# Assessment of spatial disparities in India: A contribution to advancing urban research methods in rapid growth contexts

Jain, Manisha

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# Assessment of spatial disparities in India: A contribution to advancing urban research methods in rapid growth contexts

**Kumulative Habilitationsschrift**

Zur Erlangung des akademischen Grades eines habilitierten Doktors

Vorgelegt von

**Dr.-Ing. Manisha Jain**

# Erklärung der Habilitierenden zur guten wissenschaftlichen Praxis an der TU Dresden

Mir ist die Leitlinie „Gute wissenschaftliche Praxis an der TU Dresden“ bekannt. Hiermit erkläre ich, dass ich die von mir am heutigen Tage dem Prüfungsausschuss der Fakultät Umweltwissenschaften eingereichte Arbeit zum Thema:

**„Assessment of spatial disparities in India: A contribution to advancing urban research methods in rapid growth contexts“**

vollkommen selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie Zitate kenntlich gemacht habe.

Dresden, 08.12.2021

Ort, Datum

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Unterschrift (Vorname Name)

Dr.-Ing. Manisha Jain

# Erklärung der Habilitierenden

Hiermit erkläre ich, dass meine Habilitationsschrift „Assessment of spatial disparities in India: A contribution to advancing urban research methods in rapid growth contexts" und alle vorgelegten wissenschaftlichen Arbeiten von mir selbst und ohne andere als die darin angegebenen Hilfsmittel angefertigt wurden. Ich habe kein Habilitationsgesuch an einer anderen Hochschule eingereicht.

Die Übereinstimmung dieses Exemplars mit dem Original der Habilitation zum Thema:

**„Assessment of spatial disparities in India: A contribution to advancing urban research methods in rapid growth contexts"**

wird hiermit bestätigt.

Dresden, 08.12.2021

Ort, Datum

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Unterschrift (Vorname Name)

Dr.-Ing. Manisha Jain

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# 1 Introduction: manifestation of spatial disparities in the Global South

Urbanisation in the 21st century is characterised by unprecedented population growth and, consequently, a huge demand for infrastructure (WBGU, 2016). These trends have not only dramatically transformed the urban landscape (Brenner and Schmidt, 2014) but also undermined global sustainability. Today, human land usage affects more than 70% of the global land (IPCC, 2019). This development coupled with the prevalence of neoliberal policies in the Global South to deal with the global economic crisis (Firman, 2009 a; Banerjee-Guha, 2009) has led not just to institutional and spatial restructuring but also inequality across multiple scales (Banerjee-Guha, 2009; Guarneros-Meza and Geddes, 2010). According to United Nations statistics, the level of global urbanisation is set to rise to 68% by 2050; moreover, a majority of countries in the Global South will see their populations double (UN, 2019). Evidently, it appears to be a major challenge to sustainably accommodate this growth while ensuring sufficient infrastructure provision.

Two important expressions of spatial transformation manifesting inequality under neoliberalisation are the following. The first are investments by national governments in mega projects aimed at accumulating capital (Swyngedouw et al., 2002; Brenner, 1998). Mega projects entail creative destruction by rapid and radical transformation of the landscape supported by elite group of state agencies, international donor and lending institutions and private sector (Gellert and Lynch, 2003). These projects are huge schemes involving multiple developers to develop contiguous areas and transform land uses (Fainstein, 2008), enjoy special status (Altshuler and Luberoff, 2003) and generally lack public participation in the decision-making process (Flyvbjerg et al., 2003). There is sufficient evidence that the benefits of these mega projects do not trickle down as claimed, but rather serve to exacerbate sociospatial inequalities (e.g. Swyngedouw et al., 2002; Bon, 2015; Kennedy, 2015; Zeković et. al, 2018).

Second, under contemporary urbanisation process growth is not concentrated in urban areas but takes place in “non-urban” spaces, which are operationalised to support the socio-economic dynamics and metropolitan development (Brenner and Schmidt, 2015). In the process, non-urban spaces undergo land-use, infrastructural and socio-metabolic transformations. These transformations continuously produce differentiated, unevenly developed sociospatial configurations (Lefebvre, 2003; Brenner and Schmid, 2015), which augment and reshape inequalities inherited from previous eras of urban development (Soederberg and Walks, 2018).

Consequently, escalation in inequality under neoliberalisation has been a major concern not only for researchers but also for policymakers. Recently, the debate on inequality has intensified (e.g. Wei 2015; 2016; Nijman and Wei, 2020). The key dimension of inequality is spatial disparity (Wei, 2016), which refers to the uneven distribution of infrastructure, employment as well as other activities across geographical units within a country or region (Kanbur and Venables (2007). Spatial disparities become problematic when they lead to inequality in the provision of or access to infrastructure, education, employment and other services (Grant and Nijman, 2004; Shilpi, 2013). As these problems are aggravated by poor accessibility (Liu et al., 2016; Jain and Korzhenevych, 2017; Jain and Jehling 2020a), an important factor in reducing disparity is to improve transport links.

So far, research gaps in understanding spatial disparities can be divided into two categories: First, scholars have pointed out that the majority of research on spatial disparity considers economic or income disparities, whereas more research is needed to measure other dimensions (such as sociospatial dimensions) of disparity (Wei, 2015; 2016; Liu et al., 2016; Soederberg and Walks, 2018). Since disparities are manifested at multiple scales, their analysis requires a multiscale approach (Grant, 2010; Nijman and Wei, 2020). However, few studies have attempted to explain the various dimensions and drivers of disparities at multiple scales. Further, while the problems of unemployment, low incomes, poor health, low education,

and lack of access to amenities and urban services are often concentrated in space, it is hard to identify the key drivers of such processes (Nijman and Wei, 2020). Finally, although improved accessibility is an important indicator for reducing disparities, lack of reliable data constrains research and relevant policy reforms (Salon and Gulyani, 2010; Porter, 2014).

Second, escalation of disparity under neoliberalisation has made it increasingly important to investigate trends of uneven development, both theoretically and empirically (Agnew 2001; Grant and Nijman, 2002; 2004; Wei, 2015; Liu et al., 2016). In general there is a lack of methods and metrics to measure spatial patterns and the hierarchical structure (Shi et al., 2020). Peck (2015) claims that prevalent spatial transformation cannot be captured adequately and there is an urgent need of new approaches to understand and influence the processes of uneven spatial development. In fact, it is necessary to move from high-level, abstract concepts to mediating concepts in order to capture context-specific changes on the ground (Schindler, 2017; Khan and Karak, 2019). Radcliffe (2005) and Schindler (2017) argue for fieldwork in understanding path-dependencies in disparities. However, empirical research based on fieldwork and primary data analysis on the context-specific complexities of neoliberal developments remains scarce in the Global South (Grant and Nijman, 2002; Sternberg and Anderson, 2014).

There is substantial evidence of spatial disparities in the Global South (Annez and Buckley, 2009; Barca et al., 2012; Kennedy et al., 2011; WB, 2013). Despite these developments, on the one hand, in the midst of the COVID-19 pandemic, there are calls for accelerating infrastructure investment for reactivating economies and incentivizing private sector investment (Bebbington et al., 2020). On the other hand, there is sufficient evidence to establish the role of spatial disparities in escalating the vulnerability to COVID- 19 infection (Shifa et al., 2020; Penha, 2020). These developments, coupled with the fact that the majority of the world's growing population lives in the Global South, renders it imperative to address spatial disparities in order to facilitate and restore global sustainability.

To reduce spatial disparities, governments make use of spatial development initiatives to achieve balanced (distributed) growth. Two such initiatives deemed crucial to diffuse socio-economic development to peripheral areas are spatial decentralisation (Firman, 2009 b) and corridor development (ADB, 2014; Priemus and Zonneveld, 2003). In India, spatial decentralisation has traditionally been a component of spatial planning since the first Interim General Plan for Greater Delhi of 1956. In 2007, the Indian government adopted the Delhi-Mumbai Industrial Corridor strategy aimed at creating a strong economic base. Specifically, it is intended to increase manufacturing and service sector jobs as well as enhance regional and urban-rural connectivity, thereby ensuring the trickle down of development to lagging areas (GoI, 2007; DMIC, 2014). Despite these initiatives, the Indian urban landscape is characterised by spatial disparities where growth is concentrated in large metropolitan cities (Datta 2006; Markandey and Anant 2011; Kundu 2011; WB 2008, 2013; Saitluanga 2013; Jain and Korzhenevych, 2019a; Jain and Jehling, 2020a; b; Jain et al., 2021a;b).

According to United Nations forecasts, India is one of the nine countries, which will contribute more than half of future growth in the global population. Forecasts suggest that India's population will grow by 273 million between 2019 and 2050, potentially making it the world's most populous country (currently China) around the year 2027 (UN, 2019 b). Under prevalent disparities and the country's limited institutional capacity to manage such change and provide infrastructure, accommodating this increase will be an enormous challenge (MGI, 2010; Vaidya, 2011; WB, 2011). Consequently, facilitating and restoring sustainability will be crucial for India's urbanisation process.

Taking as its study area the Indian states through which the Delhi-Mumbai Industrial Corridor will pass, this research aims to fill the previously mentioned research gaps by developing an analytical framework based on a theoretical foundation and using mixed methods approach in order to discern and explain spatial disparities across space, scale and time. The development of such a framework makes two innovative contributions to urban research: First, it underscores the relevance of classic urban theories and models for investigating and

interpreting spatial disparities associated with urbanisation in the regions of the Global South. Second, given data scarcity in these regions, the application of mixed methods approach to understand the unfolding of spatial disparities makes the framework suitable as a proactive planning tool for policymakers to formulate evidence-based policies for steering growth towards balanced (distributed) development by integrating growth with infrastructure provision.

This introduction is followed by Section 2, which illustrates the research objectives and questions addressed in this research. Section 3 describes the main characteristics of the study area. Sections 4, 5 and 6 provide a brief overview and selected highlights of the various research contributions made by the publications forming this research. Finally, Section 7 synthesises the main findings of the publications associated with this research.

# 2 Objectives and analytical framework

As mentioned above the aim of the research is *to develop an analytical framework based on a theoretical foundation and using mixed methods approach to discern and explain spatial (inter-urban and rural-urban) disparities across space, scale and time*. This aim will be achieved with the help of the following three objectives and related research questions, which are derived from the publications (refer Chapter 9) forming this cumulative habilitation:

I To describe theories and models manifesting spatial disparities (Chapter 4).

- Which theories and models are relevant to understand the dynamics of settlement structure?
- Which methods are appropriate to test the theories and models for capturing spatial disparities?

II To explain the determinants manifesting spatial disparities (Chapter 5).

- Which factors are driving the transformation of settlements?
- Which dimensions (spatial, infrastructural and transport links) of disparities can be identified?
- How did the settlement structure evolve and manifest disparities over the decade under investigation?

III To identify evidence-based policy reforms for reducing spatial disparities (Chapter 6).

- How successful are government initiatives at curtailing disparities?
- What are constrains in attaining government initiatives?
- Where and which interventions can help reduce spatial disparities?

The above research objectives and questions were addressed with the help of an analytical framework which employs mixed methods approach and cuts across space, scale and time (see Figure 1 and Table 1). An analysis was undertaken at national level (six states), regional level and metropolitan or city level. The main administrative divisions of India are as follows: states, which are composed of districts, which are composed of tehsils, which in turn consist of urban (city) and rural areas. Please refer to section 3 for more details on the study area.

A mixed methods approach was applied to discern and explain spatial disparities, wherein statistical analysis, regressions and descriptive analysis were used to provide an aggregated analysis and for generalisation. Direct observations and personal interviews were undertaken for contextualisation. In addition, political and institutional aspects were explored through a systematic literature review, extensive document analysis and a qualitative textual analysis.

The statistical analysis was predominantly conducted on data for the years 2001 and 2011 from the national census, which is only held every decade (the most recent being the 2011 census). Furthermore, better quality data was available from 2001 onwards. However, in a few instances, data from the 1991 census was also used. Various census data was used to get information on socioeconomic, demographic and infrastructure factors. Fieldwork undertaken in 2017 focused on census towns and in 2020 on the diverse states through which the Delhi-

Mumbai Industrial Corridor will pass. Additional information on built-up areas was drawn from the Global Human Settlement Layer for the years 1990, 2000 and 2014.

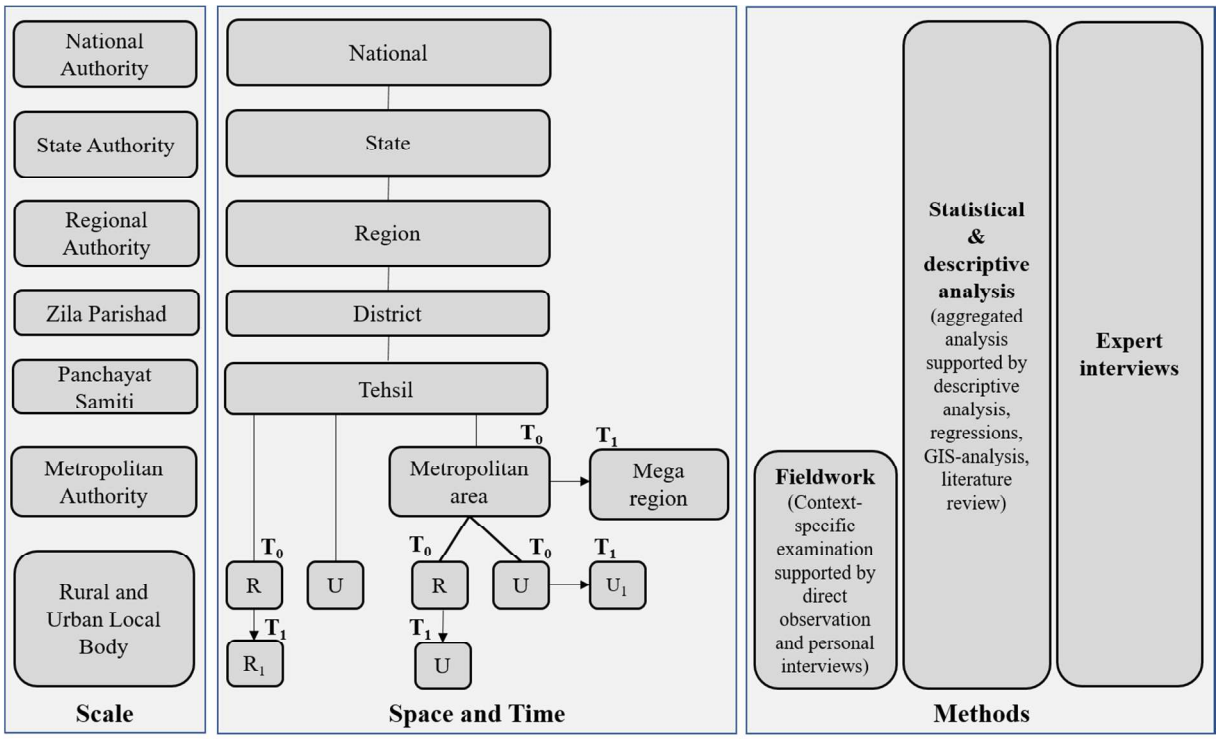


**Figure 1:** Analytical framework for discerning spatial disparities in India
Note: Time (T), Rural (R) and Urban (U)
Source: Author

# 3 Study area

To address the question of spatial disparities, which is a multiscale phenomenon, the chosen study area comprised the states through which the proposed Delhi-Mumbai Industrial Corridor will pass, thereby encompassing not only a range of states and metropolitan regions but also the National Capital Territory Delhi city, hereafter: Delhi. When completed, the corridor will link six states of India, namely Uttar Pradesh, Delhi, Haryana, Rajasthan, Gujarat and Maharashtra. These states are highly diverse with respect to their socioeconomic development. Starting in the National Capital Region at Dadri, it will pass through Rajasthan and Gujarat to terminate at Jawaharlal Nehru port in Maharashtra (see Figure 2A).

To better understand the dynamics of settlement (rural to urban) transformation and escalation of disparities, a regional level analysis was conducted of the National Capital Region of Delhi (hereafter: Delhi region) as a study area (see Figure 2B). With an area of 55,144 km$^2$ and a total population of approximately 58 million, this is one the world's largest rural-urban regions (Jain, 2018b). It is the only region in India to be composed of four states, with Delhi at the centre (regarded administratively as both a state and a city). To the east, the Delhi region shares a border with Uttar Pradesh state and to the west with Haryana state, and a part of Rajasthan state to the southeast. Regional level analyses of decentralisation and settlement links were also undertaken for Mumbai, Jaipur and Ahmedabad regions.

Since Delhi is the administrative capital of India and the second financial capital after Mumbai, the rate of urbanisation is relatively high in the region and in the metropolitan area. According to the Census of India 2011 enumeration, the Delhi region is 55% urbanised compared to the national average of 31%. This rapid pace of urbanisation made the megacity Delhi and its metropolitan area an ideal study area to measure disparities at city and metropolitan scale (see Figure 2C).

**Table** 1: Summary of publications with regard to their scale, time and methods (see list of publications in Chapter 9)

| Publication | Scale | | | | | | Time | | | | | | | | Method | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | National | State | District | Region | Tehsil | U/R | Census | | | Fieldwork | | Built-up area | | | Descriptive | Statistical | Spatial | Fieldwork |
| | | | | | | | 1991 | 2001 | 2011 | 2017 | 2020 | 1990 | 2000 | 2014 | | | | |
| 1 | | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | | | | ✓ | ✓ | | ✓ |
| 2 | | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ | ✓ | ✓ |
| 3 | | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| 4 | ✓ | ✓ | ✓ | | | | | ✓ | ✓ | | ✓ | | | | ✓ | ✓ | ✓ | ✓ |
| 5 | | ✓ | ✓ | ✓ | | | | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| 6 | | ✓ | ✓ | ✓ | | | | | ✓ | | | | | | ✓ | ✓ | | |
| 7 | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ | |
| 8 | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ | |
| 9 | | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ | |
| 10 | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 11 | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 12 | | ✓ | | ✓ | ✓ | | | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ | |

Note: Rural (R) and Urban (U)
Source: Author

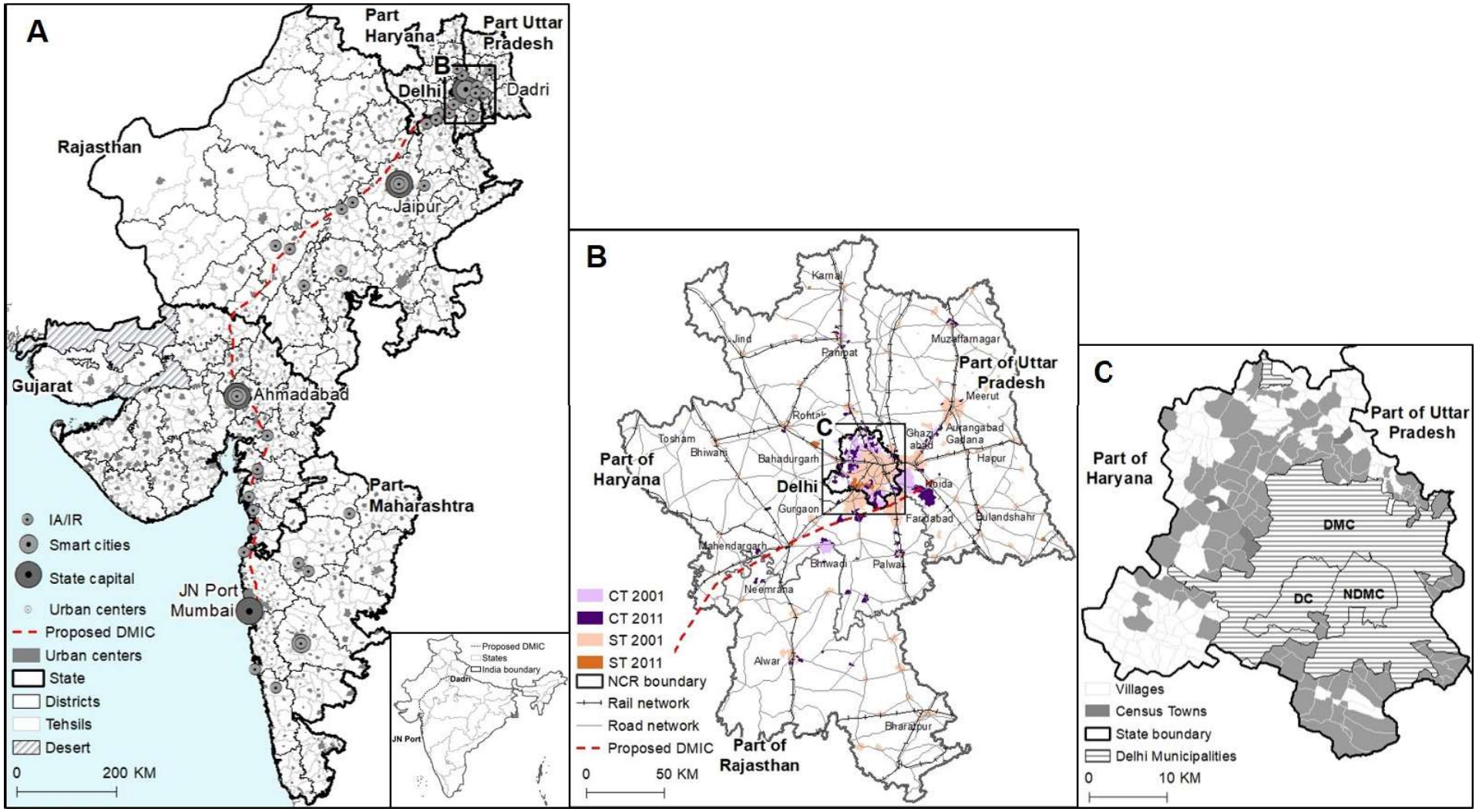


**Figure 2:** Composition of the study area. **A**- Six states through which Delhi-Mumbai Industrial Corridor will pass; **B**- National Capital Region Delhi; and **C**- Delhi
Note: Jawaharlal Nehru Port (JN Port), Delhi-Mumbai Industrial Corridor (DMIC), Investment Area/Region (IA/IR), Census Towns (CT), Statutory Towns (ST), National Capital Region (NCR), Delhi Municipal Corporation (DMC), Delhi Cantonment (DC), New Delhi Municipal Corporation (NDMC)
Source: Author

# 4 Methodological advances in the study of spatial disparities

## 4.1 Synchronising and applying spatial data on India

While spatial disparities are often highly visible and difficult to ignore in the Global South, suitable policy responses are hindered by a lack of data as well as problems in defining and measuring spatial disparities (Owusu and Yankson, 2007; Lang and Lingnau, 2015). Although several indicators have been developed in past decades to measure disparities, high reliance on aggregated data for the analysis conceals considerable differences (Grant, 2010; ISSER, 2012). The United Nations' Millennium Development Goals Report (2015) points out that data constraints are the main hindrance for research and evidence-based policy formulation.

There is sufficient evidence that improved accessibility through better transportation networks can help reduce spatial disparities. However, research on such improvements in transport networks and a consequent reduction in disparity remains limited due to a lack of reliable data (Salon and Gulyani, 2010; Porter, 2014). Transport research is hindered not only by poor availability and accuracy of maps of roads or railway networks, for example, but also by a similar lack of information on infrastructure and service locations, such as schools, hospitals, etc. (Oloo, 2018; Evans et al., 2018; Pritchard et al., 2019; Pereira, 2019). This data deficit leads to the construction of simplistic and sometimes unrealistic models rather than the sophisticated transportation models, which are actually needed (Dimitriou, 2013).

To overcome the above problem, this research (Publications 1 to 12) makes a novel contribution by developing a dataset covering three census periods (1991, 2001 and 2011) by synchronising spatial data with information on socioeconomic, demographic and infrastructural (physical and social) variables. The development of this dataset enabled the identification of disparities in the provision of infrastructure and access to employment opportunities as well as helped identifying the factors driving such disparities in the study area.

As a response to the data limitation, the mixed methods approach has emerged over the decades as a third paradigm beyond qualitative and quantitative approaches (Creswell, 1999; 2003). This approach is used to improve the accuracy of data, to produce a comprehensive understanding by combining information from various sources, and to help avoid biases within a particular method by compensating for its specific strengths and weaknesses.

This research contributes by deploying a mixed methods approach operationalised by the use of locally available data to provide a comprehensive understanding of the manifestation of spatial disparities. The publications associated with this research have made use of a convergence model in which qualitative and quantitative data is collected and examined separately. The integration of results was undertaken at the interpretation stages of the research.

In general, spatial disparities are manifested at various scales and are affected by physical proximity to services, infrastructure and jobs, and are path-dependent (Grant, 2010), thus to understand the path-dependency leading to disparities, analysis across time and scale is imperative. In this context, two methods have been recommended: First, scholars such as Radcliffe (2005) and Schindler (2017) have emphasised the importance of fieldwork, claiming that direct observation and in-depth personal interviews are necessary to understand path-dependencies in disparities. However, such empirical research based on fieldwork and primary data analysis is scarce in the Global South (Grant and Nijman, 2002). Second, scholars such as Wei (2015; 2016) and Nijman and Wei (2020) have pointed out that recent developments in Geographic Information System (GIS) now enable the spatial analysis of disparities across time and scale.

This research contributes by complementing a general understanding of spatial disparities obtained from descriptive and statistical analysis by GIS-based analysis, fieldwork and primary data analysis. This fieldwork, consisting of direct observation and face to face personal interviews enabled understanding of context-specific characteristics of growth. For detail on the fieldwork process, please refer Publications 1, 2, 3 and 11.

## 4.2 Extending classical models and theories to India

### *4.2.1 Urban cycle models*

In the Global South, generally agreed upon metrics or methodologies to measure spatial patterns and the hierarchical structure of regional urban systems are absent (Shi et al., 2020). This research (Publications 7, 8 and 9) contributes by applying a novel approach that exploits the potential of spatial and nonspatial models to measure not only spatial structures but also the hierarchy of the regional urban system.

In this regard, two classic models that have previously been applied were tested to help understand urbanisation pattern and dynamics as well as to predict where future urbanisation might take place: the differential urbanisation model and the core-ring model. These models postulate that urban regions pass through different stages of development during their cycle of growth. Each stage is associated with a specific dynamic and spatial pattern of urbanisation and, thus, the infrastructure provision that shapes it (Berg et al., 1982; Geyer and Kontuly, 1993; Klaassen et al., 1981).

The nonspatial differential urbanisation model has been criticised for its high level of generality, thereby abstracting away many of the economic, demographic, geographic, political and social processes, which influence urbanisation process (Kontuly and Geyer, 2003). The spatial core-ring urban life cycle model has been criticised for its restrictive delimitation of a functional region and for ignoring developments in small and medium-sized towns or in sparsely populated areas (Nyström, 1992). This research (Publications 7 and 9) overcomes these deficiencies by deploying both models, demonstrating that infrastructure, socioeconomic and geographic variables can be integrated to better identify and understand the trajectories of urbanisation. Also, by combining the two models, it is possible to incorporate small and medium-order settlements in the analysis, thus overcoming the delimitation of a functional region that neglects small and medium-sized settlements.

This research (Publications 7 and 9) also advances the application of the models to the context of the Global South. The information on commuting patterns has been used to delineate core and ring in the Global North (see Berg et al., 1982; Kabisch and Hasse, 2011; Turok and Mykhnenko, 2008), whereas in the Global South such delineation was previously limited to neighbouring administrative boundaries (e.g. Jain et al., 2013; Jain and Knieling, 2018). This research (Publications 7) made use of commuting information for the first time to delineate rings in the core-ring model, thereby ensuring an improved specification of core and ring.

According to proponents of the core-ring model (Klaassen et al., 1981; Berg et al., 1982) and the differential urbanisation model (Geyer and Kontuly, 1993), spatial patterns and problems at each stage of urbanisation are shaped by infrastructure provision. Despite this claim, these models have not previously been tested in regard to infrastructure provision. This research (Publications 7 and 9) developed a refined dataset of well-synchronised spatial data and demographic and infrastructure information not only to identify which cities and where in the region growth will occur, but also their infrastructural requirements. In doing so, it demonstrates that infrastructural variables can be integrated into the models to identify and understand the trajectories of urbanisation.

### *4.2.2 Central place theory*

Another classic theory much tested in both the Global North and the Global South is the central place theory. According to Christaller (1933), central place theory explains the size and frequency of urban centres by placing them in a hierarchy along with a market area for each of them as well as by considering the distance between different order centres and their geographical distribution. After flourishing in the 1970s and 1980s within debates on the settlement system, this theory more or less disappeared from the policy discourse (Coffey et al., 1998). Consequently, studies that consider the settlement hierarchy in India also date from the 1980s. The recent empirical research indicates a revival of central place theory (Blanco, 2014), fuelled by evidence of the hierarchy of central places (Chen and Zhou, 2006; Guedes et al., 2009; Hsu, 2012).

The practical significance of central place theory is the identification of functional (infrastructure) gaps in the regional settlement system to provide those functions in the settlements. The identification and provision of these functions avoids duplication of functions in the settlements and bridges the functional gaps between developed and under-developed settlements (Chaudhuri, 2009). Further, central place theory has been recognised for its policy value in planning strategies (Mulligan et al., 2012). For countries in the Global South, central place theory is particularly relevant for explaining the settlement system (Camagni and Salone, 1993; Batten, 1995; Meijers, 2007). Here a central place system of independent urban centres at different levels interlocked in a hierarchy (Berry, 1967) fosters a de-concentrated integrated system of cities and thus a balanced pattern of urbanisation. In this context, balanced development aims to reduce spatial disparity.

So far, central place theory could not be applied to explain growth dynamics at regional and national scale due to the primitive nature of GIS technology, which limited this form of analysis. However, as GIS technology has advanced, large scale analysis is now possible (Mulligan et al., 2012). Central place theory has also been criticised for being static and for not incorporating temporal aspect (Beguin, 1992; van Meeteren and Poorthuis, 2017). Specifically, in defining central places, no consideration was given to the role of time (accessibility) or potential changes in the structure of the central place system (van Meeteren and Poorthuis, 2017). Using GIS synchronised data for 2001 and 2011, this research (Publication 8) fills the above gaps and enriches current knowledge by testing the central place theory at regional scale. It further contributes by measuring the impact of time on the structure of the settlement hierarchy and by adding a “distance” variable as a dummy to “travel time” for identifying factors influencing disparities in the region.

## 4.3 Progress in policy evaluation methods

In the Global South, it is generally the case that constraints in evaluating transportation policies limit robust and effective research on transport-related disparities (Porter, 2002; Salon and Gulyani, 2010). Moreover, policies formulated under such constraints are frequently inaccurate and socially unjust (Pereira et al., 2017). Similar deficiencies have been identified in growth management strategies, which remains an under-researched area (Yang and Jinxing, 2007; Jain, 2013; Jain and Siedentop, 2014). While both qualitative (e.g. Thapa and Rasul, 2006; Zhu, 2013; Mu et al., 2016) and quantitative (e.g. Liu et al., 2011; Osman et al., 2016) methods have been used to investigate the effect of planning and policies on land use change, these studies have not attempted to measure policy performance. Su et al. (2017) recommend combining economic and geo-statistical (spatio-temporal) approaches to evaluate megaregion policy performance. This is also supported by Breheny (1987), who argues that the sole use of quantitative methods for policy assessment is no longer adequate due to changes in the philosophical basis of policy analysis, in features of practical policymaking and in the political environment of policy formulation.

This research (Publications 10, 11 and 12) contributes by demonstrating the use of qualitative methods (review, content analysis, personal interviews) and quantitative methods (regression, statistical and connectivity analysis, spatial mapping and analysis) to evaluate policy performance across multiple scales (such as city, metropolitan, state and region) and over time (2001 and 2011). Such an analysis is not only beneficial for interpreting the factors driving growth and disparity in the study area but also can serve as a proactive tool for evidenced-based policy reforms.

Few studies (e.g. Khandker et al, 2009; Bocarejo et al., 2014; Qin and Zhang, 2016; Rodriguez et al., 2016) have undertaken an *ex post* evaluation of how transport networks (roads and transit) can reduce disparities within a jurisdiction. Nevertheless, little attention has been paid to the assessment of cross-border disparity effects, especially within regions, despite the potential of such an assessment for identifying evidence-based policies for ensuring efficiency in investments (Gagliardi and Percoco, 2017). With increasing construction of mega projects, there is an increasing need for research to investigate why and how improved accessibility influences the development of an area (González-González and Nogués, 2019).

This research (Publication 4 and 10) contributes by developing an analytical framework to examine the effect of a large-scale transport corridor on rural and urban disparities. It also made possible identifying the impact of policies and commuting patterns on spatial disparities (Publications 5 and 6).

Urban growth management aims to maximise the benefits of growth by planning for the future while taking account of current needs. National governments make use of a combination of policies and instruments to manage urban growth by curtailing outward expansion and minimising the costs of infrastructure provision and maintenance while protecting open spaces and reducing car reliance (Jain, 2013). However, there is a basic lack of systematic analyses and measures to evaluate the outcome of such growth management strategies (Blanco, 1998). Moreover, few studies have produced results that are generalisable to other cases (Bollens, 1993). Consequently, a unified framework is required that adopts a holistic approach to examine the effects of land use policies by considering institutional structures and market forces as well as scale (Carruthers, 2002).

This research (Publication 11) contributes by illustrating a conceptual framework that takes account of programme design, the institutional setting and market interactions to evaluate the performance of a growth management strategy. This framework was further tested and improved to evaluate the impact of spatial strategies (decentralisation and transport corridor) across scale (Publication 10).

In sum, the publications (Publication 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12) in this section indicate the applicability of a dataset well synchronised with spatial information on socioeconomic and infrastructure variables for empirically establishing spatial disparities. This section accentuates the relevance of classical theories and models to understand the settlement system, and to establish disparities in infrastructure provision while predicting future growth. This section also stresses the importance of mixed methods approach to explain the context-specific peculiarities of spatial disparities.

# 5 Advances in discerning determinants of spatial disparities

## 5.1 Rural to urban transformation: city and metropolitan spatial structure

Rural to urban transformation leading to spatial disparities is a result of complex human-environmental interactions. Therefore, Kleemann et al. (2017) argue that the analysis of such interactions requires the application of mixed methods approach as only by combining qualitative and quantitative data is it possible to identify synergies and contradictions in those factors driving land use change in the Global South. This research (Publication 2) contributes by developing an analytical framework to uncover emerging urbanisation gradients within official rural areas. In particular, a mixed methods approach was used to analyse the rural to urban transformation. Such an approach not only enabled comparison across time, scale and space related to the situatedness of rural areas with regard to their history and networks but also identified factors driving disparities in the region (Publications 1, 2 and 3).

Rural to urban transformation has been predominantly studied with regard to land use change. However, the impact of increased connectivity on rural areas is poorly understood (Boudet et al., 2020). This research (Publications 4, 5 and 6) contributes by analysing accessibility and commuting patterns between rural and urban areas in order to identify the impact of improved accessibility on rural and urban disparities. Responding to the claim of Diao et al. (2019) that the relationship between cities of different sizes and surrounding rural areas is under-investigated, this research (Publications 1, 2 and 3) contributes by modelling the transformation of rural areas with regard to different order urban settlements.

The Census of India classifies a settlement as “urban” if it has a population of more than 5000, a population density of more than 400 people per square kilometre and more than 75% of males working in non-agricultural activities. This definition has been criticised by scholars (such as Sivaramakrishnan et al., 2005; Kundu, 2011; Denis and Marius-Gnanou, 2011; van

Duijne, 2017; Jain et al., 2019b) for its strictly population-based approach that fails to capture the characteristics of many areas that could otherwise be described as urban.

In the decade from 2001 and 2011, data from the Census of India shows that 30% of the country's urban growth was due to the expansion of census towns. Consequently, the spatial structure in the study area has been predominantly shaped by the growth of census towns. Census towns are settlements, which despite having urban characteristics and fulfilling the Census of India's criteria for an urban settlement, are not statutorily notified and administered by an urban local body. Thus, despite being urban, they remain under rural governance. This development in India has been termed "non-recognised growth" (Samanta, 2014), "unacknowledged urbanisation" (Pradhan, 2013), "denied urbanisation" (Denis et al., 2012) and "unregulated growth" (Jain, 2018a). In contrast, statutory towns are urban settlements with notified urban governing bodies as well as land use regulation and planning rights.

Under weak rural governance and the rapid pressures of growth, it is crucial that the potential of census towns be exploited to steer India's urbanisation process. However, there is a lack of empirical research to understand the unique features of census towns (Jain, 2018a; Jain et al., 2019b; Jain and Korzhenevych, 2020). This research (Publications 1, 2 and 3) contributes by testing the applicability of urbanisation theories to the formation of census towns as well as by empirically measuring the rural to urban transformation in India, as discussed below.

Previous research by Guin and Das (2015a) and Pradhan (2013) established the growth of census towns near large metropolises. Using GIS-based spatial mapping, this research (Publications 1 and 3) not only confirmed this finding but also identified the transformation of rural areas into census towns along transport network between major cities. By conducting t-tests and interviews, it could be established that while census towns offer diverse employment opportunities to attract migrants, these settlements are dependent on the public infrastructure (such as hospitals) provided by statutory towns. Also, the interdependence of census towns and statutory towns as well as between census towns and the hinterland for those seeking work was identified by daily commuting flows and inter-migration. The establishment of industrial zones, the close proximity of sugar mills and the growth of satellite services such as shops, restaurants, hotels and mustard or sugarcane farms along the highways and main roads have not only created jobs but also fostered land-use conflicts and changes, which blur the boundaries between urban settlements and their surrounding rural areas. The activities undertaken by individuals who use and appropriate this space has brought about socio-metabolic transformations such as water table depletion, crop degradation and reduced cattle breeding. Such developments validate the claims of experts on planetary urbanism (Brenner and Schmid, 2014; 2015) that close economic links, inter-regional migration and infrastructural development have together rearticulated the interdependencies between rural and urban and, moreover, internalised the relationship between them.

Fieldwork undertaken in this research contributes by not only establishing that census towns provide diverse employment opportunities in alignment with the claims of Mukhopadhyay et al. (2016) and Samanta (2012) but it goes further to establish that these towns provide affordable housing to the urban poor and rural migrants as well as land for industrial and commercial developments. Given the scarcity of developed land in the main cities, pressure of growth is transferred to peripheral rural areas with low land prices and weak land use regulation, thereby escalating land use change and promoting high-density mixed-use developments. Since these peripheral areas are outside the municipal jurisdiction, they lack an adequate provision of basic services.

Roy and Pradhan (2018) identify high non-farm activities in census towns, this research using t-tests contributes by establishing higher literacy rates and higher shares of non-agricultural employment in the towns. Moreover, through descriptive analysis, it was possible to determine that the former villages of Neemrana, Aurangabad Gadani and Khanpur Dhani were transformed to urban in the period 2001-2011 by a shift from agriculture and cultivation to urban activities, without any migration. This process is termed *in-situ urbanisation*. The above developments are clear evidence of rural to urban transformation in India, confirming the

applicability of the in-situ urbanisation concept of Zhu (2004) to census towns (Publications 1 and 3).

In order to understand how the determinants of employment and population growth differ between villages (rural areas) and census towns, the described research encompassed an Ordinary Least Square (OLS) regression and Geographically Weighted Regression (GWR). The analysis revealed that growth in villages could be explained by the provision of medical and educational facilities, whereas in census towns it was explained by an increase in built-up area. Unlike OLS, the results of the GWR made clear that growth is not uniform in space but varies depending on the distribution of socio-economic, demographic and infrastructure variables. Consequently, clustering in GWR did not reflect census villages or census towns but rather the distribution of amenities across space (Publication 2).

These findings raised questions regarding the demarcation criteria used by the Census of India, which does not incorporate information on educational and medical facilities, commercial or residential land uses and built-up area density. Similarly, Punia et al. (2017) claim that the definition of urban areas lacks clarity and that the growth of census towns is driven by industrial, institutional and real estate investments together with improved transport connectivity and infrastructure provision. In order to accurately delineate rural and urban areas, it is vital to incorporate information on infrastructure as well as land use and built-up areas. These findings support the claims of Sivaramakrishnan et al. (2005), Kundu (2011), Denis and Marius-Gnanou (2011), van Duijne (2017), Jain et al. (2019b) that the Census of India's definition for demarcating "urban" is not realistic to capture the characteristics of urbanisation (Publication 2).

While the application of mixed methods enabled theories to be tested and the identification of disparities in growth, expert interviews were undertaken to capture the institutional influence on this growth. The heads of the rural governing bodies such as *zila parishads* at the district level, *panchayat samitis* at the block level, and *gram panchayats* at the village level were interviewed. The interview analysis revealed conflicting views. On the one hand, some elected members do not wish the census towns to be notified with a municipality due to the fear of increased taxation and implementation of land use regulation, which would forfeit profit generation. On the other hand, some elected members were concerned with the rapid pace of growth in census towns under rural governing bodies, which, due to a lack of land use regulation and taxation powers, promote haphazard development and are deprived of revenue generation for service delivery (Publication 3).

These findings underline the importance of striving for integrated planning and governance of urban and rural areas, especially since non-urban spaces near major cities as well as in the hinterland are being operationalised to serve the socioeconomic development of the metropolitan areas.

## 5.2 Determination of regional and national settlement structure

In India, spatial disparities in urbanisation have disturbed the national and regional settlement structure (Anand and Sami, 2016). At the national level, the lack of employment opportunities in less urbanised states has caused migration towards cities in more urbanised states, leading to overcrowding. At the regional level, imbalances in the settlement system has contributed to the abnormal growth of large cities (Kundu, 2014; Chakraborty, 2017). Consequently, many major cities suffer from congested urban services and degradation of the urban environment (Datta, 2006; Revi, 2008). This imbalance in settlement structure (along with other factors) is an outcome of the population-based approach of state governments to define settlement hierarchy in regional planning. This approach fails to capture other important aspects (discussed in section 5.1) such as employment and infrastructure concentration, which are crucial for designating the settlement hierarchy.

Several previous studies have examined the distribution of urban amenities in India using measures based on the central place theory, such as a centrality index (Roy, 2002; Nangia and Ahluwalia, 2003; Samvanshi, 2007; Ali and Varshney, 2012; Mandal et al., 2015; Alam

and Choudhury, 2016). However, these studies have two constraints: firstly, they are limited to a particular district or sub-district and thus do not cover the state or regional level of analysis; secondly, they are limited to one time period. Consequently, these studies have failed to compare the settlement dynamic over years and across different states, and thus are unable to provide planners with crucial information for the design of place-based reforms to strengthen the settlement system and reduce disparities.

This research (Publication 8) filled these gaps by determining actual settlement hierarchy not only based on population enumeration but also by incorporating socioeconomic and infrastructure variables. This was realised by deploying the principles of central place theory as well as other methods such as descriptive analysis, spatial analysis and regression analysis of growth determinants.

A descriptive analysis based on population data for different size settlements was conducted to identify the distribution of population in the settlements. The analysis revealed that in 2011, 55% (59.3 million) of the population lived in 20 megacities and million-plus cities, which together constituted a mere 2% of urban centres, whereas 6% (approximately 7 million) of the population lived in 652 smaller towns of classes IV, V and VI, constituting 25% of urban centres. This confirmed that the settlement system in the study area is skewed towards large cities.

Measures derived from the central place theory were used to determine whether the provision of social infrastructure reflects the population size and whether rural settlements around urbanised areas have access to urban amenities. Using data for 2011, the investigations revealed that more than 70% of larger centres and less than 30% of smaller centres were underprovided with various kinds of urban amenities and that small centres were better equipped to accommodate further population growth. The analysis also found that megacities and million-plus cities serve a large dependent area but that there exists a substantial area which is not served by the urban centres and thus lacks access to amenities. Moreover, it could be shown that over the decade 2001 and 2011, there was a reduction in the extent of dependent area served by higher order settlements.

OLS analysis conducted to identify the determinants of growth showed that population growth in the majority of urban settlements is not attracted by manmade amenities such as hospitals and schools but rather the proximity to higher order urban centres, by economic factors such as the availability of employment and natural amenities such as weather.

Compared to previous works on India, this research (Publication 8) goes a step further by not only examining and establishing a settlement system across states at national level but also across two time periods, namely 2001 and 2011. This enabled a better understanding of the dynamics of change in the settlement system over a period of ten years, especially in regard to those settlements without adequate infrastructure provision. The research findings suggest that the central place theory is still useful in analysing the settlement hierarchy based on the provision of amenities and at the same time constitutes an important instrument for identifying development gaps and disparity hotspots.

Although the described methods enabled the identification of settlements with particular infrastructural deficits as well as pinpointing the determinants of growth, they could not be applied to predict future development patterns. Therefore, the next step was to use urban cycle models to identify future growth hotspots.

The applicability of the nonspatial differential urbanisation model has already been tested in the Global South in regard to understanding urbanisation patterns/dynamics and to predict where future urbanisation might take place, specifically in Africa (e.g., Geyer, 2003; Gwebu, 2006; Geyer et al., 2012; Geyer and Geyer, 2015) and – with some constraints on time period and geographical extent – in India (e.g., Mookherjee, 2003; Mookherjee and Geyer, 2010; Jain and Korzhenevych, 2019a). In contrast, more research is required to test the spatial core-ring model (Jain et al., 2013; Jain and Knieling, 2018). Compared to previous works on urban cycle models (such as Mookherjee, 2003; Mookherjee and Geyer, 2010), this research (Publications

7 and 9) goes a step further by analysing not just the socioeconomic conditions of growth but also the status of infrastructure delivery.

The investigations of the differential urbanisation model revealed that the next sub-phase for developed regions such as the Delhi region and the Mumbai region will be the *early small city sub-phase*, which implies rapid growth of small cities in those regions where rural to urban transformation is taking place. By contrast, less developed states such as Rajasthan and Gujarat will enter the *early intermediate city sub-phase*, which implies a flourishing growth of intermediate-sized cities. With regard to the core-ring model, it is predicted that the cores of megacities such as Delhi and Mumbai will decline over the next decade while the rings will continue to attract population. This decline of the cores will be so strong that the agglomerations as a whole will decline. The cores of the million-plus cities will undergo slow growth, with the rings growing rapidly and the agglomerations as a whole experiencing growth. Further, the urban cycle models indicate that socio-economic developments in employment, disadvantaged social groups and literacy rate are similar to population growth.

In addition, the population thresholds specified by the Government of India for each infrastructure category were used to identify cities lagging in infrastructure provision. The investigations showed that cities in the Mumbai region are lagging in several categories of infrastructure compared to cities in the Delhi region. Future growth in these regions (specifically in the Mumbai region) is predicted to occur in small cities, which are generally under-provisioned with educational and medical facilities. Comparing Rajasthan and Gujarat, cities in Gujarat were found to be deficient in several categories of infrastructure. Intermediate cities in these two states are projected to grow, which are under-provisioned with educational and medical facilities.

This research (Publications 7, 8 and 9) contributed by investigating and comparing the potential of these models to identify the locations of current and future spatial disparities. By linking predicted growth with infrastructure provision, it was possible to identify those cities which will require infrastructure investment. These findings not only raise concerns about the potential of small and intermediate cities to reduce the growth pressures in large cities, but also provide important insights for regional development and policy reforms.

## 5.3 Spatial links: commuting

A peculiar feature of Indian urbanisation in the period 2001-2011 was population decline in major megacities (Sudhira and Gururaja, 2012) and the continuous growth of the urban periphery. This led to an increasing numbers of daily commuters and commuting distances in the metropolises (Basu and Dhar, 2013; WB, 2013). Generally, growth in the urban periphery has driven sprawl (Taubenböck et al., 2008; Jain et al., 2013; Jain and Pallagst, 2015), making these areas difficult to serve by public transport and forcing commuters to rely on private modes of transit such as cars and motorised two-wheelers. Compared to countries of the Global North (e.g., Button, 1997; Banister and Gallent, 1998; Coombes and Raybould, 2001; Banister, 2005; Chapman, 2007), spatial analyses of commuting patterns are scant in India and other similar countries of the Global South due to a lack of relevant data (Srinivasan and Rogers, 2005; Sharma and Chandrasekhar, 2014; Ahmad and Puppim de Oliveira 2016).

This research (Publications 5 and 6) fills the above gap by analysing commuting patterns and their determinants in India's largest rural-urban region. Further, by discerning trip lengths and mode of commuting in the study area, it was possible to reflect on the spatial structure and disparities. For the analysis, data on commuting patterns from 2011 was accessed from the Census of India portal. This was in fact the first time that the Census of India released commuting data. The adopted methodology made use of mixed methods, wherein descriptive and spatial analysis was applied to identify the spatial distribution of commuting patterns and regression analysis was used to pinpoint the determinants of the commuting patterns.

Descriptive analysis showed that the proportion of short trips is higher in urban areas, whereas long trips are more frequent in rural areas, indicating that rural residents have to travel longer distances to access jobs. In rural areas inside Delhi, the proportion of short trips less than one

kilometre is much lower than in other parts of the region. The proportion of long trips is substantially higher in the rural areas outside Delhi, indicating that the limited job opportunities forces people to travel longer distances. Overall, commuting in the Delhi region is dominated by the use of non-motorised transport, followed by buses and two-wheelers. Within urban areas, the use of cars and buses is highest in Delhi, whereas in rural areas cars are less frequently used and more trips are made by bus. Road and rail network densities are much higher in urban areas than rural areas.

Statistical analysis showed a greater use of non-motorised means of transport (and a reduction in the use of cars and public transport) at increasing distances from Delhi. The effect of road density is only significant in regard to the use of mopeds and motorcycles. One important finding with regard to the relation between income and mode of commuting was that skilled workers are more likely to use individual motorised modes of transportation rather than walking or cycling. This may indicate that residents of higher-income areas can afford to use private vehicles for commuting. The large number of short trips made by households with high illiteracy rates and minority status indicate that these people work close to their residences (Publications 5 and 6).

In sum, the publications (Publications 1, 2, 3, 4, 5, 6, 7, 8 and 9) discussed in this section shows the applicability of urbanisation theories and models not only to better understand rural to urban transformation but also to enable predicting future development pattern and spatial disparities manifesting in India. This section indicates the relevance of socioeconomic and infrastructure indicators for establishing spatial disparities across space, scale and time. This section shows that information on predicted growth complemented with details of areas deficient in infrastructure together form a useful policy input.

# 6 Advances in policy evaluation and reforms required to curtail disparities

## 6.1 Spatial decentralisation strategy: metropolitan and regional scales

In India, population and economic growth are skewed towards metropolitan cities (WB, 2008; 2013; Markandey and Anant, 2011; Kundu, 2011; Saitluanga, 2013). This trend is usually described as top-heavy or lopsided urbanisation (Datta, 2006). Such disparities lead to congested infrastructure and the over-consumption of natural resources in large cities as well as the under-provision of infrastructure in small and medium-sized settlements. To avoid the problems of concentration in certain urban regions, the Indian national policy has focused on promoting spatially balanced development by adopting spatial decentralisation for major metropolitan regions. However, only a few attempts have been made to evaluate the performance of spatial decentralization policy (e.g. Nath, 1988; Jain and Siedentop, 2014; Jain and Pallagst, 2015), largely due to lack of spatial data well synchronised with socioeconomic and infrastructure information (Mookherjee et al., 2014). Nath (1988) undertook a primarily descriptive review of the objectives, strategies, policies and development programmes of the 2001 regional plan. While Jain and Siedentop (2014) as well as Jain and Pallagst (2015) attempted to measure the performance of the main components adopted for urban growth management in the Delhi region, their analyses were limited to the metropolitan area.

This research (Publications 11 and 12) contributed by using mixed methods approach to maximize on the given data for evaluating the performance of spatial decentralisation in India's largest mega rural-urban region. The three main strands of India's spatial decentralisation strategy are as follows: (i) integrating the different orders of settlements by means of public transport; (ii) establishing greenbelts and green buffers to preserve open rural spaces and agricultural land as well as preventing the merging of settlements; and (iii) decentralising the population into an identified settlement hierarchy with adequate employment opportunities and appropriate infrastructural facilities. These components were evaluated in this research.

Descriptive analysis based on population enumeration and settlement categories was conducted to compare the actual population and the proposed population of the urban centres

in the region. Results showed that in 2001, only four towns (including Delhi) achieved their targeted population; in 2011 the figure was five towns (excluding Delhi). Further, economic activity and population remained concentrated in and around Delhi. By examining the Gini coefficient, it was found that the inequality measure was much higher in the peripheral rings because these include only a few regional centres with high densities (Publications 12).

Spatial analysis was conducted by digitising the proposed transport network from official plans and superimposing this with the administrative boundaries. The analysis showed that while transportation proposals for core and periphery were completed, these targets were not met in metropolitan areas. Nevertheless, growth was high in these areas, indicating that factors other than transport drive growth in these zones, such as proximity to Delhi (the administrative capital). Moreover, the regional transport network proposals such as Regional Rapid Transport System and Orbital Rail Corridor have still not been implemented. By superimposing the Delhi Mass Rapid Transit System and the Regional Railway, a lack of coordination between the two providers was found, with no shared stations and large distances between stations of these two networks (Publications 11 and 12).

A regression analysis was conducted to identify the relationship between the change in employment density and the increase in the density of main roads in peripheral areas. The results established a positive correlation between these two factors. Also, the new jobs were more rapidly created in the areas with initially larger urban populations. Finally, higher value of infrastructure provision had a positive effect on employment growth (Publication 12).

Although the above research established a lack of decentralisation with regard to population targets and transportation infrastructure, some aspects still remained to be examined, such as the connectivity of urban centres or the effect of greenbelt and institutional structures on decentralisation, which were investigated in Publication 11.

Connectivity analysis was undertaken by deploying traditional Beta and Gamma indices to identify the level of public transport connectivity between different centres in the region. The results showed that 3 out of 9 metropolitan centres (Manesar, Noida and Kundli) and 5 out of 17 regional centres lacked a regional railway connection. Excluding the unconnected nodes, the resulting network (including Delhi) had 19 nodes and 22 links with 1.16 links per node and 43% of all possible links, indicating very low connectivity in the region. At the same time, the analysis indicated good accessibility in core areas with Delhi being most accessible, followed by Ghaziabad. Baraut, which lies on the periphery, was found to be least accessible.

GIS-based analysis revealed a continuous growth in built-up area inside the greenbelts from 1975 to 2014. The urban centres which saw a great expansion in built-up area in 1990-2000 saw low growth rates in 2000-2014, and vice versa. This slowdown observed in Delhi and metropolitan areas reflects a scarcity of land for further development. An expansion in built-up area was observed in regional centres. An absolute increase in built-up area (almost 70%) was also established in each decade inside the green buffers along roadways. Further, the built-up area in the central region coalesced along national railways and highways, resulting in the merging of settlements (Publication 11).

Although indicator-based analysis can determine whether decentralisation strategies have been successful or not, it does not help to understand the institutional environment that leads to the limited success of these strategies. For this reason, it was necessary to conduct expert interviews. These interviews investigated the institutional environment under which policies were formulated and implemented in the Delhi region. The analysis revealed a lack of corporation and coordination between the participating states. This not only led to the limited success to implement cross border infrastructure such as a transport network but also to have one unified transport system for the region. With regard to planning and implementation, a contradiction was established: according to state officials, various capacity constraints such as lack of personnel, funding and knowledge have prevented the monitoring of plans; however, experts from academia claim a lack of willingness on the part of administration to monitor the plans due to their vested interests (Publication 11).

The above research showed the limited success of decentralisation policies, which rather seem to have exacerbated spatial disparities by concentrating growth in and around major cities. This is an important finding for policymakers to enhance the planning and implementation processes to curtail further escalation of disparities.

## 6.2 Delhi-Mumbai Industrial Corridor strategy: national scale

A policy mix of spatial decentralisation and transport corridor development has been advocated to address disparities between large cities and the urban periphery (Clausen, 2010; Andriesse, 2017). Theoretically, both of these strategies can reduce disparities and achieve distributed growth (Rodrigue et al., 2009). Yet research on these two strategies, which have been historically implemented in the Global South, remains disconnected, with scholars either evaluating the performance of spatial decentralisation strategies (see Nath, 1988; Jain and Siedentop, 2014; Jain et al., 2019a) or measuring the performance of transport corridor initiatives (see Khanna, 2014; Chakrabarti, 2018; Jain and Korzhenevych, 2019b). Unfortunately, such separate evaluation hinders a comprehensive understanding of spatial disparities. This research (Publications 10 and 4) fills this gap by not only assessing the impact of the proposed Delhi-Mumbai Industrial Corridor and spatial decentralisation strategy on regional spatial disparities, but also by analysing how the integration of the decentralisation and corridor policies reduce regional spatial disparities. A mixed methods approach was adopted for the research.

Descriptive analysis based on demographic variables for the time periods 2001 and 2011 showed extremely high population densities in urban areas compared to rural areas. The majority of the urban centres selected to achieve decentralisation in the metropolitan regions did not trigger sufficient growth to reach their target populations. The connectivity analysis of the growth centres and the Delhi-Mumbai Industrial Corridor revealed a very low rail connectivity between growth centres; further, Jaipur had the lowest level of connectivity by road. Analysis also revealed that after completion of the Delhi-Mumbai Industrial Corridor, a substantial increase in road and rail connectivity is predicted in the Delhi region, whereas in other regions this will not change. Although informative, this analysis was limited to certain urban centres in the four largest regions through which the corridor will pass.

An analysis of accessibility was undertaken for the states through which the corridor will pass to understand the links between the proposed Delhi-Mumbai Industrial Corridor, Investment Regions and Industrial Areas, and the peripheral urban and rural areas. The analysis showed that the districts in the Delhi and the Mumbai regions have the highest level of accessibility, followed by less developed regions of Ahmedabad-Gandhinagar and Jaipur. While accessibility along the corridor is high, this decreases as the distance from the proposed corridor increases. Further, most of the proposed Investment Regions and Industrial Areas are located in districts with high rural-urban accessibility. A small scale rural-urban accessibility analysis (for Pune district) revealed relatively low accessibility to Investment Regions and Industrial Areas from rural areas. Moreover, districts in the north of India enjoy better access to Investment Regions than districts in the south, hindering socioeconomic development opportunities for rural areas (Publications 4).

Spatial mapping of the industrial employment growth rate between 2001 and 2011 revealed that while the majority of urban areas experienced positive growth rates, only a few rural areas enjoyed such growth. By superimposing the proposed Investment Regions with Industrial Areas, it could be seen that certain Investment Regions would be located in districts with negative manufacturing growth rates and not directly on the corridor, raising concerns about the achievement of integrated regional development (Publication 4).

To identify the determinants of these developments, OLS analysis was undertaken, taking the change in built-up area (2001 and 2011) as dependent variable. The analysis revealed that when rural and urban areas are considered together, a strong change in built-up area is associated with high agriculture employment and a high ratio of minorities. With regard to urban areas, the change in built-up area is higher when the share of government expenditure on

urban development and district planning is high, while the change in built-up area is lower in areas governed by municipalities (Publication 10).

These developments raised concerns about the integration of spatial plans with infrastructure funding policies. Therefore, the main aim of content analysis was to evaluate the vertical and horizontal integration between spatial and infrastructure policies. This analysis determined that no specific measures are prescribed in the respective state governments' spatial plans to connect the national government's Delhi-Mumbai Industrial Corridor initiative with existing settlements, revealing a lack of vertical integration. Regarding the integration of spatial plans and five-year economic plans, it was found that while the plans of the respective state governments specify and underscore the strengthening of district decentralisation, there are no mechanisms to fund the growth of urban centres, revealing a lack of horizontal integration.

A literature review was conducted to understand the institutional environment for spatial planning and infrastructure funding. The analysis revealed a lack of regional authority to plan and implement the development of the area through which the Delhi-Mumbai Industrial Corridor will pass as well as a lack of sufficient power and operational flexibility to achieve the overarching goal of shared growth while ensuring the compliance of all stakeholders. Instead, Special Purpose Vehicles are being created under the Companies Act to plan and implement these large-scale projects. It seems that the current institutional structure does not foster the integration of spatial planning instruments and infrastructure funding to reduce disparities (Publication 10).

The above research identified the lack of horizontal and vertical integration as a primary reason for the limited success in reducing disparities despite the adoption of relevant spatial initiatives. These developments draw attention towards strengthening institutional structures in order to improve the poor coordination of developments along cross-border mega-scale project.

## 6.3 The envisaged policy reforms: from national to city scale

### *6.3.1 Strong institutional structures with empowered regional authority for cross-border projects*

The analysis described in sections 5.2 and 6.2 captured disparities between and within states. The state of Gujarat has been relatively successful in implementing schemes to foster development (Ballaney, 2008; DSIRDA, 2019); similarly, Maharashtra has also introduced policies to leverage development (GoI, 2018a). By contrast, the governments of Rajasthan (ToI, 2016, 2019) and Uttar Pradesh (GoI, 2018b) are still struggling to implement necessary acts. Due to vested interests, these state governments are ignoring the risk of exacerbating existing disparities (Anand and Sami, 2016) by reforming policies favouring capital investment.

This difference in the ability of state governments to implement development initiatives is hampering the implementation of the Delhi-Mumbai Industrial Corridor and most crucially risks aggravating disparities by concentrating resources in more competitive states. Further, the success of the corridor initiative is being undermined by the lack of an established regional authority empowered to intervene and negotiate between contradicting interests.

The findings detailed in section 5.2 revealed disparities where settlement structures are skewed towards large cities and large peripheral areas remain unserved by urban amenities. The evaluation of spatial decentralisation in India showed the limited success of these strategies, with growth remaining concentrated in certain large cities (Section 6.1). In this regard, Siddle and Koelble, (2016) make a case for strong local government and adequate financing to achieve the effective decentralisation, which is yet not the case in India.

According to this research (Publications 7, 8 and 10), problems in cross-border infrastructure can be avoided and distributed growth achieved through the following reforms: i) establishment of a strong institutional structure; ii) a new scale of authority (regional or inter-state authority) empowered to develop a spatial strategy and implement respective plans; and iii) an improved horizontal and vertical coordination between states. Further, it is necessary to formulate and implement a regional strategy, which is legally binding on participating states. Such spatial

strategy must be well integrated with existing urban and rural areas; otherwise growth will remain concentrated within developed states and districts. A process to integrate the states' interests in the corridor development might create incentives to develop mutual solutions for a consistent development strategy. Moreover, there is a need for both carrot (such as development subsidies) and stick (such as reduced grants) strategies to force state governments to follow the regional authority guidelines.

### *6.3.2 Moving towards strategic spatial planning for policy integration*

The analysis conducted in section 6.2 revealed insufficient horizontal integration between different sectors, i.e. spatial plans and transport plans, as well as vertical integration between plans at national and state level. The analysis in section 6.1 uncovered coordination and cooperation problems between the participating states as well as a lack of monitoring and evaluation of plans.

As suggested by Healey (2006), Watson (2009), Vigar (2009), Todes et al. (2010) and Jain et al. (2019b), one crucial component of strategic spatial planning is policy integration, thereby bringing together infrastructure providers, funding agencies and development plans at national and regional level. Hence, the national authorities must devise a policy for the Delhi-Mumbai Industrial Corridor that is integrated with the decentralisation strategies of the participating state governments in order to connect the corridor with existing and proposed growth centres. At the state level, successful decentralisation and planned growth will depend on sufficient funding for district planning as well as the ability to promote identified growth centres and their transport connectivity. In this regard, additional legal instruments should be established to facilitate the integration of funding mechanisms with spatial plans as well as national and state level plans. Finally, in order to formulate an effective decentralisation strategy at the level of metropolitan regions, it is necessary to identify urban centres with growth potential and to fund infrastructure through relevant mechanisms in spatial plans (Publication 10).

As argued by Ansari (2004), spatial planning in India is rooted in the colonial legacy of land use regulation, with few reforms undertaken to address contemporary issues of urbanisation. This aligns with the claims of Watson (2009b) and Todes (2012) that it is necessary to devise alternative planning approaches in the Global South. One such alternative approach can be a mix of top-down and bottom-up approaches:

First, as a top-down approach, the lacking integration of economic and spatial planning will require the introduction of spatial planning at the national level, which should be followed by lower-tier planning, similar to economic plans. The economic plans, which specify spending for different infrastructure sectors, must be integrated with spatial plans. This infrastructure-integrated spatial planning at national level must be enforced in lower-tier planning (Publications 1, 2, 9, 11 and 12).

Second, as a bottom-up approach to overcome fragmented governance and multiple authorities is to empower a unified regional authority with the planning and implementation of spatial plans. Here there must be a political willingness among the states in the region to rise above vested interests in favour of regional development. The 73$^{rd}$ and 74$^{th}$ Constitutional Amendment Act (CAA) specifies a hierarchy to achieve coordinated growth in the region; however, due to the state government's lack of willingness, this hierarchy (such as the Metropolitan Planning Committees and the District Planning Committees) is broken. Thus there is a need to implement the 73$^{rd}$ and 74$^{th}$ CAA (Publications 1, 2, 9, 11 and 12).

The formulation of long-term plans (for 20-25 years) under the prevailing rapid growth context have not been effective in achieving the desired goals. Instead, plans must be monitored and reformed at shorter intervals to better respond to growth pressures. Moreover, these plans currently lack mechanisms such as fiscal instruments to generate the requisite revenue to deliver social infrastructure. This lack of mechanisms means that there is insufficient infrastructure provision to accommodate projected growth (Mohan and Dasgupta 2004; Meshram 2006). Therefore, it is necessary to not only integrate economic planning with spatial

planning but also to specify relevant funding mechanisms in spatial plans (Publications 1, 2, 9, 11 and 12).

### *6.3.3 Improving accessibility and integrating planning for urban and rural areas*

The two main factors driving growth in India are rural to urban migration and rural to urban classification, especially as census towns. Although rural to urban transformation in the form of census towns has a potential to accommodate growth, reforms are still required to avoid the degradation of natural resources and to achieve sustainable urban development.

The analysis in section 5.1 confirmed rapid changes in land use as well as high density mixed-use developments in peripheral census towns, which are under the authority of gram panchayats. These administrative bodies lack the expertise and resources for land use planning and regulation. The analysis in sections 5.1 and 5.2 predicted the growth of small cities (especially by rural to urban classification) and growth in the periphery of megacities. Evidently, it is imperative to plan and provide for this growth. In India, however, master planning is generally characterised by colonial-style land use planning with little or no integration with peripheral rural areas (Jain et al., 2019b; Jain and Korzhenevych, 2020).

In order to provide adequate infrastructure for the predicted growth and to avoid negative ecological and social consequences, this research (Publications 1, 2 and 3) established the need for the state government to enforce the 73$^{rd}$ and 74$^{th}$ CAA reforms, thereby empowering gram panchayats to conduct spatial planning and regulate growth as well as to better enable provision of infrastructure. Grants from central government should be conditional on the enforcement of the reforms by the state governments.

The investigations further showed the weak provision of public transport in the study area, explaining commuters' reliance on two-wheelers in rural areas and cars in urban areas (Sections 5.3 and 6.1). Although population growth is high in areas with better roads, especially in rural areas, these remain poorly connected to the main urban centres (Section 6.2). This finding confirms the work of Samanta (2015). Despite the major contribution of rural areas to the national GDP, their poor accessibility hinders socioeconomic development (Aggarwal, 2018), thereby sustaining urban-rural disparities. As claimed by Kim and Han (2016), indirect access hinders development.

This research (Publications 1, 2, 3 and 4) underscores the importance of connecting rural areas with urban areas, integrating the corridor development strategy and related policies, as well as reforming spatial plans and infrastructure outlay policies to improve accessibility through better public transport services. There is also a need to move towards integrated rural-urban governance in order to treat these areas as one unit for the planning and implementation of infrastructure.

### *6.3.4 Enhancing the potential of small and intermediate cities*

The findings in section 5.2 point towards the future growth of small and intermediate cities. Yet the majority of cities predicted to grow have inadequate social infrastructure. These lie in the influence zone of the proposed Delhi-Mumbai Industrial Corridor and require dedicated policies to strengthen their potential through investments in infrastructure and by empowering the local authorities.

Although the potential of India's small and intermediate cities is well established (MGI, 2010; Sridharan, 2017), the national government's initiative to foster their growth has met with limited success due to nonuniform implementation, a lack of capacity of local bodies and a lack of funding (Bhagat, 2014; Sridharan, 2017). According to the presented research (Publications 1, 2, 3, 7, 8 and 9), the following policy actions are required to strengthen the potential of small and intermediate towns:

The rural to urban transformation in the form of census towns established in Publication 3 is characterised by the creation of an industrial zone, a mining and crushing zone as well as the development of retail areas. In this way, the agriculture activities in these towns have diversified into urban activities. Such land use changes should lead to higher tax revenues,

which can be used for infrastructure projects. This is in alignment with the claim of MGI (2010) that urban centres must capitalise on their own resources to fund social infrastructure. The most important source of revenue at the local level is user charges for services such as water, sewers, electricity, garbage disposal, public transit and recreation.

Given the limited capacity of the state to fund infrastructure, Watson (2009a) makes a case for coproduction to enable poor urban communities to improve their living conditions when governments are either unwilling or unable to deliver services (Watson, 2014). In the process of coproduction, while the state has resources and technical expertise, the communities possess local skills and time resulting in synergies between the actions of both the state and communities. This process is already underway in census towns (Publication 3). However, the lack of citizen involvement in planning and implementation processes, coupled with weak local bodies, limits the potential of coproduction in India. Therefore, as proposed by the 73rd and 74th CAA, it is necessary to empower local authorities for plan preparation and implementation, and involving citizens in the process.

The analysis in section 6.1 showed how identified growth centres were unable to reach their target populations. With the aim of reducing disparities, place-based policy advocates the maximisation of local potential to generate employment opportunities. These initiatives have the potential to steer growth towards balanced regional development in countries such as Brazil, South Africa and India (Barca and McCann, 2010; Jain, 2018b). However, along the states hosting the Delhi-Mumbai Industrial Corridor, the role of the local government has been ignored in existing cities (Anand and Sami, 2016). Yet it is local governments who possess knowledge of local potentials and are able to help regional-level authorities promote growth by maximising these potentials. However, state governments have been reluctant to devolve financial resources and authority to the local authorities (Bardhan, 2009). The facilitation of the local potential to generate employment in the small and medium towns will require the empowerment of the rural and urban local authorities by the implementation of the 73rd and 74th CAA.

In sum, the publications discussed in this section (Publications 1, 2, 3, 4, 7, 8, 9, 10, 11 and 12) show the advantages and limitations of evaluating policies under certain data constraints. On the one hand, the application of mixed methods revealed the limited success of spatial decentralisation and the existence of spatial disparities along the proposed Delhi-Mumbai Industrial Corridor even before its completion. On the other hand, given the data restrictions, not all components of the decentralisation policy could be evaluated, and the analysis of rural-urban disparity was limited to district level (aggregated analysis). Nevertheless, the described analysis enabled the identification of gaps in the implementation of policies, and thus the formulation of evidence-based reforms to strengthen policy integration.

# 7 Synthesis and conclusion

Increasing spatial disparities are a persistent trend in the Global South and remain a central concern for researchers and public authorities alike (Wei, 2015; 2016; Liu et al., 2016; WB, 2009; ADB, 2011; OECD, 2011; Pike et al., 2014). The publications underlying this research applied classical urban theories and models at multiple scales to describe the manifestation of spatial disparities in India. This research contributes by establishing the relevance of these theories and models to understand the settlement system as well as to establish important gaps in infrastructure provision while predicting future growth. The publications presented here provide ample evidence that the mixed methods approach can be usefully applied to explain the context-specific peculiarities of spatial disparities. A further contribution of this research is to show that the development of a dataset well synchronised with spatial information on socioeconomic and infrastructure variables is essential for empirically establishing spatial disparities.

This research contributes by explaining the manifestation of spatial disparities across space, scale and time. It applied several indicators such as accessibility, connectivity and commuting patterns to establish the weakness of spatial links at multiple scales (such as metropolitan,

regional and inter-state). This can be considered an important contribution since improved transport links and access to employment and public services reduces spatial barriers to development (Rodríguez-Pose and Hardy, 2015). Variables on social and physical infrastructure were examined to determine a lack of adequate services in small and intermediate cities predicted to grow. This is also a crucial finding, as sufficient infrastructure and other amenities have long been considered essential to reduce spatial disparities (Diamond and Spence, 1984; Nijkamp, 1986; Jain and Korzhenevych, 2018).

This research further contributes by providing evidence-based policy reforms at multiple scale for curtailing spatial disparities. It argues for the introduction of spatial planning at the national level and its integration with economic plans. This integration needs to be promoted at lower tiers of government. At regional scale, the findings recommend an empowered regional authority to develop and implement a regional spatial strategy, which is not only integrated with plans of the respective state governments but is also legally binding for the states. At the lowest scale, it is crucial to enhance the potential of small and intermediate settlements, and to move towards an integrated rural-urban governance that treats these areas as one unit for the planning and implementation of infrastructure. This research recommends implementing the 73$^{rd}$ and 74$^{th}$ CAA to facilitate integrated planning and governance at multiple scales.

Studies on spatial disparities in the Global South are still hampered by at least two knowledge gaps: (i) a lack of research to explain the multiple dimensions and drivers of disparities at multiple scales; and (ii) a general lack of theoretical and empirical research, and the need for new approaches to describe spatial disparities. While further research will be required to sufficiently address these research gaps, the results presented above can be synthesised to present some first steps towards the empirical assessment of spatial disparities. In particular, the research measured the dynamics of spatial (inter-urban and rural-urban) disparities by investigating the settlement structure with regard to the provision of infrastructure and settlement links (Publications 1, 2, 3, 5, 6, 7, 8 and 9). To this end, the main components of the government initiatives to reduce disparities were evaluated (Publications 4, 10, 11 and 12).

While this research contributes by synergising the potential of classical urban theories and models as well as mixed methods approach, some challenges still remain. First, the lack of long-term spatial information at multiple scale did not allow for a sophisticated modelling approach. Second, the availability of census data at 10-year intervals prevents the evaluation of plans and policies at a shorter time frame, which is a crucial requirement for policy response in a rapid growth context. Third, the cost of acquiring data on land use change at regional scale limited this research to an aggregated analysis of built-up area. Fourth, lack of rural boundaries limited the rural analysis to tehsil or district level. As more detailed data becomes available for the whole region, these methods can be recalibrated to further enhance the research findings.

The tentative synthesis shows that in India under given data constrains measuring various dimensions of disparity is possible by deploying a mixed methods approach that cuts across scale, space and time. The use of the analytical framework hinged on a theoretical foundation, which is embedded in the critical debate on classical urban theories and models enabled not only discerning and measuring various dimensions of spatial (inter-urban and rural-urban) disparities, but also identifying measures to integrate spatial development with infrastructure provision. Since, the respective problems in policy integration are characteristic of many regions in the Global South, the analytical framework of this research, which is operationalised by the locally available data is thus easily transferable to other regions of the Global South. This synthesis serves as an innovative analytical framework (see Figure 1) to evaluate the actual status of development at multiple scales, to identify gaps in policy integration and to devise appropriate reforms. Therefore, it can serve as a proactive tool for policymakers to identify spatial disparities and make evidenced-based reforms to curtail these disparities. The methods within the analytical framework need to be updated as and when more data is available.

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# 9 Index of publications submitted as habilitation work

1. Jain, M., & Korzhenevych, A. (**2020**). Urbanisation as the rise of census towns in India: An outcome of traditional master planning? *Cities*, 99 (2020) 102627.
2. Jain, M., Korzhenevych, A., & Sridharan, N. (**2019**). Determinants of growth in non-municipal areas of Delhi: Rural-urban dichotomy revisited. *Journal of Housing & Built Environment*, 34, 715–734.
3. Jain, M. (**2018**). Contemporary urbanization as unregulated growth in India: The story of census towns. *Cities*, 73, 117-127.
4. Jain, M. & Jehling, M. (**2020 a**). Analysing transport corridor policies: An integrative approach to reduce spatial and social disparities in India. *Journal of Transport Geography*, 86 (2020) 102781.
5. Jain, M. & Hecht, R. (**2019**). Spatial assessment of commuting patterns in India's National Capital Region. *Built Environment*, 45 (4), 464-479.
6. Jain, M., Korzhenevych, A., & Hecht, R. (**2018**). Determinants of commuting patterns in a rural-urban megaregion of India. *Transport Policy*, 68, 98-106.
7. Jain, M. & Jehling, M. (**2020 b**). Urban cycle models revisited: Insights for regional development in India. *Cities*, 107 (2020) 102923.
8. Jain, M., & Korzhenevych, A. (**2019 a**). Detection of urban system in India: Urban hierarchy revisited. *Urban and Landscape Planning*, 190 (2019) 103588, 1-10.
9. Jain, M., & Korzhenevych, A. (**2019 b**). Counter-urbanization as the growth of small towns: Is the Capital Region of India prepared? *TESG, Journal of Social and Economic Geography*, 110 (2), 156-172.
10. Jain, M., Korzhenevych, A. & Mukherjee Basu, A. (**2021**). Integrating spatial development with infrastructure provision along an envisioned transport corridor: A conceptual framework and its application to India. *Land Use Policy*, 104 (2021), 105364.
11. Jain, M., Korzhenevych, A., & Pallagst, K. (**2019**). Assessing growth management strategy: A case study of the largest rural-urban region in India. *Land Use Policy*, 81, 1-12.
12. Jain, M., & Korzhenevych, A. (**2017**). Spatial disparities, transport infrastructure provision and decentralization policy in the Delhi region. *Journal of Urban Planning and Development*, 143 (3), XX.

# 10 Explanation of studies with co-authors

1. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization.
2. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization. Sridharan, N: Writing - review & editing.
3. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.
4. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Mathias Jehling: Methodology, Software, Validation, Formal analysis, Investigation, Visualization and Writing - review & editing.
5. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Robert Hecht: Software, Investigation and Writing - review & editing.
6. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization. Robert Hecht: Software, Investigation and Writing - review & editing.
7. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Mathias Jehling: Visualization and Writing - review & editing.
8. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization.
9. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization.
10. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization. Anurima Mukherjee Basu: Writing - review & editing.
11. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing,

Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization. Anurima Mukherjee Basu: Writing - review & editing.

12. Manisha Jain: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. Artem Korzhenevych: Methodology, Software, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization.