Geospatial Assessment of Transformations under TOD: Case of Pune

A THESIS

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by

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I hereby certify that the work which is presented is being presented in the thesis entitled **" Geospatial Assessment of Transformations under TOD: Case of Metro City"** in partial fulfilment of the requirements for the award of the Master Planning (2024-2026) and submitted in the Department of Architecture and Planning f Maulana Azad National Institute of Technology, Bhopal is an authentic record of my own work carried out during the period from **December 2025** to **May 2026** under the supervision of **Dr. Yogesh K Garg**, Professor Department of Architecture and Planning from Maulana Azad National Institute of Technology, Bhopal.

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Abstract

Urban growth in Indian cities has increasingly shifted towards transit-oriented development (TOD) as a strategy to promote sustainable, compact, and accessible urban forms. The introduction of metro systems in cities like Pune has significantly influenced surrounding land use patterns, mobility structures, and urban development intensity. In this context, the District Court Metro Station area serves as a critical case for understanding the interaction between transit infrastructure and urban transformation.

This thesis examines the spatial transformation and mobility dynamics of the District Court Metro Station TOD influence area in Pune. The study integrates land cover and built form analysis with mobility and accessibility assessment using GIS-based spatial techniques. The land use transformation analysis evaluates changes in built-up areas, green spaces, urban density, and amenity distribution, highlighting a trend toward increased urban consolidation and redevelopment near transit corridors. The built form analysis further reveals intensification of development and morphological changes influenced by accessibility.

In addition, the mobility and accessibility chapter assesses street network structure, intersection density, transit node influence, parking distribution, and pedestrian infrastructure. The findings indicate that while the study area exhibits strong accessibility near the metro station, it also shows fragmented pedestrian networks, uneven connectivity, and significant reliance on on-street parking. These conditions reflect a transitional urban environment with emerging TOD characteristics but incomplete integration.

Based on the spatial analysis, the thesis proposes a set of strategic interventions including feeder connectivity improvements, pedestrian network enhancement, traffic calming measures, green infrastructure development, parking rationalization, and mixed-use redevelopment strategies. These proposals aim to strengthen last-mile connectivity, improve walkability, and promote a more integrated and sustainable urban structure.

The study concludes that the District Court Metro Station area demonstrates partial but evolving TOD characteristics, where transit accessibility strongly influences urban form and activity concentration. However, achieving full TOD potential requires targeted improvements in multimodal integration, pedestrian infrastructure, and land-use planning.

सारांश (Abstract)

भारतीय शहरों में शहरी विकास तेजी से ट्रांज़िट-ओरिएंटेड डेवलपमेंट (TOD) की ओर बढ़ रहा है, जो सतत, सघन और सुगम शहरी स्वरूप को बढ़ावा देने की एक रणनीति है। पुणे जैसे शहरों में मेट्रो प्रणालियों की शुरुआत ने आसपास के भूमि उपयोग पैटर्न, गतिशीलता संरचना और शहरी विकास की तीव्रता को महत्वपूर्ण रूप से प्रभावित किया है। इस संदर्भ में, डिस्ट्रिक्ट कोर्ट मेट्रो स्टेशन क्षेत्र ट्रांज़िट अवसंरचना और शहरी परिवर्तन के बीच अंतःक्रिया को समझने के लिए एक महत्वपूर्ण अध्ययन क्षेत्र के रूप में उभरता है।

यह शोध प्रबंध पुणे के डिस्ट्रिक्ट कोर्ट मेट्रो स्टेशन TOD प्रभाव क्षेत्र में स्थानिक परिवर्तन और गतिशीलता की प्रवृत्तियों का विश्लेषण करता है। अध्ययन में GIS-आधारित स्थानिक तकनीकों के माध्यम से भूमि आवरण एवं निर्मित स्वरूप विश्लेषण के साथ-साथ गतिशीलता और सुगमता (mobility and accessibility) का मूल्यांकन किया गया है। भूमि उपयोग परिवर्तन विश्लेषण में निर्मित क्षेत्र, हरित क्षेत्रों, शहरी घनत्व और सुविधाओं के वितरण में आए परिवर्तनों का आकलन किया गया है, जो यह दर्शाता है कि ट्रांज़िट कॉरिडोर के आसपास शहरी सघनीकरण और पुनर्विकास की प्रवृत्ति बढ़ रही है। निर्मित स्वरूप विश्लेषण आगे यह स्पष्ट करता है कि सुगमता से प्रेरित विकास की तीव्रता और शहरी आकृति में संरचनात्मक परिवर्तन हो रहे हैं।

इसके अतिरिक्त, गतिशीलता और सुगमता अध्याय में सड़क नेटवर्क संरचना, चौराहा घनत्व, ट्रांज़िट नोड का प्रभाव, पार्किंग वितरण और पैदल यात्री अवसंरचना का मूल्यांकन किया गया है। निष्कर्ष बताते हैं कि अध्ययन क्षेत्र में मेट्रो स्टेशन के निकट उच्च स्तर की सुगमता मौजूद है, लेकिन साथ ही पैदल यात्री नेटवर्क में विखंडन, असमान कनेक्टिविटी और सड़क किनारे पार्किंग पर अत्यधिक निर्भरता भी देखी जाती है। यह स्थिति एक संक्रमणकालीन शहरी परिदृश्य को दर्शाती है, जिसमें TOD के लक्षण तो विकसित हो रहे हैं, लेकिन उनका पूर्ण एकीकरण अभी शेष है।

स्थानिक विश्लेषण के आधार पर यह शोध प्रबंध कई रणनीतिक हस्तक्षेप प्रस्तावित करता है, जिनमें फीडर कनेक्टिविटी में सुधार, पैदल यात्री नेटवर्क का सुदृढ़ीकरण, ट्रैफिक शांतिकरण उपाय, हरित अवसंरचना विकास, पार्किंग का युक्तिकरण और मिश्रित उपयोग पुनर्विकास रणनीतियाँ शामिल हैं। इन प्रस्तावों का उद्देश्य अंतिम-मील कनेक्टिविटी को मजबूत करना, वॉकएबिलिटी में सुधार करना और एक अधिक एकीकृत एवं सतत शहरी संरचना को बढ़ावा देना है।

अध्ययन यह निष्कर्ष निकालता है कि डिस्ट्रिक्ट कोर्ट मेट्रो स्टेशन क्षेत्र आंशिक लेकिन विकसित होते TOD गुणों को प्रदर्शित करता है, जहाँ ट्रांज़िट सुगमता शहरी स्वरूप और गतिविधि संकेंद्रण को महत्वपूर्ण रूप से प्रभावित करती है। हालांकि, पूर्ण TOD क्षमता प्राप्त करने के लिए मल्टीमॉडल एकीकरण, पैदल यात्री अवसंरचना और भूमि-उपयोग योजना में लक्षित सुधार आवश्यक हैं।

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List of Abbreviations

1. **BAR** – Built-up Area Ratio
2. **CMP** – Comprehensive Mobility Plan
3. **DCR** – Development Control Regulations
4. **DP** – Development Plan
5. **DPR** – Detailed Project Report
6. **FAR** – Floor Area Ratio
7. **FSI** – Floor Space Index
8. **GIS** – Geographic Information System
9. **GTFS** – General Transit Feed Specification
10. **ITDP** – Institute for Transportation and Development Policy
11. **LULC** – Land Use and Land Cover
12. **MCDM** – Multi-Criteria Decision Making
13. **MMI** – Multi-Modal Integration
14. **Mohua** – Ministry of Housing and Urban Affairs
15. **MRT** – Mass Rapid Transit
16. **NDVI** – Normalized Difference Vegetation Index
17. **NMT** – Non-Motorized Transport
18. **OSM** – OpenStreetMap
19. **POI** – Point of Interest
20. **PPP** – Public–Private Partnership
21. **SDG** – Sustainable Development Goals
22. **SPV** – Special Purpose Vehicle
23. **TOD** – Transit-Oriented Development
24. **ULB** – Urban Local Body
25. **VCF** – Value Capture Finance
26. **VOS viewer** – Visualization of Similarities Viewer (Bibliometric

Chapter 1: Introduction

The horizontal growth of Indian cities has produced urban sprawl that has created inefficient use of land, increased costs to provide infrastructure, and therefore a greater need for energy to support the increased utilisation of that land. The increase in the number of people using private vehicles adds to the already existing problems of congestion, air pollution, and road safety. These problems indicate an urgent need for a coordinated approach to managing urbanisation, integrating land-use planning with sustainable mobility strategies.

1.1 Urbanization and Emerging Challenges

The rapid growth of cities has affected the economy, culture & innovation, creating numerous issues for urban dwellers such as low-quality housing, significant homelessness and unemployment, but there is hope with the growth of cities leading to an increase in the demand for environmentally friendly solutions through better land utilization, better infrastructure development and an increased emphasis on sustainable living practices (UN 2019). The challenges of urbanisation and sustainable development are only growing as more people around the world migrate to urban centres and the continued influx of people into cities has created even greater pressures on available resources and leads to an increasing demand for affordable, environmentally sustainable housing options. Sustainable housing options in urban areas are now critical to achieving the United Nations Sustainable Development Goals.

In India, the scale of urbanization has been particularly striking. The level of urbanization increased from 17.29% in 1951 to 31.6% in 2011, and the country's urban population is expected to reach 600 million by 2030 (Ministry of Housing and Urban Affairs [MoHUA], 2017b). More than 65% of the national GDP comes from urban centres. Urban centres are becoming increasingly important because a large proportion of people live in them and they contribute greatly to the economy. Unfortunately, as more and more people move to cities, the pressure on the environment to support this increased population density has only grown. The result has been increased use of private vehicles, increased travel times for people commuting to work from their urban home, a deterioration in their quality of life, and an increased burden on their local authorities for maintaining and improving the urban infrastructure. A robust transportation service can aid in accessing such opportunities-a crucial factor for a better quality of life (Vuchic, 2017).

1.2. Emergence of Transit-Oriented Development (TOD)

In response to urban sprawl and mobility challenges, Transit-Oriented Development (TOD) has gained traction as a widely accepted global planning philosophy. TOD offers compact, mixed-use, and higher density development opportunities within walking distance of major transit stations, typically 500 to 800 meters. TOD also emphasizes the

creation of pedestrian-friendly and bicycle-friendly environments, the integration of different modes of transportation, and the effective use of land to maximise the socio-economic and environmental benefits created by public transport investments.

In 1993, Peter Calthorpe developed the TOD concept, envisioning TOD as the integration of "ecology, community and the American dream" in a compact and pedestrian friendly environment within transit corridors. Over the years, TOD has developed into a meaningful worldwide strategy to develop resilient and resource-efficient metropolitan areas. An example of a TOD Goal illustration is illustrated in Figure 1.



Figure 1: Transit Oriented Development Goals (MoHUA, 2017)

These four categories represent the core objectives of the development and adoption of Transit Oriented Development. That is, Transit Oriented Development is designed to provide convenience of transportation to the residents within the development (Mobility), create community and sustainable physical environments (Urban Form) and all socioeconomic groups will have equitable access to opportunity (Social Equity). Last, but not least, that all developments must be environmentally sustainable through reduced emissions, reduced carbon footprints, and walkability/resiliency (Environmental Sustainability). Each of these four areas are interrelated. Each of these areas is necessary to support the overall successful implementation of Transit Oriented Development.

Examples from international case studies demonstrate how Transit-Oriented Development (TOD) has been employed to transform urban environments. Urban centres in Singapore and Hong Kong have taken advantage of established metro systems to develop more compact, transit-oriented neighbourhoods using a variety of approaches. Other examples are shown in cities such as Portland (USA) and Copenhagen (Denmark), where TOD has been a tool for enhancing urban livability and environmental sustainability in urban environments. These global examples illustrate how TOD can reshape social, economic and spatial structures.

1.2.1 Integration of TOD within Transit Systems

Even though TOD is applicable to bus rapid transit (BRT) and other public transport modes, its major transformation happens in the rail connections. Rail methods of transport have a fixed rail alignment, thus providing an established Linear Development Pattern and dense population growth areas overlaying the established distances from these rail lines due to the ability of the rail lines and the way they operate to provide the space needed by the compact, mixed and high-density development that occurs along the rail line corridor (Suzuki, Cervero and Iuchi, 2013). Figure 2 shows illustration depicting impact of Mass Transit System.



Figure 2 : Illustration showing impact of Mass Transit (Wordpress.com)

While Transit-Oriented Development (TOD) can be applied around various forms of public transport—including bus rapid transit (BRT) and suburban corridors—its most transformative outcomes are typically associated with rail-based transit systems. Rail corridors, owing to their permanent alignments, high passenger capacity, and long-term operational stability, provide a strong spatial structure for compact, mixed-use, and high-density urban growth (Suzuki, Cervero, & Iuchi, 2013).

Contra to bus systems, bus networks have the advantage of being flexible, which also makes them diverse in the locations of their stops. Conversely, Rail transit networks also establish predictable corridors of accessibility, which acts as an incentive for both investors and developers and influence the real estate market. Empirical research demonstrates that accessibility improvements due to rail connectivity led to significant increases in land and property values within walking distance of stations, thereby reinforcing the economic rationale of TOD (Cervero & Murakami, 2009; Bertolini, 1999).

Using a TOD policy framework together with a rail transit plan enables Urban Growth along the designated transit corridors and eliminates outward Urban Sprawl. Globally,

this has been achieved through many different models including the Rail Plus Property approach in Japan and Hong Kong, Corridor Based TOD approach in Europe, and Regionally Based Transit Villages in the United States of America (Curtis, Renne and Bertolini, 2009). In each of these cases, rail transit serves as both an essential mobility backbone and as a Spatial Catalyst that allows for the realization of TOD policy objectives such as Density, Accessibility and Sustainability by producing a tangible Urban Form. TOD has been acknowledged in India as an essential strategic response to Urban Mobility/Sustainability challenges.

According to the National TOD Policy, TOD strategies are a way to manage urban sprawl, reduce pollution, and improve access for all socio-economic levels—including those from the economically weak sectors. The New Metro Rail Policy (2017) has been developed to ensure that all metro projects will incorporate both TOD and Value Capture Financing (VCF) methodologies, indicating that TOD should be viewed not only as an intervention for mobility but also as a catalyst for urban transformation through density, value capture, and continued viability (MoHUA, 2017a).

The history of Transit Oriented Development (TOD) within India has evolved through three distinct stages.

Stage A: Foundational (2002-2006): This stage marked the establishment of India's transport backbone with the introduction of Delhi Metro and Ahmedabad Bus Rapid Transit System (BRTS), which created physical corridors upon which to build dense urbanisation in the future.

Stage B: Establishment (2015-2017): In this two-year period, the country transitioned from the focus of infrastructure to a focus on planning, culminating in the drafting of the Delhi TOD Policy (DPTP) and ultimately the National TOD Policy (NTDPTP)(2017), formalising the adoption of high-density/mixed-use/inclusivity development around transit hubs.

Stage C: Financial Integration and Adoption (2020-2040): This most recent phase has shifted to the sustainable financing and widespread adoption of TOD through its integration into the Smart Cities Mission, the development of more mature financial mechanisms such as Premium Floor Space Index (FAR) and Land Value Capture (LVC), and the goal of the complete integration of TOD by 2040. The timeline of the evolution of TOD development in India is depicted on Figure 3.

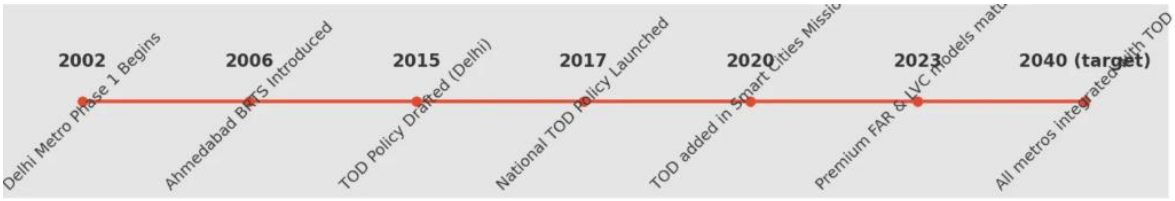


Figure 3: Timeline of TOD in India (Author)

1.3 Mass Transit Systems and Metro Rail

Mass Rapid Transit Systems (MRTS) have emerged as a vital component of sustainable urban transportation planning in rapidly urbanizing cities. Increasing population growth, rising travel demand, traffic congestion, and environmental concerns have created the need for efficient public transport systems capable of moving large numbers of people within limited urban space. MRTS, particularly metro rail systems, provide high-capacity, reliable, and time-efficient mobility solutions that help reduce dependence on private vehicles and improve overall urban accessibility (Cervero, 1998).

Metro rail systems contribute significantly toward enhancing urban mobility by reducing travel time, minimizing traffic congestion, and improving connectivity between residential, commercial, institutional, and recreational areas. Unlike conventional road-based transport systems, metro networks operate on dedicated corridors, enabling uninterrupted movement and greater operational efficiency. In addition, metro systems support sustainable urban mobility by reducing vehicular emissions, fuel consumption, and environmental degradation associated with automobile-oriented urban growth (Suzuki et al., 2013).

The integration of MRTS within urban transportation networks also promotes multimodal connectivity by linking various modes such as buses, para-transit, cycling infrastructure, and pedestrian systems. Efficient integration between transit systems and urban infrastructure improves accessibility and enhances the overall functioning of the city.

1.3.1 Metro Rail as a Catalyst for Transit-Oriented Development (TOD)

Transit-Oriented Development (TOD) is a planning approach that emphasizes compact, mixed-use, walkable, and high-density development around public transit nodes. Metro rail systems play a crucial role in supporting TOD by providing the accessibility and connectivity necessary for concentrated urban development. Transit stations function as focal points for economic and social activities, thereby encouraging organized urban growth patterns (Calthorpe, 1993).

The presence of metro infrastructure increases the attractiveness of surrounding areas for residential, commercial, and institutional development. High accessibility associated with metro stations encourages mixed land use patterns and higher development intensity within transit influence zones. TOD aims to create pedestrian-friendly environments

where daily activities can be accessed through walking, cycling, and public transportation, thereby reducing automobile dependency and promoting sustainable urban development (Dittmar & Ohland, 2004).

Metro rail systems therefore serve not only as transportation infrastructure but also as instruments for shaping urban form and guiding planned urban expansion. The integration of land use planning with transit infrastructure contributes toward the development of efficient, accessible, and liveable urban environments.

1.3.2 Influence of Metro Rail on Land Use and Urban Transformation

The introduction of metro rail systems often results in significant transformation of surrounding urban areas. Improved accessibility and connectivity influence land use patterns, built form characteristics, real estate development, and economic activities around transit corridors. Areas located near metro stations frequently experience increased commercial activity, redevelopment, densification, and changes in property values (Cervero & Murakami, 2009).

Metro stations tend to attract retail establishments, office spaces, mixed-use developments, and institutional activities due to increased pedestrian footfall and improved regional accessibility. This transformation contributes toward the emergence of active urban centers and changing spatial organization within cities. In many cases, underutilized or low-density areas surrounding transit corridors undergo redevelopment and vertical expansion, resulting in intensified urban growth patterns.

The influence of metro systems extends beyond physical transformation and also affects mobility behaviour and public space utilization. Increased pedestrian movement around metro stations generates demand for improved walkability, public spaces, last-mile connectivity, and intermodal transportation facilities. Consequently, metro-induced urban transformation often reshapes both the physical and functional characteristics of urban environments.

1.3.3 Metro Corridors as Urban Growth Generators

Metro corridors are frequently recognized as major urban growth generators because of their ability to stimulate economic development and concentrate urban activities along transit routes. Enhanced accessibility provided by metro systems attracts investment, increases land value, and encourages commercial and residential development within transit influence zones (Renne, 2009).

Transit corridors often evolve into high-intensity activity zones characterized by mixed land use, increased employment opportunities, and greater commercial concentration. Business centres, shopping complexes, hospitality establishments, and service-based activities tend to develop around metro stations due to improved connectivity and

accessibility advantages. Such growth contributes toward economic interaction and urban regeneration within the city.

However, rapid growth around metro corridors may also create challenges related to traffic congestion, parking demand, inadequate pedestrian infrastructure, and pressure on urban services if development is not supported by integrated planning mechanisms. Therefore, assessing the spatial transformation occurring around metro corridors becomes essential for understanding the effectiveness of transit-oriented development strategies and identifying opportunities for sustainable urban growth.

1.4 Urban Transformation Around Transit Nodes

The introduction of metro rail systems significantly influences the physical, functional, and socio-economic structure of surrounding urban areas. Transit nodes often emerge as centres of intensified urban activity due to improved accessibility and connectivity provided by high-capacity public transport systems. Areas located around metro stations generally experience changes in land use patterns, built form characteristics, commercial concentration, mobility behaviour, and public space utilization. Such transformation contributes toward the development of transit-oriented urban environments and reshapes the spatial organization of cities (Cervero, 1998).

Urban transformation around transit nodes is not limited to transportation infrastructure alone but also affects economic activities, pedestrian movement, accessibility, and urban growth patterns. The concentration of development around transit corridors frequently results in densification, mixed land use development, increased real estate activity, and changing mobility dynamics. However, rapid transformation may also generate challenges related to congestion, inadequate pedestrian infrastructure, parking demand, and fragmented urban development. Therefore, understanding the nature and extent of transformation occurring within transit influence zones is essential for achieving sustainable and integrated urban development.

1.4.1 Transit Nodes as Urban Activity Centres

Transit nodes, particularly metro station areas, function as important urban activity centres due to their high accessibility and connectivity advantages. The concentration of public transport infrastructure within these areas attracts a variety of urban activities including commercial, institutional, residential, and recreational functions. Metro stations facilitate the movement of large numbers of people and therefore become focal points of economic and social interaction within the city (Cervero, 1998).

The accessibility provided by transit systems encourages the concentration of commercial establishments, office spaces, retail centres, and service activities around station areas. Increased pedestrian footfall and connectivity often transform transit nodes into high-intensity urban environments characterized by continuous activity throughout the day. As

a result, metro stations influence the functional structure and spatial organization of surrounding urban areas.

1.4.2 Transformation of Built Environment and Land Use

The development of metro rail infrastructure significantly influences land use patterns and built form characteristics within transit influence zones. Areas surrounding metro stations frequently experience increased development intensity, densification, and vertical growth due to rising accessibility and land value. Improved connectivity attracts investment and redevelopment activities, resulting in the transformation of underutilized land parcels into mixed-use and high-density developments (Dittmar & Ohland, 2004).

Transit-oriented urban transformation is commonly associated with changes in land use composition, where residential, commercial, institutional, and recreational functions become increasingly integrated. Commercial activities and mixed-use developments tend to concentrate near metro stations due to higher visibility, accessibility, and economic potential. Consequently, metro corridors often emerge as dynamic urban zones that contribute toward changing urban morphology and spatial structure.

The transformation of built environments around transit nodes also affects public spaces and streetscapes. Increased urban activity generates demand for improved pedestrian infrastructure, public amenities, open spaces, and streets designed for non-motorized movement. Therefore, the quality and organization of the built environment become essential components of transit-oriented urban development.

1.4.3 Mobility and Accessibility Changes

Metro rail systems play a significant role in reshaping urban mobility and accessibility patterns. Improved regional connectivity encourages greater use of public transport and influences travel behaviour within cities. Areas surrounding transit nodes generally experience increased pedestrian movement due to the concentration of commuters and urban activities around station areas (Suzuki et al., 2013).

The effectiveness of transit-oriented environments depends largely on the quality of pedestrian infrastructure and last-mile connectivity. Walkability, street connectivity, intersection density, and accessibility to public amenities become important factors influencing mobility within transit influence zones. Efficient integration between metro systems and other transportation modes such as buses, para-transit, cycling infrastructure, and pedestrian pathways supports seamless movement and improves overall accessibility.

However, in many rapidly urbanizing cities, inadequate pedestrian facilities, fragmented street networks, traffic conflicts, and insufficient intermodal integration reduce the efficiency of transit systems. The absence of continuous footpaths, safe crossings, and

organized public spaces often limits the usability and accessibility of transit environments despite the presence of metro infrastructure.

1.4.4 Challenges in Transit Influence Zones

Although metro rail systems contribute toward urban growth and improved accessibility, rapid transformation around transit nodes may also create several planning and infrastructure-related challenges. Increased development intensity often results in traffic congestion, parking pressure, overcrowding, and strain on existing urban services. In many cases, urban growth around metro corridors occurs without adequate integration between land use planning and transportation infrastructure (Renne, 2009).

The concentration of commercial and mixed-use activities around transit stations frequently increases pedestrian-vehicular conflicts and reduces the quality of public spaces. Inadequate walkability, poor last-mile connectivity, encroachment on footpaths, and insufficient street infrastructure negatively affect the overall transit experience. Furthermore, uneven development patterns and fragmented urban growth may create accessibility disparities within transit influence zones.

These challenges highlight the need for integrated planning approaches that combine transportation infrastructure, land use planning, pedestrian systems, and public space design. Understanding the nature and extent of urban transformation around transit nodes is therefore essential for developing sustainable and efficient transit-oriented environments.

1.5 Geo-Spatial Assessment

Geospatial technologies have become important tools in contemporary urban planning and transportation studies due to their ability to analyse, visualize, and interpret spatial relationships within urban environments. The increasing complexity of urban growth and transportation systems has created the need for analytical approaches that can effectively evaluate spatial transformation and accessibility patterns. Geographic Information Systems (GIS), remote sensing, and spatial analysis techniques provide efficient methods for studying urban structure, land use dynamics, transportation networks, and infrastructure distribution in an integrated manner (Longley et al., 2015).

The development of metro rail systems significantly influences the spatial organization of urban areas and contributes toward changes in land use, built form, accessibility, and mobility patterns within transit influence zones. Understanding these transformations requires systematic spatial assessment capable of identifying and evaluating the physical and functional changes occurring around transit nodes. Geospatial analysis enables planners and researchers to examine such transformations through the integration of spatial datasets, thematic mapping, and analytical modelling techniques (Batty, 2013).

1.5.1 Role of Geospatial Techniques in Urban Planning

Geospatial technologies play a crucial role in supporting urban planning and decision-making processes by providing accurate spatial data and analytical capabilities. GIS-based analysis allows the integration of multiple datasets related to transportation, land use, infrastructure, demographics, and environmental conditions within a single analytical framework. This facilitates comprehensive assessment of urban systems and helps in understanding relationships between different spatial components (Longley et al., 2015).

In transportation planning, geospatial techniques are widely used for analysing accessibility, connectivity, mobility patterns, route efficiency, and infrastructure distribution. Spatial analysis tools such as buffer analysis, network analysis, density mapping, and overlay analysis assist in identifying areas with high activity concentration, inadequate infrastructure, and accessibility deficiencies. These techniques enable planners to evaluate the effectiveness of transportation systems and formulate evidence-based planning strategies.

The application of GIS in urban studies also supports visualization and interpretation of spatial patterns that may not be easily understood through conventional analytical methods. Mapping and spatial modelling help in identifying growth trends, urban expansion patterns, and functional relationships between transportation infrastructure and urban development.

1.5.2 Geospatial Assessment of Transit Influence Zones

Transit influence zones are areas surrounding transit stations that experience significant physical and functional transformation due to improved accessibility and connectivity. The assessment of these areas requires detailed spatial analysis of land use distribution, built environment characteristics, street networks, pedestrian accessibility, and activity concentration. GIS-based assessment provides an efficient approach for evaluating these parameters and understanding the spatial dynamics associated with transit-oriented development (Suzuki et al., 2013).

Geospatial analysis techniques are commonly used to study land use change, density patterns, intersection density, street connectivity, amenity distribution, pedestrian infrastructure, and intermodal accessibility around transit nodes. Such analysis helps identify areas of commercial concentration, mixed land use development, and infrastructure intensity within transit corridors. Spatial indicators derived through GIS also assist in evaluating the effectiveness of transit-oriented urban environments and the relationship between transportation infrastructure and urban form.

Temporal geospatial analysis further enables the comparison of urban transformation across different time periods. Satellite imagery, historical maps, and spatial datasets can be used to identify patterns of urban expansion, redevelopment, densification, and

infrastructure growth associated with metro rail systems. This helps in understanding the long-term impact of transit infrastructure on urban morphology and development trends.

1.5.3 GIS as a Tool for Transit-Oriented Planning

GIS-based assessment contributes significantly toward transit-oriented planning by supporting data-driven and evidence-based decision-making processes. Spatial analysis helps identify areas with inadequate walkability, poor connectivity, limited accessibility, and underutilized land parcels within transit influence zones. Such assessment enables planners to formulate strategies for improving pedestrian infrastructure, intermodal integration, land use efficiency, and public transport accessibility (Batty, 2013).

Overlay analysis and spatial modelling techniques are particularly useful in evaluating multiple urban indicators simultaneously. Parameters such as land use diversity, accessibility, road hierarchy, pedestrian infrastructure, intersection density, and amenity distribution can be integrated within a GIS framework to assess the overall transit-oriented character of an area. This integrated approach supports the identification of development opportunities and infrastructure deficiencies within transit corridors.

Furthermore, GIS-based visualization techniques improve the communication of planning proposals and analytical findings by presenting complex spatial information in an understandable and interpretable form. Maps, thematic layers, and spatial models facilitate better understanding of urban conditions and assist policymakers, planners, and stakeholders in making informed planning decisions.

Therefore, geospatial assessment serves as an essential approach for analysing urban transformation associated with metro rail systems and for supporting sustainable transit-oriented urban development through integrated spatial planning strategies.

1.5.4 Transformation and the Need for Spatial Evaluation

Transit systems have experienced exponential growth and change as a result of the increasing population and urbanization, as well as significant global investment in infrastructure developments. The establishment of large-scale transit systems has had significant impacts on land use and access throughout large urban areas. Specifically, the large-scale development of MRT (mass rapid transit), metro, and rail systems has changed both the dynamics of land use and the accessibility patterns of cities. Furthermore, the establishment of these transportation systems often creates new nodes of activity, as well as changing the population density, land-use mix, and real estate value along the transit corridors, thus defining the spatial structure and function of urban areas (Cervero & Murakami, 2009).

The concept of TOD (Transit-Oriented Development) is critical to understanding these changes, as it integrates land use and transportation planning to create compact, walkable, and accessible communities immediately surrounding transit stations. Even though the

global adoption of TOD principles is increasing, the extent and type of changes that may occur when utilizing TOD principles will depend on the urban form, governance structure, and socio-economic context for each location. Therefore, there is an increasing demand for spatial assessment of how TOD principles are being developed in various communities (Singh et al., 2021; Kamruzzaman et al., 2015).

The purpose of spatial evaluation is to provide a mechanism to measure and understand the change that has occurred in Land Use, Accessibility and Built Environmental changes before and after Transit implementation by considering the effects of these changes on multiple aspects of society using the latest developments in geospatial technology through the combination of different layers of data. Due to the advancements in geospatial technologies and analytical capabilities, various layers of information, such as population density, land-use diversity and network connectivity, can be combined to create a comprehensive analysis of the intensity and direction of urban transformation (Zhao et al., 2022). With this information, we are able to evaluate the success of Transit-Oriented Development (TOD) in regards to specific attributes that demonstrate the inequities in terms of both access and development potential available in each Station Area while allowing for increased evidence-based decision-making by Planners (Vale, 2015).

Ongoing urban transformations are being driven by Rapid Urbanization, Infrastructure Development and Changing Mobility Patterns in the form of existing transportation systems (esp. Mass Rapid Transit, Metro and Rail Systems) — the primary drivers of Transforming Urban Land Use Patterns and Accessibility within Urban Areas.

1.5.5 Consequences of Unchecked Transformations

To avoid the acceptance of TOD perpetuating or creating inequities in urban areas, the socio-spatial changes resulting from TOD should be examined. The main risks includes:

1. Gentrification, where increasing property values will displace low-income residents
2. Uneven Accessibility, where wealthier groups disproportionately benefit from the proximity of their property to Metro corridors;
3. Spatial Segregation, where TOD development occurs on high-value corridors while peripheral areas are left without the same level of TOD

TOD itself is not inclusive unless the correct policies and implementation methods are put into place and are monitored continuously.

1.6 Need of the Study

The rapid urbanization of Indian cities has increased the demand for sustainable transport and compact urban form. In response, Transit-Oriented Development (TOD) has emerged as a critical strategy linking transport accessibility with land use intensity (Cervero & Sullivan, 2011). However, while the policy and theoretical frameworks for TOD are well-

documented, empirical assessment of actual transformations within TOD zones remains limited in the Indian context.

Cities like Delhi, Ahmedabad, and Pune have introduced TOD policies and metro networks, yet the extent and pattern of urban transformation around these corridors particularly in terms of land use conversion, density variation, and spatial accessibility have not been comprehensively analysed (MoHUA, 2017; Kumar & Singh, 2020).

A number of studies have been conducted to assess the impact of TOD on urban transformation; however, the majority do not integrate a geospatial (spatial-temporal) perspective in order to examine the relationship between policy implementation and actual physical transformation of areas where TOD has been implemented.

Therefore, conducting a geospatial assessment will allow researchers to quantify and visualize the extent of change in these areas by using GIS, remote sensing, and spatial analytical techniques which is need of the hour. The geospatial assessment not only enables researchers to monitor the implementation of transit-oriented development (TOD) policies, but will also identify locations in the urban environment that are deviating from sustainable TOD principles.

1.6.1 Problem Statement

The rapid expansion of metro rail systems in urban areas has significantly influenced land use patterns, mobility behaviour, and urban growth dynamics within transit influence zones. Metro stations often emerge as centres of intensified development due to improved accessibility and connectivity. However, the transformation occurring around transit corridors is frequently characterized by uneven development patterns, inadequate pedestrian infrastructure, fragmented land use distribution, traffic congestion, parking pressure, and weak intermodal integration (Suzuki et al., 2013).

Despite the increasing emphasis on Transit-Oriented Development (TOD) principles, many transit node areas continue to lack efficient integration between transportation systems, land use planning, and public space design. In several urban contexts, the concentration of commercial activities and increased mobility demand around metro stations has not been adequately supported by walkable environments, accessible street networks, and effective last-mile connectivity. As a result, the overall efficiency and usability of transit-oriented environments are often reduced (Renne, 2009).

Furthermore, rapid urban transformation associated with metro systems generates significant changes in built form characteristics, accessibility patterns, and activity distribution within transit influence zones. However, these transformations are not always systematically assessed using spatial and analytical approaches. The absence of comprehensive geo-spatial evaluation limits the understanding of how transit infrastructure influences urban structure, mobility, accessibility, and land use integration.

Therefore, there is a need to undertake a geo-spatial assessment of transit-oriented urban transformation in order to evaluate the relationship between metro infrastructure, accessibility, land use dynamics, pedestrian environment, and urban growth patterns. Such assessment can help identify existing deficiencies, understand spatial transformation trends, and support the formulation of sustainable planning strategies for improving transit-oriented urban environments.

1.7 Aim

The aim of this thesis is

To assess and analyse the transformation using Geospatial techniques occurring around Transit corridors in metro cities due to the implementation of Transit-Oriented Development principles.

This study is focused on connecting the framework of Transit-Oriented Development (TOD) with analytical capabilities associated with geospatial techniques. The analysis will examine how metro transit corridors facilitate spatial and temporal land-use, built-form, and accessibility changes through time. Phase One of the methodology is structured to address the needs of the project by conducting a global and national review of TOD literature and developing a base of knowledge for use in the analysis by identifying the spatial indicators associated with the TOD concept, reviewing policies associated with TOD and identifying FSI standards as well as exploring geospatial tools that facilitate transformation analysis. Phase Two of the methodology takes those findings from Phase One and uses them to create an application-based geospatial assessment tool. This involves selecting a metro corridor, creating and geo-referencing data sets, defining the area of influence, and analysing transformation patterns based on the indicators developed in Phase One. The two phases of this methodology will provide a structured and systematic approach to developing a comprehensive TOD transformation assessment tool.

1.8 Objectives

PHASE 1:

1. To review the national and international literature to understand the evolution, principles, and global best practices of TOD.
2. To identify and adapt indicators from global and Indian contexts to assess TOD impacts.
3. To explore geospatial tools, software, and techniques for integrating and analysing data.
4. To examine TOD policies, regulations, FSI norms, and planning frameworks relevant for Metro Corridors.

PHASE 2:

1. To select City and Transit Corridor and delineate influence zones for geospatial assessment.
2. To compile and geo-reference datasets for baseline and post-TOD analysis.
3. To measure and analyse transformation shifts using indicators, capturing transformation trends.
4. To interpret results in form of Assessment maps and recommend strategies for planners and policymakers to maximize TOD's urban impact.

Each objective is designed to provide a focused sequence for both baseline assessment (Phase 1) and transformation analysis (Phase 2).

1.9 Scope

In order to investigate the impact of a metro system on urban patterns of development, land-use patterns, and accessibility patterns, this study will analyse and evaluate spatial and functional change in TOD influence zones through geospatial analysis.

The scope includes:

1. **Spatial Scope:** The research is limited to the influence zones (400–800 m) around selected metro stations, areas most impacted by transit interventions.
2. **Thematic Scope:** The study focuses on transformation, Variations and accessibility changes within TOD zones. Both quantitative (spatial) and qualitative (survey-based) data are integrated for comprehensive assessment.
3. **Analytical Scope:** Geospatial techniques including GIS mapping, remote sensing, change detection, and overlay analysis will be applied to identify and evaluate transformation trends over time.
4. **Temporal Scope:** Comparative assessment of pre- and post-metro development phases will be done to evaluate the impact of transit infrastructure on surrounding urban form and urban function.
5. **Outcome:** The study aims to develop a geospatial framework for evaluating TOD-led transformations and to provide planning and policy recommendations for promoting sustainable, transit-oriented urban development in metro cities.

1.10 Limitations

1. Data Constraints: The precision of spatial analysis depends on the availability and resolution of satellite imagery, GIS layers, and official datasets from planning and transport authorities.
2. The assessment does not cover environmental impact.
3. Temporal Mismatch: Differences in data years across various sources (e.g., census, satellite imagery, metro operation timeline) may affect direct temporal comparison.

4. Scale and Context: The study focuses on a specific metro corridor/ Stations within one metro city.
5. Methodological Dependency: The results rely on the accuracy of geospatial classification and analytical parameters; variations in resolution or processing techniques may influence certain outputs.

1.11 Methodology

The study aims to assess the current status of metro rail projects, enabling policies, regulations and management in Indian cities. The methodology is structured into two sequential phases aligned with the research objectives: (1) Baseline Understanding and Mapping, and (2) Impact Assessment and Planning Recommendations. A mixed-methods approach combining geospatial analysis, policy review, and Transformation assessment is adopted. Figure 4 explains the detailed methodology.

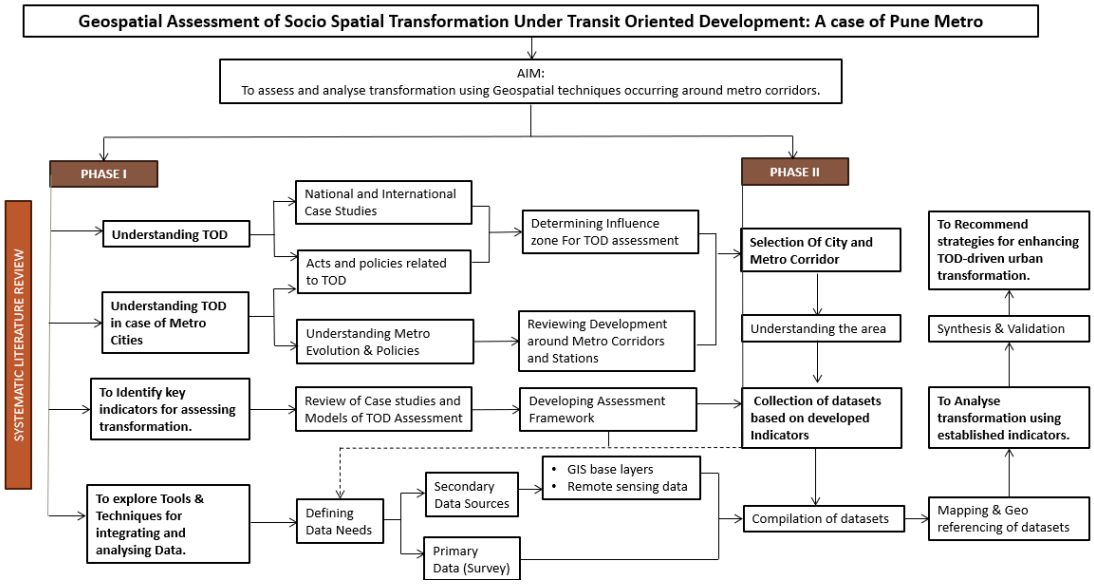


Figure 4. Methedology

1.11.1Phase I: Literature Review and Framework Development

The initial phase of the research consists of developing a foundational knowledge base and constructs the analytical framework which guides data collection and interpretation. It involves understanding TOD concepts globally and locally, identifying key transformation indicators, and selecting appropriate geospatial tools and techniques.

1. Understanding TOD

Comprehensive literature reviews of TOD, both nationally and internationally, have been completed to establish the definition of TOD, as well as to provide an overview of the role of TOD in fostering sustainable development and compact urban growth. The research then reviewed national and international case studies to identify successful TOD

implementation models and key characteristics of TOD that influence urban form and mobility.

2. Understanding TOD in the Context of Metro Cities

The study analyses how TOD principles are applied in metro-based urban systems, particularly in major Indian cities such as Delhi, Ahmedabad, and Bangalore. Case study documentation (policy documents, development plans, and metro master plans) and plans for metro development throughout India (MoHUA, 2017) have been analysed to find urban form transformations and planning responses to metro development.

3.Identification of Key Indicators

Based on literature and case study review, relevant indicators are identified for assessing transformation within TOD influence zones. These indicators are grouped into:

1. Spatial Indicators: land use mix, density, built-up intensity.
2. Accessibility Indicators: public transport accessibility, pedestrian connectivity.
3. Socio-economic Indicators: land values, employment diversity, demographic change.

4. Exploration of Tools and Techniques

The final phase of the research consists of a review of currently available GIs, Remote Sensing, and spatial modelling techniques as they can be used to integrate diverse datasets. The processes of buffer analysis, overlay analysis, and change detection have previously been used in the application of GIs as analytical tools to finalise an analytical framework.

The outcomes of Phase I include:

1. Definition of data requirements (primary and secondary).
2. Development of a geospatial assessment framework incorporating selected indicators and tools.
3. Establishment of the TOD influence zone criteria for spatial analysis.

1.11.2 Phase II: Empirical Data Collection and Analysis

The second stage of the framework will be implemented by gathering detailed data and analysing the data with GIS tools to quantify the benefits of Transit-Oriented Development (TOD).

1.Determination of Influence Area

According to the MoHUA TOD Guidelines (2017), the influence area of a metro station extends a radius of 500 to 800 metres, with this radius being defined to be the area around the metro station that has the highest potential for impact. The GIS buffer analysis will be used to delineate the boundaries of the influence zones for the identified metro stations along the selected Metro corridor.

2.Selection of Metro City and Corridor

An appropriate metro city will be chosen based upon the following factors:

1. The existence of an operating metro system,
2. The existence of TOD related policy/planning initiatives,
3. The existence of both spatial and temporal data, and
4. The city's representation of current urban transformation trends.

Within the selected metro city, one or more metro corridors or stations will be chosen for the geospatial analysis.

3.Data Collection and Compilation

Data is derived from both primary and secondary resources. Secondary data includes GIS base maps; remote sensing imaging; census data; development plans; and other policy documents. Primary data is derived through field surveys or ground truthing to verify land use, density and socio-economic characterisation. After compiling, all of the datasets will be georeferenced for insertion into the same geospatial database.

4. Through the use of GIS (Geographic Information Systems) and remote sensing, The assessment of the geospatial analysis and transformation. Spatial and temporal analysis of transformation patterns were created through mapping and quantification for the use of GIS and remote sensing tools.

5. In addition to GIS and remote sensing, recommendations for strategies that will help with enhancing the growth of Transit-Oriented Development (TOD) will also be made. The recommendations will include a focus on land use, transit integration, mixed land-use development, increasing access to transit, and improving social equity in areas affected by the metro.

Expected Outcomes

1. A geospatial framework to assess socio-spatial transformation around metro corridors.
2. Spatial maps showing the pattern and intensity of transformation.
3. Quantified indicators for TOD-based urban change.
4. Recommendations for effective TOD implementation and urban policy guidance.

CHAPTER 2: Theoretical Framework and Analytical Approach

This chapter presents the theoretical framework and analytical approach adopted for the present study. The chapter discusses the concept and indicators of transit-oriented development, stages of urban transformation around metro corridors, and geo-spatial techniques commonly used for transit-oriented assessment. The review of studies and analytical frameworks helps in identifying relevant parameters, assessment indicators, and GIS techniques that form the basis for the present research.

2.1 Introduction

The increasing expansion of metro rail systems in urban areas has significantly influenced the spatial, functional, and mobility characteristics of cities. Transit infrastructure not only improves accessibility and connectivity but also contributes toward changes in land use patterns, built form, economic activities, and urban growth dynamics within transit influence zones. As a result, the concept of Transit-Oriented Development (TOD) has emerged as an important planning approach for promoting compact, mixed-use, walkable, and transit-supportive urban environments (Calthorpe, 1993).

Understanding the relationship between transportation infrastructure and urban transformation requires a systematic evaluation of various physical, functional, and mobility-related parameters. Indicators such as land use diversity, density, accessibility, street connectivity, pedestrian infrastructure, and intermodal integration are widely used to assess the effectiveness of transit-oriented urban environments. The identification and evaluation of these indicators provide an analytical basis for understanding the extent and nature of transformation occurring around transit corridors (Ewing & Cervero, 2010).

In recent years, geo-spatial technologies such as Geographic Information Systems (GIS) and remote sensing have become essential tools for analysing urban transformation and transit-oriented development. GIS-based spatial analysis techniques enable the assessment of land use distribution, accessibility patterns, network connectivity, amenity concentration, and temporal urban change in an integrated and data-driven manner (Longley et al., 2015). These techniques support evidence-based planning and facilitate comprehensive assessment of transit influence zones.

2.2 Transit-Oriented Development (TOD)

Transit-Oriented Development (TOD) has emerged as an important urban planning approach for addressing issues related to rapid urbanization, increasing traffic congestion, environmental degradation, and excessive dependence on private vehicles. The concept promotes the integration of transportation systems and land use planning in order to create compact, accessible, mixed-use, and pedestrian-oriented urban environments centered

around public transit infrastructure. TOD aims to improve urban mobility while encouraging sustainable patterns of growth and development (Calthorpe, 1993).

The increasing expansion of metro rail systems and Mass Rapid Transit Systems (MRTS) in urban areas has further strengthened the relevance of TOD in contemporary planning practices. Transit stations and corridors often function as focal points of economic activity, mobility, and urban transformation due to improved accessibility and connectivity. As a result, planned development around transit nodes becomes essential for ensuring efficient land utilization, reduced travel dependency, and sustainable urban growth (Dittmar & Ohland, 2004).

TOD emphasizes the creation of urban environments that support public transportation and non-motorized mobility through higher density development, mixed land use, walkability, and interconnected street networks. The approach seeks to reduce automobile dependency by promoting proximity between residential areas, workplaces, commercial activities, and public amenities within accessible transit influence zones.

2.2.1 Concept and Principles of TOD

The concept of transit-oriented development was formally introduced by Peter Calthorpe in the early 1990s as an urban planning strategy focused on integrating transportation systems with compact urban development. TOD generally refers to mixed-use, high-density, and pedestrian-oriented development concentrated within walking distance of transit stations (Calthorpe, 1993).

TOD is commonly planned within a transit influence zone extending approximately 400–800 meters around transit stations, representing a comfortable walking distance for most users. These areas are designed to support public transport usage by improving accessibility and reducing travel distances between various urban activities.

Several planning principles form the foundation of TOD:

Density

Higher residential and commercial density around transit stations supports increased public transport usage and efficient land utilization. Compact development reduces urban sprawl and promotes concentration of activities within accessible transit corridors (Suzuki et al., 2013).

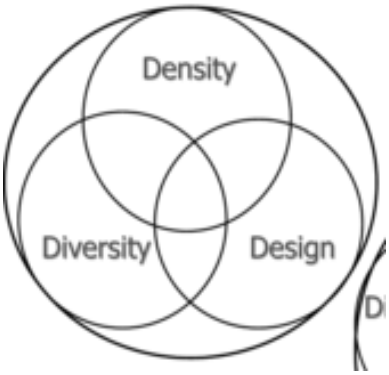


Figure 5: Principle of TOD

Diversity

TOD encourages mixed land use patterns involving residential, commercial, institutional, and recreational

activities within the same urban environment. Land use diversity reduces the need for long-distance travel and promotes accessibility through proximity between activities.

Design

Urban design within TOD focuses on creating safe, attractive, and pedestrian-friendly environments. Continuous footpaths, active streets, public spaces, landscaping, and human-scale urban design elements contribute toward improved walkability and public interaction.

Accessibility and Connectivity

Efficient street networks, pedestrian pathways, cycling infrastructure, and intermodal integration are essential components of TOD. Connectivity between transit systems and surrounding urban activities improves mobility efficiency and accessibility.

Distance to Transit

The effectiveness of TOD largely depends on proximity to transit infrastructure. Areas located within walking distance of metro stations generally exhibit higher pedestrian activity, greater accessibility, and increased development intensity compared to areas located farther away.

2.2.2 TOD Assessment

Transit-oriented development (TOD) assessment is defined as the methodical analysis of the physical, functional and spatial qualities of the area surrounding transit stations to determine how closely those qualities correspond to compact, mixed-use development that supports walking and transit, and vice versa. Recently, TOD has been considered an objectifiable spatial characteristic of development as opposed to just a planning concept, necessitating analytical methods connecting development style, transit accessibility and development potential through physical form (Vale, 2015; Sung & Oh, 2011).

TOD assessments are necessarily quantitative in nature, since development intensity, agricultural diversity, connectivity of the surrounding area/borough, and access to the area must be evaluated objectively. For example, Lyu et al. (2016) and Kamruzzaman et al. (2014) state that TOD assessment uses measurable indicators to create an objective method of comparing TOD station areas within an individual metro area and across metro areas.

The foundation of TOD assessment is geospatial analysis, GIS-based tools not only allow for identifying the distance from the centre of a station (station influence zone) to nearby development, but through the use of land use maps and satellite GIS data they enable the calculation of density and mixed-use patterns, as well as recording the physical

transformation of the area following the establishment of transit. Recent research by Wang (2019) and Kamruzzaman (2014) has used GIS tools to illustrate how the introduction of transit has resulted in significant increases in transit station/construction density and transit station developed forms, as well as shifts in accessibility and density gradients over time.

Thus, TOD assessment acts as a bridge between planning intentions and real-world outcomes. By integrating indicators with geospatial tools, TOD evaluation determines whether transit investments translate into measurable spatial transformation and whether station areas are moving toward the sustainable, transit-supportive forms (Vale, 2018).

2.2.3 Concept of TOD Assessment

For TOD assessments, there are two essential aspects: the TOD environment and the TOD outcomes. The TOD environment consists of the existing built environment, land-use configurations, street configuration, and how transit is integrated with the surrounding activity. TOD has multiple outcome categories: Built-form transformation due to transit investments that increase development intensity (e.g., increased density of residential dwelling units), a corresponding increase in the number and variety of transit modes available (e.g., improved pedestrian access), and an overall increase in the degree of mixed use for parcels along the transit corridor (Sung & Oh, 2011; Jun, 2015).

TOD assessment is inherently multi-dimensional, integrating land-use diversity, density, accessibility, and connectivity into quantifiable indicators. This multi-dimensionality allows systematic examination of how the built environment supports transit use and sustainable mobility. Measures such as the TOD Index (Lyu et al., 2016), Node–Place model evaluations (Vale, 2015), and Data Envelopment Analysis (DEA) approaches (Wang et al., 2019) demonstrate the diverse methodological paths used to assess station-area performance.

While some researchers have attempted to develop state-of-the-art modeling techniques for measuring TOD compared to widely implemented techniques (e.g., Node-Place Model and TOD Index) in planning and design. Consequently, converting spatial attributes into measurable indicators of transit-oriented station area transformation requires the use of multiple techniques; as noted by Galelo et al. (2014), a challenge in effectively evaluating TOD station area transformation is implementing best practices that result in measurable indicators that accurately match the spatial attribute transformation for a given transit-oriented development. The process for the assessment of TOD levels at rail stations is shown in Figure 6.

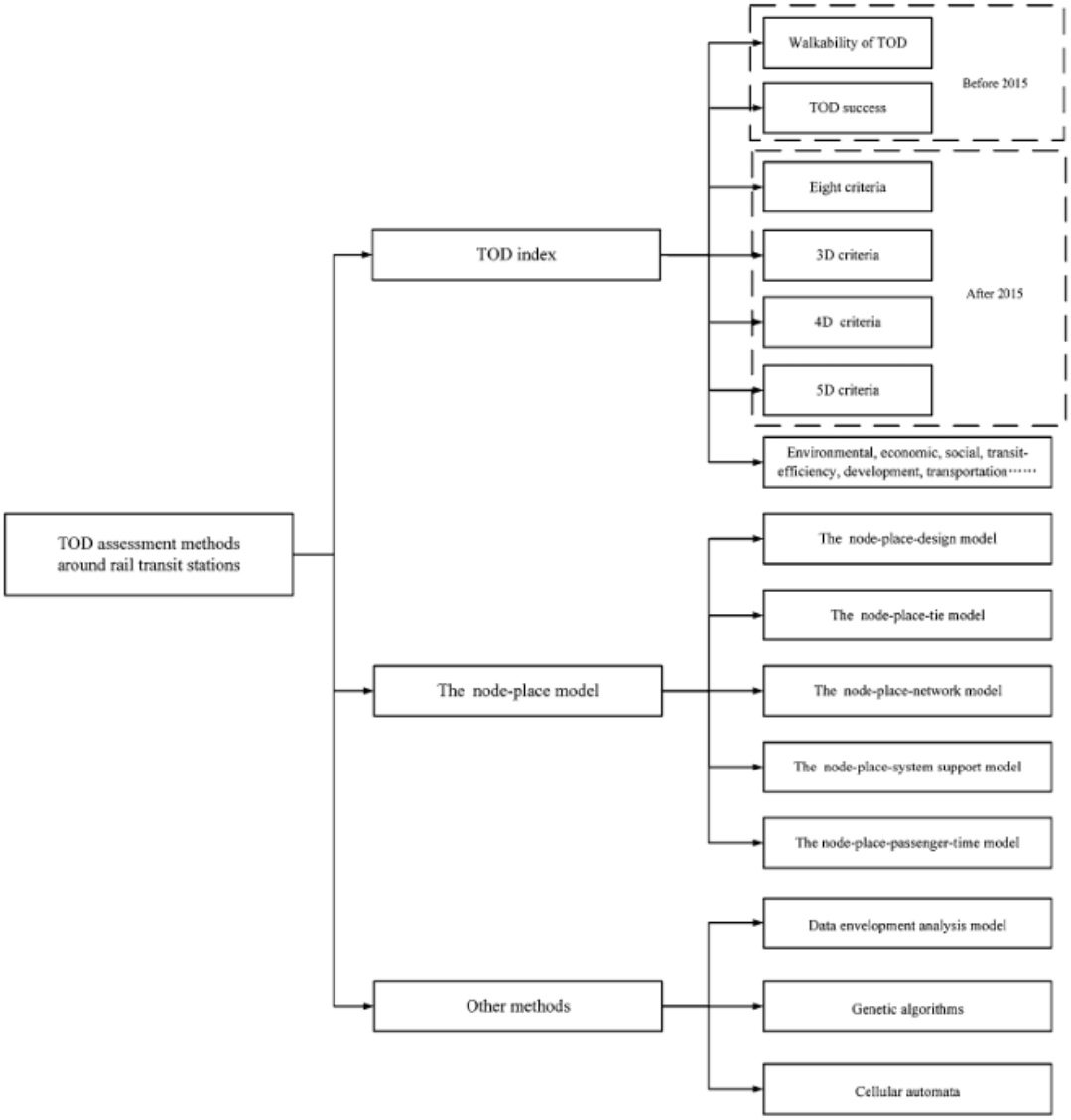


Figure 6:: Development process for the assessment of TOD levels

2.3 Tools and Techniques for Geospatial TOD Assessment

The assessment of Transit-Oriented Development (TOD) relies significantly on geospatial technology to visualise and analyse spatial change in urban areas because TOD is correlated with many aspects relating to how people live within cities; specifically, the layout of land use, the layout of streets, pedestrian access to public transportation options, and the availability of infrastructure also provided by transit. Geospatial technology can, therefore, provide an essential foundation to evaluate the impact of TOD on these different aspects of urban living. Researchers (Cervero, 2004; Curtis et al., 2009) agree that Geographical Information Systems (GIS), remote sensing and network analysis are some of the key methodological tools for evaluating and understanding TOD. Figure 7 provides the framework for measuring the Levels of Transit-Oriented Development

(TOD).

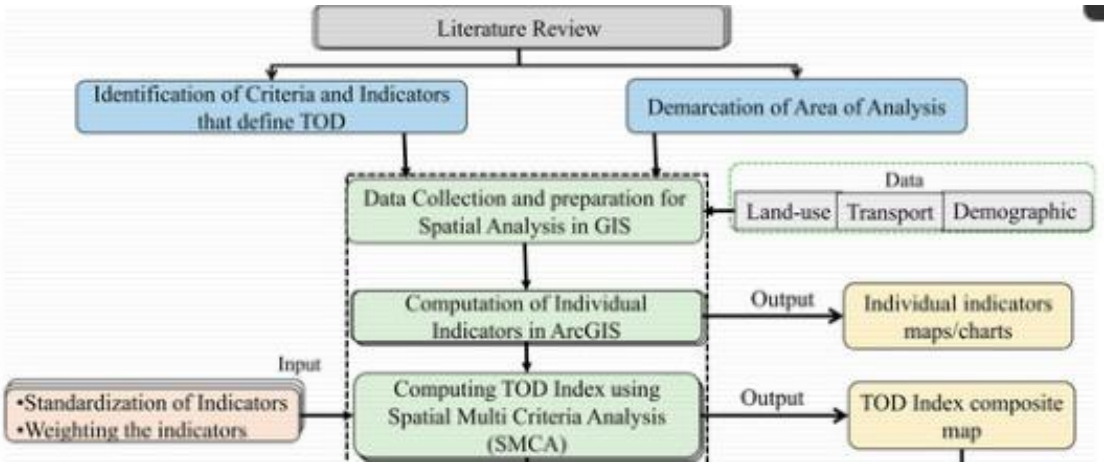


Figure 7:Methodology for Tools and Techniques (Ayesha Anwar,2024)

2.3.1 Spatial Data Sources

A range of spatial data sources are available for conducting geospatial TOD analysis. Planning documents, such as Master Plans and Development Control Regulations contain the zoning information (such as permitted uses), Floor Area Ratio (FAR) norms (such as permitted densities) and public space guidelines, which assist in the establishment of TOD. Information regarding demographics and transit demand can be ascertained from Census data. Government portals (such as Bhuvan) supply imagery and land use layers plus administrative boundaries.

A number of data sets are usually required for TOD research. These datasets consist of:

1. Master Plans, Zonal Plans, and Development Control Regulations (DCRs) relating to FAR norms and land use zoning,
2. Census data including data about the population and households,
3. OpenStreetMap (OSM) regarding the road network and amenities,
4. Satellite imagery to identify the general land cover, and
5. Government GIS portals containing data related to administrative boundaries and other planning layers.

This collection of sources provides the basic information that can be processed using GIS and/or remote sensing analytical tools.

2.3.2 Tools for Assessment

2.3.2.1 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) serve an important function in Urban and Transport Planning as they allow the Association of Several Spatial Datasets to Determine the Relationship Between Land Usage and Rules of Transit. In Research on Transit Oriented Development (TOD) GIS is frequently used to establish Metro Influence Zones,

assess land usage changes, Calculate Accessibility Degree and Assess Spatial Connectivity.

The most significant GIS Tool employed in TOD Assessment is creating Maps, Evaluating Spatial Patterns, and Integrating Various Types of Data (i.e. Land Use Maps, Road, Satellite Imagery, Census Data, Transit Locations).

The Four Primary Uses of GIS in TOD Research include:

1. Making a Boundary around the Metro Station Areas (Typically: 500m to 1,000m);
2. Analysing Historical Changes to Land Use and Building Structures.;
3. Assessing Level of Connection Between Existing Street Networks and the Future Construction of New Streets/Bike Paths/Sidewalks; and
4. Determining the Accessibility of Transit and Amenities.

Two GIS platforms are most commonly used:

ArcGIS

A professional GIS software known for powerful analysis tools. It can create walking zones, perform accessibility analysis, calculate densities, and combine many spatial layers.

QGIS

An open-source GIS software. It is free, widely used in academic research, and compatible with open data like OpenStreetMap. QGIS also allows users to perform the same major tasks as ArcGIS, including mapping, classification, spatial statistics, and network analysis.

Both platforms essentially help us understand where things are located and how they relate to each other spatially.

Role of GIS in Urban and Transit Studies

Geographic Information Systems (GIS) play a significant role in contemporary urban and transportation planning due to their capability to analyze complex spatial relationships and visualize urban phenomena. GIS facilitates the integration of various datasets including land use maps, transportation networks, building footprints, demographic information, and infrastructure data within a unified analytical framework (Batty, 2013).

In urban planning, GIS is widely used for spatial analysis, infrastructure assessment, urban growth monitoring, and decision-making processes. Spatial analysis techniques enable the identification of development patterns, accessibility conditions, land use distribution, and connectivity characteristics across urban areas. Such analysis supports

planners in understanding the interaction between transportation systems and urban structure.

GIS also plays an important role in mapping urban transformation associated with transit infrastructure. Metro rail systems and transit corridors often influence surrounding land use patterns, built form characteristics, economic activities, and mobility behavior. Through thematic mapping and temporal spatial analysis, GIS enables the comparison of urban conditions across different time periods and helps identify patterns of densification, redevelopment, commercial concentration, and infrastructure growth.

Accessibility assessment is another important application of GIS in transit studies. GIS-based network analysis and spatial modeling techniques help evaluate pedestrian accessibility, street connectivity, transit catchment areas, and intermodal integration. These analyses assist in understanding the efficiency and usability of transit-oriented environments and support the development of sustainable mobility strategies.

Geo-Spatial Methods Used in TOD Assessment

Various geo-spatial techniques are commonly used for assessing transit-oriented urban environments and analysing the spatial characteristics of transit influence zones. These methods support quantitative and spatial evaluation of land use patterns, accessibility, connectivity, mobility, and urban transformation.

Buffer Analysis

Buffer analysis is widely used in TOD studies to define transit influence zones around metro stations and transit corridors. Buffer zones are generally created within walking distances ranging from 400 to 800 meters in order to assess accessibility, land use distribution, amenity concentration, and development intensity surrounding transit nodes. Buffer analysis helps in identifying areas directly influenced by transit infrastructure.

Network Analysis

Network analysis is used to evaluate street connectivity, route efficiency, accessibility, and pedestrian movement within transit-oriented environments. GIS-based network analysis helps identify connectivity patterns, shortest paths, and accessibility conditions between transit stations and surrounding urban activities. Such analysis is important for assessing walkability and last-mile connectivity.

Density Mapping

Density mapping techniques are used to analyse the concentration and spatial distribution of urban activities, amenities, buildings, and transportation infrastructure. Density analysis helps identify high-intensity activity zones, commercial concentration, and

development patterns around transit corridors. It also assists in evaluating the compactness and accessibility characteristics of transit-oriented areas.

Overlay Analysis

Overlay analysis enables the integration of multiple spatial layers within a GIS environment to assess relationships between various urban indicators. Parameters such as land use, street connectivity, pedestrian infrastructure, accessibility, and amenity distribution can be combined to evaluate the overall transit-oriented character of an area. Overlay techniques are commonly used for composite spatial assessment and suitability analysis.

Temporal Land Use Analysis

Temporal land use analysis involves the comparison of land use patterns across different time periods to identify urban transformation associated with transit infrastructure. Satellite imagery, historical maps, and spatial datasets are used to assess changes in land use composition, built density, commercial growth, and urban expansion over time. This method helps in understanding the long-term impact of metro systems on urban development.

Spatial Modelling

Spatial modeling techniques are used to analyze and interpret relationships between urban variables and transit infrastructure. GIS-based models assist in evaluating accessibility patterns, development potential, growth trends, and spatial interactions within transit influence zones. Spatial modeling supports evidence-based planning by enabling comprehensive assessment of multiple urban parameters within a single analytical framework.

The application of these geo-spatial techniques provides an effective approach for assessing transit-oriented urban transformation and understanding the spatial dynamics associated with metro rail systems. These methods form an important analytical basis for the present study and support the evaluation of urban transformation within transit influence zones.

2.3.2.2 Remote Sensing (RS)

A significant detail about Remote Sensing is that it is a technology to acquire remotely produced images of Earth (including Land Cover Change) and Temporal Analysis of those images to look for trends over time such as Urban Form Change. Various remote sensing data products such as images from Landsat, Google Earth, and Sentinel provide users access to valuable information about the urban environment; appropriate analysis of these products may assist a user in identifying the extent to which there was an

expansion of Built-up Areas within a given time frame and assessing the degree of vegetation loss or gain from pre-transit development to post-transit development.

Tools like Google Earth Engine (GEE) allow users quick access and rapid analytical capabilities with large collections of satellite imagery. Another popular tool for remote sensing analysis is ERDAS Imagine (used by scientists for a wide variety of applications), and SNAP (used by scientists to support classification and change detection).

2.3.2.3 Network Analysis Tools

The street network is a key factor determining the walkability and accessibility (Handy et al., 2002) of TOD environments (public transportation-oriented development) with respect to residential development. Network analysis tools are used to evaluate the level of connectivity of the street network, the number of intersections in an area, and how pedestrians are connecting to the street network and the modes of transportation they use to travel the last mile to a transportation hub.

GIS software has built-in modules for analysing how well-supported a neighbourhood or community is for pedestrians and those who travel to metro stations by walking, which is an essential part of TOD (El-Geneidy & Levinson, 2006).

Open Street Map (OSM) is an open-access global mapping database that contains features such as roads, path networks, buildings, and points of interest (POI). OSM provides free vector map data on the streets, path networks, buildings, and transit stop locations (Haklay & Weber, 2008).

OSMnx is a Python library used to download and analyse data from OSM. OSMnx has been widely used in recent research to extract and analyse street networks from OSM, providing researchers with the ability to calculate metrics such as street network density, intersection density, and route effectiveness (Boeing, 2017). These metrics allow researchers to evaluate how well a neighbourhood supports pedestrian movement and public transport access.

A tool that can download street networks directly from OSM and analyse them to measure:

1. intersection density,
2. street network density,
3. route options,
4. connectivity.

Network Analyst tools in GIS

Both ArcGIS and QGIS have built-in tools that allow:

1. walking distance analysis,
2. service area creation (like 10-minute walking zones),
3. route generation,
4. connectivity assessment.

These tools help understand **how people move**, which is a key aspect of TOD.

2.4 Case Study

2.4.1 Urban Transformation Through Transit: The Case of Dubai, UAE

For the last 20 years, Dubai has seen tremendous increase in urban growth and economic growth. This rapid increase has created many problems for the infrastructure of Dubai, such as the traffic congestion, pollution, and the increasing use of sustainable urban transportation and other forms of efficient transportation. With the opening of the Dubai Metro, which is the first automated driverless rail system in the Middle East, as well as the doubling of the Metro (Red Line) in late 2009, the government of Dubai is taking action to help reduce these issues and develop sustainable urban growth with a focus on using public transportation as a mode of transportation.

1. Historical Development of Dubai Metro

Construction of the Dubai Metro was planned in the early 2000s under the leadership of Sheikh Mohammed Bin Rashid Al Maktoum and construction started in 2006 with the construction of the Red Line. The Red Line was built to provide a connection between important locations in the city, such as the Dubai International Airport and the Jebel Ali Free Zone. The Red Line's phased opening began on September 9th, 2009, when the Dubai Metro became the longest automated driverless metro system in the world. The Green Line opened in 2011 and provided service to historic locations along Dubai Creek. The Expo 2020 extension, scheduled to be completed between 2021 and 2022, added additional Metro service to the network. Figure 8 shows the Dubai Metro Network Map. There are plans for further expansion to over 320 km of metro lines by 2030 to accommodate the increased population in Dubai.

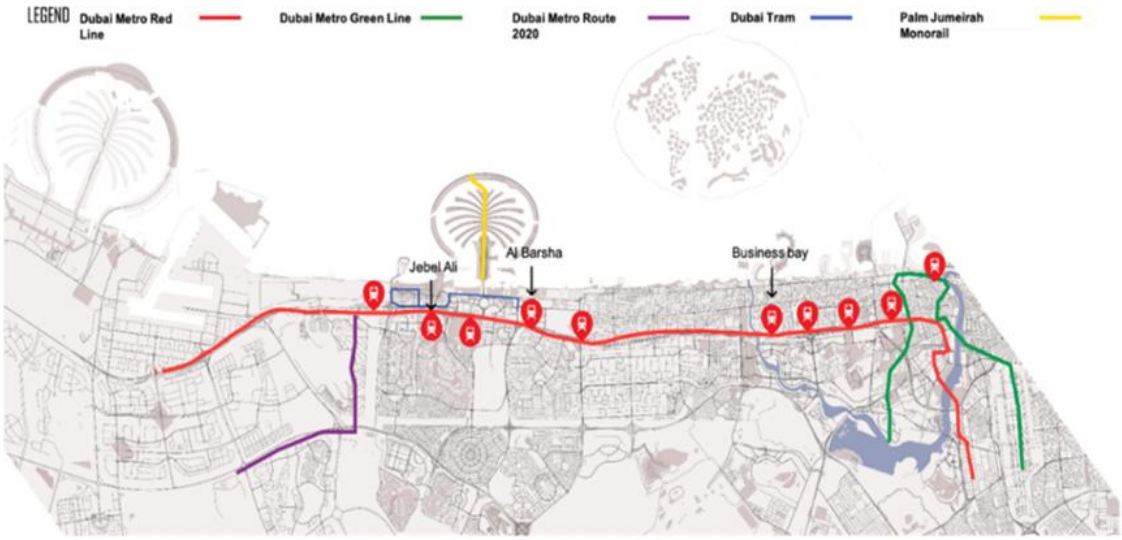


Figure 8. Metro Network in Dubai (Alefari, D,2024)

2.Population Growth and Distribution

The volume of people living in Dubai continued to expand rapidly throughout this period and has continued to do so in the last 12 years as new housing developments have developed along the Metro line. In 2008 the total population of Dubai was estimated at 1.65 million people and today (2023) is estimated to be 3.6 million people. This rapid growth in population is clearly shown in Figures 9 and 10.

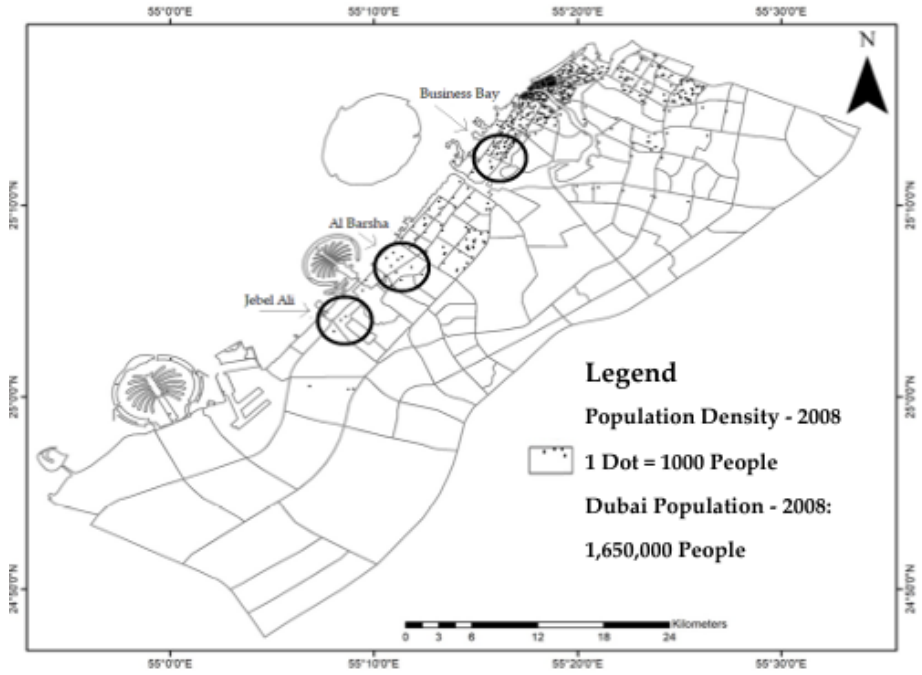


Figure 9. Population distribution pattern of Dubai in 2008 (Alefari, D,2024)

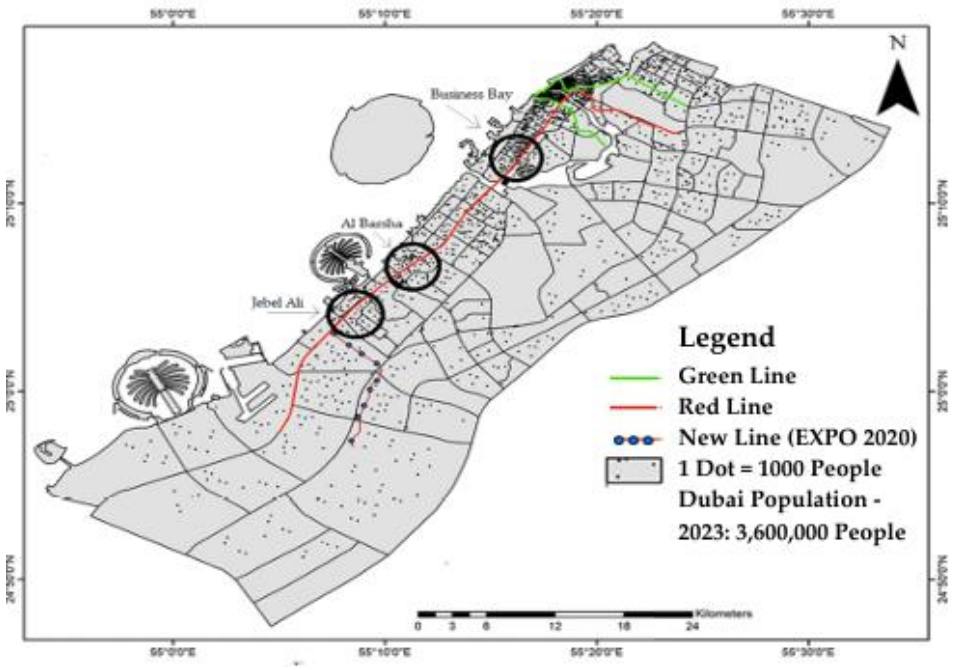


Figure 10.Population distribution pattern of Dubai in 2023 (Alefari, D,2024)

3.Land Use Change

The proximity of transit systems from Metro has created many significant changes in land use in Dubai and can be illustrated graphically through the figures below:

Jebel Ali: Residential land expanded eightfold, commercial land sixfold, and industrial areas increased significantly between 2008 and 2023. Green spaces shrunk by about 60%, reflecting trade-offs for urban expansion as seen in Table 1.

Table 1:Change in Land Use- Jebel Ali

Land Use (ha)	2008	2020	2023
Residence	37	273	301
Commercial	74	474	531
Industries	252	299	341
Green spaces	28	13	11
Lakes	8	8	7
Main Streets (km)	192	543	601

Source : Alefari, D,2024

Al-Barsha: Residential and commercial land use grew by 150% and eight times respectively, with industrial land appearing only post-Metro. Green spaces also saw a fivefold increase can be seen in Table 2.

Table 2. Change in Land Use -Al Barsha

Land Use (ha)	2008	2020	2023
Residence	10	22	25
Commercial	34	296	310
Industries	-	15	17
Green space	2	10	10
Lakes	4	4	4
Main Streets (km)	62	101	105

Source : Alefari, D,2024

Business Bay: Commercial areas surged, waterways doubled, and an advanced road network transformed the area into the new central business district as seen in Table 3.

Table 3. Change in Land Use - Business Bay

Land Use (ha)	2008	2020	2023
Residence	0	6	6
Commercial	1	5	7
Waterways	48	121	103
Green space	41	11	21
Lakes	6	10	13
Main Streets (km)	54	NA	135

Source : Alefari, D,2024

4.Changes to Patterns of Mobility

The introduction of the Dubai Metro raised the level of mobility in an urban setting and encouraged people to move away from using their own vehicles and congested roadways to an eco-friendly, rapid and consistent method of moving around the cities. With ridership increasing from 39 million in 2010 to over 109 million by 2012 - after the introduction of the Green Line - we have seen a rapid uptake in metro services. Moreover, Metro services have significantly decreased travel times, improved the reliability of metro services, decreased road congestion on major roads, decreased the number of vehicle emissions and improved the quality of air we breathe.

5. Spatio-Temporal Analyses of Impact

Using GIS and Remote Sensing, we see that metro corridors have led to populations increasingly developing in higher densities along the corridors to a greater extent between 2008 and 2023 than previously. The increased density of population in areas has come about as a result of the metro corridors creating a better connection to tradition downtown areas and expanding beyond the traditional downtown area to the metro-connected outer suburbs. Data taken from remote sensing (satellite images and land use maps) illustrate how transportation infrastructure has driven urban growth outward, reduced commuting

distances and optimised the distribution of land use. For a complete impact assessment of areas see Table 4,

Table 4:Impact on District Areas

Districts in Square Meters	Jebel Ali (2008)	Jebel Ali (2020)	Al-Barsha (2008)	Al-Barsha (2020)	Business Bay (2008)	Business Bay (2020)
Buildings in 500m radius	81.5	290394	215359	346614	28986	79342
Comments	Extremely significant change		Marginal change		Significant change	

Source: Alefari, D,2024

6. Policy Structure and Planning Approaches

Dubai Metro was developed using an integrated policy structure combining Transportation Planning, Land Use Regulations, and Sustainable Development. The Roads and Transport Authority (RTA) has used a comprehensive methodology to develop an Integrated Public Transport Plan (ITP) as well as encourage Transit Oriented Development (TOD) to ensure that the City's growth is in line with the development of a public transportation system. Additionally, there are policies in place that regulate the amount of the automobile traffic in the central areas of the City, manage parking, and encourage the use and development of energy efficient technologies.

7. Findings and Recommendations

The experience of the Dubai Metro provides important lessons regarding the construction of transit systems in rapidly urbanizing areas: phased construction of transit systems with ongoing innovation concerning technology; strong institutional leadership from government agencies; coordinated planning of land use and transportation; supporting public support for transit systems through reliability and safety of the service; and sustainable development of urban transportation systems.

2.4.2 Urban Transformation Through TOD: Case of Delhi Metro

Delhi Metro has transformed how people move around Delhi, changed the way cities are built, and changed how land is developed throughout the National Capital Region. Since its beginning in 2002, the Delhi Metro system has grown through many phases and is now the primary public transportation system in Delhi. The Metro has improved the overall organisation of Delhi as a city. The Metro case study presents examples of many different

types of urban transformations occurring in Delhi, as well as examples of transit-oriented development that can be understood.

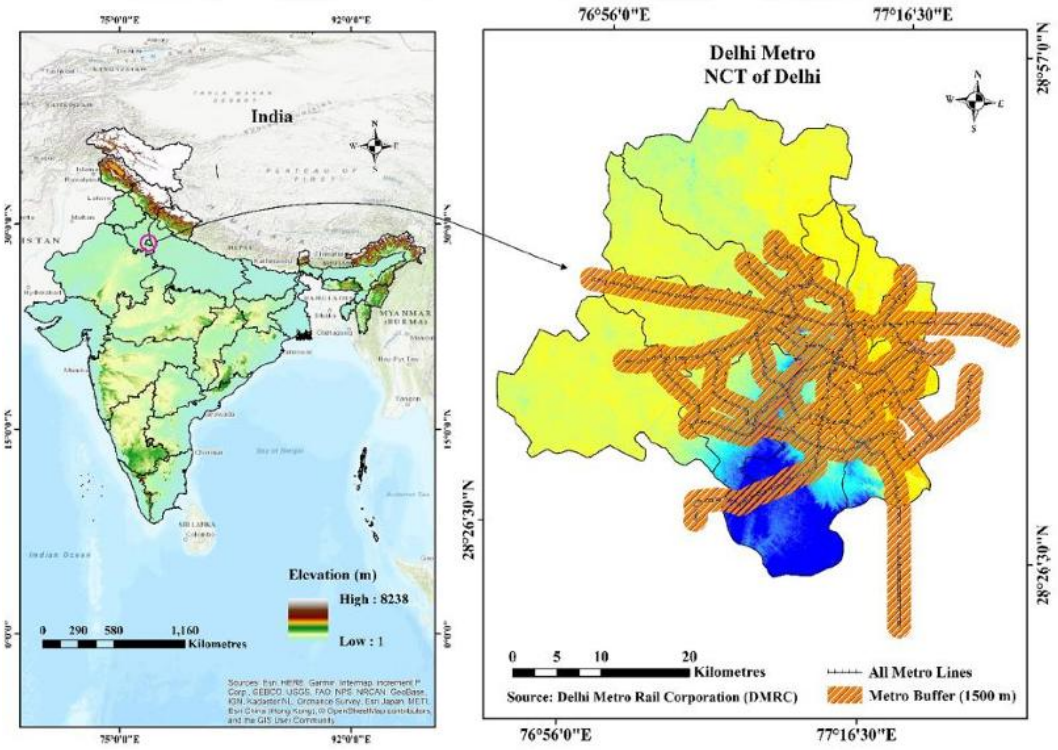


Figure 11.Location of Delhi Metro (Begam, S., Jha, P., Yadav, P.K. et al,2024)

1 Historical Context and Growth of the Delhi Metro

The Delhi Metro Rail Corporation (DMRC) began operations in 2002, marking the beginning of a new era of mass rapid transit in India. Over two decades, the network expanded through multiple phases:

1. **Phase I (2002–2006):** Introduction of three corridors
2. **Phase II (2006–2011):** Expansion to suburbs and key activity centres
3. **Phase III (2011–2024):** Integration with peripheral regions and dense urban areas
4. **Phase IV (ongoing):** Further strengthening of regional connectivity

This growth has not only improved public transport but has gradually reshaped the spatial organisation of the city.

2 Transformation in Mobility Patterns

The Metro has changed the way people travel in three ways:

1. From driving to taking public transit: Commuters who utilize the Metro experience decreased travel times and better reliability compared to driving.
2. More options available that connect to the Metro: Connecting services such as feeder buses, auto rickshaws, carsharing, and walking paths improve the ability to use public transit.

3. Increased access to periphery regions: The Metro connects to periphery regions such as Dwarka, Noida, Faridabad,etc resulting increasing access to Central Delhi.

The increase in travel choices is one of the contributing factors to the decrease in congestion on many major corridors.

3 Influence on Land Use and Urban Form

Delhi Metro has been a major catalyst for changes in land use patterns and redevelopment as shown in Table 5 and Figure 12 showing Land Use distribution over Years (a)1977 (b)1993 (c)2006 (d)2014.The influence is visible across multiple dimensions

Table 5.LULC change Matrix of Delhi

LULC Change Metric	Total Area Studied	Peak Growth Rate Comparison (2001–2011)	Conversion of Open/ Green Areas
Overall Delhi City Region (1977–2014)	1483 km² (NCT of Delhi)	13.5% decadal built-up growth rate	Net loss of Cultivated area: -22.75%. (Net change across 1483 km²) - 337.38 sq.km.
Metro Influence Zone (0-1500 m 1997–2019)	Approx 600 km² (Cumulative buffer zone)	23.87% built-up growth rate in the South West District	Direct conversion: 186.03 sq km (148.02 sq km Open land + 38.01 sq km Vegetation). - 31%

Densification Near Stations

Areas near major stations—such as Dwarka Sector-21, Karkardooma, Saket, Netaji Subhash Place, and Rajouri Garden—show increased construction activity, vertical growth, and mixed-use developments.

Conversion of Underutilised Land

Large parcels of low-density public housing and institutional land have been redeveloped for commercial or mixed-use functions, especially near interchange stations.

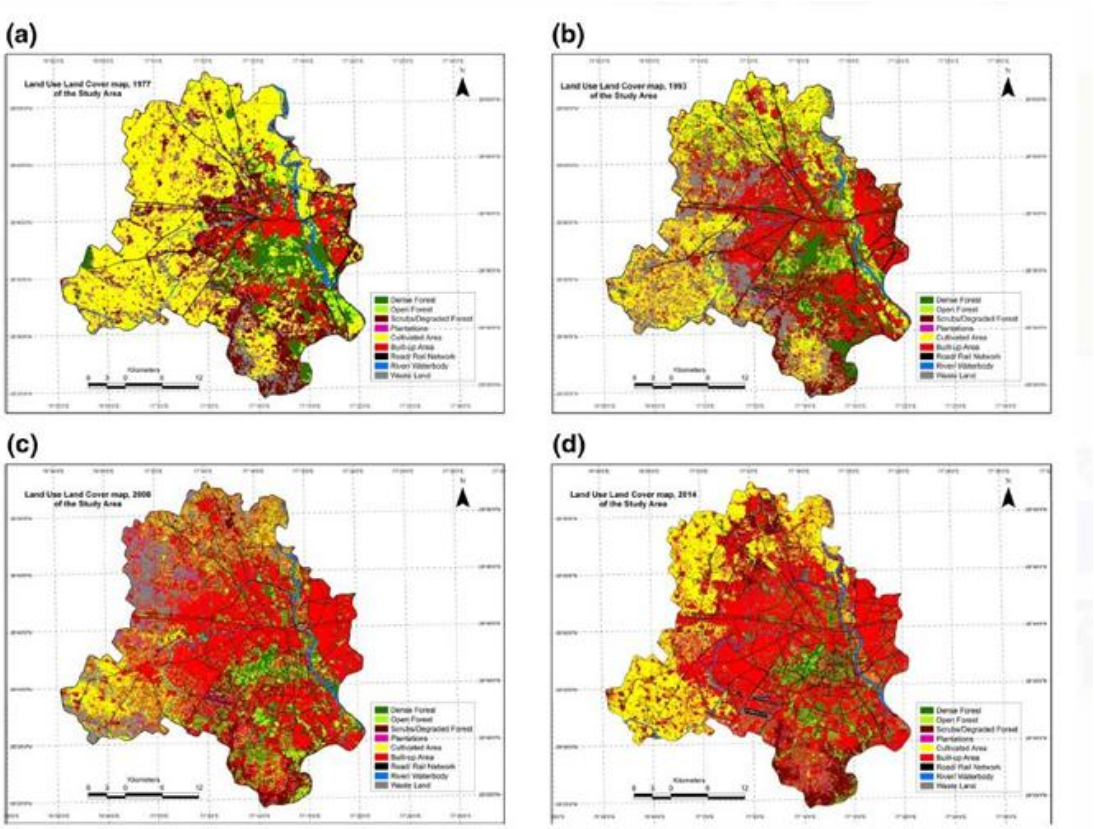


Figure 12.Land Use distribution over Years (Begam, S., Jha, P., Yadav, P.K. et al,2024)

Emergence of Activity Nodes and Walkable Environments

Metro stations act as new focal points of urban life, attracting retail clusters, offices, entertainment centres, educational institutions, and public facilities

Several station areas have gradually become more walkable, with safer pedestrian access, improved pathways, better lighting, and redesigned road sections. These transformations demonstrate that transit infrastructure can shape not only movement but also the physical structure of the city.

4 Spatio-Temporal Changes Around Delhi Metro

The growth of the Delhi Metro has completely altered how we get to places every day, while causing major changes (both spatial and temporal) in the way we live and work in this metropolitan area (see Figure 13). The transformation of the built environment, the way we develop land, the way we access different neighbourhoods throughout the city, and what types of work are available in the different parts of the city have all changed over time due to transit infrastructure. The method of spatiotemporal analysis allows us to view the transformation over time, starting with improved access to different parts of

the city and building to changes in land use, density, commercial activity, and redevelopment intensity.

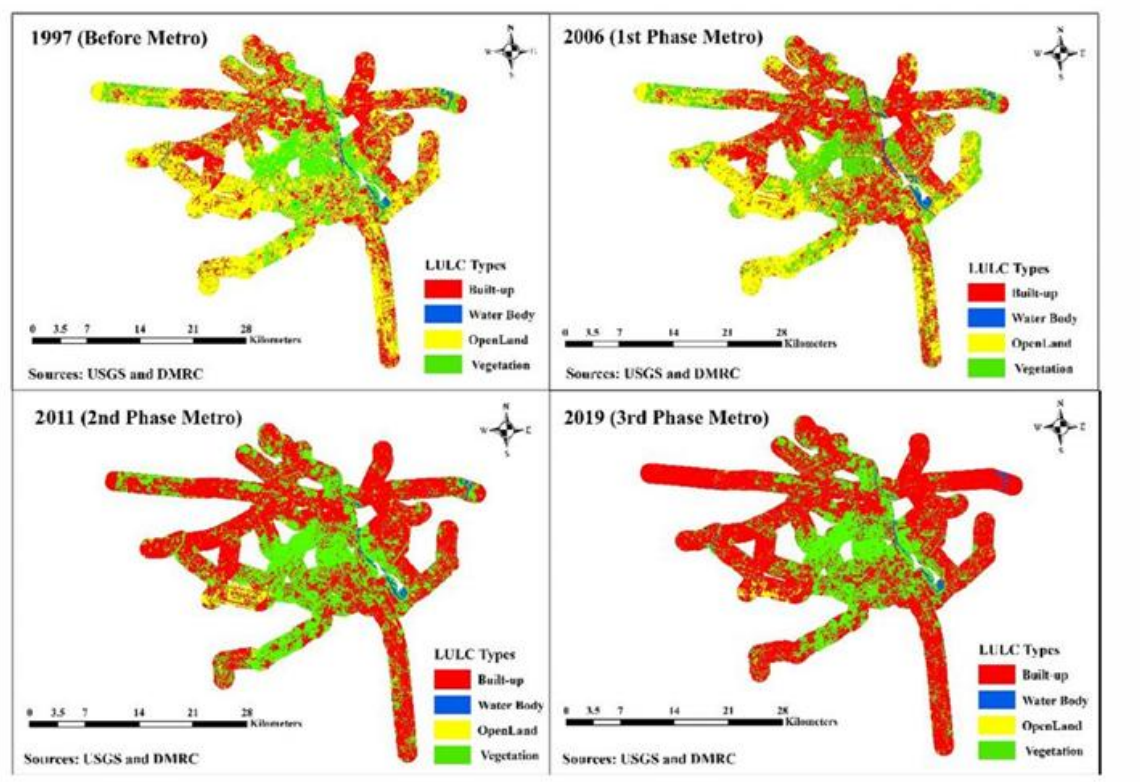


Figure 13.Spatio- Temporal LULC Changes in Delhi (Begam, S., Jha, P., Yadav, P.K. et al,2024)

Transformation in Land Development Over Time

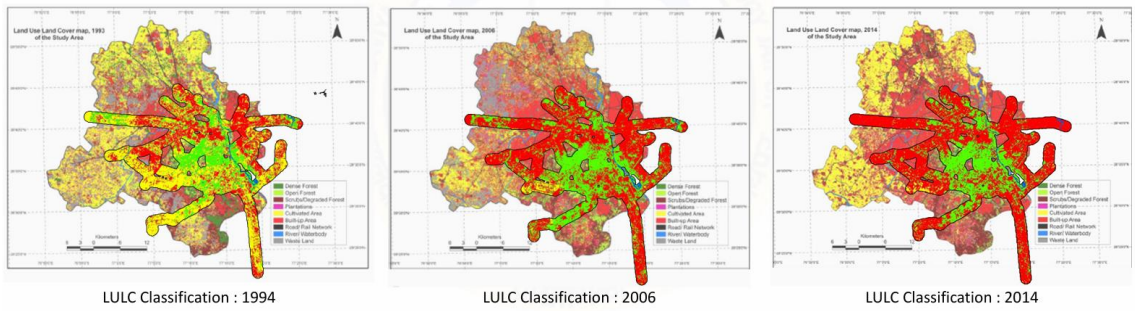


Figure 14.LULC Classification over years (Begam, S., Jha, P., Yadav, P.K. et al,2024)

The Metro system has resulted in fragmented development, lower density housing, and significant underutilised or institutional properties in a number of areas of the greater Delhi area (especially the eastern, western, and outer). The introduction of new Metro corridors over time

1. has resulted in gradual infill of underutilised land
2. redevelopment of lower density properties in subsequent phases

3. adjacent properties have seen the greatest level of intensification and the introduction of
4. commercial development and high-rise and mixed-use residential developments have come about in phases. All of these developments and trends will continue to result in on-going major changes in the city and help improve the quality of life for residents.

Figure 14 shows the impact of Metro transit on the urban restructuring process.

5 Policy and Planning Alignment

In addition, more recent planning initiatives reflect the importance of transit as a development and density driver within the larger context of Delhi. This is evidenced by

1. The endorsement of transit-oriented development (TOD) in both the Delhi Master Plan 2021 and the Delhi Master Plan 2041
2. Provisions in the planning documents for the establishment of influence zones around the Metro
3. Plans for higher-density development around the Metro
4. The identification of villages and low-density areas adjacent to Metro stations to be redeveloped and
5. Provisions for reduced parking and mixed-use zoning will encourage compact development.

6. Key Lessons from Delhi Metro's Transformation

The Delhi Metro has shown us:

1. When a strong government adopts transit projects with the support of transit land use regulations, urban areas will change in a way that supports transit.
2. As access to transit improves, new housing, offices, and mixed-use developments will be developed near transit stations, and density will increase near transit stations.
3. The infrastructure of transit systems serves as a catalyst for the creation of new activity nodes (e.g., office buildings) and other forms of activity.
4. The integration of walking, biking, and other modes of transportation with transit systems greatly facilitates the last mile of connection at transit stations.
5. Policies are necessary for the translation of transit systems into urban areas.

As such, the experience of the Delhi Metro will provide significant information on the relationship between transit investments and the urban form, land use, mobility, and socio-economic forms of rapidly growing cities.

2.5 Indicator-Based Analytical Framework

The present study adopts an indicator-based analytical framework for evaluating transit-oriented urban transformation within the study area. The framework integrates multiple

spatial indicators associated with land cover, built form, mobility, accessibility, and transit integration in order to assess the physical and functional characteristics of the transit influence zone.

Based on the review of TOD principles and geo-spatial assessment approaches, the indicators identified for the study are broadly categorized into two major components: **Land Cover and Built Form**, and **Mobility and Accessibility**. These categories collectively represent the major dimensions of urban transformation associated with metro infrastructure and support comprehensive spatial assessment using GIS-based analytical techniques.

2.5.1 Land Cover and Built Form

This category focuses on the physical characteristics and spatial transformation of the urban environment within the transit influence zone. The indicators under this category are shown in Table 6 which assess changes in land cover, built-up development, environmental quality, and concentration of urban activities associated with metro-induced transformation.

Table 6 : Indicator of Land Cover and Built Form

Main Indicator	Sub-Indicators (Spatial Measures)	Definition / Description	Typical Data Source
Land Cover	Built-up area, vegetation cover, impervious surfaces	Assesses spatial distribution and transformation of land cover characteristics	Satellite imagery, land use maps
Urban Built Form	Building footprint, development intensity, built density	Evaluates urban morphology and development concentration	Building footprint data, satellite imagery
Green Spaces	Parks, recreational spaces, green cover ratio	Assesses environmental quality and public open space availability	Satellite imagery, planning maps
Amenity Density	Commercial, institutional, recreational, and public amenities	Measures concentration and accessibility of urban services and activities	POI datasets, GIS mapping,

The indicators under land cover and built form help in understanding the spatial transformation and development intensity occurring around transit corridors. These indicators also support the assessment of mixed-use development, environmental quality, and activity concentration associated with transit-oriented urban growth.

Land cover and built form are important indicators for assessing the physical transformation of urban areas within transit influence zones. These indicators help in understanding spatial growth patterns, development intensity, environmental quality, and land utilization associated with metro-induced urban transformation. The introduction of metro infrastructure often influences changes in built-up development, land use patterns, activity concentration, and urban morphology around transit corridors. Therefore, the assessment of land cover and built form provides an understanding of how transit systems influence the physical structure and character of the urban environment.

1. Land Cover

Land cover refers to the physical characteristics of the earth's surface, including built-up areas, vegetation, open spaces, transportation surfaces, and impervious areas. The analysis of land cover helps in identifying urban expansion and transformation occurring within the transit influence zone over time.

In transit-oriented environments, metro systems often contribute toward increased built-up development and reduction of vacant or underutilized land due to improved accessibility and rising development pressure. Land cover assessment therefore helps in understanding the extent of urbanization and spatial transformation associated with transit infrastructure.

2. Urban Built Form

Urban built form represents the spatial arrangement, density, and morphology of buildings and urban structures within the study area. The assessment of built form helps evaluate development intensity, compactness, and concentration of urban growth around transit corridors.

Metro stations frequently attract high-density and mixed-use development due to improved accessibility and increased economic activity. Building footprint analysis and density assessment are therefore important for understanding physical transformation and development patterns within transit-oriented areas.

3. Green Spaces

Green spaces include parks, recreational areas, landscaped zones, and urban vegetation within the transit influence zone. These spaces contribute toward environmental quality, urban liveability, and public interaction within the urban environment.

The assessment of green spaces helps evaluate the balance between urban densification and environmental sustainability around metro corridors. Spatial distribution and accessibility of open spaces are important indicators for understanding the environmental character and public realm quality of transit-oriented areas.

4.Amenity Density

Amenity density refers to the concentration and accessibility of commercial, institutional, recreational, and public facilities within the study area. The availability of amenities within accessible distance from transit stations is an important characteristic of transit-oriented environments.

Metro systems often attract commercial activities, public services, and institutional functions around transit nodes due to increased accessibility and pedestrian movement. The assessment of amenity density therefore helps identify activity concentration, mixed-use development, and accessibility characteristics associated with transit-oriented urban growth.

2.5.2 Mobility and Accessibility

This category evaluates the movement structure, accessibility conditions, and transportation integration within the transit influence zone. The indicators shown in Table 7 focus on street connectivity, pedestrian accessibility, transit infrastructure, and intermodal mobility conditions that influence the effectiveness of transit-oriented environments.

Table 7. Indicator of Mobility and Accessibility

Main Indicator	**Sub-Indicators (Spatial Measures)**	**Definition / Description**	**Typical Data Source**
Street Network Density	Total road length, road hierarchy, network intensity	Evaluates street connectivity and accessibility efficiency	Road network maps, OpenStreetMap
Intersection Density	Number of intersections per unit area	Measures connectivity and walkability potential	GIS road network analysis
Parking Facility	On-street parking, off-street parking availability	Assesses parking infrastructure and vehicular accessibility	Google Earth

Transit Node Density	Metro stations, bus stops, transit terminals	Measures concentration and accessibility of transit infrastructure	Open street Map
Pedestrian Network	Footpaths, crossings, sidewalks	Assesses walkability and pedestrian accessibility	street mapping

The mobility and accessibility indicators help evaluate the efficiency of movement systems and accessibility conditions within transit-oriented environments. These indicators are essential for understanding connectivity patterns, walkability, transit integration, and last-mile accessibility associated with metro systems.

Mobility and accessibility are important components of transit-oriented urban environments as they determine the efficiency of movement, connectivity, and access within the transit influence zone. These indicators help in understanding how effectively the transportation network supports pedestrian movement, transit accessibility, and urban connectivity around metro corridors. The introduction of metro infrastructure often influences street patterns, pedestrian activity, intermodal movement, and accessibility conditions within surrounding urban areas.

The assessment of mobility and accessibility indicators provides insight into the relationship between transportation infrastructure and urban movement systems. Parameters such as street network density, intersection density, parking facilities, transit node accessibility, and pedestrian networks help evaluate the efficiency and usability of transit-oriented environments. These indicators collectively support the assessment of walkability, connectivity, and last-mile accessibility associated with metro systems.

Street Network Density

Street network density refers to the intensity and connectivity of road networks within the study area. It helps in evaluating the efficiency of urban movement systems and accessibility to transit infrastructure.

A well-connected street network improves accessibility to metro stations and facilitates efficient pedestrian and vehicular movement within transit influence zones. Areas with dense and interconnected road systems generally support better accessibility and mobility compared to fragmented street patterns.

Intersection Density

Intersection density measures the number and frequency of intersections within a given urban area and is commonly used as an indicator of connectivity and walkability. Higher intersection density generally indicates better route choice, shorter travel distances, and improved pedestrian accessibility.

In transit-oriented environments, highly connected street networks enhance accessibility to transit stations and surrounding urban activities while supporting efficient pedestrian movement and last-mile connectivity.

Parking Facility

Parking facilities are important components of urban mobility infrastructure and influence travel behaviour around transit corridors. The availability and distribution of parking infrastructure affect vehicular accessibility and modal choice within transit-oriented environments.

The assessment of parking facilities helps in understanding the relationship between private vehicle usage and public transport accessibility. Parking analysis includes the evaluation of on-street parking, off-street parking, and parking distribution around transit nodes.

Transit Node Density

Transit node density refers to the concentration and accessibility of metro stations, bus stops, and transit facilities within the study area. The density and distribution of transit nodes significantly influence mobility efficiency and accessibility within transit-oriented environments.

Areas with higher transit node concentration generally exhibit better public transport accessibility and increased pedestrian activity. Transit nodes also function as important activity centres influencing surrounding land use and urban development patterns.

Pedestrian Network

Pedestrian networks refer to the system of pedestrian pathways and connections that facilitate safe and continuous movement within the urban environment. These networks include footpaths, sidewalks, pedestrian crossings, walkways, and shaded pedestrian corridors that improve accessibility between transit stations and surrounding urban activities.

An efficient pedestrian network is an essential component of transit-oriented development as it encourages walking and supports last-mile connectivity. Well-connected pedestrian routes improve accessibility to metro stations, public amenities, and activity areas while enhancing walkability and user comfort within transit influence zones.

The assessment of pedestrian networks helps evaluate the continuity, connectivity, accessibility, and walkability conditions of the study area and supports understanding of pedestrian movement patterns associated with transit-oriented environments.

2.5.3 GIS Techniques Associated with Assessment Indicators

The identified indicators are analysed using various GIS-based spatial techniques as shown in Table 8 in order to evaluate urban transformation and transit-oriented characteristics within the study area.

Table 8. GIS Techniques Associated with Assessment Indicators

Indicator	**GIS Technique**	**Purpose of Analysis**
Land Cover	Temporal land use mapping	Assess land transformation and built-up growth
Urban Built Form	Building footprint analysis	Evaluate development intensity
Green Spaces	Spatial overlay analysis	Assess open space distribution
Amenity Density	Kernel density analysis	Identify activity concentration
Street Network Density	Network analysis	Evaluate connectivity and accessibility
Intersection Density	Density analysis	Assess walkability and network efficiency
Parking Facility	Spatial mapping	Assess parking distribution
Transit Node Density	Buffer analysis	Evaluate transit accessibility
Pedestrian Infrastructure	Spatial mapping	Assess walkability conditions

The table above presents the geo-spatial techniques associated with each assessment indicator used in the study. Different GIS-based analytical methods are applied depending on the nature of the indicator and the objective of assessment. These techniques help in understanding spatial transformation, accessibility conditions, connectivity patterns, and development characteristics within the transit influence zone.

Temporal land use mapping is used for analyzing land cover transformation and identifying changes in built-up areas, vegetation cover, and urban expansion over time. Building footprint analysis helps evaluate urban built form characteristics such as development intensity, building concentration, and urban morphology surrounding transit corridors. Spatial overlay analysis is used for assessing the distribution of green spaces and understanding environmental quality within the study area.

Kernel density analysis is applied for evaluating amenity density and identifying areas of activity concentration and service accessibility around transit nodes. Network analysis is used to assess street network density, connectivity efficiency, and accessibility within the urban environment. Similarly, density analysis of intersections helps evaluate walkability and movement connectivity associated with the street network.

Spatial mapping techniques are used for analyzing parking facilities and pedestrian networks in order to assess accessibility, walkability, and mobility conditions around transit corridors. Buffer analysis is applied for transit node assessment to evaluate accessibility zones and the spatial influence of metro stations and public transit systems.

The integration of these GIS-based analytical techniques supports comprehensive evaluation of transit-oriented urban transformation and provides a systematic framework for assessing spatial characteristics associated with metro infrastructure.

Chapter Summary

This chapter examined the theoretical and analytical foundations of transit-oriented urban transformation through the review of TOD concepts, geo-spatial assessment approaches, and relevant case studies. The chapter identified major indicators associated with land cover, built form, mobility, and accessibility for assessing transformation within transit influence zones.

The review of literature and case studies highlighted the importance of GIS-based analytical techniques such as temporal land use mapping, network analysis, density analysis, buffer analysis, and spatial overlay methods in evaluating transit-oriented environments. Based on these findings, an indicator-based analytical framework was developed for the present study.

The identified indicators and geo-spatial techniques provide the basis for assessing urban transformation associated with metro infrastructure within the selected study area. The

subsequent chapter focuses on the study area selection, site characteristics, and research methodology adopted for the study.

CHAPTER 3: City And Site Selection

Pune is one of the emerging metro cities in India and a significant case of transit induced urban transformation, due to its rapid urbanization, expanding metropolitan structure and the recently developed metro rail network. In the last decades, the city has experienced a significant growth in the population, commercial activities, institutional development and transportation demand. The Pune Metro system has added to the momentum for transit-oriented development and spatial transformation in the major urban corridors.

The present study adopts a multi-scale approach for study area selection beginning from the context of metro cities in India, followed by the selection of Pune as the study city, identification of the metro corridor, and final selection of the study station area. The study further examines the spatial and functional characteristics associated with the selected transit influence zone in order to assess urban transformation through geo-spatial analysis techniques.

3.1 Introduction

Rapid urbanization and transportation demand have majorly affected the spatial structure and growth of Indian cities in the last few decades. The development of metro rail systems in major cities has become a key strategy to improve urban mobility, reduce traffic congestion, and encourage sustainable transportation systems. Along with enhancing public transport accessibility, metro systems also contribute toward transformation in land use patterns, development intensity, economic activities, and urban morphology within transit influence zones (Suzuki, Cervero, & Iuchi, 2013).

Transit Oriented Development (TOD) is an increasingly important concept in Indian cities focusing on compact, mixed-use and pedestrian-oriented urban development around transit corridors. Metro infrastructure can act as a catalyst for urban change by supporting redevelopment, improving accessibility and intensifying activity around transit nodes. As a result, several Indian metropolitan cities have begun integrating transit systems with land use planning approaches in order to achieve sustainable urban growth and improved mobility conditions (Calthorpe, 1993).

The chapter discusses the rationale behind the selection of the study city and study site, introduction to the Pune Metro network, delineation of the study area and the research methodology adopted for the study. The chapter also outlines the data collection procedure, development of GIS database and indicator based analytical techniques for evaluation of transit oriented urban transformation in the selected influence zone of metro.

3.2 Metro Cities and Emerging Transit-Oriented Development in India

Over the past few decades, India has experienced rapid urbanization and metropolitan expansion, which has put mounting pressure on urban infrastructure, transportation systems and land resources. The rapid growth of population, increase in vehicle ownership and the extension of the urban boundaries have resulted in traffic congestion, deterioration of the environment and inefficient mobility conditions in the large cities. Metro rail systems have emerged as an important component of urban transportation planning in Indian metropolitan regions in response to these challenges.Figure 15 highlights Metro Cities in India.



Figure 15. Metro Cities In India

The metro systems have contributed to better urban transportation as well as urban development, land use change and accessibility conditions in and around cities. Metro corridors are often the catalysts for economic activity, redevelopment and infrastructure growth because they provide better connectivity and mobility efficiency. As a result, the integration of transit infrastructure with land use planning has gained increasing importance in contemporary urban planning practices.

3.2.1 Growth of Metro Rail Systems in India

In the last two decades, several Indian cities have developed metro rail systems, as part of efforts to improve urban mobility and reduce dependence on private vehicles. Metros have been operational in cities such as Delhi, Bengaluru, Mumbai, Hyderabad, Chennai and Pune to improve accessibility and facilitate efficient public transport networks.

The metro rail infrastructure has greatly transformed the urban mobility patterns by reducing the travel time, enhancing the regional connectivity and promoting the transit-based development. Metro systems have also helped create new commercial corridors, redevelopment districts, and high-density urban activity around transit stations.

3.2.2 Transit-Oriented Development in Indian Cities

The concept of Transit-Oriented Development (TOD) is gaining increasing importance in Indian cities in view of its focus on compact, mixed-use and pedestrian friendly

development around transit corridors. TOD aims to integrate transportation systems with land use planning in order to create accessible and sustainable urban environments while reducing automobile dependency (Calthorpe, 1993).

In India, the metro systems tend to affect the nearby urban areas through attraction of commercial activities, institutional functions, residential redevelopment and investment in infrastructure. The proximity to transit stations generally causes an increase in pedestrian movement, intensity of development, and accessibility due to a better connection to public transportation.

Therefore, many Indian cities have adopted TOD policies and planning frameworks that aim to promote higher density development, better walkability, mixed land use and intermodal integration in transit influence zones.

3.2.3 Metro Corridors as Catalysts for Urban Transformation

Metro corridors are critical to urban transformation, impacting land use, development intensity and spatial organization within the cities. Better accessibility around metro stations, often leads to higher land value, redevelopment pressure, commercial concentration and growth of infrastructure.

Metro systems affect not only transportation but also pedestrian activity, street character, urban form and public realm conditions. The agglomeration of mobility infrastructure and urban functions tends to create centres of economic and social activity in transit nodes.

Metro corridors emerge as important spaces for the evaluation of transit-oriented urban transformation and for the understanding of the relation between transportation systems and urban growth.

3.2.4 Relevance of Emerging Metro Cities for TOD Assessment

Emerging metro cities offer important opportunities to study transit-oriented urban transformation, as many of these cities are currently witnessing active infrastructural and spatial changes associated with newly operational metro systems. Unlike mature metro systems where transformation has already reached a plateau, metro cities in the making are characterized by continuous shifts in land use, mobility patterns, accessibility conditions and urban development.

Among these cities, Pune is a special case, with its fast urbanizing metropolitan structure, increasing transportation demand and its recently operational metro network. The changing urban environment and transit infrastructure of the city offer an appropriate context for the evaluation of the metropolitan influence of metro systems and the transformation of transit influence zones.

3.3 Selection of the Study City

Choosing an appropriate study city is an important step in assessing transit-oriented urban transformation, because the characteristics of urban growth, transportation infrastructure, and development patterns have a profound impact on the nature of transformation associated with metro systems. The city selected for the present study is an emerging metropolitan center with rapid urbanization, growing transportation demand, expanding urban development, and ongoing metro rail expansion.

Over the last decades, the city has experienced significant demographic and spatial growth, leading to continuous urban sprawl and increasing pressure on transport infrastructure. The growth of residential, commercial, institutional and economic activities has assisted towards increasing travel demand, traffic congestion and mobility challenges within the urban area. These conditions have further increased the need for efficient public transportation systems and sustainable urban mobility strategies.

3.3.1 Rapid Urbanization and Urban Expansion

The growing intensity of urban development and the changing patterns of land use have also led to growing demand for efficient public transportation systems that can support sustainable mobility and accessibility. These rapidly changing urban conditions make the city an important context for studying the relationship between transportation infrastructure and urban transformation.

According to the September 2025 Square Yards report, 'Cities in Motion – Tracing 30 Years of Urban Expansion', Pune saw the highest increase in built-up area in Indian metros with 332%, while maximum physical land of 400 sq km was added by Delhi NCR.

1. Massive Footprint Growth: The total built-up area across India's Top-8 cities has nearly doubled in 30 years, adding 2,136 sq.km. of urban land.
2. Delhi NCR Leads in Scale: With a total footprint of 967 sq.km., Delhi NCR remains India's largest urban agglomeration, having added the highest absolute area (400 sq.km.).
3. Pune's Explosive Expansion: Pune recorded the fastest growth rate at 332%, transitioning from a manufacturing town to a global IT and startup hub.
4. Tech-Driven Sprawl: Bengaluru (186%) and Chennai (137%) show high growth rates driven by

Table 9. Urbanisation Rate of Metro cities (Square Yards)

City	Current Built-up Footprint (sq.km.) – 2025	Total Built-up Footprint Added between 1995–2025 (sq.km.)	Percentage Change 1995–2025
Ahmedabad	285	+144	102%
Bengaluru	498	+324	186%
Chennai	467	+270	137%
Delhi NCR	967	+400	71%
Hyderabad	519	+252	95%
Kolkata	611	+283	87%
Mumbai MMR	588	+176	43%
Pune	373	+287	332%
Top-8 Cities	4,308	+2,136	98%

IT corridors, while Ahmedabad (102%) has doubled its size through economic diversification (GIFT City).

5. Vertical vs. Horizontal Growth: Horizontal: Cities like Pune and Bengaluru expanded outward into peripheral zones.

Figure 16 and Table 9 shows Urbanisation Rate of Metro cities in graph Format.

Vertical: Mumbai (MMR) saw the slowest footprint growth (43%) due to geographic constraints, and hence concentrated on high density vertical development.

Polycentric Development: Data shows a shift towards "polycentric" regions, where infrastructure such as Metros and Expressways have linked many smaller hubs to form mega-regions.

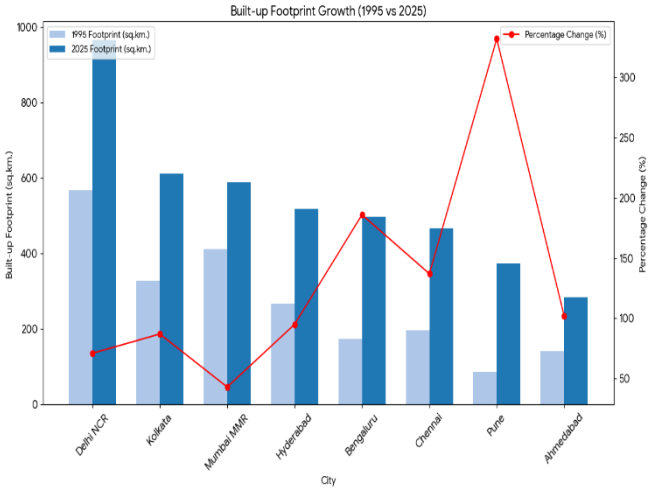


Figure 17.Urbanisation Rate of Metro cities (Square Yards)

With its expanding urban economy, educational institutes, industrial development and IT sector, Pune has emerged as one of the fast-growing metropolitan cities in India. The changing urban form of the city and its transportation problems make it a suitable case for assessing the transit-oriented urban transformation.

3.3.2 Emergence of Metro Infrastructure

Metro rail infrastructure is a major intervention in transportation to improve urban mobility, reduce traffic congestion and strengthen the public transportation system in the city. The metro network is expected to improve accessibility between major activity centres and support efficient transit connectivity across different urban corridors.

The expansion of metro infrastructure has also further improved the prospects of transit-oriented growth by encouraging compact development, mixed land use, and transformation of urban areas for accessibility around transit stations. Several metro corridors are undergoing spatial and functional transformation in relation to changing mobility patterns and redevelopment activities.

3.3.3 Potential for Transit-Oriented Development

The selected city has considerable potential for Transit-Oriented Development (TOD) characterized by mixed land use, higher development intensity, concentration of institutions, and expanding transit infrastructure. Metro corridor areas have

characteristics conducive for TOD-based planning such as high activity concentration, access to transit systems and growing pedestrian movement.

Urban transformation and metro infrastructure expansion provide opportunities to assess the impacts of transit systems on land use, built form, accessibility, and mobility conditions in transit influence zones.

3.3.4 Selection of Pune as the Study City

The selection of Pune as the study city for current research is based on the rapid pace of urbanization, expanding metropolitan structure, emerging metro infrastructure and growing potential for transit-oriented development. Figure 17 highlights Location of Pune and its Urban Growth.

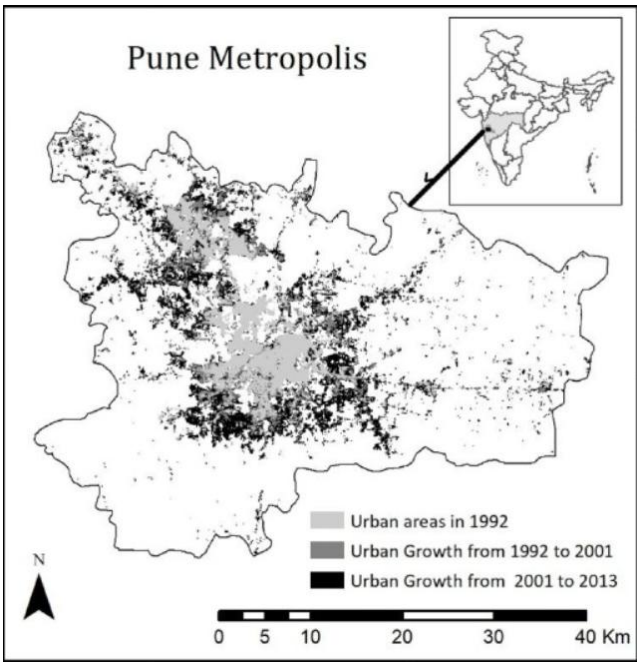


Figure 18. Urban Growth Pune (Atlas)

Unlike the older metropolitan cities with a mature metro system, Pune is at present undergoing active spatial and infrastructural change associated with the newly operational metro corridors. The city is still undergoing transformation and offers an opportunity to analyse the changing land use patterns, accessibility conditions, mobility infrastructure and urban development trends related to metro systems.

3.4 Urban Growth and Development Pattern

Understanding the patterns of urban growth and development is crucial for the understanding of the spatial transformation of metropolitan cities and the impact of transportation infrastructure on urban expansion. The direction and intensity of urban growth are often shaped by factors such as economic activities, transportation corridors, institutional development, industrial expansion, and infrastructure investments. In rapidly urbanizing cities, major transportation projects such as metro systems further influence the distribution of urban activities and the emergence of new development corridors.

The urban structure of Pune has undergone significant transformation over the past few decades due to continuous population growth and expanding economic activities. The city was originally developed in the historic core area, but rapid urbanization and increasing development pressure resulted in outward expansion towards the peripheral

areas. In many places around the metropolitan area, residential, commercial, industrial and institutional developments have created urban growth corridors.

3.4.1 Direction of Urban Growth

Pune's growth pattern has largely grown along major transport corridors and regional connectivity routes. The northern and north-western parts of the city experienced significant industrial and residential growth in the areas of Pimpri-Chinchwad, while the eastern corridors experienced growth associated with commercial and information technology activities. Figure 18 illustrates Growth Direction of Pune.

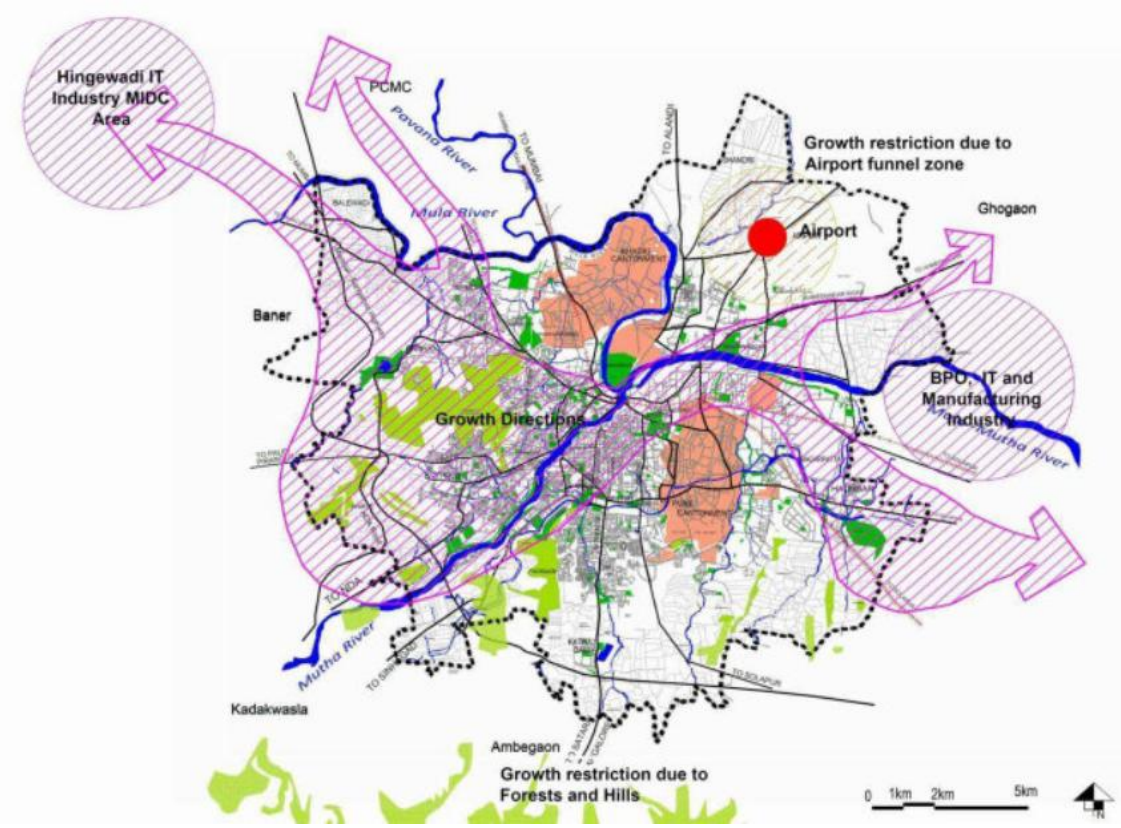


Figure 19. Growth Direction Map Pune

The southern and western parts of the city are also witnessing increasing residential and institutional development due to better connectivity through roads and expansion of urban infrastructure. Thus, the metropolitan spatial structure of Pune has transformed from a compact urban core to a dispersed and multi-nodal urban form (Bertaud, 2004). As a result, the metropolitan structure of Pune changed from a compact urban core to a dispersed and multi-nodal urban form.

Transportation infrastructure has been an important factor in directing such growth by improving accessibility and enabling urban expansion along major corridors. The introduction of metro infrastructure is also likely to impact development intensity and accessibility within transit influence zones.

3.4.2 Infrastructure-Led Urban Transformation

Projects related to infrastructure including highways, arterial roads, flyovers and metro systems play a major role in urban transformation by improving connectivity and access between different parts of a city. Transportation infrastructure investments are often associated with commercial activities, mixed-use development, institutional functions, and redevelopment projects around major mobility corridors.

The Pune Metro is an important infrastructure intervention which is expected to influence the future urban growth patterns within the city. Metro corridors are generally development generators, improving access and reducing travel times between key activity centres. The potential for redevelopment, commercial agglomeration, and pedestrianized urban transformation around metro stations, therefore, is increasing.

3.4.3 Emerging Transit-Oriented Growth Corridors

Transit-oriented growth corridors with increasing development intensity, mixed land use and improved accessibility are being developed as Pune's metro infrastructure continues to grow. Around the metro stations, there is a slow spatial transformation taking place with better public transport connectivity and increasing urban activity.

Transit-oriented growth is most prevalent in corridors where there is a high institutional, administrative, commercial and transportation significance. These zones are characterized by high potential of compact development, pedestrian movement, intermodal connectivity and accessibility-oriented urban development related to metro systems.

Thus, the changing urban structure and the ongoing infrastructure development in Pune provide an appropriate setting to evaluate the transit oriented urban transformation and to understand the relationship between metro systems and urban growth patterns.

3.5 Overview of Pune Metro Network

The metro rail network construction in Pune is a significant step in enhancing urban mobility and improving public transport infrastructure in the metro region. The metro has been introduced to address increasing traffic congestion, increasing travel demand and increasing pressure on the existing transportation system due to rapid urbanization and increasing urban activities.

The Pune Metro network is envisioned as an integrated mass rapid transit system to enhance connectivity between the main residential, commercial, institutional and industrial areas of the city. The metro corridors are expected to improve connectivity, reduce travel time and facilitate sustainable mobility while promoting transit-oriented urban development in the station areas.

3.5.1 Pune Metro Corridors

The Pune Metro is designed with multiple corridors linking key urban activity centres across the city. ‘Major operational corridors are north-south corridor from Pimpri-Chinchwad to Swargate and east-west corridor from Vanaz to Ramwadi. These corridors pass through key residential, commercial, administrative and institutional areas of the metropolitan area.

The metro network is important in connecting the emerging growth corridors and improving accessibility between different parts of the city. Several stations along these corridors are critical transit nodes due to their strategic urban location and intermodal connectivity. Figure 19 shows Metro Route Map of Pune.

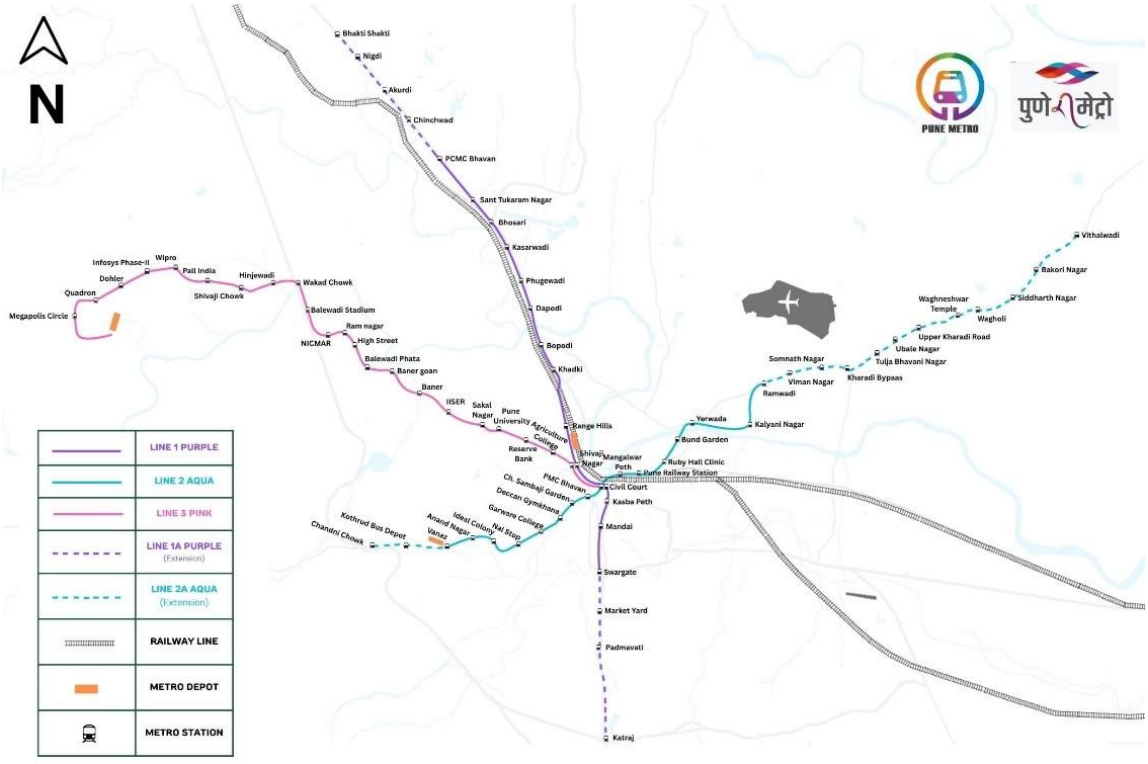


Figure 20. Route Map of Pune Metro (Pune Metro)

3.5.2 Metro Network and Urban Connectivity

Metro infrastructure has played a major role in improving connectivity of public transport within Pune by linking major urban centers with high capacity transit systems. Metro stations are located on major transportation corridors and in activity centers to facilitate efficient movement and accessibility.

The metro system strengthens intermodal connectivity by integrating with road networks, bus systems, pedestrian routes and other modes of transportation. Improved accessibility

around metro stations further increases the potential for mixed-use development and pedestrian-oriented urban growth within surrounding areas (Cervero, 1998).

3.5.3 Transit-Oriented Development Potential Along Metro Corridors

The closeness of metro corridors has a lot of potential for Transit Oriented Development (TOD) due to the increased accessibility, concentration of activity and chances for redevelopments. The enhanced connectivity makes Metro stations the attraction nodes for commercial activities, institutional functions, mixed use development and even people movement.

The concentration of urban activities around the transit stations helps increase the intensity of development and transformation of surrounding urban environments. As a result, metro corridors in Pune are emerging as important zones for studying transit-oriented urban transformation and assessing the relationship between transportation infrastructure and urban growth.

3.5.4 Selection of the Metro Corridor for Study

The present study has been selected for the Pimpri-Chinchwad to Swargate corridor amongst the operational metro corridors of Pune city for its large urban influence, strategic connectivity and active transformation potential. The corridor crosses through a variety of urban environments including institutional, commercial, administrative and mixed-use neighbourhoods.

The corridor is also one of the first operational corridors of the Pune Metro system with great potential for transit-oriented development and accessibility based urban transformation. The study corridor has major activity centres and intermodal transit connectivity, making it suitable for assessing the spatial transformation associated with metro infrastructure.

3.6 Identification and Selection of Study Stations

The selection of an appropriate study station is an important aspect of evaluating transit-oriented urban transformation. The characteristics of the surrounding urban fabric, accessibility, land use patterns, and activity intensity are key factors that affect the nature of transformation associated with metro infrastructure. Major stations along the selected metro corridor were reviewed in terms of their urban context, connectivity and

transformation potential to select a suitable study area for detailed assessment. Figure 20 and Figure 21 shows underground and Elevated stations of purple line simultaneously.

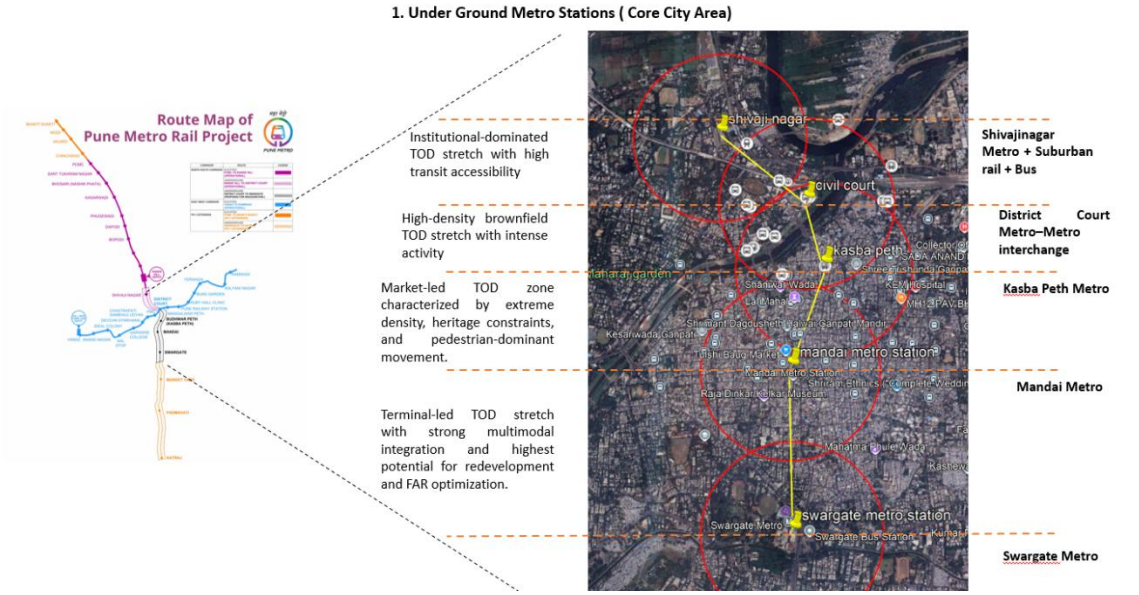


Figure 21. Under Ground Metro Stations (Core City Area)

The selected metro corridor passes through different urban settings of commercial, institutional, administrative, residential and transportation nodes. Of these stations, two sites were selected for their strategic importance and contrasting urban characteristics, and demonstrated significant potential for transit-oriented assessment.

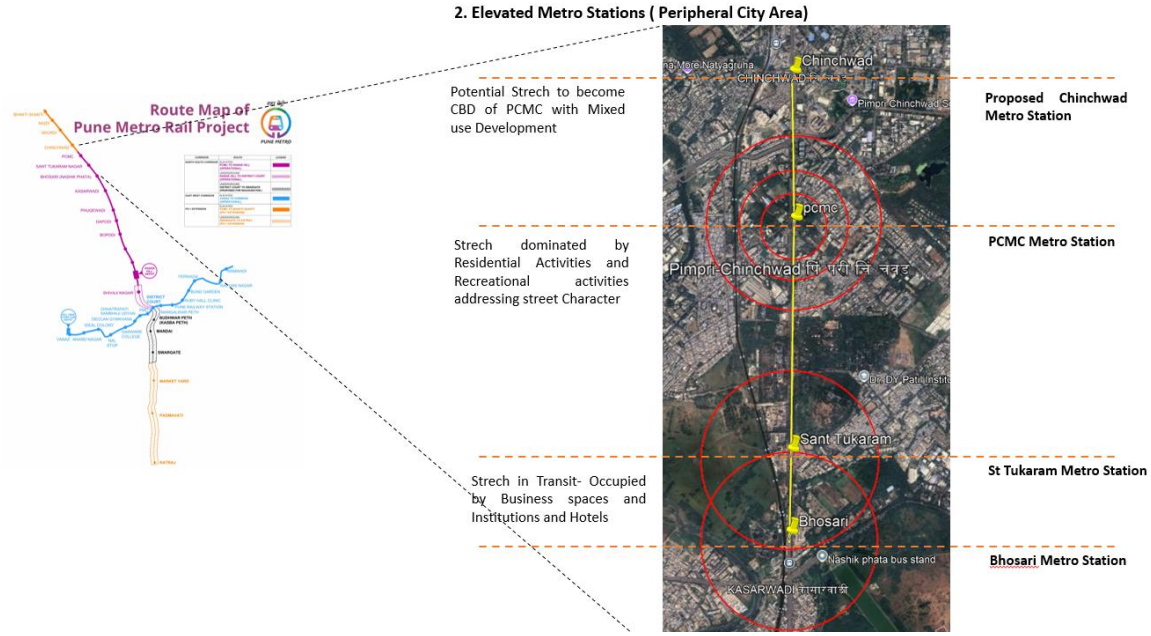


Figure 22.Elevated Metro Stations (Peripheral City Area)

3.6.1 Identification of Potential Study Stations

For comparative evaluation, two stations were selected based on accessibility, urban activity, land use diversity, and transit importance:

1. District Court Metro Station
2. PCMC Metro Station

The two stations are important urban nodes in the metro corridor; however, they are different in terms of land use characteristics around them, urban form, mobility patterns and development context.

District Court Metro Station is embedded into a thick urban fabric with a concentration of administrative, institutional and commercial activities. The station is characterized by high pedestrian flow, strong intermodal connectivity and mixed land use, typical of the central urban area.

In contrast, the PCMC Metro Station is located in an urban environment subject to industrial, residential and developing commercial development. The spatial and mobility characteristics of the station area are relatively different with peripheral urban growth.

3.6.2 Comparative Assessment of Study Stations

The two identified stations were comparatively assessed based on selected urban and transit-related parameters in order to determine their suitability for detailed TOD assessment as shown in Table 10.

Table 10. Comparison of Metro station

Parameter	**District Court Metro Station**	**PCMC Metro Station**
Urban Context	Administrative and commercial core	Industrial-residential corridor
Land Use Character	Mixed-use and institutional	Residential and industrial
Pedestrian Activity	High	Moderate

The comparative assessment indicates that District Court Metro Station demonstrates stronger characteristics associated with transit-oriented urban transformation due to its

central urban location, mixed land use pattern, high pedestrian movement, and significant accessibility conditions.

3.6.3 Final Selection of Study Site

On the basis of the comparative assessment, District Court Metro Station has been selected as a final study site for the present research.

The station area is characterized by a high potential of transit-oriented urban transformation, as a result of the concentration of administrative, institutional, commercial and transportation activities in its surrounding influence zone. It is a transit-oriented urban node of significance due to the high pedestrian movement, accessibility to multiple modes of transport and increasing urban activity.

The station is also a significant intermodal location within the metro network and demonstrates ongoing transformation related to metro infrastructure and urban redevelopment. Hence, the urban setting of District Court Metro Station area is appropriate for the assessment of land cover change, built form features, mobility aspects, pedestrian accessibility and transit oriented urban development using geo-spatial analytical techniques.

3.6.4 Stages of Transformation within the Selected Metro Corridor

Metro infrastructure related urban transformation is a slow process, comprising several phases from project planning to operational consolidation. These phases are related to land use pattern changes, accessibility conditions, mobility systems, intensity of development and urban activities in transit influence zones. The transformation process is generally driven by planning policies, infrastructure investment, improved accessibility and redevelopment activities along metro corridors.

The present study has identified the stages of transformation related to the selected metro corridor for understanding the temporal evolution of transit-oriented urban development and for assessing the nature of spatial transformation within the study area.

Pre-Announcement Stage (Before 2013)

The pre-announcement stage represents the period before formal metro planning and project declaration. During this phase, urban growth within the corridor was primarily influenced by existing transportation networks, commercial activities, and regional development patterns. Transformation associated with metro infrastructure was not yet visible; however, major arterial corridors already functioned as important urban activity zones.

This stage serves as the base condition for understanding the spatial characteristics and urban structure prior to metro-induced transformation.

Announcement and Planning Stage (2017)

The announcement and planning stage began with the initiation of feasibility studies, project approvals, and preparation of development proposals for the Pune Metro system. During this phase, the proposed alignment along major arterial corridors started influencing land value, development expectations, and planning regulations.

Planning policies and TOD provisions gradually began affecting zoning regulations and permissible development intensity around proposed metro stations. Although visible physical transformation remained limited during this stage, early anticipation of future accessibility improvements contributed toward increased redevelopment interest and land speculation within key urban areas.

Construction Phase (2018–2021)

The construction phase marked the beginning of physical transformation within the metro corridor. Civil construction activities, land acquisition processes, utility shifting, and transportation infrastructure modifications significantly altered the urban environment around station areas.

Inauguration and Initial Operation Stage (2022)

The inauguration and initial operation stage began with the commencement of metro operations along the corridor in 2022. The introduction of metro services improved accessibility between important urban activity centres and enhanced north-south connectivity within the city.

Early Consolidation Stage (2022–Present)

The chosen metro corridor is at the early consolidation phase of transit-oriented transformation. This phase is characterised by gradual re-development, increase in mixed-use activities and incremental improvement in last-mile connectivity around metro stations.

The transformation process is reflected in the intensification of development, change of land use characteristics, and appearance of pedestrian-oriented activities within station influence zones. Redevelopment is driving increasing densification and vertical growth in selected areas around transit corridors. The depth and scale of transformation, however, are contingent upon the urban context and accessibility conditions of specific station areas.

For the present study, the assessment of urban transformation is carried out primarily within the early consolidation stage, as it represents the initial phase during which measurable spatial and functional changes associated with metro infrastructure become visible within the urban environment.

3.7 Delineation of Study Area

The identification of the study area is a fundamental step in the evaluation of transit-oriented urban transformation, as it sets the spatial boundary to assess the impact of metro infrastructure. The transit influence zones are normally defined by the accessibility range, pedestrian flow and the range of the influence of transit stations on the surrounding urban activities and development patterns.

Buffer zones are used in studies based on the Transit-Oriented Development (TOD) concept to locate areas within a walkable and accessible distance from transit stations. These buffer zones help to analyze land use change, built form characteristics, accessibility conditions, mobility infrastructure, and pedestrian activity associated with metro systems.



Figure : Buffer Zone District Court

For the present study, District Court Metro Station has been selected as the primary study site due to its strategic urban location, intermodal connectivity, and significant transit-oriented transformation potential.

Figure 23.Buffer Zone District Court

3.7.1 Buffer Delineation

The study area has been delineated using buffer zones of 800m surrounding the selected metro station as shown in Figure 22.

The 500 m buffer represents the primary pedestrian influence zone, generally considered as a comfortable walking distance within TOD planning principles. This zone captures immediate transit-oriented activities, pedestrian movement, accessibility conditions, and redevelopment pressure surrounding the station area.

The 800 m buffer represents the extended transit influence zone, reflecting the broader spatial impact of metro accessibility on surrounding land use patterns, urban development, and mobility conditions. This distance is widely used in TOD studies for evaluating accessibility and urban transformation associated with metro systems (Calthorpe, 1993)..

3.7.2 Transit Influence Zone Characteristics

The delineated study area surrounding District Court Metro Station is characterized by:

1. administrative and institutional land use,
2. commercial activities,
3. mixed-use urban fabric,
4. dense transportation networks,
5. high pedestrian activity,
6. and significant intermodal connectivity.

The presence of major public institutions, commercial establishments, transit facilities, and pedestrian movement corridors contributes toward the emergence of the area as an important urban activity node within the metro network.

Due to its strategic urban significance and ongoing redevelopment activities, the selected transit influence zone demonstrates strong potential for assessing transit-oriented urban transformation through geo-spatial analysis techniques.

3.8 Data Collection and Data Sources

The evaluation of transit-oriented urban transformation needs the integration of multiple spatial data on land use, transportation infrastructure, accessibility, and urban activities. The analytical framework and spatial assessment for the selected transit influence zone in the present study has been prepared using secondary geo-spatial datasets and planning documents.

The collected datasets can be used to analyse the transformation characteristics of land cover, built form, mobility, accessibility and transit-oriented development around District Court Metro Station.

3.8.1 Secondary Data Sources

The study predominantly uses secondary spatial and non-spatial data sets, sourced from publicly available sources and planning documents. These datasets form the basis for geo-spatial analysis and thematic mapping with respect to the chosen assessment indicators.

The major secondary data sources used in the study include:

1. satellite imagery,
2. metro alignment and station maps,
3. road network datasets,
4. land use maps,
5. OpenStreetMap (OSM) data,
6. municipal development plans,
7. planning reports,
8. and publicly available geo-spatial datasets.

These datasets were used for preparation of thematic GIS layers related to:

1. land cover,
2. built-up areas,
3. road networks,
4. intersections,
5. transit nodes,
6. pedestrian networks,
7. amenities,
8. parking facilities,
9. and open spaces.

3.8.2 Geo-Spatial Data Preparation

The collected datasets were processed and integrated within a Geographic Information System (GIS) environment for analytical assessment. Data preparation involved:

1. geo-referencing,
2. digitization,
3. layer extraction,
4. attribute generation,
5. spatial classification,
6. and thematic mapping.

Separate GIS layers were prepared for individual assessment indicators in order to support spatial comparison and analysis of transformation characteristics within the study area.

The geo-spatial database also enabled temporal understanding of transformation through comparison of spatial characteristics associated with different stages of metro corridor development.

3.8.3 Data Integration for Indicator Assessment

The prepared geo-spatial database was integrated with the analytical framework developed in Chapter 2 for indicator-based assessment of transit-oriented urban transformation.

Spatial datasets corresponding to individual indicators were analyzed using GIS techniques such as:

1. buffer analysis,
2. network analysis,
3. density analysis,
4. overlay analysis,
5. and spatial accessibility assessment.

The integration of these datasets and analytical techniques supported comprehensive assessment of land cover transformation, built form characteristics, mobility infrastructure, accessibility conditions, and pedestrian connectivity within the selected transit influence zone.

The prepared geo-spatial database therefore forms the foundation for evaluating spatial transformation associated with metro infrastructure within the study area.

3.9 Chapter Summary

This chapter discussed the choice of the study area and methodological framework that was adopted to assess the transit-oriented urban transformation within the selected metro influence zone. First, the chapter discussed the context of emerging metro cities in India and justified the selection of Pune as the study city on the basis of its rapid urbanization, expanding metropolitan structure and emerging metro infrastructure.

The chapter also studied the pattern of urban growth of Pune and introduced Pune Metro network along with the selected metro corridor. A comparative assessment of potential study locations was carried out and District Court Metro Station was selected as the final study location based on its relative accessibility, land use mix, intermodal connectivity and transit-oriented development potential.

To assess the transformation characteristics of the selected metro station, the study area was demarcated by transit influence buffers to quantify the walkable and extended accessibility zone. The chapter also identified the temporal stages of metro-induced

transformation including pre-announcement, planning, construction, operational and early consolidation phases for understanding the evolution of urban transformation within the corridor.

Further, the chapter outlined the geo-spatial and indicator based methodological framework adopted for the study. Secondary geo-spatial datasets, GIS database preparation techniques, analytical methods and indicator-based spatial assessment methodologies were discussed in details. The analytical workflow has established a systematic process for assessing land cover, built form, mobility and accessibility features that are relevant to transit-oriented urban transformation.

The subsequent chapter focuses on the spatial analysis and assessment of identified indicators within the delineated transit influence zone using geo-spatial techniques and GIS-based analytical methods.

Chapter 4: Land Cover and Built Form Assessment

This chapter focuses on the assessment of land cover and built form transformation within the delineated transit influence zone surrounding District Court Metro Station. The chapter evaluates spatial characteristics associated with:

1. land cover transformation,
2. urban built-up development,
3. green spaces,
4. and amenity concentration.

The analysis is done using geo-spatial datasets and GIS based analytical techniques such as thematic mapping temporal assessment, density analysis and spatial interpretation. The assessment aims to uncover the patterns of physical change and to understand the influence of metro infrastructure on urban morphology and transit-oriented development characteristics in the study area.

4.1 Introduction

Changes in urban land cover patterns, built form features, development density and concentration of urban activities often indicate transformation of urban areas around metro corridors. The introduction of metro infrastructure impacts accessibility, land use, redevelopment potential and spatial organization within the transit influence zones, hence it triggers transit-oriented urban transformation.

Assessment of land cover and built form characteristics are therefore important to understand the physical and spatial impact of metro systems on urban environment. Changes in built-up development, dispersion of open spaces, urban density and amenity concentration can be used to understand the changing morphology and functional character of areas around transit stations.

The chapter also examines the changing spatial structure of the area in terms of accessibility and concentration of activities along the metro corridor. The results of the assessment provide a basis for the understanding of the physical dimension of transit-oriented urban transformation in the selected study area.

4.2 Land Cover Transformation Analysis

To understand the spatial changes happening in the transit influence zone around District Court Metro Station at different stages of metro development, land cover transformation analysis was carried out. The analysis evaluates the transition of land cover categories including built-up areas, vegetation cover, vacant land, and water bodies in order to assess the physical transformation associated with metro-induced urban growth.

Temporal land cover maps in Figure 23 prepared for different assessment periods illustrate gradual urban intensification and changing spatial characteristics within the study area. The transformation patterns indicate increasing development pressure and evolving urban morphology associated with improved accessibility and transit-oriented activities surrounding the metro corridor.

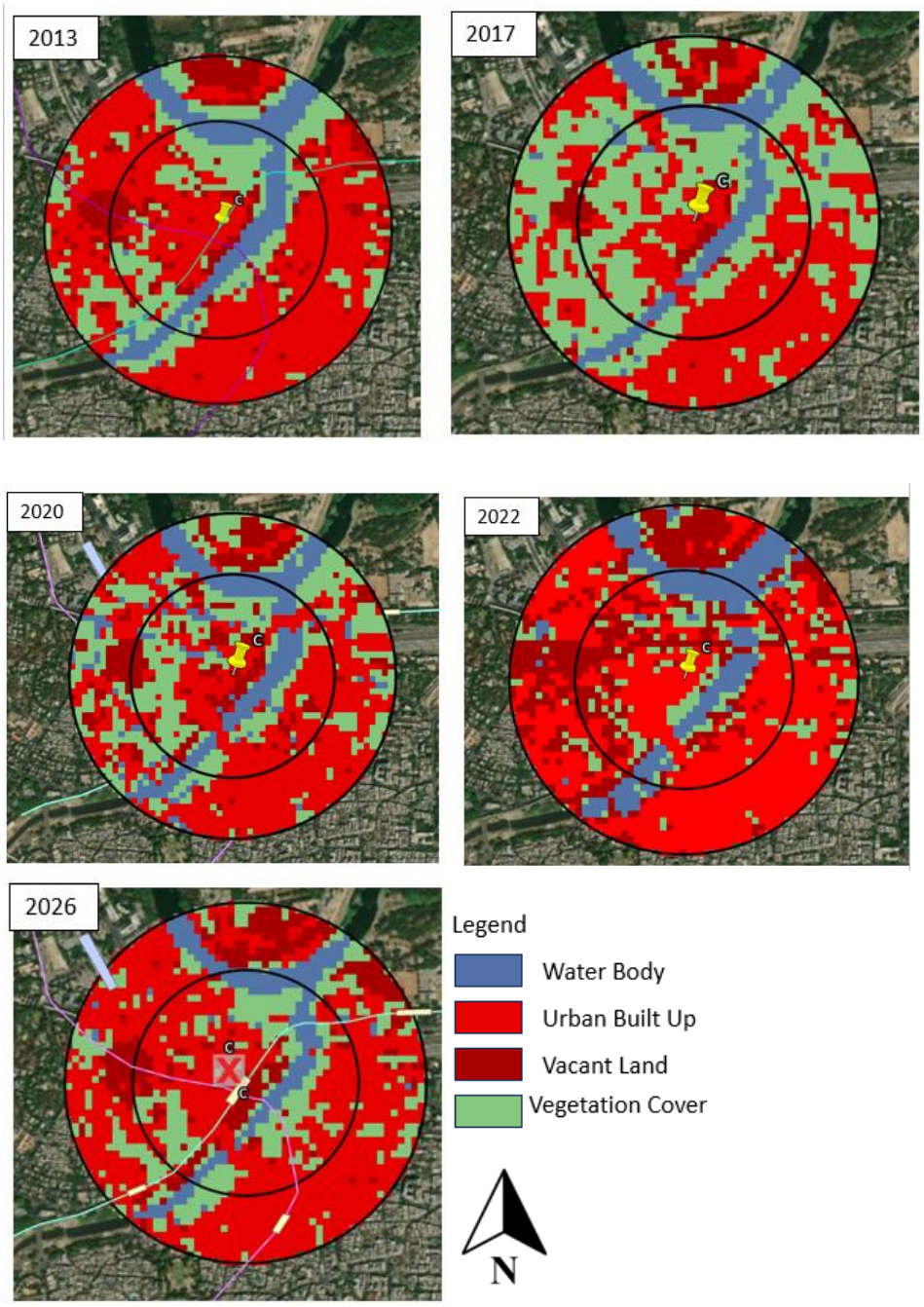


Figure 24. District Court Land Cover Temporal Analysis (Author)

Table 11.District Court Land Cover Temporal Analysis (Author)

ChangeDetection	AreaChange sqm (2013-2017)	AreaChange sqm (2017-2020)	AreaChange sqm (2020-2022)	AreaChange sqm (2022-2026)	Total
Water Body - Water Body	187532.0756	182904	195186.2171	156339.9995	721962.2922
Water Body - Urban Built Up	9830.142178	18347	31943.7319	14479.88873	74600.7628
Water Body - Vacant Land	1764.401537	228	37255.69767	7248.257354	46496.35656
Water Body - Vegetation Cover	40817.81081	5106	20791.09085	79180.98874	145895.8904
Urban Built Up - Water Body	11127.38417	14696	5195.118233	5404.173027	36422.67543
Urban Built Up - Urban Built Up	727506.9264	654375	756070.5097	877249.1364	3015201.572
Urban Built Up - Vacant Land	18574.39093	77783	63001.81143	64904.05915	224263.2615
Urban Built Up - Vegetation Cover	302521.2307	73405	36660.06189	57857.90126	470444.1938
Vacant Land - Water Body	658.583543	2659	23.400593	16741.07733	20082.06147
Vacant Land - Urban Built Up	43119.33207	9288	90598.64786	161511.3789	304517.3588
Vacant Land - Vacant Land	83112.16888	103070	135868.7522	151275.9337	473326.8548
Vacant Land - Vegetation Cover	107933.8153	14826	21331.44038	177298.9058	321390.1614
Vegetation Cover - Water Body	7224.272318	85336	56441.76266	2692.799099	151694.8341
Vegetation Cover - Urban Built Up	40845.47793	178054	126713.2658	64376.55238	409989.2961
Vegetation Cover - Vacant Land	25570.53685	67907	270109.2521	36491.54581	400078.3347
Vegetation Cover - Vegetation Cover	386833.7729	509054	149403.4826	125077.8425	1170369.098

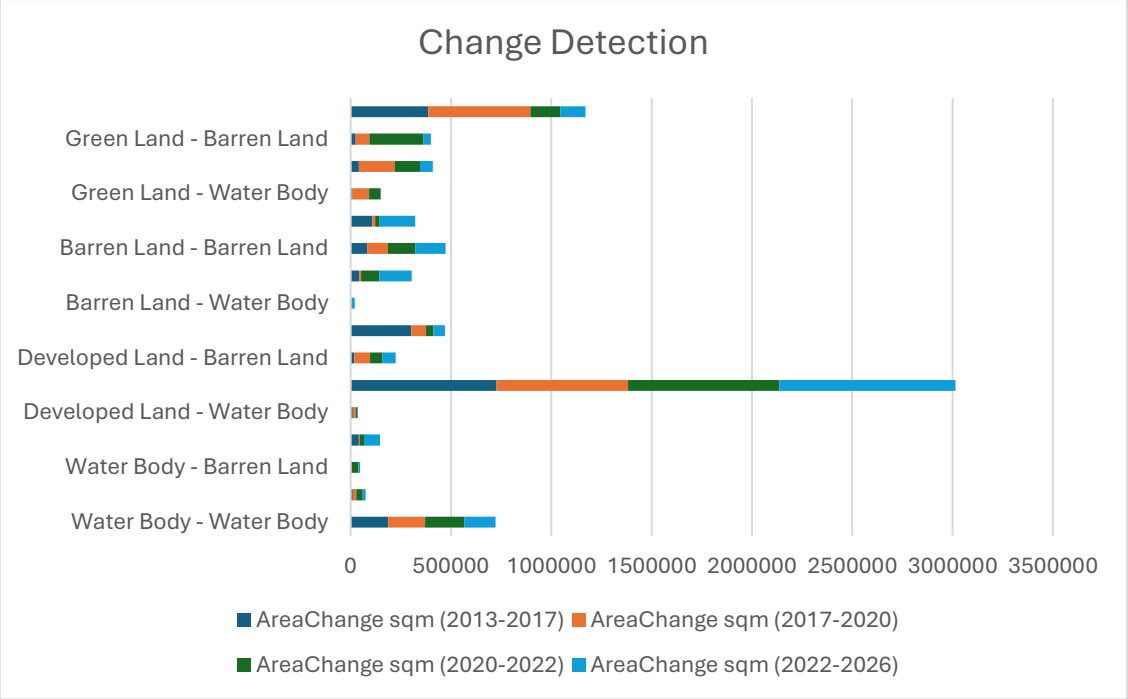


Table 12. Percentage change in Land Cover

Period	2013–2017	2017–2020	2020–2022	2022–2026	2013–2026
Built-Up Change %	-22.84	4.72	16.89	11.17	4.99
Vegetation Change %	81.18	-28.12	-62.12	92.57	-5.01
Vacant Land Change %	-45.63	92.98	103.32	-48.66	9.52
Water Body Change %	-14.00	38.27	-10.07	-29.46	-24.56

4.2.1 Built-Up Land Transformation

The analysis shows a gradual growth in urban built-up development in the study area at different stages of transformation. Vacant and underutilized land parcels have been incrementally transformed into developed urban surfaces, indicative of rising redevelopment pressure and land intensification associated with metro access.

Developed land also persisted throughout the assessment periods, reflecting the compact and established urban character of the metro influence zone. The increased concentration of built-up along major transportation corridors and activity nodes indicates a developing pattern of transit-oriented urban growth in the study area.

4.2.2 Vegetation and Green Cover Transformation

The vegetation cover in the study area exhibited a fluctuating trend for different assessment periods. While there are temporary increases in green cover in some stages, the long-term transformation pattern indicates a gradual fragmentation and reduction of ecological and open spaces due to increasing urbanization and built-up expansion.

The change of vegetation cover to urban surfaces reflects the growing intensity of development and changing spatial priorities of the transit influence zone. This observed transformation underscores the importance of integrating green infrastructure and environmental planning into fast urbanizing transit corridors.

4.2.3 Vacant Land Transformation

Vacant and underutilized land parcels within the study area demonstrate significant transformation into built-up and urbanized surfaces during the assessment periods. This trend reflects increasing land utilization and redevelopment activity associated with improved accessibility and transit-oriented development potential surrounding the metro corridor.

The transformation of vacant land indicates:

1. urban expansion,
2. increasing development intensity,
3. and consolidation of urban activities within the transit influence zone.

Such redevelopment trends further contribute toward compact urban growth surrounding metro infrastructure.

4.2.4 Water Body Transformation

The analysis indicates limited but visible transformation of water body edges and adjoining open spaces into urbanized surfaces within selected portions of the study area. Increasing urban pressure near transportation corridors and activity zones has influenced the spatial character of surrounding environmental features.

Although water bodies remain comparatively limited within the study area, the observed transformation patterns highlight the requirement for environmentally sensitive planning and protection of urban ecological systems within transit-oriented development areas.

4.2.5 Land Cover Transition Characteristics

The land cover transition matrix demonstrates dominant persistence of developed land within the study area, indicating the stable and compact urban structure surrounding the metro station area. Simultaneously, increasing transitions from vacant land and vegetation toward urban built-up categories reflect ongoing redevelopment and intensification associated with metro accessibility.

The observed transition characteristics collectively indicate:

1. increasing urban intensification,
2. redevelopment-led transformation,
3. concentration of built-up activities,
4. and emergence of compact transit-oriented urban form.

These transformation patterns demonstrate the growing influence of metro infrastructure on spatial development and urban morphology within the study area surrounding District Court Metro Station.

4.3 Urban Built Form Assessment

Urban built form assessment was conducted to understand the spatial structure, development intensity, and morphology of the study area surrounding District Court Metro Station. Built form characteristics play an important role in evaluating transit-oriented urban transformation, as metro accessibility often influences redevelopment patterns, urban density, and concentration of activities within transit influence zones.

The analysis focused on identifying patterns of urban development, spatial organization of built-up areas, and the relationship between transportation accessibility and urban form transformation within the study area.

4.3.1 Development Intensity

The study area is highly developed because of the presence of institutional, administrative, commercial and transportation activities around the metro station. The existence of major arterial corridors and intermodal accessibility also contribute to increased land utilization and redevelopment potential within the transit influence zone.

The higher development intensity is especially evident at major intersections and activity corridors with concentrations of commercial and mixed-use activities. The operationalization of the metro corridor has further strengthened the area’s role as an active urban node in the metropolitan structure.

Increasing intensity of urban development reflects the development of features of transit-oriented development associated with higher accessibility and enhanced connectivity.



Figure 25.District Court Urban Built Footprint Temporal Analysis (Author)

4.3.2 Urban Morphology and Spatial Structure

The urban morphology of the study area is characterized by a compact and dense urban fabric consisting of institutional complexes, commercial establishments, administrative buildings, transportation infrastructure, and mixed-use development.

The spatial structure of the area is strongly influenced by:

1. major transportation corridors,
2. interconnected street networks,
3. institutional land use,
4. and concentration of urban activities.

The metro infrastructure has reinforced the spatial significance of the area by improving accessibility and strengthening connectivity between important urban functions. The resulting urban form reflects a transition toward more compact and transit-oriented spatial organization within the study area.

Table 13.District Court Urban Built Footprint Temporal Analysis (Author)

Year/Period	Major Increasing Land Cover (Based on Change Values)	Major Decreasing Land Cover	Spatial Analysis	Transformation Interpretation	TOD Interpretation
2013–2017	**Vacant Land → Urban Built-Up (43119 sqm)** and **Vegetation → Urban Built-Up (40845 sqm)** show noticeable urban expansion	Reduction in vegetation and vacant parcels due to conversion into built-up surfaces	Urban growth begins around central influence areas and along mobility corridors	Initial phase of land intensification with conversion of undeveloped land into urban fabric	Early transit-induced development pressure begins emerging
2017–2020	Strong persistence of **Urban Built-Up → Urban Built-Up (654375 sqm)** indicates stabilization of developed areas; continued conversion from vegetation/open land to built-up	Vegetation cover decreases significantly through conversion into built-up land	Built-up patches become more continuous and compact near transit influence zones	Urban structure starts shifting from fragmented growth toward compact development	TOD influence becomes more spatially visible through corridor-oriented intensification
2020–2022	Very high increase in **Vacant Land → Urban Built-Up (90598 sqm)** and **Urban Built-Up persistence (756070 sqm)**	Vacant land and vegetation patches reduce rapidly	Central and corridor areas show strong urban consolidation	Large-scale urban intensification and reduction of undeveloped land become evident	Transit accessibility strongly influences land conversion and densification
2022–2026	Continued dominance of **Urban Built-Up → Urban Built-Up (877249 sqm)** and increase in built-up continuity	Vegetation and vacant land become fragmented and highly reduced	Urban form becomes denser and more continuous around the station core	Mature stage of compact urban expansion with limited remaining open land	Emerging TOD urban morphology characterized by compactness and accessibility-based growth

4.3.3 Redevelopment Characteristics

The assessment indicates gradual redevelopment and transformation of underutilized urban parcels surrounding the metro corridor. Increasing accessibility and improved transit connectivity have contributed toward growing redevelopment pressure and changing land utilization patterns within the study area.

Redevelopment trends are particularly visible along major transportation corridors and near important activity nodes where commercial and mixed-use development is gradually intensifying. The transformation reflects increasing economic and functional significance of the metro station area within the urban structure of Pune.

The observed redevelopment characteristics indicate the growing influence of metro infrastructure on shaping urban growth and built form transformation within the transit influence zone.

4.3.4 Built Form Transformation and TOD Characteristics

The built form transformation observed within the study area demonstrates several emerging characteristics associated with transit-oriented development. These include:

1. increasing compactness of urban form,
2. concentration of activities near transit infrastructure,
3. mixed-use urban development,
4. and intensification of built-up activities along accessibility corridors.

The evolving spatial structure surrounding District Court Metro Station reflects the gradual emergence of a transit-oriented urban environment influenced by metro accessibility and increasing connectivity within the metropolitan context.

The assessment therefore highlights the relationship between metro infrastructure and changing urban morphology within the study area.

4.4 Green Space Assessment

Green spaces and urban open areas are important components of sustainable and transit-oriented urban environments as they contribute toward environmental quality, recreational accessibility, and pedestrian comfort within dense urban areas. Assessment of green spaces within transit influence zones helps in understanding the relationship between urban intensification and environmental infrastructure associated with metro development.

The assessment of green space transformation surrounding District Court Metro Station was carried out through temporal analysis of park areas, recreational landscapes, sports facilities, and green open spaces within the delineated study area.

The analysis indicates that green spaces within the study area remain comparatively limited due to the dense urban character and concentration of institutional and commercial activities. However, gradual improvement in accessibility and integration of existing recreational spaces with transportation corridors becomes visible during the operational and early consolidation stages of metro development.

4.4.1 Distribution of Green Spaces

The spatial distribution of green spaces within the study area is fragmented and dispersed across institutional campuses, roadside plantations, recreational grounds, and isolated open spaces. Large continuous ecological corridors are limited within the immediate metro influence zone due to the compact urban fabric surrounding the station area.

The assessment indicates that recreational landscapes and sports grounds constitute a significant portion of the available green infrastructure within the study area. Public open spaces remain relatively sparse but strategically positioned near institutional and transportation corridors.



Figure 26.District Court Green Spaces Temporal Analysis (Author)

4.4.2 Temporal Transformation of Green Spaces

Temporal assessment of green space transformation demonstrates comparatively stable green area distribution between 2013 and 2020, indicating limited environmental intervention during the early planning and construction stages of metro development.

A noticeable increase in total green space area becomes visible during the operational phase after 2022, primarily due to improvement in accessibility and integration of existing recreational landscapes within the evolving transit network. The analysis suggests that metro development has contributed more toward improving connectivity and accessibility to green spaces rather than large-scale creation of new ecological areas.

The percentage of green space within the study area shows a gradual increase during later transformation stages, reflecting emerging consideration of public realm and environmental quality within the transit-oriented urban structure.

Table 14.District Court Green Spaces Temporal Analysis (Author)

Year	Park Area (sqm)	Sport Pitch	Recreational Landscape Area (sqm)	Total Green Space Area (sqm)	Green Space % of Study Area	% Change in Green Space
2013	2765.43	34545.03	15241.07	52551.54	2.62	—
2017	2765.43	34545.03	15241.07	52551.54	2.62	0.00
2020	2765.43	34545.03	15241.07	52551.54	2.62	0.00
2022	3594.52	37201.04	20026.20	60821.77	3.03	15.74
2026	3594.52	37201.04	20026.20	60821.77	3.03	0.00

4.4.3 Green Spaces and TOD Transformation

The transformation assessment indicates that early stages of metro development focused primarily on transportation infrastructure and corridor development, with limited direct influence on environmental and recreational landscapes. However, during the operational and early consolidation phases, the integration between transit accessibility and recreational spaces becomes increasingly visible.

Improved pedestrian accessibility and connectivity between transit corridors and existing open spaces contribute toward strengthening the public realm character of the study area. Green spaces gradually begin functioning as supportive environmental and recreational components within the evolving transit-oriented environment.

The analysis therefore indicates an emerging relationship between mobility infrastructure and environmental integration within the TOD influence zone surrounding District Court Metro Station.

4.4.4 Environmental Interpretation

The observed transformation patterns suggest that although green spaces remain limited in quantity, their functional accessibility and spatial integration within the urban environment have improved over time. The transition from isolated recreational patches toward more connected public spaces reflects gradual enhancement of environmental infrastructure associated with transit-oriented urban transformation.

However, increasing urban intensification and redevelopment pressure continue to pose challenges for preservation and expansion of ecological spaces within the dense urban corridor. The findings emphasize the need for:

1. integrated green infrastructure planning,
2. pedestrian-oriented public realm enhancement,
3. and environmentally sensitive TOD strategies

within future urban development interventions surrounding the metro corridor.

4.5 Amenity Density Analysis

Amenity concentration is an important indicator for assessing transit-oriented urban transformation as it reflects intensity of urban activities, accessibility to services, and functional characteristics of the transit influence zone. Areas with higher amenity concentration generally demonstrate stronger mixed-use characteristics and greater pedestrian activity, which are essential components of transit-oriented development.

The amenity density assessment surrounding District Court Metro Station was conducted using geo-spatial analysis of commercial, institutional, public, financial, and recreational facilities within the delineated study area.

Kernel density analysis was used to identify spatial concentration patterns and activity clusters associated with urban services and public facilities surrounding the metro corridor.

4.5.1 Spatial Distribution of Amenities

The study area demonstrates a high concentration of amenities due to its strategic location within the central urban structure of Pune. Commercial establishments, institutional facilities, administrative offices, banks, healthcare services, recreational facilities, and transportation-related functions are concentrated along major road corridors and around important activity nodes.

Higher amenity concentration is particularly visible near:

1. major intersections,
2. institutional zones,
3. transportation corridors,
4. and mixed-use commercial areas.

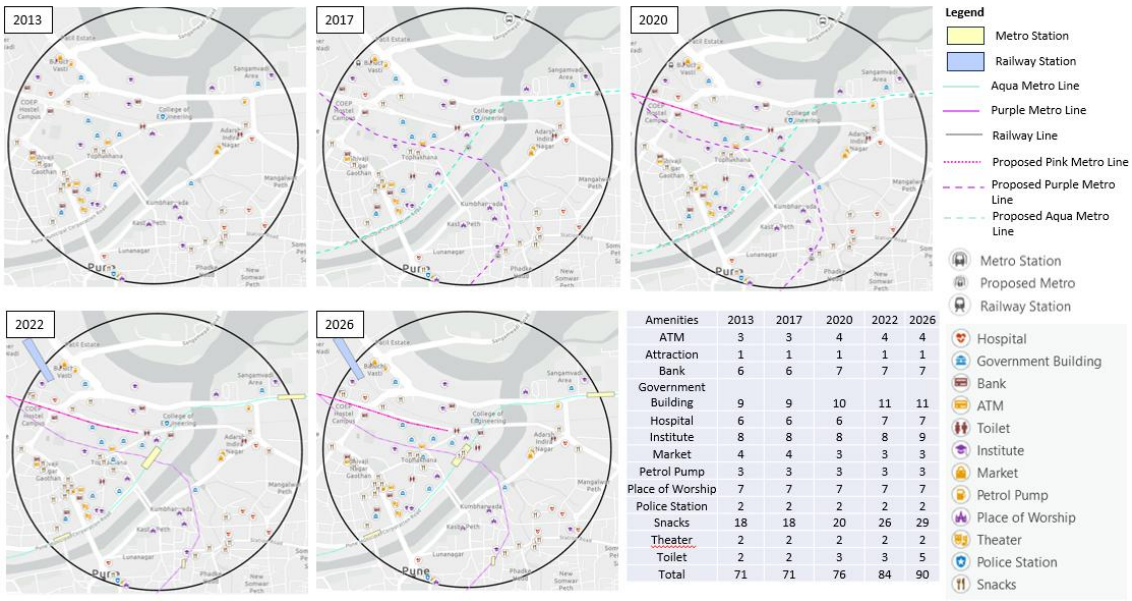
The spatial distribution of amenities reflects the role of the study area as an important administrative and commercial activity center within the metropolitan structure.

4.5.2 Amenity Density and Activity Concentration

The density analysis indicates strong clustering of urban amenities surrounding the metro station influence zone. Areas with higher accessibility and better transportation connectivity demonstrate greater concentration of commercial and public activities.

The metro corridor has further strengthened accessibility to existing urban services, thereby contributing toward increased activity intensity and functional integration within the study area. The concentration of amenities within walkable distance of the station area supports the emergence of transit-oriented urban characteristics associated with mixed-use development and pedestrian movement.

The analysis also demonstrates that activity concentration gradually increases during later stages of metro development due to improved accessibility and strengthening of transportation connectivity.



Amenities	2013	2017	2020	2022	2026
ATM	3	3	4	4	4
Attraction	1	1	1	1	1
Bank	6	6	7	7	7
Government Building	9	9	10	11	11
Hospital	6	6	6	7	7
Institute	8	8	8	8	9
Market	4	4	3	3	3
Petrol Pump	3	3	3	3	3
Place of Worship	7	7	7	7	7
Police Station	2	2	2	2	2
Snacks	18	18	20	26	29
Theater	2	2	2	2	2
Toilet	2	2	3	3	5
Total	71	71	76	84	90

Figure 27.District Court Amenities Temporal Analysis (Author)

4.5.3 Transit-Oriented Characteristics of Amenities

The observed amenity distribution demonstrates several characteristics associated with transit-oriented development including:

1. concentration of activities near transit infrastructure,
2. mixed-use urban environment,
3. pedestrian accessibility to services,
4. and functional integration between transit and urban activities.

The presence of institutional, commercial, financial, and recreational facilities within the transit influence zone contributes toward continuous urban activity and increasing pedestrian movement surrounding the metro station area.

The integration of urban amenities with transportation accessibility further strengthens the role of the metro station as an emerging urban activity node within the city structure.

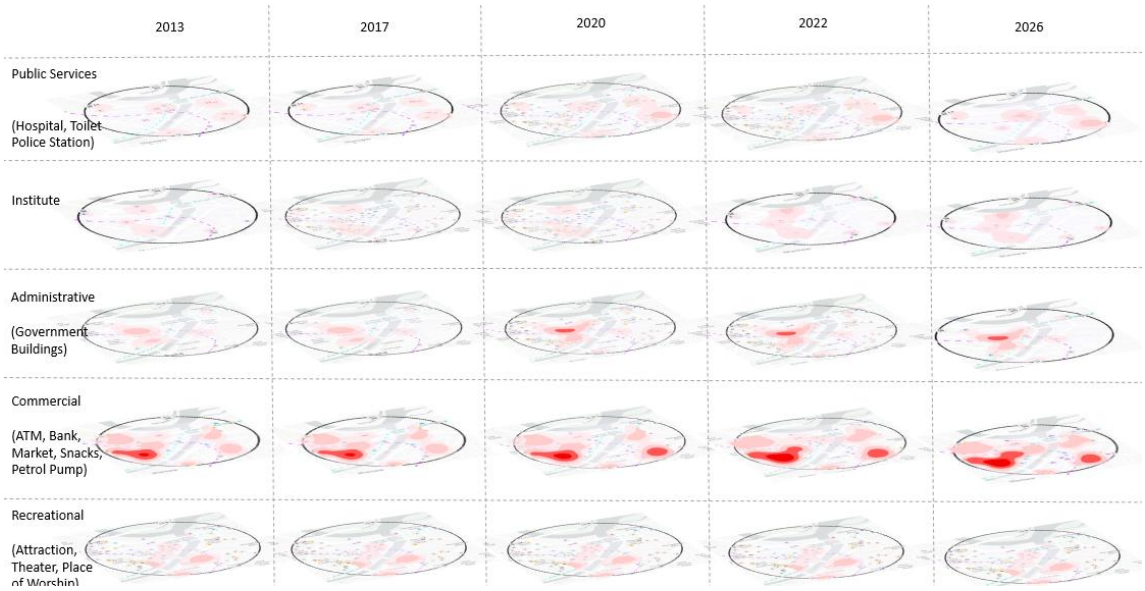


Figure 28.District Court Activity Concentration Temporal Analysis (Author)

4.5.4 Spatial Interpretation

The amenity density assessment indicates that the study area exhibits strong functional characteristics associated with transit-oriented urban environments. Improved metro accessibility and concentration of urban services have contributed toward increasing urban activity intensity and strengthening mixed-use development patterns within the transit corridor.

The observed spatial concentration of amenities reflects:

1. increasing urban integration,
2. enhanced accessibility,
3. and growing transit-oriented activity concentration within the study area surrounding District Court Metro Station.

These transformation characteristics demonstrate the influence of metro infrastructure on shaping functional urban structure and activity distribution within the central urban environment.

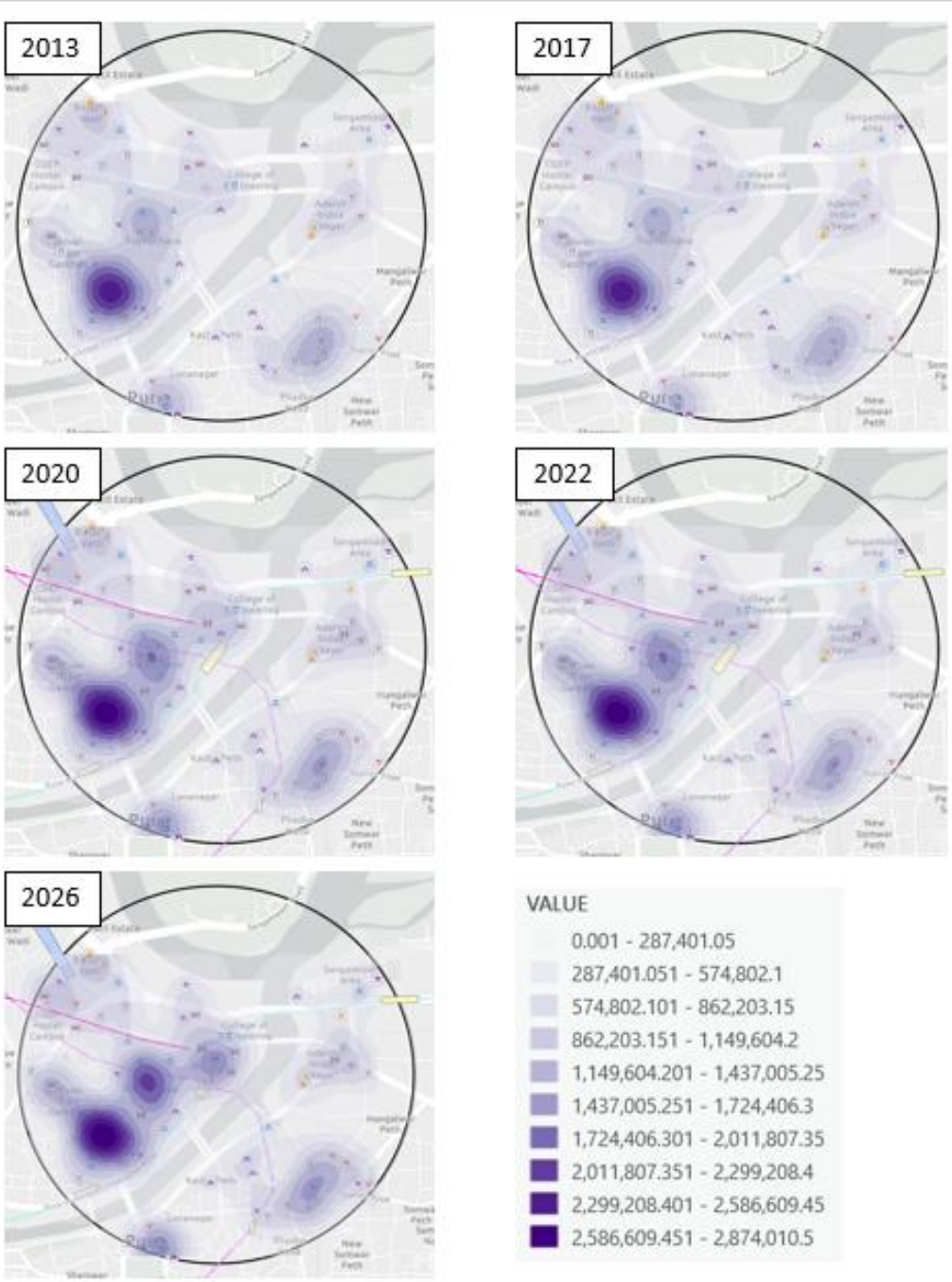


Figure 29. District Court Amenities Density Temporal Analysis (Author)

4.6 Spatial Interpretation of Land Cover and Built Form Transformation

4.6.1 Land Cover Transition and Urban Expansion Patterns

The land cover analysis reveals a clear and continuous transformation from non-built uses to built-up land within the study area. Over the observed time periods, vegetated areas, vacant plots, and open lands have progressively reduced, while impervious and built-up surfaces have expanded significantly. This pattern indicates ongoing urban expansion

driven by increasing development pressure and changing land use demands. The spatial distribution of this transformation is not uniform; rather, it is concentrated along major corridors and in proximity to key accessibility nodes, suggesting a strong relationship between accessibility and land conversion processes. The conversion of peripheral and underutilized land into developed parcels reflects a transition toward a more compact and intensified urban structure.

4.6.2 Built Form Intensification and Morphological Change

The built form assessment highlights a noticeable intensification of urban development within the study area. Building footprints have increased both in number and spatial coverage, indicating infill development and redevelopment of previously low-density plots. In addition to horizontal expansion, certain pockets exhibit vertical growth, reflecting a shift toward higher-density construction patterns. The overall urban morphology is gradually evolving from a dispersed and heterogeneous form to a more consolidated and structured urban fabric. This transformation is particularly evident in areas with improved connectivity, where redevelopment activities are more pronounced. The increasing built density reflects a response to rising land value and growing urban demand.

4.6.3 Green Space Fragmentation and Environmental Implications

The analysis of green spaces indicates a reduction in both extent and continuity of vegetated and open areas. Existing green patches are increasingly fragmented and isolated due to surrounding built-up expansion. This fragmentation has led to a decline in larger, contiguous open spaces, resulting in a more constrained environmental structure within the urban fabric. The reduction in green cover not only affects the ecological balance of the area but also limits the availability of accessible public open spaces for residents. The spatial pattern suggests that green spaces are often confined to institutional or residual parcels rather than forming a planned and connected network.

4.6.4 Amenity Clustering and Emergence of Activity Nodes

The kernel density analysis of urban amenities reveals a distinct pattern of clustering, with high concentrations of commercial, institutional, and public facilities emerging in specific zones. These clusters are primarily located near major transport corridors and nodes, indicating a strong dependency on accessibility. The spatial concentration of amenities suggests the formation of urban activity nodes that function as local centers of economic and social interaction. In contrast, peripheral areas show relatively low amenity density, highlighting spatial disparities in service distribution. This uneven distribution reinforces the role of accessibility in shaping urban activity patterns.

4.6.5 Transit Influence and Emerging TOD Characteristics

The spatial patterns observed in land cover, built form, and amenity distribution collectively indicate a significant influence of transit infrastructure on urban development. Areas in close proximity to metro stations and major transit corridors

exhibit higher development intensity, increased redevelopment activity, and stronger amenity concentration. This reflects the emergence of Transit-Oriented Development (TOD) characteristics within the study area. The integration of land use intensification and improved accessibility has led to the formation of nodal development patterns, where urban growth is increasingly concentrated around transit-accessible locations. This trend suggests a gradual shift from auto-oriented expansion to transit-influenced urban structuring.

4.6.6 Integrated Spatial Interpretation of Urban Transformation

The combined analysis of land cover, built form, green spaces, and amenities presents a comprehensive understanding of urban transformation in the study area. The findings indicate a clear transition toward a more compact, intensified, and accessibility-driven urban structure. Built-up expansion, morphological densification, and amenity clustering collectively point toward increasing urban consolidation around key nodes. Simultaneously, the reduction and fragmentation of green spaces highlight environmental trade-offs associated with this growth pattern. Overall, the spatial interpretation confirms that accessibility, particularly transit proximity, is a key driver shaping the evolving urban form, leading to the gradual emergence of a TOD-influenced urban landscape.

4.7 Chapter Summary

4.7.1 Overview of Land Cover Transformation

This chapter examined the spatial and temporal changes in land cover within the study area using GIS-based analysis. The results indicate a consistent expansion of built-up areas accompanied by a reduction in vegetated land, open spaces, and other non-urban surfaces. This transformation reflects increasing urbanization pressure and a shift toward more intensive land utilization. The spatial distribution of change suggests that land conversion is more pronounced along accessible corridors and nodes, highlighting the influence of connectivity on urban expansion.

4.7.2 Summary of Built Form Changes

The built form analysis revealed significant changes in urban morphology, characterized by an increase in building footprint density and localized vertical development. The study area shows a gradual shift from low-density and fragmented development toward more consolidated and compact built patterns. Redevelopment and infill development are evident in several locations, particularly in areas with better accessibility and proximity to transit infrastructure. These changes indicate increasing land value pressures and evolving urban development dynamics.

4.7.3 Green Space and Amenity Distribution Outcomes

The assessment of green spaces highlights a reduction in spatial extent and increasing fragmentation of open and vegetated areas. The remaining green spaces are often isolated and lack connectivity, limiting their functional role within the urban environment. In

contrast, amenity analysis shows strong spatial clustering of commercial, institutional, and public facilities, particularly near major nodes and corridors. This uneven distribution reflects a growing concentration of urban services in accessible locations, reinforcing spatial disparities within the study area.

4.7.4 Key Spatial Transformation Insights

The integrated analysis of land cover, built form, green spaces, and amenities reveals a broader pattern of urban transformation characterized by intensification, consolidation, and nodal development. The study area is gradually evolving into a more compact urban structure, where growth is concentrated around key accessibility points. However, this transformation is also accompanied by environmental trade-offs, particularly in the reduction of green cover and open spaces. Overall, the spatial analysis highlights a clear shift toward a transit-influenced urban form.

4.7.5 Transition to Mobility and Accessibility Assessment

The findings of this chapter establish the physical and morphological foundation of urban transformation in the study area. While land cover and built form changes explain the structural evolution of the urban fabric, the next chapter focuses on how these changes influence and are influenced by movement systems. Chapter 5 therefore builds upon these findings by examining mobility patterns, connectivity, pedestrian infrastructure, and transit accessibility to provide a comprehensive understanding of urban dynamics within a Transit-Oriented Development framework.

CHAPTER 5: Mobility and Accessibility Assessment

This chapter examines the mobility structure and accessibility patterns of the study area in order to understand how movement systems have evolved in response to urban transformation. It focuses on the performance and spatial distribution of street networks, pedestrian infrastructure, transit nodes, parking systems, and intersection density. The analysis is framed within a Transit-Oriented Development (TOD) perspective to evaluate how effectively the study area supports connectivity, last-mile accessibility, and multimodal integration.

5.1 Introduction

The efficiency with which people, commodities, and services move within a city is determined by mobility and accessibility, two essential elements of urban structure. They have a direct impact on the distribution of land use, the level of development, and the general functionality of metropolitan areas. Mobility patterns undergo substantial changes that alter the spatial organization of the city in quickly changing urban environments, especially those impacted by transportation investments like metro systems.

Mobility in the context of Transit-Oriented Development (TOD) encompasses not just movement but also the convenience of accessing important urban activities using a variety of transport options. Accessibility becomes a crucial indicator of how well various areas of the city are connected to public facilities, employment hubs, and transit hubs. Therefore, assessing how well transit infrastructure directs sustainable urban expansion requires an awareness of mobility and accessibility patterns.

This chapter focuses on using a GIS-based spatial analytic framework to evaluate the study area's mobility and accessibility structure. It looks at the development and state of:

1. The form and interconnectedness of street networks
2. Urban permeability and intersection density
3. Accessibility and effect areas of transit nodes
4. Parking distribution and its geographic fluctuations
5. Walkability and the continuity of the pedestrian network

The goal of the analysis is to comprehend how movement patterns and accessibility levels have been impacted by the development and existence of transport infrastructure, especially metro connectivity. It also looks at how various transport system elements work together to facilitate or hinder last-mile connectivity.

The chapter offers insights into the level of integration between land use and transportation systems by analysing these indicators. By showing the degree to which the study area's mobility structure reflects the principles of transit-oriented development, it also aids in identifying locations with strong and weak accessibility features.

5.2 Geo-Spatial Database Preparation for Mobility and Accessibility

This section describes the preparation and organization of the spatial datasets used for the analysis of mobility and accessibility. A structured GIS database is built to ensure consistency, comparability and spatial precision of all mobility measures. To assess connectivity, movement patterns and accessibility conditions within the study area, the database includes a number of transport-related layers.

The main datasets prepared for this investigation are road network data, intersection sites, transit nodes, parking places and pedestrian infrastructure. Each dataset is extracted, digitised and standardised for integrated geographical analysis.

5.2.1 Road Network Preparation

Base maps and satellite data are used to create the road network, which is then categorised using a functional hierarchy. Collector streets, local streets, arterial roads, and sub-arterial roads are all included in the classification. This categorisation aids in comprehending the movement hierarchy and connectivity structure within the studied area.

To guarantee topological correctness, the road network is further processed by eliminating disconnected segments, overlaps, and gaps. This makes it possible to analyse network connection and density accurately.

5.2.2 Intersection Data Preparation

GIS topology tools are used to produce intersection points from the road network. These locations serve as the urban network's nodes of connectivity. To eliminate redundant or overlapping nodes, each junction is checked and cleaned.

Intersection density and the spatial distribution of connectivity throughout the research region are examined using the final dataset.

5.2.3 Transit Node Mapping

Major bus stops and metro stations are examples of transit nodes that are mapped as point features. Satellite imagery and government sources are used to confirm their locations.

In order to evaluate the geographical impact of transit nodes on nearby land use and accessibility, buffer zones are established around them. These buffers aid in determining the degree of activity concentration and transit accessibility surrounding nodes.

5.2.4 Preparing Parking Data

The study area's parking facilities are plotted, including both on- and off-street parking spots. Field data, satellite interpretation, and accessible secondary sources are used to identify these points.

The dataset is used to examine patterns of geographical distribution and comprehend shifts in parking concentration and demand, especially with regard to transit accessibility.

5.2.5 Pedestrian Network Preparation

Base maps and high-resolution satellite photos are used to digitise the pedestrian network. It consists of pedestrian-accessible roads, walkable corridors, and walkways.

Where appropriate, continuous pedestrian pathways and shaded walkability corridors are identified with extra care. The network is then utilised to evaluate last-mile accessibility and pedestrian connectivity to transit hubs and important urban locations.

5.2.6 Clipping and Data Integration

For consistent analysis, all geographic datasets are combined into a single coordinate system and trimmed to the research boundary. This removes outside distortions and guarantees spatial consistency.

Street network evaluation, intersection density mapping, transit accessibility assessment, parking analysis, and pedestrian network evaluation are all based on the final geospatial database.

This structured GIS database enables a comprehensive assessment of mobility and accessibility patterns and supports the evaluation of Transit-Oriented Development characteristics within the study area.

5.3 Street Network Analysis

The basic spatial framework that controls accessibility, mobility, and urban structure in the study region is the street network surrounding the District Court Metro Station TOD, Pune. The road network, which is situated in an extremely busy institutional and commercial setting, is essential for connecting metro accessibility with nearby land uses. In order to comprehend how the street network contributes to the features of Transit-Oriented Development (TOD), this section examines its hierarchy, density, and connection.

5.3.1 Road Hierarchy and Functional Structure

Hierarchical street network in the study area comprises arterial, sub-arterial, collector and local roads. Arterial highways are the principal transportation corridors. They carry a large volume of traffic and provide connectivity at the city and regional level. These are secondary links connecting internal metropolitan neighbourhoods and key corridors.

Collector and local streets provide the primary fine-grained access to residential pockets, commercial structures, and institutional buildings.

The hierarchy is significantly affected by the presence of major institutional land uses such as the District Court complex and associated administrative services. These large blocks of land channel traffic in pre-defined channels and reduce direct permeability in certain areas, influencing the ways in which people move around.

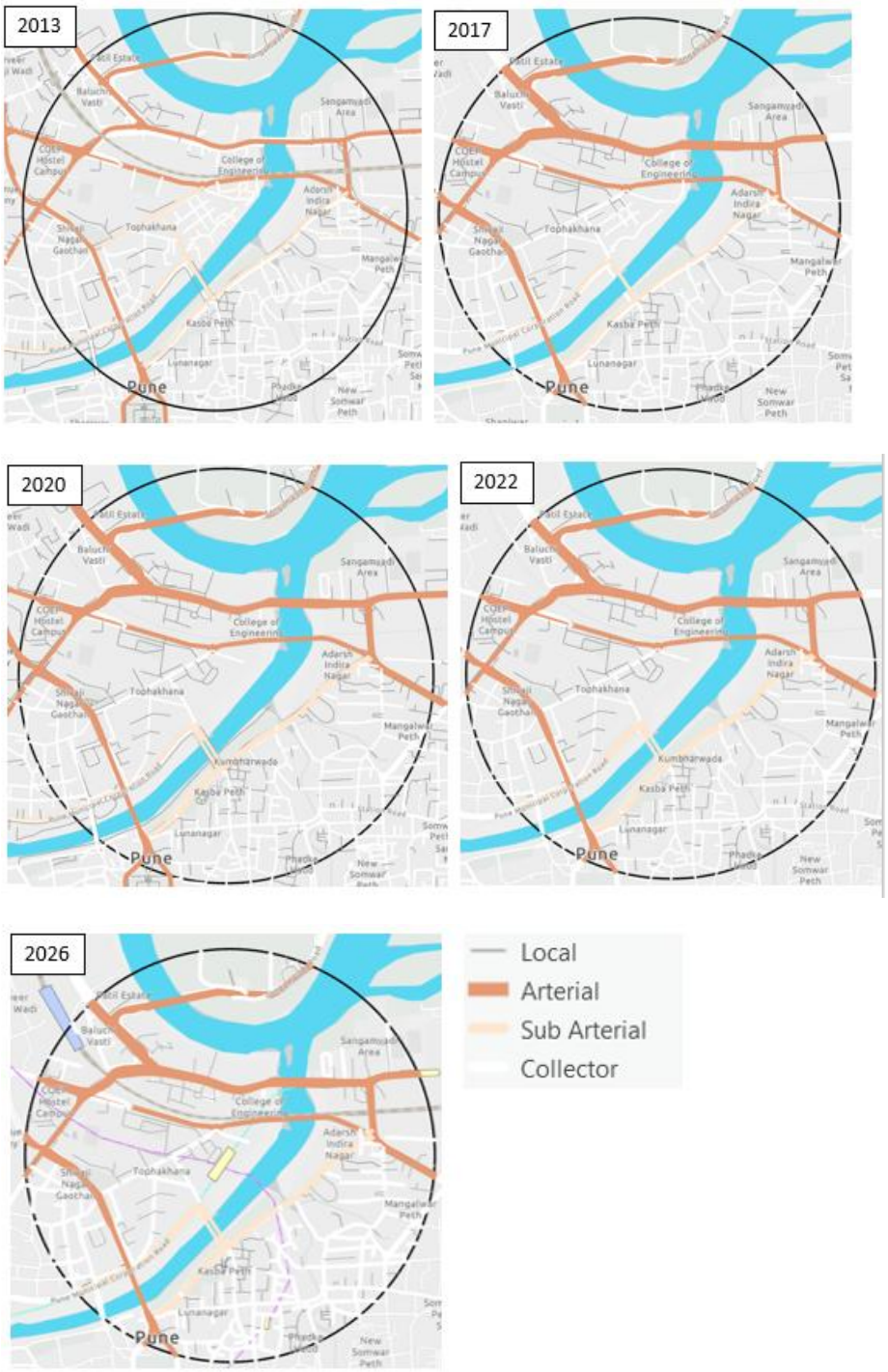
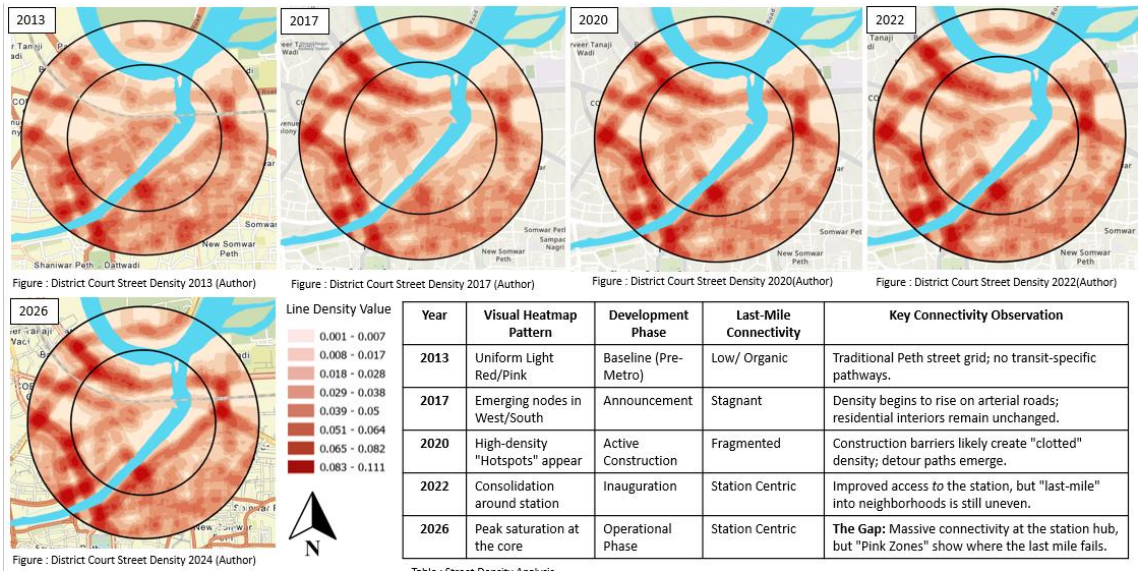


Figure 30.District Court Street Network Temporal Analysis (Author)

5.3.2 Network Density and Spatial Distribution

The density of the road network shows the differences of the research area in terms of urban design and development intensity. The density of the network is higher in the core TOD effect zone around the metro station where land use is more mixed and denser. This neighbourhood has a close street layout which provides better accessibility and a variety of movement options.

In contrast, the peripheral and institution-dominated areas have lower road densities because of larger plot sizes and limited access. This difference results in a specific spatial gradient, easier access close to the metro station, gradually decreasing towards the areas less well connected.



Year	Visual Heatmap Pattern	Development Phase	Last-Mile Connectivity	Key Connectivity Observation
2013	Uniform Light Red/Pink	Baseline (Pre-Metro)	Low/ Organic	Traditional Peth street grid; no transit-specific pathways.
2017	Emerging nodes in West/South	Announcement	Stagnant	Density begins to rise on arterial roads; residential interiors remain unchanged.
2020	High-density "Hotspots" appear	Active Construction	Fragmented	Construction barriers likely create "clotted" density; detour paths emerge.
2022	Consolidation around station	Inauguration	Station Centric	Improved access *to* the station, but "last-mile" into neighborhoods is still uneven.
2026	Peak saturation at the core	Operational Phase	Station Centric	**The Gap:** Massive connectivity at the station hub, but "Pink Zones" show where the last mile fails.

Figure 31. District Court Street Density Temporal Analysis (Author)

5.3.3 Connectivity and Accessibility Structure

The accessibility pattern of the street network connection appears to be rather strong but not equally distributed. The surrounding areas of the metro station are well connected due to many crossings and connected segments of the road network that facilitate efficient movement and reduce the length of the travel.

The overlap of the high-connectivity zone with areas of intense commercial and institutional activity shows a strong relationship of accessibility with urban usefulness. However, some parts of the study area have lower permeability due to boundary walls, gated institutional complexes and large impermeable land parcels that block direct circulation paths.

5.3.4 Spatial Implications of Street Network

The overall street network structure of the District Court Metro Station TOD area is typical of an evolving transit-influenced urban form. High density and well-connected street segments around metro station support intensified land use and enhanced accessibility, reinforcing principles of TOD.

However, the fragmented connectivity in institutional and low permeability zones indicates that the network is not fully integrated. These discontinuities prevent the fluid movement of pedestrians and vehicles, thus creating spatial imbalances in accessibility.

The street network as a whole is important in the spatial organization of the study area, promoting development based on accessibility. It also points out the areas where improvements in connectivity are needed to improve the performance of TOD.

5.4 Intersection Density Analysis

Intersection density is a key indicator of urban connectivity and network permeability, reflecting the degree to which a street system supports multiple route choices, shorter travel paths, and efficient movement. In the context of the District Court Metro Station TOD, Pune, intersection density analysis helps in understanding how fine-grained the street network is and how it influences accessibility, pedestrian movement, and transit-oriented development patterns.

5.4.1 Spatial Distribution of Intersections

The spatial distribution of intersections within the study area is uneven but structured, with a higher concentration observed in the immediate influence zone of the District Court Metro Station. These areas typically correspond to mixed-use corridors, commercial stretches, and institutional-adjacent streets where the street network is more closely spaced.

In contrast, zones occupied by large institutional campuses, court complexes, and enclosed administrative plots show relatively fewer intersections. This results in spatial discontinuities, where access points are limited and internal permeability is reduced due to restricted land parcels and boundary-controlled developments.

5.4.2 Intersection Density and Network Permeability

Higher intersection density is observed in areas closer to the metro station, indicating a more permeable and accessible street network. This fine-grained network structure allows for greater route flexibility, reduced travel distances, and improved accessibility for both pedestrians and vehicular movement.

Such conditions are highly supportive of TOD principles, as they enhance last-mile connectivity between the metro station and surrounding land uses. Conversely, low

intersection density areas exhibit longer block lengths and fewer connection points, which limit movement efficiency and reduce overall accessibility.

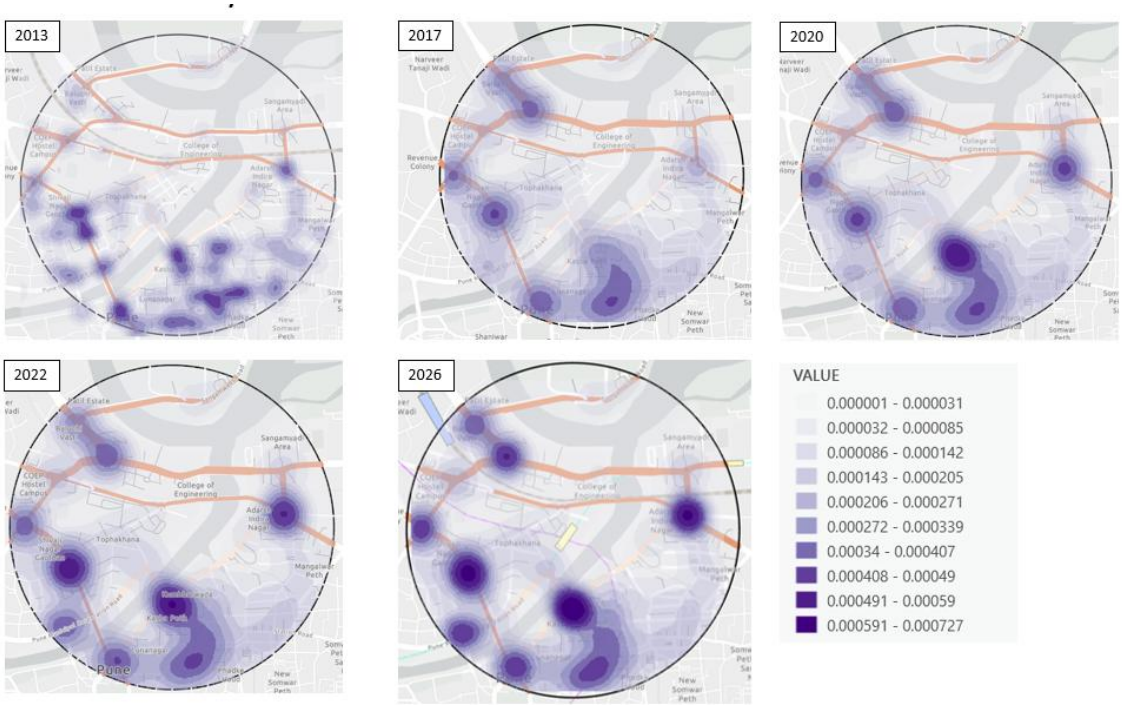


Figure 32.District Court Intersection Density Temporal Analysis (Author)

5.4.3 Relationship with Land Use and Activity Concentration

Intersection density shows a strong spatial correlation with land use intensity and activity concentration. Areas with higher intersection density align closely with commercial corridors, institutional edges, and mixed-use developments, where urban activity is more intense and continuous.

Lower intersection density zones correspond to large institutional plots and underutilized edge areas, where limited connectivity restricts the intensity and diversity of urban functions. This indicates that street network structure directly influences the spatial distribution of urban activities around the metro station.

5.4.4 Spatial Implications of Intersection Density

The overall pattern of intersection density highlights a transition toward a more connected and accessibility-driven urban structure within the District Court Metro Station TOD area. High-density zones reinforce pedestrian-friendly conditions and support transit-oriented development by strengthening connectivity between the metro station and surrounding urban fabric.

However, the presence of low-density areas due to institutional barriers and large impermeable land parcels creates fragmented connectivity in certain parts of the study area. This limits the full realization of TOD principles, particularly in terms of seamless pedestrian movement and uniform accessibility.

Overall, intersection density acts as a critical structural indicator of urban permeability, reinforcing the role of connectivity in shaping the evolving TOD character of the study area.

5.5 Transit Node Assessment

Transit nodes form the core of a Transit-Oriented Development (TOD) system, as they act as focal points for accessibility, movement, and urban activity concentration. In the District Court Metro Station TOD, Pune, the metro station and surrounding transit facilities significantly influence spatial organization, land use intensity, and mobility patterns. This section evaluates the role of the metro station as a transit node and its spatial impact on the surrounding urban fabric.

5.5.1 Spatial Context of the Transit Node

The District Court Metro Station is located within a dense institutional and administrative zone, surrounded by court complexes, government offices, and commercial establishments. This strategic location positions the station as a high-demand transit node that serves both daily commuters and institutional users.

The surrounding road network provides multiple access points to the station, although the quality and continuity of access vary across directions due to institutional barriers and large plot developments. Figure 32 shows maps presenting Temporal Analysis of Transit Network

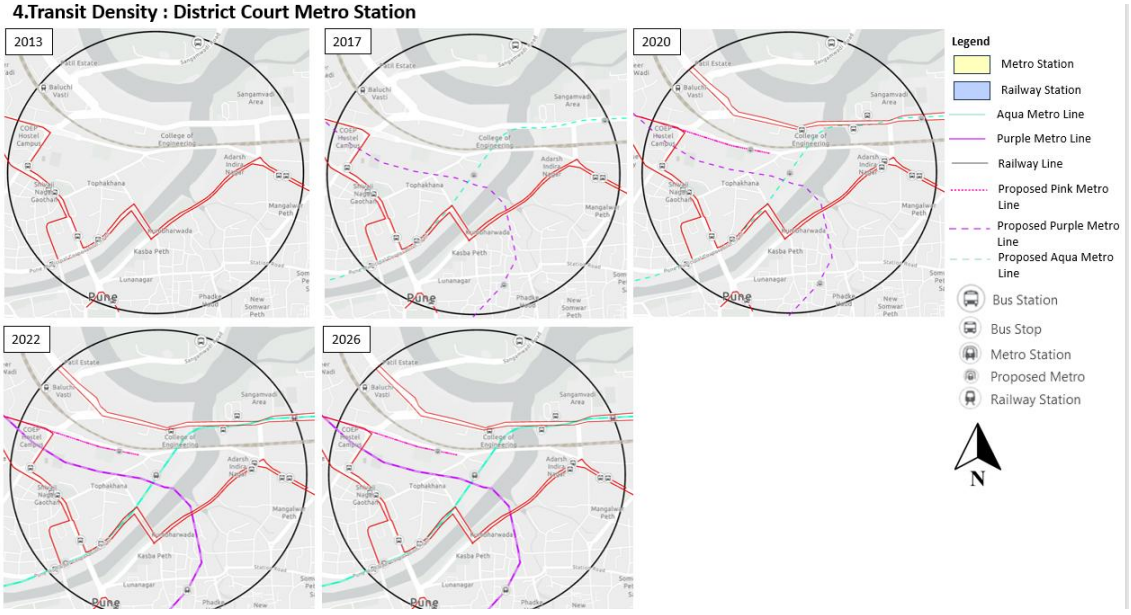


Figure 33.District Court Transit Network Temporal Analysis (Author)

5.5.2 Transit Accessibility and Influence Zone

The accessibility of the metro station is assessed through its spatial influence zone, which reflects the extent to which surrounding areas are functionally connected to the transit

node. The immediate catchment area exhibits high accessibility, characterized by short walking distances, strong road connectivity, and active land use integration.

Within this zone, commercial and institutional activities are more concentrated, indicating a strong dependence on transit accessibility. As distance from the station increases, accessibility gradually reduces, and land use intensity becomes more dispersed. In Table 15. analysed Temporal Analysis of Transit Network is shown.

Table 15. District Court Transit Network Temporal Analysis (Author)

Year	Transit Structure	Bus Network Condition	Metro Influence	Integration Level	Key Observation
2013	Bus-dominated	Primary mobility network	None	Low	Conventional road-based transit
2017	Transitional	Bus routes remain unchanged	Proposed metro influence	Low	Metro planning begins affecting corridor importance
2020	Overlapping systems	Existing routes continue despite construction pressure	Under-construction metro	Low–Moderate	Spatial conflict between systems
2022	Parallel systems	Bus routes largely retain earlier structure	Operational metro sections	Moderate	Metro introduced without major feeder restructuring
2026	Metro-led but partially integrated	Bus routes still operate independently with limited feeder organization	Strong metro presence	Moderate	Incomplete multimodal integration persists

5.5.4 Transit Node and Urban Activity Concentration

A strong spatial relationship is observed between the transit node and urban activity concentration. Areas closer to the District Court Metro Station exhibit higher levels of commercial activity, institutional services, and pedestrian movement intensity.

This concentration reflects the typical TOD pattern, where transit accessibility acts as a catalyst for increased development intensity and land use diversification. The metro station functions as an anchor point around which urban activities are organized and intensified.

5.5.5 Spatial Implications of Transit Node Influence

The analysis indicates that the District Court Metro Station plays a significant role in shaping the spatial structure of the surrounding area. It acts as a central accessibility node that drives development intensity and supports the emergence of a transit-oriented urban form.

However, the effectiveness of the transit node is partially constrained by physical barriers, uneven pedestrian connectivity, and incomplete intermodal integration. These limitations reduce the uniformity of accessibility across the study area.

Overall, the transit node strongly reinforces TOD characteristics by concentrating activity and improving accessibility, while also highlighting areas where mobility integration can be further strengthened.

5.6 Parking Assessment

Parking is an important component of urban mobility systems, particularly in dense institutional and commercial areas where competing demands for space influence travel behaviour and accessibility. In the District Court Metro Station TOD, Pune, parking patterns reflect the interaction between high institutional activity, commercial demand, and the introduction of metro-based transit. This section analyses the spatial distribution of parking facilities and evaluates how parking demand has evolved in relation to transit accessibility.

5.6.1 Spatial Distribution of Parking Facilities

The distribution of parking spaces within the study area is largely concentrated along major roads and institutional edges. On-street parking is commonly observed along arterial and sub-arterial corridors, especially near commercial establishments and institutional complexes. Off-street parking facilities are primarily associated with institutional buildings, court complexes, and organized commercial developments.

The spatial pattern indicates a strong dependence on informal and semi-organized parking arrangements, particularly in areas with high activity intensity. However, the availability of designated parking spaces remains uneven across the study area. Figure shows maps defining Temporal Analysis of On Street Parking.

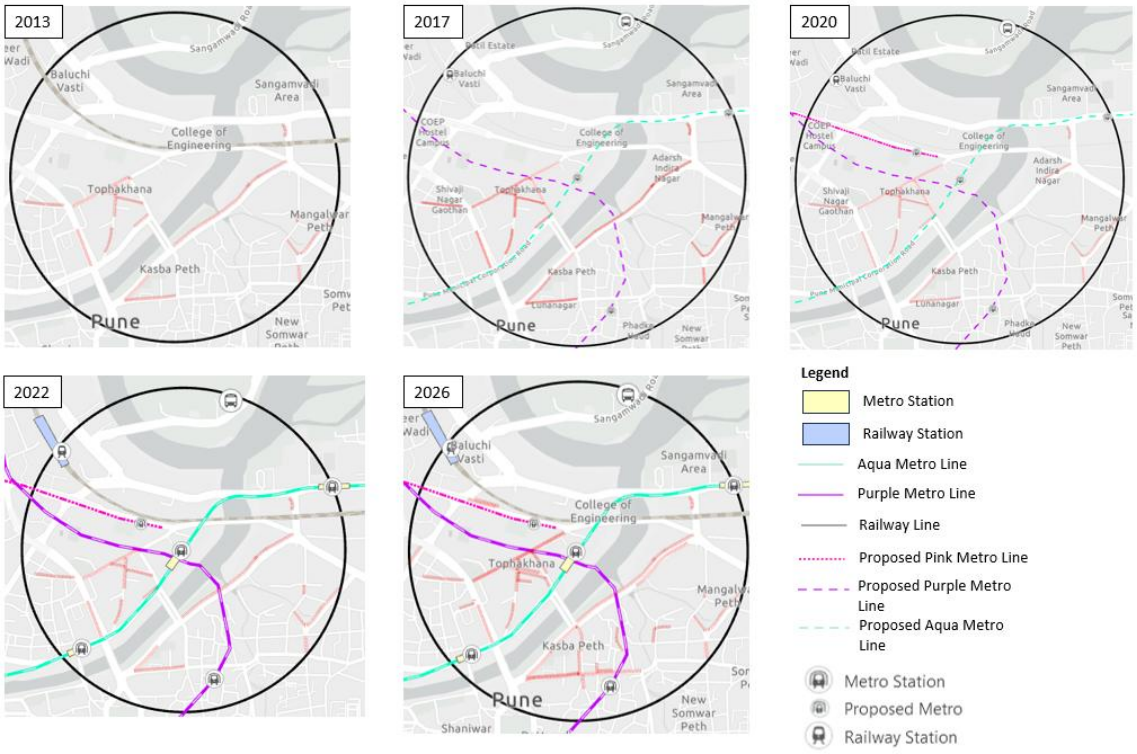


Figure 34. District Court On Street Parking Temporal Analysis (Author)

5.6.2 On-Street Parking Characteristics

On-street parking dominates in commercially active and transit-influenced corridors, where high demand leads to occupation of road edges. This often contributes to reduced effective carriageway width and impacts traffic flow and pedestrian movement.

Off-street parking, on the other hand, is mostly confined within institutional premises such as the District Court complex and adjacent administrative buildings. These facilities provide more organized parking supply but are spatially restricted due to limited land availability and controlled access conditions.

5.6.3 Parking Demand and Post-Metro Influence

The introduction of metro connectivity has influenced parking demand patterns in the study area. Areas in close proximity to the District Court Metro Station show relatively higher turnover of parking spaces, indicating short-duration usage linked to transit access and institutional visits.

In contrast, some reduction in long-term parking dependency is observed in select zones, suggesting a gradual shift toward public transport usage. However, the persistence of on-street parking indicates that private vehicle dependence still remains significant, particularly for institutional and court-related travel. Table shows the Temporal Analysis District Court On Street Parking.

Table 16.District Court On street Parking Temporal Analysis (Author)

Year	Total Parking Length (m)	Parking Capacity (4W)	Percent Increase	Parking Density	Spatial Pattern	Transit Condition
2013	2879.05	479	-	Moderate	Scattered along arterial and internal roads	Bus-dominated system
2017	3387.22	564	17.75	Increased	Expansion near commercial and institutional streets	Metro proposal phase
2020	3834.90	639	13.30	High	Parking overlaps transit construction corridors	Metro under construction
2022	4879.21	979	27.23	Very High	Persistent curbside parking near metro influence zone	Partial metro operation
2026	5018.32	1003	2.83	Highest	Extensive roadside parking across secondary streets	Metro-led multimodal node

5.6.4 Spatial Relationship with Accessibility

Parking distribution shows a clear spatial relationship with accessibility and land use intensity. High parking concentration areas correspond with zones of strong commercial and institutional activity, particularly near major roads and transit access points.

However, this concentration also creates localized congestion points, where parked vehicles compete with moving traffic and pedestrian movement. This highlights the need for better parking management strategies within the TOD influence zone.

5.6.5 Spatial Implications of Parking Patterns

The overall parking pattern reflects a transitional mobility environment influenced by both high institutional demand and emerging transit usage. While metro accessibility has

contributed to changes in travel behaviour, parking demand remains significant due to continued reliance on private vehicles for institutional and mixed-use trips.

The spatial imbalance in parking availability and demand highlights the need for integrated parking management within the TOD framework. Improved regulation and structured parking provision can help enhance mobility efficiency and support sustainable urban movement patterns in the study area.

5.7 Pedestrian Network Assessment

Pedestrian infrastructure is a critical component of Transit-Oriented Development (TOD) as it directly influences last-mile connectivity, accessibility to transit nodes, and overall urban walkability. In the District Court Metro Station TOD, Pune, pedestrian movement plays a significant role due to the presence of institutional complexes, commercial corridors, and high commuter activity around the metro station. This section evaluates the spatial continuity, quality, and connectivity of the pedestrian network within the study area.

5.7.1 Pedestrian Corridor Structure and Distribution

The pedestrian network in the study area is primarily formed by footpaths along major roads, institutional walkways, and informal walking routes. Continuous pedestrian corridors are observed mainly along arterial and sub-arterial roads leading to the metro station, where footfall is high and movement demand is consistent. Figure 34 shows Temporal Analysis of pedestrian network around metro station.

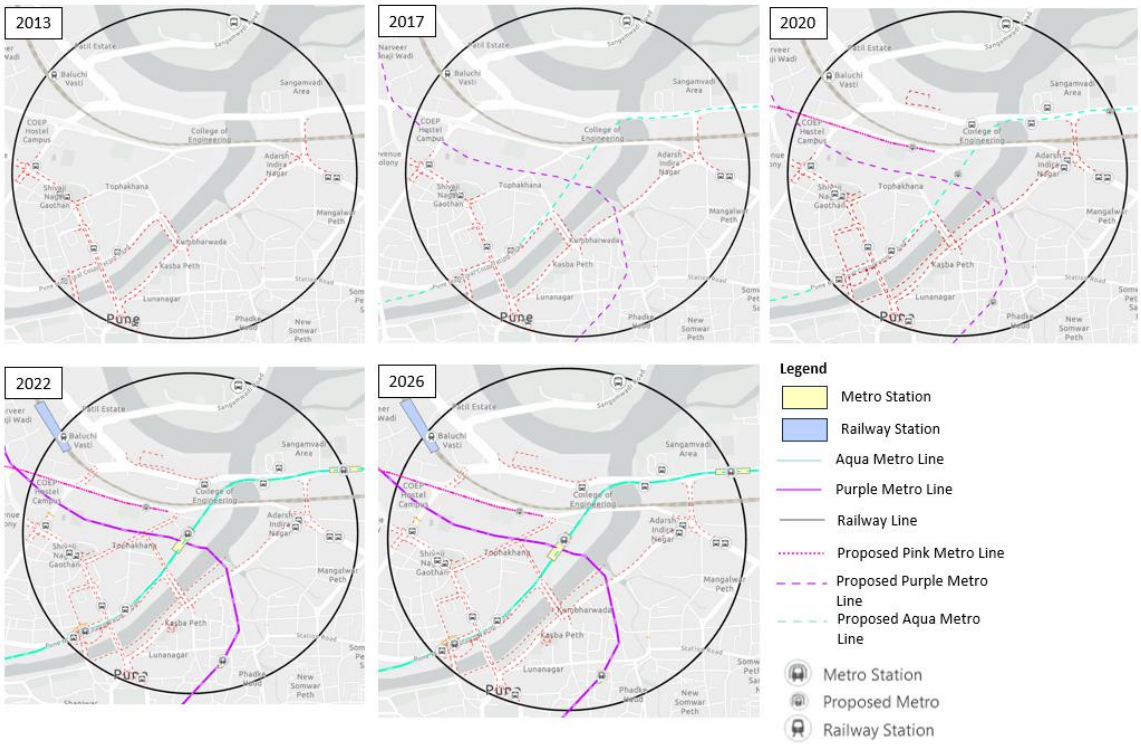


Figure 35.District Court Pedestrian Network Temporal Analysis (Author)

However, the distribution of pedestrian infrastructure is uneven. While some stretches provide defined and usable walkways, other segments lack dedicated pedestrian space, forcing movement onto carriageways or informal edges. This discontinuity affects the overall comfort and safety of pedestrian travel.

5.7.3 Connectivity to Transit Nodes

Pedestrian connectivity to the metro station is strongest within the immediate influence zone, where multiple approach routes allow direct access to the station. These routes are characterized by high pedestrian volumes and strong interaction with commercial and institutional land uses.

However, in certain directions, connectivity is weakened due to large institutional plots, gated boundaries, and limited crossing points. These barriers increase walking distances and reduce the efficiency of last-mile connectivity, particularly for users coming from peripheral zones.

5.7.4 Pedestrian Network Gaps and Constraints

The analysis identifies several gaps in the pedestrian network, including missing footpath links, interrupted corridors, and unsafe crossing points. Encroachments by informal activities and on-street parking further reduce effective pedestrian space in key mobility corridors.

These constraints create fragmented walking environments, where continuity and comfort are compromised. As a result, pedestrian movement is often secondary to vehicular movement in several parts of the study area, despite high transit dependency.

5.7.5 Spatial Implications of Pedestrian Network

The pedestrian network pattern reflects a partially developed TOD environment, where strong pedestrian activity exists near the metro station but weak continuity persists in peripheral and institutional zones. This uneven distribution limits the full potential of walkable urban structure.

Overall, while the core influence zone demonstrates TOD-aligned pedestrian intensity, the lack of seamless and universally connected pedestrian infrastructure highlights the need for improved walkability planning. Strengthening pedestrian corridors is essential to enhance last-mile connectivity and support a fully integrated transit-oriented urban system.

5.8 Integrated Assessment

The integrated mobility and accessibility assessment combines the findings from street network, intersection density, transit node influence, parking systems, and pedestrian infrastructure to develop a comprehensive understanding of the overall movement structure in the District Court Metro Station TOD, Pune detailed in Table 17. This synthesis helps in identifying how different mobility components interact with each other

and collectively shape accessibility patterns and transit-oriented development characteristics.

Table 17. Assessment (Author)

Transformation Component	Spatial Observation	Impact on Urban Form	TOD Interpretation	Planning Need
Land Cover & Built-Up	Built-up areas increased continuously while vacant land and vegetation gradually decreased, especially near transit corridors and station influence zones	Urban structure became denser, more compact, and continuous over time	Reflects transit-induced densification and compact urban growth pattern	Controlled densification and protection of environmental/open spaces
Amenities & Activity Pattern	Amenities gradually concentrated near metro corridors, intersections, and major roads while scattered low-intensity areas reduced	Activity nodes and service concentration increased within accessible areas	Indicates emerging mixed-use and accessibility-driven development	Strengthen mixed-use integration and public activity spaces
Green & Recreational Spaces	Green spaces remained limited and fragmented despite slight improvement in accessibility to existing parks	Weak environmental integration within rapidly urbanizing areas	TOD development remains mobility-focused with limited ecological balance	Develop connected green networks and recreational landscapes
Street Network	Major transit corridors became stronger movement spines, though some local areas	Improved accessibility and corridor connectivity	Supports transit-oriented movement and accessibility structure	Improve local street connectivity and network integration

	still lacked permeability			
Intersection Density	Higher connectivity observed near station core and major junctions, while peripheral areas remained less connected	Increased walkability potential and movement efficiency near transit zones	Supports pedestrian-oriented urban form	Junction redesign and traffic-calming measures
Pedestrian Infrastructure	Footpaths improved near transit areas but remained discontinuous and encroached in several sections	Uneven pedestrian environment affects seamless mobility	Partial implementation of walkability principles	Continuous footpaths, crossings, and pedestrian-friendly streetscape
Transit Accessibility	Accessibility significantly improved within metro influence areas and along corridors	Transit infrastructure became a major driver of spatial transformation	Strong TOD accessibility characteristics emerging	Improve feeder systems and last-mile connectivity
Parking & Vehicle Dominance	High roadside and informal parking concentration visible near commercial and transit activity zones	Increased vehicle pressure and congestion in key movement corridors	Contradicts TOD objective of reducing private vehicle dependency	Parking management and shared mobility planning
Multimodal Connectivity	Metro, railway, bus, and road connectivity improved near interchange zones, but	Mobility integration improved but remains spatially fragmented	Emerging multimodal transit-oriented structure	Strengthen intermodal integration and non-motorized connectivity

	pedestrian transfer between modes remained weak			

5.8.1 Integration of Street Network, Intersections, and Connectivity

The combined analysis of street network structure and intersection density reveals a moderately high level of connectivity within the core influence zone of the metro station. Areas with dense street networks and higher intersection frequencies demonstrate improved route choice availability, reduced travel distances, and stronger spatial permeability.

This integrated structure supports efficient movement patterns, particularly in zones where road hierarchy is well-defined and connectivity is continuous. However, discontinuities created by large institutional plots and restricted-access areas interrupt this integration in certain locations, resulting in uneven accessibility distribution.

5.8.2 Transit-Oriented Accessibility Structure

Transit accessibility emerges as a dominant organizing factor in the study area. The influence of the District Court Metro Station is clearly visible in the spatial concentration of activities, pedestrian movement intensity, and higher connectivity levels in its immediate surroundings.

The integrated analysis shows that areas within the metro influence zone exhibit stronger alignment between land use intensity and mobility infrastructure. This reflects typical TOD behaviour, where accessibility gradients decrease with increasing distance from the transit node, creating a nodal development structure cantered around the metro station.

5.8.3 Last-Mile Connectivity and Pedestrian Integration

Last-mile connectivity plays a crucial role in linking transit access with surrounding urban functions. The integration of pedestrian network analysis highlights that while the core area near the metro station supports strong pedestrian movement, connectivity weakens in peripheral directions due to missing links, barriers, and inconsistent infrastructure quality.

This results in a partially integrated pedestrian system, where accessibility is strong but not uniformly distributed. The effectiveness of last-mile connectivity is therefore constrained by gaps in pedestrian continuity and limited permeability in institutional zones.

5.8.4 Interaction between Parking and Mobility Systems

Parking patterns significantly influence mobility dynamics in the study area. The integrated assessment shows that areas with high parking concentration often overlap

with high-activity commercial and institutional zones. This creates localized pressure on road space and pedestrian movement.

Despite the presence of metro connectivity, continued reliance on private vehicles sustains parking demand, particularly for institutional users. This indicates a transitional mobility system where both public transport and private vehicle usage coexist, shaping a hybrid accessibility structure.

5.8.5 Overall Spatial Mobility Structure and TOD Implications

The integrated mobility assessment reveals that the District Court Metro Station TOD area exhibits partial but emerging TOD characteristics. Accessibility is strongly concentrated around the metro node, supported by relatively dense street networks and high intersection density in the core zone.

However, spatial inequalities in connectivity, pedestrian discontinuities, and parking pressures indicate that the system is still evolving toward a fully integrated TOD model. The urban mobility structure is therefore characterized by a clear accessibility core with gradually weakening connectivity toward peripheral zones.

Overall, the study confirms that transit infrastructure plays a central role in organizing mobility patterns, but full TOD efficiency depends on improving last-mile connectivity, pedestrian continuity, and integrated parking management.

5.9 Chapter Summary

This chapter presented a detailed assessment of mobility and accessibility patterns in the District Court Metro Station TOD, Pune, using a GIS-based spatial analysis framework. It examined the structure and performance of the urban movement system through key indicators, including street network configuration, intersection density, transit node influence, parking distribution, and pedestrian connectivity.

The analysis of the street network revealed a structured hierarchy with relatively strong connectivity in the core influence zone of the metro station. However, variations in network density highlighted spatial inequalities, with higher accessibility concentrated near transit corridors and reduced connectivity in institutional and peripheral areas. Intersection density further reinforced this pattern, indicating a more permeable urban fabric in the TOD core and fragmented connectivity in restricted or large-plot developments.

Transit node assessment demonstrated that the District Court Metro Station acts as a dominant accessibility anchor, shaping surrounding land use intensity and activity concentration. The influence of the metro station is evident in increased pedestrian movement, commercial clustering, and improved connectivity within its catchment area, although intermodal integration remains partially developed.

Parking analysis highlighted a transitional mobility environment, where metro introduction has influenced travel behaviour but private vehicle dependence still persists,

especially in institutional zones. On-street parking continues to create localized congestion, indicating the need for better parking regulation within the TOD framework.

The pedestrian network assessment revealed strong movement intensity near the metro station but uneven infrastructure quality and connectivity across the study area. Gaps in footpath continuity, physical barriers, and inconsistent walkability conditions limit seamless last-mile connectivity in several directions.

Overall, the integrated mobility assessment indicates that the study area exhibits emerging Transit-Oriented Development characteristics, with a strong accessibility core around the metro station. However, fragmented pedestrian systems, uneven connectivity, and persistent parking pressures highlight that the TOD structure is still evolving rather than fully established.

The findings of this chapter provide a critical foundation for the final stage of analysis, where land use transformation and mobility systems are collectively interpreted to derive comprehensive conclusions and planning recommendations for strengthening TOD performance in the District Court Metro Station area.

CHAPTER 6: Proposals for Strengthening Transit-Oriented Development (TOD)

The proposed strategies are derived from the spatial assessments carried out with GIS in the previous chapters, so that the interventions are context-specific and based on observed urban conditions. Collectively, these interventions seek to shift the study area from an emerging TOD environment to a more integrated, walkable and transit-supportive urban fabric.

The proposals are grouped by key themes including feeder connectivity, pedestrian infrastructure, street network improvements, green infrastructure, parking management and mixed-use redevelopment strategies.

6.1 Introduction

Based on the spatial analysis of the land use change and mobility systems presented in earlier chapters, this chapter provides planning recommendations for strengthening Transit-Oriented Development (TOD) around the District Court Metro Station, Pune. The analysis shows a clear concentration of urban activities and accessibility around the metro station, as well as increasing development intensity and changing land use patterns. However, the study has also revealed a number of structural and functional shortcomings like disjointed pedestrian networks, uneven connectivity of the roadways, a buildup of unofficial parking and lack of integration between the feeder and non-motorized transportation systems.

In this respect, the recommendations are supposed to address these gaps and to improve the overall sustainability, efficiency and accessibility of the study area. The emphasis is on enhancing multimodal integration, improving last mile connectivity, restructuring mobility infrastructure and encouraging transit-supportive land use patterns.

6.3 Walkability Enhancement Strategy

Assessment

The pedestrian analysis reveals discontinuous footpaths inconsistent quality of infrastructure and weak pedestrian connectivity in internal streets in the metro influence zone. These voids compromise comfort, safety and continuity of pedestrian networks.

Tactics

1. Development of continuous pedestrian corridors connecting transit nodes, institutional areas and commercial zones.
2. Creation of shaded paths, tree-lined pedestrian routes and protected from the weather.

3. Safe pedestrian crossings including raised crossings and signalised junctions.
4. Provision of universal accessibility features (e.g. ramps, tactile paving, barrier-free design).

Walkability Assessment Interpretation (District Court Metro Station TOD, Pune)

The walkability assessment map depicts the influence area of the pedestrian layout and proposed upgrades for Pune's District Court Metro Station TOD. The analysis includes pedestrian comfort corridors, planned pedestrian networks and existing pedestrian routes connection to bus, train and metro transit nodes.

The map shows that the highest footfall is clustered around the metro station core and major institutional corridors such as COEP Hostel, College of Engineering, Shivaji Nagar, and the surrounding administrative and commercial areas. However, the pedestrian network is discontinuous in several internal streets where continuous walkways are either not present or irregular, and walkability is reduced in some areas.

The proposed pedestrian network (dashed pink lines) as shown in Figure 35 fills these gaps by adding continuous walking linkages between transportation nodes, institutional clusters, and commercial areas. These proposed links are expected to reduce dependency on vehicle movement for short distance travel and help in strengthening last mile connectivity to the metro station.

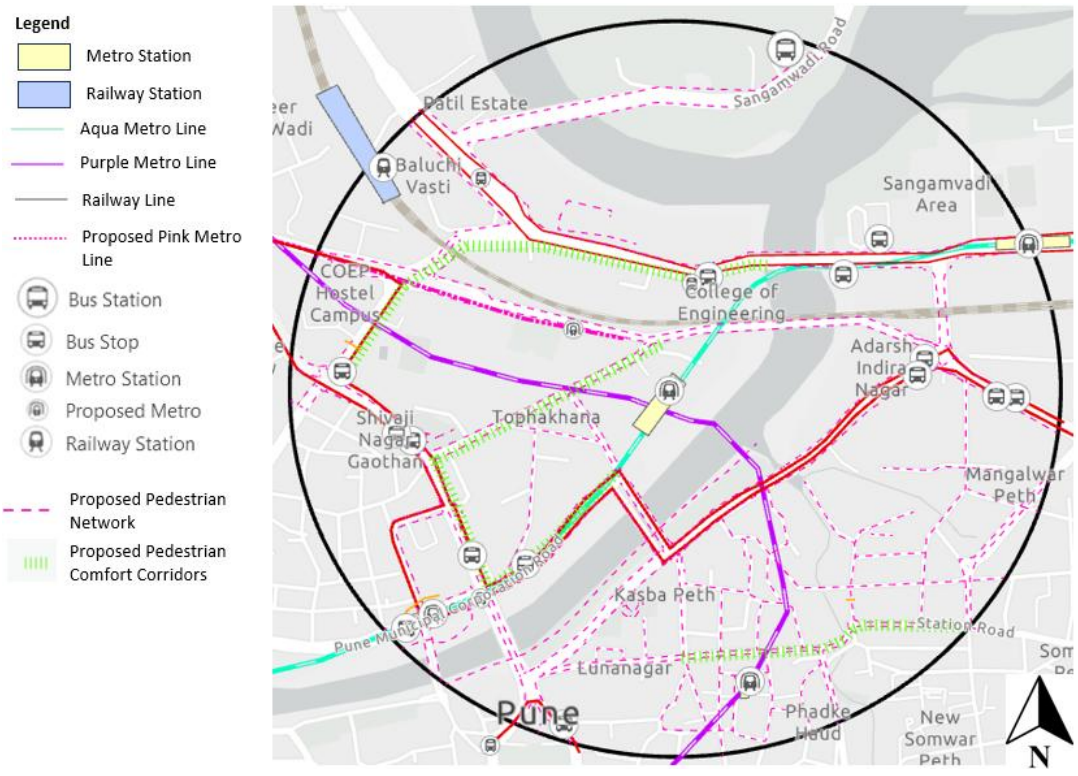


Figure 36.Proposed Pedestrian Network (Author)

Green hatching is also used to highlight priority streets for walkability improvements, i.e., pedestrian comfort corridors. These corridors are along busy roads connecting commercial centres, educational institutions and transit points. The plan aims at upgrading these corridors with street level engagement, safe crossings, continuity of footpaths and shading.

In general, the map shows a transition from a fragmented pedestrian system to a more integrated and continuous walkable system. The suggested actions are expected to enhance accessibility and reduce pedestrian-vehicle conflict and encourage a Transit-Oriented Development (TOD) approach by prioritizing non-motorized movement within the metro influence zone.

TOD Impact

Improved walkability will improve last-mile connectivity and non-motorised movement and enhance the functional integration of transit infrastructure with the surrounding urban fabric.

6.2 Feeder Connectivity & Multimodal Integration Strategy

Assessment

Transit accessibility in the study area is mainly around the District Court Metro Station and the surrounding institutional, administrative and mixed-use areas have poor last-mile connectivity. Lack of structured feeder systems results in dependency on informal modes and limited access to metro station.

Strategies

1. Introduction of feeder bus routes connecting the metro station to the surrounding residential neighbourhoods, institutional clusters and commercial corridors.
2. Establishment of dedicated shared auto-rickshaw stands near station exits and major pedestrian entry points.
3. Integration of feeder stops with pedestrian networks for seamless mode transfer.
4. Establishment of clearly defined pick-up and drop-off zones to reduce roadside congestion and informal stopping.

6.2.1 Feeder Bus Route Proposed for District Court

To strengthen last-mile connectivity and improve multimodal integration within the District Court Metro Station influence area, two dedicated feeder bus routes are proposed. These routes are designed to connect major residential zones, institutional clusters, commercial centers, and transit interchanges with the metro station, thereby enhancing accessibility and reducing dependence on private vehicles and informal transport systems.

1. Feeder Route 1: South–Eastern Connectivity Corridor (District Court – Hadapsar Belt)

Description:
The feeder route is proposed to be a high-demand connectivity corridor to the southern and south-eastern region connecting the District Court Metro Station to major employment hubs and dense residential areas. The route goes through important administrative nodes (Collector Kacheri, GPO), principal transit interchange points (Pune Railway Station, Mahatma Gandhi Bus Stand) and fast developing IT and residential zones like Magarpatta and Hadapsar shown in Figure 36.

The corridor's design ensures smooth integration of metro services and peripheral urban zones serving institutional commuters and daily office-goers. It also links old parts of the city and new growth poles, balancing access to different urban environments.



Figure 37. Proposed Feeder Bus Route 1 (Author)

District Court Station - Kumbharwada Collector Kacheri - GPO - Pune Railway Station - Westend - Juna Pulgate - Mahatma Gandhi Bus Stand - Pulgate - Race Course - Bhairoba Nala - Fatima Nagar - Ramtekdi - Vaiduwadi - Magarpatta - Hadapsar Gaon - Hadapsar Gadita

Feeder Route 2: Central–Western Heritage and Institutional Loop (Swargate – District Court – Shivajinagar Corridor)

Description:
This feeder route links the District Court Metro Station to key economic, historic and institutional areas in a circular ring around the centre of the city. It connects busy areas such as Shaniwarwada, Appa Balwant Chowk, Mandai and Swargate with good connectivity between the old city cores and the metro system. The route is highlighted in Figure 37.

This loop system ensures uninterrupted movement of passengers along the entire stretch of central Pune and provides access in both directions. It also improves the overall multimodal network by improving connectivity between various transport hubs like Swargate and Shivajinagar-adjacent nodes.



Figure 38. Proposed Feeder Bus Route 2 (Author)

Swargate - Hira Baug - Bhikardas Maruti Mandir - Shanipar - Appa Balwant Chowk - Shaniwarwada - Ma.Na.Pa Nava Pul (PMC) - Shivaji Maharaj Putla - **District Court Metro Station** - Patil Estate - Wakdewadi (Mariaai Gate) - Navin ST Stand - loop back through COEP Hostel - Mandai - returning to Swargate Station

Integrated Feeder and Pedestrian Connectivity Proposal

The proposed feeder connectivity network aims to enhance the integration of the District Court Metro Station with surrounding residential, institutional, and commercial areas through a coordinated multimodal accessibility framework. The proposal combines feeder bus services with an improved pedestrian network to address existing gaps in last-mile connectivity identified during the analysis as shown in Figure 38. While transit accessibility within the study area has increased significantly with the introduction of the metro system, feeder integration and pedestrian mobility remain inadequate, limiting seamless access to transit facilities.

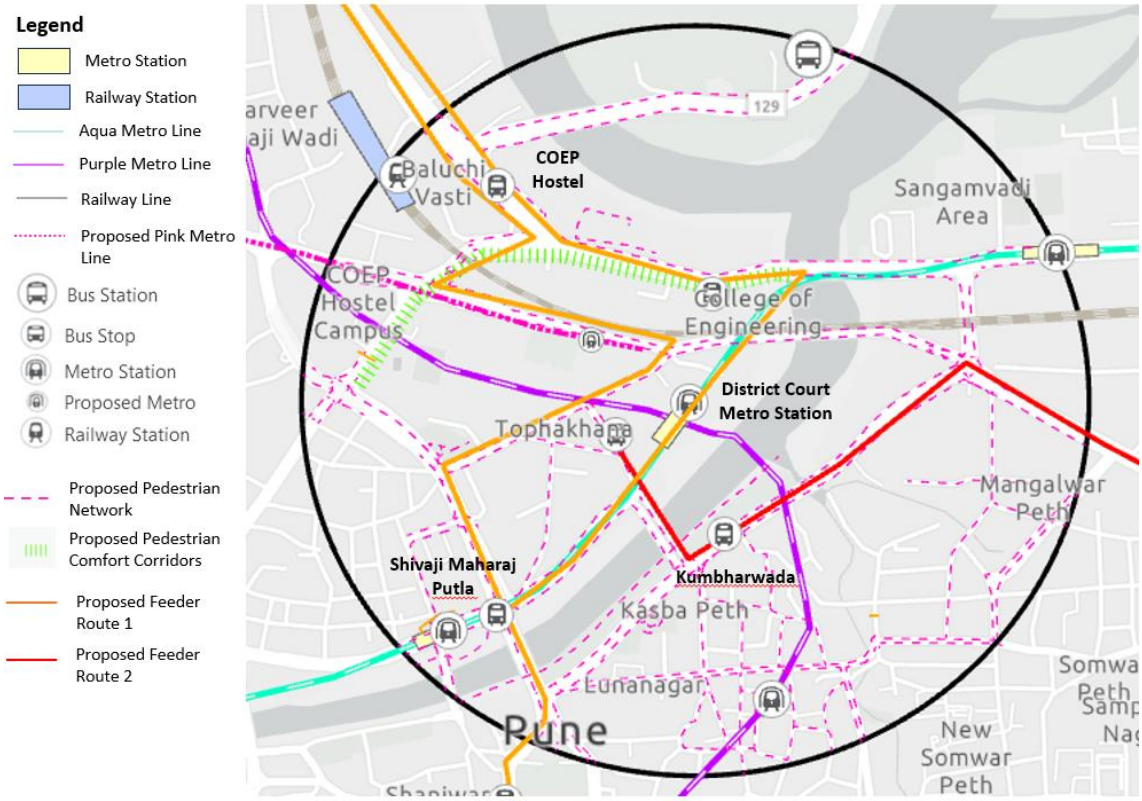


Figure 39. Integrated Feeder and Pedestrian Connectivity Proposal (Author)

The proposed network strengthens connections between major transit nodes, activity centers, and surrounding neighborhoods, enabling efficient transfers between metro, bus, and pedestrian modes. Complementing the feeder services, the proposed pedestrian corridors and comfort corridors improve walkability by creating continuous and accessible routes between transit stops and key destinations. This integrated approach prioritizes sustainable mobility, reduces dependence on private vehicles, and enhances the overall user experience within the station influence area.

By improving intermodal connectivity and supporting safe, convenient, and comfortable pedestrian movement, the proposal contributes to the development of a more accessible and transit-oriented environment around the District Court Metro Station. The intervention supports the broader objective of creating a cohesive mobility network that promotes public transport usage while strengthening first- and last-mile accessibility for commuters.

TOD Impact

In order to enhance the last mile connectivity to a significant level, reduce the private vehicle usage and improve the accessibility inside a dense urban block, the multimodal integration should be further enhanced to boost the transit-oriented mobility patterns.

6.4 Street Connectivity Improvement Strategy

Assessment

Consequently, the accessibility is reduced and movement patterns are inefficient in some parts of the study area.

Strategy

1. Strengthening of secondary street connections and missing internal links.
2. Improving linkages between transit nodes and surrounding activity areas.
3. Introduce selective one-way street systems within congested internal corridors to improve circulation efficiency.
4. Traffic calming measures, such as raised crossings, curb extensions, narrowed carriageways and pedestrian-priority streets.

TOD Impact

Streets will be connected to improve circulation efficiency, reduce travel distances, and promote a more integrated and transit-supportive urban form.

6.4.1 Traffic Calming & Pedestrian Priority Strategy

The proposed traffic calming plan's main goals are improving the overall walkability, pedestrian safety and vehicle domination of the District Court Metro Station TOD effect area. The study area particularly the vicinity of COEP Hostel, Shivaji Nagar, Topkhana, Kasba Peth and Adarsh Indira Nagar, was observed to have high traffic intensity on the main institutional corridors with conflicts between pedestrians and vehicles at transit access points and limited safe crossing opportunities.

The suggested plan as shown in Figure 39 highlights important traffic calming nodes (red circles) at the critical conflict points where high movement of vehicles intersect with pedestrian activity zones. These nodes are envisaged to control vehicular speeds through architectural interventions such as elevated crossings, curb extensions, carriageway narrowing and regulated entry points. The aims are to enhance pedestrian safety and to reduce the risk of accidents in areas with heavy traffic.

Additionally, along key pedestrian circulation arteries that connect residential districts, institutional clusters, and transportation nodes, pedestrian priority traffic calming corridors (orange routes) are suggested. By implementing features like shared street design, speed limits, better crossings, continuous walkways, and street-edge activation,

these corridors prioritise non-motorized mobility.

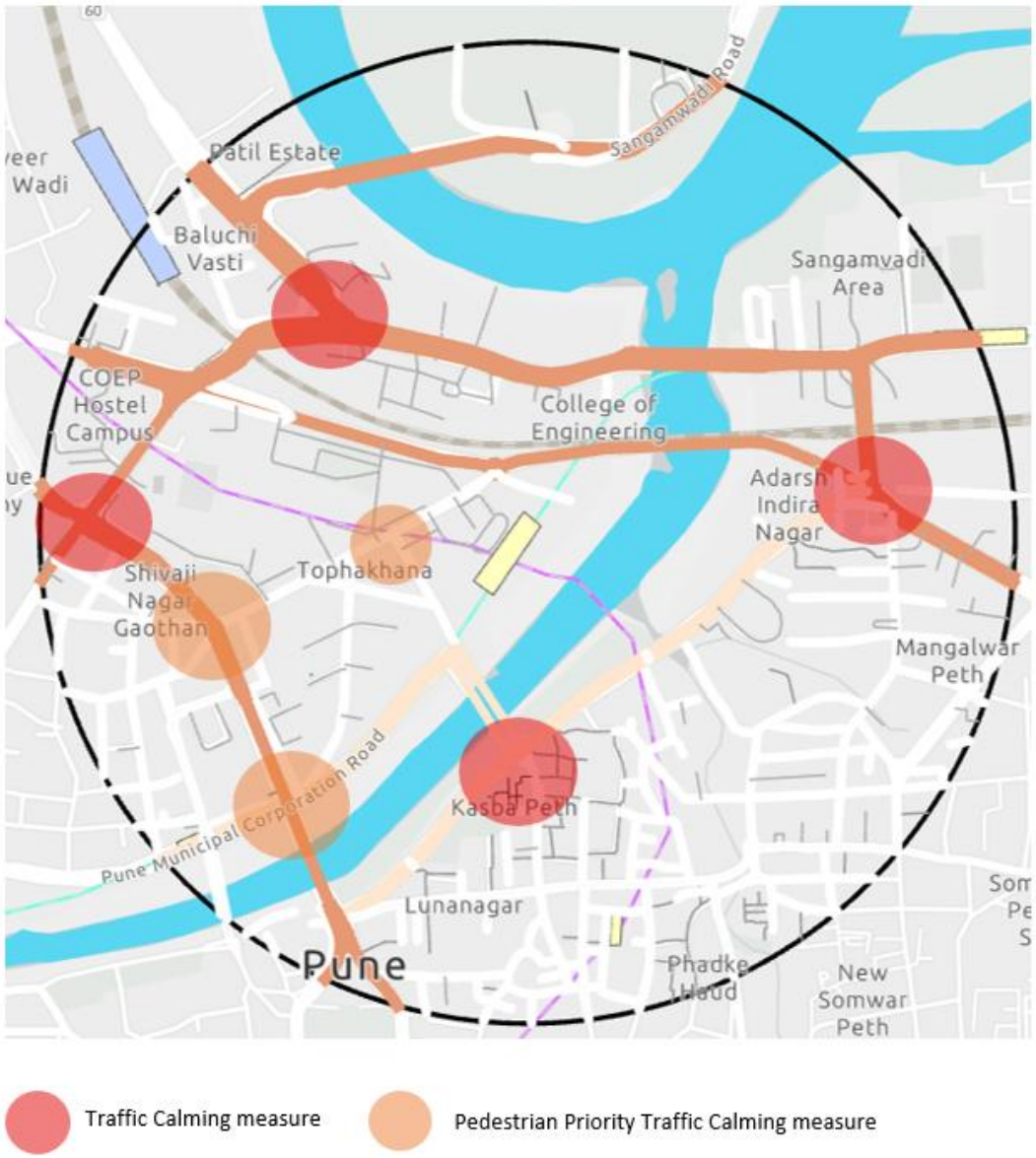


Figure 40.Proposed Traffic Calming Measures (Author)

In high-accessibility zones, especially those close to the metro station and the adjacent commercial and educational areas, the suggested system creates an organised hierarchy of movement where pedestrian safety and comfort are given priority. The plan promotes a more transit-oriented urban environment and improves last-mile connection by lowering vehicle speeds and enhancing crossing conditions.

The overall goal of the traffic calming approach is to create a balanced and safer mobility system that is in line with TOD principles by converting specific routes into pedestrian-friendly corridors while preserving essential vehicular circulation.

6.5 Green Infrastructure & Commercial Activation Strategy

Assessment

The study area's restricted and dispersed open spaces are highlighted by the green space analysis, especially along newly developed commercial routes. Environmental quality and pedestrian comfort are negatively impacted by a lack of ongoing green infrastructure.

Approach

1. The creation of landscaped plazas, pocket parks, and green corridors close to transit zones.
2. Including resting spots and spaces with shade along pedestrian pathways.
3. Adding more flora to the streetscape along institutional and commercial areas.
4. Making underutilised areas into small public open spaces.

TOD Impact

Improved green infrastructure will boost foot traffic, enhance pedestrian comfort, encourage business, and improve the general standard of the public space.

6.6 Multilevel Parking Strategy

Assessment

Parking demand is highly concentrated around the metro station and surrounding institutional-commercial zones, leading to on-street congestion and inefficient use of road space.

Strategy

1. Development of multilevel parking facilities at strategic peripheral locations outside the core TOD zone.
2. Consolidation of fragmented parking into shared, organized parking structures.
3. Restriction of on-street parking in pedestrian-priority and high-accessibility corridors.
4. Introduction of parking regulation within the metro influence zone.

6.6.1 Proposal for Multilevel Parking Development

To address the existing on-street parking demand and reduce congestion in the study area, two multilevel parking facilities (P1 and P2) are proposed. The intervention aims to shift parked vehicles from critical road edges to structured off-street parking, thereby improving mobility, safety, and street functionality.

Existing Condition

The current on-street parking demand in the area is approximately:

On-street parked vehicles = 1003 ECS (Equivalent Car Spaces)

This demand contributes to:

1. Road narrowing and reduced carriageway width
2. Increased congestion near activity nodes
3. Pedestrian safety issues and reduced walkability

Proposed Multilevel Parking Capacity (3 Levels)

To manage increasing parking demand and reduce the intrusion of private vehicles within the core transit influence area, two multilevel parking facilities (P1 and P2) are proposed along the periphery of the District Court Metro Station influence zone. Locating these facilities at the outer edge of the study area will intercept private vehicles before they enter the congested central zone, thereby minimizing traffic pressure, reducing on-street parking demand, and promoting the use of public transport for onward travel. This strategy supports transit-oriented development principles by prioritizing pedestrian movement and multimodal accessibility around the metro station while limiting vehicle dominance in the station precinct. Figure 40 illustrates the proposed locations of the multilevel parking facilities within the study area.



Figure 41. Proposed Multilevel Parking (Author)

Parking 1 (P1)

1. Area per level = 20,000 sq.m
2. Number of levels = 3

Total built-up area:

$$20000 \times 3 = 60000 \text{ sq.m}$$

$$20000 \times 3 = 60000$$

Capacity:

$$N_1 = \frac{60000}{30} \approx 2000 \text{ cars}$$

$$N_1 = \frac{60000}{30} \approx 2000$$

Parking 2 (P2)

- Area per level = 11,350 sq.m
- Number of levels = 3

Total built-up area:

$$11350 \times 3 = 34050 \text{ sq.m}$$

$$11350 \times 3 = 34050$$

Capacity:

$$N_2 = \frac{34050}{30} \approx 1135 \text{ cars}$$

$$N_2 = \frac{34050}{30} \approx 1135$$

Total Proposed Parking Capacity

$$N_{total} = 2000 + 1135 = 3135$$

$$N_{total} = 3135$$

Summary

Component	Capacity
P1 (3 floors)	~2000 cars
P2 (3 floors)	~1135 cars
Total	~3135 cars

Interpretation

With a total capacity of over 3135 vehicles, the proposed three-level parking infrastructure greatly outpaces the current on-street parking demand of 1003 ECS. As a result, there is excess capacity that can:

1. Allow for potential increases in parking demand
2. Cut down on parking spillover onto nearby streets
3. Encourage transit-oriented development by making room on the road for bike infrastructure, buses, and pedestrians.

All things considered, the plan guarantees full absorption of present demand while significantly future-proofing parking infrastructure.

TOD Impact

By preventing excessive private vehicle usage in the central region, an organised parking system will ease traffic, free up street space for pedestrians, and promote transit-oriented mobility.

6.7 Mixed-Use Redevelopment Strategy

Assessment

Along important corridors, land use patterns show a progressive conversion of residential buildings into commercial and mixed-use complexes, indicating growing urban demand and transit effect.

Approach

1. In the TOD influence zone, planned mixed-use redevelopment is encouraged.
2. Promotion of vertical mixed-use typologies with residential or office uses on upper floors and busy commercial bottom floors.
3. Reducing parking standards in the vicinity of metro corridors.
4. Encouragement of shared parking systems rather than parking at the plot level.
5. Limiting excessive surface parking in TOD areas.

TOD Impact

Mixed-use intensification will boost urban vibrancy, enhance land-use efficiency, and make the area surrounding the metro station more dynamic and transit-friendly.

Chapter 7: Conclusion

In this thesis, Geospatial Assessment of Transformations under Transit Orientated Development (TOD): Case of Pune, spatial changes within a metro influence zone were studied using an organised geospatial framework. The study looked at the impact of Pune metro infrastructure implementation on land use, mobility systems, pedestrian infrastructure, parking patterns, green areas and urban form.

In this chapter the results are summarized and linked to the suggested planning solutions, although the previous chapters have shown that the construction of metro systems has resulted in substantial, but uneven, urban development. Finally, the conclusion discusses how the proposed strategies collectively address the identified gaps and advance the area of study towards a functional TOD model.

7.1 Synthesis of Key Findings and Planning Gaps

The geospatial assessment indicated that the study area is undergoing a transition phase of TOD development, with partial improvements in accessibility, but persistent structural deficiencies in urban form and mobility integration.

The major gaps identified are:

1. Poor connectivity to the last mile outside the immediate metro station impact zone
2. Discontinuous and fragmented pedestrian infrastructure
3. Low permeability of internal streets and poor connectivity at the block level
4. Unplanned and growing parking demand along activity corridors
5. Fragmented green and open space structure in dense urban pockets
6. New but unregulated mixed-use development patterns near transit corridors

These gaps suggest that while metro infrastructure has improved regional accessibility, urban systems necessary for full TOD implementation are still underdeveloped.

7.2 Evaluation of Proposed TOD Strategies

The proposed strategies collectively address the identified gaps in a multi-dimensional manner, focusing on mobility, land use, public realm, and urban structure.

7.2.1 Feeder Connectivity & Multimodal Integration Strategy

The last-mile connection gap identified in the study is directly addressed through the implementation of dedicated shared auto-rickshaw spaces and organised feeder bus routes. Peripheral communities are still poorly connected, with accessibility concentrated around the metro station centers.

This approach formalizes feeder routes and integrates them with pedestrian access points, strengthening network continuity between the surrounding urban areas and high capacity transportation. In addition, dedicated pickup/drop-off zones improve the efficiency of the station area and reduce traffic on the road.

In short, this intervention connects neighborhood mobility at the micro level with metro infrastructure at the macro level and reinforces the hierarchy of transportation networks.

7.2.2 Walkability Enhancement Strategy

The walkability strategy addresses promptly the problem of the disjointed pedestrian infrastructure of the study area. Upgrades to pedestrian lanes, covered walkways and universal accessibility are ongoing with the aim of making walking a reliable and enjoyable means of transportation.

Walkability is the basis of first and last mile connection and therefore, this intervention is critical to the success of TOD. This approach promotes non-motorised travel by emphasising pedestrian-oriented streetscape design near stations and minimising reliance on motorised short journeys.

It also makes the urban movement networks more inclusive, more comfortable and safer.

7.2.3 Street Connectivity Improvement Strategy

The report states that there are a number of urban blocks with low permeability and disjointed internal street network. The suggested strategy seeks to improve secondary street connections, implement traffic calming techniques and install some one-way systems.

These measures focus on pedestrian safety, but also improve circulation efficiency. Traffic-calming devices such as raised crossings, curb extensions and restricted carriageways are examples of measures that help reallocate roadway space from cars to pedestrians.

This method enhances the fine-grained urban structure and results in a better integration of transportation hubs and the adjacent activity zones.

7.2.4 Green Infrastructure & Commercial Activation Strategy

The survey found fragmented green spaces and poor public realm quality particularly in newly developed commercial corridors. The green infrastructure plan aims to fill this gap with shaded pathways, pocket parks and landscaped plazas.

In addition to its environmental benefits, this approach supports TOD by improving pedestrian comfort and bringing more foot traffic to business districts. Bringing plants into transportation areas creates livable active streets and enhances place identity.

Thus, green infrastructure is the ecological and economic driver of TOD.

7.2.5 Multilevel Parking Strategy

As demand for limited street space increased, parking pressure was shown to be a significant barrier in transit-influenced locations. The proposed multilevel parking plan shifts parking demand to peripheral structured facilities.

This tactic aggregates scattered parking into structured facilities and limits on-street parking in priority corridors, freeing up street space for pedestrians and transit-oriented uses.

It is also consistent with TOD principles reducing over-reliance on private vehicles and encouraging more efficient land use.

7.2.6 Mixed-Use Redevelopment Strategy

The land use study also found that residential properties near main corridors were gradually but unplanned converted into commercial and mixed use activities. The proposed approach formalises this propensity through planned mixed-use redevelopment.

Vertical mixed-use construction enhances land-use efficiency and promotes vibrant street life by placing commercial activity at ground level and residential or office uses above. Furthermore, compact, transit-supportive development is directly supported by the suggestion to lower minimum parking requirements close to metro corridors.

By ensuring that land-use transition becomes organised rather than market-driven, this approach upholds the density and diversity objectives of TOD.

7.3 Integrated Impact of Proposed Strategies

When considered collectively, the proposed strategies create a comprehensive TOD framework addressing all major dimensions of urban transformation:

1. **Mobility Integration:** Improved through feeder systems and multimodal coordination
2. **Pedestrian Priority:** Strengthened through continuous walkable networks and street redesign
3. **Urban Structure:** Enhanced through improved street connectivity and permeability
4. **Environmental Quality:** Improved through green infrastructure integration

5. **Land Use Efficiency:** Achieved through mixed-use redevelopment and density optimization
6. **Parking Management:** Rationalized through structured, off-street systems

Together, these interventions shift the study area from a transit-adjacent development pattern toward a more integrated and functional Transit Oriented Development model.

Final Conclusion

Pune is a case in point to the fact that metro infrastructure alone is not enough to bring about complete TOD transformation. The metro has significantly improved regional accessibility and prompted changes in localised development, but the supporting urban systems like pedestrian infrastructure, feeder connectivity, street permeability and land-use control need targeted intervention.

The study concludes that TOD in the study area is in a transition phase where infrastructure-led growth is moving faster than spatial and regulatory adaptation. The options put forward provide a coherent road map to fill this gap, integrating public realm enhancement, land use reform and mobility planning.

Ultimately, the realization of true TOD requires a step beyond transit provision to comprehensive station-area planning, in which all elements of the urban system—streets, buildings, open spaces, and mobility networks—work as an interconnected and mutually reinforcing framework.

Therefore, TOD is a process of urban restructuring, rather than a destination, and to realize its full potential, it requires on-going coordination, policy alignment and spatial refinement.

References

Calthorpe, P. (1993). *The next American metropolis: Ecology, community, and the American dream*. Princeton Architectural Press.

Cervero, R. (1998). *The transit metropolis: A global inquiry*. Island Press.

Cervero, R., & Murakami, J. (2009). Rail and property development in Hong Kong: Experiences and extensions. *Urban Studies, 46*(10), 2019–2043. https://doi.org/10.1177/0042098009339431

Dittmar, H., & Ohland, G. (2004). *The new transit town: Best practices in transit-oriented development*. Island Press.

Renne, J. L. (2009). *Transit-oriented development: Making it happen*. Ashgate Publishing.

Suzuki, H., Cervero, R., & Iuchi, K. (2013). *Transforming cities with transit: Transit and land-use integration for sustainable urban development*. World Bank.

Batty, M. (2013). *The new science of cities*. MIT Press.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic information systems and science (4th ed.). Wiley.

Ewing, R., & Cervero, R. (2010). Travel and the built environment. Journal of the American Planning Association, 76(3), 265–294. https://doi.org/10.1080/01944361003766766

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic information systems and science (4th ed.). Wiley.

Dittmar, H., & Ohland, G. (2004). *The new transit town: Best practices in transit-oriented development*. Island Press.

Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association, 76*(3), 265–294. https://doi.org/10.1080/01944361003766766

Suzuki, H., Cervero, R., & Iuchi, K. (2013). *Transforming cities with transit: Transit and land-use integration for sustainable urban development*. World Bank.

Batty, M. (2013). *The new science of cities*. MIT Press.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information systems and science* (4th ed.). Wiley.

Bertaud, A. (2004). *The spatial organization of cities: Deliberate outcome or unforeseen consequence?* World Development Report Background Paper, World Bank.

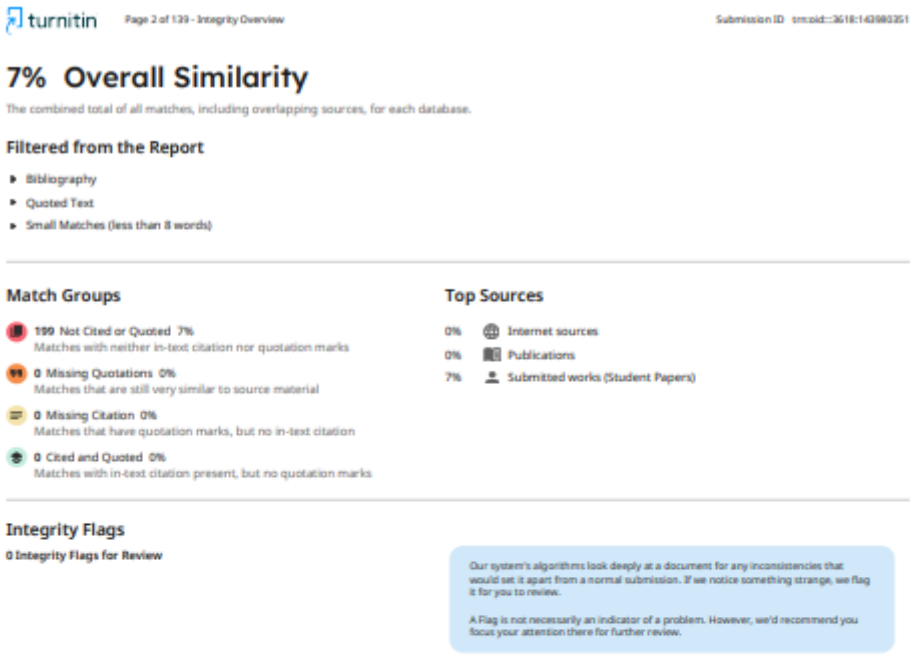
Vuchic, V. R. (2017). *Urban transit systems and technology*. John Wiley & Sons.

Annexure

Assessment Maps

Plagiarism Report





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