ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

Final Report
ARCP2014-12CMY-SELLERS

Mega-Regional Development and Environmental Change in China and India

The following collaborators worked on this project:

1. Bharath Aithal, Indian Institute of Science/Indian Institute of Technology, India, bharathaithal@gmail.com
2. Jingnan Huang, School of Urban Design, Wuhan University, P.R.C, huangjn73@qq.com
3. Uttam Kumar, Indian Institute of Science/Indian Institute of Information Technology, India, uttam215@gmail.com
4. Yong Liu, Southwest University/Chongqing University, P.R.C., ly6505@163.com
5. Mingjun Peng, Wuhan Land Resources Planning and Information Center, China, pmj@wpl.gov.cn
6. T.V. Ramachandra, Indian Institute of Science, India, cestvr@ces.iisc.ernet.in
7. Jefferey M. Sellers, University of Southern California, USA, sellers@usc.edu

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Project Overview

Project Duration	:	2013-2017
Funding Awarded	:	US$ 31,500 for Year 1; US$ 37,000 for Year 2
Key organisations involved	:	Indian Institute of Science, India (T.V. Ramachandra, co-PI, Uttam Kumar, co-PI, Bharath Aithal, co-PI) Southwest University, China (Yong Lui, co-PI) University of Southern California, USA (Jefferey Sellers, PI) Wuhan University, P.R.C (A/P Jingnan Huang affiliated)

Project Summary

Urbanization in Asia and elsewhere in the developing world represents one of the largest anthropogenic global shifts ever to take place, with major crosscutting implications for land use, biodiversity, greenhouse gas emissions and human welfare. Worldwide, the largest proportion of urban growth in the coming decades will occur in China and India. Throughout the developing world, however, urban growth increasingly clusters in wider areas beyond the bounds of individual metropolitan regions. Reflective of long-standing trends in developed countries, diffuse or distributed patterns of urbanization more have emerged across large scale regions or transportation corridors of 100,000 square kilometres (Florida et al., 2008; Seto et al., 2012). Mega-regional development is common to both India and China, but major national institutional, economic and social differences shape its dynamics. An earlier APN project undertaken by the same team showed that the dynamics of peri-urban land expansion and urban form had diverged systematically between the two countries (Ramachandra et al., 2012; Sellers et al., 2013a, 2013b).

This project employs remote sensing images and GIS to examine mega-regional dynamics and their consequences at the macro and the micro scale in emerging Chinese and Indian regions. The coordinated research program under the grant examined several interrelated topics: 1) large-scale regional dynamics of urban development, 2) policy, economic and institutional sources of variations in trajectories of mega-regional development, 3) the effects of these variations on regional environmental change, and 4) based on projections of future developmental trajectories and their consequences, recommendations of future policies to address the dynamics and the environmental consequences from regional trajectories of urban development.

Keywords: Urban expansion, regional dynamics, environmental change, China, India

Project outputs and outcomes

Project outputs:

a) Completion of a study of regional interurban networks in the Yangtze River Basin, and a comparison of networks in the Coastal and Inland Areas.

b) Completion of a study of the impacts of land finance on urban sprawl in China, based on the example of Chongqing.

c) Completion of a systematic study of urban sprawl and its impacts on urban environmental quality in China, based on the example of Chongqing.

d) Completion of a study of urban dynamics and land use change in the Mumbai Pune interurban corridor.

e) Completion of a study of urban dynamics and land use change in the proposed Mangalore – Bangalore- Chennai industrial corridor.

f) Completion of a study modelling land use dynamics in the Mumbai Pune Express Corridor.

g) Completion of a study visualizing landscape dynamics in the proposed mega industrial corridor Mangalore-Bangalore-Chennai.

h) Completion of a study of spatial socioeconomic and infrastructure disparities in three urbanizing regions of India.

i) Completion of a critical study of urban environmental management in India, using the example of Bangalore.

j) Public stakeholder forum on the policy challenges of regional infrastructure development, urban dynamics and environmental degradation in urbanizing corridors of India, including comparative insights from China and the United States.

k) Open workshop for students and stakeholders on regional urban development and environmental consequences in China, including comparative insights from India and the United States.

l) Training for ten young scientists working on the project.

m) Participation and training for at least seventy stakeholders, faculty and students who participated in the workshops.

Completion of three master's theses:

1. Brigit, M. B. (2017). *Landscape Dynamics of Mumbai-Pune Industrial Corridor* (Master's Thesis). Department of Natural Resources, TERI University, New Delhi, India.

2. Revathi, N. (2017). *Modeling and Urban Dynamics of Chennai-Mangalore Industrial Corridor* (Master's Thesis). Department of Geography, Bharatidasan University, Thiruchirappali, India.

3. Wang, C. (2017). *The Spatial Pattern Evolution and Driving Forces Analysis of Cheng-yu Urban Agglomeration* (Master's Thesis). Wuhan University, China.

Project outcomes:

- Improved understanding of distinctive trajectories of mega-regional growth and its drivers and conditions in the two countries, as well as of variations within each country

- Local and state-level capacity to monitor urban development and anticipate the consequences of patterns

- T.V. Ramachandra, advisory roles: Member Governing Council, Karnataka State Remote Sensing Application Centre, Government of Karnataka (GoK); Member, Bellandur Lake rejuvenation monitoring main committee, GoK, 2017; Member, Bellandur Lake rejuvenation monitoring subcommittee, BDA, GoK, 2017; Member, ICT based Technical committee, Smart Cities Development, KUIDFC, Bangalore; Member, DBT Taskforce on Energy Biosciences, Mission Innovation, Government of India (GoI) (2017-); Chairman, Expert committee to identify environment friendly activities, Karnataka Lake Development Authority (2017), GoK; Chairman, Joint Inspection Committee, NGT (National Green Tribunal), Bellandu-Agara Wetlands; Member, Governing Council, Karnataka Municipal Data Society (KMDS), GoK; Member, Technical Advisory Committee, Municipal Reforms Cell, GoK; Member, Expert Committee – Restoration and Comprehensive management of Bellandur and Varthur Lakes, GoK (2016)

- Stakeholder and media attention to the degradation of freshwater resources and harms from pollution in and around Bangalore

- Attention in Karnataka and national Indian media to the effects of corridor development on depletion of green space and other environmental harms

- A better understanding of the role of fiscal incentives in favour of urban sprawl in China

- Awareness of how and why urban environmental quality varies within Chinese urban regions

Key facts/figures

- Based on current trends, built up land will expand to 50% of the total in the corridor between Mumbai and Pune in 2027. Without new, more sustainable policies, vegetation in the corridor will decline dramatically from 25% in 2015 to 10% in 2027.

- In recent years (2010-2015), 95% of newly built urban areas in China are developed through the transformation of vegetated land (mainly farmland and woods)

- 12 articles or working papers produced to date, along with 3 Master's Theses
- 10 young scientists trained
- 9 awards or fellowships for work on the Project

Potential for further work

Additional publications can synthesize and fully compare the results between the two countries. In each country, the research program this project has supported holds enormous potential to contribute in numerous ways to addressing the pressing challenges urbanization poses for sustainability, economic development and the quality of life.

In India, work on environmental quality and planning for urbanization are high on the national policy agenda, and further work along numerous lines could contribute to informed decisions related to this agenda: smart townships with holistic land management, smart applications like transport, reuse and recycle of wastewater, smart metering, recovering energy from solid waste, etc., reducing greenhouse gas (GHG) footprints, improving power, treated water supply, communication and infrastructure connectivity and security, and re-development of existing built-up areas considering the level of existing and scope for improvement of infrastructure and basic amenities.

In China, further work can explore the efficiency and environmental consequences of urban growth in different cities and regions, using 1) indicators for the spatial efficiency of urban growth in terms of spatial metrics, for example compactness, complexity, open space ratio, etc.al. ; 2) the socio-economic performance by indicators such as GDP, revenue, personal income, and employment; 3) analysis of the correlation between the spatial growth and socio-economic performance; and 4) analysis of the relationship to environmental quality.

Publications

1. Liu, Y., Fan, P., Yue, W., & Song, Y. (2018). Impacts of land finance on urban sprawl in China: The case of Chongqing. *Land Use Policy*, *72*, 420–432. https://doi.org/10.1016/j.landusepol.2018.01.004

2. Liu, Y., Yue, W., Fan, P., Zhang, Z., & Huang, J. (2017). Assessing the urban environmental quality of mountainous cities: A case study in Chongqing, China. *Ecological Indicators*, *81*, 132–145. https://doi.org/10.1016/j.ecolind.2017.05.048

3. Sellers, J., & Wang, H. (2017). *The Emerging Face of Suburban India: The Geography of Housing Markets* (Working Paper). Los Angeles, California: Lusk Center for Real Estate Research, University of Southern California.

4. Bharath, H. A., Vinay, S., Chandan, M. C., Gouri, B. A., & Ramachandra, T. V. (2018). Green to gray: Silicon Valley of India. *Journal of Environmental Management*, *206*, 1287–1295. https://doi.org/10.1016/j.jenvman.2017.06.072

5. Huang, J., Wang, C., & Sellers, J. (2017). Difference measuring of coastal and inland urban agglomerations: A comparison between Wuhan metropolitan area and Yangtze River Delta urban agglomeration based on urban flows. *Modern Urban Research*, *2017*(7), 114–123. (In Chinese)

6. Huang, J., Chen, S., Sellers, J., & Xing, X. (2017). An exploration of multi-scale network structure of the Yangtze River middle reaches urban agglomerations based on an interlocking model. *Urban and Rural Planning*, *2017*(5), 65–75. (In Chinese)

7. Ramachandra, T. V., Sellers, J., Bharath, H. A., Vinay, S., & Brigit, M. B. (2017). *Spatial pattern of land use dynamics in Mumbai Pune Express corridor* (ENVIS Technical Report No. 137). Bangalore, India: Indian Institute of Sciences.

8. Brigit, M. B., Bharath, H. A., Nityanandam, Y., & Ramachandra, T. V. (2017). Analysis of landscape dynamics in the Pune-Mumbai industrial corridor. In *Proceedings of International Conference on Urban Geoinformatics, February 2017*. New Delhi, India: TERI University.

9. Yue, W., Zhang, L., & Liu, Y. (2016). Measuring sprawl in large Chinese cities along the Yangtze River via combined single and multidimensional metrics. *Habitat International*, *57*, 43–52. https://doi.org/10.1016/j.habitatint.2016.06.009

10. Ramachandra, T. V., Sellers, J., Bharath, H. A., Vinay, S., & Brigit, M. B. (2016). *Urban dynamics in the proposed Mangalore-Bangalore-Chennai industrial corridor* (ENVIS Technical Report No. 115). Bangalore, India: Indian Institute of Sciences.

11. Ramachandra, T. V., Sellers, J., Bharath, H. A., Vinay, S., & Brigit, M. B. (2018). Geo-visualisation of landscape dynamics in the proposed mega industrial corridor. Abstract submitted to the BDCC 2018 2nd International Workshop on Biodiversity and Climate Change, IIT Kharagpur, West Bengal, India.

12. Ramachandra, T. V., Sellers, J., Bharath, H. A., & Bharath, S. (2018). Micro level analyses of environmentally disastrous urbanisation in Bangalore. Presented at the BDCC 2018 2nd International Workshop on Biodiversity and Climate Change, IIT Kharagpur, West Bengal, India.

Awards and honours

- Shuyi Cheng, master student, received National Scholarship (20,000 RMB) in 2015
- Jingnan Huang, National Key Research and Development Program: “Spatial Information Key Service and Application Demonstration of Urban Agglomeration Economic Zone Construction and Management”, Theme 4: “Space Development Planning Management and Supporting Decision-Making in Urban Agglomeration Economic Zone”, Task 5 (sub-theme): “Ecological Environment Sustainability and Evaluation of Urban Spatial Growth Efficiency of Urban Agglomeration”, 2017, (485,000 RMB) (PI), Ministry of Science And Technology of People's Republic of China
- Cunsong Wang, master student, received National Scholarship (20,000 RMB) in 2016.

- T.V. Ramachandra, Namma Begalurean, 2016 (Namma Bangalore Foundation, Bangalore)
- T.V. Ramachandra, Citizen Extraordinaire Award [Rotary Exemplars 2017], Rotary Club, Bangalore
- Jefferey Sellers, Lusk Center for Real Estate Research Award, University of Southern California (USD 12,000), 2016
- Jefferey Sellers, Lusk Center for Real Estate Research Award, University of Southern California (USD 12,000), 2017
- Bharath Setturu, Second Prize in Oral Presentation, Second International Workshop on Biodiversity and Climate Change, IIT Kharagpur, 24-27 February 2018
- Best Paper Award (Hydrological regime dependence on catchment vegetation dynamics, Authors: Ramachandra T V, Vinay S, Subash Chandran M D, Bharath S, Sashishankar A) – International Symposium Water Urbanism and Infrastructure Development in eco-Sensitive Regions, Organised by IIT Kharagpur, 6-7 Jan 2017

Pull quote

From Project Report of the Indian Team (T.V. Ramachandra, Bharath Aithatl, Vinay S.): *"The current research will help in identifying the future growth poles to design sustainable regions with the provision of essential infrastructure and basic amenities. Environmentally sound urban centres with essential basic amenities and advanced infrastructures (such as sensors, electronic devices and networks) would stimulate sustainable economic growth and improvements in citizen services."*

Bingzhao Chen, former dean of School of Architecture an Urban Planning, Tongji University, China. The comparative study of the Wuhan Metropolitan Area and Yangtze River Delta Urban Agglomeration "solid and logical with rich data and innovative data acquisition".

From the Final Technical Report (Jefferey Sellers, Principal Investigator): *"Both China and India face an urban future that is increasingly a reality. In both countries, urban land expansion is now taking place on a regional scale as well as around cities themselves. In both, the spread of urban settlement poses new challenges for environmental quality, for economic productivity, for the quality of life, and ultimately for planning and policy. Different configurations of land and construction markets, governmental structures, legal norms, policies, and planning in each country have produced remarkably divergent patterns of megaregional development and distinctive challenges for each country".*

Dr. Bharath Aithal (earlier Post-Doctoral Fellow and now faculty at IIT Kharagpur): *"As rightly said by Frank Herbert "One learns from books and example only that certain things can be done. Actual learning requires that you do those things". The project "Mega-Regional Development and Environmental Change in China and India" gave the opportunity of research while creating new knowledge and paradigms. This project did enhance my analytical abilities and knowledge. We had an opportunity to interact with stakeholders and accomplished researchers, which helped in augmenting right footsteps in my career, in realizing that 'research means to understand something you do not know curiously'."*

Vinay. S, Research Scholar, Energy and Wetlands Research Group, CES, IISc, Bengaluru:

“My research focus is towards understanding hydrological aspects and their relation with land use. This study helped me in understanding various agents and their behaviour in landscape dynamics. Modelling and Visualisation of landscape help to understand the probable future growth of an area; this understanding of landscape dynamics would help in modelling and managing water resource sustainably without imparting growth in the system. The proposed corridors allow industries to be set up along the highways in a fragmented way along the highways, creating ample job opportunities to local people and sustainably utilizing resources.”

Bharath Setturu, Research Scholar, Energy and Wetlands Research Group, CES, IISc, Bengaluru: *“My PhD research work is on Modeling Landscape Dynamics with Biodiversity, Ecology and Social Aspects. The research under the project helped me to understand policy interventions and response from economic and social parameters at a micro level. It also helped me in capturing both rural and urban dynamics. The proposed corridors will boost urbanization and improve local people’s livelihood in a positive note.”*

Acknowledgements

Thanks to Mrs Ningrui Du, associate professor, School of Urban Design, Wuhan University, China for her suggestions in the regional study; and to the Lusk Center for Real Estate Research at the University of Southern California for additional research support.

1. Introduction

Urbanisation in Asia and elsewhere in the developing world represents one of the largest anthropogenic global shifts ever to take place, with major implications for the environment as well as for human welfare. Worldwide, the largest proportion of urban growth is taking place in China and India. This project examines the increasingly important regional dynamics of urbanization in these two countries.

To date, the large-scale regional dynamics of urbanization have been a major gap in research on urbanization and its consequences. Increasingly, urban growth throughout the developing world has begun to cluster in wider areas beyond the bounds of individual metropolitan regions. Reflective of long-standing trends in developed countries, “mega-regions”, “megapolitan areas” or “urban corridors” of 100,000 square kilometres or more (Seto, Reenberg, et al., 2012) have emerged. New urban centres have appeared beyond the periphery of existing agglomerations. The new development has emerged along transportation corridors. Region-wide patterns of migration and settlement have fueled diffuse trends toward urban growth. Although most of urbanization in the developing world is now taking place outside the largest urban concentrations, much of it remains linked through distal relations in ways that are not yet fully understood (Seto et al., 2012). Policy choices in domains from economic development, planning and infrastructure to migration often shape these dynamics (Alberti & Waddell, 2000; Davis & Henderson, 2003; Schneider, 2006). As regional dynamics beyond the largest urban centres play out in areas of institutional fragmentation and limited governmental capacities, an array of new challenges for policymaking and governance has emerged (Laquian, 2005; United Cities and Local Governments, 2008). Urbanization dynamics at this wider regional scale are especially critical to such cumulative environmental consequences from urbanization as land degradation, increasing greenhouse gas emissions and loss of biodiversity (Alberti et al., 2006; Alberti & Waddell, 2000; Seto, Güneralp, et al., 2012). Studies of the environmental consequences from urbanization at the mega-regional scale, however, remain rare.

The project centres around the deployment of remote sensing images and GIS to analyze matched Chinese and Indian regions. It also employs a wide variety of additional methods to analyse the causes, manifestations and consequences of urban development patterns at the regional scale. The analysis demonstrates divergent region-wide dynamics of urban land conversion in the two countries, and distinctive needs for policies to enhance sustainability in each setting.

2. Methodology

The project began with matched case studies of urbanization patterns in large scale regions in each country. Along with a number of parallels, these revealed markedly divergent dynamics. In each country, the team developed a phased research program that drew on multiple methods to explore the sources of the regional patterns, the dynamics at the micro-level, and the environmental consequences. In India, the research focused primarily on the transportation corridors that have increasingly become the main sites of regional urbanization and initiatives for economic development. In China, recent urban sprawl has primarily taken place in the regions around large cities. The Chinese team focused its analysis on the explanation of these dynamics and their environmental consequences.

a. Site selection

1) India

Mumbai Pune Industrial Corridor: Mumbai, the financial capital of India and the capital city of Maharashtra, extends from 18° 55'N and 72° 50' E. The fifth largest city in the world had a total population of 12 million inhabitants in 2011. It is bordered by the Arabian sea to the west and Bombay harbour and Thane creek inlet to the east. The city has great natural landscape consisting of natural resources such as lakes, coastal waters, forest areas, wetland systems and mangroves. By the recent predictions of United Nations, by the continuous growth of Mumbai's urban area, the total population will reach up to 27 million by 2025, and thus becoming one of the largest urban regions worldwide.

Pune is the cultural capital of Maharashtra located on the Deccan plateau at the foot of the northern part of the Western Ghats. Pune Municipal Corporation (PMC) covers an area of 243.96 sq.km. The population of Pune city increased by 9 million in 2011. Since the introduction of Foreign Direct Investments (FDI) in 1991, the region has been witnessing fast industrialization and urbanization.

In order to connect the Business Hub and Educational Hub for more opportunities, reduce the existing traffic congestions/accidents along the existing National Highway (NH 4), Mumbai Pune Express Highway was constructed. Also known as Yeswantrao Chavan Mumbai – Pune Expressway is India's first six lanes high speed tolled expressway under PPP model. The total length of the expressway is 94.5 km connecting Kon (Mumbai) to Dehu (Pune). It has five interchanges Kon (Shedung), Chowk, Khalapur, Kusgaon and Talegaon and six tunnels of approximately 5.6 km with automatic lighting and ventilation. The Navi Mumbai is well connected to Mumbai and Pune, and the availability of developable land increases the investment potential of Navi Mumbai. Lonavala is an emerging township and a hill station through which both the prominent road lanes pass through. In the current study, 10 km buffer zone was considered along the highway from Mumbai to Pune encompassing an area of 3022 sq.km covering districts of Mumbai, Raigarh, Thane and Pune. Figure 2 depicts the location of the Corridor and figure 3 Depicts Factor of growth in the study area (Express high way and buffer)

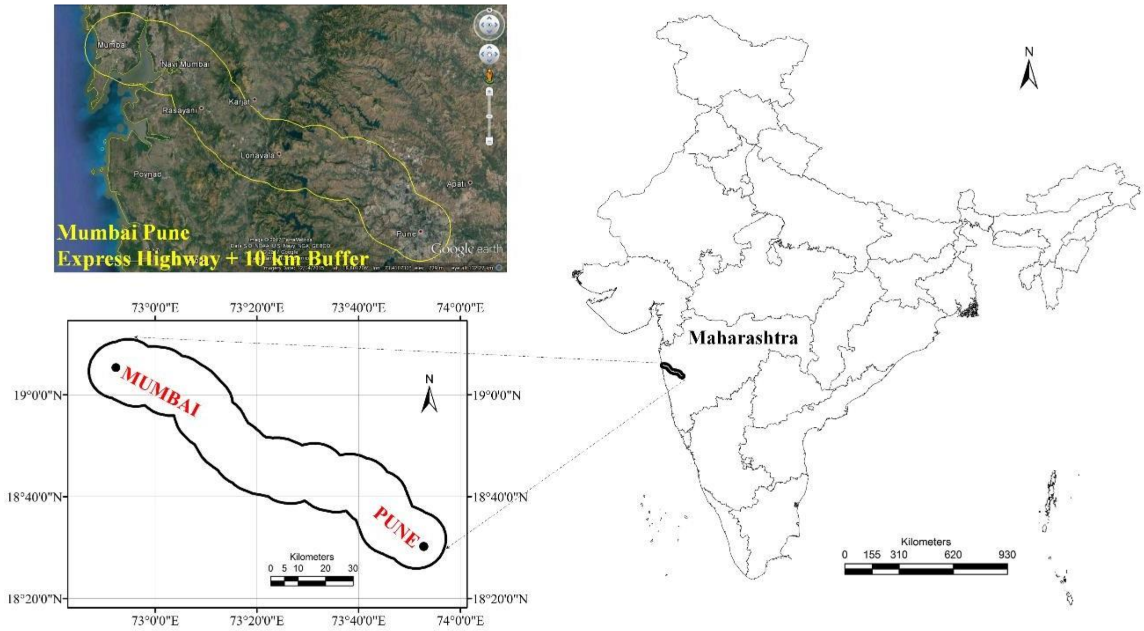

Figure 2: Mumbai Pune Express Corridor

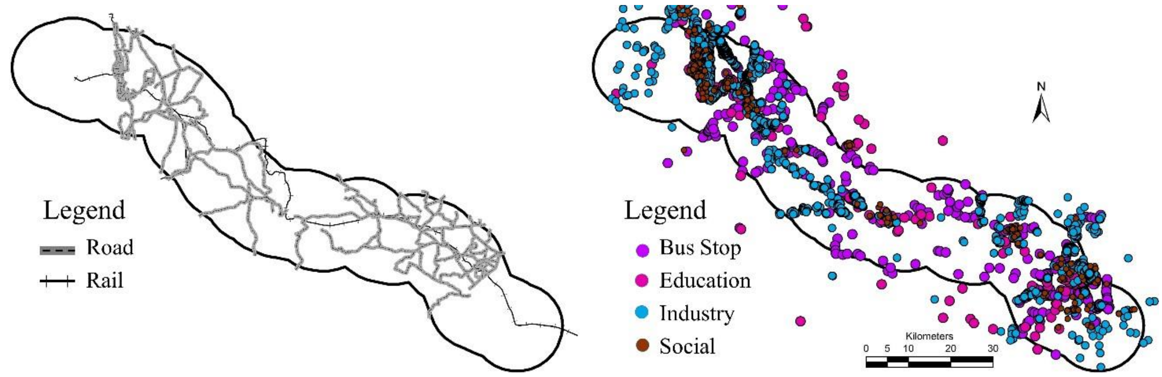

Figure 1 Factors Contributing to Growth along Mumbai Pune Corridor

Chennai – Bangalore - Mangalore Corridor: *Chennai*, Capital of Tamil Nadu State, also known as Detroit of India for its Automobile Industries. Located in the East coast, it is the 5th largest in India and 36th largest urban area in the Globe (Office of the Registrar General & Census Commissioner, 2011). Chennai Metropolitan Area has been ranked the fourth-largest economy in India and the third-highest GDP per capita. As a growing metropolitan city, Chennai confronts substantial pollution and other logistical and socio-economic problems. Chennai is i) second leading exporter of Information Technology (IT) and Business Process Outsourcing (BPO) services in India ii) leading commercial centre of South India. The credit of the booming economy of the city goes to the leading industries including automobile, software services, petrochemicals, financial services, textiles and hardware manufacturing.

Bangalore, the IT hub of India, is located in the southern part of the country of Karnataka state. The region was known as “Bendakaaluru” (land of boiled beans), “land of lakes” where a large number of lakes were constructed to store water, during the regime of the erstwhile princely state. Numerous parks, gardens such as Lalbhag, Cubbon Park etc. exist in the region, which was named as “Garden City”. In the last decade (2001 to 2011) population of urban areas of

India is 31.8% and in Karnataka is 31.5%, but Bangalore has a decadal increase of 44% very large compared to that of the state and country. Bangalore has a population of 8.4 Million (2011) with a density of 11330 persons/sq.km. Bangalore is witnessing a tremendous growth in industry, trade and commerce leading to the rapid growth of the city and large scale urbanization. During the post-independence due to industrialization, unplanned urbanisation the city has witnessed the decline in parks as well as water bodies/lakes. With the spurt in IT industries in the region during the late 1990s, the city was termed “Silicon Valley”. This policy intervention created job opportunities for a different category of people. The city has grown spatially during the last year by 10 times, and the current spatial extent is about 741 km^2.

Mangalore is one of the leading port city of Karnataka located along the east coast of India about 350 km from the Capital City Bangalore. Mangalore is one of the most cosmopolitan non-metro cities of India having an area of 132 sq.km and population of 0.6Million. Mangalore's economy consists of industrial, commercial, agricultural processing and port-related activities. Along the west coast is one of the wood importer of south India. Mangalore is now one of the destinations for IT-oriented companies and has 2 SEZ.

The Chennai–Bangalore-Mangalore Industrial Corridor extends between 13°11′37.9″ to 12°25′2.97″ N and 77°45′33.96″ E to 80°21′7.83″ E along the National Highway (NH 48 and NH4) covering a distance of 630 km (Figure 4). Industrial corridor connected the major Tier I cities such as Chennai and Bangalore and Tier II city Mangalore. A buffer of 10 km on either side was considered to understand the effects of the industrial corridor on its immediate neighbourhood. The study area is about 13572.37 km^2. The industrial corridor passes through 15 districts including Chennai, Chittoor, Dharmapuri, Kancheepuram, Thiruvallur, Vellore, Thiruvannamalai, Bangalore, Bangalore Rural, Hassan, Mandya, Tumkur, Dakshina Kannada and Kasargod. Rivers that flow through the Corridor are Koovam, Adayar, Palar, Ponnaiyar, Shimsha, Hemavathi, Agalatti, Netravathi and Gurupura. There are nearly 5 dams, which are present in the study area. It includes Krishnagiri dam, Kelvarapalli dam, Marakonahalli reservoir, Gorur dam and Thippagondanahalli reservoir.

Karnataka government has proposed to extend Chennai Bangalore Industrial Corridor to Mangalore. Corridor aims to connect the Mangalore and Chennai Sea Ports. The corridor is connected by 3 Airport. Figure 5 depicts the agents of growth that would be responsible for development along the Chennai Mangalore Corridor.

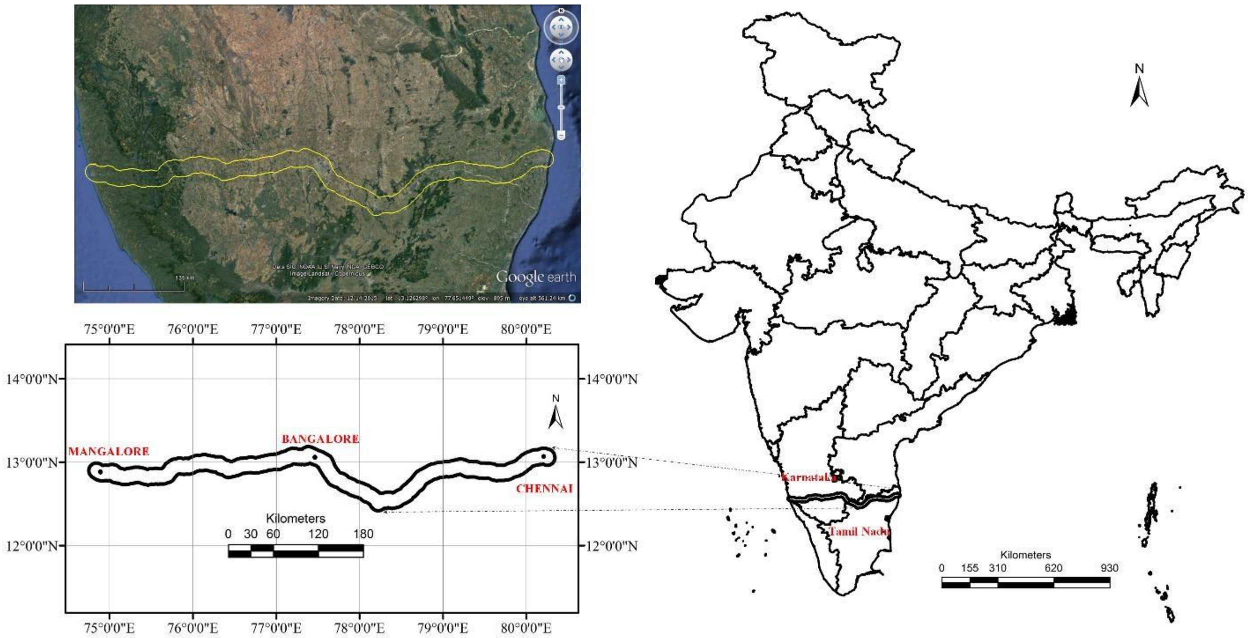

Figure 1 Chennai -Mangalore Industrial Corridor

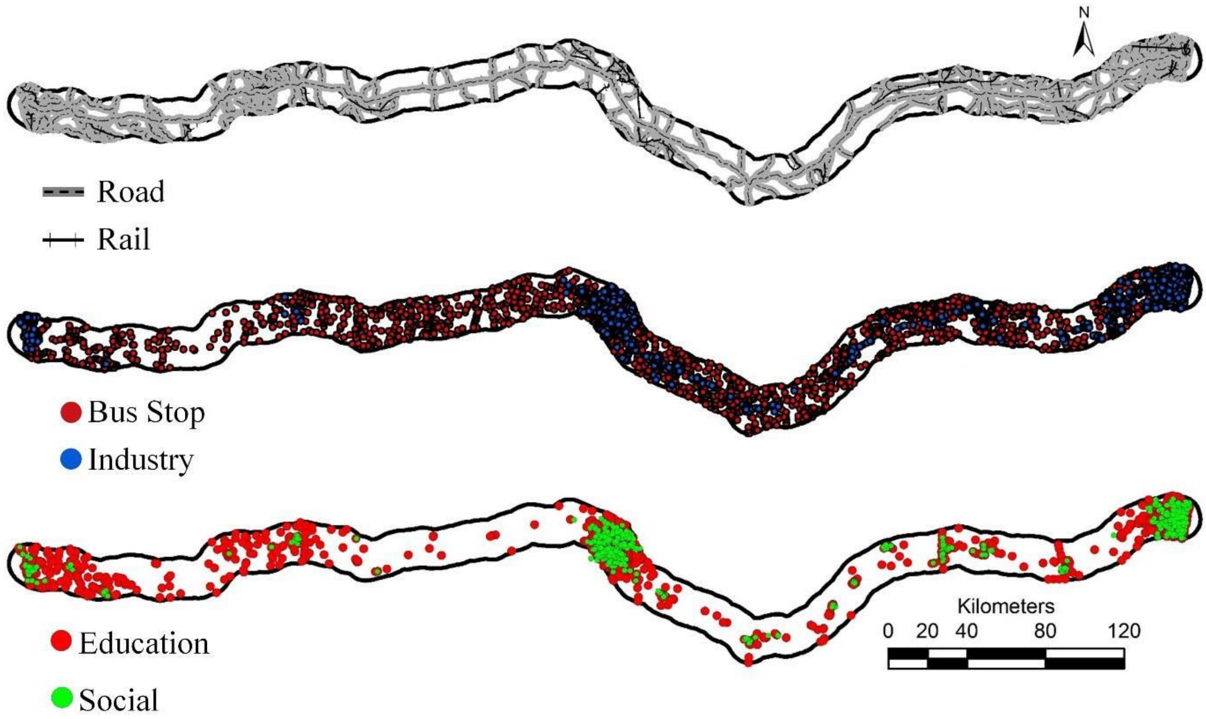

Figure 2 Factors Contributing to Growth along Chennai-Mangalore Industrial Corridor

2) China

China's unprecedented urbanization in the past decades has captured worldwide attention. Mostly focusing on the urban agglomeration in the coastal regions, while the ones in inland areas have been largely ignored. The research explored the land use/land cover change of Chengdu-Chongqing urban agglomeration, the most representative urban cluster in the central and western regions of China in the past three decades. TM remote sensing images of 1990, 2000, 2010 and 2015 were employed to extract the land use information, mainly the built-up area. The spatial change of new development and its relation to terrain, transportation lines, and other socio-economic factors were further investigated.

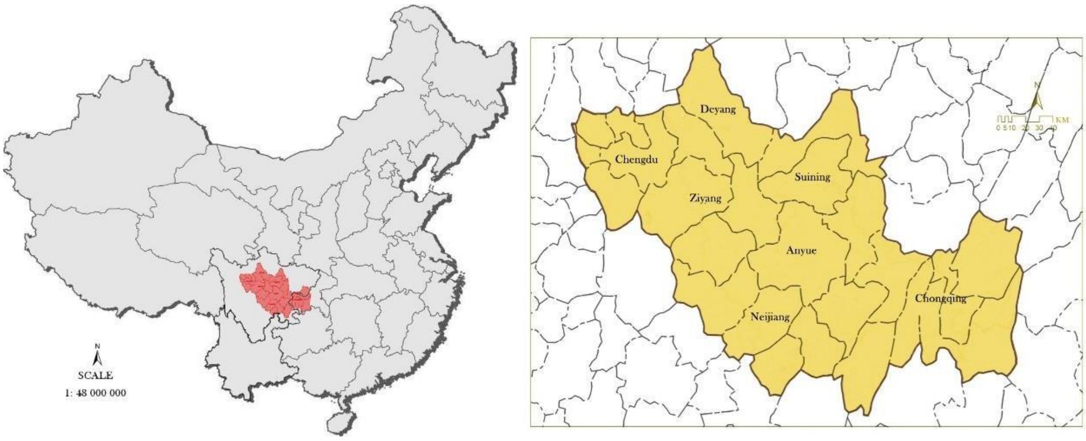

Figure 3 The study area of Chengdu-Chongqing urban agglomeration

Rather than along continuous corridors, the cities that experienced fast-paced and massive urbanization in China were distributed across wider regions. Chengdu and Chongqing lie at the eastern end of the Yangtze River Economic Basin, a region that extends almost 2.05 million square kilometres along a Yangtze River. The Basin contributes more than 40% of the national GDP and includes more than 40% of the national population.

A second study focused on cities in this wider mega-region. Seven big cities were selected as cases in consideration of their various population scales, geographic locations and economic levels in the YREB (Figure 4). These cities have experienced urban land expansion along with economic development. They were also selected to capture any variations in urban sprawl between the coastal areas to the inland.

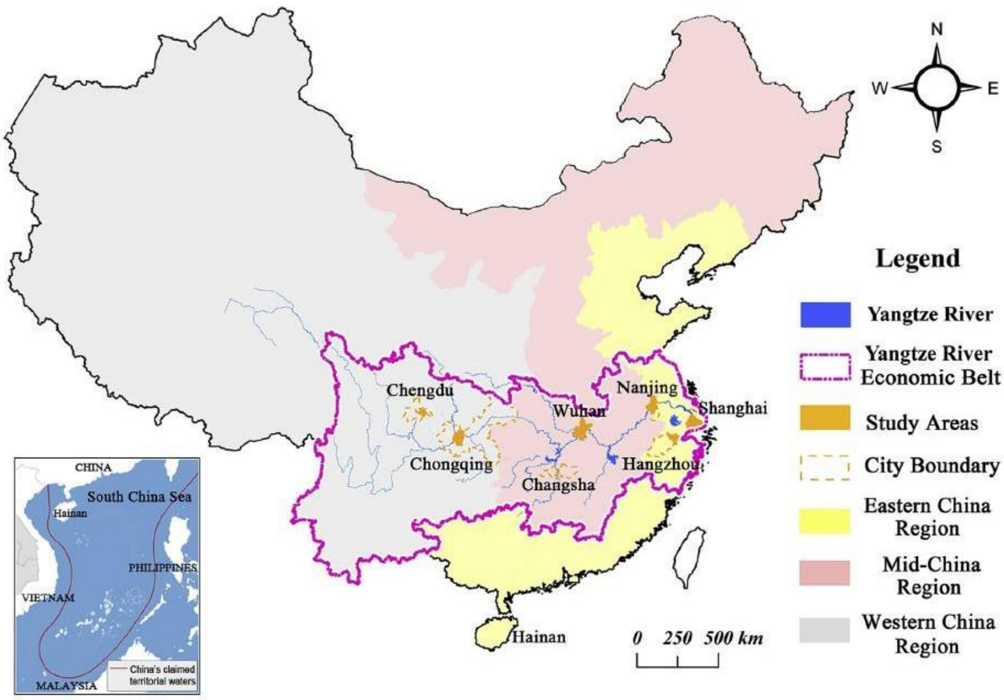

Figure 4 The study area of the Yangtze River Economic Belt

Other papers focused on the case of Chongqing to illustrate how to analyze land finance and urban sprawl, and analyze the consequences for environmental quality in Chinese cities. Chongqing, located on the upper reaches of the Yangtze River, is the largest city in Western China and a directly controlled "municipality" under the State Council. Chongqing has become one of the rapidly growing cities in China in the last decade as indicated by increases in the urban population [from 2.89 to 7.58 million during 1994–2016] and in gross domestic product [over 10% annual growth rate during 2002–2016]. To survive fierce inter-city competition, Chongqing local governments played an active role in generating abundant LCFs that rank in the top five among Chinese cities in recent years. However, the heavy dependence on land finance has stimulated Chongqing's transformation from a previously compact city to a highly sprawling city, featured by massive land consumption. To analyze urban sprawl, we selected the central Chongqing that covers nine urban districts around the city core as the study area

b. Data and methods of analysis

1) India

a) Analysis of mega-regional land use dynamics

The process involved in understanding land use dynamics along the Industrial Corridors is as specified in Figure 1. The process involves i) Data Acquisition, ii) Data Pre Processing, iii) Classification, iv) Modelling and Prediction, v) Spatial Pattern Analysis.

Land use classification based on spatial pattern recognition technique applied on multispectral remote sensing data is one of the common method used for image analysis to derive information (Jensen, Narumalani & Hlady, 2001).

i) Data Acquisition: The process of data acquisition involves the collection of Primary and Secondary Data. Primary Data includes a collection of Remote Sensing Data and Field Data. Remote Sensing Data from 1997 till 2015 was downloaded from USGS web portal (United States Geological Survey., 2015). GPS and AGPS based field surveys were done to supplement land use analysis. Secondary Data collection involves the collection of ancillary data such a French institute Puducherry vegetation maps (Pascal, 1982), Geographical Survey of India topographic land use maps, and Virtual earth data such as Google Earth (Google, 2016), Bhuvan (National Remote Sensing Centre, 2016). The Secondary data provide additional input to the field data for data pre-processing and classification.

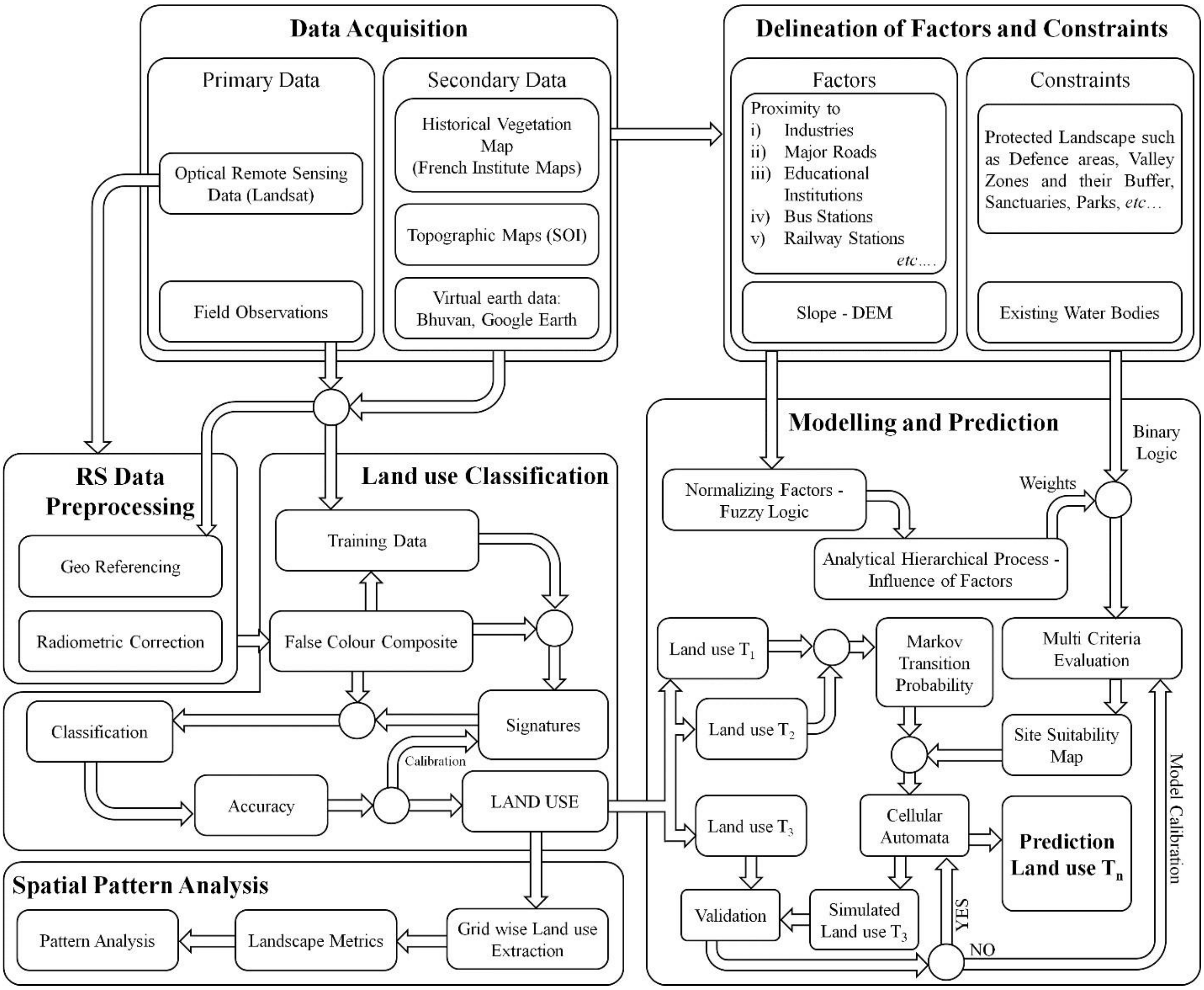

Figure 5 Method

ii) Data Pre-processing: Data Pre-processing involves Geo-referencing and Radiometric correction of RS data. GPS based field data along with Google earth (http://earth.google.com), Bhuvan (bhuvan.nrsc.gov.in) are used to geo-reference the remote sensing data.

Remote sensing data was checked for radiometric errors, and enhancement was carried out for those datasets having errors. The correct image was cropped to the area of interest.

iii) Classification: Image classification is a process of producing thematic map by assigning categories to each pixel based on the spectral signatures obtained from stack of multi-band RS data (Gonzalez & Woods, 2007; Jensen & Lulla, 1987; Lillesand, Kiefer & Chipman, 2004; Natural Resources Canada, n.d.; Sabin, 1997). The process of classification involves the following steps

a. **Creation of False Colour Composite** which helps in identifying the heterogeneous feature. NIR, Red and Green bands are stacked to create an FCC.

b. **Creating of Training Data Sites:** Secondary data and Field data are used in association with Remote Sensing data to delineate heterogeneous features covering at least 15% of the scene area. Features such as Forests (evergreen, deciduous, scrub, mixed forest), Grasslands, Built-up, Agriculture (Sown and Fallow), Plantation (Coconut, Rubber, Tea, Coffee, etc.), Water bodies, Others (Quarry, Sand, Open lands, Rocky outcrops) were identified and Training data were delineated.

c. **Signatures:** Optical bands of Landsat were stacked. The Training datasets were overlaid on the data stack, and signatures were prepared for each Feature Class. Of all the signatures, 60% were used for classification, and 40% were used for Accuracy assessment.

d. **Classification:** The signatures were used to classify the stacked RS data into various land use classes based on a supervised pattern classification technique. Maximum likelihood classifier is one of the most commonly used classification tool (Bharath, Rajan & Ramachandra, 2014; Jensen, 1996; T. V. Ramachandra, Bharath & Vinay, 2013; T. V. Ramachandra, Bharath, Gouri & Vinay, 2017; T. V Ramachandra et al., 2016) was used to classify the data into four land use classes namely

   i. Built up: Residential Area, Industrial Area, Paved surfaces, mixed pixels with a built-up area

   ii. Water: Tanks, Lakes, Reservoirs, Drainages

   iii. Vegetation: Forest, Plantations

   iv. Others: Rocks, Quarry pits, Open ground at building sites, Unpaved roads, Croplands, Nurseries, Bare land

e. **Accuracy Assessment:** Accuracy assessment was carried out to understand how close the classified land use image to the reference map/ground data. 40% of the signatures were used for measuring the accuracy of the classifier output. If the accuracy was below 80%, the process was repeated by adding additional training data sites and classifying the data.

iv) Spatial Pattern Analysis: Landscape metrics or spatial metrics is used to quantify the spatial structure and composition of the landscape. These metrics are used to quantify the spatial characteristics of patches, classes of patches or the entire landscape. The study area was divided into Segments each Segment covering a distance of 25km. The landscape metrics were computed for each region using classified land use images at the class level to understand the landscape dynamics due to urbanization. Metrics were computed with the help of FRAGSTATS (McGarial & Marks, 1995), landscape metrics such as Number of Patches (NP), Edge Density (ED), Largest Patch Index (LPI), Normalized Landscape Shape Index (NLSI) are presented in the document for each corridor.

b) Modelling and prediction

Modelling and simulation of land use change are necessary to simulate trends in land use transformation based on existing dynamics. Understand trend in landscape change, the direction of change, influencing factors and constraints, the model can be used to foresee the influence of change decisions and policies, interventions (Bharath et al., 2014; Bharath et al., 2017; Das Chatterjee, Chatterjee & Khan, 2015). The model outputs can be used in the decision support system, which helps in understanding various aspects of "what if situations, evaluation of likely scenarios, evaluation of alternatives, etc.". The following are the steps involves in Modelling:

a) Agents contributing to urban dynamics namely road network, bus and railway stations, industrial areas, educational institutes, hospitals and other socio-economic features were delineated from the virtual earth databases such as Google Earth, Bhuvan, open street maps and the Survey of India topographic maps

b) **Fuzzy Logic** (Zadeh, 1965) is used to standardize criteria for agents of growth (Gorsevski, Donevska, Mitrovski & Frizado, 2012) due to its good capability to mimic human control logic (Steven, 2010). Standardization process transforms and rescales (considering variable values, while allowing intermediate values) criteria into comparable units (Gorsevski et al., 2012; Sui, 1992). Process of standardization (Fuzzy) is based on simple rules, which takes into account the rate of change along with significant values in a membership function (Dernoncourt, 2013). The membership functions can be monotonically increasing or decreasing; sigmoidal, *etc*. these membership functions represent the magnitude of participation of each criterion (Eastman, 2012).

c) Similar to Fuzzy, **Boolean algebra** is used to standardize the constraints of growth. Boolean, unlike Fuzzy, doesn't consider variable values, it considers either 0(false) or 1(true), true for all the possible pixels of change and false where there is no change. In modelling "*continuous factors of multi-criteria decision making are fuzzy membership functions, whereas Boolean constraints are crisp set membership functions* (Eastman, 2012)

d) **Analytical Hierarchical Process** is a **multi-criteria decision-**making approach which uses a pairwise comparison approach for decision making (Saaty, 1990), wherein the factors are organized in a hierarchical structure (Triantaphyllou & Mann, 1995). Decision making involves various criteria's, which are used to rank the agents of change (Saaty, 2008). Weightage of criteria's in AHP depend on the expert's opinion to derive the priorities/ranks i.e., normalized principal vectors (Kardi, 2005) are the factors compared by scaling one's importance over the other. The weights, once assigned are subjected to validation by calculating the consistency ratio.

e) **Site Suitability** / site selection (Dapueto et al., 2015) is one of the major aspects that need to be understood for identifying potential locations for development and a complicated spatial decision process since it has a large number of alternatives and involves decision making (Kamruzzaman & Baker, 2013; Krois & Schulte, 2014). Integrating GIS with MCE allows solving spatially complex issues (Li, Huang, Peng & Zhou, 2013). Weights along with appropriate factors from the AHP and constraint maps from the Boolean are used to derive site suitability maps using Multi-Criteria Evaluation (MCE) which depicts pixels indicating locations and levels (high to low) of change for various land use types. These site suitability maps are used in the current study along with the CA Markov to derive future landscapes.

f) Based on the Current and Historical Land use, **Markov Chains** are run. Markov chain model is based on the progression of the formation of Markov stochastic process systems for the prediction of one statue being changed to another status (Grinblat, Gilichinsky, & Benenson, 2016; Guan et al., 2011; Muller & Middleton, 1994). It is used to model and simulate changes and trends of land use/cover. The Markov chain analysis describes the probability of land cover change from one period to another using a transition probability matrix between t1 and t2.

g) **Transition probability** matrix and Site Suitability can be used as an input for modelling land cover change. Markov analysis considers only the temporal changes that occurred in the landscape. In order to obtain the spatial dynamics of the landscape, CA is integrated with Markov Chain.

h) **Cellular Automata** is a cell-based approach to model processes in a two- dimensional space. In CA, the state of a cell can change only based on the transition rules, and it gives the result of spatial modelling based on the transition rules. These rules control the transformation of a cell state to another cell state over the specific period depending on the neighbourhood of the cells. We employed a straightforward transition rule for the cellular automation model, following Li and Yeh (2000).

i) Based on the Simulated land use, **validation** was carried out by comparing the Simulated Land use map as against the Actual Land use map using Kappa Statistics. The model was calibrated by varying the input variables in order to achieve higher accuracy. The calibrated model was used to predict and visualize the urban growth for the year 2020 or above.

2) *China*

The Chinese research drew on a parallel corridor analysis using remote sensing data. The divergent conditions of imegaregional development and the distinctive trajectories it took required several additional elements: analysis of regional sprawl dynamics, comparison of those regional dynamics and their causes, and scrutiny of sprawl and its effects on environmental quality within the neighbourhoods of the cities in the study.

a) *Analysis of sprawl using remotely sense satellite images*

The Chongqing-Chengdu corridor study drew on a parallel methodology to the Indian corridor studies to which it was matched. This study employed the TM remote sensing image data of 1990, 2000, 2010 and 2015 for the Chengdu-Chongqing urban agglomeration area as the main data sources. See the Appendix for a table of the images used.

In scaling up the analysis of sprawl to the mega-regional scale, the second study of sprawl in seven major cities along the length of the Yangtze River relied on multitemporal nightlight data from the US National Geophysical Data Center of the National Oceanic and Atmospheric Administration. The Operational Line Scan System of the Defense Meteorological Space Program provides this data at a resolution of 1 square kilometer from 1992 to the present. The study used the nightlight data to simulate the urban spatial extent of each city in 1992 (DMSP satellite 12), 2000 (DMSP satellites 14 and 15), and 2010 (DMSP satellite 18) This data was joined to a variety of other administrative, spatial, economic and demographic data for jurisdictions mapped onto the nightlight data.

b) Analysis of regional linkages

The analyses of linkages among cities employed a GIS platform and spatial analysis, but incorporated primary data collected from official sources on the bus, rail and other transport connections among the cities in each study. See Appendix for tables of this data.

c) Local drivers of sprawl

The analysis of land finance as a source of sprawl relied on data from land transactions in the open land market of Chongqing in 2003–2015. We obtained the annual Land Conveyance Fees (LCFs) by adding the transaction fees of the individual land parcels. We collected the data of the local finance revenue reported by Chongqing's Fiscal Reports and Statistical Yearbooks (2000–2016). Moreover, we collected Chongqing's geospatial data, including urban land use maps (1997, 2006, and 2016), road maps (2006 and 2016), bus route maps (2006 and 2016), cadastral map (2016), and master plans (1998–2020, 2007–2020). Most data were provided by Chongqing's local agencies, such as the Bureau of Urban Planning, Bureau of Transportation, Bureau of Land Resources, and Geomatics Center. Cadastral, urban land use, road network, and bus route maps were utilized to calculate the relevant geospatial information.

The multiple forms of urban sprawl can be measured based on a single or combined indexes according to their respective characteristics. We selected specific indexes according to different forms of sprawl by considering the accessibility of data. For example, the sprawl of industrial parks was measured mainly by leapfrog development. The sprawl of residential communities was measured by leapfrog development and low density. The sprawl of peri-urban informal development was measured mainly by unplanned development. Table 1 presents the selected indexes, which are described as follows. (1) Leapfrog development (LEAP) is considered a typical form of sprawl compared with infilling and edge-expansion. We used the proximity of the newly increased urban patches to the contiguous urban area to illustrate leapfrog growth. (2) Sprawl is regarded as a condition of the relatively low density of urban activities in a newly urbanized area (Frenkel and Ashkenazi, 2008; Knaap et al., 2005). We, therefore, used a proxy index of Floor-Area Ratio (FAR)to reflect the density of the dwelling units. The communities with FAR lower than 1.5 are regarded as low-density considering local experiences, although this criterion in Chongqing would be higher than US-European cities. (3) The unplanned growth of urbanized areas is often considered as urban sprawl. We used the degree of spatial mismatch between actual development and urban planning (UNPLAN)to reflect the inconsistency of urban growth.

d) *Analysis of consequences for urban environmental quality*

The analysis of Urban Environmental Quality at the micro level in Chongqing drew on a variety of diverse data and metrics. Along with high and medium resolution remote sensing images, it employed a variety of maps of road networks, cadaster, and soil erosion, and selected field sampling, along with official statistics (Liu et al., 2017). Table 1 lists the methods and data used to derive indicators for this assessment. The flowchart in Figure 6 details the protocols applied to collect, aggregate and process this data.

Table 1 Selected factors for assessing Urban Environmental Equality (UEQ)

Selected factors for assessing UEQ.

Variables (Abbreviation)	Definition	Data sources	Methods
Physical environment			
Forest coverage (*FOREST*)	Percentage of forest in a 500-m buffer	Urban land map from the local Urban Planning Bureau, interpreted from Worldview-2 (0.5 m) and QuickBird (0.61 m) images in 2011	Object-oriented classification and spatial statistics
Air pollution (*AQI*)	Interpolated value of AQI	The observed data of air pollution sources and the annual AQI from 16 fixed air monitoring stations in 2013	Monitoring and kriging method
Road-induced pollution (*ROAD*)	Total length of road networks in the buffer in km/km^2	Road maps (1:5000) from the local Surveying Bureau	Line density
Soil pollution (*HG*)	Interpolated value of Hg content in μg/kg	Hg content of 260 topsoil samples (0–20 cm) in the vegetated areas collected in 2010	Field sampling, standard soil analysis, and kriging method
Land surface temperature (*LST*)	LST in Celsius degrees	Landsat ETM+ images (path: 128, row: 39/40, thermal band: 60 m) from the United States Geological Survey in 2010	Single-channel algorithm
Built environment			
Impervious surface fraction (*IMP*)	Fraction of impervious surfaces in the grid	Urban land map from the local Urban Planning Bureau in 2011	Object-oriented classification and spatial statistics
Industrial land ratio (*IND*)	Percentage of industrial land in the buffer	Urban land map from the local Urban Planning Bureau in 2011	Object-oriented classification and spatial statistics
Floor-area ratio (*FAR*)	The gross floor area of buildings divided by the plot size of land	Cadastral map (1:5000) from the local Surveying Bureau	Spatial statistics
Natural hazards			
Flooding risk (*FLOOD*)	Percentage of developed land on flood-prone area below 194.3 m	DEM (1:10000) from the local Surveying Bureau	Spatial statistics
Landslides risk (*SLIDE*)	Point density of past landslide events in the buffer	Nearly 500 sites of landslide events from the local Urban Planning Bureau	Point density
Soil erosion (*EROSION*)	Degree of soil erosion	Soil erosion map from the local Urban Planning Bureau	Classification
Sloping development (*SLOPE*)	Percentage of developed land on steep slopes beyond 25%	DEM (1:10000) from the local Surveying Bureau	Spatial statistics

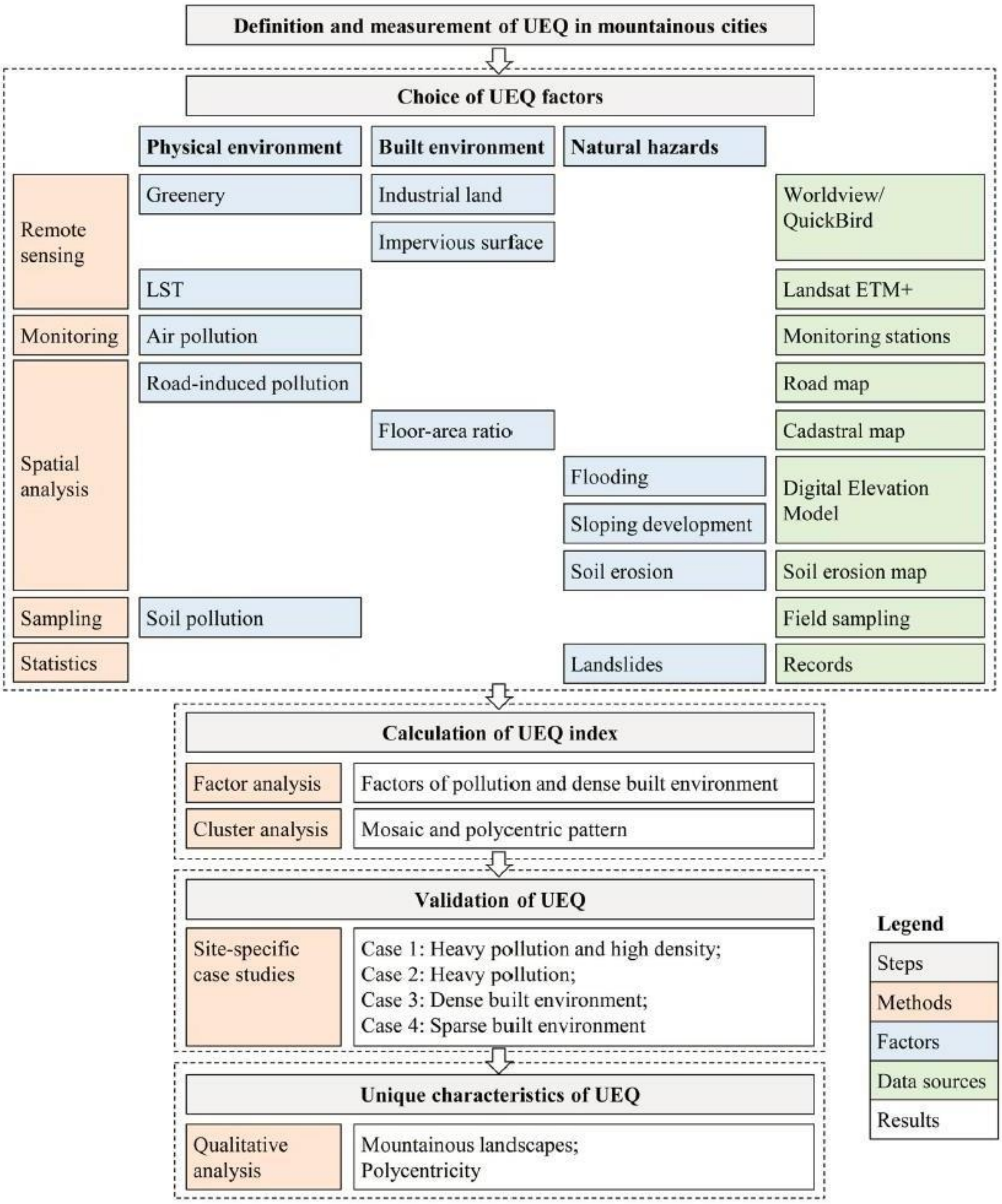

Figure 6 Flowchart for analysis of Urban Environmental Quality

3. Results & Discussion

a. India

In India, regional development concentrated in the corridors between urban regions alongside the peri-urban regions surrounding the large urban centres. New infrastructure and industrial policies have reinforced this concentration.

1) Mumbai-Pune interurban corridor

One Indian case study visualized growth along the rapidly developing 140-kilometre corridor between the large cities of Mumbai and Pune. The analyses there focused on a 10-kilometre buffer on either side of the highway (Figure 3). The built-up proportion of land in the corridor grew from 3.66% in 1997 to 19.81% in 2015, expanding both along the expressway and around smaller urban nodes. Agent-based models based on recent trends predict the expansion of built-up land to half of the total in 2027. Without new, more sustainable policies, vegetation in the corridor will decline dramatically from 25% in 2015 to 10% in 2027.

Mumbai Pune Industrial Corridor: Fieldwork was carried out along the Mumbai Pune Express highway on April 2016, and the GPS readings overlay on Google earth is as depicted in Figure 7.

Figure 7 GPS data Overlay on Google Earth

LULC analysis was carried out for the Mumbai-Pune Industrial corridor for analyzing the changes that had taken place from 1997 to 2015. Land cover analysis indicates that the vegetation cover along the study area has decreased from 40.5% in 1997 to 24% in 2015, whereas non-vegetation has increased from 59.5% to 76%. Figure 8 and Table 2 depict the variations in the land cover changes along the corridor.

Table 2 Land cover statistics from 1997 to 2015

Year	Vegetation cover (Ha)	Area (%)	Non Vegetation (Ha)	Area (%)
1997	126267.6	40.55	185536.1	59.56
2003	113383.17	36.42	198420.5	63.69
2009	105652.5	33.9	206151.2	65.7

Year	Vegetation cover (Ha)	Area (%)	Non Vegetation (Ha)	Area (%)
2015	74729.81	23.99	237073.9	76.09

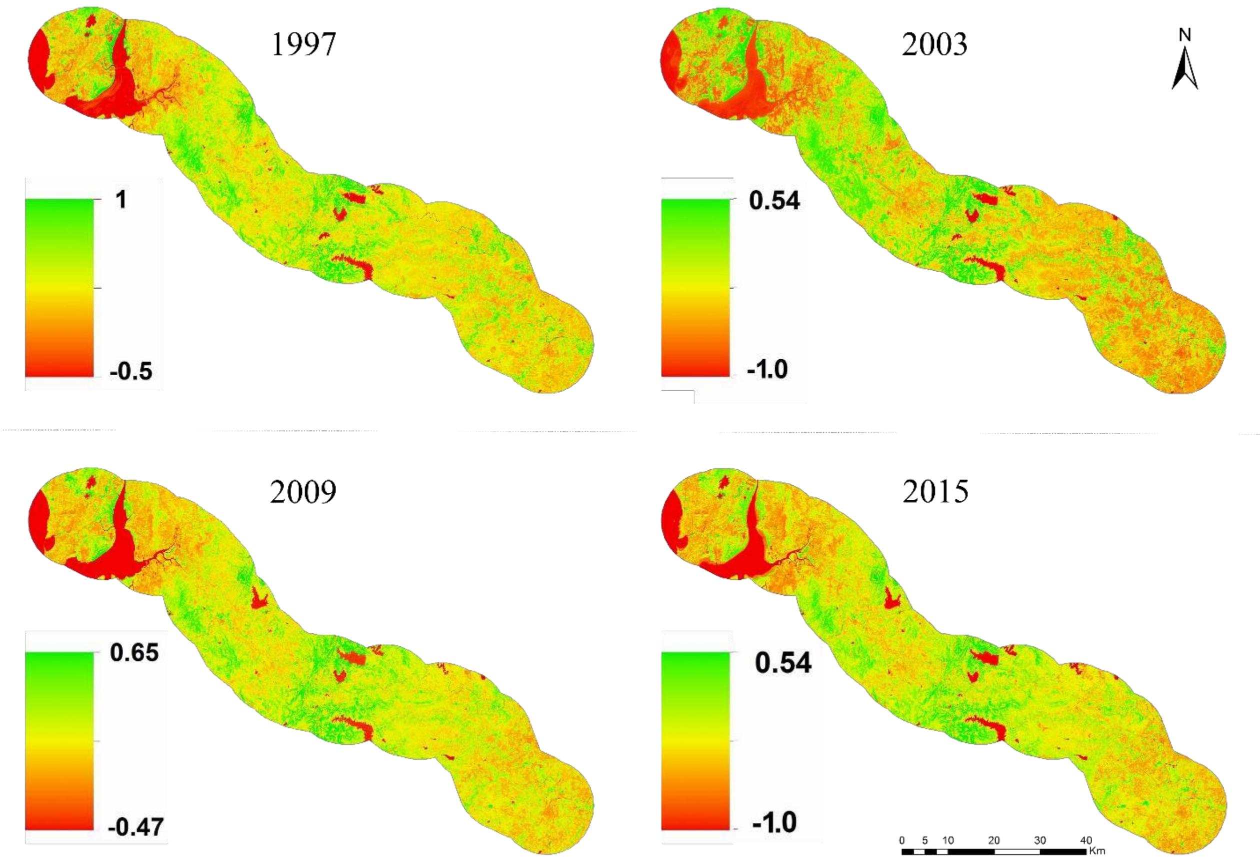

Figure 8 Land cover dynamics between 1997 and 2015

Temporal land uses in the corridor during 1997 and 2015 is given in Table 3 and Figure 8. Land use change analysis reveals that area under built-up has increased by 5 folds, i.e., from 3.66% in 1997 to 19.81% in 2015. The evident decline in the vegetation area was observed between 1997 (41.27%) and 2015 (26.64%). Water bodies have remained almost the same throughout. Overall accuracy and Kappa was over 90% and 0.8, respectively, is as shown in Table 4. Land use analysis shows that Mumbai, Navi Mumbai, and Pune indicates intense urbanization process, whereas Lonaval has started with the urbanization process.

Table 3 Land Use Dynamics in Mumbai Pune Express highway

LU	Urban		Vegetation		Water		Others	
Year	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
1997	11084.94	3.66	124914.42	41.27	22086.54	7.30	144600.03	47.77

LU	Urban		Vegetation		Water		Others	
2003	21296.70	7.04	110892.24	36.64	21545.2	7.12	148951.71	49.21
2009	34728.03	11.47	97868.97	32.33	23525.37	7.77	146563.5	48.42
2015	59950.71	19.81	74555.46	24.64	21364.94	7.06	146763	48.5

Table 4 Accuracy and Kappa

1997		2003		2009		2015	
OA	K	**OA**	K	**OA**	K	**OA**	K
92	0.82	91	0.80	90	0.81	91	0.85

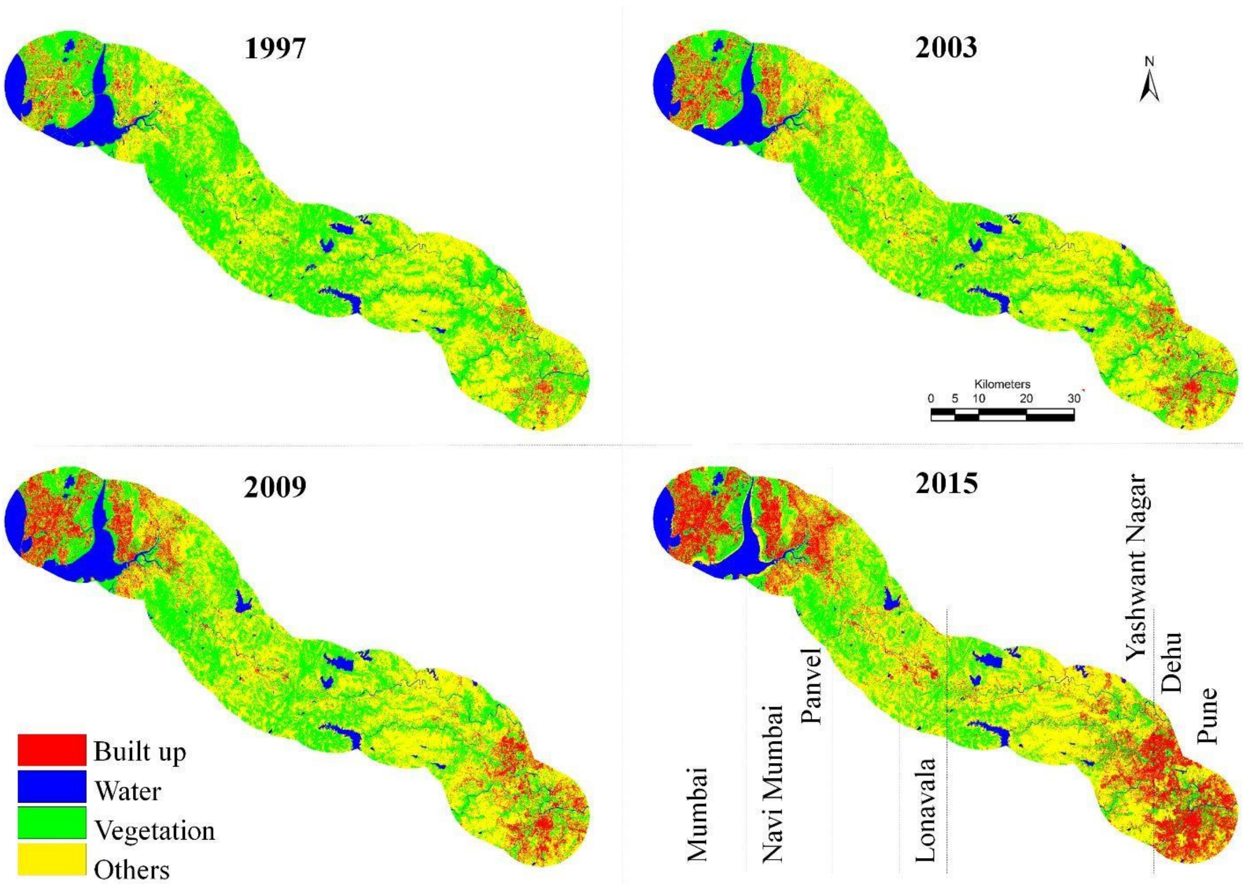

Figure 9 Land use dynamics along the Mumbai Pune Express Corridor

Spatial pattern Analysis was carried out by dividing the area into Segments of 25 km as shown in Figure 9. Five Segments (zones) were delineated wherein Segment 1 covered entire Mumbai, Segment 2 Navi Mumbai to Kharsundi/ Khalapur, Segment 3 from Khalapur passing through Loaval to Devghar, Segment 4 from Devghar/Karla to Dehu Road (Yashwant Nagar), and Segment 5 covering Pune. Segment 1 and Segment 5 showed the highest urbanization, whereas Segment 3 showed the highest vegetation cover, details are as presented in Figure 10 and Table 5.

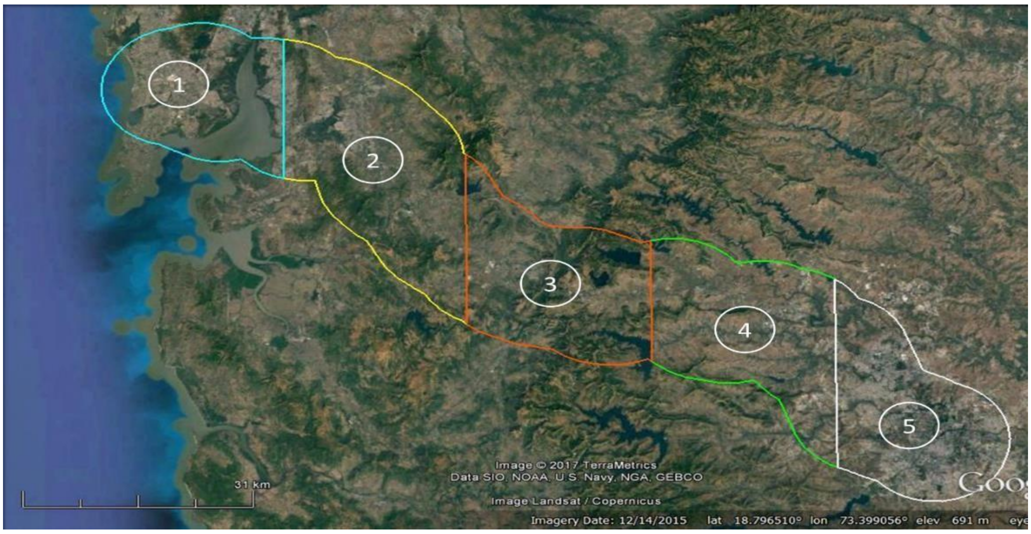

Figure 10 Segments along the Corridor

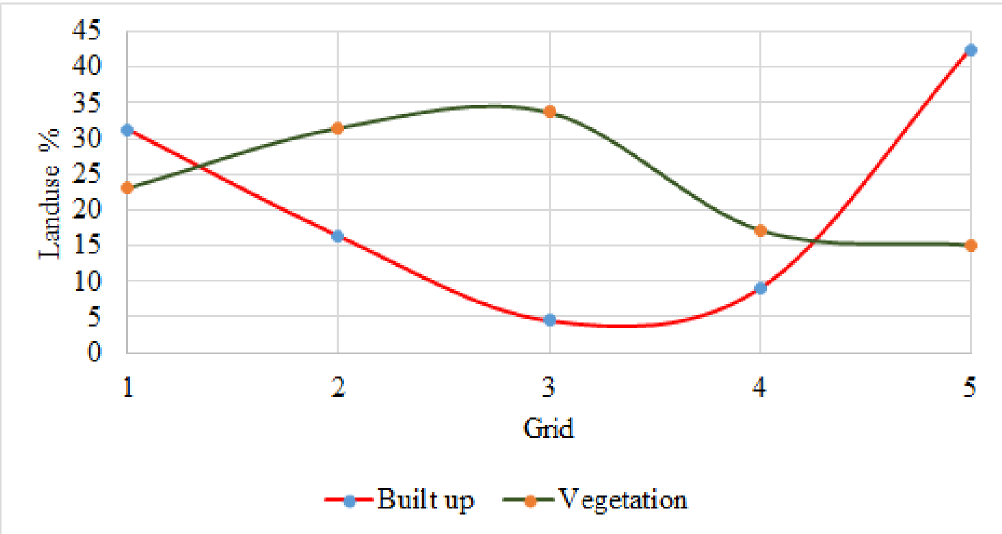

Figure 11 Built-up and Vegetation Land use in each Segment - 2015

Table 5 Zone wise Land use along the Corridor

Segment	Land use	Urban	Vegetation	Water	Others
	Year	%	%	%	%
1	**1997**	9.31	35.31	32.23	23.16
	2003	17.41	31.60	31.0	19.99
	2009	24.86	27.56	31.99	15.56
	2015	31.27	23.10	27.43	18.21

Segment	Land use	Urban	Vegetation	Water	Others
	Year	**%**	**%**	**%**	**%**
2	**1997**	1.83	49.20	1.42	47.55
	2003	4.76	41.50	1.27	52.47
	2009	8.97	39.13	2.04	49.86
	2015	16.40	31.56	2.18	49.86
3	**1997**	0.39	51.88	5.12	42.6
	2003	0.87	46.91	5.11	47.10
	2009	1.35	43.21	6.16	49.27
	2015	4.55	33.74	5.87	55.83
4	**1997**	0.61	33.38	1.49	64.52
	2003	1.28	31.23	1.71	65.78
	2009	2.57	26.84	2.10	68.48
	2015	9.05	17.20	2.37	71.38
5	**1997**	7.93	33.35	1.07	57.66
	2003	13.70	29.66	1.19	55.45
	2009	23.45	21.8	1.25	53.44
	2015	42.49	15.08	1.42	41.01

Spatial Metrics Analysis: Landscape metrics for the industrial corridor was calculated on a zonal basis and the results are as below and in Figure 10

NP: This metric explains the order of fragmentation or clumped growth in terms of urban area calculated as a patch. Segment 1, i.e., Mumbai indicates a reduction in a number of patches since 1997, indicating concentrated growth, Segment 2,3 and 4 show an increase in the number of patches since 1997. Rampant unplanned growth in the outskirts of Mumbai and Pune can be demonstrated in Segments 2 and 4 since they have the highest number of patches.
Segment 5 consisting Pune shoed the highest number of patches in 2009 whereas in 2015 number of patches have reduced showing infilling.

NLSI: NLSI is concerned with the shape, and the value ranges from 0 (maximally compact patch) to 1 (disaggregated landscape). All the Segments showed increasing NLSI from 1997 till 2015. Segment 1 and 5 showed lowest NLSI closer to 0.4 indicating clumped and uniform shaped growth, whereas Segments 2,3 and 4 NSLI values were closer to 1 indicating irregular shapes and sprawl in the region

LPI: Largest patch index quantifies the percentage of total specific landscape area comprised of the largest patch. Largest Patch index depicts increasing patch size across time. Segment 1 and Segment 5 showed the largest LPI. Larger patch sizes indicate clumped growth as against smaller patch sizes indicating clustered growth.

ED: Edge Density refers to the ratio of a total number of edges of all patches to the total area, and it is the measure of fragmentation of the landscape. ED approaches zero when there is no edge or fragmentation in the landscape The edge density has declined for Mumbai in 2015 indicating less fragmentation, but all other zones including Pune city show increasing fragmentation during the study

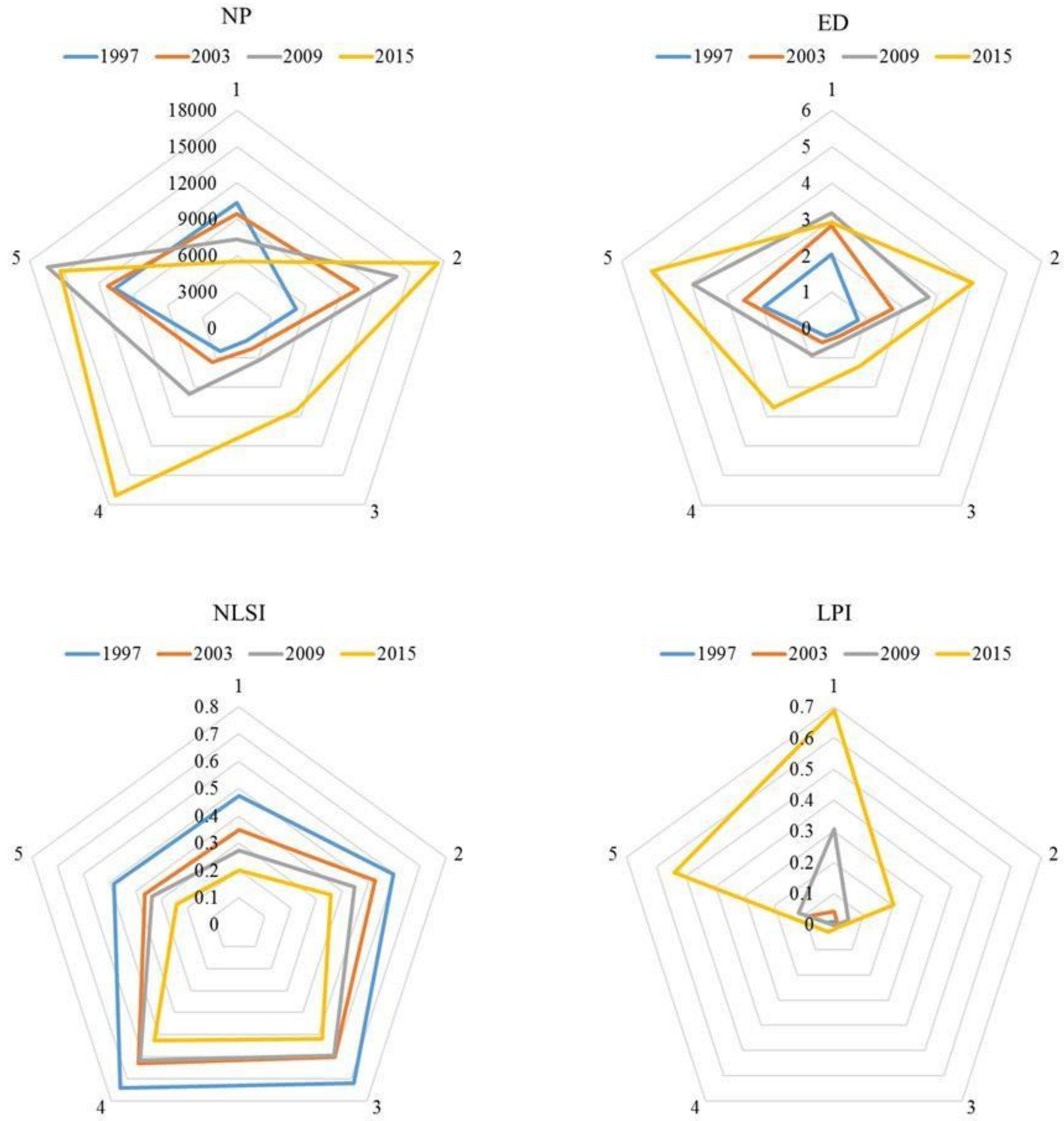

Figure 12 Spatial Metrics

Modeling, Simulation and Prediction: Roads, Industries, Educational Institution, Distance from City Centre, Protected Areas, etc. were accounted as factors of growth to model and simulate land use. Factors were normalized using fuzzy logic (0 to 255, 255 representing the higher influence and 0 representing lower influence) and constraints using Boolean logic (0 and 1, 0 representing areas which shall not alter, 1 representing areas can alter). AHP based weights for the factors are as depicted in Table 6. Of all the Factors, Road network had higher influence on land use changes, i.e., about 31.4% followed by Industries and Bus stations with 20%. Educational Institutions had weight of 15.2%. Consistency ratio of 0.06 was obtained. Site Suitability map developed using factors as described and is as depicted in Figure 11.

Table 6 Weights generated under each factor – Urban Growth

Factor	Weightage
Road Network	0.3142
Industries	0.2007
Educational Institutions	0.1997
Bus Station and Railway stations	0.152
City Centers	0.0698
Airports	0.0206
Social (Police Station, Community halls, Religious Places *etc.*)	0.0421

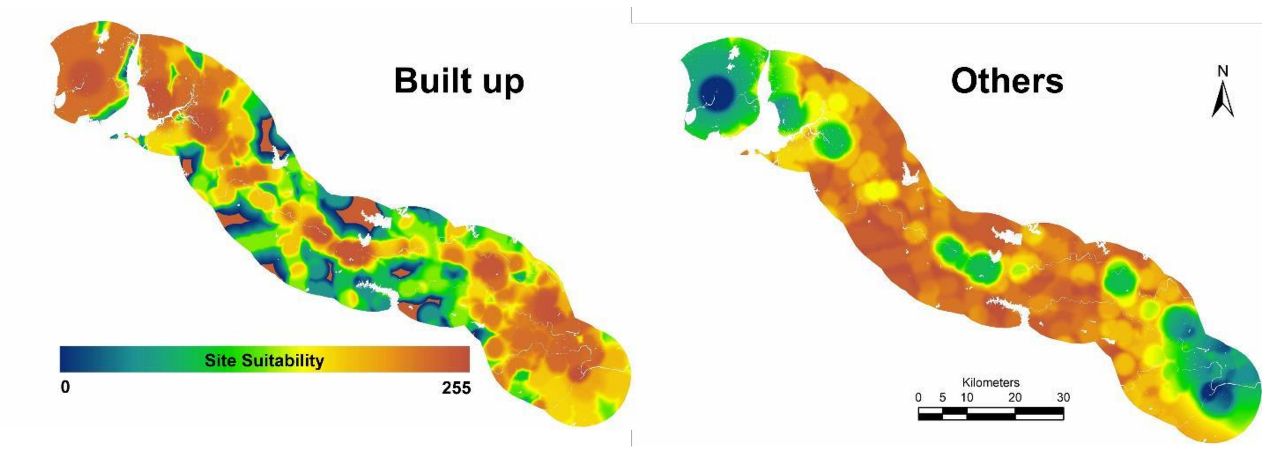

Figure 13 Site Suitability Map

AHP-CA-Markov Agent-based model was designed to simulate land use for the year 2015 based on 2003, and 2009 land uses. Markov chain was used to understand the landscape dynamics between 2003 and 2009, to simulate for the year 2015. Transition probability with an allowable error of 15% for the year 2015 is tabulated in Table 7. Transition probability shows that about 28% of other land use has chances of being urbanized, 30% of Vegetation and has the probability of becoming other land uses.

Table 7 Markov transition probability 2003 – 2009 to 2015

Year		2015			
	Land use	Water	Vegetation	Built-up	Others
2009	Water	0.85	0.05	0.05	0.05
	Vegetation	0.00	0.65	0.05	0.30
	Built up	0.05	0.05	0.85	0.05
	Others	0.00	0.00	0.28	0.72

Simulated landscape for the year 2015 is depicted in Figure 12 and land use statistics are presented in Table 8. Simulated output for the year 2015 was compared with 2015 land use (actual) to understand the efficiency of the model, the accuracy of the model is 91.5%, with Kappa (standard) of 0.89. The calibrated model was further used to predict land use for the year 2021 and 2027.

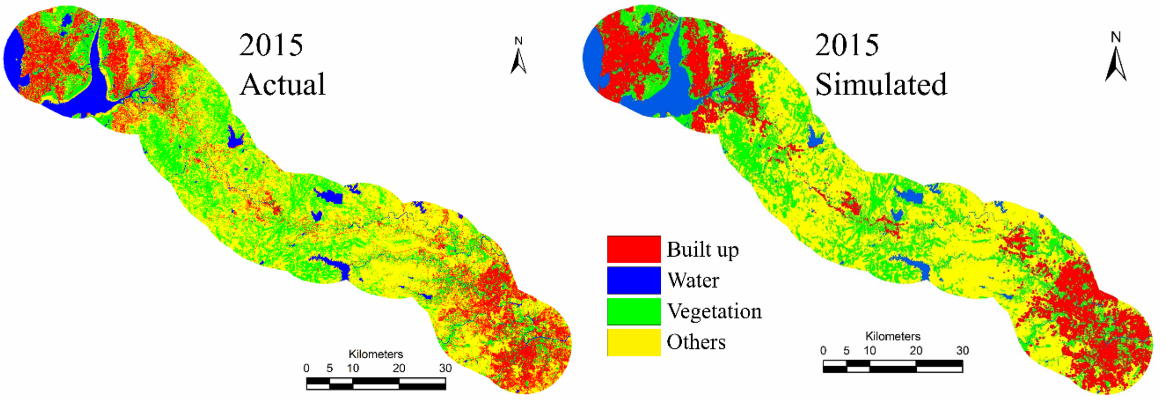

Figure 14 Actual versus simulated Land use 2015

Table 8 Land use Statistics Actual versus Simulated

LU >	**Urban**		**Vegetation**		**Water**		**Others**	
Year	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
2015 (Actual)	59763	19.7	74555	24.63	24761	8.18	143577	47.45
2015 (Simulated)	64162	21.2	74395	24.59	24761	8.18	139718	46.01

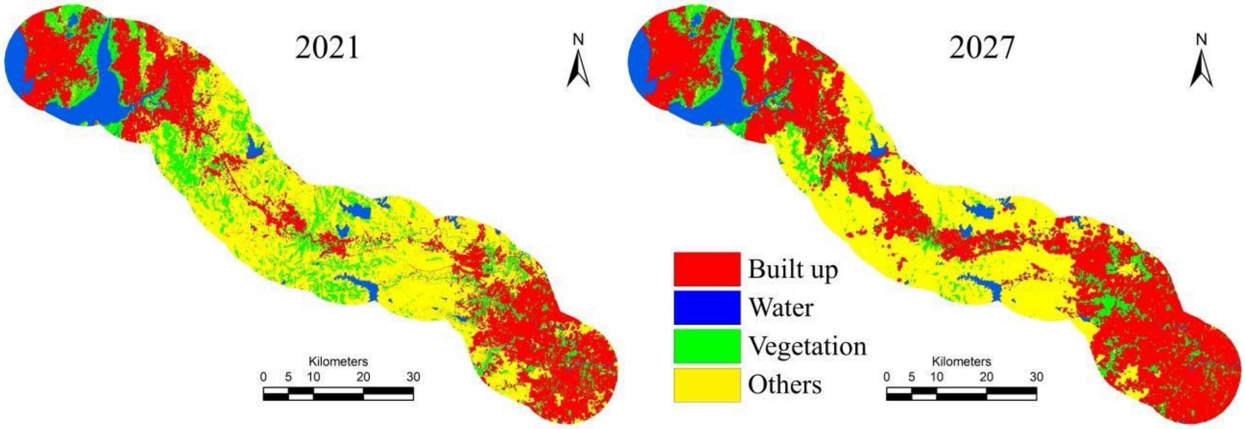

Figure 15 Predicted Land use 2021, 2027

Land use prediction for the year 2021 and 2027 is as presented in Figure 15 and Statistics is as presented in Table 9. Built up are is predicted to increase from 19.81% in 2015 to 47.12% by 2027. Pune, Mumbai and Navi Mumbai would be saturated by 2021, and outward concentrated growth would continue. High urban growths can be observed near industries along the corridor. Vegetation is expected to reduce from 24.6% in 2015 to 11.10% in 2027. Ambivali, Panvel, Chinchwad, Khopli, Dehu, Yashwanth Nagar showed rampant growth, which can be attributed to the connectivity and proximity of the corridor.

Table 9 Predicted Land use 2021, 2027

Land use	**Urban**		**Vegetation**		**Water**		**Others**	
Year	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
2021	97343	32.16	51442	17.00	24761	8.18	129110	42.66
2027	142621	47.12	33593	11.10	24761	8.18	101680	33.60

2) Chennai-Bangalore-Mangalore interurban corridor

Fieldwork was carried out along a side major interurban corridor, the Chennai Mangalore Express Corridor, on August 2016 and the GPS overlay on Google earth is as depicted in Figure 16 from Bangalore to Mangalore and Bangalore to Chennai.

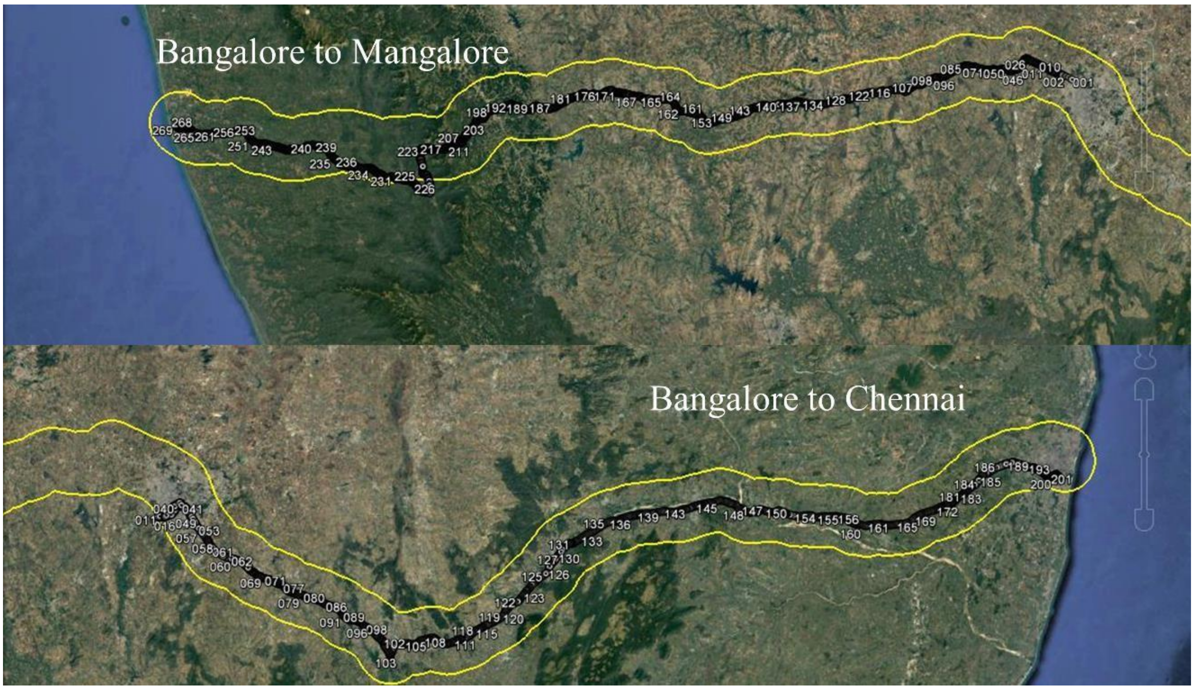

Figure 16 Chennai-Bangalore-Mangalore corridor: GPS overlay on Google earth

The land cover analysis was carried out between 1997 and 2014; there results are as depicted in Figure 15 and Table 10. Land cover analysis indicates that the vegetation cover in the corridor has reduced from 44% in 1997 to 37.3% in 2014.

Table 10 Land cover Chennai Mangalore Corridor

LU Year	Vegetation		Non-Vegetation	
	Hectare	%	Hectare	%
1997	599035	44.08	760102	55.91
2004	564765	41.52	794735	58.45
2009	548847	40.39	810175	59.63
2014	507086	37.29	851746	62.65

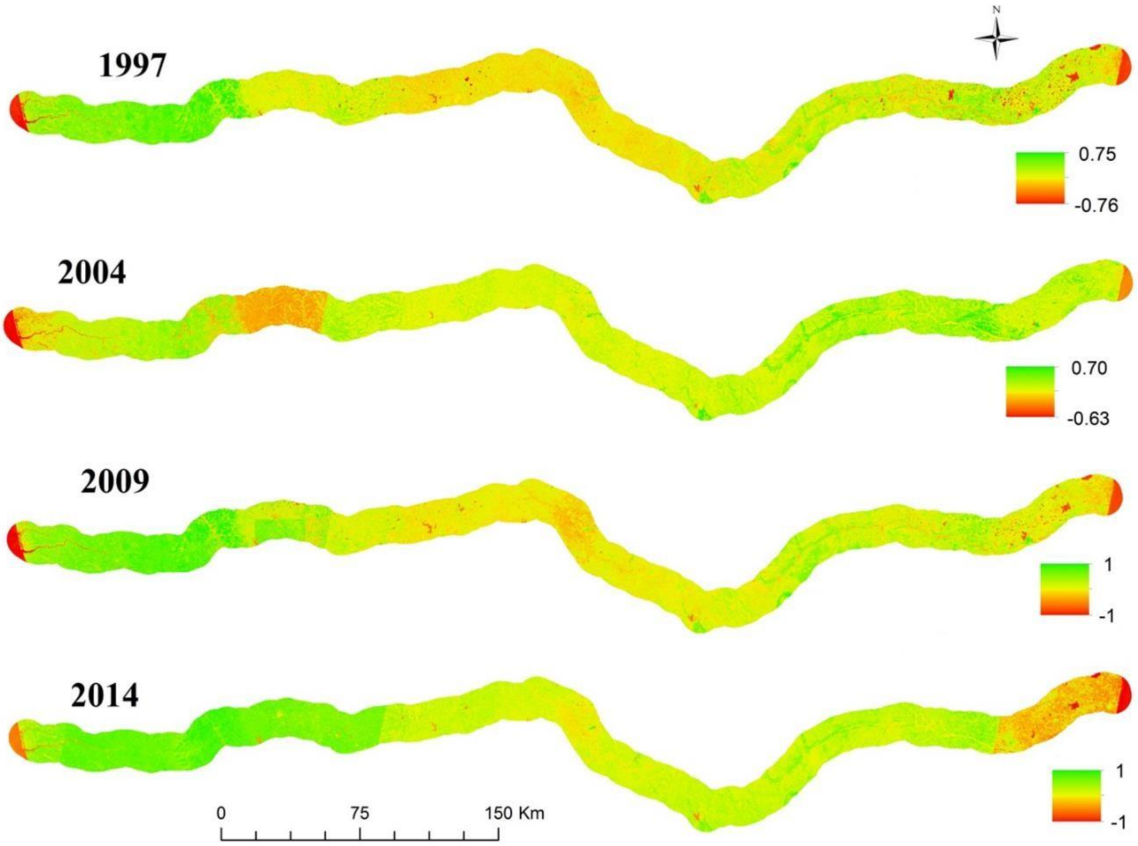

Figure 17 Land cover Mosaic of Chennai Mangalore Industrial Corridor

Land use analysis shows that built-up area in the study region (Corridor + 10 km buffer) indicated that urban area has increased by 4 fold, i.e., from 2.27% in 1997 to 8.54% in 2014, Vegetation area has declined from 44.51% to 40.89% between 1997 and 2014. Details are described in Table 11 and Figure 16.

Table 11 Land use statistics

LU Year	Water		Vegetation		Urban		Others	
	Ha	%	Ha	%	Ha	%	Ha	%
1997	72992	5.37	604135	44.51	30298	2.27	650883	47.95
2004	62818	4.62	597607	44.03	55296	4.07	643471	47.41
2009	59879	4.41	578238	42.60	79860	5.88	640230	47.17
2014	49414	3.64	555056	40.89	116006	8.54	638599	47.05

Spatial-Temporal Land use analysis indicates that built up area in and around Bangalore and Chennai area growing at a higher pace as against other cities such as Mangalore, Vellore, Hosur, Kanchipurum, Kunigal, Hassan show moderate growth. Water bodies in an around Bangalore and Chennai are lost due to unplanned development.

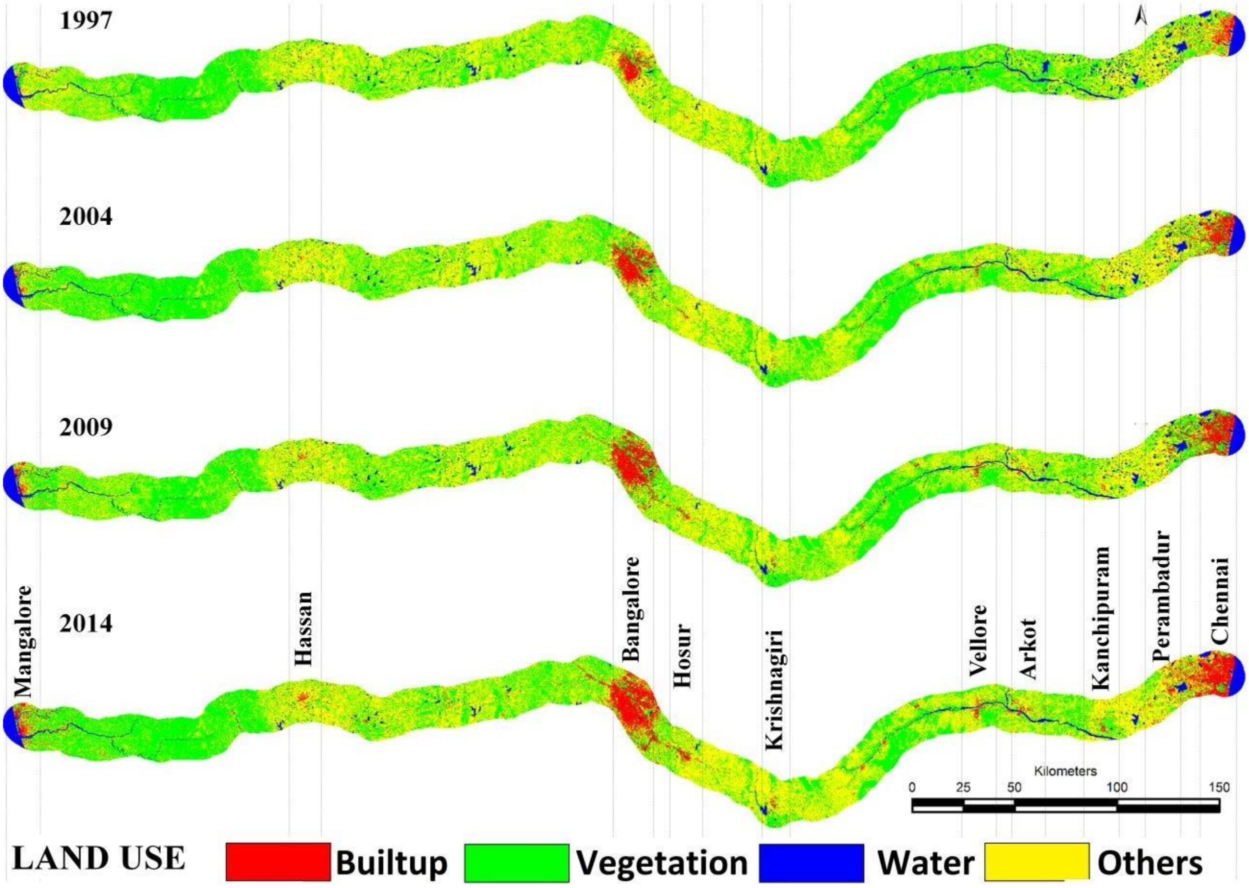

Figure 18 Land use Chennai Mangalore Corridor

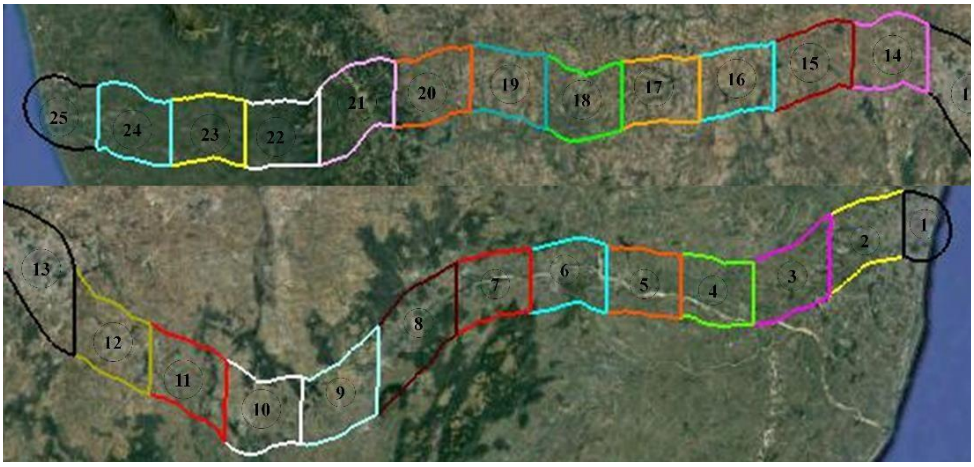

Figure 19 Segments (zones) along the Chennai Mangalore Corridor

Figure 19 depicts Segments (zones) along the corridor. Segments 1, 2, consisting of Chennai; Segment 13, consisting of Bangalore, showed the highest urban growth, followed by Segment 25 (Mangalore).

Spatial Metrics Analysis: Landscape metrics for the industrial corridor was calculated on a zonal basis, and the results are as below and in Figure 18.

NP: This metric explains the order of fragmentation or clumped growth in terms of urban area calculated as a patch. Segment 1, i.e., Chennai indicates a reduction in a number of patches since 1997 indicating concentrated growth, Segment 2, 13 surrounding Chennai, Bangalore followed by Segments 19, 20, 24, 25 shows higher in the number of patches since 1997. Excessive unplanned growth in the outskirts of Chennai and Bengaluru is demonstrated in Segments 2 and 13 since they have the highest number of patches. Segment 13, consisting of Bangalore and surroundings showed the highest number of patches in 2009 whereas in 2015 the number of patches has reduced showing infilling.

NLSI: NLSI is concerned with the shape, and the value ranges from 0 (maximally compact patch) to 1 (disaggregated landscape). All the Segments showed increasing NLSI from 1997 till 2015. Segments 1, 8 and 13 showed lowest NLSI less than 0.2 in 2014 indicating clumped and uniform shaped growth, whereas Segments 12, 25 NLSI values less than 0.4 indicating near compact growth and Other Segments indicated sprawl with non-uniform shapes.

LPI: Largest patch index quantifies the percentage of total specific landscape area comprised of the largest patch. Largest Patch index depicts increasing patch size across time. Segment 1 and Segment 13 showed the largest LPI. Larger patch sizes indicate clumped growth as against smaller patch sizes indicating clustered growth.

ED: Edge Density refers to the ratio of a total number of edges of all patches to the total area, and it is the measure of fragmentation of the landscape. ED approaches zero when there is no edge or fragmentation in the landscape The edge density declined for Chennai in 2014 indicating less fragmentation, but other Segments such consisting Bangalore, Mangalore, Hosur, Hassan, Vellore, Kanchipurum, Kunigal shows increasing fragmentation during the study

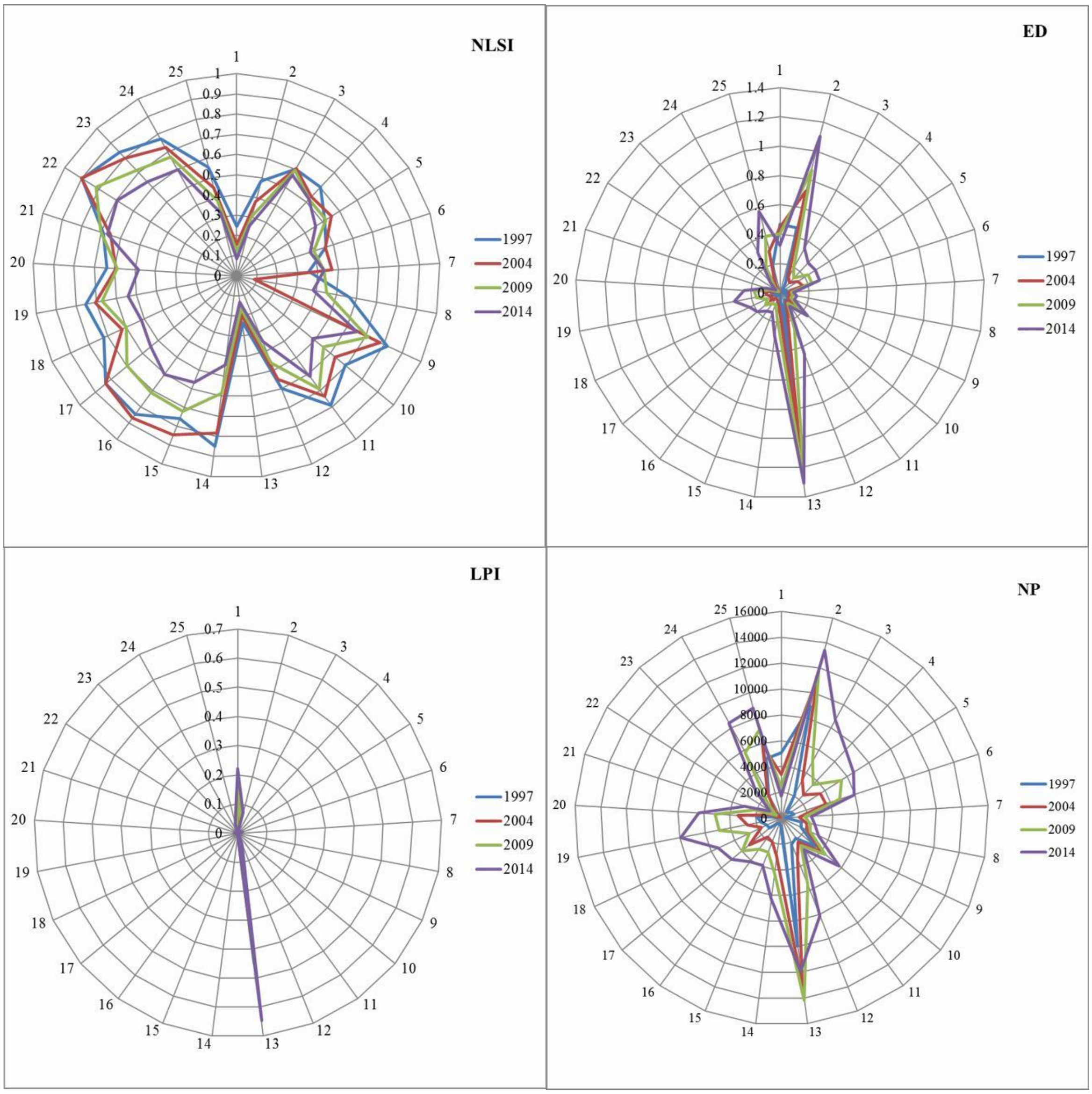

Figure 20 Spatial Metrics Chennai Mangalore Corridor

Modelling, Simulation and Prediction: Various Factors such as Roads, Industries, Educational Institution, Distance from City Centre, Protected Areas, etc. were accounted to model land use. Factors were normalized using fuzzy logic (0 to 255, 255 representing the higher influence and 0 representing lower influence) and constraints using Boolean logic (0 and 1, 0 representing areas which shall not alter, 1 representing areas can alter). AHP based weights for the factors are as depicted in Table 12. Of all the Factors, Road network had higher influence on land use changes, i.e., about 30.2% followed by Industries with 20.3%. Educational Institutions and Bus stations had almost same weights of 17.5%. Consistency ratio of 0.06 was obtained.

Table 12 Weights generated under each factor – Urban Growth

Factor	Weightage
Road Network	0.302

Factor	Weightage
Industries	0.203
Educational Institutions	0.176
Bus Station and Railway stations	0.175
City Centers	0.076
Airports	0.025
Social (Police Station, Community halls, *etc.*)	0.022
Religious (Worship places)	0.021

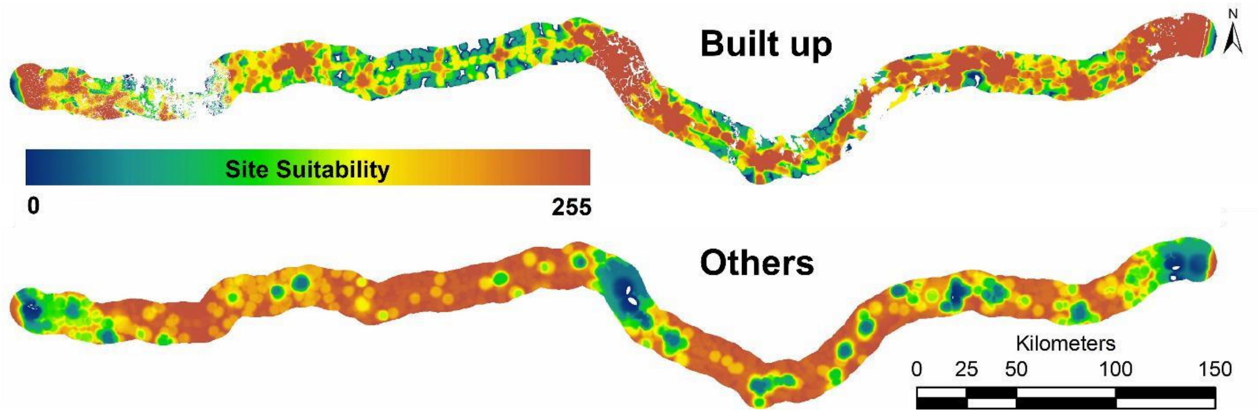

Figure 21 Site Suitability Map – Chennai Mangalore Corridor

Site Suitability Maps were developed for various landscapes considering both factors and constraints of growth. Site suitability essentially involves creating agent-based interactive land maps to access the most suitable and least suitable regions for further simulations. Agents are necessarily ranked based on their characteristics and influences, and this would provide a weighted score to calculate the most suitable and least suitable areas for a class Figure 18 Depicts Site Suitability Maps.

An agent-based model was calibrated to simulate land use for the year 2014 based on 2004 and 2009 land use. Markov chain was used to understand the landscape dynamics between 2004 and 2009, to simulate for the year 2014. Allowable errors such as 0.15, was used to calibrate the model. Transition probability with an allowable error of 15% for the year 2014 is tabulated in Table 13. Transition probability shows that about 19.2% of other land use has chances of being urbanized, 33.1% of Vegetation has the probability of becoming Other landscape. 2.3% of vegetation cover has a probability of becoming urban by 2014.

Table 13 Markov transition probability 2003 – 2009 to 2014

	Year	2014			
Year	Land use	Water	Vegetation	Built-up	Others
2009	Water	0.85	0.05	0.05	0.05
	Vegetation	0.00	0.646	0.023	0.331
	Built up	0.05	0.05	0.85	0.05
	Others	0.00	0.00	0.192	0.808

The simulated landscape for the year 2014 is as depicted in Figure 15; Land use statistics are as presented in Table 14. Simulated output for the year 2014 was compared with 2014 land use (actual) to understand the efficiency of the model, the accuracy of the model is 93.7%, with Kappa (standard) of 0.88. The calibrated model was further used to predict land use for the year 2019, 2024 and 2029.

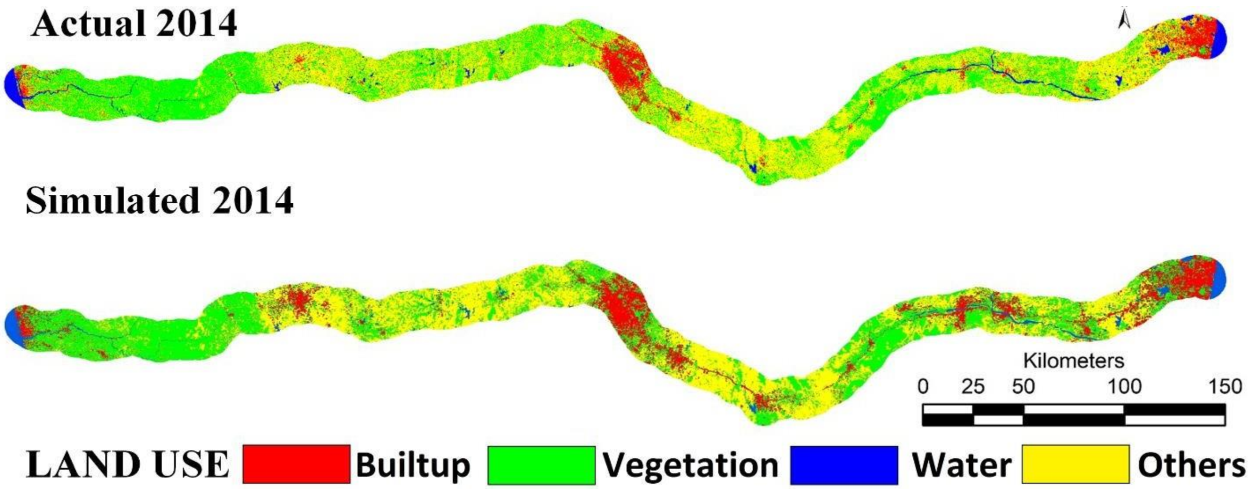

Figure 22 Simulated versus Actual Land scape 2014

Table 14 Land use Statistics Actual versus Simulated

LU	Water		Vegetation		Urban		Others	
Year	Ha	%	Ha	%	Ha	%	Ha	%
2014(Actual)	49414	3.64	555056	40.89	116006	8.54	638599	47.05
2014(Simulated)	53001	3.9	538164	39.6	168788	12.42	599047	44.08

Land use prediction for the year 2019, 2024 and 2027 is as presented in Figure 23 and Statistics is as presented in Table 15. Built-up area is predicted to increase from 8.54% in

2014 to 35.4% by 2029. Bangalore, Chennai would be saturated by 2024 and outward concentrated growth would continue. High urban growths can be observed in close proximity to the road network, industries and CBDs along the corridor, namely Mangalore, Hassan, Vellore, Kanchipurum, Hosur, Arkot. Vegetation is expected to reduce from 40.8% in 2014 to 10.6% in 2029.

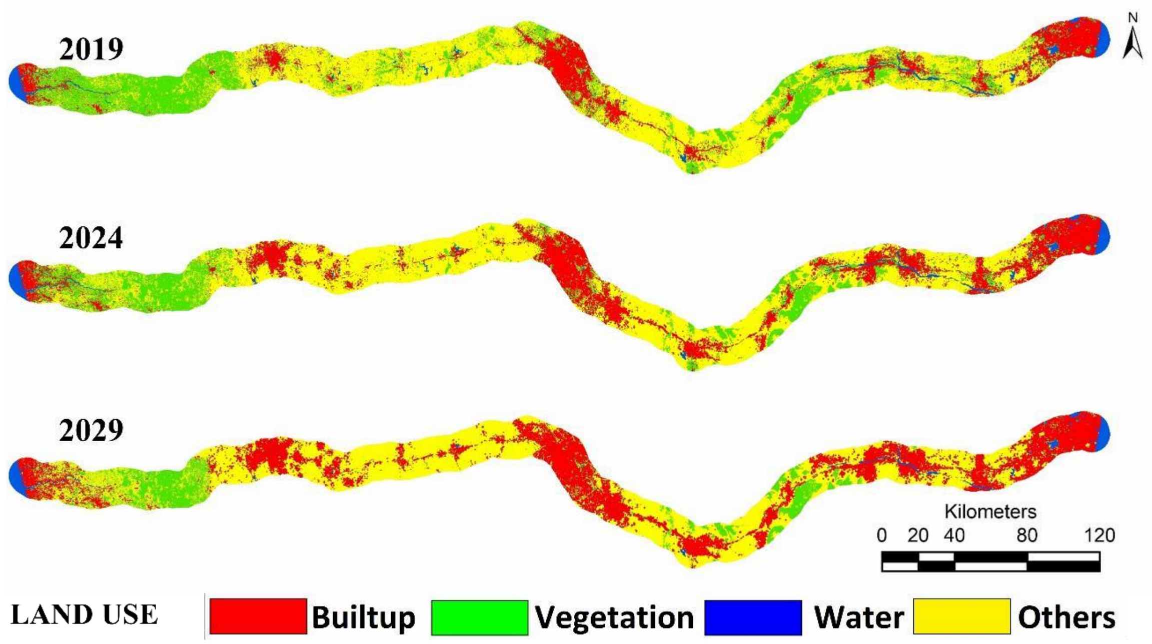

Figure 23 Predicted Land use for 2019, 2024 and 2029

Table 15 Predicted Land use statistics

LU	Water		Vegetation		Urban		Others	
Year	Ha	%	Ha	%	Ha	%	Ha	%
2019	50643	3.7	382628	28.2	237929	17.5	687119	50.6
2024	45570	3.4	243573	17.9	359935	26.5	709435	52.5
2029	41659	3.1	14390	10.6	480692	35.4	692209	51.0

Pune- Mumbai Corridor has witnessed a wave of urbanization during the last two decades, which has accelerated with the identification of the region as an industrial corridor. Temporal land use analysis which obtained an overall accuracy of 90% reveals a steady urban growth of 3.38% along the corridor from 1997 to 2003 and the growth increased to 4.43% from 2003 to 2009 and has reached to 8.34% growth from 2009 to 2015. The analysis of changes in vegetation cover shows a decline from 41.27% (124914 ha) to 24.64% (74555 ha) during 1997 and 2015. By dividing the urban study area into five Segments, an analysis was carried out, through which the core urban areas of Mumbai (Segment 1) and Pune (Segment 5) has witnessed urban growth of 22% and 34.56% during 1997 to 2015. Along with that, the adjacent areas of Mumbai (Segment 2) have undergone 14.5%, and the regions near Pune (Segment 4) have been 8.44% urbanized during the study period. This indicated the spread of urban region along the corridors, which could be considered as urban sprawl. The spatial pattern of urbanization analysis through the computation of selective metrics confirms that the core urban areas of Mumbai and Pune Cities is having a clumped growth from 1997 to 2015 and the resulted spread or sprawl is being experienced to the outskirts of the metropolitan area. The land use changes for 2021 and 2027 were predicted through Modelling in which it is expected to have a 13% increase in urban growth from 2015 to 2021 and 15% growth from 2021 to 2027 while the vegetation cover decreases 7.2% from 2021 to 2027.

Chennai - Mangalore industrial corridor connects Tier I cities (Chennai and Bangalore) and Tier II city (Mangalore). The corridor mainly runs through an agricultural and forest area. So these areas are analyzed for sustainable urban growth. Land use analysis reveals that urban area has increased from 2.27% in 1997 to 8.54% in 2014 with an overall increase of 6.27%. The decline in vegetation and water bodies has also observed. The analysis of changes in vegetation cover using NDVI shows a decline from 44.08% in 1997 to 37.29% in 2014. LULC analysis reveals that urban sprawl has occurred near the vicinity of the existing urban areas and along the outskirts from 1997 to 2014. The high rate of urban sprawl is observed in Chennai and Bangalore, followed by Mangalore. Urban growth pattern along the corridor has been carried out in 25 Segments using landscape metrics, which indicated that urban patches are becoming more dispersed along the corridor and more compact growth is observed in Chennai and Bangalore. Prediction result shows that urban area would be increased from 2.27% in 1997 to 19.98% in 2029. These land use changes occurring in the area are due to the influence of national highway that connects Chennai and Mangalore along with the major cities such as Kanchipuram, Vellore, Krishnagiri, Hosur, Bangalore and Hassan.

b. China

1) Chengdu-Chongqing interurban corridor

Part of the research on China focused on the Chengdu-Chongqing urban agglomeration, the most representative urban cluster in the central and western regions and a matched set to the Indian corridors (Wang, 2017). There built up areas increased by several times. The largest new built-up areas, however, appeared in the areas close to the big cities of Chengdu and Chongqing. Although most of the new urban areas replaced vegetation along the newly established transportation corridor such as railways and highways, the overwhelming proportion of new development appeared around existing towns, and in low lying areas with gentle terrain. The confinement of most urban land expansion to the areas around the main cities contrasted with the corridor patterns emerging in the Indian regions.

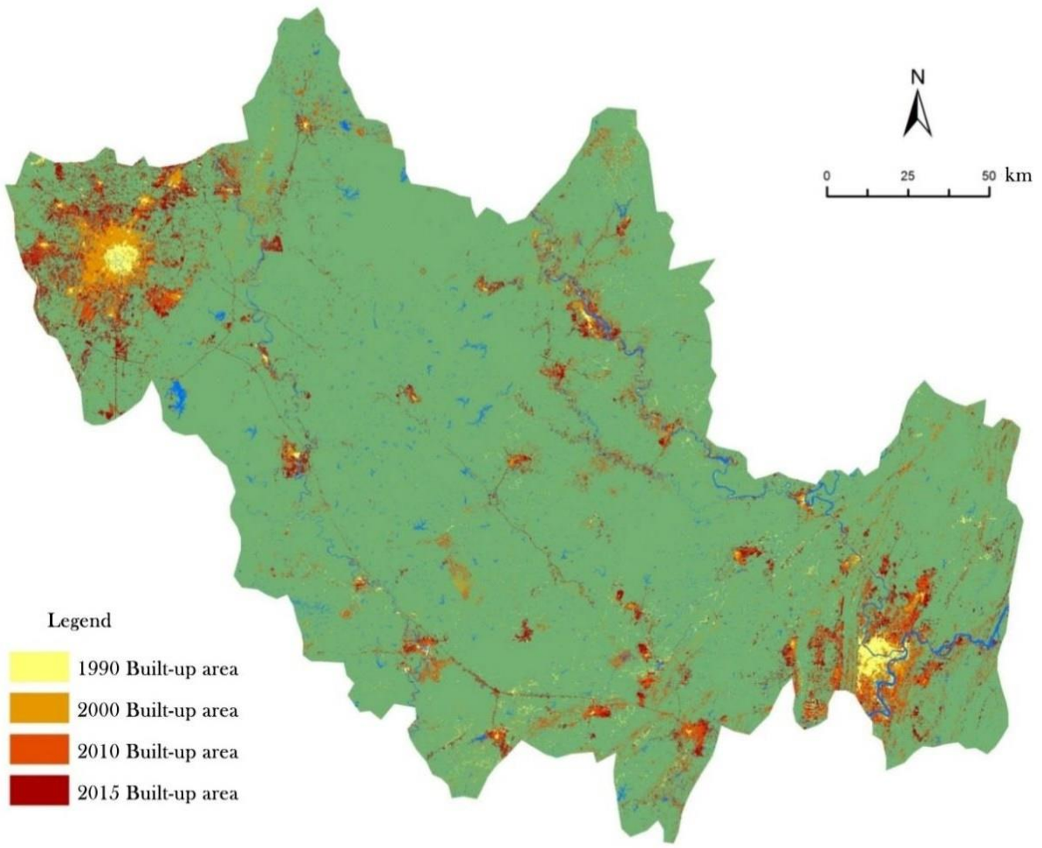

Figure 24 Built-up area change in the four periods. Chengdu-Chongqing urban agglomeration

The study found that the built-up area of Chengdu-Chongqing urban agglomeration has constantly been expanding from 1990 to 2015, but the development speed is distinct in different periods in different cities. This paper compared the statistical data between the urban and the urban agglomerations in Chengdu and Chongqing and points out that the main driving factors to promote the expansion of Chengdu-Chongqing urban agglomeration are population factor, economic factor and traffic factor. However, urban planning and local laws also played an important role in deepening of the expansion of the urban agglomeration. In the end, the paper put forward a constructive planning strategy to guide the development of Chengdu-Chongqing urban agglomeration from the traffic system, industrial adjustment, policy utilization, and so on other angles.

2) Urban sprawl in a megaregional setting: The Yangtze River Economic Belt

To further investigate urban sprawl in the Chinese context, seven large cities in the Yangtze River Economic Belt were compared (Yue et al., 2016). Large cities throughout China are increasingly experiencing urban sprawl. Urban sprawl in Chinese cities has resulted in overwhelming problems, such as inefficient use of urban land, loss of farmland, and environmental degradation, all of which pose challenges to urban sustainability. An integrated framework combining single-indicator and multidimensional-indicator measurements was employed to quantify the magnitude of sprawl. Urban spatial expansion was determined by spatially simulating the built-up area for each city based on DMSP/OLS nighttime light data, population census, and statistical data in 1992, 2000, and 2010. The single-indicator measurement employed a comprehensive metric of growth ratio to represent the mismatch of land expansion and population growth. Multidimensional measurement was composed of three key dimensions of sprawl, namely, low density, discontinuity of land use, and poor accessibility. In most cases, results of the single-indicator measurement were generally consistent with the results of the multidimensional measurement. The case studies demonstrated the applicability of the new measurement framework in quantifying sprawl. They also confirmed that sprawl around Chongqing is among the most extensive, but also that similar processes had taken place around large cities throughout the region. The major features of sprawl, policy implications, and usage of methods were discussed.

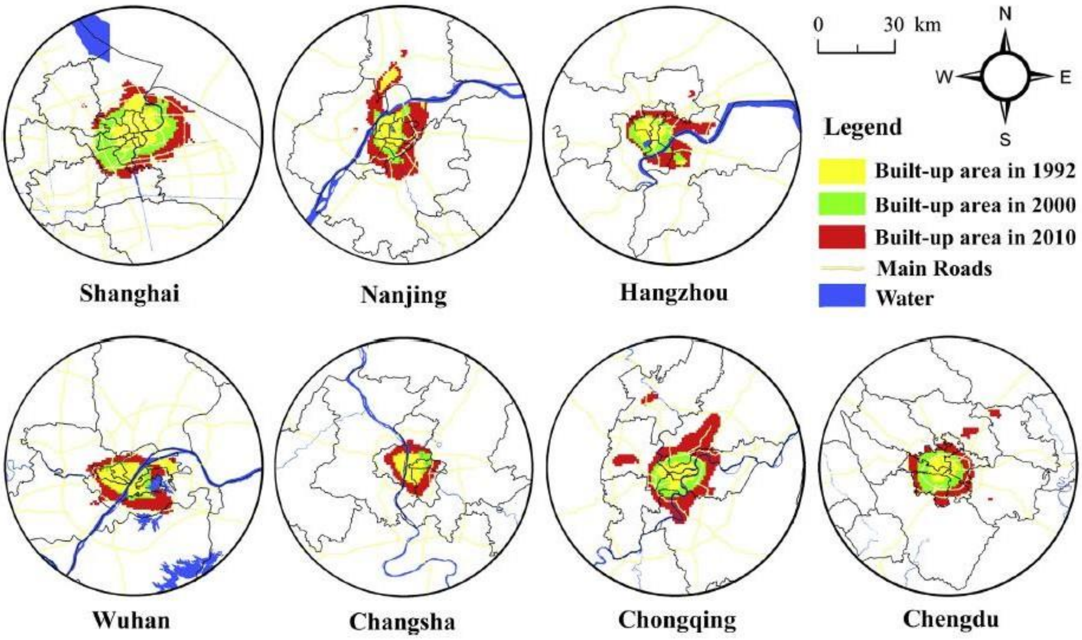

Figure 25 Expansion of built-up area, 1992-2010

3) Megaregional linkages through transportation networks

A further line of research focused on large scale regional drivers of these urbanization patterns, such as dynamics of relations between cities within wider regions. Research on urban agglomerations and regional dynamics in China has been more concentrated in the mature ones in the developed coastal areas, while the inland ones still in developing stage has been largely ignored. Research on inland urban agglomerations, moreover, could be extended to the scale of relations between cities within provinces, the coordination mechanisms, spatial characteristics and development strategy. Exploration of multi-scale city linkages among urban agglomerations within provinces has been lacking. A paper on this topic (Huang, Chen, et al., 2017) explored the city network of the Yangtze River Middle Reaches Urban Agglomeration based on an Interlocking Model, including Wuhan Metropolitan Area, Changsha-Zhuzhou-Xiangtan City Cluster, The Poyang Lake City Cluster and Wan River City Belt. The research was conducted at three scales: sub-region, region and the country scale. The analysis indicated that in the sub-region scale, the three sub-regions differed in their polycentric networks. At the regional scale, the cities were decentralized by size distribution, but the networks among them remained very weak in function. On the country scale, the four regional central cities maintained stronger linkages with the national central city than among themselves. In conclusion, the paper advocated cooperation among the four regions in transportation, infrastructure and governance.

A second paper analysing networks among agglomerations compared patterns between coastal and inland urban agglomerations (Huang, Wang, et al., 2017). This paper focused on two paired, typical coastal and inland urban agglomerations, the Yangtze River Delta Urban Agglomeration and Wuhan Metropolitan Area. Research on urban agglomerations in China has remained limited to coastal regions, such as Yangtze River Delta, Pearl River Delta and the Jing-Jin-Tang, while the inland urban agglomeration has been largely ignored. The comparison measured differences in terms of two types of interurban transportation flows, including passenger flow and information flow based on the urban flow intensity model built on a GIS platform. The result showed that the intensity of the urban flow of inland urban agglomerations was weak compared with that of the coastal ones. Moreover, coastal urban agglomerations are more mature in terms of urban systems, which exhibit polycentric urban forms, while the inland urban agglomeration remained dominated by mono-centric patterns. The conclusion to the article puts forward some suggestions for the inland urban agglomeration's development from the perspective of spatial planning.

4) *Drivers of urban sprawl at the city level*

Uneven land reform and entangled land-use regulations are extensively regarded as the key to urban sprawl in large cities in China. Although the significance of land issues has been substantially recognized, conflicts regarding land finance seem to be a generally under-evaluated factor in explaining the phenomenon of urban sprawl. A further study conducted extensive literature research and proposed a conceptual framework to demonstrate the effects of land financial incentives on urban sprawl in China (Liu et al., 2018). Urban sprawl in China manifests in multiple forms, such as leapfrogged industrial parks, low-density residential communities that are discontinuous from existing urban centres, and chaotic peri-urban informal development. These forms of urban sprawl may be closely associated with failures in government and market forces under the land financial incentives. We used this framework to analyze the experiences of Chongqing and found that local governments have heavily relied on land finance through the proactive approach of land leasing. Stimulated by the incentives, Chongqing has accelerated its urban development beyond the existing restrictions of natural barriers and sprawled toward the peri-urban areas. The causes of urban sprawl were highlighted from the inherent impulses and conflicts of land finance, such as the oversupply of underpriced industrial land at the current loss of land finance, overreliance on the continuously increasing land finance from residential land, and fierce competition on slicing the pie of land finance through formal and informal means. The proposed framework and the challenges of anti-sprawl policies were also discussed

Although uneven land reforms and entangled land-use regulations are acknowledged to play a key role in urban sprawl in China, the analysis of Chongqing stressed the important but less-recognized role of land financial incentives. Since the tax-sharing system reform, local governments play a crucial role in accumulating land revenues and financing urban expansion. Local governments have attempted to generate land revenues from property development, and subsidize manufacturing in industrial parks and finance infrastructure extending to the urban fringes. Stimulated by the overreliance on land finance, urban sprawl was particularly rapid in the peri-urban areas in Chongqing. Multiple forms of urban sprawl are closely related to land financial incentives. For example, industrial sprawl arises from below-cost compensation of industrial land at the current loss of land finance. Low-density residential sprawl is mainly caused by the pursuit of profit from a lump-sum payment of LCFs. Peri-urban informal development is the result of the incentive of profiting of land finance by the rural collectives. Although several policies to control urban sprawl have been employed in Chongqing, their performance appears to ineffective. Therefore, it is crucial for long-term efforts to curb urban sprawl created by strong land financial incentives.

5) Consequences of sprawl for urban environmental quality

A final focus of Chinese research was to scrutinize the environmental consequences and of the sprawl taking place in the regions around major urban centres.

Despite the degradation of the urban environment associated with the rapid urbanization, limited studies had examined the spatial patterns and driving factors of urban environmental quality (UEQ) in mountainous cities in China. The case study of Chongqing measured UEQ in mountainous cities in the dimensions of the physical environment, built environment, and natural hazards, followed by an exploration of its spatial pattern (see Figure). It was found that the UEQ has been significantly affected by the factors of pollution and the densely built environment. Pollution factor was highly correlated with industrial land ratio and land surface temperature, and densely built environment factor bore close relationship with road density, impervious fraction, and floor–area ratio. Through cluster analysis, Chongqing was classified into five UEQ clusters, and their spatial distribution was found as a combined polycentric and mosaic pattern. While mountains and hill ridges, riverside banks, small hills, and streams showed high UEQ indices, valley floors exhibited low UEQ values. Polycentric urban development adapting to mountainous landscapes was believed to contribute to an extremely low UEQ in the urban centre and subcenters. However, polycentricity, leading to appropriate spatial match of jobs/housing, also resulted in high UEQ in the peripheries.

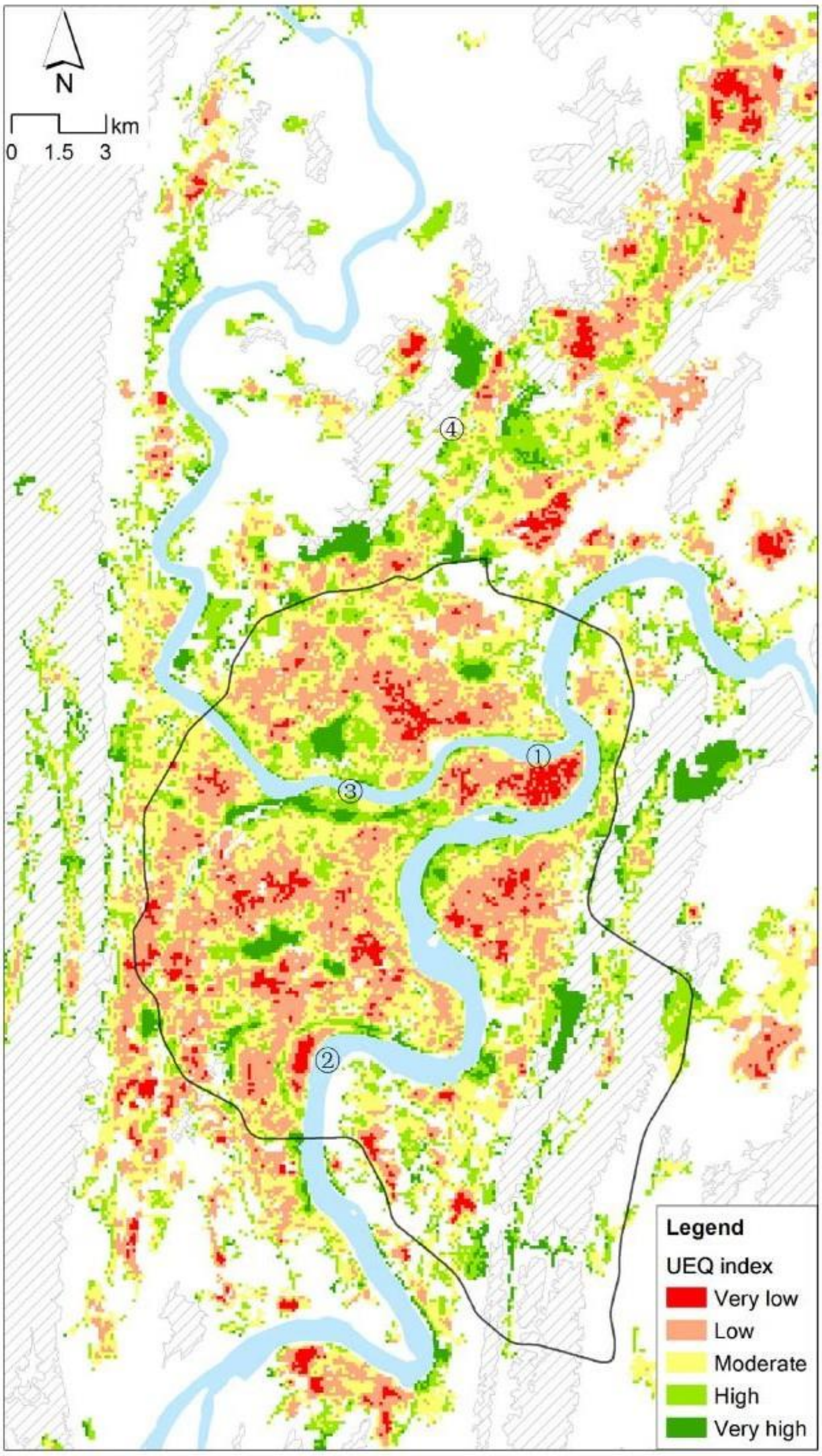

Figure 26 Urban environmental quality (UEQ) in Chongqing, by neighborhood

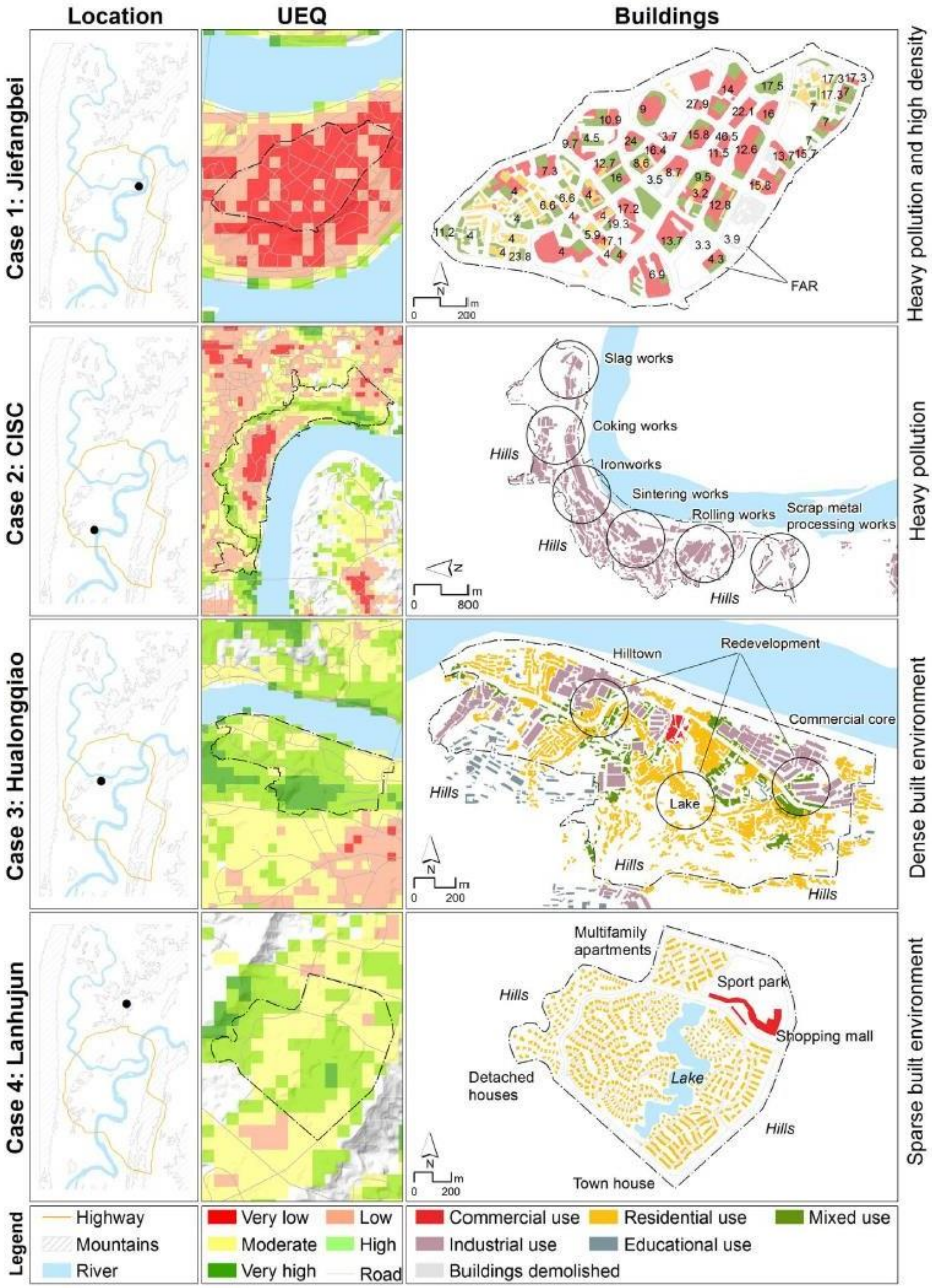

Figure 27 Neighborhood UEQ and its sources: four local case studies.

4. Conclusions

Both China and India face an urban future that is increasingly a reality. In both countries, urban land expansion is now taking place on a regional scale as well as around cities themselves. In both, the spread of urban settlement poses new challenges for environmental quality, for economic productivity, for the quality of life, and ultimately for planning and policy. Different configurations of land and construction markets, governmental structures, legal norms, policies, and planning in each country have produced remarkably divergent patterns of megaregional development and distinctive challenges for each country. Along with matched case studies coordinated between the two countries, the Chinese and Indian teams carried out additional research to illuminate the divergent institutional and economic drivers of urbanization, the different regional patterns it followed, the divergent impacts on environmental change and the policy options available in each setting.

In India, markets for land are dominated by private owners. Although state development authorities often play a pivotal role in the conversion of rural land for urban development, and owners of agricultural land face restrictions, urban land expansion has been a consequence of private as well as public initiatives. Earlier research by the same team showed that much of recent urban land expansion took place through intensified settlement on the outskirts of existing cities. As urban development has expanded, a variety of factors have directed it along transportation corridors outside urban centres. Along both the corridors studied here, this development first emerged through private land market dynamics rather than as a result of planning. It has dispersed increasingly beyond existing urban centres and has concentrated in proximity to rail and road transport networks, to new industrial facilities, to educational institutions and other services. Industrial corridors outside Indian cities have recently been planned and promoted by the Government of India as instruments to achieve accelerated industrial growth by integrating industry and infrastructure and attain agglomeration effects from local concentrations of labour and investment. Current trends in land use indicate that the natural vegetation cover and agriculture lands are declining rapidly along the highways and surrounding the urban centres. It is important to plan, manage and improve land use to conserve natural resources along these corridors, to sustain the ecosystem. Monitoring and quantifying the landscape dynamics along the urbanizing regions are essential for evolving planned strategies towards sustainable development.

In India, this research will help in identifying the future growth poles to design sustainable regions with the provision of essential infrastructure and basic amenities. Environmentally sound urban centres with essential basic amenities and advanced infrastructures (such as sensors, electronic devices and networks) would stimulate sustainable economic growth and improvements in citizen services. The deployment of information and communication technology infrastructures for effective and integrated governance support social and urban growth through the improved economy and active participation of citizens. Indian cities, while exhibiting technological innovations and connectedness, should also focus on increased living comfort through adequate infrastructure, green spaces and essential basic amenities to every citizen.

In China, where land rights have been collectivized, urban land expansion instead takes place through the decisions of public entities or local collective owners, such as the villages. This ownership structure, the fiscal incentives of different owners, and a complex set of regulatory protections on agricultural land have brought about very different regional patterns of urban land expansion. Driven by distinct institutional fiscal logics for industrial development, low-density residential development, and informal housing, urban sprawl across most of the country has concentrated in the regions around large cities. Along urban corridors, it has only taken place in a few nodes beyond the urban centres. In western and central China, as compared to coastal regions, limited interconnectivity among cities has also offered fewer economic incentives to lay the groundwork for development along infrastructure corridors.

Where urban sprawl has concentrated, it has had decidedly mixed consequences for the environment and the quality of life. It has resulted in overwhelming problems, such as inefficient use of urban land, loss of farmland, and environmental degradation, all of which pose challenges to urban sustainability.

In China, the research has taken numerous steps toward providing a view of the distinctive regional urbanization patterns that are emerging and how they vary across the country. Case studies have also illuminated the fiscal incentives and market drivers of these different patterns. Finally, the papers from the project have identified numerous challenges to sustainability that large scale urban development poses in the Chinese context.

5. Future Directions

A complex, multifaceted research program has emerged from this and the previous APN-funded project. One future objective will be to synthesize the results into to a volume comparing urbanization, its drivers and its environmental consequences in these two critical national contexts, along with a possible edited collection to include central papers from the research program.

In both countries, building on this research program has the potential to contribute to emerging policy agendas related to the challenges of urbanization, and its consequences for sustainability. The “Smart Cities” mission launched by the Government of India recently (in June 2015), for instance, envisages developing physical, institutional, social infrastructure in select cities with central assistance targeted at improving the quality of life as well as economic visibility of urban centres. Four strategic components are (i) greenfield development through smart townships by adopting holistic land management, (ii) pan-city development through adoption of smart applications like transport, reuse and recycle of wastewater, smart metering, recovering energy from solid waste, etc., (iii) retrofitting to make existing area more efficient and livable by reducing greenhouse gas (GHG) footprint, improving power and treated water supply, improving communication and infrastructure connectivity and security, (iv) re-development of existing built-up area, creation of new layout through mixed land use, adoption of appropriate floor area index (FAI) considering the level of existing and scope for improvement of infrastructure and basic amenities, which helps in keeping the city’s growth within the region’s carrying capacity and urban infrastructure becomes inclusive.

Extensions of the current project could provide support for many aspects of this mission. In India, effective implementation of the Smart Cities mission would also entail efficient decision making through (i) integrated land use planning as per the city’s requirements considering mobility, etc., to minimize mobility related to jobs; (ii) enhancement of functional capacity through user friendly and economic public transport support; (iii) development of mass rapid-transport systems for easy mobility in inter and intra cities; and (iv) effective use of ICT’s as enabling technologies to improve the level of services. These measures have to be

Implemented quickly as most cities are in civic and financial disarray due to unplanned rapid urbanisation. The performance of the Smart Cities programme in India has also been disappointing, due to misallocation of resources, failure to implement effective governance, and failure to capitalize on the existing IT capabilities in cities.

In China, the project also points to a need to assess the efficiency and sustainability of urban growth in a wider sample of different cities and regions. This can be investigated in several steps: 1) to study the spatial efficiency of urban growth in terms of some spatial metrics, for example, compactness, complexity, open space ratio, etc.al.; 2) to study socio-economic performance through such indicators as GDP, revenue, personal income, and employment; 3) to analyse the correlation between the efficiency of spatial growth and socio-economic performance, and 4) to analyse the relationship of both spatial growth and socioeconomic performance to indicators of environmental sustainability.

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7. Appendix

a. Funding sources outside the APN

1. University of Southern California (in-kind support for administration of grant)($28,250)
2. Lusk Center for Real Estate Research, Sol Price School of Public Policy, University of Southern California ($24,000)
3. Shuyi Cheng, master student, received National Scholarship(20,000 RMB) in 2015
4. Jingnan Huang, National Key Research and Development Program: "Spatial Information Key Service and Application Demonstration of Urban Agglomeration Economic Zone Construction and Management", Theme 4: "Space Development Planning Management and Supporting Decision-Making in Urban Agglomeration Economic Zone", Task 5 (sub-theme): "Ecological Environment Sustainability and Evaluation of Urban Spatial Growth Efficiency of Urban Agglomeration", 2017, (485,000 RMB) (PI), Ministry of Science And Technology of People's Republic of China

b. List of young scientists trained

Name	Task	Note
Bharath H. Aithal, bharathh@iisc.ac.in	Field Work, Land use, Preparation of Database, Rule based model and Agent based Modeling	Graduated, now Assistant Professor at Indian Institute of Technology-Kharagpur
Uttam Kumar, uttam215@gmail.com	Field Work, Land use, Preparation of Database, Rule based model and Agent based Modeling	Graduated, NASA Fellowship, now Assistant Professor at Indian Institute of Information Technology
Yong Liu, ly6505@163.com	Study the environmental change in the micro scale of Chongqing	Promoted to Associate Professor in Southwest University, China
Cunsong Wang	Study The Spatial Pattern Evolution and Driving Forces Analysis of Cheng-yu Urban Agglomeration	Graduated at Wuhan University , China in July 2017, now work at Wuhan Urban Planning Institute
Shuyi Chen	Study The Spatial Pattern Evolution and Driving Forces Analysis of Cheng-yu Urban Agglomeration	Graduated at Wuhan University , China in July 2016, now work at Wuhan Transportation Planning Institute
Chengyue Li	Study environmental change in Wuhan Metropolitan Area	Graduated at Wuhan University , China in July 2016, now work at Cantong Planning Institute

Yue Li, liyue728@gmail.com	Analysis of land use metrics	Ph.D. candidate, USC
Vinay S., svinay@iisc.ac.in	Field Work, Preparation of Database, Rule based model and Agent based Modeling	Ph.D. candidate, IISc
Bharath Settur, setturb@iisc.ac.in	Field Work	Ph.D. candidate, IISc
Haoshi Wang, haoshiw@usc.edu	Remote sensing analysis of exurban zones in India	B.S. in Geodesign expected 2018

c. Conferences/Symposia/Workshops

1) Bangalore Workshop Schedule

Centre for *Infrastructure*, Sustainable Transportation and Urban Planning (C*i*STUP),

Indian Institute of Science, Bangalore 560 012

http://cistup.iisc.ernet.in

Tel:080-22933099, 3503 extn 101/107 (E mail:cestvr@cistup.iisc.ernet.in)

Workshop:

MEGA-REGIONAL DEVELOPMENT AND ENVIRONMENTAL CHANGE IN INDIA AND CHINA

Dates: 12-13 May 2015

Venue: CiSTUP-SID Conference Hall,

Center for *infrastructure*, Sustainable Transportation and Urban Planning (CiSTUP)

Indian Institute of Science, Bangalore 560012, India

Co-ordinators: Ramachandra T V [**cestvr@cistup.iisc.ernet.in]**, Bharath H. Aithal [bharath@ces.iisc.ernet.in], Jefferey M. Sellers [sellers@usc.edu]

Location: Center for *infrastructure*, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore 560012, India

May 10 – 11: Arrival of participants (Resource persons accommodated at IISc Main Guest House, Tala marg, Indian Institute of Science campus, Phone 080-22932289/2293 2311)

Date	Time	Lecture Details
12-05-2015	9:30 am	Inauguration
	9.45 am	Initiatives at CiSTUP – Overview: **J M Chandra Kishen**
	9.55 am	About the workshop:, **T.V.Ramachandra**
	10-1030	**Tea**
	10:30 a.m.	Overview of Comparative Research Program: Urban Development and Environmental Change in India and China – • **Jefferey Sellers** (Department of Political Science and Public Policy, University of Southern California, USA)
	11:00 a.m.	Mega-Regional Development in India: Overview of the Research • **T.V. Ramachandra**, (Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science) • **Bharath H. Aithal**, (Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science)
	12:00 p.m.	Mega-Regional Development in China: Overview of the Research • **Jingnan Huang** (Wuhan University, P.R. China) • **Yong Liu** (Southwest University, P.R. China)
	1 – 2 p.m.	Lunch
	2 – 4 p.m.	Interactive sessions with stakeholders
	4 – 4:30 p.m.	Concluding session
13-05-2015	9:30 a.m.	Development of Urban Corridors in India and China • India: **Bharath Aithal** • China: **Jingnan Huang, Yong Liu** • Discussion: **Jefferey Sellers**
	12 – 1 p.m.	Lunch break

	1 p.m.:	Peri-urban Development Around Indian and Chinese Cities: Research Update and Discussion • **Jefferey Sellers**
	2:30 – 3 p.m	Tea
	3 – 4:30 p.m.	Next Steps and Second Year Activities
14-05-2015	8-6 pm	Field visit (Co-ordinated by Bharath Aithal)

Background: Understanding the regional dynamics and ecological consequences of urban expansion is critical to crafting policies and institutions to manage urbanization. The workshop will deliberate on urban expansion and its environmental consequences at multiple scales in four paired mega-regions of China and India.

Organised by:

- Center for *infrastructure*, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore 560012, India
- Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science
- Asia-Pacific Network for Global Change Research (APN), ARCP2013-22NMY-Sellers
- Department: Political Science and Public Policy, University of Southern California, USA
- Wuhan University, P.R. China
- Southwest University, P.R. China

Meeting Report

12-13 May, 2015 Workshop on Mega-regional development and environmental change in India and China

CiSTUP, EWRG, Asia Pacific Network for Global Change and Research (APN), USC, Wuhan University (China), Southwest University (China)

1. Welcome address and description of CiSTUP's work by Dr. J.M. Chandra Kishen (Chairman, CiSTUP)

2. Overview of the workshop by Dr. T.V. Ramachandra: The objective of the workshop is to gain insights while studying smart cities and industrial corridors (particularly Mangalore-Bangalore-Chennai and Bombay-Pune) in India and their environmental impacts, with lessons from China and the US.

3. Participants were introduced. Representatives from the BMTC (Bangalore Metropolitan Transport Corporation), KSRTC (Karnataka State Road Transport Corporation), KIADB (Karnataka Industrial Areas Development Board) and BDA (Bangalore Development Authority) were in attendance. Further, Assistant Professors (structural engineering) from VDRIT were also in attendance.

4. Speech by Dr. Jeffery Sellers outlining the scope of the project and findings of the first phase. It was found that the growth in China is concentrated but sprawling, whereas

the peri-urban development in India is fragmented and privatized.

5. Dr. T.V. Ramachandra and Dr. Bharath Aithal discussed the trajectory of urban regions of India, through case studies of Delhi, Kolkata, Ahmadabad, Pune, Bhopal, Bangalore and Mumbai. Through spatial data, loss of tree cover, loss of tanks and pattern of urbanization was discussed. The pattern of urbanization was compared with the CDP using FUZZY-AHP-CA Markov analysis and the projections for 2020 were calculated for two scenarios (i) violation of the CDP (ii) improper implementation of CDP. Due to variance from the CDP, urban floods have become common. All cities studied (except Pune and Chennai) urbanized from the centre outwards. Tier 2 cities in Karnataka also showed a very high growth rate. Fuzzy and AHP model, integrated with Cellular Automation was used to project the growth pattern based on proximity to public transport. The resultant suitability maps for (i) built-up (ii) vegetation (iii) other uses took water-bodies as constraints. On validation, it was found that Fuzzy-AHP-CA Markov was the most accurate, though even Geomod is suitable when data is available.
6. Dr. Jingnan Huang presented a paper "*An Exploration in to City Network System of Mega Region Based on Interlocking Model– A case of City Cluster in Middle Reaches of the Yangtze River"*

   This was a study of four city-clusters: (i) Beijing, Tianjin and Heibei (ii) Middle reaches of the Yangtze River (iii) Pearl River Delta (including Hong-Kong) (iv) the Chengdu-Chonquin City Cluster (the biggest inland city cluster)

   The clusters were analysed to determine whether the national strategy of creating city-clusters was correct and it was found that the creation of the Chang-Zhu-Tan cluster was not feasible. The parameters for this analysis included: accessibility, roadways, population, GDP, size, passenger flow, flights, speed trains, every large city and low speed trains. Cities within the cluster were well-linked but cities beyond the clusters were not.. Guangzhou (correct city??)had stronger connections beyond the cluster than within, whereas the reverse was true for Wuhan. Due to poor outside connectivity, the plan to develop the Chang-Zhu-Tan was set aside. The Jianghuai has the highest linkage within the cluster and to adjacent harbours along the river, the links forming a pyramid-like shape. The other two clusters are triangular in shape.

   BREAK FOR LUNCH

7. Paper presentation by Dr. Dr. Yong Liu "*Effect of Urban Development on Environmental Quality in Mountain Cities: The Case of Chongquing, China*"This paper examines the Urban Environmental Quality (UEQ) against the backdrop of rapid development and environmental hazards in the mountain regions. The spatial metrics of Chinese mountain-cities were compared with Chinese flatlands, mountain cities globally and global flatlands. How natural limits and urban development affected UEQ was also studied. UEQ was modeled using this 3-dimensional matric: (i)Physical ecological characteristics: green space, thermal discomfort, air and soil pollution (ii) Natural hazards: River flooding, landslides, sloping development. (iii) Built environment characteristics- industrial land, floor area, impervious. It was found that (i)congestion and pollution affected the UEQ (ii) the growth along the mountains was polycentric (iii) the interplay among the 3 factors modeled impact UEQ (iv) The unique mountain landscape had a significant impact on UEQ and that UEQ was affected by redevelopment.
8. INTERACTIVE SESSION LED BY Dr. T.V. Ramachandra

The topics discussed included the disappearance of greenery, affordability of public transport, design of the bus depots, poor air quality in bus depots, the FAR and City Development Plan (CDP). The BDA stated that they had no control over town-planning, though they have in-house expertise and that implementation of the town plan/ sanction plans granted were beyond their control. The BDA also stated that it would have been possible to revive dead tanks but they never thought of it then.

Interactions with the member from the KIADB showed that the industrial corridor policy was being interpreted differently. The policy spoke of regional development based on the raw materials available whereas the KIADB member understood it as the establishment of any industry. Apart from industrialisation, service facilities were to be created in the corridor.

The issue of the development of buildings over lakebeds was also discussed with the BDA- there was no clarity in whom to approach. The efforts of the US in reducing GHGs and water scarcity were also discussed. How the local authorities would adapt to the sprawl was also discussed.

TEA. MEETING RECONVENED ON 13 MAY at 0900

9. Dr. Jingnan Huang spoke of the spatial and economic trends in the three clusters in the middle reaches of the Yangtze River. The Chengdu (NW)-Chongquing cluster is bounded by mountains, and will be connected by a Nothern and Southern corridor of trains and roadways. The rate of urbanization is very high. Chengdu and Chongqing are both very prosperous, the former hosts service industries and the latter, manufacturing industries. Most investment is in real estate and it is found that the people spend beyond their income. As these cities urbanized, the vegetation decreased by approximately 10% and water bodies by 2% in each 10-year interval. In the question-answer session, the nuclear capabilities of China were discussed and debated. China and the World Nuclear Association used different numbers.

10. Presentation by Dr. Bharath Aithal on the urban dynamics and environmental impact in the (i) Mangalore-Chennai-Bangalore and (ii) Mumbai-Pune regions.

    Each region was modeled with a 10 km buffer using data from village level. The zoning/ break-up of the corridor into regions was discussed. It was debated whether this should be based on a number, or functionally. Even though the corridor is continuous, the proposed activity is not- fragmented based on the raw material output. Chennai is growing more in the outskirts where water is available, and near educational institutions. Between Chennai and Bangalore, there are no plans at the local level, though these areas will also urbanise. While modeling for Pune, slope, elevation, wind speed and direction was taken into account, especially for polluting industries. Projections for Mumbai showed that there would be a spread outside Navi Mumbai by 2020. Found that cities will saturate in CBD by 2030 and high urban build up, with ribbon development along corridors.

11. Discussion oriented in designing and coordinating study led by Dr. Jeffery Sellers

Both India and China had more data on cities but India had village level data which China did not. The county level planning in China did not involve zoning and land use. In both India and China the problems are similar: (i) administrative gap along the cities (ii) no urban government in smaller areas (iii) environmental issues (iv) poor/ lacking regulatory tools. Variables to be used and the standards followed were also suggested, including: policy towards landlords, rehabilitation, land-availablity, . The methods adopted should enable the study of future impact and economic impact. The role and power of Panchayats as a corridor urbanizes (also in places where people commute to work) was discussed.

LUNCH

12. Interactive session: What sort of urban formations would be best? Should there be a megalopolis or non-urbanized areas? Should new cities be created?

13. Smart cities in India is the use of ICT to smooth traffic, police and for public transport. The BMTC was asked how they used technology. Real-time data and accessibility of public transport were problems. The development of brad roads and resultant unplanned development of rural areas (with urban demands) in the US was also discussed. In the US, telecommuting to work altered traffic patterns and being able to interact with the city online enabled prompt action. NYU is analyzing big data from traffic flow and determines how it would influence policies. In the US, ‘smart cities’ were more about finish and smarter growth. In China, it was the use of CCTVs and traffic cameras. The development of passenger rail in the US was also discussed. It was found that people do not rely on cars as much and do use public transport. Light rail and cargo rail in the US have become more popular but the plans for high-speed rail are only in the pipeline. The idea of a smart village and reverse-migration were also discussed. Adaptation of crops to climate change was discussed: the Krishi Bhavan releases farmers’ bulletins and there are several radio programs in regional languages about what to plant, when to plant, possible outbreaks and precautionary measures. California is also facing water shortage and is trying to cut back on agriculture, rotate crops and so on. Piped water in villages in China is common. China faces some water-shortage in the north but diverts the Yangtze River. A member from KSRTC spoke of his dissertation-in-progress on consumer complaints.

CLOSING COMMENTS, DISTRIBUTION OF CERTIFICATES, VOTE OF THANKS AND TEA.

II. LAKE 2016 : Conference on Conservation and Sustainable Management of Ecologically Sensitive Regions in Western Ghats

The 10th Biennial Lake Conference: Wetlands for Our Future
Date: 28th - 30th December 2016

Venue: V.S. Acharya Auditorium, Alva's Education Foundation, Vidyagiri, Moodbidri, D.K. Dist., Karnataka, India - 574227

TECHNICAL SESSION IV: GEOSPATIAL TECHNOLOGIES

http://wgbis.ces.iisc.ernet.in/energy/lake2016/proceedings.php#pr

1. Bharath H. A, Urban Observatories for Enhancing Quality of Urban Life, Proceedings Lake 2016, 28th - 31st December 2016

3. Chandan, M. C, Vinay, S, Bharath H. Aithal, Ramachandra, T.V., Land use assessment and urban growth monitoring in Hyderabad region, India, Proceedings Lake 2016, 28th - 31st December 2016

2) Chongqing Workshop Schedule

College of Resources and Environment,

Southwest University, Chongqing, 400715 P.R. China

http://zihuan.swu.edu.cn/

Telephone: 86-023-68251249, E-Mail: zihuan_b@swu.edu.cn

Workshop:

MEGA-REGIONAL DEVELOPMENT AND ENVIRONMENTAL CHANGE IN INDIA AND CHINA

Dates: 8-9 May 2017

Co-ordinators: Jefferey M. Sellers [sellers@usc.edu], Yong Liu [ly6505@163.com], Jingnan Huang [huangjn73@qq.com], Ramachandra T V [cestvr@cistup.iisc.ernet.in], Vinay S. [vinay@ces.iisc.ernet.in]

Location: Room 1414, The Central Library, Southwest University, Chongqing 400715, P.R. China

May 7: Arrival of participants

May 8

9:00 a.m. Inauguration (Yong Liu)

9:15 a.m. About the workshop, Jingnan Huang

9:30-10:00 a.m. Overview of Comparative Research Program: Urban Development and Environmental Change in India and China

Jefferey Sellers (Department of Political Science and Public Policy, University of Southern California, USA)

10:00-10:30 a.m. Tea

10:30-12:00 a.m. Mega-Regional Development in China: Overview of the Research

Spatial evolution and driving forces in Chengyu urban agglomeration
Jingnan Huang (Wuhan University, P.R. China)
Urban sprawl in China and land financial incentives: The case of Chongqing
Yong Liu (Southwest University, P.R. China)

12:00 a.m.-2:30 p.m.: Lunch break

2:30 - 3:30 p.m. Mega-Regional Development in India: Overview of the Research

T.V. Ramachandra, (Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science)
Vinay S., (Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science)

3:30 – 4:00 p.m. Tea

4:00 – 5:00 p.m. Mega-Regional Development in China: Overview of the Research
Measuring sprawl in large Chinese cities along the Yangtze River
Linlin Zhang (Zhejiang University, P.R. China)
Spatial-temporal change of urban area and terrestrial carbon pool in Three Gorges Reservoir
Jinzhu Wang (Southwest University, P.R. China)

5:00 – 5:30 p.m. Concluding session

May 9

9:00 a.m. Development of Urban Corridors in India and China

India: T.V. Ramachandra, Vinay S.

China: Jingnan Huang, Yong Liu

Discussion: Jefferey Sellers

12 a.m. – 2:30 p.m.: Lunch break

2:30 p.m.: Peri-urban Development around Indian and Chinese Cities: Research Update and Discussion

Jefferey Sellers

3:30 – 4:00 p.m. Tea

4:00 – 5:30 p.m. Next Steps

May 10

8 a.m.-6 p.m. Field visit (Arranged by Yong Liu)

Organized by:
Asia-Pacific Network for Global Change Research (APN), ARCP2013-22NMY-Sellers
Department: Political Science and Public Policy, University of Southern California, USA
Wuhan University, P.R. China
Southwest University, P.R. China
Zhejiang University, P.R. China
Center for infrastructure, Sustainable Transportation and Urban Planning (*CiSTUP*), Indian Institute of Science, Bangalore 560012, India
Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science

d. Remote sensing data employed in Chongqing-Chengdu corridor analysis

Strip Number	Data ID	Date	Cloud（%）
127-38	LT51270381988156BKT00	1988-06-04	0
	LT51270381998279BKT00	1998-10-06	0.05
	LT51270382010216IKR00	2010-08-04	7.3
	LE71270382015286EDC00	2015-10-13	8.7
128-38	LT51280381988179BKT41	1988-06-27	15.91
	LT51280381998302BKT00	1998-10-29	0.87
	LT51280382009140BJC00	2009-05-20	12.58
	LE71280382015197EDC00	2015-07-16	0.24
	LT51290381991242BJC01	1991-08-30	3.88
	LT51290382000107BJC00	2000-04-16	3.93

129-38			
	LT51290382010118BKT01	2010-04-28	14.29
	LE71290382016159EDC00	2016-06-07	1.41

130-38	LT51300381992316BJC00	1992-11-11	2.75
	LT51300382000146BKT00	2000-05-25	27.44
	LT51300382009202BKT00	2009-07-21	38.7
	LE71300382016038EDC00	2016-02-07	8.77
127-39	LT51270391990225BJC00	1990-08-13	86.29
	LT51270392000141BJC00	2000-05-20	5.4
	LT51270392010200BKT00	2010-07-19	50.06
	LE71270392016113NPA00	2016-04-22	4.18
128-39	LT51280391991139BKT00	1991-05-19	0
	LT51280391999129BKT00	1999-05-09	4.49
	LT51280392010079BKT00	2010-03-20	0
	LE71280392016232EDC00	2016-08-19	1.45
129-39	LT51290391988026BKT00	1988-01-26	9.56
	LT51290392001125BJC00	2001-05-05	27.48
	LT51290392010086BKT01	2010-03-27	23.87
	LE71290392016255EDC00	2016-09-11	0.57
130-39	LT51300391992316BJC00	1992-11-11	33.05
	LT51300392000146BKT00	2000-05-25	22.13
	LT51300392009010BKT01	2009-01-10	32.63
	LE71300392015195EDC00	2015-07-14	17.7

e. Transportation connections among Yangtze Region cities

1) Number among major cities in the Yangtze River Delta

City	Shanghai	Nanjing	Wuxi	Changzhou	Suzhou	Nantong	Yangzhou	Zhenjiang	Hangzhou	Ningbo	Jiaxing	Huzhou	Shaoxing	Jinhua
Shanghai	-	159	133	113	140	1	1	76	81	46	58	2	36	8
Nanjing	-	-	126	120	137	2	3	83	56	31	14	37	28	2
Wuxi	-	-	-	98	117	1	1	69	14	11	12	0	10	2
Changzhou	-	-	-	-	117	1	1	54	15	11	12	0	10	2
Suzhou	-	-	-	-	-	1	1	73	15	11	12	0	10	2
Nantong	-	-	-	-	-	-	2	0	0	0	0	0	0	0
Yangzhou	-	-	-	-	-	-	-	0	0	0	0	0	0	0
Zhenjiang	-	-	-	-	-	-	-	-	9	7	9	0	7	2
Hangzhou	-								-	75	44	35	63	10
Ningbo	-	-	-	-	-	-	-	-	-	-	21	16	69	0
Jiaxing	-										-	2	21	5
Huzhou	-	-	-	-	-	-	-	-	-	-	-	-	16	0
Shaoxing	-												-	0
Jinhua	-	-	-	-	-	-	-	-	-	-	-	-	-	-

2) Bus number among major cities in the Yangtze River Delta

City	Shanghai	Nanjing	Wuxi	Changzhou	Suzhou	Nantong	Yangzhou	Zhenjiang	Hangzhou	Ningbo	Jiaxing	Huzhou	Shaoxing	Jinhua
Shanghai	-	3	6	3	13	56	15	1	8	9	4	16	4	2
Nanjing	-	-	19	28	26	34	78	49	12	6	7	8	6	-
Wuxi	-	-	-	36	116	26	16	5	15	8	13	8	5	2
Changzhou	-	-	-	-	13	20	20	3	12	5	5	9	4	3
Suzhou	-	-	-	-	-	46	34	0	69	24	61	39	12	4
Nantong	-	-	-	-	-	-	0	8	8	4	4	2	2	1
Yangzhou	-	-	-	-	-	-	-	56	7	5	2	2	2	0
Zhenjiang	-	-	-	-	-	-	-	-	4	1	2	2	1	0
Hangzhou	-								-	63	40	50	88	16
Ningbo	-	-	-	-	-	-	-	-	-	-	23	3	13	16
Jiaxing	-										-	18	8	2
Huzhou	-	-	-	-	-	-	-	-	-	-	-	-	11	2
Shaoxing	-												-	8
Jinhua	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Tab. High speed railway train number among major cities in Wuhan Metropolitan Area

City	Wuhan	Huangshi	Erzhou	Xiaogan	Huanggang	Xianning	Xiantao	Qianjiang	Tianmen
Wuhan	-	8	5	10	0	38	10	22	21
Huangshi	-	-	2	0	0	0	0	1	0
Erzhou	-	-	-	0	0	0	0	0	1
Xiaogan	-	-	-	-	0	1	0	0	0
Huanggang	-	-	-	-	-	0	0	0	0
Xianning	-	-	-	-	-	-	0	1	0
Xiantao	-	-	-	-	-	-	-	5	4
Qianjiang	-	-	-	-	-	-	-	-	10
Tianmen	-	-	-	-	-	-	-	-	-

Tab.Bus number among major cities in Wuhan Metropolitan Area

City	Wuhan	Huangshi	Erzhou	Xiaogan	Huanggang	Xianning	Xiantao	Qianjiang	Tianmen
Wuhan	-	46	37	22	-	15	28	5	4
Huangshi	-	-	24	-	0	0	0	1	0
Erzhou	-	-	-	3	1	7	0	4	1
Xiaogan	-	-	-	-	1	1	1	1	3
Huanggang	-	-	-	-	-	2	1	4	4
Xianning	-	-	-	-	-	-	0	1	0
Xiantao	-	-	-	-	-	-	-	1	1

Qianjiang	-	-	-	-	-	-	-	-	3
Tianmen	-	-	-	-	-	-	-	-	-

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