FINAL REPORT for APN PROJECT
ARCP2009-05CMY-Sellers

Peri-Urban Development and Environmental Sustainability: Examples from China and India

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Minimum 2pages (maximum 4 pages)

Non-technical summary

Large-scale urban development is likely to be one of the primary sources of environmental change in Asia over the next decades, and more of this development will take place in India and China than in any other two countries. Understanding the dynamics and the ecological consequences of urban expansion is critical to crafting policies and institutions to manage it properly. Comparative analysis of these processes within and between different countries is an indispensable prerequisite to such an understanding.

This study has assembled remote sensing, demographic, environmental and other data over a period of forty years for a systematic comparison of urbanizing regions in China and India. Data on trajectories of urban development in parallel samples of 10 Chinese and 10 Indian cities over 1970-2010 were compared to examine how urban forms have changed and the consequences for environmental change.

The analysis has revealed strikingly different transformations of urban form in Chinese and Indian urban regions. In China peri-urban expansion has proceeded consistently regardless of city size in coastal regions with strong external investment, but less systematically in some inland regions and little in others. In India, peri-urban expansion has been less dramatic and has varied less between regions with higher and lower external investment. Indian patterns of peri-urban expansion also differ systematically from corresponding Chinese patterns.

The sources of these variations in different land market institutions, policymaking structures, national policy, infrastructure investment, transnational investment flows and patterns of rural-urban migration. Detailed qualitative and quantitative case studies in several paired urban regions of China and India have scrutinized these dynamics more closely. Meetings with stakeholders in both countries have provided lessons for policy and aided the analysis. Results have also been presented at the IHDP Conference on Urbanization and Global Environmental Change and other international scientific fora.

Objectives

The main objectives of the project were:

1. To build a research team and database for the study of urban development and its environmental consequences in Asia-Pacific countries.
2. To train researchers in the integrated analysis of socioeconomic and remote sensing data, and in cross-national comparative analysis of urban development patterns in developing countries.
3. To compare overall patterns of urban development and their environmental consequences among a similar selection of ten cities in the two largest, fastest developing countries.
4. To compare the drivers of peri-urban development, their causes and their consequences at the micro or neighborhood scale using high-resolution data in intensive case studies of emerging urban regions in each country.
5. To generate two scholarly papers based on each of the analyses of c) and d), and lay the groundwork for additional publications, research, and policy or planning tools.
6. To meet with stakeholders to present results and address policy alternatives.

Amount received and number years supported

The Grant awarded to this project was:
US$ 40,000 for Year1, 2008-2009;

US$ 40,000 for Year 2, 2009/2010.

Activity undertaken

Understanding the dynamics and the ecological consequences of urban expansion is critical to crafting policies and institutions to manage it properly. Comparative analysis of these processes in different countries is an indispensable prerequisite to such an understanding. This study collected remote sensing, demographic, environmental and other data over a period of 40 years, from the early 1970s to 2010. Data on 20 selected Chinese and Indian cities were used to compare overall variations. Detailed case studies in 6 paired peri-urban regions in China and India enabled closer examination of the microdynamics of change on the urban fringe. Several types of analysis were carried out: (1) comparative mapping of peri-urban development, (2) comparative explanation of the local, regional and national variation in peri-urban dynamics, (3) examination of the effects from urban developmental pathways on environmental degradation, (4) policy-relevant findings, and local and international capacity-building workshops. Fieldwork provided ground-truth checks and aided data collection.

Results

Both the macro analysis and the micro case studies have converged around similar conclusions. Although China and Indian have experienced parallel trajectories of land market liberalization and peri-urban expansion, urban development has proceeded under the influence of distinct social, institutional and policy conditions. These influences have reinforced and even magnified divergences in the patterns of urban expansion. The macro-level comparative perspective of this study enabled the first systematic comparative overview of these patterns, and an assessment of their wider consequences for peri-urban development.

In China, a variety of institutional, social and economic conditions that have set distinctive terms of peri-urban development from those in India. Conditions of state control might be expected to enable a more controlled process of urban expansion. The macro-level findings demonstrate how the state-dominated development process has in certain circumstances created powerful growth machines that have driven peri-urban expansion far beyond the extent evident in Indian cities. Peri-urban expansion has also brought fragmented, sprawling, systematically complex and irregular patterns of development on the urban fringe. These consequences have proven especially dramatic in the coastal cities where Special Economic Zones have been established and economic growth has occurred fastest, but have increasingly occurred around inland cities as well. Closer examination indicates that these patterns contribute to widespread inefficiencies in land use that have been the object of numerous critiques and recent attempts at reform. Even as new peri-urban development has often preserved or restored a portion of the original open space, expanded development has further degraded land and water resources as well as the potential of remaining agricultural land.

In India, peri-urban development has followed what appears from the micro perspective to be a more disordered course. Although state interventions in delimited economic development zones often drive peri-urban development, they do not determine its shape or even its intensity. Particular firms and households, including software enterprises, manufacturers, real estate developers and even individual property owners, influenced by available property, infrastructure, and land rents, have shaped peri-urban development.

From a macro perspective, the process of peri-urban expansion in Indian urbanizing regions has proceeded more slowly than in Chinese counterparts despite equally dramatic growth in urban populations. In urban regions of greater sprawl, such as Bangalore and Delhi, intensification and infill development have matched and partly counterbalanced ongoing expansion. Greater compactness, less irregularity in shape along the urban border, and retention of small rural village centers in the exurban periphery mark the overall Indian patterns of peri-urban development.

The deficiencies in infrastructure, the environmental degradation, the poverty and the lack of basic urban services on much of the periphery of Indian cities pose difficulties that in many ways exceed those on the urbanizing border of Chinese cities. But the amount of peri-urban land exploited for development remains more limited, and the more compact, more intensified forms of development there could ultimately produce the basis for more efficient and more sustainable cities.

Relevance to APN's Science Agenda and objectives

Expanding urban regions have emerged as one of the major anthropogenic sources of global environmental change. Urbanization brings numerous stresses to landscapes, vegetation, natural habitats, soil, air and water. Much of urban growth worldwide in the next decades will take place in China and India.

This research undertakes a pioneering comparative application of remote sensing and GIS to analyze urbanization and its effects on land use and ecosystems in multiple regions of these two large, diverse nations. As a comparative study that has aggregated data from a two-country, stratified sample of cities, the study represents an important step beyond single case studies or global datasets toward context-sensitive accounts of the macro-level dynamics of urban change and their consequences. Models of expected urban developmental trajectories and assessments of alternative policies and institutions have contributed to capacity building that can make urbanization more sustainable. Regional workshops with diverse stakeholders as well as participation in international intergovernmental and academic forums have reinforced capacity building and helped validate the analyses.

Self evaluation

The project has succeeded in its objectives of building a collaborative international research team, carrying out the first multicity comparative study of Chinese and Indian urban development, generating five conference papers for publication, building capacity for further research, meeting with stakeholders, and networking with other researchers in the area.

Potential for further work

Plans for further work include additional studies of the sources of peri-urban development patterns, studies of the ecological consequences from different development patterns, studies of the contribution of urban form to greenhouse gas emissions, and agent based modeling of urbanization trajectories to derive lessons for planning.

Publications (please write the complete citation)

Sun Sheng Han, "Urban Expansion in Contemporary China: What Can We Learn From a Small Town?" *Land Use Policy* 27(3)(2010): 780-787.

Jingnan Huang, Jefferey Sellers and XiXi Lu, "Chinese Urban Form in the Past Three Decades: Pattern and Process," paper presented at Planning Conference, Shanghai, China, July 2009 and First Urbanization and Global Environmental Change Conference, Tempe, Arizona, USA, October 2010.

Jefferey Sellers, Jingnan Huang, T.V. Ramachandra and Uttam Kumar, "Forty Years of Changing Urban Form in China and India: A Twenty-City Analysis," presented at First Urbanization and Global Environmental Change Conference, Tempe, Arizona, USA, October 2010.

Jefferey Sellers, T.V. Ramachandra, Jingnan Huang and Uttam Kumar, "Agents of Peri-urban Change in China and India: Evidence from Two Cities," Paper to be presented at IALE Conference, Beijing, China, August 2011.
Uttam Kumar and T.V. Ramachandra, "Axes of Peri-urban Change in an Indian City," Paper presented at First Urbanization and Global Environmental Change Conference, Tempe, Arizona, USA, October 2010.

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TECHNICAL REPORT

Minimum 15-20 pages (excluding appendix)

Preface

Large-scale urban development is likely to be one of the primary sources of environmental change in Asia over the next decades, and more of this development will take place in India and China than in any other two countries. Understanding the dynamics and the ecological consequences of urban expansion is critical to crafting policies and institutions to manage it properly. Comparative analysis of these processes within and between different countries is an indispensable prerequisite to such an understanding.

This study has assembled remote sensing, demographic, environmental and other data over a period of forty years for a systematic comparison of urbanizing regions in China and India. Data on trajectories of urban development in parallel samples of 10 Chinese and 10 Indian cities over 1970-2010 were compared to examine how urban forms have changed, and the consequences for environmental sustainability.

The analysis has revealed strikingly different transformations of urban form in Chinese and Indian urban regions. In China peri-urban expansion has proceeded consistently regardless of city size in coastal regions with strong external investment, but less systematically in some inland regions and little in others. In India, peri-urban expansion has been less dramatic and has varied less between regions with higher and lower external investment. Indian patterns of peri-urban expansion also differ systematically from corresponding Chinese patterns.

The sources of these variations lie in different land market institutions, policymaking structures, national policy, infrastructure investment, transnational investment flows and patterns of rural-urban migration. Detailed qualitative and quantitative case studies in paired urban regions of China and India have scrutinized these dynamics more closely. Meetings with stakeholders in both countries have provided lessons for policy and aided the analysis. Results have also been presented at the IHDP Conference on Urbanization and Global Environmental Change and other international scientific fora.

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1.0 Introduction

In the next half century, the vast majority of global population growth will center in the rapidly urbanizing areas of the developing world. Urban development in these areas has already emerged as one of the most important anthropogenic causes of global environmental change. Worldwide, the largest proportion of urban growth in the coming decades will occur in China and India. The forms that urbanization takes there will be a consequence of technological, economic, social, and political forces that are still only partly understood. Urbanization can have positive consequences for efficient resource use. But it often leads to fragmented and inefficient settlement, insufficient infrastructure, loss of prime agricultural land, vegetation and open space, threats to ecologically sensitive habitats, deterioration of air, water and soil quality, and growth in greenhouse gas emissions. This project developed analyses and a database to fill crucial gaps in knowledge about urbanization and its environmental consequences in two critical settings.

Urban populations are currently growing at about one percent per annum in China and 2.3 percent per annum in India. The United Nations projects that India's urban population will increase from 28.3 percent in 2003 to 41.4 percent by 2030, and China's from 40.5 to 60.5 percent.[1] In both countries, a growing body of research has harnessed new technologies of remote sensing and GIS to describe pathways of urban and peri-urban development in individual urban regions. Yet this existing research has been slow to exploit the potential of precise metrics from these new technologies for systematic comparison of urban developmental pathways and the associated environmental change. Gaps in existing knowledge about these pathways are especially severe for the mid-size urban regions where the biggest proportion of the urban population lives. Comparative analysis holds the potential to illuminate the social, economic and institutional sources of both urban developmental pathways themselves and their consequences for environmental sustainability.

Work on urbanization in developing countries has generally been based on global samples that include a wide variety of world regions,[2] or on case studies that focus on a single country, sub-national region or city.[3] Growing communities of researchers have examined urban development and its consequences within India[4] and within China[5]. But to date, researchers working on both countries have proceeded in mutual isolation. Comparative research designs that systematically test the consequences of national, regional and local contexts and planning strategies remain exceedingly rare.

To fill this gap, the project analyzed urban developmental pathways and the environmental consequences of development on the urban fringe in a stratified sample of Chinese and Indian urban regions. Comparative analysis was employed to illuminate effects from land use markets and state interventions as well as the demographic, social and cultural sources of urban developmental pathways, and the consequences for selected environmental consequences. The results should generate arrangements for projections of the consequences from future developmental trajectories, and provide arrangements for making urbanization more sustainable.

The extraordinary size and diversity of these countries necessitate a research design that can encompass the wide variety of local urban development trajectories as well as national and global

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[1] United Nations, 2005.

[2] Schneider, 2006; Angel et al, 2005; Huang, Lu and Sellers, 2007.

[3] Seto and Fragkias, 2005; Ramachandra, 2002.

[4] Jyothimani 1997; Lata et al. 2001; Subudhi et al. 2001 ; Sudhira et al. 2004; Sudhira et al. 2003.

[5] Zhang 2005; Chen, 1996; Gaubatz, 1999; Han, 2000; Han 2004; Han and He 2000; Han and Wang 2003; Logan, 2001; Logan, et al.1999; Wu, 2002a, 2002b; Xu, 2001; Yeh and Wu, 1995; Seto and Fragkias 2005.

tendencies. Within both countries, a vast regional and local divergence among developmental pathways indicates the importance of regional and local conditions. In both, regions with growing investment have experienced some of the most dramatic peri-urban expansion[6]; local state initiatives to extend infrastructure or to build new settlements have shaped development patterns[7]; and trajectories of unplanned development have assumed a variety of forms[8].

In both countries economic liberalization, government decentralization, and local planning have generally fostered aggressive pursuit of urban development among local and intermediate level officials. In both, poor rural residents have moved in growing numbers to the cities, and new development is expanding into peri-urban regions[9]. Yet important national institutional and economic differences also persist. Chinese local governments possess institutional instruments to control new peripheral settlement that Indian local governments usually lack,[10] but these very instruments may undermine the sustainability of developmental trajectories[11]. Legal rules and planning practices that surround private property in India have also remained limited in China.[12] Chinese residency restrictions, although recently partly relaxed, may still limit movement of rural residents to the cities.[13] Previous research by this team pointed to more fragmented, more haphazard peri-urban settlement in India than in China.[14]

This project undertook to advance analysis of these variations beyond the proliferation of one- or two-city studies that currently characterizes the literature[15]. A nested research design combined a sample designed to capture the wide variation of urban trajectories within each country with paired case studies selected for closer scrutiny. This design enabled the analysis to sort out influences on urban development pathways and the environment at global and national as well as regional and local scales.

2.0 Methodology

The study employed remote sensing and GIS to map land use transformations and environmental degradation on the urban periphery of 20 Chinese and Indian urban regions. Local demographic, environmental and administrative data supplemented this information. A macro analysis used LANDSAT remote sensing data on a sample of twenty urban regions with populations over one million. Based on this sample, six peri-urban districts in India and China were selected for paired comparative case studies. Case studies will be analyzed using fieldwork and various data sources for (1) patterns in higher resolution remote sensing data (Google Earth) (2) sources of national, regional and local differences in patterns of urban development, (3) consequences for environmental

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[6] Shaw and Satish 2005; Yu and Ng 2006.

[7] Yu and Ng 2006; Cheng and Messer 2003; Iyer et al. 2003.

[8] Schneider, Seto and Webster, 20003; Sudhira et al., 2004, 2005; Xiao et al. 2006.

[9] E.g., Shaw and Satish 2007; Wu and Yeh 1997; Xiao et al. 2006.

[10] Yeh and Wu, 1995; Han, 2000; Seto and Fragkias, 2005.

[11] Han, 2007.

[12] Kundu, 1997; Ramachandran, 1989; Webster 2002; Han and Wang 2003; Zhang, 2005.

[13] Gaubatz, 1999; Wu, 2002.

[14] Huang, Lu and Sellers, 2007.

[15] Young et al. 2006.

degradation (green space and farmland depletion, impermeable surfaces, fragmentation of landscapes). Regional workshops with stakeholders enabled validation and contributed to capacity-building.

a. Macro data analysis.

Case selection for twenty-city analysis. The selection of the twenty urban regions for analysis was designed to provide a parallel comparative overview of patterns in each national setting. The samples in each country, the samples encompass several types of urban regions and developmental trajectories (Table 1):

The sample encompasses all the megacities (with populations of 10 million or more) in each country: Beijing and Shanghai in China, and Delhi, Kolkata and Mumbai in India. In both countries these cities include the national capital agglomeration. As the largest, most built out agglomerations, these urban regions were among the first to experience rapid peri-urban expansion. Over the period of the study their population growth rates have generally averaged lower than the national urban average, and in the last decades sprawl has generally proceeded more slowly than in some smaller urban regions. Delhi presents an important exception.

Beyond the biggest urban concentrations, the sample extends to a range of the regional urban centers with populations of 3.5 to 8 million in each country, including six of the ten next largest cities in China (Guangdong, Wuhan, Chengdu, Xi'an, Nanjing and Haerbin in China, and all five of the next largest cities in India (Chennai, Bangalore, Hyderabad, Ahmadabad and Pune). Rapid growth in many of these cities is in the process of transforming them into megacities over the next several decades. In both countries the cities in this group feature a variety of developmental trajectories, economic bases and regional locations.

A final group of cities range between one and three million in population (Hangzhou and Zhengzhou in China, and Bhopal and Coimbatore in India). (Note that the narrower administrative boundaries of the Indian cities make urban regions with smaller populations there more comparable in urban form to Chinese cities with larger populations.)

Several additional criteria in addition to size enabled controls for a variety of economic and social variables in the process of selection. In each country, both the regional centers and smaller cities included some with population growth rates above the national average for cities over 1980-2005, and others with rates below average (Table 1).

The selection also encompassed the urban regions with the most intensive foreign direct investment (Guangdong, Nanjing and Shanghai in China, and Bangalore, Pune, Hyderabad and Chennai in India) as well as ones with low levels (Chengdu, Xi'an and Haerbin in China and Ahmadabad, Bhopal, and Coimbatore in India)

Centers of developing information technology industries (Hangzhou in China or Bangalore and Pune in India) can also be compared in each country with centers of manufacturing (Guangdong, Zhengzhou and Haerbin in China, or Chennai, Bhopal and Coimbatore in India).

Table 1: Population and growth of macro case study cities since 1980

	Population							Growth rates (%)						
Chinese cities:	1980	1985	1990	1995	2000	2005	2010	1975-80	1980-85	1985-90	1990-95	1995-2000	2000-05	2005-10
Shanghai	7608	7901	8205	10423	13243	14503	14987	0.76	0.76	0.76	4.79	4.79	1.82	1.7
Beijing	6448	6890	7362	8486	9782	10717	11106	1.33	1.33	1.33	2.84	2.84	1.83	1.82
Guangzhou, Guangdong	3005	3417	3918	5380	7388	8425	8829	2.34	2.57	2.73	6.34	6.34	2.62	2.29
Wuhan	3072	3458	3833	5053	6662	7093	7243	2.84	2.37	2.05	5.53	5.53	1.26	1.23
Chengdu	2293	2639	2955	3403	3919	4065	4123	3.65	2.81	2.26	2.82	2.82	0.73	0.97
Xi'an, Shaanxi	2047	2429	2873	3271	3725	3926	4009	3.54	3.43	3.35	2.6	2.6	1.05	1.24
Nanjing, Jiangsu	2076	2302	2611	3013	3477	3621	3679	1.38	2.06	2.52	2.87	2.87	0.81	1.04
Haerbin	2467	2702	2991	3209	3444	3566	3621	1.51	1.82	2.03	1.41	1.41	0.7	1.02
Hangzhou	1164	1291	1476	1887	2411	2831	3007	1.18	2.08	2.68	4.91	4.91	3.21	2.88
Zhengzhou	1368	1542	1752	2081	2472	2590	2636	2.17	2.4	2.56	3.44	3.44	0.93	1.11
Average all Chinese cities	949	1074	1240	1444	1726	1909	1985	2.60	3.16	3.54	3.33	3.34	2.11	2.09
Indian cities:	1980	1985	1990	1995	2000	2005	2010	1975-1980	1980-1985	1985-1990	1990-1995	1995-2000	2000-2005	2005-2010
Mumbai (Bombay)	8658	10341	12308	14111	16086	18202	18978	4.02	3.55	3.48	2.73	2.62	2.47	1.96
Delhi	5558	6769	8206	10092	12441	15053	15926	4.56	3.94	3.85	4.14	4.18	3.81	2.45
Kolkata (Calcutta)	9030	9946	10890	11924	13058	14282	14787	2.71	1.93	1.81	1.82	1.82	1.79	1.74
Chennai (Madras)	4203	4748	5338	5836	6353	6918	7163	3.05	2.44	2.34	1.78	1.7	1.71	1.77
Bangalore	2812	3395	4036	4744	5567	6465	6787	5.74	3.76	3.46	3.23	3.2	2.99	2.24
Hyderabad	2487	3209	4193	4825	5445	6117	6376	3.52	5.1	5.34	2.81	2.42	2.32	2
Ahmedabad	2484	2855	3255	3790	4427	5122	5375	3.84	2.78	2.62	3.04	3.11	2.92	2.23
Pune (Poona)	1642	1998	2430	2978	3655	4411	4672	3.99	3.92	3.91	4.07	4.09	3.76	2.55
Bhopal	655	831	1046	1228	1426	1644	1727	5.75	4.75	4.6	3.21	3	2.84	2.31
Coimbatore	907	995	1088	1239	1420	1619	1696	2.25	1.85	1.79	2.6	2.73	2.62	2.23
Average all Indian cities	1115	1316	1553	1800	2086	2404	2522	4.24	3.73	3.66	3.15	3.07	2.91	2.34

SOURCE: United Nations 2007

The sample in each country includes a variety of regional cultures, mixes of policy and planning strategies and topographies. Visual inspection of remote sensing images was also employed to screen out cases that might complicate either the twenty city analysis or any eventual paired comparisons. Beyond the largest urban regions for each country, the selection process excluded urban regions in which mountainous surroundings or irregular coastlines posed natural barriers that would make the spatial metrics there incomparable to those for the other urban regions.

Figure 1. Selected Chinese Cities

Remote sensing images. Images in four periods, including Late 1970s(or early 1980s), Late 1980s(or early 1990s), Late 1990s(or early 2000s), and Present, were downloaded from the GLCF (Global Land Cover Facility) or the USGS(U.S. Geological Survey) which offers comprehensive, free satellite images of places worldwide(Table 1). Those missing from these two sources were collected from the China Remote Sensing Satellite Ground Station(CRSSGS) and the Indian Remote Sensing agency.

To enable a general and consistent analysis, spatial consistency among images from various sources had to be assured. Images from GLCF and USGS apply UTM/WGS84 system while those from CRSSGS use Gauss-Kruger/Beijing 1954 system. All images were thus re-projected into UTM/WGS84 given the condition that most of the images adopted it. MSS, TM, ETM images with different spatial resolution, were resampled into the same size of 30 meter. Such operation in spatial resolution consistency is critical for the computation of some spatial metrics especially for those bear relevance to edge (boundary) features such as fractal dimension and compactness index.

Figure 2. Selected Indian Cities

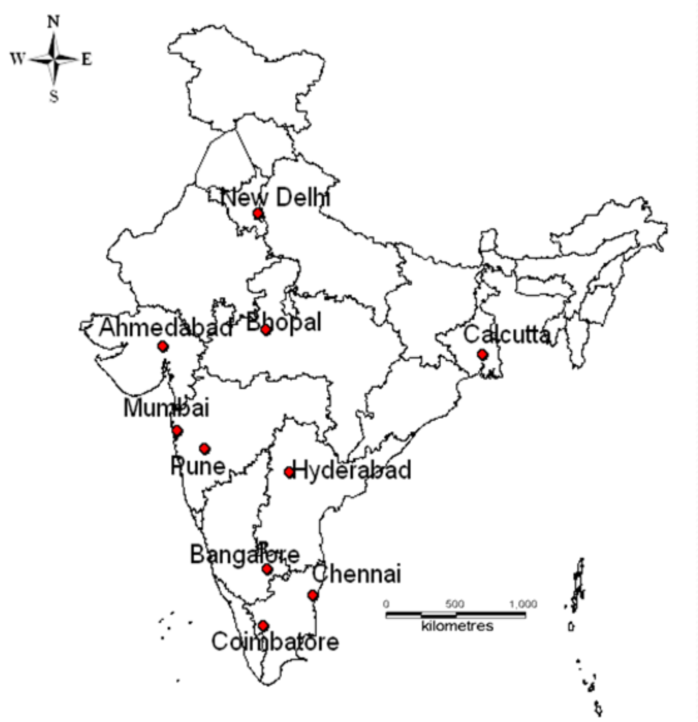


Table 2. Images downloaded for Chinese cities

City	late 1970 or early 1980s	late 1980 or early 1990s	late 1990 or early 2000s	Present
Beijing	19780920	19881215	19990802	20070528
Chengdu	19780821	19920816	20001102	20070506
Guangzhou	19791019	19901013	20000914	20061110
Hangzhou	19780705	19910723	20001011	20070329
Harbin	19760828	19890912	19991018	20070829
Nanjing	19790806	19880705	20000916	20070726
Shanghai	19790804	19890811	19991103	20070728
Wuhan	19781016	19890211	20010722	20060829
Xi'an	19780819	19880823	19990814	20060809
Zhengzhou	19790521	19880514	19991129	20070519

Table 3. Images downloaded for Indian cities

	1970s	1980s	1990s	2000s
Ahmedabad	1975	1981	2000	2010
Bangalore	1972	1992	1999	2010
Bhopal	1977	1992	2000	2010
Chennai	NA	1991	2000	2006
Coimbatore	1973	1989	1999	2002
Delhi	1972	1980	1992	2010
Hyderabad	1973	1989	1999	2009
Kolkata	1977	1981	1999	2010
Mumbai	1973	1992	1998	2009
Pune	1977	1992	2000	2010

As each scene of satellite image covers a huge area, the urban regions were clipped respectively according to the latest developed area indicated by the final images. Subset image increase the accuracy of classification as land use types in the clipped image are relatively limited compared to the whole scene. Four land use types were classified, including vegetation(e.g. forest, shrubbery, grassland and growing agricultural plants), urban area, water bodies, and others (except for the former three land use types). Images combination of 3,2,1 bands for MSS , and 4, 3, 2 bands for TM and ETM in RGB was made. Such combination facilitated the differentiation of urban area from the non-urban area as the urban area appeared bluish-grey to steel-grey.[16] Supervised classification of Maximum Likelihood was carried out with the same probability of 0.99 (i.e. value lower than this threshold was assigned into “other” type) . Three land use types, including vegetation, urban area, water bodies which are easy to interpret from the images were classified, and all the other land use types which are not of concern to our research and are also difficult to discern were aligned into the types of “Others”.

Post classification including clump and eliminate was applied to remove noises and dissolve the spurious pixels within a large single class patch. Image processing were implemented in ENVI 3.5, a professional remote sensing platform of RSI (Research Systems Inc.), and post classification were finished in Erdas 8.6. Afterwards, classified images were transformed into “shape” files, and introduced into ArcGIS 8.3, a GIS package of ESRI (Environmental Systems Research Institute, Inc) for further edition. The clipped urban image was superimposed as the background for correcting misclassification.

16 Gupta and Prakash, 1998.

Figure 3. Flowchart for image processing for Chinese data

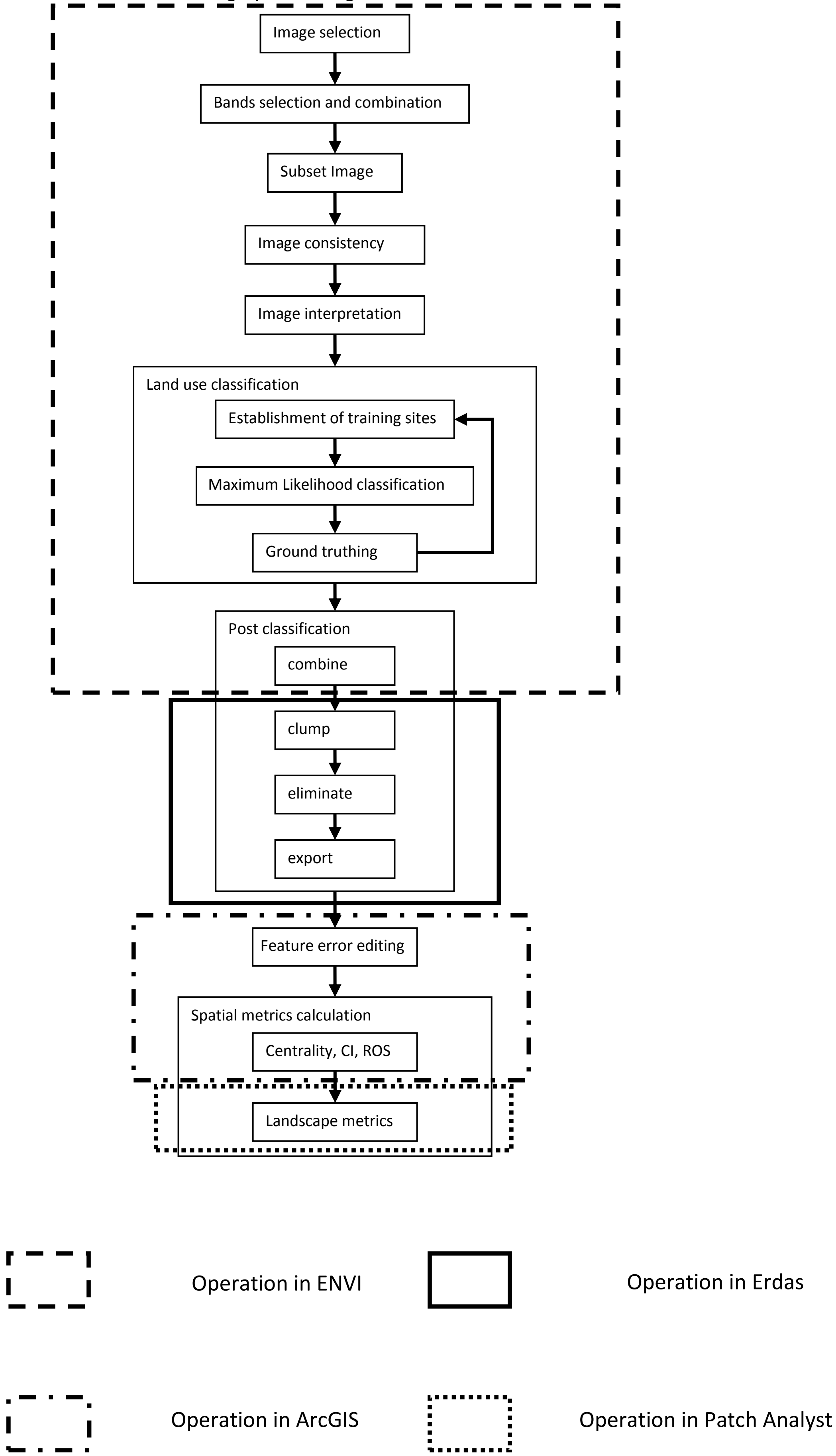
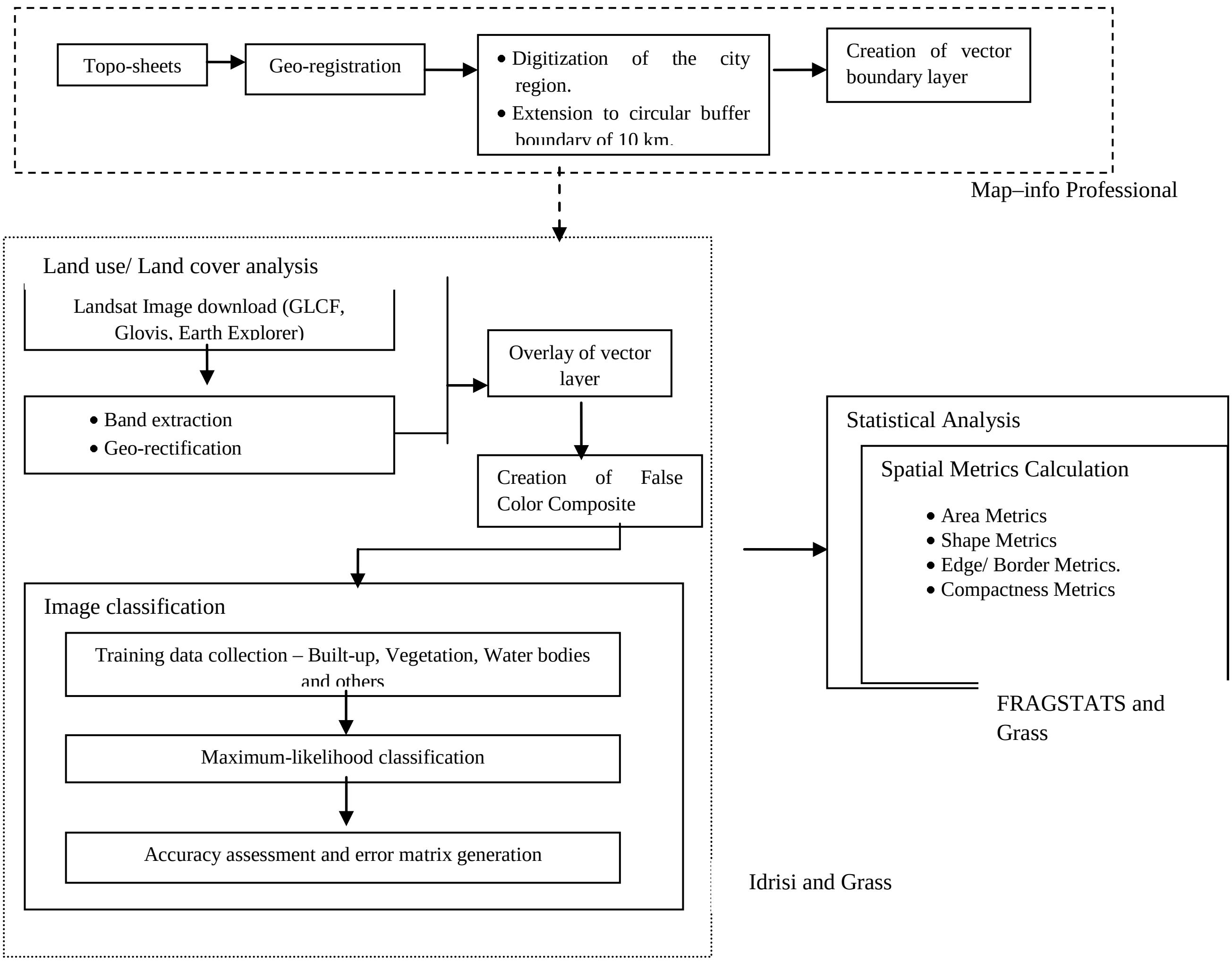


Figure 4. Flowchart for Image Processing and Analysis, Indian Cities



Spatial metrics

Landscape metrics are imperative tools for understanding the structure, function and dynamics of landscapes and thus have a pivotal role in quantifying any kind of landscape. They are used to assess the heterogeneity of the individual patch or the patch belonging to the same class or of the landscape as a collection of patches. Under the name of landscape metrics, spatial metrics are already commonly being used to quantify vegetation in natural landscape.[17] Outside the frame of landscape ecology, spatial metrics can be defined as measurements derived from the digital analysis of thematic-categorical maps exhibiting spatial heterogeneity at a specific scale and resolution.[18] Based on the work of O' Neill in 1988 for landscape characterization, a large number of metrics were developed and further modified by Li and Reynolds in 1993 and Mc Garigal and Marks in 1994. Fractal methods were used by Batty and Longley in 1988 to describe land use structures. Use of metrics for describing natural and geographic phenomenon has been described very well by De Cola

[17] Gustafson, 1998; Hargis, Bissonette & David, 1998; Mc Garigal, Cushman & Neel, 2002 and O' Neill et al., 1988.

[18] Herold et al., 2005.

and Lam (1993), Mandelbrot (1983) and Xia and Clarke (1997). There has been increasing interest in applying spatial metrics technique in urban environment as they can bring out the dynamics of change and growth process of a landscape.[19] Mesev et al., (1995) developed fractal indices to describe structure and changes in urban morphology. Gardner et al., in 1993 and Keitt et al., in 1997 applied these metrics for detecting landscape pattern, habitat fragmentation and biodiversity characterization. Their use for depicting temporal change in landscape was given by Dunn et al., 1991 and Frohn et al., in 1996. Alberti and Waddell in 2000 substantiate the importance of spatial metrics in urban modeling. They proposed specific spatial metrics to model the effect of complex spatial pattern of urban land use and cover on social and ecological processes.

Thus the rapid development of remote sensing technology together with spatial metrics provides a better interpretation and verification of the characteristics of urban forms. Combination of remotely sensed data with spatial metrics allows the evaluation of actual spatial structures over time, and permits the relation of changes to specific processes, albeit spatial rather than socio-economic dynamics. Thus the two in conjugation can be used as an efficient tool for urban modeling.

For the present study, using the remotely sensed land cover data, selected spatial metrics at the patch level, class level and landscape level were calculated using FRAGSTATS software program.[20] These metrics were also used to analyze whether the urban patterns were aggregated, compact or dispersed. Table 4, 5, 6 and 7 list spatial metrics (grouped with respect to subject area) considered for the study.

The central objective of the study was to quantify urban sprawl of the major cities of India. For the quantification, spatial metrics were computed to show spatio-temporal urban growth dynamics since the past four decades. The metrics captured several fundamental dimensions of urban form: area, shape, border definition and compactness or dispersion.

Area metrics: Area metrics quantify the composition of the landscape and provides information about the area occupied by various patches in the landscape. Table 4 provides description of area metrics.

Table 4: Description of the Area metrics (Source: Mc Garigal and Marks, 1994)

Indicator	Abbreviation	Formula	Description
Class Area **(Class level)**	CA	$CA = \sum_{j=1}^{n} a_{ij} \left(\frac{1}{10,000}\right)$ Range: CA>0, without limit	CA shows how much of the landscape is comprised of one patch type. Equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000.a_{ij} area (m^2) of patch ij.

[19] Alberti &Waddell, 2000; Barnsley and Barr, 1997 & Herold, Clarke and Scepan, 2000.

[20] Mc Garigal and Marks, 1994.

Number of patches (Built-up) **(Class level)**	NP	$N = n_i$ Range: NP≥ 1	NP equals the number of patches of the corresponding patch type. ni is the number of patches of a particular type.
Percentage of landscape (Built-up) **(Class level)**	PLAND	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ Range: 0<%Land≤ 100	PLAND equals the percentage the landscape comprised of the corresponding patch type. a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).
Mean Patch Size **(Class/Landscape)**	MPS	$MPS = \frac{A}{N_{patch}}(10000$ Range: MPS > 0, without limit	MPS equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10000 (to convert to hectares).
Largest patch **(Class/ Landscape)**	LP	$LP = \frac{max_{j=1}^{n}(a_{ij})}{A}$ LP > 0, without limit	Total image area occupied by the largest sized patch of the built-up class.
Patch Density (Class level)	PD	$PD = \frac{n_i}{A}(10{,}000)(100)$ Range: PD> 0	PD is the number of patch of urban patch divided by total landscape area.
Patch Density (Landscape level)	PD	$PD = \frac{N}{A}(10{,}000)(100)$ Range: PD> 0	PD is the number of patches of landscape divided by total landscape area.
Largest patch Index (Built-up)	LPI	$LPI = \frac{max_{j=1}^{n}(a_{ij})}{A}(100)$ Range: 0< LPI≤ 100	LPI approaches 0 when the largest patch of the built-up patch becomes increasingly small and LPI = 1 when the entire landscape of the patch type of the built-up class.
Largest patch Index (Landscape)	LPI	$LPI = \frac{max_{j=1}^{n}(a_{ij})}{A}(100)$ Range: 0< LPI≤ 100	LPI approaches 0 when the largest patch in the landscape is increasingly small and LPI = 100 when the entire landscape consist of single patch.
Patch Area Distribution coefficient of variance	PADCV	$PADcv = \frac{SD}{MPS}(100)$ Range: PADCV ≥ 0, without limit	Calculates coefficient of variation of patch area on a raster map.

(Class level)			

Shape Metrics: Shape metrics quantify the landscape configuration by measuring shape complexity of patches at patch, class and landscape level. Shape is a difficult parameter to quantify concisely in a metric (Mc Garigal and Marks, 1994). All the shape indices are based on perimeter to area ration and thus they help in interpreting irregularities in urban patches. Table 5 lists the various shape metrics.

Table 5: Metrics to compute shape complexity of patches (Source: Mc Garigal and Marks, 1994)

Indicator	Abbreviation	Formula	Description
Mean Shape Index **(Class level)**	MSI	$MSI = \frac{\sum_{j=1}^{n}\left(\frac{0.25p_{ij}}{\sqrt{a_{ij}}}\right)}{n_i}$ Range: MSI $\geq$ 1, without limit.	It measures the average patch shape for a particular class. MN (Mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type. p_{ij} = perimeter of patch ij in terms of number of cell surfaces.
Area-Weighted Mean Shape Index **(Class/ Landscape)**	AWMSI	$AWMSI = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\frac{0.25p_{ij}}{\sqrt{a_{ij}}}\right)\left(\frac{a_{ij}}{A}\right)\right]$ a_i and p_i are the area and perimeter of patch i, and N is the total number of patches. Range: AWMSI $\geq$ 1, without limit.	It weights patches according to their size, larger patches are weighed more heavily than smaller patches.
Mean shape Index co-efficient of variation **(Class level)**	SHAPE_CV	$MSI_{CV} = \frac{SD}{MSI}(100)$ Range: Shape_CV ≥ 0	Calculates coefficient of variation of patch shape on a raster map. SHAPE_CV value will be zero when patches of the built-up class will have same shape or entire landscape has only 1 patch.
Normalised landscape shape Index **(Landscape**	NLSI	$NLSI = \frac{e_i - \min e_i}{\max e_i - \min e_i}$ Range: 0 to 1	Normalized Landscape shape index is the normalized version of the landscape shape index (LSI) and, as such, provides a simple measure of class aggregation or clumpedness. It measures the perimeter-to-area

level)			ratio for the landscape as a whole.

Edge/Border Metrics: Edge metrics quantify length and distribution of the amount of edge between patches.[21] They represent landscape configuration, even though they are not spatially explicit at all.[22] These edge attributes can provide critical information for quantifying and understanding urban and landscape fragmentation. The most commonly used Edge metrics are listed in Table 6:

Table 6: Quantification of urban and landscape fragmentation through selected Edge/ Border Metrics (Source: Mc Garigal and Marks. 1994).

Indicator	Abbreviation	Formula	Description
Edge Density **(Landscape level)**	ED	$ED = \frac{E}{A}(10{,}000)$ Range: ED $\geq$ 0 when there is no edge in the landscape; that is when entire landscape and landscape border if present consist of single patch	ED standardizes edge to a per unit area basis that facilitate comparison between landscapes of different sizes.
Mean patch Fractal Dimension	MPFD	$MPFD = \sum_{j=1}^{n}\left(\frac{2\ln(0.25p_{ij})}{\ln a_{ij}}\right)$ Range: 1 $\leq$ MPFD $\leq$ 2, MPFD approaches 1 for shapes with simple perimeters, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.	Fractal dimension quantifies the degree of complexity of planar shapes.
Area weighted mean patch fractal dimension **(Class/ Landscape)**	AWMPD	$AWMPFD = \frac{\sum_{i=1}^{N} 2\ln 0.25\, p_i/\ln a_i}{N} \times \frac{a_i}{\sum_{i=1}^{N} a_i}$ Where a_i and p_i are the area and perimeter of patch i, and N is the total number of patches Range: 1 ≤ AWMPD ≤ 2	It weighs patches according to their size.
Mean Patch Fractal Dimension Co-efficient of Variation.	MPFD_CV	$MPFD_{CV} = \frac{SD}{MPFD}(100)$ Range: MPFD_CV ≥ 0	Calculates coefficient of variation of patch shape on a raster map.

21 Frohn, R and Hao, Y, 2005.

22 Mc Garigal and Marks, 1994.

Area-weighted Perimeter Area Ratio	PARA_AM	$\mathrm{PARA_{AM}} = \sum_{j=1}^{n}\left[\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right]$ Range: PARA_AM < 0, without limit	, AM (area-weighted mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric value multiplied by the proportional abundance of the patch
Perimeter-Area Fractal dimension	PAFRAC	$\mathrm{PAFRAC} = \frac{\sqrt[2]{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}(\ln P_{ij}\,\ln a_{ij})\right] - \left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]}}{\left(N\sum_{i=1}^{m}\sum_{j=1}^{m}\ln p_{ij}^{2}\right) - \left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)}$ Range: $1 \leq$ PAFRAC ≤ 2,	PAFRAC greater than 1 indicating the increase in shape complexity.

Compactness Metrics/ Contagion and Interspersion Metrics: Compaction is the formation of rounded patches in a circular shape that makes them more compact.[23] These metrics quantify landscape configuration. Compactness Metrics is the measure of individual patch shape and fragmentation of overall landscape. Table 7 provides description of various compactness metrics.

Table 7: Compactness metrics to assess individual patch shape and fragmentation of overall landscape

Indicator	**Abbreviation**	**Formula**	**Description**
Compactness Index	CI	$\mathrm{CI} = \frac{\sum_i P_i / p_i}{N} = \frac{\sum_i 2\lambda\sqrt{a_i/\lambda}/p_i}{N}$	si and pi are the area and perimeter of patch i, Pi is the perimeter of a circle with the area of si and N is the total number of patches.
Revised Compactness Index	R_CI	$\mathrm{CI} = \frac{\sum_i P_i / p_i}{N^2} = \frac{\sum_i 2\lambda\sqrt{a_i/\lambda}/p_i}{N^2}$	si and pi are the area and perimeter of patch i, Pi is the perimeter of a circle with the area of si and N is the total number of patches.
Compactness Index of the Largest Patch.	CILP	$\mathrm{CILP} = \frac{2\pi\sqrt{a/\pi}}{p}$	Where s and p are the area and perimeter of largest patch
Area- weighted Euclidean Nearest Neighbor	ENN_AM	ENN = hij	Where hij= distance from patch ij to nearest neighboring patch of the same type based on patch

[23] Aguilera, F; Valenzuela, L and Leitao, A, 2011.

Distance Distribution			edge-to-edge distance.
Euclidean Nearest Neighbor Distance Distribution co-efficient of variation	ENN_CV	$ENN_{CV} = \frac{SD}{ENN\_MN}(100)$ Range: ENN > 0	ENN_CV accounts for variability in measures of the edge-to-edge distance (m) between patches of the urban class. It is in percent.
Clumpiness Index	Clumpy	$G_i = \left[\frac{g_{ii}}{(\sum_{k=1}^{m} g_{ik}) - \min e_i}\right]$ $CLUMPY = \begin{cases} \left[\frac{G_i - P_i}{P_i}\right] \text{for } G_i < P_i \; P_i < 5; e \\ \frac{G_i - P_i}{1 - P_i} \end{cases}$ Range: Clumpiness ranges from -1 to 1	Clumpy = -1 when the focal patch type is maximally disaggregated, Clumpy = 0 when the focal patch is distributed randomly and approaches 1, when patch type is maximally aggregated.
Aggregation Index	AI	$AI = \left[\frac{g_{ii}}{\max g_{ii}}\right](100)$	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the single-count method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type (class) i (see below) based on the single-count method.
Interspersion and Juxtaposition Index **(Landscape level)**	IJI	$IJI = \frac{-\sum_{K=1}^{m}\left(\left[\frac{e\,ik}{\sum_{k=1}^{m} e_{ik}}\right]\ln\left[\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right]\right)}{\ln(m-1)}(100)$ Range: 0 < IJI ≤ 100	eik = total length (m) of edge in landscape between patch types I and k. m= number of patch type present in landscape.
Landscape Division Index **(Landscape level)**	LDI	$DIVISION = \left[1 - \sum_{j=1}^{n}\left(\frac{a_{ij}}{A}\right)^2\right]$ Range: 0 to 1	DIVISION = 0 when the landscape consists of single patch. DIVISION approaches 1 when the focal patch type consists of single, small patch one cell in area.

Micro case studies

To ascertain the dynamics of peri-urban change at the micro-level, a second project focused in greater detail on neighborhood or district level dynamics within one similar urban region in each country. The two cities selected for these case studies, Bangalore and Wuhan, were each mid-sized, rapidly growing regions that reflected characteristic dynamics of change in each country. Micro case studies included closer visual examination of Landsat images processed for the macro case studies, along with high-resolution data, field visits, interviews and documentary research. The mixed methods employed in this part of the study enabled closer examination of the dynamics and individual agents that produced the wider patterns.

Case selection focused on three disparate neighborhoods or local areas (including small town or local district) cases within greater Bangalore and greater Wuhan. To single out areas for this analysis, a structured spatial sampling technique was carried out in each urban region, employing parallel criteria.

The local units for this analysis mostly comprised administrative units in the city's governance hierarchy or zones specifically laid out for economic development. Each local unit included numerous specific projects for documentation and analysis. Field studies and additional research revealed projects with housing, factories, shops, social services and infrastructure. The additional detail, supplemented by higher resolution satellite images, enabled an examination of the types of construction that made up the "built up" classification employed in the macro data analysis, along with the policy, institutional and economic dynamics driving peri-urban change.

In Wuhan the micro cases comprised the three national level development zones in the city, including East Lake Hi-tech Development Zone(East Lake Hi-tech) to the east of the urban center, Wuhan Economic &Technological Development Zone(normally known as Zhuankou) to the southwest of the center, and Wujiashan Taiwanese Businessmen Investment Zone(Wujiashan) to the northwest.

In Bangalore parallel case studies were carried out in Peenya Industrial area to the northwest of the city center, an informal zone of high-tech and residential development in Bangalore South i.e.Hulimavu, Beguru (Bannerghatta Road), and in the Whitefield area to the east of the city.

This selection of cases reflected several different but parallel dimensions of variation in the timing and drivers of peri-urban dynamics. All six areas ranked among the leading areas of strategic public and private investment in their respective cities. They also reflected different phases in initiatives toward peri-urban expansion, from industrial initiatives the 1980s (Eastlake and Peenya) to high tech and associated residential strategies in the 2000s (Whitefield, Bangalore South and parts of Eastlake).

Analysis of land use dynamics at regional levels (given in Figure 5) involved

i.) Acquiring temporal remote sensing data – Temporal LANDSAT data is available at public domains such as GLCF, GLOVIS, etc. The data is downloaded from GLCF (Global Land Cover Facility i.e. http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp) and USGS (http://www.usgs.gov/).

ii.) Georectification of data with the ground control points (collected from the Survey of India (SOI) toposheets of scale 1:50000, Google Earth (available freely), and using high resolution GPS (Global Positioning System). Downloaded LANDSAT data required pre processing like Geo correction and Scan line correction (as in ETM+ data, Scan line Correction). After geometrically correcting the data, data of diverse resolutions were resampled to 30 M to maintain a common resolution across all the data sets.

iii.) Collection of training data using GPS to train the images for classification of data

iv.) Supervised classification of remote sensing data (with the help of training data): This approach preserves the basic land cover characteristics through statistical classification techniques using a number of well-distributed training pixels. The maximum likelihood classifier often used in supervised classification has been proven effective at identifying land uses. Remote sensing data were classified using four categories- urban, vegetation, water bodies, others (open space, barren land, etc) using open source GIS – GRDSS (http://ces.iisc.ernet.in/foss) having robust support of processing both vector and raster data.

v.) Accuracy assessment: 30% of training data were retained for accuracy assessment. kappa statistics were calculated to verify the classification accuracy which is given in Table 1.

vi.) Creation of thematic layers

vii.) Statistical analysis of data

Figure 5. Flowchart of Micro Case Study Procedure

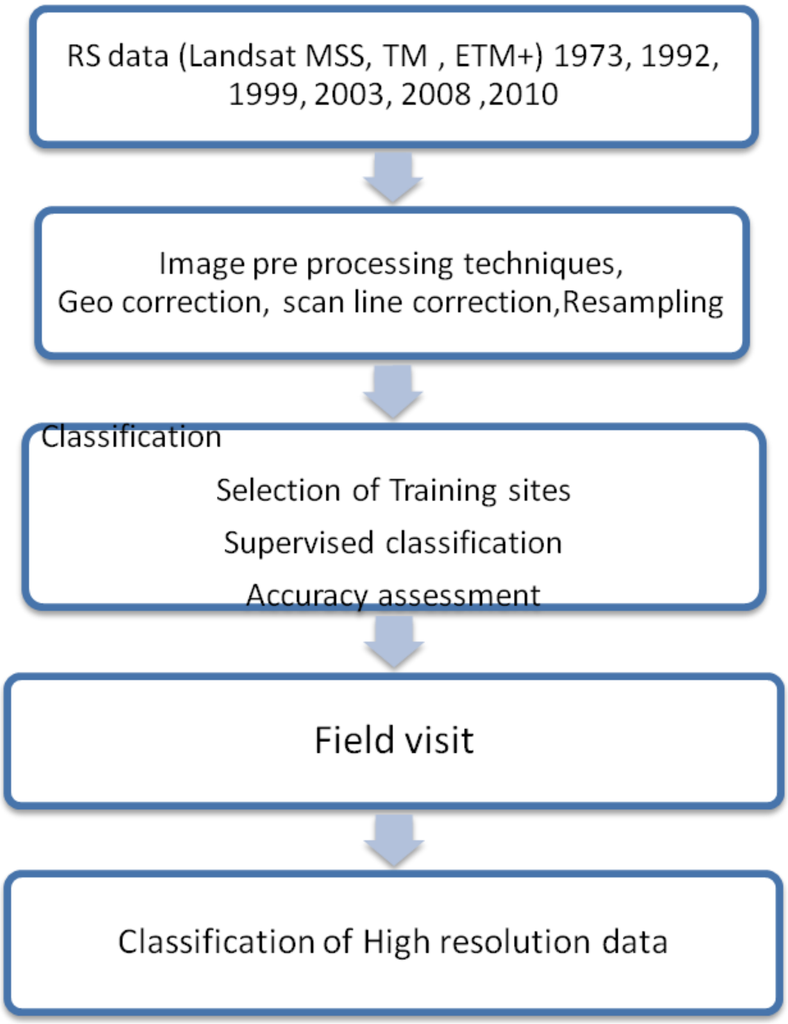


Table 8. Accuracy Assessment of Classification, Landsat Images (Kappa Statistics)

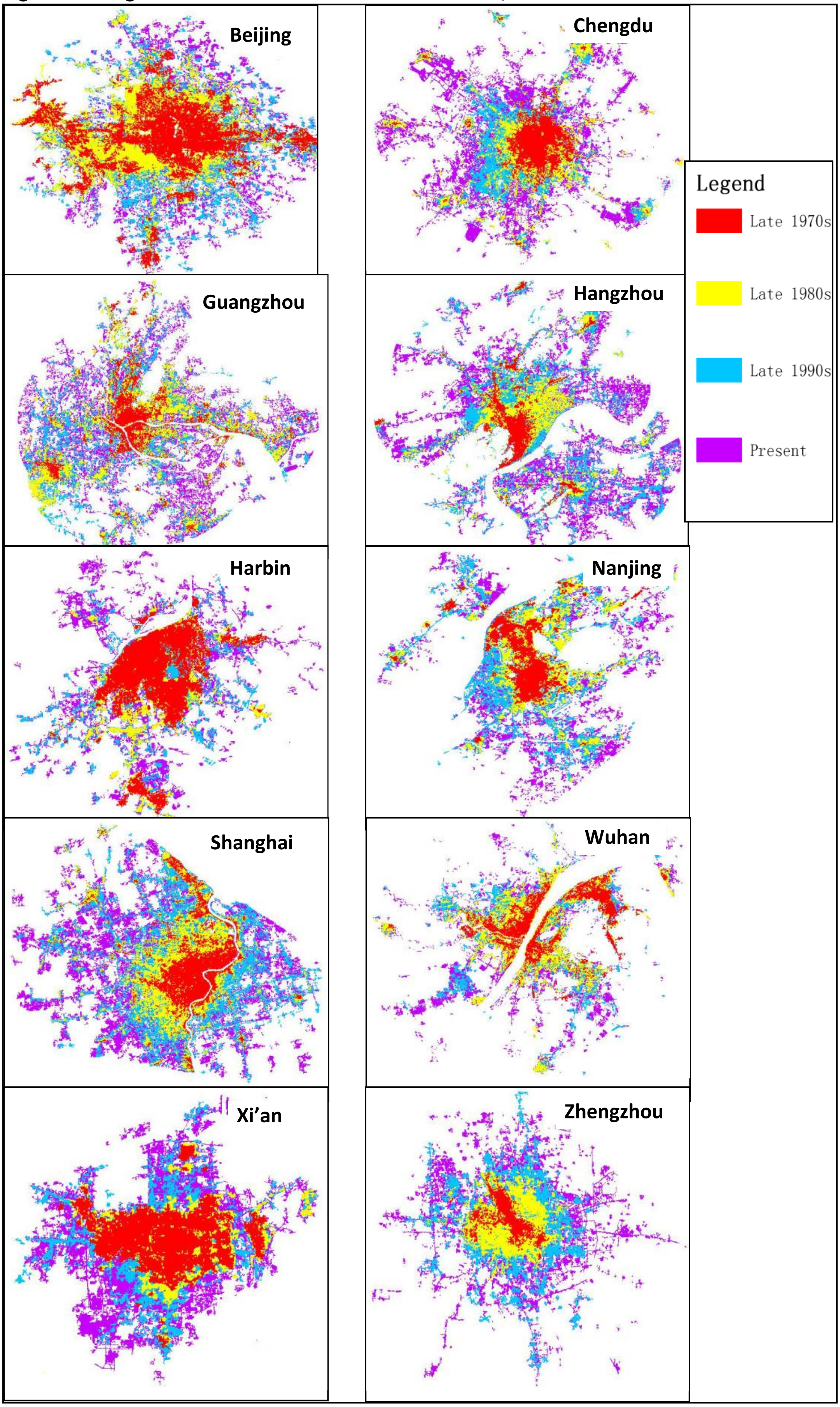
a) Wuhan

YEAR	KAPPA COEFFICIENT	OVERALL ACCURACY (%)
1978	0.67	77.3
1989	0.81	81.6
2001	0.85	91.7
2006	0.78	84.6
2008	0.94	88.2

b) Bangalore

YEAR	KAPPA COEFFICIENT	OVERALL ACCURACY (%)
1973	0.88	93.6
1992	0.63	79.52
1999	0.82	88.26
2003	0.77	85.85
2008	0.99	99.71
2010	0.74	82.73

Figure 6. Progression of urbanization in Chinese cities, 1970s-2000s



3.0 Results & Discussion

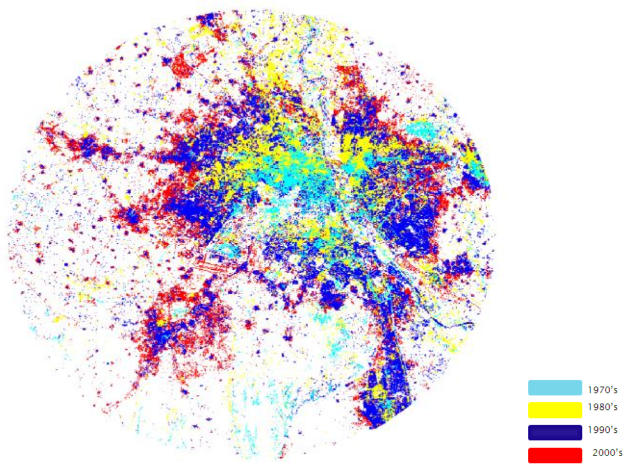
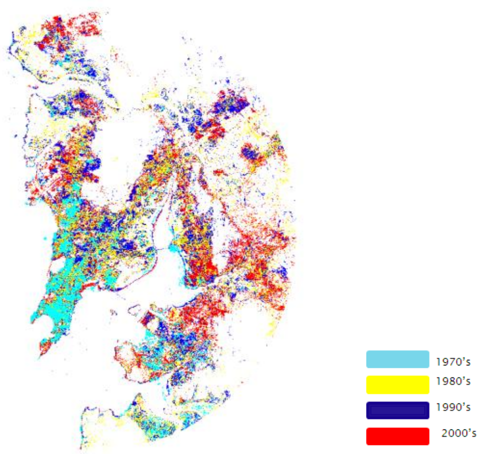
The macro and micro study components of the research will be discussed in turn. Results will be synthesized and discussed at the end of each section. Overall results will then be summarized and discussed in the Overall Conclusion (Part 4.0).

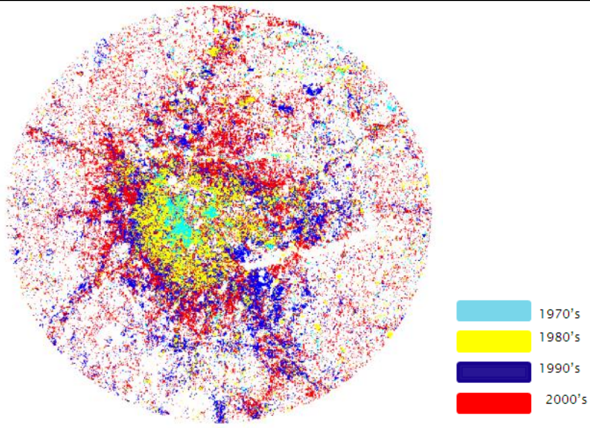
a. Macro data analysis results.

Image processing generated clear pictures of the overall progression of built-up areas in all ten cities. In the larger cities of China, expansion began in the 1980s and demonstrates a continuous progression over each decade. In several of these cities (Beijing, Shanghai, Guangzhou), the built up areas by the late 200s extend throughout most of the landscape area (Figure 6). Elsewhere, development becomes more fragmented and dispersed than before.

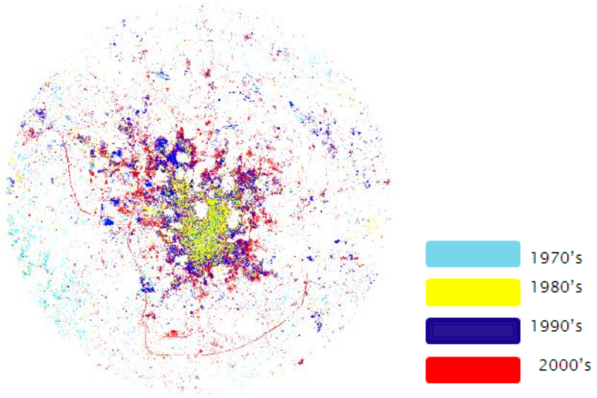
In the Indian cities, the most rapid peri-urban expansion occurs following liberalization in the early 1990s. Over the 1980s, a tight band of new development appears around several larger Indian cities (Delhi, Bangalore, and Ahmedabad) (Figure 7). In the 1990s, new construction advanced out transportation corridors in these and other cities. Over the final decade, infill development in some areas accompanies greater dispersion in others. Here, the largest cities (Delhi, Mumbai and Kolkata) exhibit less intensive expansion than their Chinese counterparts. New patches of development generally tend to be tighter and closer to other developed areas than around Chinese cities. In the smallest cities of Bhopal and Coimbatore, however, settlement patterns remain dominated by the dispersed network of villages that predated the late 20th century wave of urbanization.

Figure 7. Progression of urbanization in Indian cities, 1970s-2000s

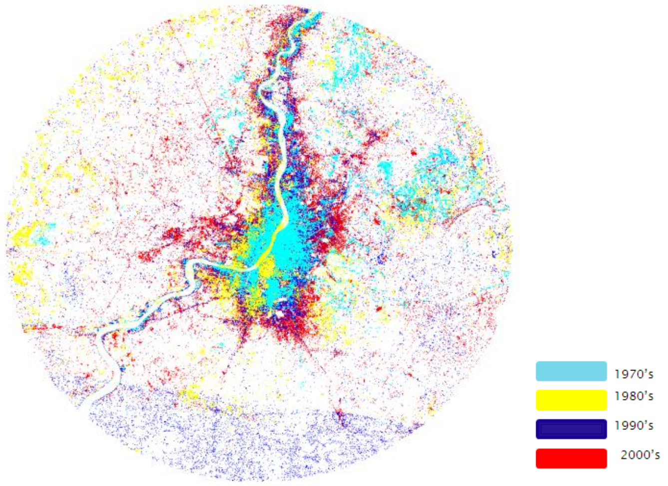
Delhi	Mumbai
	
Bangalore	Hyderabad



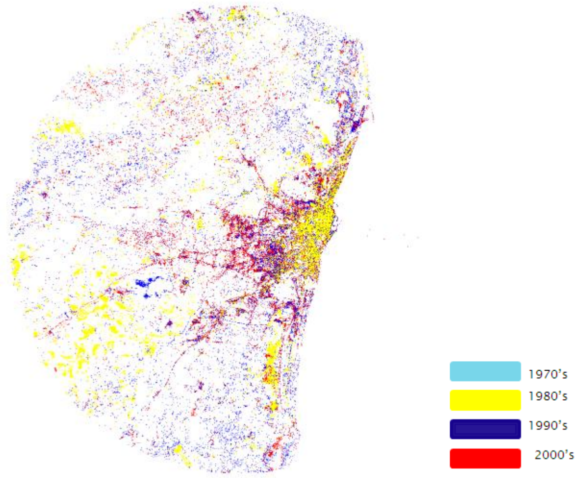
Kolkata



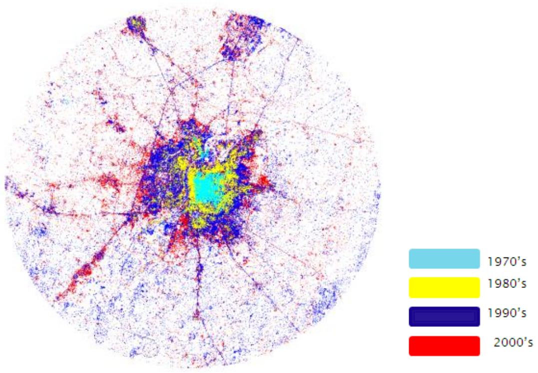
Chennai



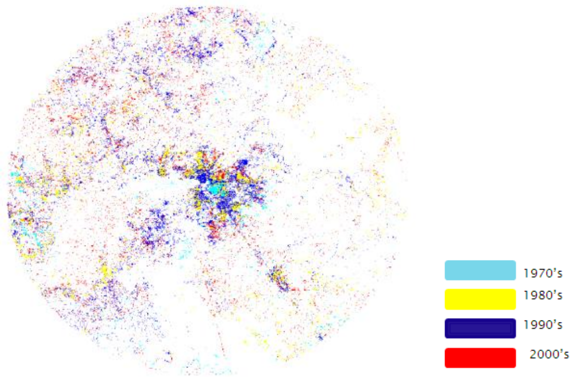
Ahmedabad



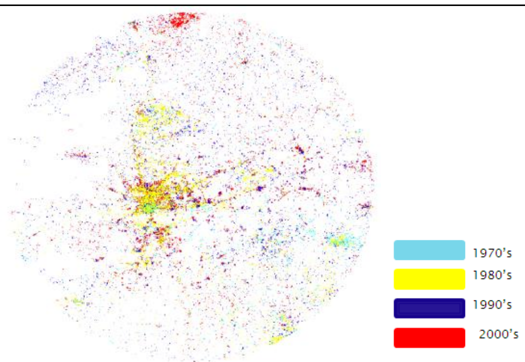
Bhopal

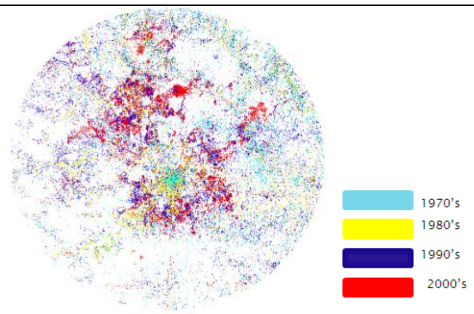


Coimbatore



Pune

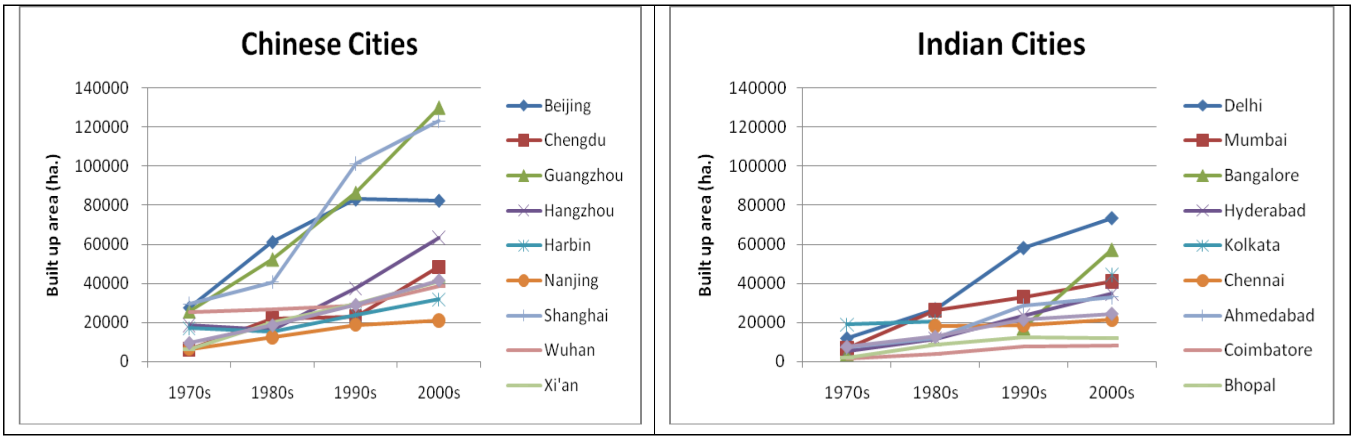




Comparison of Metrics

Comparing spatial metrics points to markedly different trajectories of urbanization in China and India, as well as between different cities in each country. Simple figures on the urbanized area, both in terms of the total size as well as the percent of the landscapes, point to a major difference between the expansion of the coastal Chinese urban regions with the strongest outside investment, and similar processes in both other Chinese cities and in their Indian counterparts (Figure 8). In Shanghai, Guangzhou, and Beijing, and to a lesser extent in the smaller coastal city of Hangzhou, the expansion of the built up area has proceeded at a pace that outstrips the rates elsewhere. Among the Indian cities, only Delhi as the national capital, and in the last decade Bangalore, have expanded to extents that stand out in this way.

Figure 8. Urbanized area (hectares)



The different institutional and policy conditions of property markets, combined with contrasts in the preexisting structures of settlement and have brought about major cross-national contrasts in the shape of urban built up areas.

In China, the legacies of development from the state socialist period had given rise to large blocks of developed areas that dominated urban form in urban regions like Shanghai, Guangzhou and Xi'an (Figure 9), and generally larger portions of the built up area in the most central and largest urban patches (Figure 10). In India, and to a lesser degree in some of the Chinese urban regions, the small village centers of the surrounding rural region dominated the regional landscapes of the 1970s.

Over the study period, mean patch size in Chinese urban regions has generally increased. Especially in the 1990s, the increase in the size of the largest patch also shows a growing consolidation of new development into an enlarged patch. In the 2000s, however, this pattern gives way to growing fragmentation of development in most Chinese urban regions.

Despite some growth in the mean patch size in large Indian urban regions like Delhi and Mumbai, the more fragmented peri-urban landscapes there persisted throughout the study period. Especially in the faster growing cities of Bangalore and Delhi, however, the new development of the 2000s marks a dramatic consolidation of the largest urban patch. At the end of the decade the proportions of the built up environmental in these main patches had risen to higher levels than in most Chinese cities.

Figure 9. Mean patch size (hectares)

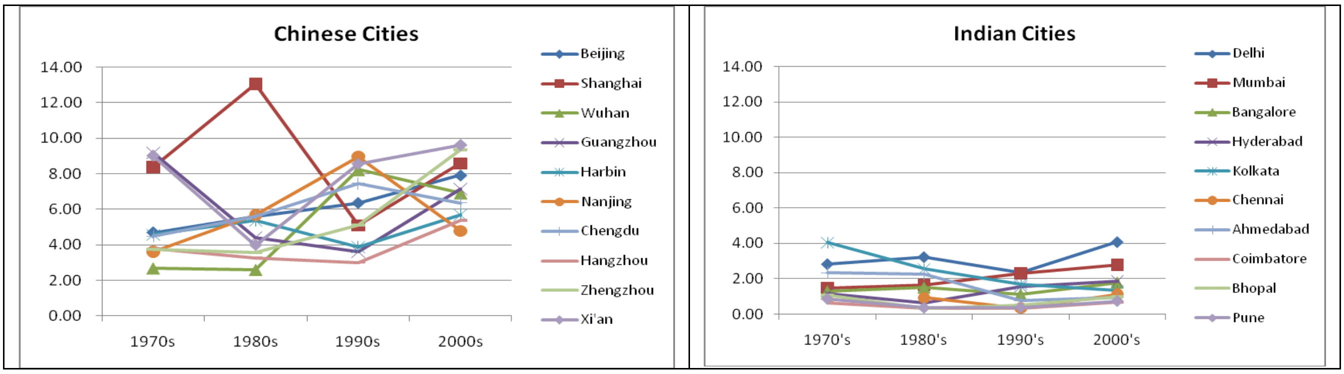
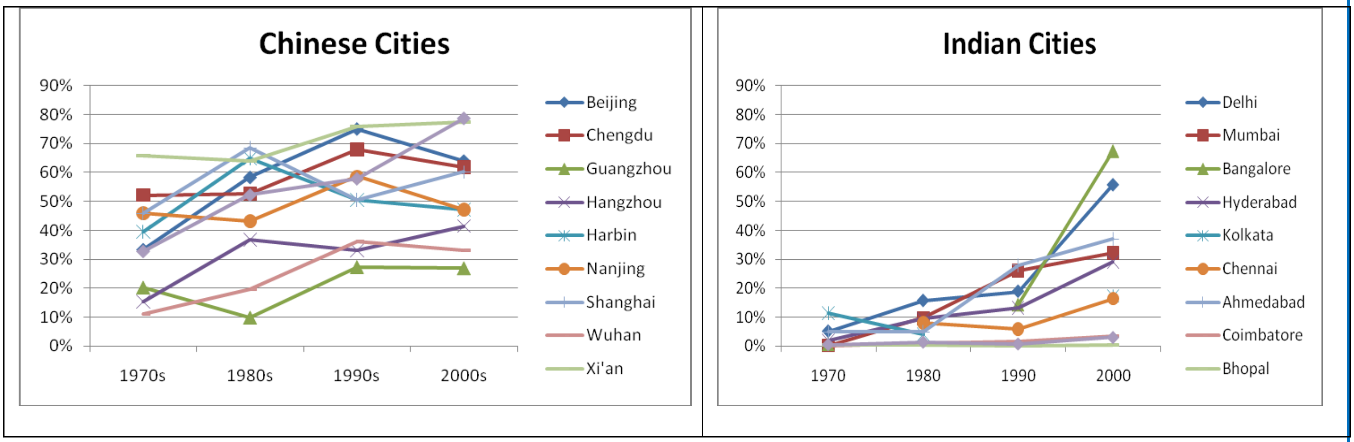


Figure 10. Largest patch index (percent of built up area)



The metrics also revealed a variety of other characteristic systematic contrasts between Chinese and Indian patterns of urban development. Several indicators of the overall shape of urbanized patches pointed to consistent irregularities in the Chinese built-up patches by comparison with the Indian urban regions. A simple compactness index that measured the dispersion of the landscape as well as individual patches, for instance, produced consistently higher values for all the Indian cities than in any of the Chinese cities (Figure 11). The revised Compactness Index designed by Li and Yeh (2004) to control for bias due to large numbers of small patches an opposite cross national contrast (Figure 12). With the control for small exurban patches, somewhat higher compactness marked most Chinese urban regions. Clumpiness, another measure of relative dispersion across the landscapes, also showed consistent high values in all the Chinese regions (Figure 13). Only in the largest and fastest growing Indian urban regions did the values for this index approach the uniform levels in China.

Figure 11. Compactness Index

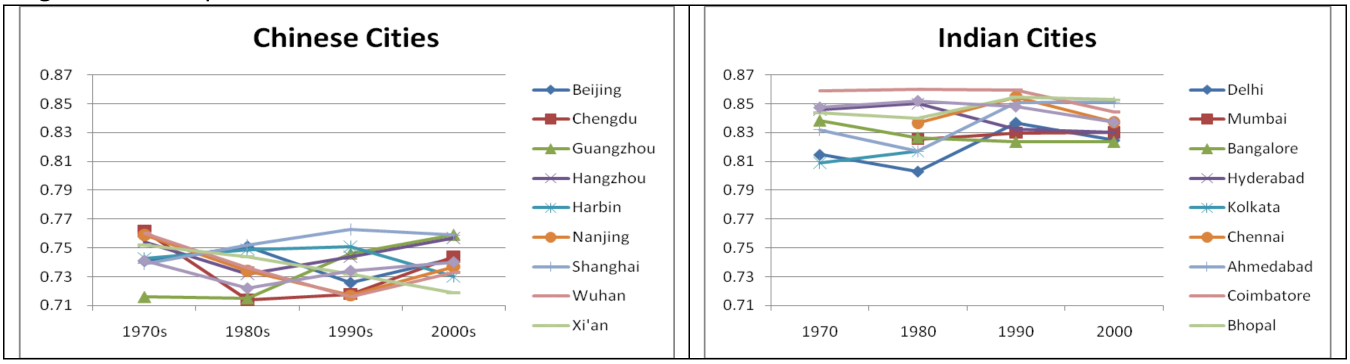


Figure 12. Revised Compactness Index

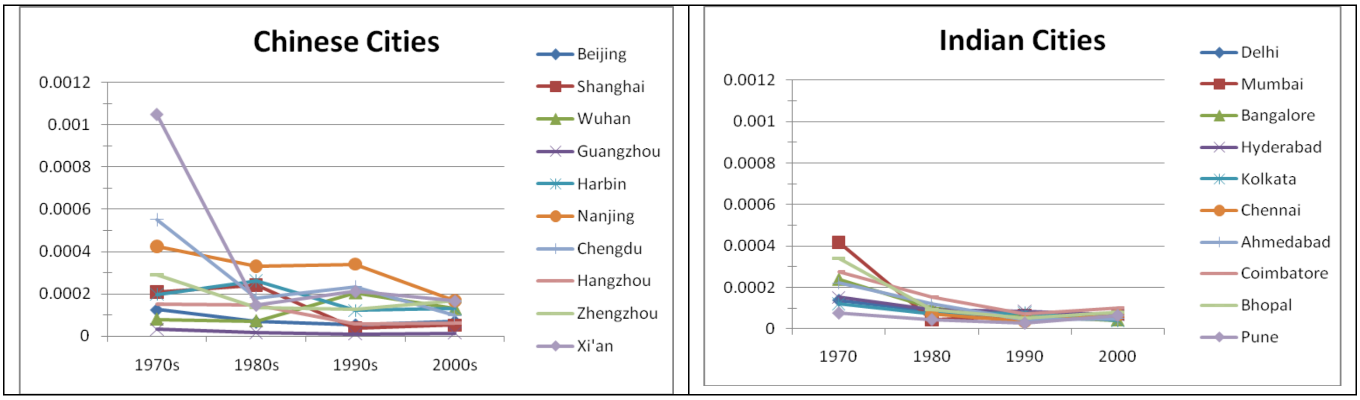
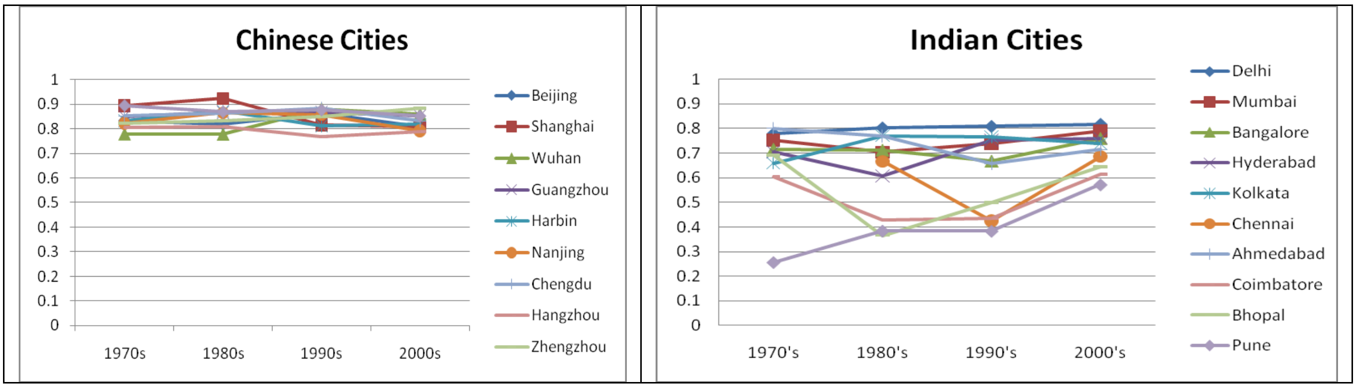


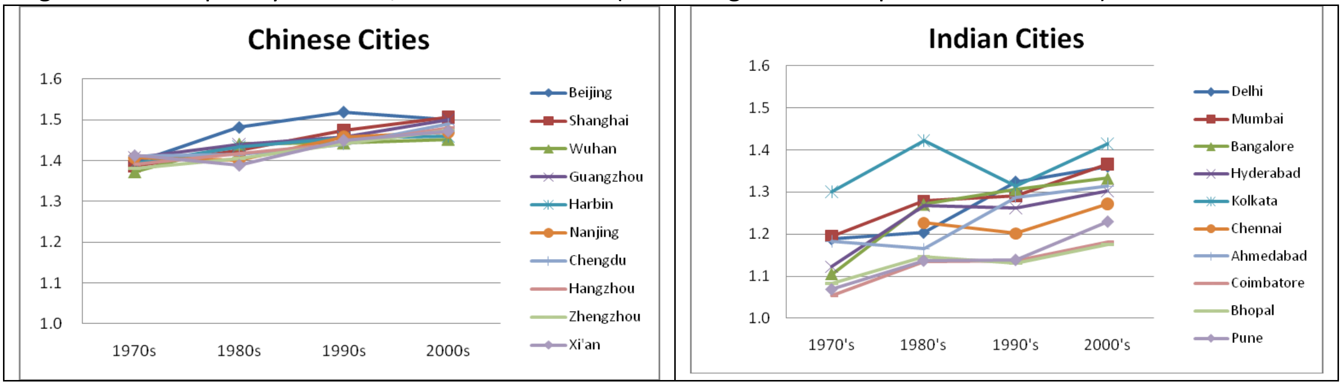
Figure 13. Clumpiness Index.



Differences in the border between urban and nonurban land types accompanied these cross national contrasts in the shape of urban settlement. In Chinese cities, the fractal measure of the complexity in the border between urban and nonurban land uses showed highly consistent levels that rose over time (Figure 14). These values appear related to national rules that have provided for similar policies to preserve a proportion of agricultural land in newly developed peripheral areas.

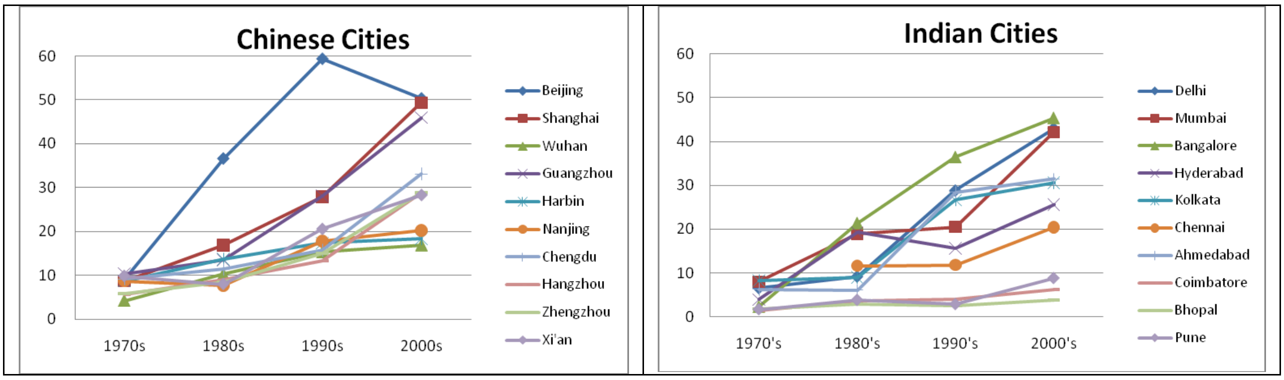
In the Indian urban regions, by contrast, the complexity of the urban boundary was both lower and differed more widely. It remained lowest in the smaller urban regions of Bhopal and Coimbatore, where small village patches continued to dominate the landscape. In the more economically dynamic urban regions of Delhi, Mumbai and Bangalore, the complexity of the boundary rose to levels approaching the uniform values in the Chinese urban regions. Boundaries in most Indian cities began the 1970s with much less complex urban boundaries than in Chinese cities, but grew more rapidly in complexity over this time.

Figure 14. Complexity of urban/nonurban border (Area weighted mean patch fractal index)



The broad national differences in trajectories of peri-urban expansion often went along with even greater variations within the two countries. An index for the shape of urban patches revealed largely parallel contrasts between the largest, most rapidly growing cities of both countries and the others (Figure 15). In China, the two megacities and the sprawling industrial region of Guangzhou stand out as highest. In India, rapidly growing Bangalore edges out the megacities of Delhi and Mumbai. Although values have risen dramatically in most urban regions of both countries, patch shapes in the three smallest Indian cities remain considerably lower than in Chinese counterparts.

Figure 15. Shape of Patches (Area weighted mean shape index)



Overall Variations in Trajectories of Peri-urban Growth

To examine the overall patterns of variation in urban form between both countries and over time, we employed the factor analytic technique of principal components analysis for the entire universe of metrics over the entire forty-year period. This procedure was first carried out with the entire set of land use metrics, then with separate measures designed to capture specific dimensions of variation in the land use patterns.

The overall principal components analysis examined the associations in variation among a total of 24 different land use indicators. This analysis proved especially helpful to bring out the systematic similarities and differences between the cities of the two countries, between the larger and smaller cities, and among all the cities over the entire study period.

Three components that emerged from this analysis with eigenvalues of over 1.5 were responsible for a total of 70 percent of the overall variance in all the indicators (Table 9). The first component, encompassing 42 percent of the variance, loaded at +/- .6 or better for 16 of the twenty four metrics. Positive loadings on such metrics as built-up land, patch size and density, edge complexity, clumpiness and open space within urban boundaries demonstrated parallel variations in all of these characteristics. Strong negative loadings for centralization and compactness showed that the peri-expansion captured in the other metrics had led to declines in these properties. This component thus captured a particular kind of peri-urban expansion. Linked to the growth of buildup land at growing distances from urban centers and an increasingly complex urban border, this was along a form of expansion that privileged larger built up patches and greater clumpiness of development patterns.

Table 9. Principal components analysis

a) Total Variance Explained

	Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %
1	10.034	41.810	41.810
2	4.403	18.345	60.154
3	2.401	10.002	70.157
4	1.452	6.048	76.205
5	1.278	5.326	81.531

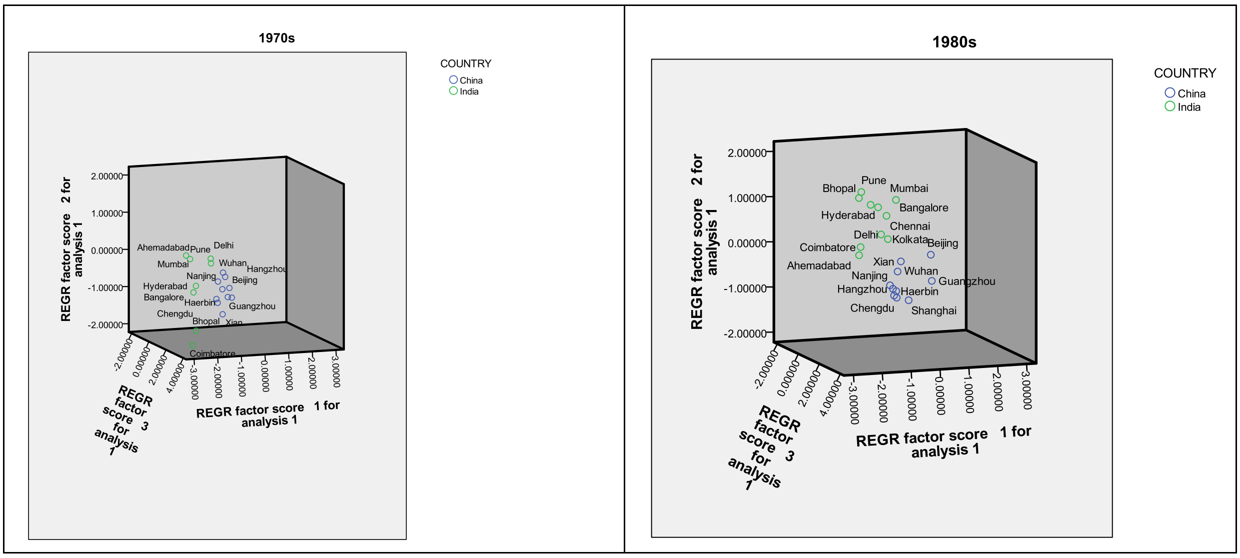
b) Component Matrix

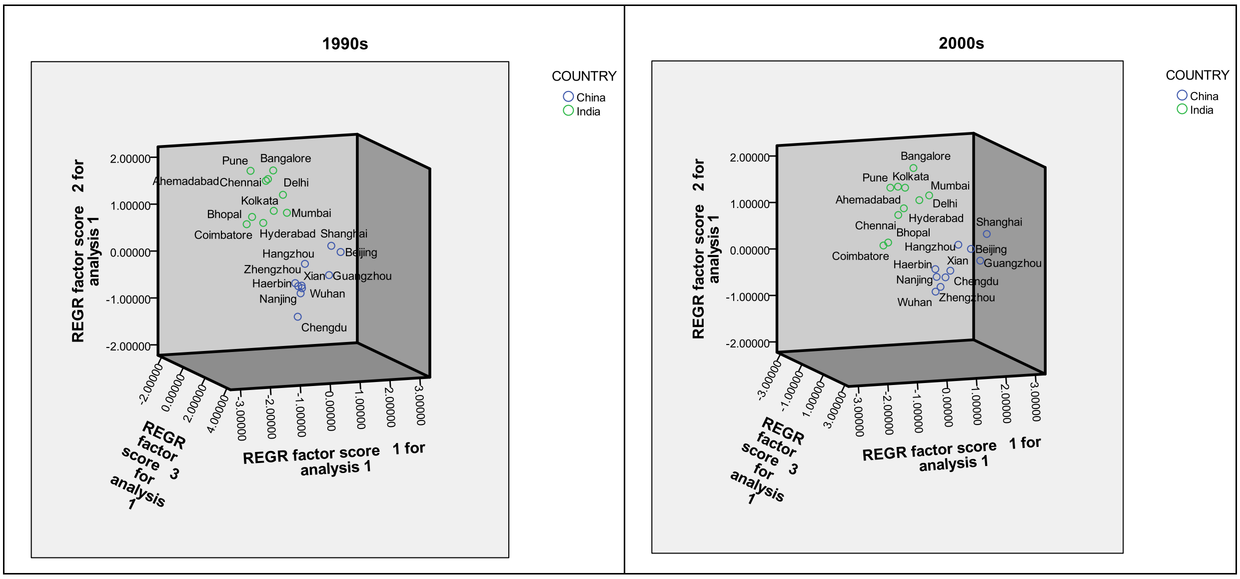
	Component				
	1	2	3	4	5
Shape index (COV)	.900	.104	.176	.009	.017
Fractal index (area-weighted)	.871	.225	-.101	.191	.052
Percent land built-up	.854	.154	.174	-.247	.271
Shape index (area-weighted)	.800	.361	.201	.103	.284
Total land area	.756	.305	.482	.096	.107
Edge density	.753	-.140	.258	-.425	.189
Shape index	.749	-.433	.094	-.252	-.139
Mean patch size	.728	-.503	.055	.012	-.038
Clumpiness	.691	-.509	-.191	.302	.040
Ratio of open space	.652	.441	-.124	.275	.352
Patch density	.571	-.103	.134	-.468	.220
Number of patches	-.174	.867	.086	-.131	-.118
Fractal index (COV)	.324	.694	-.042	-.003	-.480
Compactness index	-.697	.616	.017	.152	.185
Average distance to largest patch (area weighted)	.245	-.057	.906	.053	-.209

Average distance to largest patch	-.054	.407	.724	.435	-.201
Centralization (area-weighted)	-.702	-.389	.489	-.044	.139
Revised compactness index	-.187	.025	-.075	.436	.518
Largest patch index	.439	-.446	-.145	.300	-.157
Euclidean nearest neighbor distance (COV)	.243	-.644	.088	.269	-.312
Centralization	-.828	-.205	.390	.098	.165
Euclidean nearest neighbor distance (area weighted)	-.611	-.612	.221	.067	.280
Compactness of largest patch	-.794	-.230	.283	-.184	.020
Normalized landscape shape indexes	-.695	.394	.000	-.265	.038

As examination of the variations in component scores by city and over time showed (Figure 16), all the cities registered negative scores on this component in the 1970s. Although the Chinese city scores were generally higher than in the Indian cities, the cross-national differences remained slight. By the 1980s, however, the Chinese cities of Beijing and Guangzhou registered significantly higher scores than other cities. Over the next two decades all the Chinese cities shifted in a positive direction. Beijing and Shanghai, and in the last period Guangzhou, continued to stand out. Delhi and Mumbai, the largest Indian cities, also received somewhat higher scores than other Indian cities over this period. However, variations among the Indian cities remained more limited. By the 2000s, all the Chinese cities had exceeded nearly every Indian city along this dimension.

Figure 16. Component Scores by City, Country and Decade





Indian cities differed more according to the second component. Encompassing 18 percent of the total variation, this component loaded most heavily on the number of patches, which was significantly higher across the board among Indian cities. High positive loadings for more numerous patches and greater compactness went along with greater variation in the complexity of patch boundaries and the distance between near patches. At the same time, this component loaded negatively on mean patch size and clumpiness. This form of peri-urban change thus took the form of a more fragmented form of built up patches that contrasted with the larger ones and clustered together.

As with the first component, all the cities in both countries scored negatively on this component in the first phase of the study in the 1970s. Following the 1970s, component scores for this component correlated positively at .82 or above with India rather than China. Rapidly growing Bangalore registered the highest scores on this component in the 1990s and 2000s. The smaller, more slowly growing cities of Bhopal and Coimbatore remained at the bottom. Other larger cities like Delhi, Chennai and Ahmedabad followed less consistent trajectories that suggested a degree of consolidation in settlement patterns by the late 2000s. In China, the coastal cities scoring high on the first component also scored highest on this one.

The third component, capturing ten percent of the overall variance, loaded more heavily on the two measures of average distance from the largest patch than on any other metrics. It was also positively associated with the area-weighted measure for centralization and with greater total land area. This measure most clearly corresponds to the higher values in these metrics for the Chinese coastal cities of Beijing, Guangzhou, Hangzhou and Shanghai in the final decade of the study period. For this period it correlates (.50, $p<.05$) with Chinese cities.

Additional components with eigenvalues under 2 explained only five and six percent of the variance. The overall analysis thus helped to bring out several systematic differences in urban form between the two countries, within both countries, and over a period of broad peri-urban expansion. Trajectories of urbanization in China have proceeded more according to the patterns highlighted in the first and third components; those in India have followed along the lines of the second and, in part, the first.

Dimensions of Peri-urban Change

The principal components analysis of all the metrics demonstrated numerous correlations among the metrics, but these occurred for various reasons. In part, the metrics themselves were selected to capture several distinct analytical properties of the patterns in urban form. Application of principal components analysis to the multiple metrics designed to capture each of these dimensions generated more precise comparative metrics for understanding how each dimension has varied. This analysis in turn generated a set of indicators for assessment of the drivers of peri-urban change.

1. Patch concentration. One set of focused on the size, number and concentration of patches in relation to the built up area and the landscape. This analysis generated a single component that captured 51 percent of the variance in these metrics, and loaded significantly in the expected direction on each of the metrics (Table 10).

Table 10. Principal Components Analysis, Patch size and Density

a) Component Matrix[a]

	Component
	1
Mean patch size	.880
Number of patches	-.729
Largest patch as percentage of built-up area	.703
Patch density	.507

Extraction Method: Principal Component Analysis.

a. 1 component extracted.

b) Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.057	51.437	51.437	2.057	51.437	51.437
2	.954	23.849	75.285			
3	.643	16.067	91.353			
4	.346	8.647	100.000			

Extraction Method: Principal Component Analysis.

2. Patch shape. A second common dimension of measurement focuses on the shape of the patches, including both average properties and variation. Within this dimension we also include the metric for open space within the patches, which Huang Lu and Sellers (2007) call "porosity".

Two components account for 86 percent of the variance in these metrics. The first accounts for 63 percent of this variance. This component, termed "shape irregularity," loads positively on both the mean and the area-weighted mean versions of the shape index, and on the ratio of open space. Since it also loads negatively on the index of landscape aggregation among patches, and positively on variation in patch shapes, this component captures both greater irregularity and more systematic variation in patch shapes.

The second component, termed "shape aggregation," accounts for an additional 22 percent of the variance. It reflects shapes that are more regular and more aggregated, but that still contain more open space within patches.

Table 11. Principal components Analysis, Shape Regularity

a) Component Matrix[a]

	Component	
	1	2
Shape_coefficient of variation	.933	.020
Shape_area-weighted	.884	.349
Ratio of open space	.766	.580
Normalized landscaped shape index	-.693	.495
Shape_mean	.676	-.634

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

b) Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.177	63.545	63.545	3.177	63.545	63.545
2	1.104	22.085	85.630	1.104	22.085	85.630
3	.443	8.855	94.485			
4	.151	3.016	97.500			
5	.125	2.500	100.000			

Extraction Method: Principal Component Analysis.

3. Centrality. A further set of metrics measured mean and area-weighted distances from the center of the city. Variants here measured this distance from the central urban patch, but also from the largest patch.

Principal components analysis generated two distinct components that accounted for 90 percent of the variance in these metrics. One, the most consistent measure of centrality, loaded on all of the metrics but especially heavily on the two centrality metrics. This component comprised 54 percent of the variance.

The second corresponded to higher average distance from the largest patch to with lower distances from the central patch. It corresponded to expanded urban forms where the central patch did not correspond to the largest patch. This component encompassed 37 percent of the variance.

Table 12. Principal Components Analysis, Centrality

Component Matrix[a]

	Component	
	1	2
Centrality (area weighted)	.857	-.481
Centrality	.845	-.507
Average distance from the largest patch (area weighted)	.591	.710
Average distance from the largest patch	.615	.685

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.176	54.402	54.402	2.176	54.402	54.402
2	1.461	36.522	90.924	1.461	36.522	90.924
3	.351	8.769	99.692			
4	.012	.308	100.000			

Extraction Method: Principal Component Analysis.

4. Edge complexity. Metrics for the complexity of the border between urban and nonurban uses measured a further dimension of urban form. These included a fractal index of complexity, a measure of the variation in this index between patches in a landscape, and a measure of edge density in relation to the built-up area. A single component that loaded on all three of the metrics demonstrated the correspondence between them. All three loaded at more than .6 on this component, and it accounted for nearly 57 percent of all the variance in them.

Table 13. Principal Components Analysis, Edge Complexity

a) Component Matrix[a]

	Component
	1
Fractal index (area weighted)	.896
Edge density	.736
Fractionalization (coefficient of variation)	.603

Extraction Method: Principal Component Analysis.

a. 1 component extracted.

b) Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.708	56.941	56.941	1.708	56.941	56.941
2	.920	30.680	87.621			
3	.371	12.379	100.000			

Extraction Method: Principal Component Analysis.

5. Compactness and dispersion. A final set of metrics measured the overall dispersion or aggregation in built up patches across the urban landscapes. Metrics employed here included the two compactness indexes, a further compactness index for the largest patch, and indicators for clumpiness of the built up patches, Euclidean Nearest Neighbor Distance, and the coefficient of variation for the latter.

Two subtly distinct components accounted for 76 percent of the variance in these metrics. The first, encompassing 43 percent of the variance, loaded heavily on clumpiness and on variation in the nearest neighbor distance but negatively on one of the compactness indexes.

The second corresponded to high compactness for all built-up patches according to the other of the compactness indexes, along with compactness of the largest patch. Compactness as measured by this component also went along with greater dispersion among the patches as measured by Euclidean distance. The component accounted for a further 33 percent of the variance.

Table 14. Principal Components Analysis, Compactness and dispersion.

a) Component Matrix[a]

	Component	
	1	2
Clumpiness	.904	-.013

Compactness index	-.886	-.025
Euclidean nearest neighbor distance (coefficient of variation)	.669	.448
Euclidean nearest neighbor distance (area weighted)	-.211	.847
Compactness index of the largest patch	-.586	.723
Revised compactness index	.403	.722

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

b) Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.600	43.335	43.335	2.600	43.335	43.335
2	1.962	32.696	76.031	1.962	32.696	76.031
3	.524	8.727	84.758			
4	.473	7.891	92.649			
5	.275	4.579	97.228			
6	.166	2.772	100.000			

Extraction Method: Principal Component Analysis.

Causes of Variation in Trajectories of Urban Development

The final step in the macro-level analysis has been an examination of the sources of the differences in urban form. As measures of the diverse dimensions of the built up areas over time, the metrics provide the first fully systematic overview of the contrasts and similarities in Chinese and Indian urban development trajectories. Analysis of the demographic, economic, and geographic correlates of these variations underscores the important national contrasts in these trajectories, but also highlights a number of variations common to both countries.

This analysis compared how differences in the dimensions of urban form generated through the principal components analysis corresponded to several potential drivers of peri-urban expansion:

1) Total built up land area, as measured using the satellite images;
2) Population in the urban agglomeration (United Nations 2009);
3) Population density, measured in relation to the built up area and the overall landscape area;
4) Foreign direct investment
5) Coastal regions, in both countries often more open to foreign investment and in China often privileged by national policymaking;
6) National differences in institutions and policies, represented by a dichotomous variation with 0 for China and 1 for India.

This analysis confirmed numerous broad dimensions of contrast between the patterns in India and China (Table x). For the three decades after the 1970s, despite the equivalence of population in the cities, the total land area in the Chinese cities was somewhat higher than in the Indian cities ($p<.1$). Even more striking, however, was the consistently greater population density of the Indian cities in relation to the built up area. Measurement of density in relation to the built up area generated the strongest correlation with national differences (.52 to .74).

Even more systematic contrasts between the two countries characterized several of the dimensions of urban form. Patch concentration, shape irregularity, clumpiness and edge complexity were systematically higher in Chinese cities. Three of these four relationships strengthened from the 1980s to the 2000s. These results point to a growing divergence between the trajectories of Indian and Chinese peri-urban expansion. Other dimensions offer evidence of at least partial convergence. Centrality as measured from the central patch was significantly higher in Indian cities in the 1970s, this country contrast gradually disappeared over the following two decades. The aggregated shape index remained consistently higher in Indian cities, but this relationship also declined slightly.

Predictably, greater total land area corresponded to more irregular patch shape, greater distance of built up land from the urban center, and greater edge complexity. Population also correlated at significance levels of $p<.10$ or better with shape irregularity, shape aggregation, distance from the center, and (negatively) with compactness.

Foreign direct investment and location in coastal regions also correlated with several components of urban form consistent with migration of large facilities and blocks of development on urban peripheries, as well as with each other (at $p<.10$). Development patterns linked to both corresponded to greater expansion out from the urban center, greater distance of patches from the largest patch, greater edge complexity, and greater shape irregularity.

Table 15. Bivariate Correlations Between Drivers and Dimensions of Urban Form

		Total land area	Population	Population/ urban extent	Population density	FDI (z-score)	Coastal regions	Country (0=China, 1=India)	n
Total land area	1970s	1.000	.508*	-.492*	0.030		.361	0.221	19-20
	1980s	1.000	.465*	-0.305	-0.118	0.857**	.668**	-0.429	20
	1990s	1.000	.565**	-0.266	-0.273	0.688**	.626**	-0.390	20
	2000s	1.000	.514*	-0.248	-0.248	0.572**	.608**	-0.409	20
Population	1970s	.508*	1.000	0.189	.723**		.392	0.154	19
	1980s	.465*	1.000	.594**	.666**	0.906**	.461*	0.269	20
	1990s	.565**	1.000	.612**	.545*	0.596**	.463*	0.149	20
	2000s	.514*	1.000	.634**	.634**	0.653**	.351	0.215	20
Population/urban extent	1970s	-.492*	0.189	1.000	0.375		-.216	.629**	19
	1980s	-0.305	.594**	1.000	.783**	0.125	-.078	.736**	20
	1990s	-0.266	.612**	1.000	.951**	0.044	.060	.520*	20
	2000s	-0.248	.634**	1.000	1.000**	0.236	.056	.623**	20
Population density	1970s	0.030	.723**	0.375	1.000		-.084	0.440	
	1980s	-0.118	.666**	.783**	1.000	0.089	.178	.589**	20
	1990s	-0.273	.545*	.951**	1.000	0.084	.097	.562**	20
	2000s	-0.248	.634**	1.000**	1.000	0.236	.056	.623**	20
FDI (z-score)	1980s	.857**	.906**	0.125	0.089	1.000		.a	20
	1990s	.688**	.596**	0.044	0.084	1.000	.537*	0.000	20
	2000s	.572**	.653**	0.236	0.236	1.000	.535*	0.000	20
Country (0=China, 1=India)	1970s	0.221	0.154	.629**	0.440		-.218	1.000	19-20
	1980s	-0.429	0.269	.736**	.589**		-.218	1.000	20
	1990s	-0.390	0.149	.520*	.562**	0.000	-.218	1.000	20
	2000s	-0.409	0.215	.623**	.623**	0.000	-.218	1.000	20
Patch_concentration	1970s	.466*	0.018	-.501*	-0.303		.294	-.889**	19
	1980s	.488*	-0.045	-.485*	-.504*	0.465	.284	-.874**	20
	1990s	0.336	0.016	-0.310	-0.406	-0.119	.078	-.871**	20
	2000s	0.406	-0.075	-.527*	-.527*	0.009	.202	-.918**	20
Shape_irregular	1970s	.511*	0.212	-.544*	-0.132		.321	-.761**	19
	1980s	.790**	0.286	-0.291	-0.256	0.789**	.462*	-.638**	20
	1990s	.666**	0.435	-0.161	-0.275	0.217	.322	-.711**	20
	2000s	.773**	0.385	-0.306	-0.306	0.423	.473*	-.725**	20
Shape_aggregated	1970s	-.492*	0.048	.848**	0.261		-.332	.618**	19
	1980s	-0.147	0.348	.656**	.494*	0.841**	-.066	.888**	20
	1990s	-0.045	0.422	.533*	.585**	0.157	-.018	.854**	20
	2000s	0.230	.634**	.500*	.500*	0.427	.159	.656**	20
Centrality_center	1970s	-0.368	-0.289	0.040	0.026		-.097	.509*	19
	1980s	0.070	0.143	0.186	0.438	0.177	.314	0.351	20
	1990s	0.112	0.061	0.124	0.243	0.343	.487*	0.230	20
	2000s	0.383	-0.029	-0.146	-0.146	0.180	.416	-0.019	20
Centrality_distance	1970s	.892**	.476*	-.534*	0.005		.655**	-0.454	19
	1980s	.798**	.502*	-0.151	0.160	0.490	.660**	-0.141	20
	1990s	.811**	.512*	-0.064	-0.055	0.724**	.770**	-0.210	20
	2000s	.889**	0.345	-0.230	-0.230	0.427	.618**	-0.342	20
Edge_complexity	1970s	.654**	0.257	-0.400	-0.218		.382	-.814**	19
	1980s	.620**	0.401	-0.139	0.114	0.299	.316	-0.384	20
	1990s	.674**	0.378	-0.221	-0.302	0.255	.500*	-.692**	20
	2000s	.706**	0.309	-0.312	-0.312	0.358	.495*	-.744**	20
Dispersion_clumps	1970s	0.358	0.131	-0.242	-0.250		.288	-.711**	19
	1980s	.492*	0.045	-0.426	-0.406	0.114	.257	-.852**	20
	1990s	0.346	0.137	-0.173	-0.307	-0.014	.120	-.851**	20
	2000s	0.371	-0.063	-0.440	-0.440	-0.071	.124	-.906**	20
Dispersion_compact	1970s	-.668**	-0.455	0.110	-0.085		-.418	0.299	19
	1980s	-0.402	-.643**	-0.323	-.487*	-0.559	-.392	-0.313	20
	1990s	-0.413	-.449*	-0.131	-0.158	-0.358	-.340	-0.407	20
	2000s	-0.418	-.508*	-0.214	-0.214	-0.404	-.280	-0.337	20

b. Micro case study results.

The micro case studies in six urbanizing district around Wuhan and Bangalore illuminated how the drivers of these urban trajectories have worked, and the agents and structures that have brought about the contrasts between Chinese and Indian patterns.

China Micro case study 1: East Lake Hi-tech (Wuhan east)

East Lake Hi-tech with the full name of East Lake Hi-tech Development Zone (ELHDZ), located in the east part of Wuhan, was named after its nearby Wuhan as well as China's biggest inner-city-lake of East Lake. The development zone laid its foundation of education and Research & Development (R&D) on the large number of colleges and institutes within this area. Two China's top ten university, including Wuhan University and Huazhong University of Science & Technology (HUST) provide it with intelligence support. Wuhan Institute of Posts and Telecommunications (WRI), China's cradle of optical communication technology, provides a R&D platform for product and solution of information and telecommunication.

ELHDZ was established in October, 1988 by the Wuhan municipality. In March, 1991, it was elevated to one of the first batch of National High-tech Industrial Development Zone by the State Council. In July, 2001, Optics Valley of China was born within ELHDZ. Designated as the nation's only optoelectronic information industry base, the central government envision its development as a national strategy with the promise to parallel with the Silicon Valley. In March 2006, ELHDZ was approved as one of six China's pilot world level scientific park.

Over the past two years, ELHDZ has developed into not only an important Hi-Tech R&D centre, but also an optoelectronics manufacturing base in China. Nowadays, it is China's biggest optical fiber and optical cable (domestic market share of 55% and 25% in the world) as well as optoelectronic devices manufacturing base (domestic market share of 60%), biggest optical communications R&D centre, and biggest laser industry base (domestic market share of 60%).

By the end of 2009, the development zone has attracted more than 900 large enterprises and institutions aggregated here, including 20 World Top 500 and many national level enterprises and research centers. Most of them focus on five pillar industries, including optoelectronics, biotechnology, energy, environmental protection, and consumer electronics. In 2010, all the large enterprises within ELHDZ generated an output value of 291.8 billion RMB (about 42.7 billion US dollars). According to the latest plan of Wuhan Technology New Town, ELHDZ would develop into world class scientific park and manufacturing base in the coming ten year with an expanded extensive area of 220 km^2. In this research, we limit to our study into its original development area of about 50 km^2 (according to the document from the official administration websites).

As can be seen, the most prominent change for the land use change in the past three decades in ELHDZ is consistent and substantial increase of urban area, from 4.7% in 1978 to 44.4%, namely by an order of ten. On the contrary, both water body and other land use types have seen a dramatic decline, from 30.5% to 13.1% and 41.2% to 15.5%, respectively. However, it was also noticed that the area of vegetation (mainly farmland and forests) remained almost invariant.

Figure 17. East Lake Hi-tech area (in Google Earth)

Table 16. Land cover dynamics of East Lake Hi-tech area

Land cover type	Urban		Vegetation		Water		Other	
Year	Ha	%	Ha	%	Ha	%	Ha	%
1978	244.0	4.7	1220.7	23.5	1582.8	30.5	2139.2	41.2
1989	588.9	11.4	1649.0	31.8	1369.7	26.4	1579.1	30.4
2001	1529.8	29.5	1594.1	30.7	793.0	15.3	1269.8	24.5
2006	2258.0	43.5	1342.0	25.9	823.8	15.9	762.8	14.7
2008	2302.7	44.4	1399.3	27.0	681.5	13.1	803.3	15.5

Figure 18. Land cover change of East Lake Hi-tech area during 1978-2008

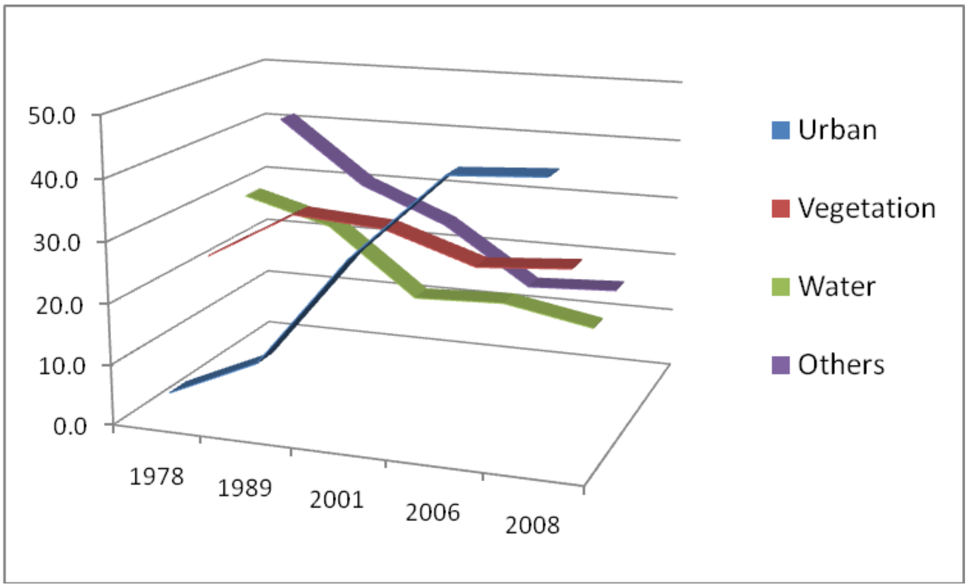
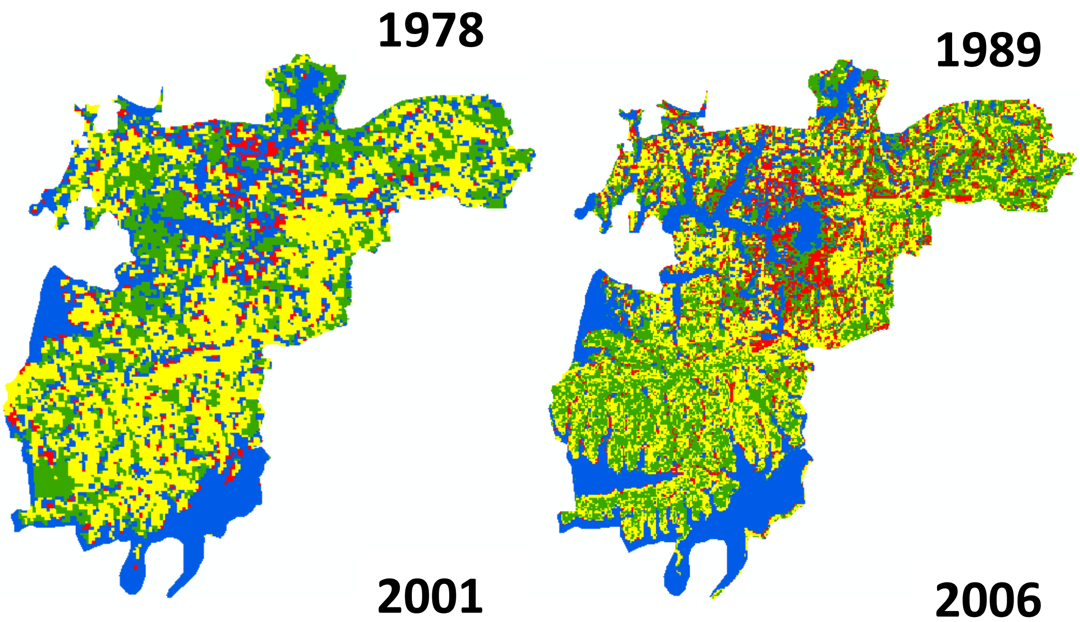
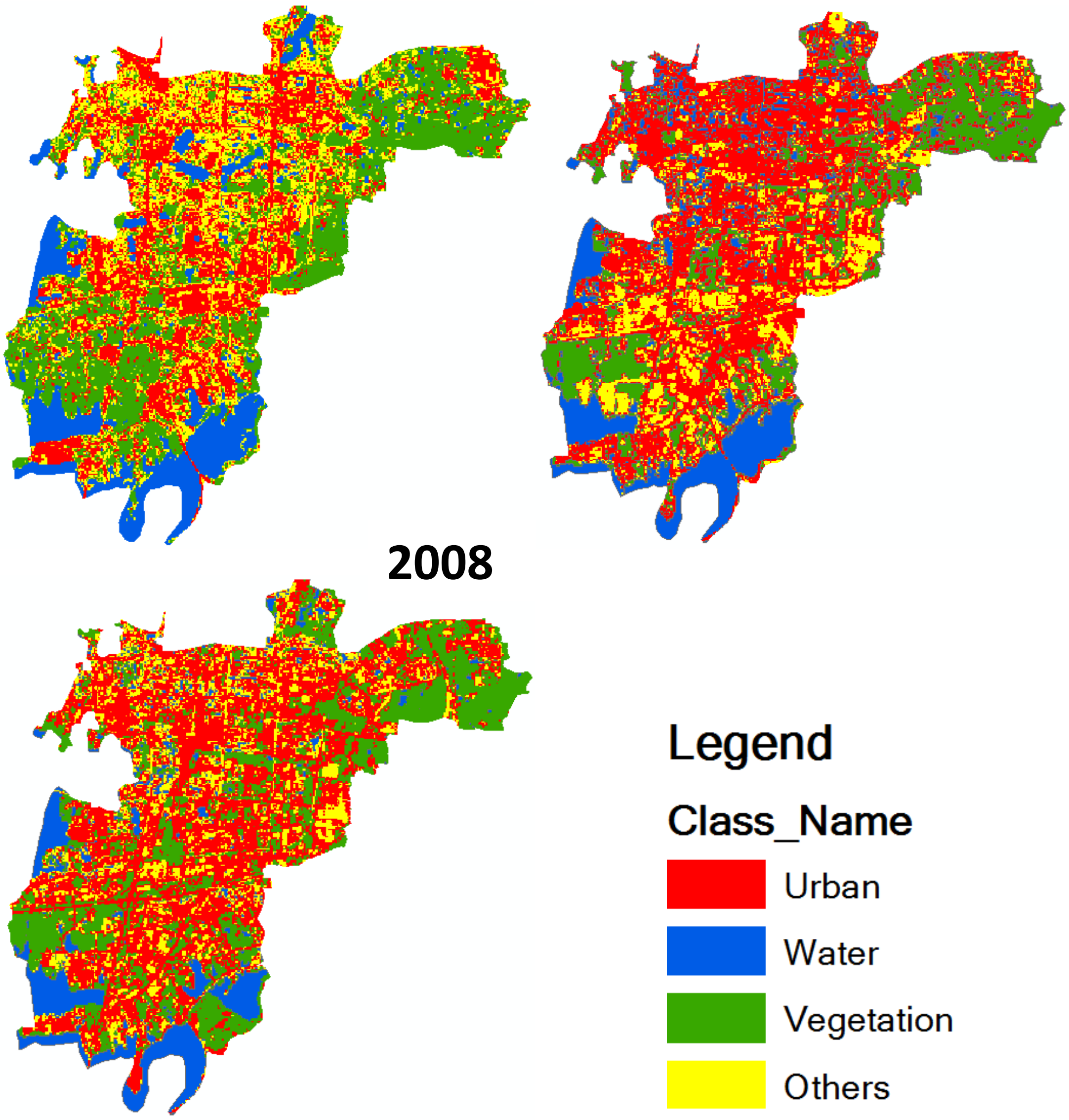


Figure 19. Land cover dynamics of East Lake Hi-tech area during 1978-2008





Visual observation of land use change revealed more underlying details in the past three decades. First, all land use patterns has universally become more regular over time. Second, large number of water bodies in the north and central part has disappeared. It was obvious that this is caused by the gradual expansion of urban area that surrounding them. Third, other land use types were more utilized and converted into urban areas. Fourth, although vegetation kept stable in area, they were more aggregated in the east and south parts which emerged large and compact patch.

China Micro case study 2: Zhuankou (Wuhan South-West)

Zhuankou is township name where the Wuhan Economic &Technological Development Zone (WEDZ) is located. Situated in the south-west of Wuhan and the north bank of the Yangtze River, WEDZ started construction in May 1991, and designated as national level development zone by the State Council in April 1993. In April 2000, an Export Processing Area with an area of 2.7 km^2 was approved within WEDZ, which is the only of its kind in Central China. After several rounds of expansion in the past almost twenty years, the development zone now covers a spacious area of 192.7 km^2 among which 40 km^2 has been fully developed. In this research, we limit the study area to its initial development boundary of about 80 km^2.

WEDZ embraces a very favorable geographical position for development. Besides to its proximity to the “Golden Waterway” of the Yangtze River, two national arterial highways comes across the zone, No.318 (Shanghai -- Lhasa) from the east to the west, and Jingzhu(Beijing —Zhuhai) form the north to the south, which render it easy accessible to anywhere in China .

The development of WEDZ is based on auto industry which is the longstanding basic industry in the city of Wuhan. As the headquarters of Dongfeng Company (East Wind, with literally translation, is essentially China’s Second National Auto Company), several joint ventures has set up in WEDZ, including Dongfeng and Nissan, Dongfeng and PSA, Dongfeng and Honda. In 2010, WEDZ produced nearly 660 thousands cars, which make Wuhan one of “Auto Capital of China”. In addition to auto industry, WEDZ is also a manufacturing centre of machinery, electronic, food processing and beverage, building material processing, pharmaceutical and biology engineering, etc.

By the end of 2009, WEDZ has attracted 2300 big enterprises and a total investment of 80.6 billion RMB (11.8 billion US dollars) from home and abroad, among which 4.4 billion US dollars are Foreign Direct Investment. In 2010, large industrial enterprises in WEDZ generated a total output value of RMB 150.8 billion (22.1 billion US dollars). WEDZ has become the largest and fastest-growing national-level development zone in Central and Western China.

Figure 20. Zhuankou area (in Google Earth)

Table 17. Land cover dynamics of Zhuankou area

Land cover type	Urban		Vegetation		Water		Other	
Year	Ha	%	Ha	%	Ha	%	Ha	%
1978	187.1	2.4	3541.1	44.5	2010.0	25.3	2210.5	27.8
1989	638.4	8.0	3690.3	46.4	1344.0	16.9	2276.0	28.6
2001	1896.8	23.9	3435.6	43.2	1188.2	14.9	1428.1	18.0
2006	2446.1	30.8	2852.4	35.9	945.3	11.9	1704.9	21.4
2008	3536.3	44.5	1944.6	24.5	1060.6	13.3	1407.3	17.7

Also can be seen, the prominent change of land use in Zhuankou is the dramatic increase of urban area, from 2.4 per cent in 1978 to 44.5 per cent in 2008. In contrast, both vegetation and water body has undergone a considerable decline. In particular, the area of vegetation remained stable before 2001. However, it descended sharply from 43% in 2001, through 36% in 2006, to 24% in 2008.

Figure 21. Land Cover Change of Zhuankou Area During 1978-2008

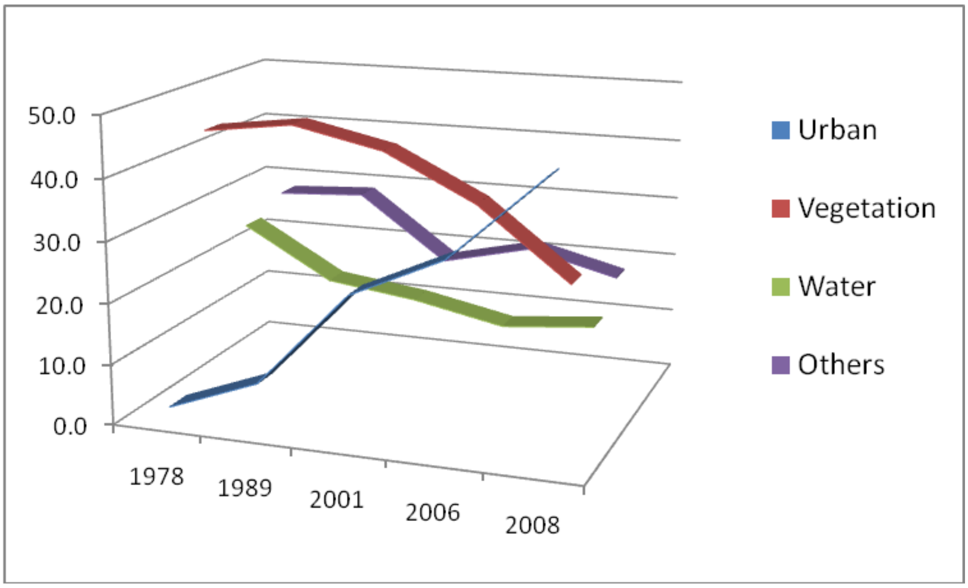
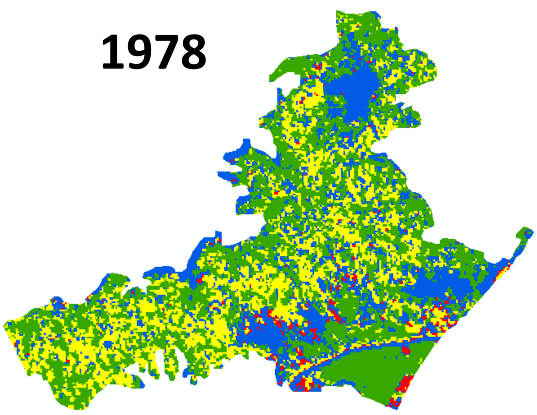
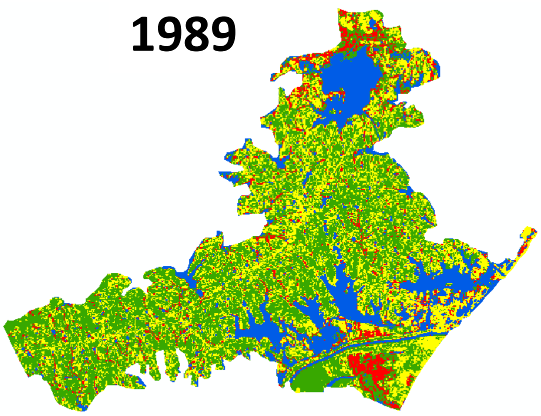
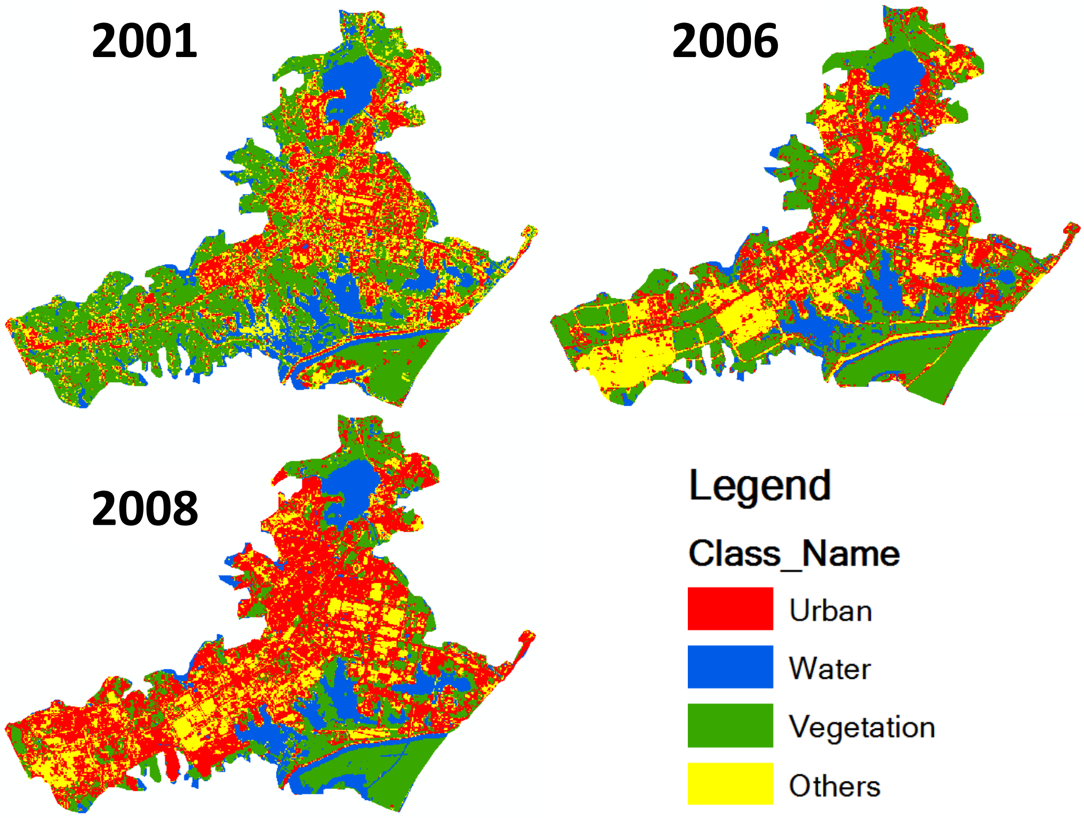


Figure 22. Land cover dynamics of Zhankou area during 1978-2008







Visual land use change exhibited that in before 2001, urban development was basically limited to the north part where the previous Zhuankou township is located. After 2001, most of urban area emerged along the main road that runs through the development zone.

China Micro case study 3: Wujiashan (Wuhan West)

Wujiashan is the shortened name of Wujiashan Taiwanese Businessmen Investment Zone (WTBIZ). located in the west part of Wuhan and about 10 kilometers from Hankou, the historical commercial downtown of the city, WTBIZ is the biggest Taiwanese investment zone in Mainland China. The Yangtze River and its largest branch of Hanshui River semicircles the zone. The two major railway arteries, i.e., Beijing-Guangzhou Railway and Beijing-Kowloon Railway also pass through it. The water transportation, railway and highway network have made it a hub, connecting the south and east, combining the north and the south.

Located in the far suburban Dongxihu District (East-West Lake District), a traditionally agriculture-based district, the development of the zone was initially trigged by some food processing manufactures which made use of its rich agricultural products in the early 1990s. Most of these projects are invested by Taiwanese businessmen. In 1992, the district established the Wujiashan Economic &Technological Development Zone to promote the development of food processing industry. One year later, WTBIZ was approved by Wuhan government. In 2000, it was elevated to a provincial development zone by the Hubei government. In November 2010, it was finally approved by the State Council as a national level development zone.

Led by the Taiwan businessman's projects, presently there are more than 2000 enterprises aggregated here, including 13 World Top 500. In 2010, the total large enterprises in WTBIZ generated an output value of about 40 billion RMB (about5.85 billion US dollars). The pillar industries are food processing as well as logistics due to its favorable and unique geographical location. The total area of WTBIZ is 150 km^2, homing 420 thousand residents. In the past ten years, the output value and fiscal income in WTBIZ has witnessed an unprecedentedly rapid increase, outstripping most of the districts in Wuhan city and cities in Hubei Province, which has make it the third growing pole of the city.

Figure 23. Wujiashan area (in Google Earth)

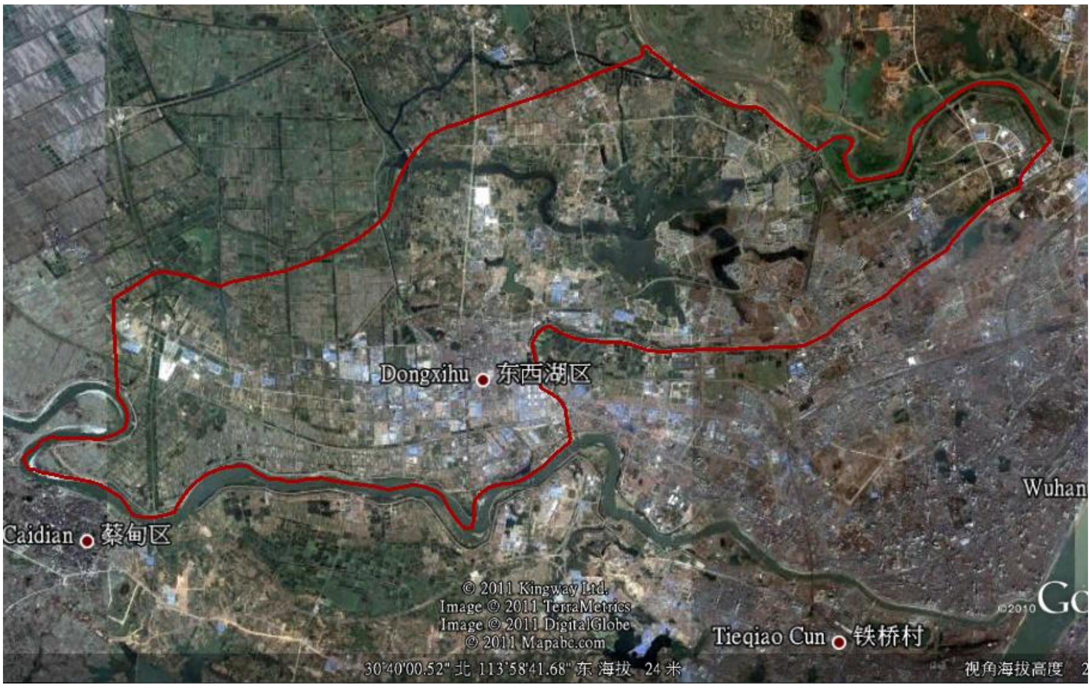


Table 18. Land cover dynamics of Wujiashan area

Land cover type	Urban		Vegetation		Water		Other	
Year	Ha	%	Ha	%	Ha	%	Ha	%
1978	943.0	6.3	3317.2	22.3	4977.9	33.5	5633.8	37.9
1989	1030.2	6.9	6063.3	40.8	3350.3	22.5	4428.2	29.8
2001	3015.8	20.3	4448.5	29.9	2998.9	20.2	4408.7	29.6
2006	4449.9	29.9	6989.1	47.0	2195.4	14.8	1237.5	8.3
2008	5321.5	35.8	5458.4	36.7	2331.4	15.7	1760.6	11.8

Similar to the former two development zones, the most noticeable change is the dramatic increase of urban area from 6.3% in 1978 to 35.8% in 2008. However, it was also noticed that before 1989, the urban area kept stable in a low value less than 7%, but soared sharply by three times during the period between 1989 and 2001. Also different to the land use change of the former two development zones, the area of vegetation always take a considerable share of about one thirds. Both water and other land use types has declined consistently.

Figure 24. Land cover change of Wujiashan area during 1978-2008

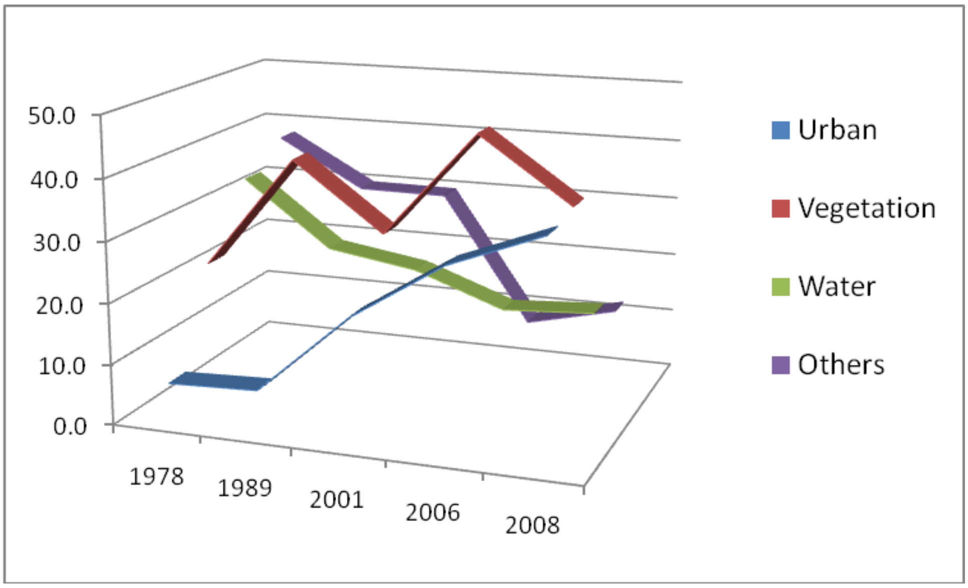
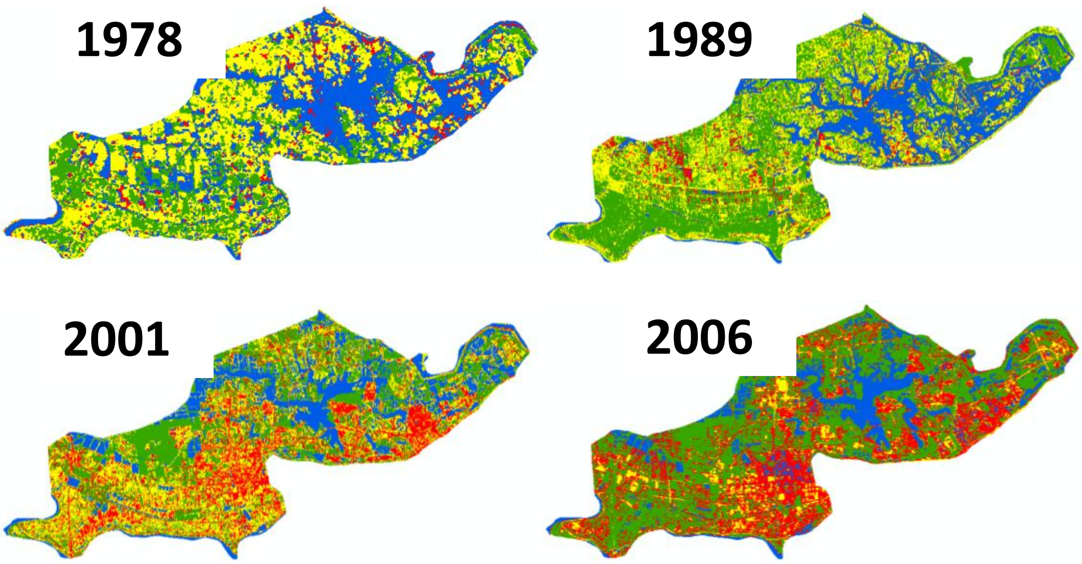
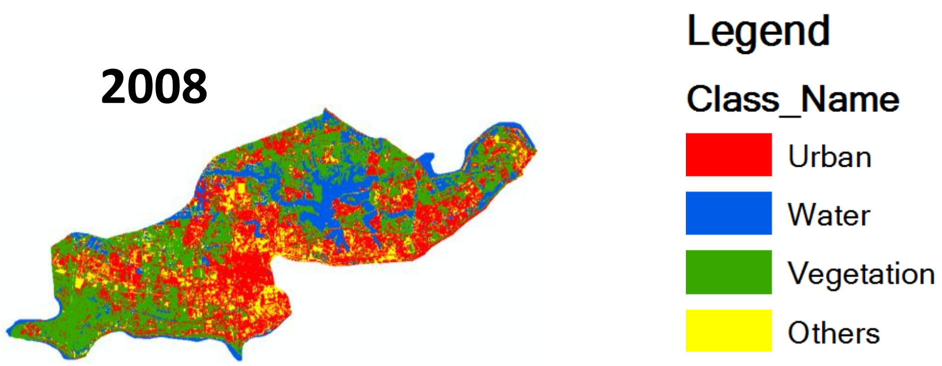


Figure 25. Land cover dynamics of Wujiashan area during 1978-2008





It was noted that urban areas were first aggregated in the central part where the Dongxihu district centre is located. After 2001, most of new urban area emerged in the east part, surrounding the big lake of the area. Meanwhile, a considerable share of new urban area appeared in the west part, in particular along the main road.

India Micro case study 1: Peenya Industrial area (Bangalore north west)

Peenya is one of the oldest and largest industrial areas in south-east Asia having latitude & longitude of 13.03°N 77.514°E. To promote and protect the small scale entrepreneurs Peenya industrial estate was established in 1977 by the Karnataka State Small Industries Development Corporation (KSSIDC) in two stages.

The KSSIDC established Peenya Industries as an objective of the promotion and development of Small Industries in the State, construction and utilization of infrastructure, especially in backward areas, procurement and marketing of Raw Materials, technical support and assistance. The industrial estate houses small, medium, as well as large scale industries and it lies between Bangalore-Mangalore Highway (NH-48) and Bangalore- Mumbai (NH-4), convenient for transportation. This industrial area is known for manufacturing and production of engineering as well as electrical products, it also has business firms of the major IT player like Wipro Technologies, ABB Global Services over here. Furthermore it is divided into 4 phases, phase 1 consists major industrial units, while 2, 3 and 4 are residential settlements. There are more than 4000 companies in which around 4000 small scale industries around 25 medium scale industries and having employers of 3, 50,000. The Spatio-temporal land use dynamics for the Peenya Industrial area is given in Table 18 and illustrated in Figure 27. Built-up area shows an increasing trend from 1973 to 2010 (Figure 28).

Figure 26: Peenya Industrial Area (Google Earth)

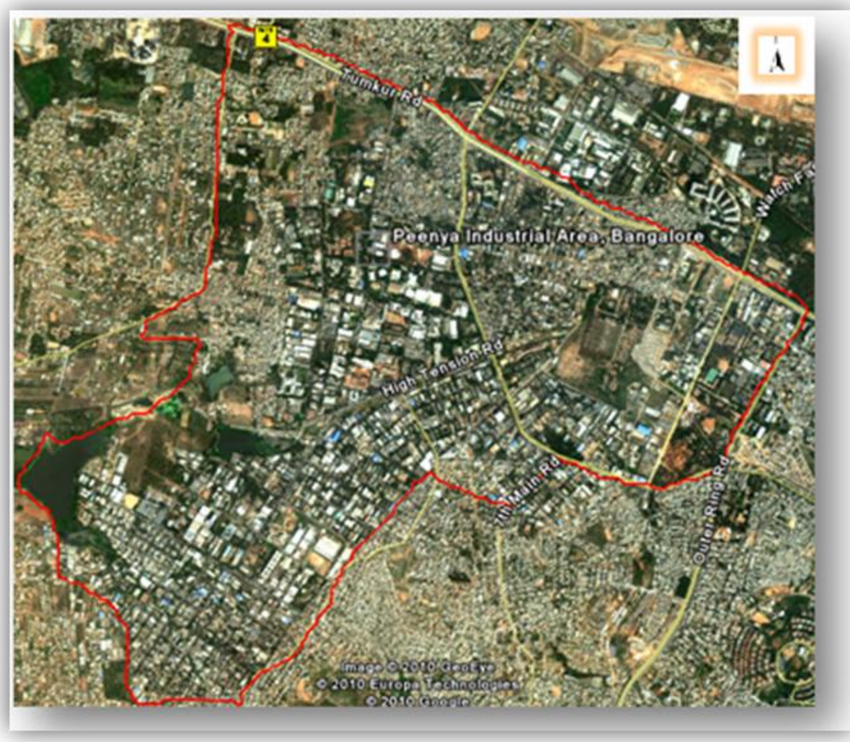


Table 19. Land Cover Dynamics of Peenya Industrial Area.

Land cover type	**Urban**		**Vegetation**		**Water**		**Other**	
Year	Ha	%	Ha	%	Ha	%	Ha	%
1973	3.06	**0.33**	647.37	70.22	2.79	0.3	268.65	29.14
1992	301.32	**32.69**	508.05	55.11	5.31	0.58	107.19	11.63
1999	485.28	**52.64**	354.42	38.45	0.27	0.03	81.9	8.88
2003	645.57	**70.03**	191.79	20.8	0	0	84.51	9.17
2008	686.79	**74.5**	147.96	16.05	8.1	0.88	79.02	8.57
2010	716.67	**77.74**	158.49	17.19	1.26	0.14	45.45	4.93

Figure 27: Land cover dynamics during 1973-2010 in Peenya industrial locality

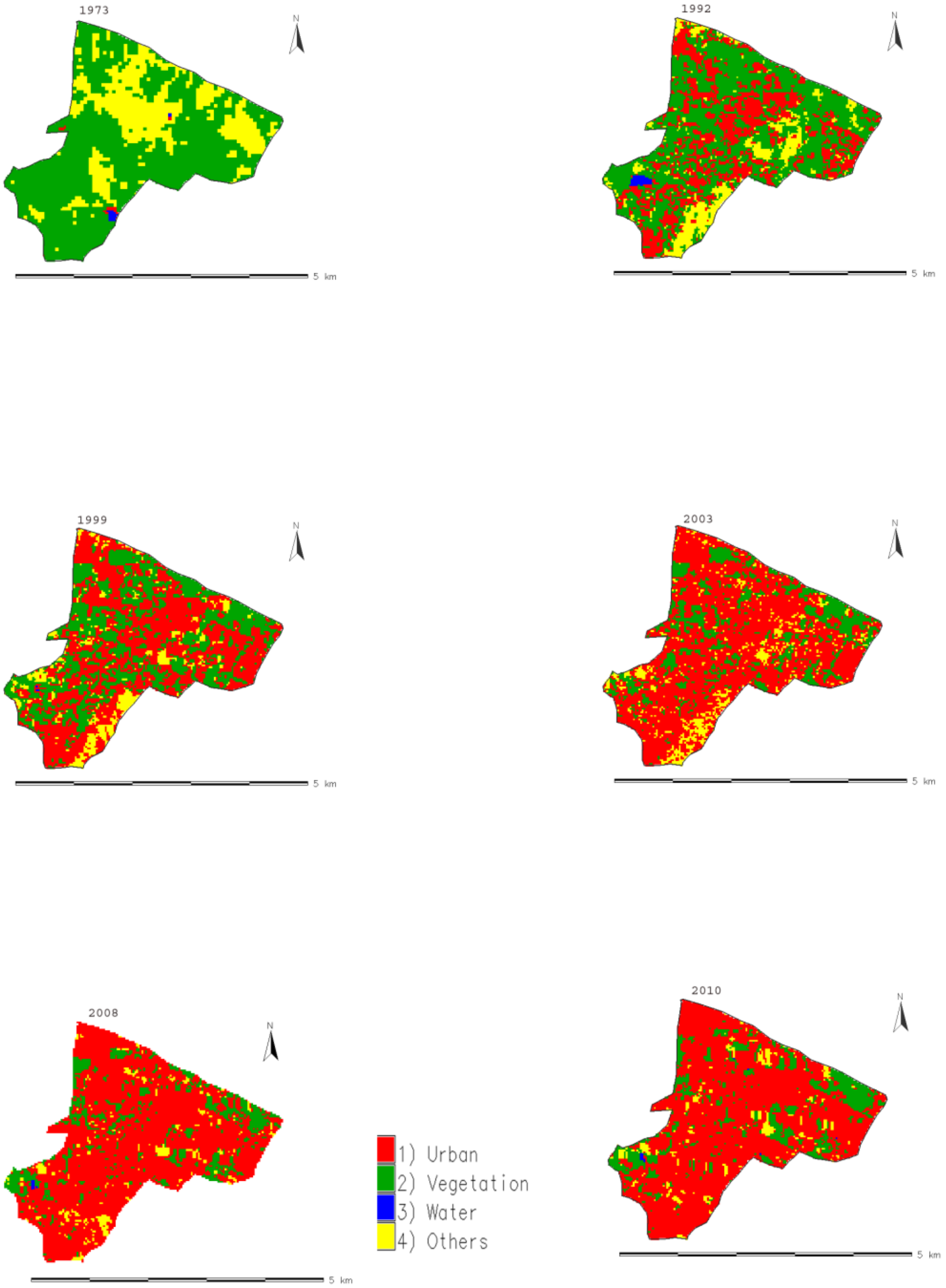
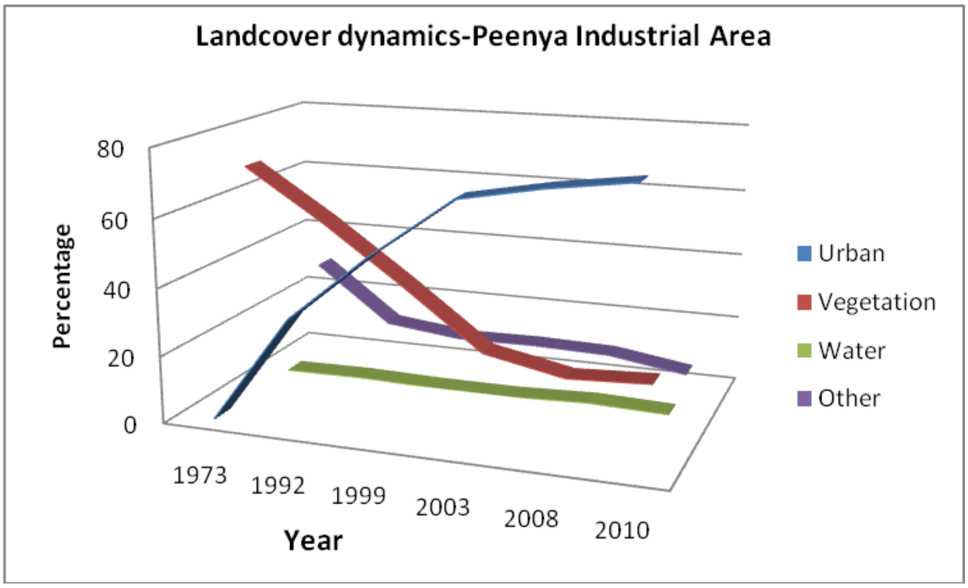


Figure 28: Changes in land uses during 1973 to 2010 in Peenya Industrial area



India Micro case II: Whitefield (Bangalore East)

This region is developed with an intention of attracting major global technology players, a number of multinational information technology (IT) companies and having latitude & longitude of 12.98°N 77.715°E (Figure 6). Until the late 1980s, Whitefield was a small village which was a retirement colony of Anglo-Indians. It has since become a major hub for the Information technology industry (in early 90's). The Export Promotion Industrial Park (EPIP) at Whitefield of one of the country's first information technology parks –(ITPB) which houses offices of many IT and ITES companies. Now Whitefield is officially part of Bangalore city with it being included into BBMP (Bruhat Bengaluru Mahanagara Palike). Whitefield has major medical facilities such as the Satya Sai Baba Hospital which specializes in cardio and neurological surgeries. In Whitefield area the residential constructions were started later 1990s and especially during 2002 onwards more apartment complexes have come. The recent attractions on Whitefield area are Forum Value Mall and Hyper city Mall at Kundanhalli Gate.

Figure 29: Whitefield Area

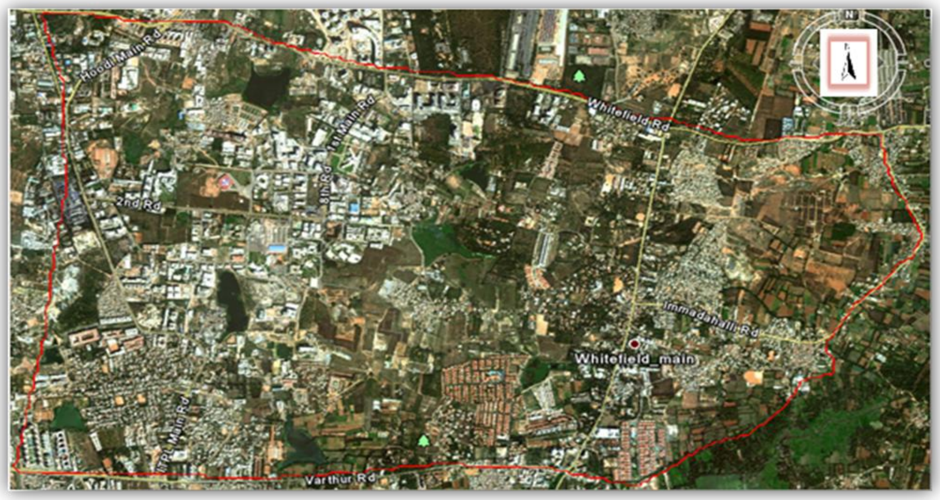


Figure 30 depicts the temporal changes in land uses during 1973-2010 in Whitefield area. Table 20 lists spatio-temporal land use dynamics. This illustrates a drastic land use changes during 90's with the setting up of new IT companies and new residential constructions (Figure 31).

Figure 30: Land use dynamics in Whitefield area during 1973 to 2010

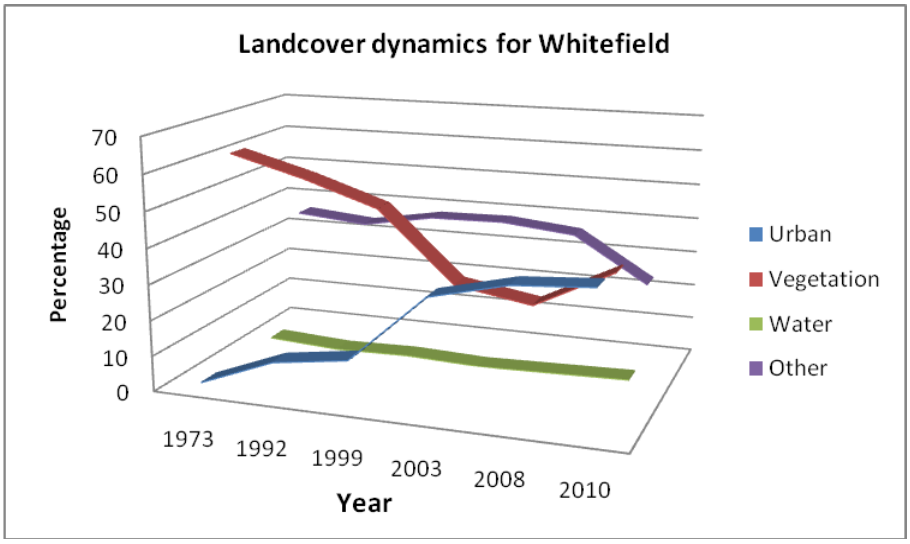
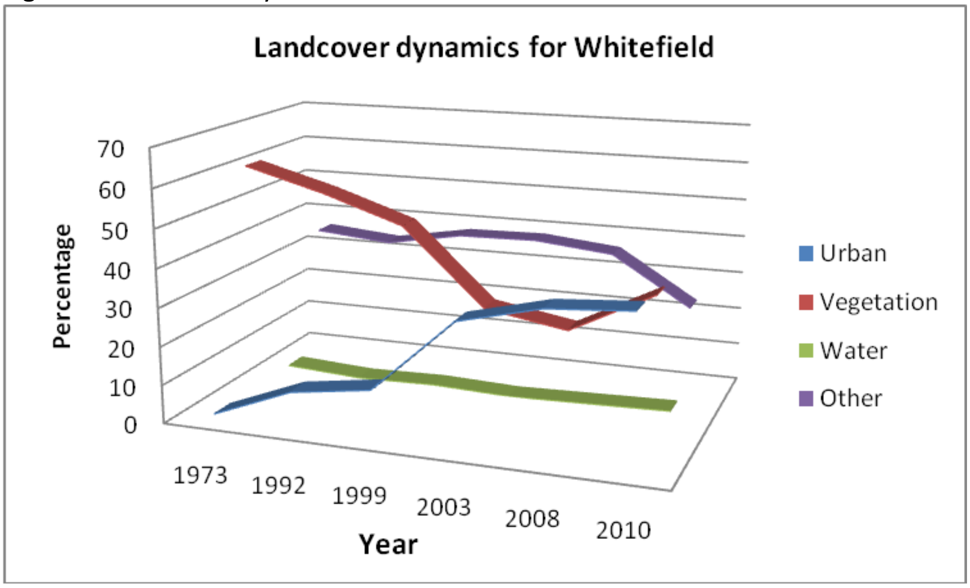


Table 20. Land Cover Dynamics of Whitefield Area

LAND COVER TYPE	URBAN		VEGETATION		WATER		OTHER	
YEAR	HA	%	HA	%	HA	%	HA	%
1973	35.46	1.61	1357.11	61.54	25.65	1.61	787.05	35.69
1992	217.98	9.88	1232.73	55.9	8.64	0.39	745.92	33.82
1999	278.82	12.92	1082.25	49.08	18.81	0.85	825.39	37.43
2003	712.17	32.29	658.62	29.87	0.99	0.04	833.49	37.8
2008	825.93	37.45	580.41	26.32	12.42	0.56	786.51	35.67
2010	858.60	38.93 ↑	821.07	37.23	24.21	1.1	501.39	22.74

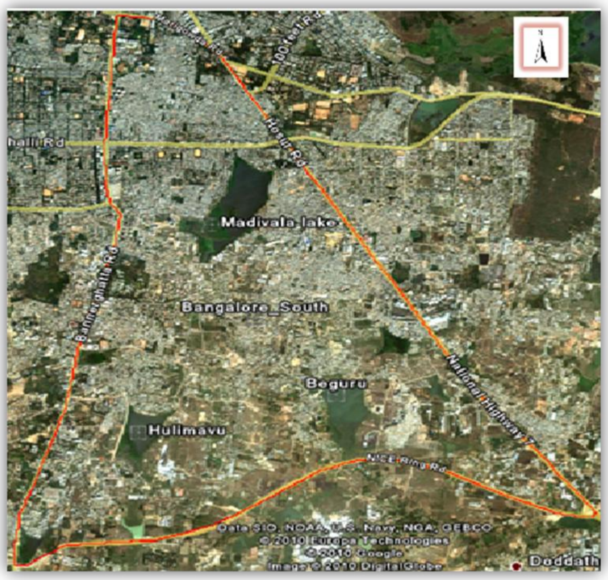
Figure 31: Land use dynamics for Whitefield



India Micro Case Study III: Bangalore South (Residential layouts)

Hulimavu & Beguru are in the south of Bangalore under the Bommanahalli municipal corporation and located on Bannerghatta Road and is about 15 kilo meters from the city having latitude & longitude of 12.87°N_77.60°E (Figure 9). Training data were collected from Hulimavu, Beguru, and other nearby areas. New residential layouts being developed by public authorities (BDA- Bangalore Development Authority) and private agencies layouts were mapped using GPS. The spurt in residential complexes in this locality could be attributed to the proximity to IT and BT industries, Bommanahalli industrial estate and large number of educational institutions.

Figure 31: Bangalore South Area



Land use dynamics during 1973 -2010 in Bangalore south are given in Figure 32. Statistics pertaining to land uses are listed in Table 21. The classified images are showing the increase in built-up area from 1973 to 2010 (Figure 33).

Figure 32. Land use dynamics in Bangalore South during 1973 to 2010

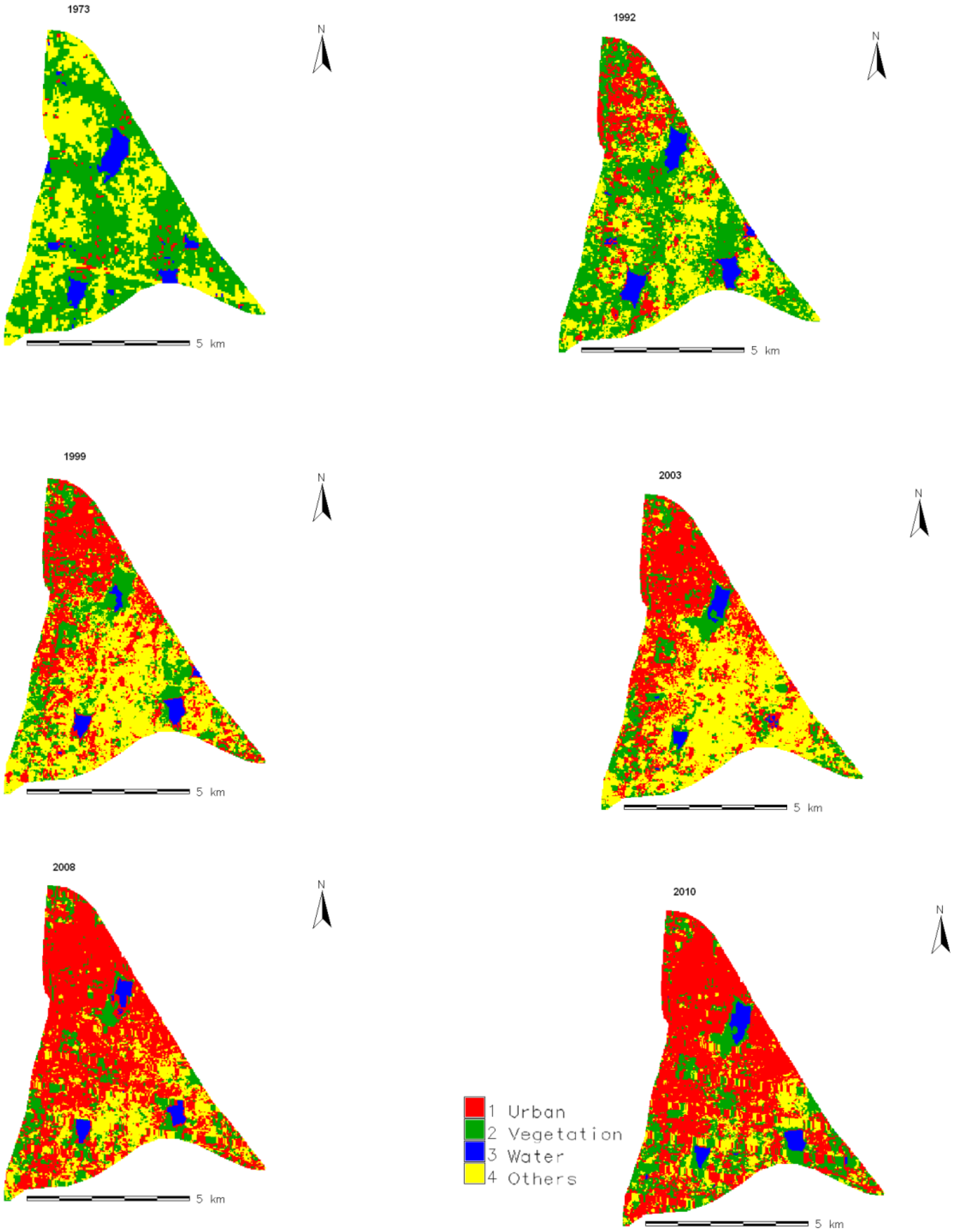
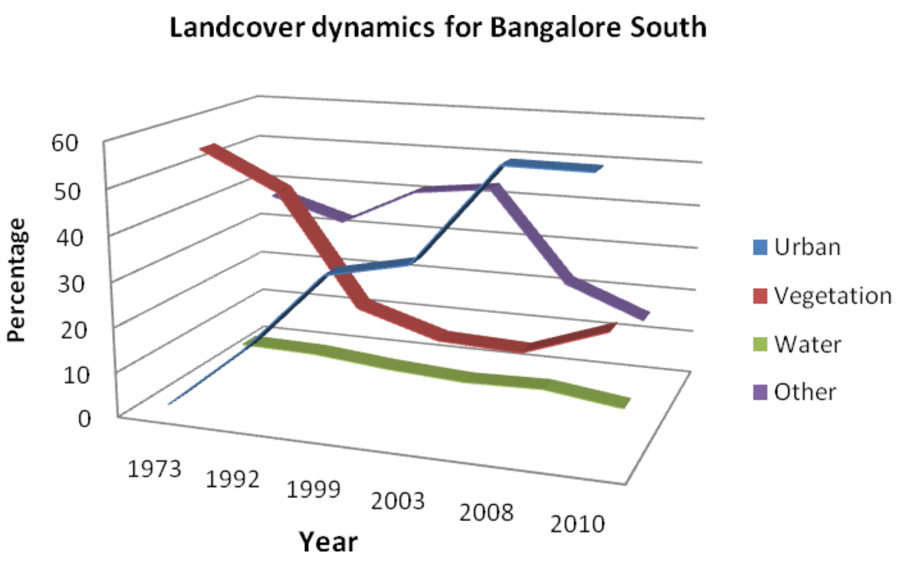


Table 21. Land Cover Dynamics for Bangalore South Area

LAND USE TYPE	URBAN		VEGETATION		WATER		OTHER	
YEAR	HA	%	HA	%	HA	%	HA	%
1973	72.18	2.11	1888.11	55.17	172.98	5.05	1298.25	37.67
1992	563.76	16.47	1588.86	46.72	159.03	4.65	1110.87	32.46
1999	1171.53	34.23	769.68	22.49	77.94	2.98	1403.37	41
2003	1299.87	37.98	583.92	17.06	64.98	1.9	1473.75	43.06
2008	2026.08	59.2	558.9	16.33	81.09	2.37	756.45	22.1
2010	2021.58	59.07	780.12	22.79	105.21	3.07	515.61	15.07

Figure 33. Land cover dynamics in Bangalore South



Conclusions from the Micro Case Studies

In all six local micro cases, analysis of the specific agents of urban land use change included an examination of the business and institutional organizations that had instituted new projects, along with a survey of the general patterns and directions of development for local land use. Combined with the historical data, this research yield an array of findings about the commonalities as well as the contrasts in patterns of peri-urban change.

Remarkable commonalities linked the trajectories in both sets of case studies. In each, the prominent drivers of new projects were factories, large real estate developments and state actors. Especially in the latter developments, both city governments had clearly drawn on science park strategies that have become well established, setting government facilities and new training institutes or universities alongside private company facilities.

The trajectories over time in the two countries also demonstrate a common evolution of local economic development strategies. In both countries the earliest project concentrations, in Peenya in Bangalore and in several locales around Wuhan, center around manufacturing activity. The later phases in each country, including the Optics Valley concentration in Wuhan and the Whitefield area in Bangalore, show a growing emphasis on high tech forms of production. In both countries a large proportion of the major developments have been controlled either by subsidiaries of foreign companies or by domestic companies enmeshed in production chains with foreign companies. In both countries, these agents of change have brought about a transformation of most land within the study areas.

A number of contrasts between the two countries also shed light on the sources of the differences in trajectories of urban land conversion. In Wuhan, the local governments and companies have clearly been the main drivers. Development has proceeded through the conversion of large parcels, usually with fully laid out infrastructure (especially roads, but also parks, utilities, etc.). The main dynamics driving shifts in development patterns have been intergovernmental: for instance, the promotion of the western district of --- from a local to a national development zone.

These conditions help to account for the higher rates of land conversion and the greater irregularity of urban/rural boundaries, but also the greater clumpiness and aggregation of land use in the Chinese cities more generally. Without the constraints of land rents calibrated by small, individual plots, and with infrastructure largely assured by the local government seeking to develop a plot, peri-urban land conversion follows a logic dictated by relations between the local government and the variety of firms interested in implanting their facilities in a given urbanizing neighborhood. This generally yields a more extensive, relatively porous pattern of urban development, with built up areas that include open space and limited densification of development. Requirements that a certain percentage of land remain agricultural or nonurban reinforce these consequences.

In Bangalore, despite the state initiatives of the Peenya and Whitefield projects, peri-urban development has been more the result of decisions by private actors, firms and even households. The filling in of peri-urban zones has occurred within a preexisting landscape consisting of a network of villages. Despite a number of large-scale projects, decisions of individual firms and households have created urban expansion through a cumulative process. The expansion in Bangalore South exemplifies how village structures give way to piecemeal expansion through single family homes, smaller scale developments, then larger scale infrastructure and high rise housing. Whitefield represents a partial adoption of business park model, but even there much of the new development has come about through new housing, malls and other commercial installations outside the economic development zone itself. In the very different developmental trajectories of Peenya and Bangalore South, these processes have produced an intensification of the built up area beyond that in any of the micro case areas studied in Wuhan. A similar result seems likely as development in the Whitefield area fills in.

4.0 Overall Conclusions

The macro analysis and the micro case studies have converged around similar conclusions. Although China and Indian have experienced parallel trajectories of land market liberalization and peri-urban expansion, the two societies entered this era with distinct patterns of urban form. Urban development has proceeded under the influence of distinct social, institutional and policy conditions in each country. These influences have reinforced and even magnified divergences in the patterns of urban expansion.

In China, a variety of institutional, social and economic conditions that have set distinctive terms of peri-urban development from those in India. These include restrictions on private property, the state-led nature of local property markets, the fiscal dependence of local governments on new development projects for financing local services, the conditions of state-designated special economic zones, the major role of state firms in manufacturing, the intensive participation of foreign capital in economic development, and the migration of temporary residents without local citizenship rights to the fastest growing urban regions.

Conditions of state control might be expected to enable a more controlled process of urban expansion. At a micro level perspective, it is evident that local governments have worked with state firms as well as other domestic and foreign firms to organize development around large plots of land and planned district frameworks rather than small-scale projects. Infrastructure has regularly been reassured, and protections on agricultural land and even resettlement policies for displaced rural residents have involved additional new housing.

The macro-level comparative perspective of this study for the first time makes it possible to assess the wider consequences for peri-urban development from a comparative perspective. The macro-level findings demonstrate how the state-dominated development process has in certain circumstances created powerful growth machines that have driven peri-urban expansion far beyond the extent evident in Indian cities. Along with expansion has come fragmented, sprawling, systematically complex and irregular patterns of urban form. These consequences have proven especially dramatic in the coastal cities where Special Economic Zones have been established and economic growth has occurred fastest, but have increasingly characterized inland cities as well. Closer examination indicates that these patterns reflect widespread inefficiencies in land use that have been the object of numerous critiques (e.g., Bertaud 2007) and recent attempts at reform. Even as new peri-urban development has often preserved or restored a portion of the original open space, expanded development has further degraded land and water resources as well as the potential of remaining agricultural land.

In India, many of the same influences from land rents, foreign direct investment, and migration to the cities have driven peri-urban expansion. But here stronger private property rights in land, weaker local governments, fewer capacities for infrastructure construction, fewer public incentives to develop peripheral areas, and often lower levels of participation by foreign capital have left peri-urban development a more fragmented, piecemeal, and privatized process.

Under these conditions, peri-urban development has followed what appears from the micro perspective to be a more disordered course. State interventions in delimited zones, such as the Peenya Industrial Zone and the Whitefield Export Promotion Industrial Park, often drive development. They do not, however, determine its shape or even its intensity. Particular firms and households, including software enterprises, manufacturers, real estate developers and even individual property owners, work through private decisions and property markets to delineate the urban frontier. Sufficient infrastructure must be secured from the state or by private provision. Its absence or inadequacy often curtails the possibilities for exploitation of exurban land.

From the macro perspective of this study, these micro dynamics produce a process of peri-urban expansion through market dynamics and private choices. Bangalore South, the case study zone without a major economic development zone, exemplifies a process that has also been important to expansion of the Whitefield and Peenya areas. Networks of rural villages give way to a scattering of small-scale villa developments or single-family houses. High-tech firm offices or plants, large development projects for high-rise housing, and ultimately commercial developments like malls then follow.

As a result of these processes, the built up areas of Indian cities have expanded significantly more slowly than Chinese counterparts despite equally dramatic growth in urban populations. In urban regions of greater sprawl, such as Bangalore and Delhi, intensification and infill development have matched and even counterbalanced ongoing expansion. Greater compactness, less irregularity in shape along the urban border, and retention of small rural village centers in the exurban periphery mark the overall Indian patterns of peri-urban development.

These macro-level processes have come about through a progression that appears disordered and even haphazard at the micro level. The deficiencies in infrastructure, the environmental degradation, the poverty and the lack of basic urban services on much of the periphery of Indian cities pose difficulties that in many ways exceed those on the urbanizing border of Chinese cities. But the amount of peri-urban land exploited for development remains more limited. The more compact, more intensified forms of development that result may ultimately produce more efficient and more sustainable cities.

5.0 Future Directions

This project represents one of the first of what might be termed mid-level investigations of urbanization and its consequences in developing countries. Rather than strive for generalizations at a global scale, or micro level understandings of one or two intensive case studies, the design has enabled an analysis that links micro-level analysis of dynamics of urban change to patterns at the national scale. To lay the groundwork for this analysis, a great deal of effort and care has gone into standardizing the analytical framework and the data, both between individual cities and over time, as well as between the divergent contexts of the two countries. An important and exciting research program has emerged as a result.

Several additional steps are planned. One will employ the data generated in this project to investigate in greater depth the patterns of urban development. Pooled time series and other analytical techniques will be employed to relate patterns of urban change in the two countries systematically to such subnational drivers as regional wealth and inequality, ethnic and demographic composition of cities, policies and institutions for control of land use, and physical geography.

A second area of investigation concerns the environmental consequences from different trajectories of urbanization. Part of the analysis in this project has already investigated effects from urbanization on the loss of agricultural land and water bodies. Subsequent investigations could focus on the consequences for such features as fragmentation of habitat, degradation and changes in vegetation and other environmental changes measurable through remote sensing and related techniques. It would be especially useful to investigate these consequences not just on the immediate urban periphery alone, but in the wider region surrounding expanding cities. The environmental consequences of urbanization in these wider regions through patterns of migration, agricultural transition, and the emergence of new nodes for development presents an important frontier for understanding the environmental consequences of urbanization. Consequences for greenhouse gas emissions from different patterns of urbanization comprise a further important object of investigation that can build on the results here.

Finally, the results will be employed in modeling of alternative urbanization trajectories. The aim of this portion of the research program will be to generate policy relevant conclusions that fit the circumstances of different varieties of cities.

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Appendix

<u>Conferences/Symposia/Workshops</u>

APN Bangalore Workshop, 5/10/2009 – 5/12/2009

Project participants:
Dr. Jefferey Sellers, University of Southern California.
Dr. Sun Shen Han, University of Melbourne.
Dr. Huang Jingnan, Wuhan University, P. R. China.
Dr. T. V. Ramachandra, IISc, India.
Dr. Sudhira H. S., IISc, Bangalore.

Workshop Agenda:

5/10/2009 (TVR, SSH, HJ, JS, HS Sudhira)
Venue: Citrine Hotel conference room
(Breakfast in hotel)

Meet 9:30 a.m. at hotel:
Morning agenda
--discuss findings from macro dataset
--analyze patterns emerging in the macro data, application of hypotheses
--initial discussion of progress to date and plans on micro cases
--administrative issues (budget, plans for next year, etc.)

LUNCH

Afternoon agenda
1. Macro case analysis
--finalize protocol for the macro dataset analysis, including data exchange and steps toward final analysis of indicators
--outline first paper(s) on macro dataset
2. Micro case analysis
--case selection
--outline of protocol
--preparation for stakeholder meeting
--planning for research schedule (site visits, etc.)
3. Planning
--remaining administrative issues
--schedule for 2009-2010

DINNER

5/11/2009 (TVR, SSH, HJ, JS, HS Sudhira)
Venue:

Indian Institute of Science
(Breakfast in Citrine Hotel)

9:30 am Inauguration
9.45 am Initiatives at CiSTUP - Overview, T.G. Sitharam
9.40 am About the Brainstorming session, T.V.Ramachandra
10-1030: Tea

Time Lectures
10.30 -11 am Comparing Peri-urban Development in China and India: Overview
Jefferey Sellers
11 -1130 am The Institutional Context of Peri-urban Development in China
Sun Sheng Han
1130 – 12 noon Comparing Indicators of Urban Expansion in China and India
Jingnan Huang
12-12 30 noon Urban Development and Environmental Aspects
Ramachandra T.V.
12 30 – 1 pm Spatial metrics in the regional analysis of urban form
Sudhira H S
1 -2 pm Lunch
2 -4 pm Interactive sessions - All stakeholders
4- 4 30 pm Concluding Session

DINNER

5/12/2009 (TVR, HJ?, JS, HS Sudhira)
Venue:
Citrine Hotel
(Breakfast in Citrine Hotel)
9:30: Optional meeting (if we decide it's necessary)
Possible agenda:
--Outcomes from Brainstorming Session
--Remaining agenda items

Address and locations

Citrine Hotel address:
#211, S.C. Road, Sheshadripuram
Bangalore 560 020
Tel.: +91 80 4000 3000
enquiry@thecitrinehotel,com

Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore - 560012

Brainstorming Session

on

Urban Development and Environmental Sustainability

Date: 11th May 2009 (Monday), 9:30 am to 4:30 pm

Venue: Golden Jubilee Seminar Hall, Department of Civil Engineering,

Indian Institute of Science, Bangalore

Background: Expanding urban regions have emerged as one of the major anthropogenic sources of global environmental change. Beyond multiple environmental stresses from land use change, land degradation, and air and water pollution, urban development often creates new human vulnerabilities from unhealthy living conditions for residents of urban peripheries. Much of urban growth worldwide in the next decades will take place in the developing countries of Asia. India's urban population is currently growing at about 2.3 percent per annum with an unprecedented population growth and migration. The number of urban agglomerations and towns in India has increased from 3697 in 1991 to 4369 in 2001. It is projected that the country's urban population would increase from 28.3 percent in 2003 to about 41.4 percent by 2030. Cross-national comparative analysis and assessment of the environmental consequences from these processes is crucial to understanding the policy alternatives to address them. The brainstorm session addresses how urban sprawl has affected the environment in the urban periphery in two distinct national contexts and suggests alternative policies and institutional arrangements for making urbanization more sustainable. Comparison of urban sprawl and its consequences with case studies from developing countries holds special interest for the global problem of sprawl and urban environmental sustainability.

Resource Persons:

- Jefferey Sellers, Professor of Political Science, Geography and Public Policy (University of Southern California, USA): Interdisciplinary researcher with doctorates in Political Science and Law. Strong background in comparative research on cities and environmental policy
- Sun Sheng Han (University of Melbourne, Australia); doctorate in urban and economic geography. Strong background in urban and regional development studies and in GIS applications. Experienced in Pacific-Asia urban research and managed research projects from conception to completion.

- Jingnan Huang (School of Urban Design, Wuhan University, Peoples' Republic of China); application of GIS and Remote Sensing in the urban area. Strong background in Urban Planning and Urban studies for Chinese cities
- Xi Xi Lu (National University of Singapore, Singapore); Associate Professor in physical geography in GIS and Map Resource Unit, National University of Singapore, with teaching and research experiences in GIS and remote sensing applications.
- T.V. Ramachandra, Energy & Wetlands Research Group, Centre for Ecological Sciences (CES), Indian Institute of Science (IISc), India; Research in urban sprawl dynamics, spatio-temporal analysis (GIS, remote sensing, digital image processing], Energy, environment issues and regional development studies. Experienced in urban ecosystem, aquatic ecosystem research and coordinated research projects from conception to completion.
- Sudhira H .S. Energy & Wetlands Research Group, Centre for Ecological Sciences (CES), Indian Institute of Science (IISc), India; Research in Urban Dynamics, Sprawl, Geo-simulation, Planning Support Systems, Development Economics, Urban Governance

Tentative Programme:

9:30 am Inauguration

9.45 am Initiatives at CiSTUP - Overview, T.G. Sitharam

9.40 am About the Brainstorming session, T.V.Ramachandra

10-1030: Tea

Time	Lectures
10.30 -11 am	Comparing Peri-urban Development in China and India: Overview Jefferey Sellers
11 -1130 am	The Institutional Context of Peri-urban Development in China Sun Sheng Han
1130 – 12 noon	Comparing Indicators of Urban Expansion in China and India Jingnan Huang
12-12 30 noon	Urban Development and Environmental Aspects Ramachandra T.V.
12 30 – 1 pm	Spatial metrics in the regional analysis of urban form Sudhira H S
1 -2 pm	Lunch
2 -4 pm	Interactive sessions - All stakeholders
4- 4 30 pm	Concluding Session

Invitees:

1. The Principal Secretary, Urban Development Department, Government of Karnataka.
2. The Commissioner, BDA.
3. Deputy Conservator of Forests, BDA
4. The Commissioner, BBMP
5. The Commissioner, BMRDA.
6. The Member Convener, BMLTA and Commissioner, DULT
7. The Chairman, KSPCB.
8. CEO, Lake Development Authority
9. Deputy Conservator of Forests, Urban, Karnataka Forest Department
10. Participants from DULT, BMLTA
11. Secretary, Department of Forest Ecology and Environment, Government of Karnataka
12. Secretary, Karnataka State Council for Science and Technology
13. The Chairman, BWSSB
14. The Chairman, Karnataka Urban Water Supply and Drainage Board
15. Directorate of Town Planning
16. The Chairman, Karnataka Urban Infrastructure Development and Finance Corporation

Contact details

Prof. T. G. Sitharam [sitharam@civil.iisc.ernet.in], Chairman, CiSTUP

Dr. T.V. Ramachandra [cestvr@ces.iisc.ernet.in]

Wuhan workshop on "Peri-urban Development and Environmental Sustainability: Examples from India and China"

May 9- 12, 2010

Project participants:
Dr. Jefferey Sellers, University of Southern California.
Dr. Sun Shen Han, University of Melbourne.
Dr. Huang Jingnan, Wuhan University, P. R. China.
Dr. Lu Xi Xi, National University of Singapore,
Dr. T. V. Ramachandra, IISc, India.
Ph.D. candidate Uttam Kumar, IISc, Bangalore.

May 7-8: arrival of participants

May 9

Opening Session, 9 a.m.

Venue: meeting room of School of Urban Design (SCD), Wuhan University, open seminar.
Attendants: project member, professor of SCD, graduates.

Chair: Professor and vice dean of SCD, Qingming Zhan.

Speaking time: 15 minutes. Question time: five minutes

Speaker	Topic
Professor Jeffery Sellers	Project introduction
Dr Jingnan Huang	Urban form change of Chinese cities in the past three decades
Professor T.V. Ramachandra	Changing urban form in Indian urban regions
Professor Sun Sheng Han	Toward a comparative case study of urban growth: outline of a research design
Dr Uttam Kumar	A case study of Indian urban growth: Bangalore
Dr Ningrui Du, Wuhan University School of Design	Wuhan's water environment change in the past two decades
Professor Zhengdong Huang, Wuhan University School of Design	Wuhan transport
Professor Qingming Zhan, Wuhan University School of Design	Time series land use change of Wuhan city

Afternoon Working Session

Start time: 2 p.m.

Venue: meeting room in Fengyi Hotel. Attendants: project members

Agenda:

1. Overviews of macro case data for Chinese and Indian cities
2. Discussion/comparative analysis
3. Full presentation of material to date on micro case studies
4. Discussion of comparative micro case study design

May 10

Visit to Wuhan Urban Planning and Land Use Administration, and meeting with local experts, officials, and other stakeholders

Field trip to Wuhan High Technology Development Zone, other sites around south and east Wuhan.

May 11

Morning: Symposium on Low Carbon Cities

Afternoon: Organizational meeting for final phase of project, Wuhan University campus (TVR, UK, HJ, JS)

Agenda:

1. Final thoughts on macro analysis paper
2. Analyze material to date on micro case studies
3. Outline remaining research on first micro comparative case studies
4. Outline plans for second and third micro case studies, papers based on micro case studies
5. Plans for website, International Human Dimensions Program activities
6. Plans for final Bangalore workshop (projected date: first week of December 2010), other subsequent activities

May 12

Morning-afternoon: Field visit to Xiangxi District office, other suburban locations in southeast Wuhan

May 12 and subsequently: Departure of participants

Final Schedule

Bangalore APN Workshop, December 4-6, 2010

Venue: Center for Ecological Studies, Indian Institute of Science, Bangalore.

Participants: T.V. Ramachandra, Uttam Kumar, Jingnan Huang, Jefferey Sellers, Uttam Kumar (Ph.D. Student, IISc) (uttam@ces.iisc.ernet.in), Anindita Dasgupta (Ph.D. Student, IISc) (anindita_dasgupta@ces.iisc.ernet.in), Bharath Settur (Ph.D. Student, IISc) (settur@ces.iisc.ernet.in), Bharath H Aithal (Ph.D. Student, IISc) (bharath@ces.iisc.ernet.in), Sowmyashree (Student, IISc) (Sowmyashree@ces.iisc.ernet.in)

Schedule

Prior to workshop (by 3 December 2010):

Exchange of powerpoints between Bangalore and Wuhan among all participants

Exchange of datasets including all metrics

(If possible, assuming datasets received by 12/2) preliminary comparative analysis

Saturday, December 4

9 a.m. Presentation of final Indian macro data (especially charts of metrics)

10 a.m. Presentation/discussion of Indian micro case study

11 a.m. Initial discussion of strategies for comparative macro and micro analysis

LUNCH

2 p.m. Presentation of final Chinese macro data (especially charts of metrics)

3 p.m. Presentation/discussion Chinese micro case study

4 p.m. Discussion: plans for first macro case study paper, second macro case study paper, and coordination of remaining micro case study work

Sunday, December 5

Morning:

Field visit to micro case study sites

Afternoon/evening:

Working sessions to compile and analysis Chinese and Indian macro data

Monday, December 6

9 a.m. (with HJ participating) Discussion/ working session on initial comparative macro analysis, further coordinating discussion on remaining micro case study work

LUNCH

(afternoon time to be arranged) Concluding discussion, plans for final report and papers

Funding sources outside the APN

U.S.- China Institute Faculty Research Grant, University of Southern California ($7500)
University of Southern California, Dornsife College Faculty Development Grants (total: $10,500)
University of Southern California, Center for International Studies Faculty Grant ($2500)
University of Southern California, overhead for project administration (in-kind) (total: $25800)
Indian Institute of Science, overhead, partial housing and meal subsidies, software licenses, miscellaneous extras during workshop (total: $5966)
Wuhan University School of Urban Design, overhead, miscellaneous workshop expenses, software licenses, satellite images (total: $2000)

List of Young Scientists

Los Angeles:
Vanessa Hongsathavij, A.B. USC, Ph.D. candidate, Yale University, conducted background research on policy history of Indian cities.
Doreen Grosvirt-Dramen, A.B., USC graduate, worked on the statistics and background research during the first year of the project.
Seanon Wong, Ph.D. candidate, USC (swong@usc.edu), researched economic, social and other demographic statistics for Chinese cities.

Bangalore:
H.S. Sudhira, Ph.D., Research Scholar, IISc 2009 - 2010, carried out initial versions of Indian remote sensing and metric data.
Uttam Kumar, Research Scholar and Ph.D. candidate, IISc (uttam@ces.iisc.ernet.in).
Anindita Dasgupta, Research Scholar and Ph.D. candidate, IISc (anindita_dasgupta@ces.iisc.ernet.in).
Bharath Sttur, Research Scholar and Ph.D. candidate, IISc (settur@ces.iisc.ernet.in).
Bharath H Aithal, Research Scholar and Ph.D. candidate, IISc (bharath@ces.iisc.ernet.in).
Sowmyashree, Research Scholar, IISc (Sowmyashree@ces.iisc.ernet.in).

From Uttam Kumar, Indian Institute of Science, Bangalore, India.

Email: uttam@ces.iisc.ernet.in

I have been involved in the APN project from the first APN Bangalore Workshop (10-12 May, 2010) and subsequently participated in the second and third Workshops at Wuhan (9-12 May, 2010) and at Bangalore (4-6 December, 2010) respectively. During the project implementation and data analysis, I participated in data collection, both remote sensing imageries and ground based observations. I was able to guide other students and researchers while performing classification of the satellite images of the ten Indian cities. While doing the metrics analysis, I had reviewed several published literatures to narrow down to a few selected spatial metric that could describe a landscape appropriately. In the process, I was much benefited from the fruitful discussions with Prof. Jefferey Sellers, Dr. T. V. Ramachandra, Huang Jingnan along with several students participating in the work. The selected metrics were applied for the analysis of Bangalore city from 1973 to 2010 with respect to 8 trajectories from the city centre (north, north-east, east, south-eat, south, south-west, west, and north-west). It gave very interesting results while revealing many facts about the city's growth pattern, which would otherwise have been difficult to capture. This led to further statistical analysis focused on the growth poles. The entire study constituted a chapter in my PhD thesis. I along with many other short-term students and researchers were benefited with the APN Project. The study carried out as part of the project can be extended further to many other cities that would form the starting point for further research on urban growth pattern in India and other countries.

In Wuhan:

name	Type	Age	Working time	assignment
Huang Jingnan	Recent graduated Ph.D (in 2008/07 from National University of Singapore); staff of School of Urban Design, Wuhan University	37	2008/03-2011/03	Design of framework of satellite image data processing , calculation of spatial metrics; writing of report
Zhang Penglin	Associated professor; staff of School of Remote Sensing and Information Engineering, Wuhan University	41	2008/12-2010/06	Instruction of satellite image processing
Du Ningrui	Recent graduated Ph.D(in 2009/02 from Utrecht University, the Netherland); staff of School of Urban Design, Wuhan University	42	2009/08-2010/12	Correlation Analysis of socio-economic indicators and spatial metrics; interpretation of evolution of urban form of Chinese cities.
Li Zhen	First year of Ph.D student of School of Urban Design, Wuhan University	25	2009/07-2010/12	Processing of TM images of Chinese cities in four periods in past three decades
Liu Chenhai	Second year of Master student of School of Remote Sensing and Information Engineering, Wuhan University	24	2009/07-2010/12	Processing of TM images of Chinese cities in four periods in past three decades