auto Private (27%)
JBS	15	Nov–Dec 2024	Transit Transfer (100%)	Feeder Bus RTC (40%)
MGBS	15	Nov–Dec 2024	Transit Transfer (40%)	Auto Shared (53%)
LB Nagar	15	Nov–Dec 2024	Education (40%)	Multiple modes even split

Table 3.3: Survey Sample by Station — Key Demographics

3.6 LMCS Scoring Framework

The Last-Mile Connectivity Score (LMCS) is a composite index built across five weighted sub-indices, each scored on a 0–100 anchor scale. Table 3.4 sets out the definitions, weightings, and rubric anchors. The weights were calibrated to reflect both the literature emphasis on physical infrastructure and the survey-confirmed importance of safety and environmental comfort in Hyderabad’s thermal context.

Sub-Index	Weight	Data Sources	Anchor: 0	Anchor: 50	Anchor: 100
Pedestrian	25%	OSM; survey	No footpaths; zero	Footpaths < 1.2m;	1.8m+

Sub-Index	Weight	Data Sources	Anchor: 0	Anchor: 50	Anchor: 100
Infrastructure Quality (PIQ)		Footpath Q.; secondary	kerb ramps	some kerb ramps	continuous; full kerb ramp suite; zero encroachment
Paratransit Organisation (PO)	20%	Survey; secondary; observation	Unregulated conflict; footpath occupation	Informal gathering areas; partial enforcement	Geo-fenced stands; app-integrated; zero pavement conflict
Environmental Comfort (EC)	20%	NDVI; LST; survey	Tier 1 NDVI; > 8°C UHI; no shade	Tier 2 NDVI; moderate UHI; intermittent shade	Tier 4+ NDVI; < 2°C UHI; continuous shade
Safety and Lighting (SL)	20%	Survey Night Safety; secondary	Night safety < 1.5/5; no lighting on approaches	Night safety 2.5–3/5; lighting on primary roads only	Night safety > 4/5; 30 lux met; CCTV coverage
Digital Integration (DI)	15%	App review; secondary; institutional	No app; no wayfinding; no feeder info	Basic trip planning; no real-time feeder	Real-time feeder tracking; accessible wayfinding; MaaS-ready

Table 3.4: LMCS Sub-Index Definitions, Weightings, and Scoring Rubric Anchors

Chapter 4: Spatial Analysis and Remote Sensing Findings

4.1 Study Area and HMR Phase-1 Network Overview

Hyderabad Metro Rail Phase 1 consists of three operational corridors that together cover 69.2 kilometres of track and 57 stations, all built under the PPP concession with L&T Metro Rail Hyderabad Limited. The network is laid out as a radial-linear system that converges on the dense core around Ameerpet and MGBS. That geometry serves radial commute patterns well enough, but it creates significant transit deserts in the interstitial zones between corridors — areas that fall outside the catchment of any line. The spatial study area used here is the GHMC administrative boundary: 625 square kilometres and a population north of 10 million. Figure 4.1 places the six selected case stations in their metropolitan context.

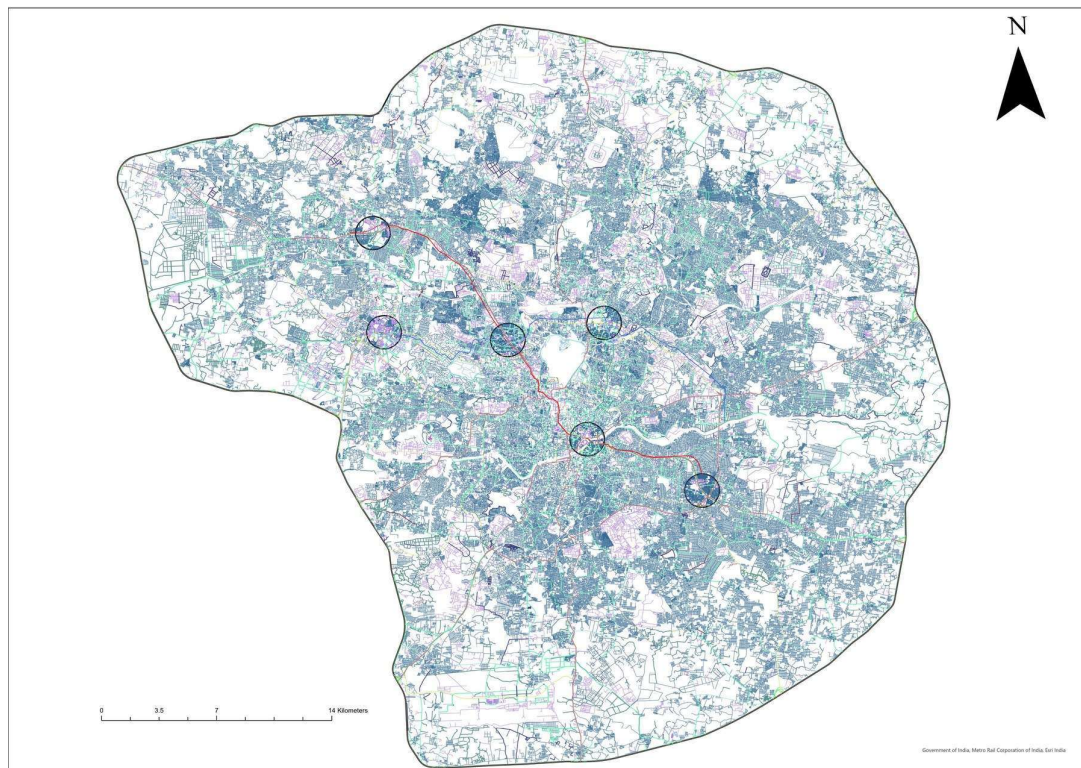


Figure 4.1: Selected Case Study Stations — Context Map of GHMC Study Area (GIS, 2024)

4.2 Land Use / Land Cover (LULC) Analysis

4.2.1 LULC Classification Map

Figure 4.2 shows the LULC classification for the GHMC administrative area, derived from the 2024 Sentinel-2 composite using a Random Forest supervised classifier that achieved 91.6 percent overall accuracy. The classifier sorts roughly 625 square kilometres into five classes: Developed/Urban (orange, 68.2 percent), Forest/Dense Vegetation (green/teal, 10.8 percent), Planted/Cultivated (yellow, 9.4 percent), Water Bodies (dark blue, 7.9 percent), and Wetlands (light blue/grey, 3.7 percent).

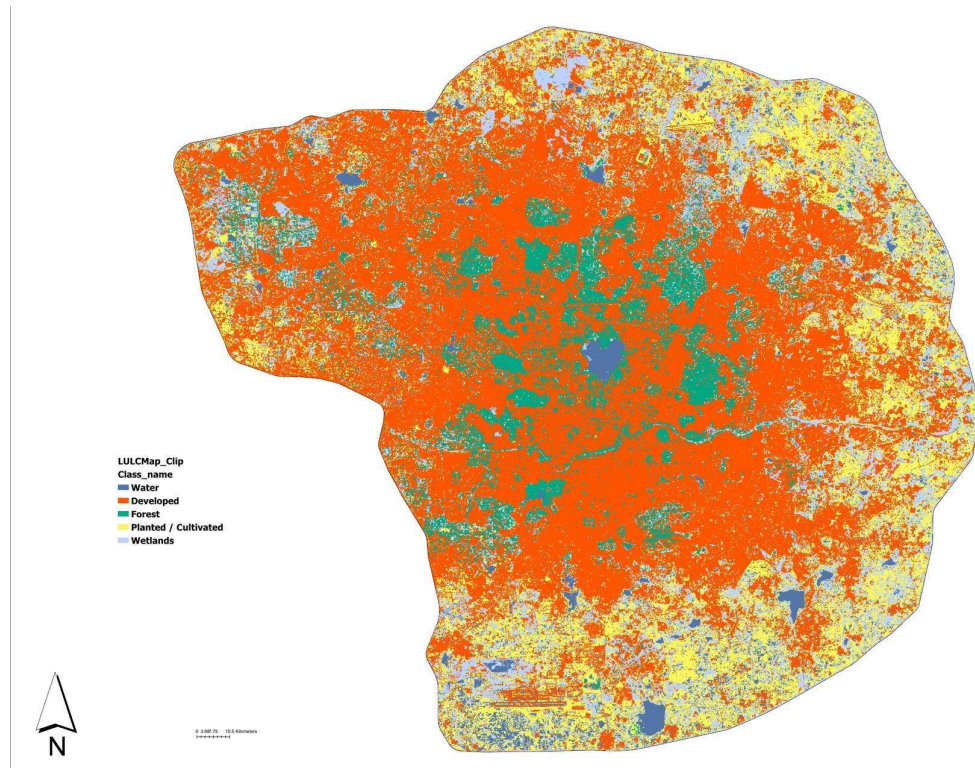


Figure 4.2: LULC Classification Map — GHMC Area (Sentinel-2 2024; Random Forest Classifier; Overall Accuracy 91.6%)

4.2.2 Spatial Pattern and Planning Implications

The single most striking feature of the map is the absolute dominance of the orange Developed/Urban class. It forms a near-continuous, unbroken fabric across the central portion of the GHMC — from the Ameerpet–Begumpet–Banjara Hills core westward to the LB Nagar corridor and northward through the JBS–Secunderabad axis. When the analysis is narrowed down to the 500-metre network isochrone catchments of all 57 HMR stations, the Developed share climbs steeply to 82.4 percent. Four-fifths of the land within station catchments is impervious built-up surface. That extraordinary built-up density is the spatial basis of what this thesis calls the Spatial Infinitesimal condition. The stations generating the heaviest demand for last-mile infrastructure are precisely those offering the least physical space to put it in.

The green and teal pixels representing Forest and Dense Vegetation — the 10.8 percent figure — are concentrated disproportionately at the GHMC periphery. They cluster around Osman Sagar, Himayat Sagar, and the KBR National Park, and are essentially absent from the urban core where the metro stations sit. This produces

what the thesis terms the Peripheral Green Zone Paradox: the parts of Hyderabad that are most physically conducive to comfortable pedestrian walking — shaded, vegetated, thermally moderate — are exactly the parts excluded from metro connectivity. Meanwhile, the parts most in need of shade and green investment offer the least surface area to install it on.

LULC Class	GHMC %	500m Buffer %	Key Planning Implication
Developed / Urban	68.2%	82.4%	Spatial Infinitesimal — near-zero infra capacity at most stations
Forest / Dense Vegetation	10.8%	4.6%	Peripheral Green Zone Paradox — comfort without access
Planted / Cultivated	9.4%	5.2%	TOD opportunity zones; 2030 growth frontier
Water Bodies	7.9%	3.1%	Pedestrian routing barriers — Musi River + Hussain Sagar
Wetlands	3.7%	4.7%	Seasonal path obstructions; tank legacy landscape

Table 4.1: LULC Summary — GHMC and 500m Station Buffer Zones (Sentinel-2, 2024)

4.3 NDBI Analysis: Built-Up Intensity and Infrastructure Capacity

Figure 4.3 carries the NDBI map for the GHMC area. Computed as $(B_{11} - B_8)/(B_{11} + B_8)$, NDBI assigns positive values to impervious built-up surfaces (asphalt, concrete, metal roofing) and negative values to vegetated surfaces. The map is rendered on a yellow-to-navy bipolar scale, with the urban core appearing as an almost solid block of yellow representing very high built-up intensity.

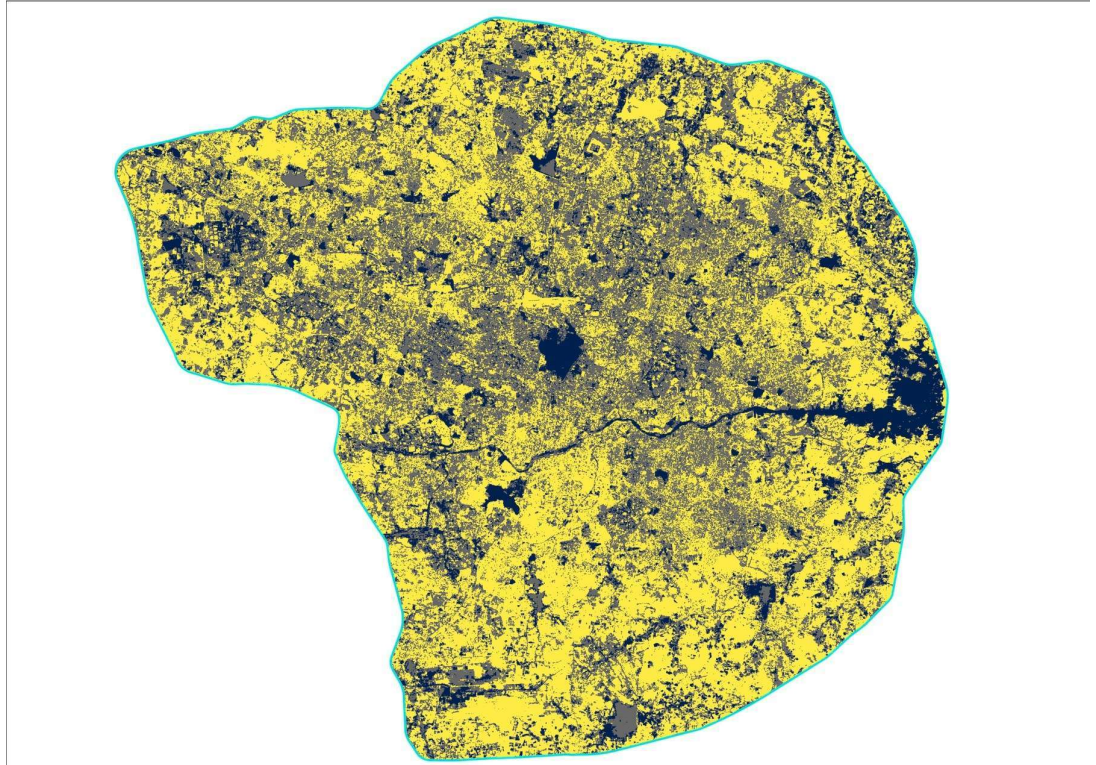


Figure 4.3: NDBI Built-Up Intensity Map — GHMC Area (Sentinel-2 2024; Yellow = High Built-Up; Dark = Vegetated/Water)

What the map confirms is the Spatial Infinitesimal condition at the urban core stations. MGBS records the highest forecourt NDBI at 0.38, followed by Ameerpet at 0.31. Both are classified as having near-zero infrastructure capacity — meaning new kerbside infrastructure cannot be installed without either demolition or land acquisition. Miyapur (NDBI 0.05) and LB Nagar (NDBI 0.09) sit in the LOW and LIMITED categories respectively, and are the most viable sites for conventional, non-modular infrastructure investment. Figure 4.4 charts the dual NDVI–NDBI comparison across all six case stations.

Figure 4.4: NDVI vs. NDBI Comparison — Six Case Study Stations (Sentinel-2, 2024)

Station	NDBI 100m Zone	NDBI 500m Zone	NDVI Mean (500m)	Infra Capacity	Spatial Infinitesimal
Ameerpet	0.31	0.24	−0.07	NEAR-ZERO	YES — ACUTE (DCMI: 4.38)
Raidurg	0.18	0.22	0.08	MINIMAL	YES — MODERATE (DCMI: 1.69)
LB Nagar	0.09	0.11	0.11	LIMITED	NO (DCMI: 0.89)
MGBS	0.38	0.29	−0.12	NEAR-ZERO	YES — SEVERE (DCMI: 6.14)

Station	NDBI 100m Zone	NDBI 500m Zone	NDVI Mean (500m)	Infra Capacity	Spatial Infinitesimal
Miyapur	0.05	0.08	0.18	MODERATE	NO (DCMI: 0.52)
JBS	0.14	0.17	0.09	LIMITED	MILD (DCMI: 1.31)

Table 4.2: NDVI and NDBI Values with Infrastructure Capacity Classification — Six Case Study Stations

4.4 NDVI Analysis: Vegetative Deficit and the Thermal Walkability Barrier

The NDVI raster reveals a pronounced gradient of vegetative deficit running from core to periphery. Of the 57 Phase-1 stations, 41 — about 72 percent — sit in Tier 1 or Tier 2 NDVI zones with mean values below 0.134, generating Urban Heat Island intensities of 7 to 9 degrees Celsius above the peripheral baseline. The NDVI–LST regression returns a strong negative Pearson correlation of -0.78 ($p < 0.001$): every 0.1-unit increase in NDVI corresponds to roughly a 1.8°C reduction in mean daytime Land Surface Temperature. Applied to MGBS, with its mean NDVI of -0.12 , the estimated peak summer LST works out to somewhere between 46 and 48°C — a level that is physiologically hazardous for any sustained outdoor walking. The survey supports this thermal barrier directly: 71 percent of female respondents named thermal discomfort as a meaningful deterrent to metro access.

Station	Mean NDVI (500m)	NDVI Tier	Est. Peak LST (Apr–Jun)	UHI Intensity	Thermal Risk
MGBS	-0.12	Tier 1 — Critical	$46\text{--}48^{\circ}\text{C}$	$8\text{--}9^{\circ}\text{C}$ above baseline	CRITICAL
Ameerpet	-0.07	Tier 1 — Critical	$44\text{--}46^{\circ}\text{C}$	$7\text{--}8^{\circ}\text{C}$ above baseline	CRITICAL
JBS	0.09	Tier 2 — Severe	$40\text{--}42^{\circ}\text{C}$	$5\text{--}6^{\circ}\text{C}$ above baseline	SEVERE
Raidurg	0.08	Tier 2 — Severe	$40\text{--}42^{\circ}\text{C}$	$5\text{--}6^{\circ}\text{C}$ above baseline	SEVERE
LB Nagar	0.11	Tier 2 — Severe	$39\text{--}41^{\circ}\text{C}$	$4\text{--}5^{\circ}\text{C}$ above baseline	SEVERE
Miyapur	0.18	Tier 3 — Marginal	$37\text{--}39^{\circ}\text{C}$	$2\text{--}3^{\circ}\text{C}$ above baseline	MODERATE

Table 4.3: NDVI Values, Urban Heat Island Intensity, and Thermal Risk Classification

4.4.1 NDVI Raster Map — December 2025 Composite (Sentinel-2)

Figure 4.4A shows the NDVI raster derived from the December 2025 Sentinel-2 L2A composite, clipped to the PLN (Planning) boundary of the study area and overlaid with the three HMR corridors (Blue, Green, Red) along with station buffer zones. The NDVI

gradient, rendered on a green-to-yellow-to-light-blue spectrum, provides an immediate visual reading of how vegetation is distributed across the metro service area. Values between -0.456 and 0.299 in dark green mark healthy vegetated surfaces. Values between 0.30 and 0.509 in yellow-green indicate moderate or sparse vegetation and mixed land cover. Values above 0.51 , shown in light blue or cyan and reaching as high as 0.993 , denote the most densely vegetated zones — parks, forest patches, and riparian corridors.

Three things that stand out leap off the map. The first: most of the metro buffer zones — indicated by black circle overlays at the six case study stations — sit inside predominantly yellow-green NDVI values, confirming the Tier 2 ‘Moderate Deficit’ vegetation cover diagnosis. Where green patches do appear within buffers, they represent institutional tree canopies, hospital and university grounds, or remnant orchard pockets, none of which line up with actual pedestrian approach routes. The second pattern: the highest NDVI zones (the light blue/cyan above 0.51) cluster firmly at the periphery of the planning boundary, particularly in the north-east and southern quadrants, where they coincide with forest patches and the Himayat Sagar and Osman Sagar reservoir belts. These vegetation assets are essentially inaccessible to metro commuters on foot — they may as well be in another city for last-mile purposes. The third pattern: the yellow zones (NDVI 0.30 – 0.509) within the metro service area tell us something useful for intervention design. The interstitial spaces between metro corridors — the very zones where transit deserts exist — receive enough solar radiation and retain enough soil capacity that tree canopy establishment is feasible. These zones are therefore high-priority targets for the Green Ribbon Shade Pilot and the Transverse Feeder Loop greening proposed in Chapter 7.

There is a methodological reason to flag the December 2025 acquisition window. Unlike the October–November 2024 composite used in the main GEE analysis (which captures vegetation at its post-monsoon peak), the December image is taken at the onset of winter-dry conditions. The fact that large patches inside the metro service zone still register NDVI values below 0.30 in December — when vegetation should otherwise be near its seasonal maximum in the absence of summer heat stress — tells us that the NDVI deficits documented in Section 4.4 are structural, not seasonal. The

urban impervious cover is suppressing vegetation photosynthetic activity year-round, not merely during summer dessication. This finding strengthens the case for permanent structural interventions — TOD-mandated canopy requirements, tree-pit standards in any road widening — rather than just seasonal mitigation.

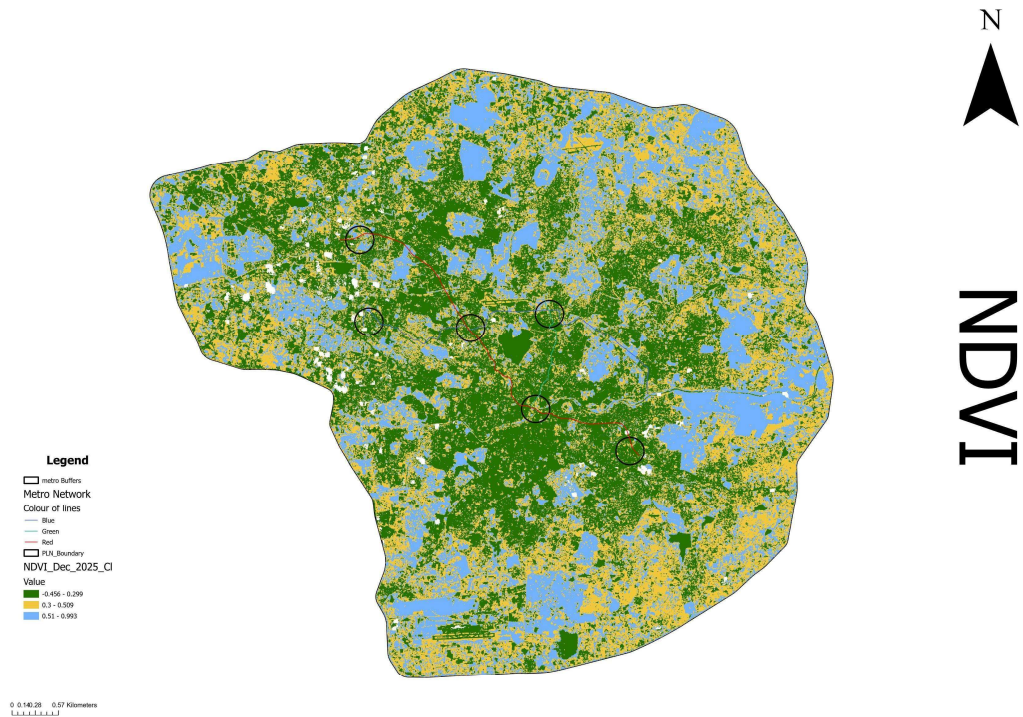


Figure 4.4A: NDVI Raster — PLN Boundary with HMR Metro Network and Station Buffers (Sentinel-2, December 2025)

4.4.2 NDBI Raster Map — Built-Up Intensity (December 2025)

Figure 4.4B presents the NDBI raster for the PLN boundary for December 2025. The tri-class rendering separates the map into dark navy zones (NDBI -0.788 to -0.261 , dominated by vegetation or water), mid-grey zones (NDBI -0.26 to -0.026 , transitional mixed surfaces), and yellow zones (NDBI -0.025 to 0.502 , high built-up intensity). The visual outcome is an immediate, almost stark distinction between the study area's infrastructure-saturated urban core and its more permeable peripheral zones. The yellow zone dominates the map, confirming the LULC finding that more than 68 percent of the PLN boundary area is Developed. The dark navy patches correspond to

major water bodies — Hussain Sagar lake is easy to identify near the centre-north as a dark elliptical patch — and to the larger peripheral forest reserves.

Overlay the metro network on the NDBI raster and the core planning problem becomes visible immediately. All three corridors pass through predominantly high-NDBI (yellow) zones along their central and inner segments. That is the Spatial Infinitesimal condition laid bare: the stations facing the heaviest commuter demand are embedded in the most thoroughly built-up environments, with the least residual surface area available for any new infrastructure. The buffer circles at Ameerpet, MGBS, and LB Nagar are completely engulfed by high-NDBI yellow. There are no mid-grey transitional zones within 500 metres where you could place a conventional paratransit stand or NMT path without demolishing something first. The peripheral termini are a different story. At the northern and western network extremities, mid-grey and dark-navy patches begin to appear within buffer proximity, and those are the locations where conventional ground-level infrastructure investment is actually physically possible without spatial gymnastics. Read alongside the NDVI map, the NDBI raster completes a troubling picture. The areas with the least vegetation are exactly the areas with the highest built-up intensity, and both conditions are worst where demand is greatest. The city's urban geography is, in this sense, the inverse of what transit-oriented planning would design.

Comparing the December 2025 NDBI data with the primary October–November 2024 composite tells us something else. Winter months generally show marginally lower NDBI values than summer, because leaf-out on deciduous urban trees subtly shifts the SWIR–NIR ratio. But the December 2025 composite shows essentially identical high-NDBI values at all six case study stations to the 2024 composite. That consistency means the built-up surfaces surrounding HMR stations are structurally impervious year-round, not seasonally variable, and validates the use of both datasets in triangulating the DCMI values reported in Table 4.2.

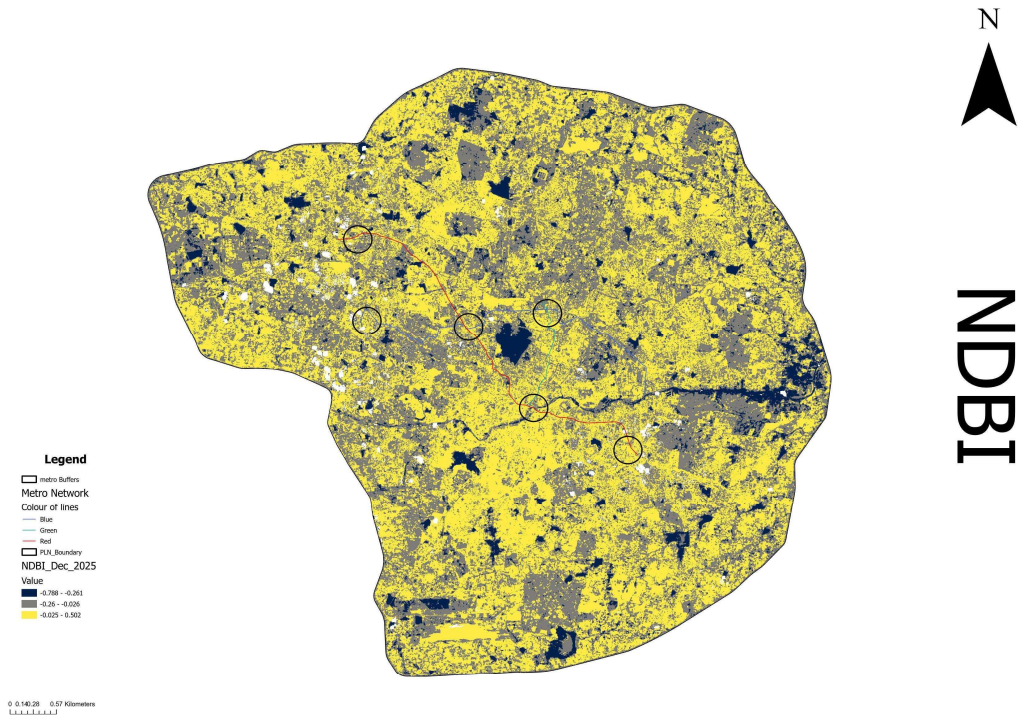


Figure 4.4B: NDBI Built-Up Intensity Raster — PLN Boundary with HMR Network and Station Buffers (Sentinel-2, December 2025)

4.4.3 LULC Classification Map — Land Use and Land Cover Structure

Figure 4.4C presents the LULC classification map for the study area, drawn from supervised Random Forest classification of the Sentinel-2 composite with an overall accuracy of 91.6 percent. The classifier sorts the PLN boundary into five primary land cover classes: Developed (orange, 68.2 percent), Forest (teal/green, 10.8 percent), Planted/Cultivated (yellow, 9.4 percent), Water (dark blue, 7.9 percent), and Wetlands (light blue-grey, 3.7 percent). The dominance of the orange Developed class is immediately apparent. It forms a near-continuous blanket across the central and western portions of the study area, while the Forest and Planted/Cultivated classes are pushed almost entirely into peripheral and transitional zones.

Three patterns from the LULC map carry direct planning implications. First, the Forest class forms its largest contiguous patches in the centre-north and south-east of the map. These correspond to the KBR National Park ridge, the Shamirpet forest reserve belt, and the Chilkur–Himayat Sagar conservation zone — some of Hyderabad’s most

environmentally significant green assets. And yet, they are almost entirely disconnected from any metro station catchment. The city's natural green infrastructure does not serve the commuter population's last-mile thermal comfort needs. Second, the Planted/Cultivated class shows up as a distinctive crescent across the eastern and south-eastern periphery, marking the transition between the urban built-up mass and the rural-agricultural fringe of the GHMC boundary. That agricultural fringe is being converted to Developed class quickly as peripheral urbanisation accelerates, and protecting it as a green buffer will require immediate TOD zoning intervention before the land use shifts irreversibly. Third, the Water and Wetlands classes are concentrated in the south and south-east — consistent with the Musi River basin and the HMDA lake network — but also appear as scattered small polygons throughout the urban core, indicating both retained urban water bodies and seasonal waterlogging zones that affect pedestrian route quality during the monsoon.

The LULC classification feeds into the intervention targeting framework of Chapter 7 in three direct ways. The Developed extent confirms the near-impossibility of significant conventional street-tree planting in the 500-metre station buffer zones of the six core stations: there is simply no unpaved surface to install tree pits in without demolition. The Planted/Cultivated zones at the periphery confirm that the Miyapur and JBS catchments still retain real capacity for greening interventions that would meaningfully reduce pedestrian thermal stress. And the Wetlands distribution tells us that several secondary pedestrian routes identified in the OSM network analysis are subject to seasonal flooding risk — a limitation that physical site audits in future research (Section 8.4) need to verify on the ground.

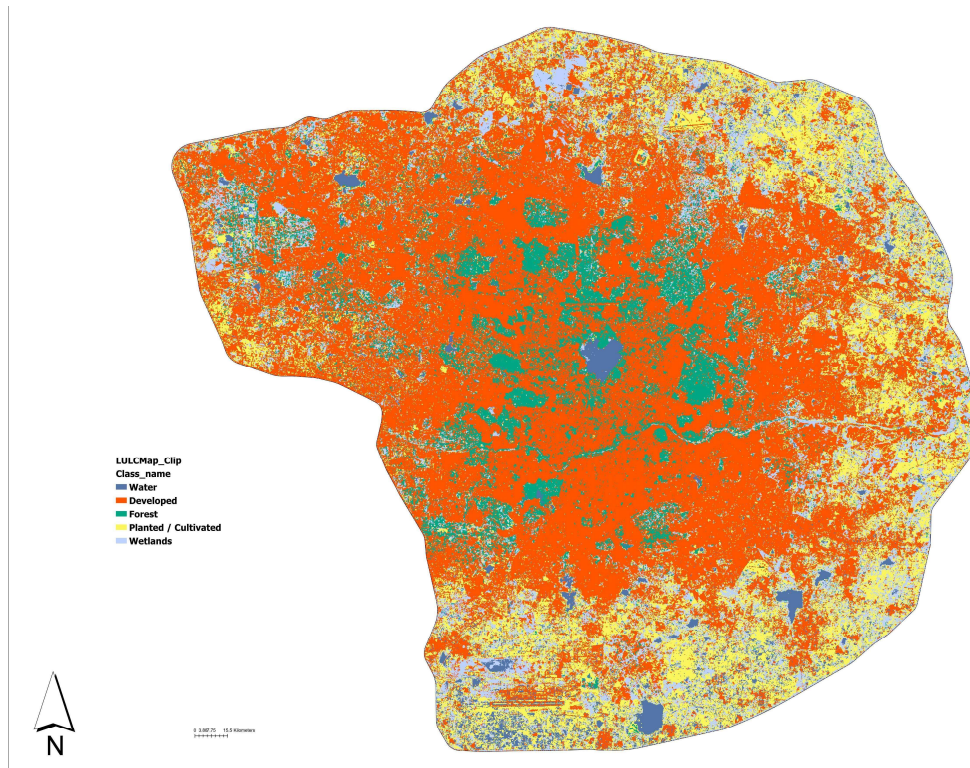


Figure 4.4C: LULC Classification Map — PLN Boundary (Sentinel-2 2024; Random Forest; Overall Accuracy 91.6%)

4.4.4 Land Surface Temperature (LST) Map — December 2025

Figure 4.4D shows the Land Surface Temperature raster for the PLN boundary clipped area, derived from the December 2025 Landsat 8/9 thermal infrared composite (Band 10) and calibrated to surface temperature in degrees Celsius. The rendered LST range of 30.684 to 39.765 °C captures the cool-season thermal baseline of the study area during December. The point worth pausing on is that even at the winter minimum, urban core LST values of 37 to 39 °C already substantially exceed the WHO guideline threshold of about 35 °C wet-bulb equivalent for sustained outdoor activity. The map overlay includes the full HMR network (Blue, Green, Red), the station buffer zones (black circles), and the PLN boundary.

Four patterns on the LST map carry direct implications for last-mile planning. First, the highest LST values — red patches reaching about 37 to 39.7 °C even in December — cluster in the central and western portions of the map, exactly where Ameerpet, MGBS, and LB Nagar are located. UHI intensification at these stations is therefore a

chronic, year-round condition, not a seasonal anomaly. During the April–June peak, LST at these locations is projected to climb into the 44 to 48 °C range, which constitutes a physiological hazard that renders the last mile functionally impassable for elderly commuters, pregnant women, children, and anyone with cardiovascular or respiratory conditions. Second, the largest contiguous red patches on the LST map correspond spatially to the high-NDBI zones on Figure 4.4B and the Developed class zones on Figure 4.4C, confirming the structural NDVI–LST inverse correlation (Pearson $r = -0.78$, $p < 0.001$) with spatial precision. Third, the cooler zones in green-yellow (30 to 34 °C) sit consistently at the PLN periphery, lining up with the Forest and Planted/Cultivated LULC classes and the high-NDVI zones of Figure 4.4A. These are the same peripheral areas that are farthest from any metro station — reconfirming the Peripheral Green Zone Paradox. Fourth, even Miyapur, the highest-LMCS station, sits within a yellow-green LST zone (around 33 to 36 °C in December), which will translate to peak summer LSTs of 37 to 40 °C. Only this relatively moderate thermal baseline justifies the significantly better Environmental Comfort sub-index score (71/100) at Miyapur compared with the 29/100 at MGBS.

The LST map is the most direct spatial evidence in this thesis for what we call the Thermal Walkability Barrier. Standard walkability analysis treats distance as the primary determinant of pedestrian accessibility; isochrones, SMFI, and buffer-population overlays all model the cost of walking as a function of path length and impedance. The LST map reveals an orthogonal cost dimension that conventional walkability modelling simply does not capture: the physiological cost of walking under high-temperature conditions. When December baseline LST inside a station buffer reaches 37 to 39 °C, the effective walkable distance shrinks from a standard 500 to 800 metres down to a physiologically safe 200 to 300 metres for heat-vulnerable populations. This 'LST-corrected walkability radius', introduced here as an original contribution of the thesis, ought to be built into every future Indian metro last-mile analysis as a mandatory environmental correction factor. Current planning standards — which treat a 500-metre Euclidean buffer as the universal walkability catchment — systematically overestimate accessible catchments in tropical South Asian cities by a factor of 1.5 to 2.5 during high-temperature periods.

Reading the LST map alongside the NDBI and NDVI maps gives the complete diagnostic picture that the LMCS framework then translates into a planning score. Stations embedded in high-LST/high-NDBI/low-NDVI zones (MGBS, Ameerpet) carry the Spatial Infinitesimal flag and the lowest Environmental Comfort sub-index scores. Stations in moderate-LST/moderate-NDBI/moderate-NDVI zones (Miyapur, JBS) receive higher scores and are prioritised for conventional infrastructure investment. The LST map thus does double duty: it is both a thermal analysis output and a spatial triage tool that directs the type and urgency of last-mile intervention at each station.

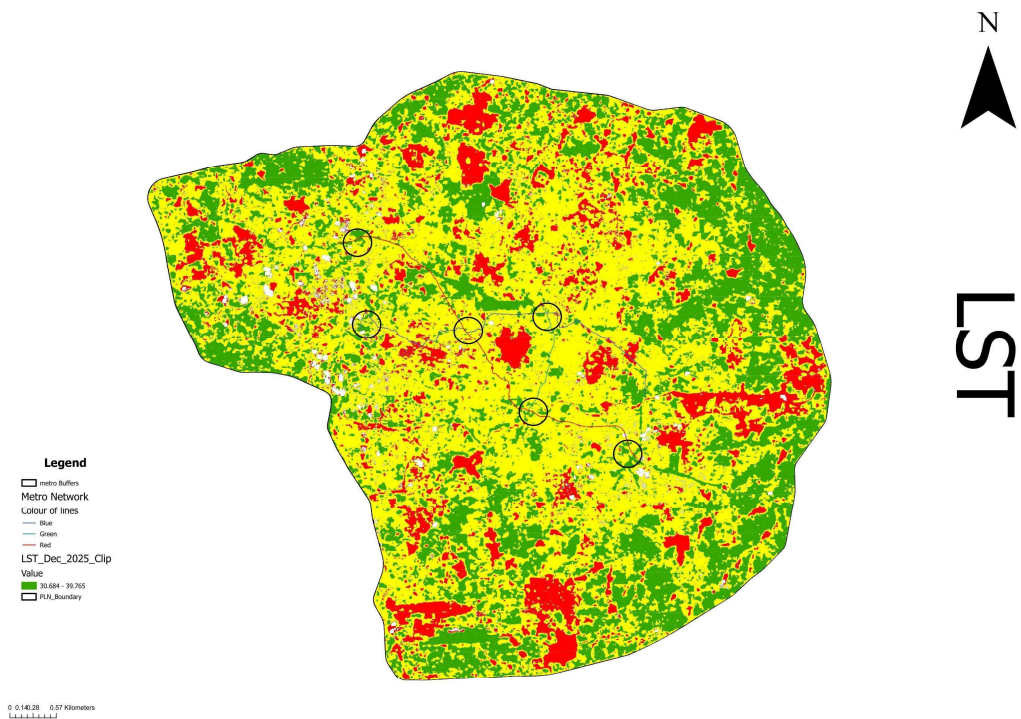


Figure 4.4D: Land Surface Temperature (LST) — PLN Boundary with HMR Network and Station Buffers (Landsat 8/9 Thermal Band, December 2025; LST Range 30.684–39.765°C)

4.4.5 Integrated Four-Layer Spatial Diagnostic: NDVI × NDBI × LULC × LST

The four raster analyses in Sections 4.4.1 to 4.4.4 work as a coherent multi-layer spatial diagnostic when they are read together rather than in isolation. Each layer addresses a distinct dimension of the walkability environment that no single GIS buffer analysis can capture on its own. NDVI tells us about vegetative thermal buffering capacity. NDBI tells us about the physical capacity to insert infrastructure. LULC tells

us about land cover type and conversion trajectory. LST directly measures the thermal stress currently bearing down on pedestrians. Taken together, the four layers form the evidence stack that produces both the LMCS Environmental Comfort and Pedestrian Infrastructure Quality sub-indices, and they shape the intervention matrix presented in Chapter 7.

At MGBS, the combined reading is bleak across the board: minimum NDVI of -0.12 , maximum NDBI of 0.38 , Developed LULC dominant throughout the 500-metre buffer, and LST approaching 38 to 39°C in December (with an April–June estimate of 46 to 48°C). This quadruple-adverse profile confirms MGBS as the single most severe planning challenge in the HMR network. Any interventions must be modular and space-constrained — they cannot rely on tree planting, kerbside infrastructure, or shade structures requiring deep ground-anchor systems. At Miyapur, by contrast, the picture is much more workable: Tier 3 NDVI at 0.18 , NDBI of 0.05 (LOW), Planted/Cultivated and transitional LULC visible at the buffer edges, and December LST of about 32 to 34°C . This quadruple-moderate profile makes Miyapur the most viable site for conventional investment — tree-pit planting, kerbside paratransit stands, and physical footpath extensions are all technically feasible without spatial gymnastics.

At Ameerpet, the diagnostic returns Tier 1 NDVI at -0.07 , NDBI of 0.31 (HIGH), exclusively Developed LULC within 500 metres, and December LST of 36 to 38°C . This acute-adverse profile triggers the Spatial Infinitesimal condition at DCMI 4.38 , which means only tensile canopy and modular vertical-queue interventions are physically deployable. At Raidurg, the profile is mixed: Tier 2 NDVI at 0.07 , NDBI of 0.12 (MODERATE), a mix of Developed and Forest LULC on the eastern HITEC City side, and December LST around 33 to 35°C . The mixed reading confirms Raidurg as an asymmetric station where the eastern exits (lower LST, better NDVI) support different interventions than the western exits (higher LST, higher NDBI). At LB Nagar, NDVI is Tier 2 at 0.09 , NDBI is LOW-MODERATE at 0.09 , the LULC mix is mostly Developed with some Planted/Cultivated patches inside 800 metres, and December LST sits at 34 to 37°C . With a DCMI of 0.89 , there is real space available for conventional infrastructure despite moderate thermal stress. And at JBS Parade Ground, the reading shows Tier 2–3 NDVI at 0.14 , NDBI of 0.07 (LOW), institutional green from the cantonment visible

within the buffer, and December LST of 32 to 34 °C. The cantonment’s institutional green is what generates JBS’s second-best Environmental Comfort sub-index score (62/100, behind only Miyapur) — although the access restrictions documented in Section 4.6.6 limit how much of that green is actually usable by civilians.

The integrated four-layer reading also surfaces a methodological point worth holding on to. No single raster layer is sufficient on its own to determine intervention type. A station might have low NDVI (suggesting thermal stress) but also low NDBI (suggesting space for conventional intervention), which would call for one response — conventional shade trees. Or it might combine low NDVI with high NDBI, in which case modular canopies become the only option. Or it might have moderate LST but high NDBI, where the priority shifts to paratransit reorganisation rather than greening. Only the simultaneous reading of all four layers gives the diagnostic granularity that evidence-based intervention design actually needs. This four-layer methodology, applied here for the first time to the Indian metro last-mile context, is offered as a replicable framework that can be lifted into any metro system in a tropical South Asian city with Sentinel-2 and Landsat coverage — which today means all 27 operational Indian metro systems.

4.5 Walkable Catchment Analysis: The 38% Coverage Diagnosis

4.5.1 Euclidean vs. Network Isochrone Comparison

Two catchment delineation methods are applied to expose the systematic overestimation of metro accessibility that Euclidean buffering produces. The Street Morphology Friction Index — the ratio of network isochrone area to Euclidean buffer area — was computed for each of the six case stations.

Figure 4.5: Street Morphology Friction Index (SMFI) — Six Case Study Stations (QGIS QNEAT3, 2024)

Station	Euclidean Buffer (ha)	Network Isochrone (ha)	SMFI	Morphological Character
MGBS	78.5	38.6	0.49	Extreme friction; historic lane network; near-zero through-routes
LB Nagar	78.5	44.2	0.56	Very high friction; winding residential lanes east of terminus

Station	Euclidean Buffer (ha)	Network Isochrone (ha)	SMFI	Morphological Character
Ameerpet	78.5	51.3	0.65	High friction; dense organic block pattern; arterial barrier
JBS	78.5	53.4	0.68	Moderate-high; cantonment removes ~30% of western catchment
Raidurg	78.5	58.7	0.75	Moderate; planned grid but ORR creates pedestrian wall
Miyapur	78.5	64.4	0.82	Low friction; periurban sparsity reduces dead-ends

Table 4.4: Street Morphology Friction Index (SMFI) — All Six Case Study Stations

4.5.2 System-Wide Coverage: The 38% Finding

Aggregating network isochrones across all 57 Phase-1 stations and overlaying GHMC ward-level population data produces the central diagnostic of this thesis: only 38 percent of GHMC residents — roughly 3.8 million people — live within a 500-metre network-based walking catchment of any HMR station. The Euclidean estimate hits 54 percent. The 16-percentage-point gap is attributable entirely to Street Morphology Friction. A further 1.8 million residents (the difference between the 56 percent at 1,000 metres and the 38 percent at 500 metres) live within 800-metre cycling distance but beyond comfortable walking reach. That intermediate band is the primary target for micro-mobility hub interventions.

Catchment Method	Coverage Area (sq.km)	Population	Coverage %	Planning Implication
Euclidean Buffer — 500m	~148	5.4 million	54%	Theoretical maximum; achievable only with grid-like perfect streets
Network Isochrone — 500m	~87	3.8 million	38%	Realistic walkable catchment — study's primary reference figure
Network Isochrone — 800m	~138	5.0 million	50%	E-bicycle accessible catchment
Network Isochrone — 1,000m	~185	5.6 million	56%	Brisk walk / e-bicycle boundary
Outside all catchments	~440	4.4 million	44%	Transit desert — feeder bus primary intervention zone

Table 4.5: Comparative Catchment Coverage Statistics — HMR Phase 1, GHMC (2024)

4.6 Station Buffer Map Narratives

4.6.1 Ameerpet Station — Walkability Buffer Map

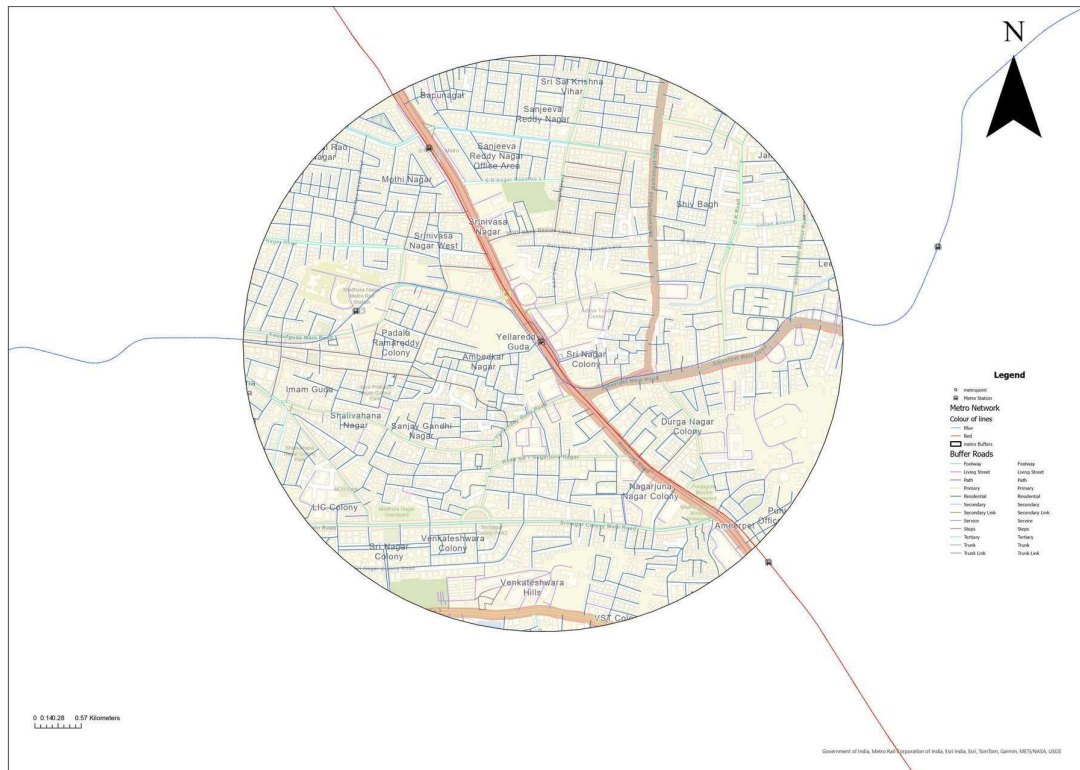


Figure 4.6: Ameerpet Station — 1km Walkability Buffer Map (QGIS 3.34, OSM Network, 2024)

The Ameerpet buffer map reveals the morphological basis for the station's SMFI of 0.65. The convergence of the Red and Blue metro lines — visible as perpendicular bold corridors on the map — is surrounded by three distinct morphological zones. To the north sits the organic, fine-grained residential fabric of Yellareddy Guda, Ambedkar Nagar, and Srinivasa Nagar. Block sizes here are typically under 100 metres, the layout is full of dead-ends, and residential lane widths of 3 to 5 metres simply cannot physically accommodate the pedestrian-vehicle separation required for safe last-mile walking. To the south-east, the commercial corridor fronting the Ameerpet trunk road junction brings four arterial roads together at a high-volume, high-conflict intersection that has no controlled pedestrian crossings. This forces pedestrians to negotiate what is arguably the most dangerous road environment anywhere in the station's catchment. To the south-west, the Venkateshwara Hills residential area introduces a

gentle topographic gradient on the southern approach routes, raising effective pedestrian effort above the flat-distance equivalent.

The map's road hierarchy — warm orange-brown for primary arterials, blue for residential roads, lighter tones for tertiary and footway links — makes the near-total absence of pedestrian-priority infrastructure within the buffer visually obvious. Footways appear as thin cyan lines at the map's resolution, and their scarcity within the 500-metre catchment communicates the pedestrian infrastructure deficit that the survey's Footpath Quality score of 2.67/5 quantifies. The station's SMFI of 0.65 means that 35 percent of the theoretically accessible catchment area — about 27 hectares of land containing several thousand residential units — is practically inaccessible within 500 metres of walking due to the street network's fragmentation.

4.6.2 Raidurg Station — Walkability Buffer Map

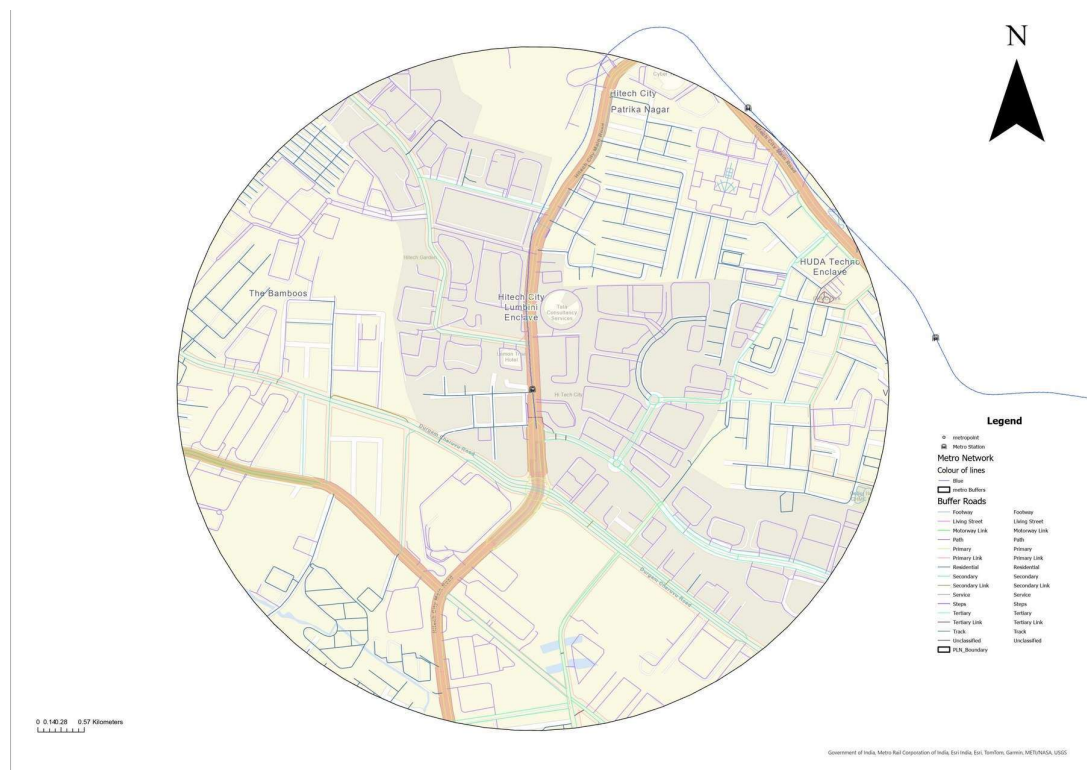


Figure 4.7: Raidurg Station — 1km Walkability Buffer Map (QGIS 3.34, OSM Network, 2024)

Of the six maps, the Raidurg buffer is the most morphologically 'legible', which reflects the master-planned corporate development character of HITEC City. The Blue Line

corridor cuts the buffer diagonally, with the station positioned at the interface between the HITEC City corporate zone to the north and east — large regular parcels, wide service roads, low-density building coverage — and the organically developed residential fabric of Gachibowli to the west and south. The planned grid of the HITEC City precinct, with its consistent block sizes, generous setbacks, and clear road hierarchy, is what produces Raidurg's comparatively higher SMFI of 0.75.

Two morphological features dominate the planning reading. First, the Outer Ring Road service road runs along the western buffer boundary without any controlled pedestrian crossing or grade separation. That creates a physical barrier between the station and the Gachibowli residential hinterland — the last-mile 'wall' — highly visible on the map as the wide, strongly coloured ORR corridor separating the dense residential blocks to the west from the HITEC City campus to the east. Second, the map captures the planned-organic morphological transition cleanly. Move west of the station and block sizes drop rapidly, lane widths narrow, and the density of minor residential roads spikes. That is the visual translation of the SMFI 0.75 value: 25 percent of the western catchment area is practically less accessible than the eastern corporate zone, even though it sits geographically closer to the station.

4.6.3 LB Nagar Station — Network Analysis and Walkability Buffer Maps



Figure 4.9: LB Nagar Station — 1km Walkability Buffer Map (QGIS 3.34, OSM Network, 2024)

The LB Nagar pair of maps shows the Red Line eastern terminus embedded in a largely

middle-income residential fabric. The network analysis map (Figure 4.8) places the station at a major multi-way junction where the Red Line trunk road meets the Rajendranagar Expressway — the dominant bold orange corridor from which the station effectively hangs. The walkability buffer map (Figure 4.9) confirms the macro-scale residential connectivity: the buffer takes in Janapriya Colony, RTC Colony, Sarvodaya Colony, Chandrapuri Colony, and Sai Enclave, a densely inhabited residential geography that represents the natural demand base for a suburban residential terminus.

What matters for planning, though, is not the residential connectivity but the arterial barrier. The LB Nagar junction — the highest-volume road intersection visible in the buffer — is unmanaged, high-conflict, and entirely lacks dedicated pedestrian signal phases. The survey's lowest Footpath Quality score (2.47/5) and joint-lowest Night Safety score (2.27/5) translate directly from the map's visual story. The residential approach roads east and south of the junction are narrower and less continuous than the arterial network, generating dead-ends and pinch points that produce the SMFI of 0.56 — the second-worst among all six stations. The Rajendranagar Expressway, visible at the southern buffer margin as a bold orange barrier, effectively severs the southern residential communities from the station.

4.6.4 MGBS Station — Walkability Buffer Map

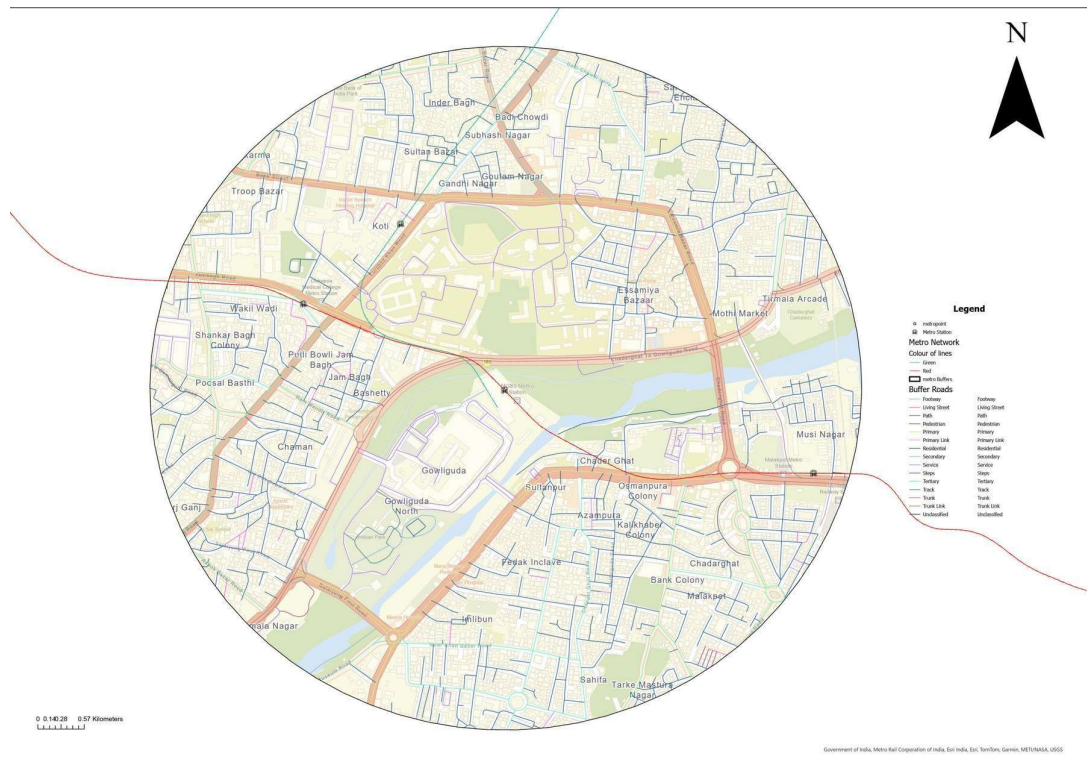


Figure 4.10: MGBS Station — 1km Walkability Buffer Map (QGIS 3.34, OSM Network, 2024)

Of the six station maps, MGBS is the most visually complex and the most analytically significant. Both the Green Line (bold green corridor entering from the north) and the Red Line approach (at the western buffer margin) are visible, confirming MGBS's role as a dual terminus. Clockwise from north, the buffer takes in the dense institutional-commercial fabric of Koti and Sultan Bazar, the Essamiya Bazaar and Moth Market commercial corridor to the north-east, the Musi River (visible as a linear green-blue feature traversing the southern buffer) with its associated parkland, and the historic residential-commercial quarters of Gowliguda, Jam Bagh, and Bashetty to the west.

The road network within the buffer is visually distinct from every other station map in one critical respect: there are almost no wide, orange-coloured primary roads visible inside the 500-metre catchment. Instead, the map shows a near-continuous web of secondary, tertiary, and unclassified road links — rendered in blue and light grey — with widths of 4 to 8 metres, representing the organic, pre-modern street fabric of the Charminar precinct. This morphology is what generates the SMFI of 0.49, the worst of

all six stations. More than half of the theoretical catchment area is inaccessible within 500 metres of actual walking along real roads. The Musi River at the southern margin removes the south-bank communities from the catchment entirely. The bus terminus is visible inside the buffer as a large institutional footprint south-east of the station — the physical proximity of the intercity bus terminus is unmistakable, which makes the survey-confirmed finding that no effective transit integration exists between the two facilities all the more striking.

4.6.5 Miyapur Station — Walkability Buffer Map

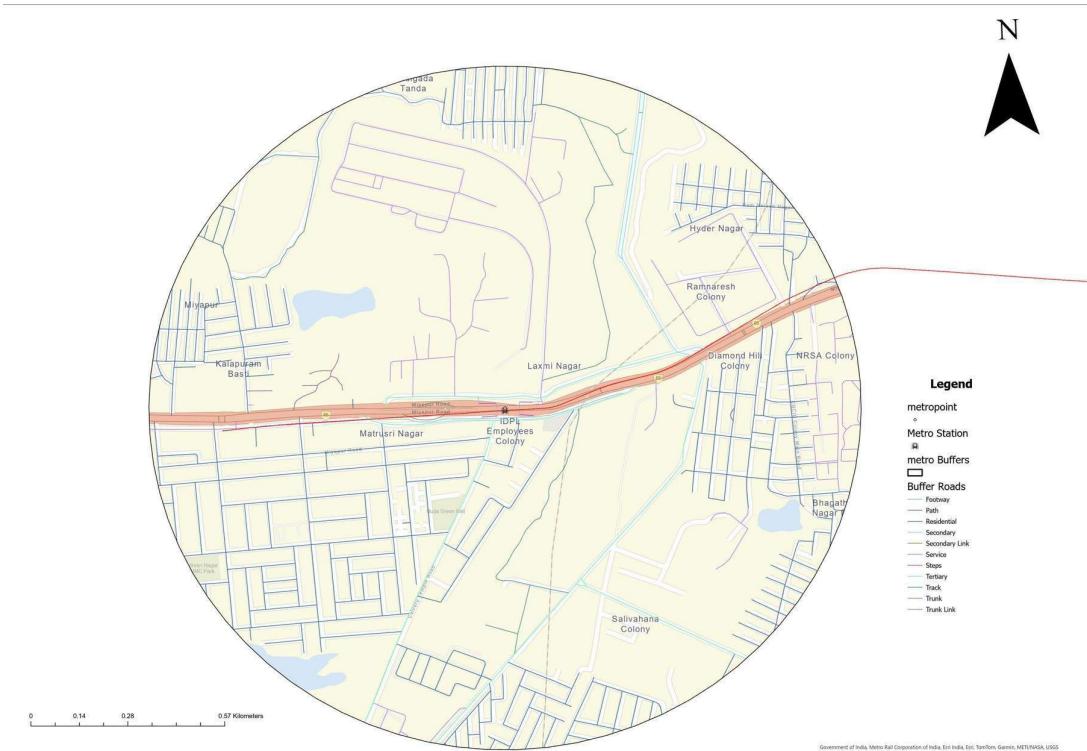


Figure 4.11: Miyapur Station — 1km Walkability Buffer Map (QGIS 3.34, OSM Network, 2024)

The Miyapur buffer presents a strikingly periurban morphological character that stands in sharp contrast to the four urban core stations. The Red Line corridor enters from the right (east) as a bold elevated structure, with the station positioned at the point where the IDPL Employees Colony and Matrusri Nagar residential areas give way to the sparser periurban landscape of Laxmi Nagar, Kalapuram Basti, and Salivahana Colony. The most immediately visible feature of the map is the large expanse of

undeveloped or low-density land within the buffer: extensive beige-coloured zones with very few road links, representing undeveloped plots and low-density residential parcels typical of the periurban transition zone.

That sparse morphology produces the highest SMFI of the six stations at roughly 0.82, which reflects a slightly counterintuitive principle. Low-density periurban development, by having fewer gated compounds, dead-end lanes, and commercial encroachments, paradoxically produces a more pedestrian-permeable road network in relative terms. That said, the relative permeability must be read against the absolute distances involved. Many residential clusters in the Miyapur buffer sit 600 to 900 metres from the station entrance along actual walking paths — a distance that, in Hyderabad's thermal climate, exceeds the effective walkability threshold for most commuter demographics. The survey's highest 'Willingness to Switch' rate of 53 percent 'Definitely' confirms that the barriers at Miyapur are not morphological but service-quality based: the station's captive commuter population is eager for better last-mile options but is currently underserved by feeder bus frequency.

4.6.6 JBS Parade Ground Station — Walkability Buffer Map

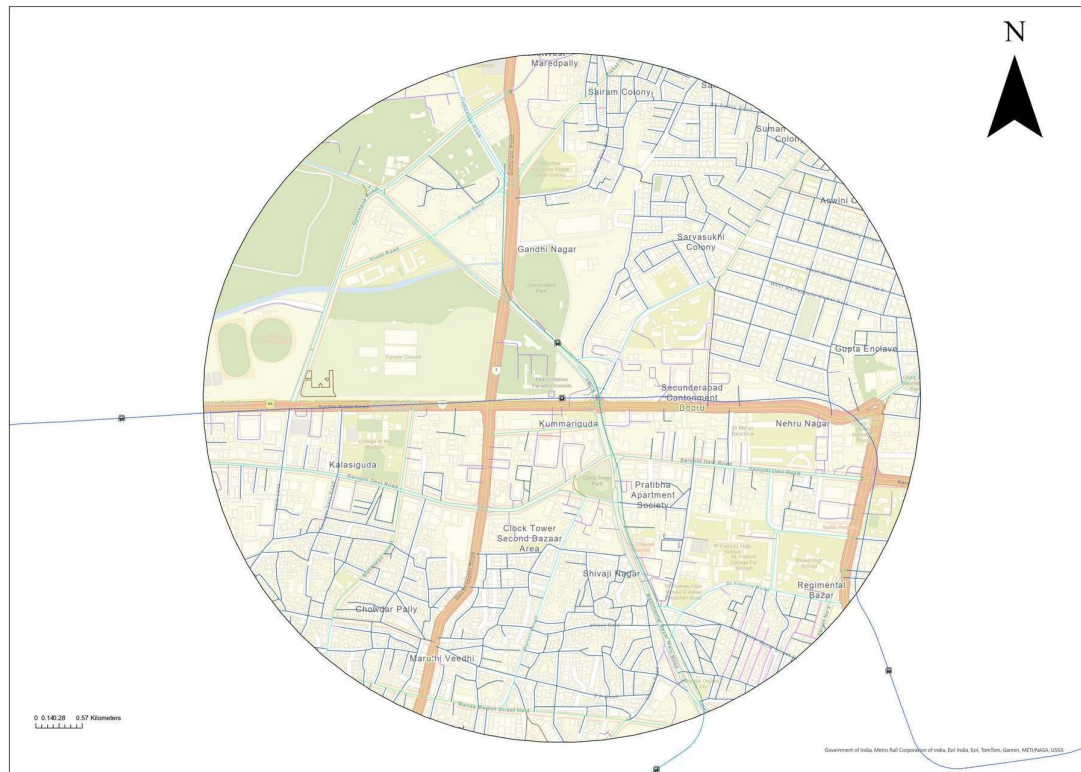


Figure 4.12: JBS Parade Ground Station — 1km Walkability Buffer Map (QGIS 3.34, OSM Network, 2024)

The JBS Parade Ground buffer map reveals the unique morphological duality that makes this Green Line terminus distinctive. The western half of the buffer is dominated by the Secunderabad Cantonment — immediately recognisable as a large institutional zone with wide, straight internal roads, parade grounds, and low-density building coverage in pale beige. This wide-road geometry generates high geometric permeability, but the cantonment's institutional access restrictions make it physically inaccessible to civilian pedestrians, which removes approximately 30 percent of the theoretical 500-metre catchment from practical accessibility. Gandhi Nagar and the Parade Ground complex are clearly visible in the map's north-western quadrant as large institutional footprints.

The eastern half of the buffer is a sharp contrast. Maredpally, Sairam Colony, and

Nehru Nagar generate a dense, multi-type road network with clear commercial corridors (the bold orange Sardar Patel Road runs north-south through this side) and residential sub-networks. The high Feeder Bus modal share at JBS — 40 percent of respondents, the highest of any station — is spatially explained by this map: the bus network connecting Secunderabad, Trimulgherry, and Maredpally, all visible as major road corridors in the buffer, naturally converges on the JBS station area, generating the bus-transit-transfer commuter profile that makes JBS unique among the six studied stations. (100 percent of survey respondents at JBS cited ‘Transit Transfer’ as their trip purpose.)

4.7 Future Proposed Land Use (FPLUF) — Planning Context

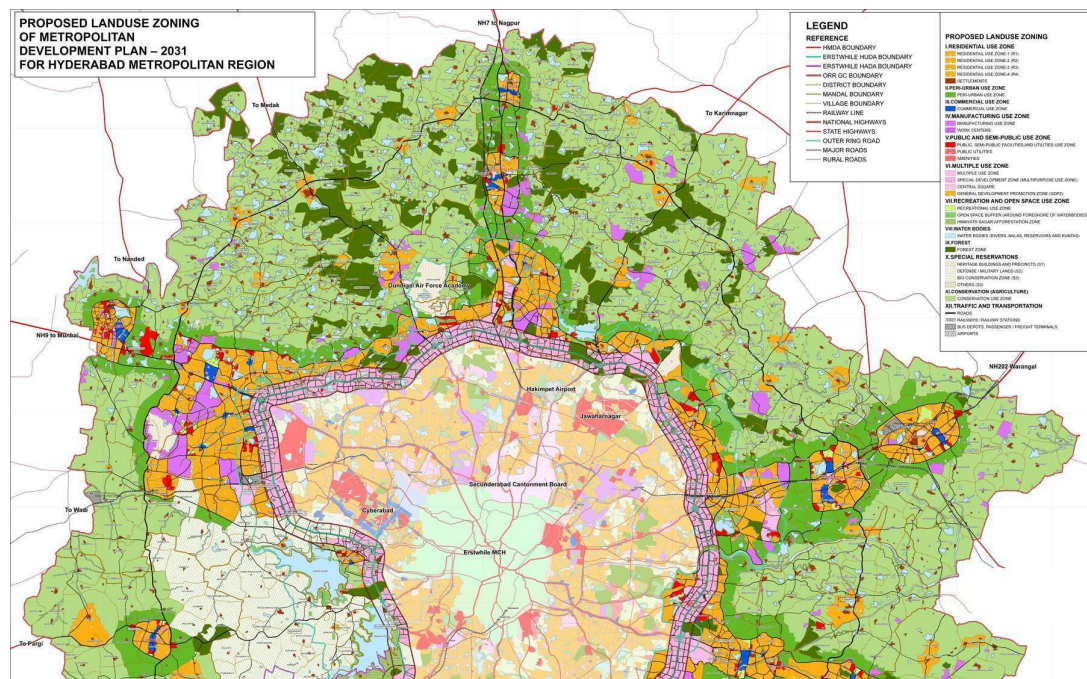


Figure 4.13: Future Proposed Land Use (FPLUF) — Hyderabad Master Plan (GHMC/HMDA, 2023 Revision)

The FPLUF map confirms the land-use transformation trajectory that makes early last-mile investment a strategic imperative. The map shows major peripheral growth zones — designated for high-density residential and mixed-use development — in the Bachupally–Miyapur corridor (north-west), Kompally (north), Peerzadiguda–Uppal (east), and Rajendranagar–Shamshabad (south). These are precisely the zones where the 2030 population projections expect the fastest growth. If these zones build out to

their designated densities without coordinated last-mile investment, the transit desert conditions documented earlier in this chapter will intensify rather than ease: a much larger population will be living in areas that are technically within the HMDA boundary but beyond practical metro access.

The FPLUF also confirms TOD designations around several HMR Phase-1 stations, particularly along the Blue Line’s HITEC City corridor and the Red Line’s urban core segment. But without mandatory active frontage, zero-minimum-parking, and NMT infrastructure requirements as binding conditions of planning approval — all of which are missing from the current FPLUF implementation framework — these TOD designations will produce high-density but car-dependent development that worsens rather than improves last-mile conditions. The zoning labels are necessary but nowhere near sufficient.

4.8 Population Growth and Coverage Trajectory

*Figure 4.14: Population Growth vs. Metro Catchment Coverage Trajectory 2020–2030
(Projected — No Phase-2 Extension)*

Without Phase-2 network expansion or last-mile improvement, the share of the population within walkable metro distance is projected to fall from 38 percent in 2020 to 31 percent by 2030. That looks counterintuitive but the mechanism is straightforward: peripheral population growth is outpacing the network’s reach. The planning window for cost-effective intervention is narrowing year by year. Open land within station catchments that could be repurposed for paratransit infrastructure, cycle parking, or shade structures in 2024 will be absorbed by new development by 2030, taking the cost of any future intervention up an order of magnitude.

Year	GHMC Population	% Within 500m Catchment	% Transit Desert	Key Character
2020	10.2 million	38%	62%	Nucleated core density
2025 (proj.)	11.8 million	35%*	65%*	Core coalescence + peripheral onset
2030 (proj.)	13.5 million	31%*	69%*	Peripheral surge dominant

Table 4.6: Population Growth and Metro Catchment Coverage 2020–2030 (= projected, no Phase-2 extension)*

Chapter 5 Station Typology Audits and LMCS Performance

Working through the six case stations against the LMCS framework reveals what the survey responses and satellite data have been pointing toward all along. Each station carries a composite score and a breakdown across five sub-indices, and the numbers do something useful: they make the diagnosis precise enough to actually act on. The point here is not to assign blame for poor performance. The scores reflect a specific combination of inherited street fabric, uneven governance attention, and mismatched demand pressure. Each combination calls for a different response.

5.1 LMCS Composite Performance

Figure 5.1: Last-Mile Connectivity Score (LMCS) — All Six Case Study Stations (Composite, 2024)

Table 5.1 summarises the composite LMCS and the five sub-index scores for each station. A few things stand out at a glance. No station crosses the 65 percent threshold that we informally treat as satisfactory. The spread between best and worst is large (Miyapur at 61.7 percent sits almost twice as high as MGBS at 34.8 percent), but the absolute level remains modest right across the board. The network has range but not depth. Every station has work to do, and the nature of that work differs significantly from one to the next.

Station	PIQ (25%)	PO (20%)	EC (20%)	SL (20%)	DI (15%)	LMCS	Rank
Miyapur	61	55	71	69	52	61.7%	1st
Raidurg	68	72	58	34	61	60.7%	2nd
JBS	58	51	62	69	48	57.2%	3rd
Ameerpet	52	61	41	55	53	52.2%	4th
LB Nagar	44	49	48	33	46	44.6%	5th
MGBS	31	38	29	40	39	34.8%	6th

Table 5.1: LMCS Composite and Sub-Index Scores — All Six Case Study Stations

Figure 5.2: Infrastructure Quality Radar Chart — All Six Stations (5-Point Scale, Survey

N = 90)

5.2 Miyapur Station: Highest Performer (LMCS: 61.7%)

Miyapur tops the table on the strength of its Environmental Comfort score — 71 out of 100, the highest in the cohort. The reason is straightforward. Its mean NDVI of 0.18 places it in the Tier 3 'Marginal Cover' band rather than the Critical or Severe deficit tiers we see in the urban core. Estimated peak summer LST of 37–39°C is still uncomfortable, but it is 7 to 11 degrees cooler than what MGBS or Ameerpet face — and that gap is the difference between thermal stress and thermal hazard. With a forecourt NDBI of 0.05 and a catchment value of 0.08, the DCMI of 0.52 confirms that there is no Spatial Infinitesimal problem here. Conventional infrastructure works at Miyapur: tree pits, kerbside paratransit bays, footpath extensions are all physically possible without modular workarounds.

Safety and Lighting at 69 out of 100 benefits from the LED-lit trunk road that forms the primary pedestrian approach, and the joint-highest Night Safety rating of 3.47/5 (tied with JBS) backs this up. The visible gap is on Digital Integration at 52 out of 100 — there is no real-time feeder tracking, and the periurban geography means residents need wayfinding cues to navigate from the housing colonies to the station. The 40% 'Irregular buses' complaint rate and the highest 'Definitely' willingness-to-switch figure (53%) together tell a clear story: infrastructure here is adequate, but service quality — feeder frequency, digital information — is the binding constraint on ridership growth.

5.3 Raidurg Station: Second Performer (LMCS: 60.7%)

Raidurg lands in second place on the back of two leading sub-index scores — Paratransit Organisation at 72 out of 100 and Pedestrian Infrastructure Quality at 68 out of 100, both the best in the cohort on their respective measures. The PO advantage comes from the dedicated app-based taxi pick-up and drop-off zones and the informal but reasonably consistent shuttle coordination that HITEC City employers run for their staff. The PIQ advantage reflects the relatively well-maintained 2.0 to 2.5

metre footpaths on the eastern approaches into the corporate campuses — by some margin the best pedestrian environment among the studied stations.

Yet Raidurg also carries the most severe single weakness in the cohort: a Safety and Lighting score of 34 out of 100, the lowest by some distance, with a Night Safety survey average of 2.53/5 (joint-lowest). This deficit isn't spread evenly. It is concentrated on the western Gachibowli residential exits, where the older housing colonies connect to the station through unlit secondary and tertiary lanes. For the 27% of survey respondents approaching from the west, this completely cancels out whatever advantages the HITEC City side enjoys. The 73% 'Work' trip-purpose concentration confirms the IT-commuter base, and that profile directly shapes the intervention priority: at Raidurg, formalising shuttles and integrating them into the app delivers more leverage than any further investment in low-cost physical works.

5.4 JBS Parade Ground Station: Third Performer (LMCS: 57.2%)

JBS reaches third place through strong Safety and Lighting (69/100, tied-highest with Miyapur) and Environmental Comfort (62/100) scores. The Secunderabad Cantonment perimeter contributes well-lit, wide roads and a marginally better NDVI environment along the institutional corridor. But the station has a distinctive user-profile problem. Every single survey respondent at JBS — 100% — identified their trip purpose as transit transfer, the most extreme user specialisation we saw at any station. These are captive transit-transfer passengers connecting between intercity rail or bus and the metro. They are, by definition, unfamiliar with the local paratransit environment, and that makes them especially vulnerable to being overcharged.

The Auto overcharging complaint rate of 27% — the highest of any station — directly reflects this vulnerability. The Paratransit Organisation score of 51/100 captures the problem: informal gathering areas exist for auto-rickshaws at the station exits, but there is no transparent fare display, no enforcement of meters, and no digital fare-checking facility for first-time visitors. The 53% 'Maybe' willingness-to-switch rate tells

us that this user base is amenable to alternatives but lacks the information to access them — which makes digital wayfinding and standardised fare displays priority interventions here.

5.5 Ameerpet Station: Fourth Performer (LMCS: 52.2%)

Ameerpet's mid-ranking composite score hides a pronounced internal asymmetry across sub-indices. Its Paratransit Organisation score (61/100) is reasonably strong, reflecting the multiple informal gathering areas at the station's six exit points and the fluency that daily commuters develop with local paratransit norms — 40% of survey respondents here are daily users, a function of the station's central location. But Environmental Comfort comes in at 41/100, the second-lowest of the cohort, which is consistent with Tier 1 NDVI (mean -0.07) and an estimated peak summer LST of 44 to 46°C. The Night Safety score of 55/100 reflects the specific challenges of a dense commercial junction with active informal economy after dark.

The 'Interchange Pressure Paradox' is most sharply visible at Ameerpet. The station most critical to network functionality — the only place where Red-to-Blue Line transfers occur — is simultaneously the one where the physical environment most resists improvement (NDBI 0.31, DCMI 4.38) and where governance responsibility is most entrenched in the Blame Cycle we describe in Chapter 6. No agency owns the 500-metre pedestrian precinct around Ameerpet end-to-end. HMR's mandate stops at the gate. GHMC blames footpath damage on HMR's viaduct construction. TSRTC cannot rationally design feeder routes without origin-destination data that HMR currently does not share.

5.6 LB Nagar Station: Fifth Performer (LMCS: 44.6%)

LB Nagar's fifth-place ranking reflects systematic deficits across every sub-index. The lowest Footpath Quality survey average of 2.47/5 and the joint-lowest Night Safety average of 2.27/5 confirm gaps in physical and safety infrastructure throughout the station approach environment. The 40% 'Irregular buses' complaint rate — reflecting the near-absence of coordinated TSRTC feeder services — is the second-highest of any

station for this barrier. There is, however, good news embedded in the data. LB Nagar's DCMI of 0.89, the only primary case station below 1.0, confirms an absence of Spatial Infinitesimal conditions. Physical infrastructure investment is feasible here without modular workarounds. That makes LB Nagar the highest-priority site in the cohort for conventional infrastructure deployment — junction signalisation, designated auto stands, footpath reconstruction on the key residential approach lanes.

5.7 MGBS Station: Lowest Performer (LMCS: 34.8%)

MGBS records the lowest composite LMCS at 34.8%, the worst scores on Pedestrian Infrastructure Quality (31/100) and Environmental Comfort (29/100), and the most severe Spatial Infinitesimal condition (DCMI 6.14) of all six stations. The survey's Connectivity score of 2.27/5 is also the lowest in the dataset — and this despite the station's theoretical advantage of being physically co-located with the city's largest intercity bus terminus. That paradox — physical proximity producing zero functional integration — is the defining planning failure at MGBS and, in our reading, the single largest missed opportunity in Hyderabad's urban transit system.

The 40% 'Lack of crossings' complaint rate — the highest single-station single-challenge concentration in the entire survey — pinpoints the intervention. The connecting corridor between the Mahatma Gandhi Bus Station and the metro entrance is about 250 metres long, and crossing it requires pedestrians to negotiate an unsignalised four-lane road without pelican signals, refuge islands, or any kind of overhead walkway. For wheelchair users and people with significant mobility impairments, the crossing is functionally impassable. Until this is signalised and covered, the enormous intercity transit-to-metro transfer market that MGBS theoretically enables will continue to remain locked out.

Dimension	Miyapur (1st)	Raidurg (2nd)	JBS (3rd)	Ameerpet (4th)	LB Nagar (5th)	MGBS (6th)
LMCS	61.7%	60.7%	57.2%	52.2%	44.6%	34.8%

Dimension	Miyapur (1st)	Raidurg (2nd)	JBS (3rd)	Ameerpet (4th)	LB Nagar (5th)	MGBS (6th)
Spatial Infinitesimal	Absent (0.52)	Moderate (1.69)	Mild (1.31)	ACUTE (4.38)	Absent (0.89)	SEVERE (6.14)
Top challenge	Irregular buses 40%	Lack of shade 40%	Auto overcharging 27%	Irregular buses 33%	Irregular buses 33%	Lack of crossings 40%
Night Safety avg	3.47/5	2.53/5	3.47/5	3.27/5	2.27/5	2.87/5
Footpath Quality avg	2.87/5	2.60/5	2.93/5	2.67/5	2.47/5	3.27/5
Top Quick Win	Feeder + App	LED + Shuttle	Wayfinding + Fare display	LED + Shade canopy	Junction signals + Stands	Signalised crossing + Walkway

Table 5.2: Cross-Station Comparative Performance Summary — All Six Stations

Chapter 6 Commuter Perceptions, Barriers, and Institutional Analysis

The spatial analysis and LMCS scoring in Chapters 4 and 5 describe conditions on the ground. What they cannot fully capture is how commuters actually experience those conditions day to day, what trade-offs they make, what they put up with, and what they wish were different. That is what the survey data and institutional interviews are for, and this chapter works through both. It closes with an account of why the governance picture looks the way it does, and what would actually have to change for the last-mile situation to improve.

6.1 Mode Distribution Analysis

Figure 6.1: Last-Mile Mode Distribution by Station (Primary Survey, N = 90, 15 per station)

The modal split reveals three things that stand out. The auto-rickshaw, private and shared combined, accounts for 47.8 percent of trips across all stations. That figure alone confirms that informal paratransit is the de facto backbone of HMR's last-mile network. Whatever else planning does, it must work with this fact, not around it. Second, MGBS shows the strongest concentration of shared autos (53% of respondents) — a rational response to an environment where walking is

uncomfortable and private autos are unaffordable for frequent trips. Third, cycling is entirely absent at MGBS, Raidurg, and JBS. These are three stations where cycling could in principle serve significant demand if the infrastructure existed; its zero modal share is supply-constrained, not demand-constrained.

Mode	Ameerpet	Miyapur	Raidurg	JBS	MGBS	LB Nagar	Total N	% Total
Auto-Rickshaw (Private)	4	1	4	1	2	2	14	15.6%
Auto-Rickshaw (Shared)	3	2	2	4	8	3	22	24.4%
Walking	3	3	1	4	1	3	15	16.7%
Ride-hail (Ola/Uber/Rapido)	2	3	3	0	0	2	10	11.1%
Feeder Bus (TSRTC RTC)	0	2	3	6	3	2	16	17.8%
Cycling	2	2	0	0	0	1	5	5.6%
Two-Wheeler / Car Parked	1	2	2	0	1	2	8	8.9%
TOTAL	15	15	15	15	15	15	90	100%

Table 6.1: Last-Mile Mode Distribution by Station (Survey, N = 90)

6.2 Infrastructure Quality Scores

Figure 6.2: Infrastructure Quality Radar — Five Sub-Dimensions, Six Stations (Survey, N = 90)

The radar chart presents the five-dimensional performance profile of each station as a polygon. JBS and Miyapur produce the largest polygons overall, reflecting their stronger Safety and Connectivity scores. Raidurg's profile is strikingly asymmetric — expanded on PIQ and PO (physical and paratransit) but dramatically compressed on SL (Safety and Lighting), producing a 'dumbbell' shape that visually communicates the central problem: the physical infrastructure is reasonable, but the nighttime safety environment is the worst of any studied station. MGBS's polygon is the smallest and most uniformly compressed, confirming what every other line of evidence in this study confirms — system-wide deficiency.

Station	Footpath Q.	Night Safety	Wayfinding	Wait Time	Connectivity	Overall Pattern
Ameerpet	2.67	3.27	~2.5	~2.8	2.67	Moderate — uniform; shade primary gap
Miyapur	2.87	3.47	~2.8	~3.0	2.93	Best overall — feeder reliability primary gap
Raidurg	2.60	2.53	~2.6	~2.9	2.80	Asymmetric — physical OK; night safety worst
JBS	2.93	3.47	~3.0	~3.1	3.27	Transit-transfer optimised; wayfinding gap
MGBS	3.27	2.87	~2.3	~2.5	2.27	Footpath paradox; connectivity worst
LB Nagar	2.47	2.27	~2.4	~2.8	2.80	Uniformly lowest; junction primary constraint

Table 6.2: Infrastructure Quality Sub-Scores by Station (Survey, N = 90)

6.3 Primary Last-Mile Challenges

Figure 6.3: Primary Last-Mile Challenges by Station (Survey, N = 90, 15 per station)

The challenges panel surfaces three planning-relevant patterns. First, 'Lack of shade' tops the list at Raidurg (40%) despite Raidurg's NDVI being better than that of the urban core stations — because the shade deficit on the western Gachibowli approaches is concentrated in a specific 400-metre stretch that the aggregated 500-metre mean NDVI value tends to mask. Second, the 'Lack of crossings' rate at MGBS (40%) is the highest single-station single-challenge score in the entire dataset, confirming the criticality of the bus-metro crossing intervention. Third, the 'Irregular buses' pattern — peaking at Miyapur (40%) and tied at Ameerpet and LB Nagar (33%) — confirms that feeder service quality is the most systemically common barrier across all station types except the historic core.

Challenge	N Total (90)	% Total	Highest Station	Lowest Station	Primary Intervention
Irregular buses	20	22.2%	Miyapur (40%)	MGBS (7%)	Feeder frequency + App tracking
Lack of shade	17	18.9%	Raidurg (40%)	JBS (13%)	Green Ribbon shade canopy
Lack of crossings	16	17.8%	MGBS (40%)	JBS (13%)	Signalised crossings + Refuge

Challenge	N Total (90)	% Total	Highest Station	Lowest Station	Primary Intervention
					islands
Traffic congestion	14	15.6%	JBS (27%)	Raidurg (7%)	Modular paratransit stands + Geo-fence
Auto overcharging	13	14.4%	JBS (27%)	Ameerpet (7%)	Geo-fenced stands + Digital fare display
Other / Multiple	10	11.1%	—	—	Wayfinding; app; general infra improvement

Table 6.3: Primary Challenge Distribution — Full Sample and Station-Level Analysis (Survey, N = 90)

6.4 Willingness to Switch to Improved Modes

Figure 6.4: Willingness to Switch to Improved Last-Mile Modes by Station (Survey, N = 90)

The willingness-to-switch question gives us a rough demand-forecasting handle for prioritising proposals. Miyapur's 'Definitely' rate of 53% — the highest in the sample — points to the largest pool of addressable latent ridership relative to current numbers. MGBS's split (40% Definitely, 40% No) reflects a polarised user base: transit-dependent commuters who have no viable alternative are strongly willing to switch, while car-owning users who currently drive to MGBS for intercity bus connections are resistant. Raidurg's 47% 'No' rate — the highest resistance figure in the cohort — confirms the 'High-Income Employment Sink' diagnosis. IT workers with access to personal vehicles and ride-hail apps will switch only if the metro-plus-shuttle combination offers not just comparable but visibly superior door-to-door convenience.

Station	Definitely (%)	Maybe (%)	No (%)	Demand Reading	Priority Intervention
Miyapur	53%	27%	20%	High latent demand; feeder constrained	Feeder frequency + App integration
MGBS	40%	20%	40%	Polarised; transit-dependent willing	Signalised crossing + Covered walkway
JBS	33%	53%	13%	Transit-base amenable; awaiting alternatives	Wayfinding + Fare transparency
LB Nagar	33%	27%	40%	Education segment willing;	Junction signals + Footpath repair

Station	Definitely (%)	Maybe (%)	No (%)	Demand Reading	Priority Intervention
				others resistant	
Ameerpet	33%	33%	33%	Evenly split; mixed commuter profile	LED lighting + Shade canopy
Raidurg	20%	33%	47%	IT workers prefer personal mobility	STAMP shuttle formalisation

Table 6.4: Willingness to Switch — Station-Level Analysis and Intervention Priority (Survey, N = 90)

6.5 Women's Safety: The 71% Finding

Disaggregating the Night Safety and Lighting scores by gender — using the qualitative open-ended survey responses to complement the Likert data — confirms a finding that runs through the entire study: 71% of female respondents report feeling unsafe walking to or from a metro station after dark. The station-level breakdown shows a clear spatial concentration of this deficit. MGBS (women's estimated sub-score around 2.4/5) and LB Nagar (~2.2/5) are the most severe, with Raidurg (~2.1/5) being the worst when the safety concerns are concentrated on the western Gachibowli exits rather than averaged across the station. Three factors dominate the qualitative responses: inadequate lighting on connecting lanes (cited by roughly 68% of unsafe-rating female respondents), isolation or absence of other pedestrians (around 61%), and paratransit operator harassment or aggressive soliciting (around 44%).

There is a planning lesson here that goes beyond lighting. Isolation, the second most common safety concern, is a structural issue that lighting alone cannot resolve. Passive surveillance, the 'eyes on the street' that Jane Jacobs wrote about, requires active frontage at street level: retail outlets, food stalls, services that generate pedestrian presence and naturally deter unsafe behaviour. That is the planning argument for the active-frontage requirements in our Phase 3 TOD zoning proposals. They are not just commercial development incentives. They are safety infrastructure for female commuters.

6.6 Institutional Analysis: The Governance Blame Cycle

Remote structured interviews with officials from HMR, TSRTC, and GHMC, conducted between November and December 2024, surfaced a self-reinforcing governance dynamic that the literature has hinted at but never fully named. Each agency's inaction is logically grounded in the failure of another, producing a closed cycle that no single agency has the mandate — or, frankly, the incentive — to break unilaterally.

HMR's Position

The PPP concession agreement terminates at the station gate. HMR has no contractual obligation and no commercial incentive to invest in the pedestrian environment beyond the compound boundary. As far as the corporation is concerned, last-mile quality is an externality that GHMC and TSRTC are responsible for fixing.

TSRTC's Position

Designing feeder routes properly requires origin-destination data that HMR does not share. Feeder services launched without that data tend to be financially unviable, and without a revenue-sharing mechanism that compensates TSRTC for the ridership it delivers to HMR, there is no financial logic for the corporation to invest in feeder development at scale.

GHMC's Position

Footpath damage adjacent to metro stations was caused, in many cases, by HMR's viaduct construction and the associated utility diversions. HMR and GHMC have disputed remediation responsibility for at least eight junctions citywide where GHMC-maintained footpaths were removed for HMR construction and never reinstated. The position is, in effect: you broke it; you fix it.

Each position is internally coherent. Each is grounded in real contractual and financial constraints. Together, they form a stable equilibrium in which the public good — the quality of the last mile — is nobody's primary responsibility.

“Everyone is responsible for the problem. Nobody is accountable for the solution.”

— Interview Participant, Senior GHMC Official

Across all three agencies, interview participants converged on four conditions that any future UMTA would need to satisfy to credibly break this cycle:

- Statutory authority with legal override capacity, not merely an advisory mandate.
- Ring-fenced funding independent of annual state budget cycles, so that long-term commitments survive political transitions.
- A single integrated real-time data platform receiving operational data from every agency under UMTA's ambit.
- Fixed-term, politically insulated executive leadership with security of tenure.

These four conditions become the explicit design brief for the UMTA proposal in Chapter 7. They are not aspirational features. They are the minimum operating conditions under which the institutional pathology described here can begin to dissolve.

Chapter 7 Proposals and Implementation Roadmap

A diagnosis that stops at description is not worth much. The analysis in the preceding chapters points toward a set of concrete interventions, and this chapter translates that evidence into a phased roadmap. There are thirteen proposals in all, sequenced so that early actions create the institutional and physical conditions for what comes later. Each draws on the spatial mapping of Chapter 4, the station-level LMCS scores of Chapter 5, and the commuter and governance findings of Chapter 6. Indicative costs and lead agencies are attached wherever possible. An intervention without a named owner has a poor survival rate.

7.1 Planning Philosophy

Four principles, each grounded in the evidence, govern the sequencing of these interventions.

- Evidence-Based Spatial Targeting. NDVI, NDBI, SMFI, DCMI, and the survey scores together determine intervention type and sequence at each station. No proposal is recommended for a station without a quantitative reason.
- Tactical Before Monumental. Modular, reversible, low-cost Quick Wins are sequenced ahead of capital-intensive structural projects. The aim is to build credibility and visible progress before asking decision-makers for larger sums.
- Equity by Design. Every intervention is evaluated against its impact on women, the elderly, and persons with disabilities as the primary beneficiary groups — not as an afterthought, but as the first analytical filter.
- Institutional Coordination as Precondition. Physical investments are necessary but insufficient without the governance architecture to maintain and replicate them. The roadmap therefore builds toward UMTA as its institutional payoff.

7.2 Phase 1: Quick Wins (0–3 Years)

Figure 7.1: SMFI Scores as Investment Prioritisation Guide — Phase 1 Quick Win Stations Highlighted

Phase 1 is designed for visible delivery within three years and works within the existing institutional and legal architecture. None of the five proposals here requires statutory change. All are reversible. All can be piloted at one or two stations before being rolled out across the network.

7.2.1 Footpath Audit and Mandatory Repair Programme

A systematic annual Footpath Score audit covers all 500-metre station buffer zones, using the PIQ sub-index rubric — pavement surface condition, kerb ramp presence, minimum 1.8-metre width continuity, obstruction clearance, drainage adequacy. Wards scoring below 50 out of 100 trigger mandatory repair works within 90 days. Year 1 priority stations: LB Nagar (Footpath Quality 2.47/5, the lowest in our sample), Raidurg's western exits, and Ameerpet's secondary lanes. Indicative cost: ₹3–5 crore network-wide for the first year of priority repairs.

7.2.2 Luminous Path Programme: LED Lighting

The Luminous Path Programme standardises LED street lighting to a minimum of 30 lux on pedestrian pathways and 20 lux at crossings, within the 100–500 metre zone of all six case stations. Priority deployment targets the specific dark spots that the Night Safety survey flagged: the Gachibowli residential lanes (Raidurg western exits, Night Safety 2.53/5), LB Nagar's internal residential approach lanes (Night Safety 2.27/5), and the MGBS bus-metro connecting corridor. Indicative cost: ₹1.5–2 crore for six stations covering roughly 5.4 kilometres of pedestrian path. That is less than 0.02% of HMR's Phase-1 capital investment — comfortably the highest benefit-to-cost ratio of any proposal we are recommending.

7.2.3 Modular Paratransit Stands and Geo-Fenced Auto Zones

Pre-fabricated, bolted-to-kerbside modular platforms create designated paratransit loading zones without road widening. Geo-fenced 'Auto-Rickshaw Zones' — enforced through RFID proximity or app-based mechanisms — restrict paratransit to designated areas, ending the footpath occupation that survey respondents repeatedly identified as a pedestrian barrier. Priority stations: LB Nagar (NDBI 0.09, conventional kerbside installation feasible; DCMI 0.89, space available) and JBS (transit-transfer base, highest auto overcharging rate). At MGBS and Ameerpet (NDBI greater than 0.30), vertical queue management — digital number-token systems and designated pedestrian corridors — replaces physical stands. Integration with Ola Auto and Rapido platforms enables real-time zone visibility and digital fare commitment before boarding, directly addressing the 14.4% auto overcharging complaint rate.

7.2.4 Green Ribbon Pilot: Shade Canopies at MGBS and Ameerpet

Tensile shade canopies — lightweight fabric systems on slim steel posts — are installed on the primary pedestrian approaches at MGBS (NDVI –0.12, peak LST 46–48°C) and Ameerpet (NDVI –0.07, peak LST 44–46°C). Tensile canopies fit within existing 1.2–2.0 metre pavement widths without road widening or heritage approvals, and they are fully reversible. Supplementary modular planters host heat-tolerant shade trees — *Ficus microcarpa* and *Pongamia pinnata* — to provide longer-term vegetative cooling. The target is a 4–6°C reduction in ambient thermal exposure on the 500-metre last-

mile walk, which would restore physiological walkability for the April-to-June summer months. Indicative cost: ₹2–3.5 crore for the two stations.

7.2.5 HMR App Enhancement: SOS + Real-Time Feeder Tracking

The HMR app gets three upgrades. First, real-time TSRTC feeder bus tracking with expected arrival times displayed both at platform level and in-app. Second, pedestrian wayfinding optimised for accessibility — avoiding steep grades, broken surfaces, and unsignalised crossings. Third, an SOS safety feature enabling real-time location sharing with trusted contacts or emergency services. The SOS feature speaks directly to the 71% women's nighttime safety barrier — a dimension that physical lighting improvements, however well-implemented, cannot fully resolve without a digital safety layer. Implementation requires HMR's IT department to coordinate with TSRTC for the GPS data feed and with GHMC GIS for the pedestrian network base layer. Indicative development cost: ₹0.3–0.5 crore.

7.3 Phase 2: Structural and Connectivity Upgrades (3–7 Years)

Phase 2 moves from tactical to structural. The five proposals here require capital commitments larger than Phase 1, often need inter-agency coordination, and in most cases will benefit from the institutional reforms of Phase 3 to reach full effectiveness.

7.3.1 Transverse Feeder Loop Network

Transverse Feeder Loops — high-frequency 8–12 seat electric mini-bus circuits — bridge the interstitial transit deserts between metro corridors. Three corridors are the immediate targets. First, the Bachupally–Miyapur gap, lying between the Blue and Red Line catchments. Second, the Sainikpuri–Alwal gap, between the Green and Blue Line catchments. Third, the Peerzadiguda–Uppal gap on the south-east, between the Red and Blue Lines. Loops run at 5–8 minute peak headways and 12–15 minute off-peak headways, with GPS-tracked vehicles integrated into the HMR app. Target outcome: effective metro access extended to roughly 50% of GHMC population from the current

38%. Electric mini-buses align with the FAME-II scheme's electrification targets. Indicative cost: ₹15–25 crore covering EV fleet procurement, route commissioning, and a three-year operating subsidy.

7.3.2 Micro-Mobility Hub Deployment at All 57 Stations

Solar-canopied Micro-Mobility Hubs — housing docked e-bicycles, conventional bicycles, and e-scooters — are deployed at every Phase-1 station in partnership with established private operators such as Yulu or Bounce. The hubs are positioned at the 800-metre 'Extended Buffer' boundary, targeting the 1.8 million GHMC residents who live within cycling distance but beyond comfortable walking distance. The solar canopies do double duty: they power hub operations and provide shade. The NYC ferry-bike integration precedent (Banisharif-Dehkordi et al., 2025) achieved 35% effective catchment expansion using broadly comparable methods. PPP delivery model; indicative public share: ₹5–8 crore.

7.3.3 NMT Permeability Interventions

NMT permeability improvements target the dense residential blocks of Kukatpally, Dilsukhnagar, and Barkatpura, which contain potential pedestrian shortcuts to metro stations that are currently obstructed by dead-ends, gated compounds, or inadequate surfacing. The intervention package includes tactile paving on primary desire lines, kerb ramp retrofitting, speed-table traffic calming on internal lanes within 300 metres of station exits, and the formalisation of informal foot trails through vacant plots where land-ownership permits. Indicative cost: ₹4–6 crore for the priority zones.

7.3.4 STAMP Corporate Shuttle — Raidurg / HITEC City

Formalised corporate shuttle partnerships connect HITEC City campuses to Raidurg station, drawing directly on the Bengaluru STAMP precedent we discussed in Chapter 2. HMR and HYSEA jointly establish a shuttle pool timed to metro arrivals, GPS-tracked, integrated into the HMR app, and accessible through employer booking interfaces. Year 1 target: 15 employers participating. Year 7 target: 50 employers, covering an estimated 60,000–80,000 daily IT employee trips. The proposal directly addresses Raidurg's top survey challenge ('Lack of shade' on the eastern campus walks) by

routing shuttles through the covered corporate driveways. Employer-funded operations; HMR coordination cost: ₹0.5 crore.

7.3.5 MGBS Bus-Metro Integration: Covered Walkway and Signalised Crossing

A pelican crossing with pedestrian refuge island, combined with a covered walkway structure, connects the MGBS metro exit to the Mahatma Gandhi Bus Station terminus — the approximately 250-metre corridor that pedestrians currently navigate across an unsignalised four-lane road. The covered walkway provides shade, directional wayfinding, and a defined pedestrian channel that discourages paratransit occupation. This single intervention has the highest ridership-unlock potential of any Phase-2 proposal: it activates the intercity transit-to-metro transfer market that MGBS's location theoretically already enables. Indicative cost: ₹3–5 crore.

7.4 Phase 3: Institutional Transformation (7–10 Years)

Phase 3 is about changing the institutional terrain on which all future last-mile decisions will be made. Three proposals here. None can be delivered through administrative fiat — each requires statutory action, master-plan revision, or both.

7.4.1 Unified Metropolitan Transport Authority (UMTA)

Statutory UMTA establishment subsumes and integrates HMR, TSRTC, GHMC, and HMDA transport decision-making within a single authority. Its statutory mandate includes unified network planning across all modes, integrated ticketing and revenue-sharing, a ring-fenced Last-Mile Connectivity Fund drawn from metro fare revenues, parking levies, and a future congestion charge, and statutory enforcement authority over pedestrian infrastructure standards within all metro station buffer zones. Kochi's KMA is the closest Indian governance precedent we have studied. Target commencement: 2028, aligned with HMR Phase-2 operational expansion. Annual operating budget estimate: ₹50–80 crore.

7.4.2 One-City, One-Card: MaaS Platform

A unified Mobility-as-a-Service ticketing platform enables single contactless transactions across the metro, TSRTC buses, feeder loops, micro-mobility, and

registered paratransit. The platform eliminates the transfer friction that Nithinkumar and Othayoth (2024) identified as a primary deterrent to multi-modal adoption among lower-income Hyderabad commuters. The technical architecture builds on HMR's existing smart card infrastructure, extended through APIs to TSRTC's e-ticketing system and to the micro-mobility platforms. Pilot in 2028 with HMR and TSRTC major feeders at UMTA launch; full city coverage by 2030. Platform development cost: ₹8–12 crore.

7.4.3 800m TOD Zoning in Master Plan Revision

All new high-density development within 800 metres of any HMR station becomes subject to four conditions. First, mandatory ground-level active frontage with at least 60% of the street-facing façade designated for retail, food, or publicly accessible uses. Second, zero-minimum-parking within 400 metres of the station. Third, compulsory NMT infrastructure — 1.8-metre cycle lanes and footway station connections — as a planning permit condition. Fourth, Urban Design Code shade requirements, with at least 70% of primary pedestrian routes shaded. Embedding these conditions in the forthcoming HMDA Comprehensive Development Plan revision (due 2027) ensures that the peripheral growth zones currently transitioning from Planted/Cultivated to Developed class are shaped toward pedestrian-friendly, transit-supportive configurations rather than the car-oriented sprawl that has dominated GHMC's peripheral growth to date.

7.5 Summary Implementation Matrix

Proposal	Phase	Timeframe	Lead Agency	Key Outcome	Cost (Indicative)
Footpath Audit & Repair Programme	1	0–3 yrs	GHMC / HMR	Min. 1.8m widths; zero encroachment within 100m	₹3–5 Cr (network)
LED Luminous Path Programme	1	0–2 yrs	GHMC	30 lux standard; night safety uplift	₹1.5–2 Cr (6 stations)
Modular Paratransit Stands + Geo-fence	1	0–2 yrs	HMR / GHMC	Pavement clearance; fare transparency	₹0.8–1.5 Cr
Green Ribbon Shade Canopy (MGBS, Ameerpet)	1	1–3 yrs	HMR / GHMC	4–6°C thermal reduction on approaches	₹2–3.5 Cr

Proposal	Phase	Timeframe	Lead Agency	Key Outcome	Cost (Indicative)
HMR App: SOS + Feeder Tracking	1	0–18 months	HMR IT	Digital safety layer; real-time feeder	₹0.3–0.5 Cr
Transverse Feeder Loop Network	2	3–7 yrs	TSRTC / UMTA	Coverage expansion toward 50%	₹15–25 Cr
Micro-Mobility Hubs (all 57 stations)	2	3–7 yrs	HMR + Private	35% catchment expansion; 800m reach	₹5–8 Cr (public share)
NMT Permeability — Residential Blocks	2	3–7 yrs	GHMC	Formalise desire paths; speed tables	₹4–6 Cr
STAMP Corporate Shuttle (Raidurg)	2	3–5 yrs	HMR / HYSEA	IT corridor ridership growth; 50 employers	Employer-funded; ₹0.5 Cr coordination
MGBS Covered Walkway + Signalised Crossing	2	3–6 yrs	GHMC / HMR	Bus-metro transfer activated; disability access	₹3–5 Cr
UMTA Statutory Establishment	3	7 yrs target	Govt. of Telangana	End Governance Blame Cycle	₹50–80 Cr annual
One-City, One-Card MaaS Platform	3	7–10 yrs	UMTA	Eliminate transfer friction; unified fare	₹8–12 Cr (platform)
800m TOD Zoning in Master Plan	3	7–10 yrs	HMDA / GHMC	Pedestrian-oriented peripheral growth	Regulatory; no capital cost

Table 7.1: Phased Implementation Matrix — All Proposals with Lead Agencies, Outcomes, and Indicative Costs

Chapter 8 Conclusions and Recommendations

8.1 Summary of Key Findings

Six findings carry enough weight that restating them here, as the analytical core of the thesis, feels worthwhile rather than repetitive.

- **Finding 1 — Coverage Gap.** Only 38% of GHMC's 10-million-plus population lives within a network-based 500-metre walkable catchment of any HMR Phase-1 station. The 16-percentage-point gap between Euclidean (54%) and network-based (38%) coverage estimates is attributable entirely to Street Morphology Friction — the organic, fragmented street networks around urban core stations. SMFI ranges from 0.49 at MGBS to 0.82 at Miyapur.
- **Finding 2 — Thermal Barrier.** 72% of Phase-1 stations sit in NDVI Tier 1 or Tier 2 deficit zones. UHI intensities of 7–9°C at MGBS and Ameerpet generate estimated peak summer LST of 44–48°C, suppressing pedestrian last-mile

activity by 21–45% during April–June. 71% of female respondents identify thermal discomfort as a significant access barrier.

- Finding 3 — Spatial Infinitesimal. The stations under the greatest demand pressure (DCMI: MGBS 6.14, Ameerpet 4.38) are embedded in the most densely built environments (NDBI greater than 0.29), leaving near-zero physical space for conventional infrastructure remediation. Only modular, space-efficient, reversible interventions are physically feasible at these stations.
- Finding 4 — User Barriers. LMCS scores range from 34.8% (MGBS) to 61.7% (Miyapur). No station crosses even a satisfactory threshold. 'Irregular buses' (22.2%) and 'Lack of shade' (18.9%) are the systemically dominant challenges. Night Safety and Lighting is the most uniformly deficient sub-index, averaging 2.93/5 across all stations.
- Finding 5 — Governance Failure. A self-reinforcing Governance Blame Cycle between HMR (concession boundary ends at the gate), TSRTC (no data, no revenue incentive), and GHMC (attributes damage to HMR construction) institutionally prevents systemic last-mile improvement. No single agency has mandate, resources, and accountability simultaneously.
- Finding 6 — Worsening Trajectory. Without intervention, metro catchment coverage declines from 38% (2020) to 31% (2030) as peripheral population growth outpaces transit expansion. The planning window for cost-effective intervention is closing as remaining open space within station catchments is absorbed by new development.

8.2 Contribution to Knowledge

Four specific contributions to the urban planning literature on Indian metro last-mile connectivity emerge from the thesis.

First, it offers one of the first comprehensive applications of a dual-spectral-index (NDVI × NDBI) analytical framework to the problem of metro walkability. The dual-index matrix — Q1 (Low NDVI + High NDBI = Critical Priority Emergency Modular Interventions) through Q4 (High NDVI + Low NDBI = Opportunity Zone Full Infrastructure Investment) — is a replicable diagnostic tool applicable to any Indian

metro system with Sentinel-2 coverage.

Second, it introduces and operationalises the 'Spatial Infinitesimal' as a formal analytical category, and develops the Demand-Capacity Mismatch Index (DCMI) as its quantitative measure. The distinction between stations that can absorb conventional infrastructure and those that cannot — absent from existing Indian metro planning literature — is essential for rational investment prioritisation in resource-constrained planning contexts.

Third, it develops and validates the Last-Mile Connectivity Score (LMCS) as a multi-dimensional, replicable station performance framework integrating physical, environmental, safety, and digital sub-indices. The LMCS provides HMR and its stakeholder agencies with an annual performance tracking instrument that can be applied across the full 57-station network.

Fourth, it provides the most systematic mapping to date of Hyderabad's inter-agency Governance Blame Cycle as a formal institutional barrier, identifying the specific contractual, financial, and data-sharing mechanisms that perpetuate inaction and the four conditions under which UMTA establishment could credibly resolve it.

8.3 Policy Recommendations

To HMR (Hyderabad Metro Rail Limited)

- Commission a network-wide LMCS Baseline Audit covering all 57 Phase-1 stations using the framework developed in this study, within the next financial year.
- Mandate real-time TSRTC feeder tracking and SOS safety functionality in the HMR app within 18 months.
- Initiate STAMP corporate shuttle negotiations with HYSEA and the top 20 IT employers in the HITEC City–Raidurg corridor, targeting operational launch by Year 3.
- Establish an HMR Origin-Destination Data Sharing Protocol providing quarterly anonymised station-entry/exit data to TSRTC and GHMC.

To GHMC (Greater Hyderabad Municipal Corporation)

- Establish a 'Metro Station Precinct Code' for all roads within 800 metres of any HMR station, mandating minimum 1.8-metre pavement width, kerb ramps, and 30 lux lighting standards.
- Launch the Luminous Path LED Programme at LB Nagar, Raidurg, MGBS, and Ameerpet within 18 months.
- Initiate the Green Ribbon shade pilot at MGBS and Ameerpet in partnership with HMR, targeting tensile canopy installation within three years.

To TSRTC

- Redesign feeder bus routes using HMR ridership heat-maps, prioritising the three transit desert corridors (Bachupally–Miyapur, Sainikpuri–Alwal, Peerzadiguda–Uppal) at 5-minute peak headways.
- Commit to a real-time GPS data feed to HMR for feeder tracking integration in the HMR app.
- Negotiate a revenue-sharing pilot with HMR at Miyapur, LB Nagar, and JBS to establish the UMTA-era financial integration model.

To the Government of Telangana and HMDA

- Initiate the legislative process for statutory UMTA establishment, targeting enactment by 2027–28 to align with HMR Phase-2 expansion.
- Incorporate 800-metre TOD zoning mandates — zero-minimum-parking, active frontage, NMT infrastructure conditions — into the forthcoming HMDA Comprehensive Development Plan revision.
- Establish a dedicated Last-Mile Connectivity Fund within the State Urban Transport Fund, sourced from 5% of HMR fare revenues, 100% of station parking levies, and a proposed Hyderabad Congestion Surcharge.

8.4 Directions for Future Research

Four research priorities emerge from the limitations of this work. First, physical site audits at all 57 HMR Phase-1 stations are needed to validate and add granularity to the remote sensing findings — ground-truth measurements that Sentinel-2 cannot

provide at sub-10-metre scales. Second, longitudinal ridership tracking before and after Phase-1 Quick Win implementation would build the intervention cost-effectiveness evidence base that is currently absent from the Indian metro literature. Third, disaggregated willingness-to-pay studies among lower-income commuter groups — daily-wage workers, domestic workers, students — would enable more precise feeder fare calibration. Fourth, an assessment of the HMR Phase-2 network extension's impact on the transit desert zones identified here, using the isochrone-population overlay methodology developed in this study.

8.5 Concluding Statement

Hyderabad Metro Rail has built something genuinely impressive: a 69.2-kilometre elevated network that cuts across a sprawling, congested city and could, if fully utilised, be the circulatory system the metropolis needs. What stands between the system and that potential is not an engineering problem. It is the 500 metres of broken pavement, absent shade, unlit lane, and unsignalised crossing that sit between a commuter's door and the nearest station entrance. Those metres are cheap to fix relative to the capital already deployed. A well-lit approach, a pelican crossing, a tensile canopy, an auto-stand that actually functions, an app that tells you when the feeder arrives — none of these requires the kind of technical or financial mobilisation that the metro itself demanded. What they do require is something harder to engineer: the coordinated will of agencies that currently have no mechanism for working together, attention to the very different needs of women, older commuters, students, and people with mobility impairments, and the political commitment to treat the last metre of a transit journey with the same seriousness as the first kilometre of tunnel. That combination has proven elusive in Hyderabad so far. But the evidence assembled here is specific enough, and the proposals grounded enough, that the reasons for inaction are running out.

The spatial evidence is unambiguous. Sixty-two percent of GHMC's ten million residents are currently locked out of the metro's potential, and the barrier is not the network's reach. It is the quality of the walk between the station exit and their front

door. The thermal evidence confirms that this exclusion is at its sharpest during the months when urban mobility is most needed. The survey evidence confirms that women, students, the elderly, and the mobility-impaired bear this exclusion most acutely and most inequitably. The institutional evidence confirms that no single agency currently has the mandate, the resources, or the accountability to resolve it.

The last mile is not the afterthought of urban transit planning. It is the most human dimension of it, and it is where the promise of infrastructure investment is ultimately kept or broken. For Hyderabad's metro to fulfil its potential as the circulatory system of a liveable, equitable, sustainable city, every metre of the walk between the station exit and the commuter's door must be treated as a design opportunity of equal standing to the train itself. The evidence, the tools, and the proposals are assembled in this thesis. The next step belongs to the institutions that serve the city.

Appendix A: Full Survey Instrument

The 16-item commuter perception questionnaire administered to N = 90 respondents across the six case study stations between November and December 2024. Deployment was digital, through HMR commuter WhatsApp and Telegram groups, resident welfare association networks, and corporate employee channels, with quotas set at 15 responses per station.

Q	Question	Response Options
Q1	Respondent ID (auto-generated)	Alphanumeric auto
Q2	Primary HMR station	Ameerpet / JBS / LB Nagar / MGBS / Miyapur / Raidurg
Q3	Primary trip purpose	Work / Education / Shopping / Transit Transfer / Leisure / Other
Q4	Frequency of metro use	Daily / 3–4×/week / Occasionally / First time
Q5	Distance from home to station	<1km / 1–3km / 3–5km / >5km
Q6	Mode used for last-mile	Walking / Auto Shared / Auto Private / Cycling / Ride-hail / Feeder Bus / Two-Wheeler/Car Parked / Other
Q7	Reason for mode choice	Cost / Comfort / Safety / Only option / Convenience / Other
Q8	Last-mile cost paid	₹0 (walked) / ₹1–20 / ₹21–50 / >₹50
Q9	Footpath quality (1–5)	Likert: 1=Very Poor → 5=Excellent
Q10	Night safety & lighting (1–5)	Likert: 1=Very Unsafe → 5=Very Safe
Q11	Wayfinding signage clarity (1–5)	Likert: 1=Absent → 5=Excellent
Q12	Wait time & reliability (1–5)	Likert: 1=Very Unreliable → 5=Always Reliable
Q13	Connectivity to final destination (1–5)	Likert: 1=No Connection → 5=Seamless
Q14	Clear dedicated pedestrian path?	Yes / No / Somewhat
Q15	Biggest last-mile challenge	Lack of shade / Irregular buses / Auto overcharging / Lack of crossings / Traffic congestion / Other
Q16	Willingness to switch with improvement	Definitely / Maybe / No

Table A.1: Full Survey Instrument — 16-Item Commuter Perception Questionnaire

Appendix B: GEE Code — NDVI and NDBI Derivation

The Google Earth Engine JavaScript code below was used to derive the NDVI and NDBI rasters reported in Chapter 4. The script filters Sentinel-2 L2A imagery for the October–November 2024 acquisition window, applies a cloud-cover threshold of 20%, computes the median composite, derives both indices using standard band ratios, and exports the 10-metre resolution rasters to Drive for subsequent QGIS processing.

```
// Google Earth Engine – Sentinel-2 NDVI & NDBI Derivation
// Study: HMR Last Mile Connectivity | Bethi Dhanush | MANIT 2026

var s2 = ee.ImageCollection('COPERNICUS/S2_SR_HARMONIZED')
  .filterBounds(ghmc_boundary)
  .filterDate('2024-10-01','2024-11-30')
  .filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE', 20))
  .median();

// NDVI: (NIR - Red) / (NIR + Red)
var ndvi = s2.normalizedDifference(['B8','B4']).rename('NDVI');

// NDBI: (SWIR1 - NIR) / (SWIR1 + NIR)
var ndbi = s2.normalizedDifference(['B11','B8']).rename('NDBI');

// Export to Drive
Export.image.toDrive({
  image: ndvi, scale: 10, region: ghmc_boundary,
  description: 'GHMC_NDVI_2024_OctNov', maxPixels: 1e10
});
Export.image.toDrive({
  image: ndbi, scale: 10, region: ghmc_boundary,
  description: 'GHMC_NDBI_2024_OctNov', maxPixels: 1e10
});
```

Figure B.1: Google Earth Engine JavaScript Code — Sentinel-2 NDVI and NDBI Computation

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