

**URBAN TRANSFORMATION IN CHINA:
From an Urban Ecological Perspective**

Ruibo Han

**Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
In partial fulfillment of the requirements
For the PhD degree in Geography**

**Department of Geography
Faculty of Arts
University of Ottawa**

Dedication

This work is dedicated to my parents,
Cuilian Qu and Zhaoyin Han

My beloved wife,
Linna Wang

And our forthcoming baby.

Table of Contents

List of Tables.....	vi
List of Figures	vii
List of Acronyms.....	ix
Abstract	xi
Résumé.....	xv
摘要.....	xx
Acknowledgements	xxii

Chapter 1 Introduction 1

1.1 Background	1
1.1.1 Urbanization: The context of urban system and urban ecology.....	2
1.1.2 Urban system: System of cities and cities as systems	6
1.1.3 Urban ecology: Understanding human-dominated ecosystems	10
1.1.4 Research direction	12
1.1.5 Urban development in China	15
1.2 Research questions and research scheme	19
1.2.1 Research questions	19
1.2.2 Research scheme	20
1.3 Methodology	25
1.3.1 Thesis framework.....	25
1.3.2 National urban system – National scale (Macro scale).....	28
1.3.3 Regional urban cluster or subsystem – Regional scale (Meso-scale)	32
1.3.4 Urban ecological system – City scale (Micro-scale).....	35
1.3.5 Thesis structure	39
1.4 Anticipated contributions	41

Chapter 2 Challenges Facing China’s Urban Development in the New Era45

2.1 Introduction	45
2.2 Challenges and opportunities for China’s urban development	48

2.2.1	Drivers behind the institutional transition.....	49
2.2.2	Urban structural transition.....	65
2.2.3	Spatial transition.....	80
2.3	Targeting a sustainable urban development.....	86
Chapter 3 Studying the Urban Hierarchical Pattern and Spatial Structure of China Using A Synthesized Gravity Model.....		88
3.1	Introduction.....	88
3.2	Methodology.....	92
3.2.1	Building the Synthesized Gravity Model.....	92
3.2.2	Delineation of the nodal and hierarchical structure.....	97
3.3	Applying the SGM to China’s urban system.....	101
3.4	Findings and discussions.....	107
3.4.1	Evolving urban clusters.....	107
3.4.2	Unbalanced development within urban clusters.....	112
3.4.3	Uneven spatial development.....	115
3.5	Conclusion.....	119
Chapter 4 The Spatiotemporal Transition of China’s JingJinJi Metropolitan Area: Detection, Modeling and Prediction.....		122
4.1	Introduction.....	122
4.2	Research methodology.....	126
4.2.1	JingJinJi Metropolitan Area.....	126
4.2.2	Data acquisition.....	127
4.2.3	The CA-based SLEUTH model.....	130
4.2.4	Incorporation of socioeconomic data into the SLEUTH model.....	133
4.2.5	Data input preparation.....	136
4.2.6	Dynamic spatial modeling.....	138
4.3	Results and discussion.....	141
4.3.1	Result of the Calibration Phase.....	141
4.3.2	Land use/land cover change during the Calibration Phase.....	143

4.3.3	Scenarios of the Prediction Phase	147
4.4	Driving forces of JJJ's urban growth	153
4.4.1	Urban policies	153
4.4.2	Industry restructuring	155
4.4.3	Rural-urban migration	157
4.4.4	Reclassification of urban boundaries	159
4.5	Conclusions	161
Chapter 5 Urban Transformation of Beijing: Patterns and Process of Landscape Change		164
5.1	Introduction	164
5.2	Methodology	168
5.2.1	Study Area - Beijing as a city	168
5.2.2	Research Design	170
5.3	Results and analysis	178
5.3.1	Social landscape of Beijing	178
5.3.2	Landscape ecological analysis	189
5.3.3	Spatial Regression Analysis	197
5.4	Discussion and conclusion	208
5.4.1	Suburbanization of Beijing	208
5.4.2	Urban dynamics and social segregation	212
5.4.3	Relocation of the secondary industry	215
5.4.4	Towards sustainable urban development	217
Chapter 6 Conclusion.....		219
6.1	Review of findings	219
6.2	Limitations of this thesis	228
6.3	Future research directions	231
Appendix: Use of Fuzzy Logics in Mapping Urban Areas from Landsat TM Imagery		234
References		252

List of Tables

Table 1.1 Structure of the proposed thesis	40
Table 2.1 The variation of the ranking scale of China's cities.....	53
Table 2.2 Chinese cities by region in 1985, 1995 and 2005	81
Table 2.3 Parameters about the standard deviation ellipses of Chinese cities	83
Table 3.1 Delineation of city levels	100
Table 3.2 Rotated component matrix in 1995 and 2005	102
Table 3.3 Total variance explained in 1995 and 2005	102
Table 3.4 Cities with highest scores of the principal components in 1995 and 2005	103
Table 3.5 Variation of largest linkages and influential factor.....	114
Table 3.6 Chinese cities by hierarchy and region in 1995 and 2005	117
Table 3.7 Comparison between the ranks of influential factor and non-agricultural population.....	118
Table 4.1 Acquisition date for each scene	129
Table 4.2 Socioeconomic factors included in the SLEUTH model.....	136
Table 4.3 Data requirement and generation methods.....	138
Table 4.4 Calibration process for the Breed Coefficient in SLEUTH model	140
Table 4.5 The optimum of the coefficient set trough calibration phases	141
Table 4.6 Land and land cover statistics for the JingJinJi Metropolitan Area.....	145
Table 4.7 Land use and land cover conversion statistics	146
Table 5.1 Overall performance of analysis	179
Table 5.2 Variance explained by components	180
Table 5.3 Component matrix of the factor analysis, 1990 & 2000	182
Table 5.4 OLS regression models in 1990.....	199
Table 5.5 OLS regression models in 2000.....	200
Table 5.6 GWR results for PLAND and LSI in 1990 and 2000	203
Table 7.1 Error Matrix of the Classification from Landsat TM Data	248

List of Figures

Figure 1.1 Urbanization as a process	5
Figure 1.2 Conceptual framework of an integrated human ecosystem	14
Figure 1.3 Conceptual framework of China's urban system.....	23
Figure 1.4 Theoretical framework to study China's urban system	26
Figure 1.5 Flowchart of the methodology at different scales.....	27
Figure 1.6 Hypothetical interaction patterns of China's national urban system	31
Figure 1.7 A conceptual model for a regional urban cluster.....	35
Figure 1.8 A conceptual model for the urban system of a city	36
Figure 2.1 Urban population and urbanization rate of China and selected counties, 1950-2020	46
Figure 2.2 Urban development phases of China	49
Figure 2.3 Open cities in China since 1979	55
Figure 2.4 Distribution of urban population among cities at different scales	58
Figure 2.5 Urban built-up area and urban density, 1981-2005	59
Figure 2.6 Rank-Size Distribution of Chinese cities in 1985, 1995, and 2005.....	66
Figure 2.7 Rank-Size diagrams of cities with population of over 100,000 in China, US, Russia and UK.....	68
Figure 2.8 Urban clusters identified from DMSP night-time light images.....	71
Figure 2.9 Comparison of urban population from different statistical criteria	76
Figure 2.10 Standard deviation ellipses of Chinese cities in 1985, 1995, 2005	83
Figure 3.1 Flowchart of the methodology.....	92
Figure 3.2 Schematic illustrations about influence between cities	93
Figure 3.3 Hierarchical structure of Chinese cities in 1995.....	106
Figure 3.4 Hierarchical structure of Chinese cities in 2005.....	106
Figure 3.5 Urban development of China since 1978.....	109
Figure 3.6 Urban clusters discerned from the DMSP nighttime light images	112
Figure 3.7 Evolution of the Yangtze River Delta urban cluster.....	114
Figure 3.8 Evolution of the JingJinJi urban cluster.....	114
Figure 4.1 Study area of the JingJinJi Metropolitan Area	127
Figure 4.2 Landsat TM mosaics of 1978 and 2009.....	128
Figure 4.3 The behavior rules of a growth cycle year.....	133
Figure 4.4 Urban expansion from 1978 to 2009	144

Figure 4.5 The urban area of the JJJ up to 2050 under three scenarios	151
Figure 5.1 Administrative divisions of Beijing.....	170
Figure 5.2 Conceptual model of Beijing as an urban system.....	171
Figure 5.3 Flowchart of the methodology	172
Figure 5.4 Zoning maps of the study area.....	175
Figure 5.5 Social space of Beijing, 1990	184
Figure 5.6 Social space of Beijing, 2000	187
Figure 5.7 The PLAND metric over time and space.....	192
Figure 5.8 The NP metric over time and space	193
Figure 5.9 The LSI metric over time and space	194
Figure 5.10 The PAFRAC metric over time and space	195
Figure 5.11 Coefficients of PLAND's GWR model, 1990	205
Figure 5.12 Coefficients of PLAND's GWR model, 2000	207
Figure 5.13 Population shift of Beijing since the 1980s	210
Figure 5.14 Industry structure by employment in Beijing	217
Figure 7.1 Location of study area and true-colour 3D image from Landsat TM and DEM	238
Figure 7.2 Flowchart of Landsat image processing	239
Figure 7.3 Statistics of training areas	241
Figure 7.4 Multi-criteria decision tree of the expert system	243
Figure 7.5 Hierarchical structure of the fuzzy expert system	246
Figure 7.6 Land cover classification results.....	247

List of Acronyms

AICc	Akaike Information Criterion
ANFIS	Adaptive-neural-based Fuzzy Inference System
BG	Balanced Growth
BR	Breed Coefficient
CA	Cellular Automata
CLCs	County-Level Cities
DEM	Digital Elevation Model
DI	Diffusion (Dispersion) Coefficient
DLM	Deltatron Model
DMSP OLS	Defense Meteorological Satellite Program's Operational Linescan System
EP	Environmental Protection
ETM+	Enhanced Thematic Mapper Plus
FD	Function Distance
GCP	Ground Control Points
GDEM	Global Digital Elevation Model
GDP	Gross Domestic Product
GIO	Gross Industrial Output
GIS	Geographical Information System
GM	Gravity Model
GNP	Gross National Product
GWR	Geographically Weighted Regression
HPF	Housing Provident Fund
HRS	Household Responsibility System
HU	Historical Urban Growth
IF	Influential Factor
IP	Influential Potential
LSI	Landscape Shape Index
MSS	Multispectral Scanner System
NP	Number of Urban Patches
OLS	Ordinary Least Squares
PAFRAC	Perimeter-Area Fractal Dimension
PCA	Principal Component Analysis
PD	Patch Density
PLAND	Percentage of Landscape
PLCs	Prefecture-Level Cities
PLMs	Provincial-Level Municipalities
PRC	People's Republic of China

PRD	Pearl River Delta
RG	Road Gravity Coefficient
SEZ	Special Economic Zones
SGM	Synthesized Gravity Model
SP	Spread Coefficient
SQ	Status Quo
SR	Slope Resistance Coefficient
SUG	Simulation of Urban Growth
TM	Thematic Mapper
TVEs	Town and Village Enterprises
UGM	Urban Growth Model
USGS	United States Geological Survey
WTO	World Trade Organization
YRD	Yangtze River Delta

Abstract

China has undergone significant urban growth and industrialization over the last 30 years and its incredible development continues to move ahead at an increasingly rapid pace. In terms of urban expansion, China has just recently surpassed the world's average urbanization rate of 50%, as it moves its massive population from rural to urban areas at an astonishing speed. It's massive population and fast urbanizing speed aside, China is also unique in terms of its socio-political system and historical-cultural context: it is a hybrid of government planning and market forces. Since it encompasses a large part of the global population and has had a vastly different urbanization experience than that of Western countries, around which most theories are based, studying China's urbanization is an opportunity to contribute to the field of urban studies in an unprecedented manner. However, these differences also make it difficult to develop a comprehensive study of China's urban system since the predominant theories in the field are best suited to Western cities.

This research rises to this challenge by systematically studying the relationship between the socioeconomic and biophysical processes in the Chinese urban system to understand the interaction between human and physical factors, and the landscape patterns that result from these interactions. This complex urban system is examined using a hierarchical, top-down approach. At the highest level is a Macro-scale analysis of the national urban system, followed by a study of the regional urban system: the JingJinJi

Metropolitan Area at the Meso-scale, and finally a Micro-scale examination with a focus on the city of Beijing. Since urban systems develop over both time and space, the urban system is analyzed spatio-temporally on all three levels.

Research at the national scale is composed of two parts. First, the challenges and opportunities of China's urban development since the foundation of the People's Republic of China in 1949 are investigated in a general context. The institutional barriers that impede the management and continuation of China's urban development are also discussed. Rank-size Analysis and satellite images are used to present the structural transitions of city scaling and urban clusters. These changes come with a series of challenges that are also iterated and discussed. This is followed by an analysis of the spatial distribution and transition patterns of China's urban system using Centographic Analysis, particularly since the post-1979 reforms. Second, the Macro-scale research focuses on a study of the urban hierarchy that is based on inter-city interactions as determined by the Synthesized Gravity Model (SGM). Under this model socioeconomic variables are synthesized and represented by the Influential Factor, while the Function Distance is derived from a Network Analysis that is based on multiple transportation methods. As an improvement on the conventional Gravity Model (GM), the SGM is used to accurately establish and represent the nodal structure of China's urban system, the evolution of its hierarchical structure, and the relationships that exist between the nodal structure and socioeconomic factors. The results

based on the SGM indicate that China's national urban system is characterized by the emergence of urban clusters with stronger inter-city interactions since the 1990s. However, development among cities within certain urban clusters is not even, although the general pattern indicates a lessening inequality among cities. Spatially, while most cities at the top of the hierarchy are located in the east of China, cities in the middle and west of the country are also gaining higher positions in the hierarchy over time.

On the Meso-scale, the applicability of the Cellular Automata (CA)-based SLEUTH model for regional urban growth pattern is studied through a focus on the JingJinJi Metropolitan Area (Beijing-Tianjin-Hebei). By integrating socioeconomic factors into a modified SLEUTH model, the urban growth dynamics and future development scenarios of the area are simulated and predicted. The results based on the CA model show that this region is characterized by a dynamic development pattern with high spreading and breeding growth rules that relies greatly on the growing transportation systems. It also allows for the projection of three possible future urban growth scenarios, each occurring under different environmental and development conditions, showing the future urban growth with or without further intervention. This research confirms that four factors play essential roles in the formulation of the urban growth mechanism of the JingJinJi Metropolitan Area: Urban policies, Industry restructuring, Rural-urban migration, and Reclassification of urban boundaries.

The Micro-scale study of Beijing is conducted from two perspectives: the social and natural. The social aspect adopts the factorial ecology approach to identify the social landscape patterns and the factors that have shaped Beijing's social space in 1990 and 2000. The social mosaic has experienced a significant change due to suburbanization, resulting in a more dynamic and complex internal structure since the 2000s. From a natural perspective, Beijing's physical landscape patterns are extracted by processing remotely sensed images that have the same temporal span. The physical change through landscape metrics demonstrates that Beijing's expansion has generated a more complex and fragmented land use/cover pattern. Meanwhile, transportation systems play a significant role in urban expansion, although the expansion across the space (zonal rings and directional sectors) is not even. Finally, the relationship between the social and physical landscapes is quantitatively defined by the Geographically Weighted Regression (GWR) technique, using physical landscape metrics as dependent variables and social areas as independent variables. The GWR is able to demonstrate the relationship between the social and physical landscapes at this level: as a city's social mosaic becomes more varied over time it results in the fragmentation of that city's physical space.

Résumé

La Chine a subi une croissance urbaine et industrielle significative au cours des 30 dernières années et ce développement se poursuit encore aujourd'hui à un rythme soutenu. L'urbanisation en Chine progresse également à très grande vitesse alors que le taux de gens vivant en milieu urbain vient de passer au-dessus de la barre des 50% de la population totale du pays. Si ces avancées placent la Chine dans un contexte particulier, il va sans dire que le système politique et le contexte culturel historique ayant mené à une forme hybride de gouvernement la rendent d'autant plus unique. Puisque le pays compte une grande proportion de la population mondiale et que son processus d'urbanisation est très différent des pays occidentaux sur lesquels sont basés les principales théories, l'étude du développement de l'urbanisation en Chine est une opportunité sans précédent de contribuer au champ des études urbaines. Toutefois, le fait que les théories dominantes de ce champ d'étude soient faites pour le contexte occidental rend difficile la réalisation d'une étude compréhensive du système urbain chinois.

Cette recherche vise à relever ce défi en étudiant systématiquement la relation entre les processus socioéconomique et biophysique du système urbain chinois afin de comprendre les interactions diverses entre les facteurs humains et physiques, ainsi que les modèles de paysages urbains résultant de ces interactions. Ce système complexe est analysé selon une approche verticale de type "top-down". Au plus haut niveau se trouve une analyse

à l'échelle macro du système urbain national, suivi du système urbain de la région métropolitaine de JingJinJi à l'échelle méso et de la ville de Beijing à l'échelle micro. Puisque les systèmes urbains se développent à la fois à l'échelle géographique et temporelle, les divers systèmes urbains de l'étude sont analysés selon une approche spatio-temporelle.

La recherche à l'échelle nationale est divisée en deux parties. Premièrement, les défis et les opportunités offertes par le développement urbain de la Chine depuis l'instauration de la République Populaire de Chine en 1949 sont examinés dans un contexte général. Les barrières institutionnelles ayant nui au développement et à la gestion de la croissance urbaine chinoise sont également discutées. Une analyse rang-taille ainsi qu'une analyse par images satellitaires sont utilisées afin de présenter la transformation des échelles urbaines et des pôles urbains. Ces changements sont accompagnés d'une série de défis qui sont également inclus dans la discussion. Ceci est suivi d'une analyse de la distribution spatiale et des modèles de transitions du système urbain chinois en utilisant une approche centrographique, plus particulièrement suite aux réformes économiques de 1979. Deuxièmement, la recherche à l'échelle macro est centrée sur l'étude de la hiérarchie des villes en fonction des interactions interurbaines, déterminée par le modèle de gravité synthétisée. Avec ce modèle, les variables socioéconomiques sont synthétisées et représentées par un facteur d'influence, tandis que la fonction de la distance est obtenue grâce à une analyse des réseaux de transports fondée sur une multitude de moyens de

transport. Le « Synthesized Gravity Model (SGM) » est utilisé afin de représenter la structure nodale du système urbain chinois, l'évolution de sa structure hiérarchique, ainsi que la relation existante entre le système nodal et les facteurs socioéconomiques. Les résultats basés sur le SGM indiquent que le système urbain chinois est caractérisé par l'apparition de pôles urbains ayant des interactions interurbaines plus fortes depuis les années 1990. Toutefois, il faut noter que le développement urbain de ces pôles n'est pas égal, même si le modèle indique que les écarts entre les différentes villes rétrécissent. Spatialement, alors que la majorité des pôles se trouvent dans l'Est de la Chine, les villes du Centre et de l'Ouest avancent graduellement dans la hiérarchie.

À l'échelle Méso, le modèle CA-based SLEUTH pour analyser le schéma de croissance urbaine régionale est utilisé avec la région métropolitaine de JingJinJi (Beijing-Tianjin-Hebei). En intégrant les données socioéconomiques à un modèle SLEUTH modifié pour la cause, des dynamiques de croissance et des formes urbaines sont simulées et prédites. Les résultats montrent que cette région est caractérisée par une dynamique de croissance à haute diffusion, s'étalant et reproduisant des règles de croissance en fonction de la progression des systèmes de transports. Ultimement, trois scénarios de croissance urbaine, chacun opérant dans des conditions environnementales et de développement urbain unique, sont proposés afin d'expliquer le développement urbain futur de la région dans les prochaines décennies. Cette recherche conclue que quatre facteurs jouent un rôle crucial

dans le développement urbain de la région métropolitaine de JingJinJi: les politiques urbaines, la délocalisation des industries, les migrations urbaines-rurales ainsi que la reclassification des frontières urbaines.

L'analyse à l'échelle micro de la région de Beijing est conduite selon les perspectives sociale et naturelle. Le côté social adopte l'approche de l'écologie factorielle afin d'obtenir le modèle de paysage social ainsi que les facteurs ayant contribué à former l'espace social de Beijing entre les années 1990 et 2000. La mosaïque sociale a subi de profondes transformations à cause de la prolifération des banlieues, ce qui a créé des dynamiques beaucoup plus complexes et ce depuis les années 2000. Du côté de la perspective naturelle, les modèles de paysage de Beijing sont obtenus grâce à l'utilisation de méthodes de télédétection, via des images comportant la même durée temporelle. Les changements physiques obtenus grâce à des mesures métriques démontrent que l'expansion du paysage de Beijing s'est traduite par une complexification de l'utilisation des sols. Pendant ce temps, le système de transport urbain a joué un rôle significatif au sein de l'expansion urbaine, même si celle-ci (anneaux de zone et secteurs directionnels) n'est pas égale partout. Finalement, la relation entre les paysages sociaux et physiques est définie quantitativement avec la technique de régression géographiquement pondérée, en utilisant les paysages physiques comme variable dépendante et les caractéristiques sociales comme variable indépendante. La technique de régression pondérée géographiquement est capable de

démontrer la relation entre les paysages physique et social à l'échelle micro: plus la mosaïque sociale d'une ville devient variée avec le temps, plus la fragmentation de l'espace physique est grande.

摘要

近 30 年来，中国城市化和工业化水平显著提高。本文通过系统分析中国城市体系中社会经济发展过程和生物物理演化过程的关系来解释人类活动因素和自然因素之间的内在联系以及由此产生的城市景观格局变化。这种复杂的城市系统可以用一种自上而下的等级体系来阐释。在本研究中，首先，对中国城市系统从整体上进行宏观尺度上的分析；然后，对区域性的城市系统—京津冀都市圈进行中观尺度的分析；最后，在微观尺度上对北京市进行了具体的研究分析。由于城市系统的发展涉及到地理空间和历史时间两个尺度，本研究将会从时间和空间相结合的角度分别对三个级别的城市系统进行剖析。

全国范围的宏观尺度分析由两部分组成。首先，从整体上阐述自 1949 年建国以来城市发展的机遇与挑战，以及阻碍城市发展的体制因素。在这一部分中，城市的结构转变以及城镇聚类过程将应用位序规模分析并结合卫星影像来进行解释说明。接下来本研究应用中心点分析方法来研究中国城市系统，尤其是 1979 年改革开放之后的空间分布和演化特征。其次，在中观尺度的分析上，本研究将采用综合重力模型，根据城市之间的内在联系模拟城市的等级序列。在这个模型中，表征社会经济的变量将被合并用影响力表现出来；而本模型中的功能距离来自于以多重交通运输网络为基础的网络分析。通过综合重力模型，中国城市系统的等级结构，演变过程，及其与社会经济因子之间的关系将被建立并表现出来。综合重力模型的模拟结果显示，宏观尺度上的中国城市系统主要形成于 20 世纪 90 年代以后，由一些彼此之间有着内在联系的城

市聚集而成。然而，即使总体的景观格局在属于同一城市聚类圈的城市之间表现出来的差异很小，这些城市的发展也是不均衡的。从空间上看，尽管大多数处于等级上层的城市分布在中国东部，但是随着时间的推移，中西部城市在等级序列里也会相对提升。在中观尺度上，对京津冀大都市圈（北京-天津-河北）的研究将采用模拟区域性城市发展模式的 SLEUTH 模型来对细胞自动机的适用性进行分析。通过将社会经济因子整合到改良后的 SLEUTH 模型中，本研究模拟出城市发展的动力机制，同时预测出区域的发展远景。京津冀区域的发展是以大规模的辐射，传播以及再生为特征的，并且极度依赖于城市交通系统。最后，本研究模拟出在不同的条件下可能产生的三个城市发展远景。本研究再次证实了京津冀大都市圈的城市发展主要依赖于四个因素：城市政策；工业重组；城乡移民和城市边界的再划分。

在微观尺度研究里，本研究主要从社会和自然两个角度来分析北京市。在社会条件分析方面，本研究主要采用了分解生态学分析方法来分析社会景观格局以及从 1990 年到 2000 年间对北京的社会格局形成产生影响的因素。2000 年后，由于郊区化的影响，社会景观格局发生了显著改变并导致了更为复杂的社会结构。从自然的角度来看，北京的自然景观格局可以从同一时间跨度的遥感影像中提取。根据景观指数得出的物理形态变化显示，北京的城市扩张逐渐形成了一种更为复杂、破碎的土地利用和景观格局。同时，研究显示，城市在空间上的扩张不平衡，但城市交通系统确实对这种扩张产生了显著的影响。最后，本研究使用基于空间权重的回归技术对社会和自然景观之间的关系进行了量化。

Acknowledgements

I would like to express my gratitude to a number of people and institutions for their support, encouragement, and assistance during the preparation of this thesis and the doctorate itself.

It would not have been possible to write this doctoral thesis without the support, encouragement and assistance from the kind people around me, to only some of whom it is possible to express my gratitude here.

First and foremost I offer my sincerest gratitude to my supervisor, Dr. Huhua Cao, who has supported me throughout my thesis with his patience and knowledge, as well as spiritual and financial assistance. The continual enthusiasm, inspiration, and genuine dedication that he brings to his career have always motivated me to move ahead with this doctorate when my energy and belief in this path failed.

Professional thanks go to my thesis committee: Dr. Konrad Gajewski, for his willingness to make time for my research and helping to make this happen; Dr. Peter Foggin, for providing warm guidance and constructive support, as well as assistance in Geomatics and China studies; Dr. Abdou Bannari, his encouragement and insightful comments, especially on remote sensing topics; Dr. Michael Sawada, for his endless help, resources, and extensive technical background in GIS and statistical analysis; and to the other jury members for their constructive comments and contributions.

I would like to acknowledge the financial support of the Faculty of Graduate and Postdoctoral Studies, as well as the teaching and research positions that were kindly offered by the Department of Geography at the University of Ottawa. I am also thankful for the University of Ottawa's Map Library for providing many types of digital maps, other data, and software resources that were invaluable to my research.

I would also like to thank the LAGGISS lab and my lab mates. We have shared years of memories that are full of kindness, friendship, and laughter. I also owe my colleagues and friends my gratitude: Melanie Zahab, Matt Gaudreau, Jun Lu, Yuanyuan Zhai, Jennifer Horton, Juanxia He, Tania Shephard, Ziwei Liu, Jingle Liu, Kevin Depault, Jean-François Parent etc. Thank you all for your support on this thesis, as well as data processing and editing contributions.

Last but not least, a special thank you goes to my parents and sisters who have always supported me, encouraged me, and sent their best wishes. I am very grateful to my wife, Linna Wang, who is always there believing in me, and standing by me through the good times and the bad. This thesis would not have been possible without your love, support and constant patience. All my family, especially our forthcoming baby, has provided me with endless motivation and support to finish this thesis.

Chapter 1 Introduction

1.1 Background

Cities have played a crucial role in the development of modern society. As cities have rapidly expanded, the accompanying growth of both the urban population and its supporting infrastructure has had significant impacts on both physical and social landscapes of urban areas. Within this context, urban studies seek to understand the city, its dynamics and functions, and to present insights into the social and economic challenges of urban development (Knox and McCarthy 2005). Urban studies is an interdisciplinary field that employs tools from sociology, economics, geography, as well as other social and physical sciences, to develop a better understanding of the urban system¹. Similar to natural ecosystems, urban systems are composed of a variety of components that interact with one another and as such the ecosystem framework can be applied to the study of urban systems. However, urban systems are distinguishable from natural ecosystems as urban systems are a hybrid of natural and human elements. The interactions between these natural and human elements are effected not only by the physical environment, but also by human behaviour, culture, politics, economics, and social organization. Treating urban areas as an ecological system is useful because it makes possible the study of how urban systems function

¹ In a general sense, an urban system is defined as the network of a set of interdependent urban places. In this thesis, however, urban system is interpreted in two interlocked aspects: system of cities (the regional or national system composed of a set of cities and towns) and cities as systems (city as an organism composed of physical and social elements), see section 1.1.2 for more details.

according to the interactions between its natural and human components. In this context, urban landscapes are both the results and representations of socio-physical interactions: the surrounding environment affects human behaviour, while this behaviour in turn impacts the surrounding environment.

The following sections present a discussion of the key concepts and theories that are central to the field of urban studies. The research questions addressed in this thesis are based on an understanding and discussion of preceding studies.

1.1.1 Urbanization: The context of urban system and urban ecology

In order to improve their standard of living, people from rural areas move en masse into cities to seek new and more lucrative economic opportunities, which has resulted in the process of urbanization characterized by population migration and industrial transformation. The process of urbanization transforms rural land into urban areas, and changes people's lifestyles from rural into urban. Due to its occurrence across the world, urbanization is recognized as a significant global and ecological trend (Antrop 2004; Grove and Burch 1997; Knox and McCarthy 2005). Statistically, the global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005, and current projections estimate that 60% of the global population will live in cities by 2030 (United Nations 2005, 2007). Furthermore, these highly concentrated human populations are having increasingly visible impacts on urbanizing areas and the

surrounding land. Urbanization has been considered as a paramount demographic development and a crucial part of global land transformation (Pickett *et al.* 2001). Though only 1% to 6% of the planet is urbanized, the ecological impact of cities is immense, affecting systems well beyond urban boundaries (Alberti *et al.* 2003).

While approximately 50% of the world's population resides in cities, this urban population is not equitably distributed across regions and countries. Highly developed regions such as North America and Western Europe have much higher urbanization levels than developing regions like China or India. However, those highly urbanized regions are now experiencing a slower pace of annual urbanization because a much smaller proportion of the population now live in non-urban areas. Regarding future trends, it is estimated that Asia and Africa are going to experience remarkable urban growth over the next forty years, and three-quarters of the world's urban population will be concentrated in Asia and Africa by 2050. China and India are largely responsible for these projections as their size and rapid growth means that they will account for about a third of the increase in global urban populations (United Nations 2010). As these rapid changes occur, they undoubtedly will continue to have significant impacts on economy, society, and politics at local, regional, and global scales (Pickett *et al.* 2001; Wu 2008a). Urbanization not only causes these complex effects, but it is also the result of a complicated and intricate process that makes any attempt to understand the process difficult.

The process of urbanization is driven by a series of interrelated processes of changes: economic, political, demographic, cultural, technological, social, and environmental. Simultaneously, this urbanization process affects the character and dynamics of these components of the urban system (the regional or national system composed of a set of cities and towns), and also results in changes to the physical and social landscape within cities and towns (Berry 1964; Knox and McCarthy 2005). The study of urbanization as a process can be analyzed using the System Theory². A system is a distinct group of interacting and inter-related phenomena that functions by way of the Inputs-Outputs-Feedback mechanism. As suggested by Figure 1.1 urbanization is not only influenced by the direct effects of inputs, but it also experiences feedback effects, such as the influence that the outcomes of the urbanization process have on further development. For instance, urban sprawl³ can be understood by a product of the social and biophysical processes driven by continuous interactions and feedbacks (Alberti *et al.* 2003). These processes include population migration, socioeconomic behaviour, housing preferences, and biophysical processes, etc. (Alberti *et al.* 2003; Knox and McCarthy 2005). Different regions and different stages of the urbanization process are usually characterized and mainly driven by different combinations of these factors. For example, in China, urbanization prior to the 1980s was managed

² Systems theory is a framework by which one can analyze and/or describe the nature of complex systems that work in concert to produce some result (Knox and McCarthy 2005).

³ Urban sprawl is described as low-density, scattered, urban development without systematic large-scale or regional public land-use planning.

mainly by macro-level governmental control, but with the introduction of economic reforms, the effects of the free market have been playing an increasingly significant role since the 1980s (Cui 1990; Deng and Huang 2004; Small 2002).

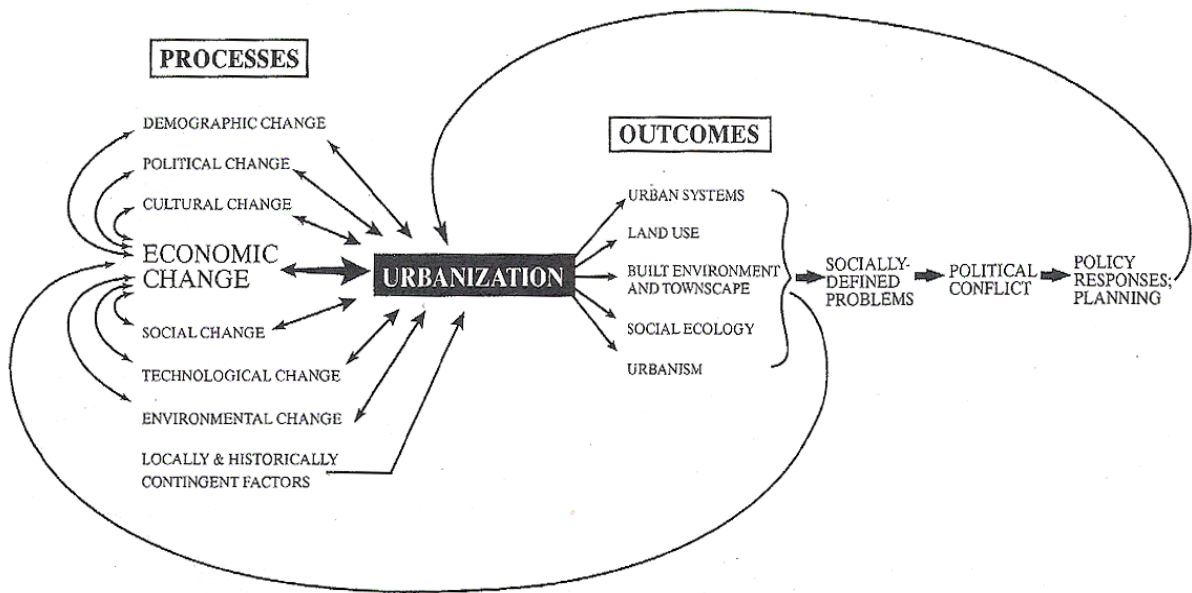


Figure 1.1 Urbanization as a process (Knox and McCarthy 2005 P. 9)

Despite its numerous human benefits, urban development comes with important economic, social, and environmental costs (Burchell and Mukherji 2004). For instance, high levels of industrialization and urbanization have resulted in expanding transportation networks and economic growth, but have also resulted in increased demands for natural resources and environmental degradation (Alberti *et al.* 2003; Cui 1990; Wu 2008a), such as the loss of agricultural and forest land, the splintering of animal habitats, the over extraction of groundwater, and also in the pollution of air and water. For example, between 2000 and 2007, China experienced the loss of over one million hectares of agricultural land

annually to urban growth and the construction of roads and industries (National Bureau of Statistics of China 2001, 2008). Rapid urbanization has occurred alongside a propagation of slums, segregated neighbourhoods, and a lack of social services, especially in developing countries (Knox and Pinch 2006; Knox and McCarthy 2005). Other social consequences include a breaking down of the traditional family structure, urban violence, political instability, crime and aggressive behaviour (Haddad *et al.* 1999; Montgomery and Hewett 2005).

Since cities have a high concentration of people, environmental and social problems are at their most devastating in urban areas. Urban problems both cause and are caused by a series of socio-political and environmental conditions. It is clear that they must be dealt with in a more ecologically sound manner, because systems are a complex hybrid of human and natural components. A balance between the two must be struck if a satisfying quality of human life is to be permanently achieved in urban systems (Wu 2008a).

1.1.2 Urban system: System of cities and cities as systems

Successive eras of economic and urban development within the urban system have an increasingly complex urban structure as these cities continue to transform. Compared with the traditional view of an urban system as a closed and self-regulating entity with a single equilibrium, the new understanding sees the urban system as an open, dynamic, and

multi-equilibrium system that is volatile, and therefore subject to frequent disturbances (Alberti *et al.* 2003; Grove and Burch 1997; Pickett *et al.* 1997; Zipperer *et al.* 2000).

Urban systems are now widely recognized as being characterized by complex and dynamic interactions. Cities are connected by a variety of networks that interact with one another on different temporal and spatial scales, which is made more complex by the fact that geographic space is constantly evolving. The modern transport and communications technologies have had a significant impact on the relative positions of cities and towns. More specifically, these changes have resulted in travel time reductions that have been termed “time-space contraction” or “time-space convergence.” Depending on the scale of analysis this time-space contraction has different effects; for instance cities appear to be closer together at the inter-urban (between cities) scale. Conversely, the urban centres within individual cities appear to be dilating, which increases a city’s scope of influence, and therefore the size of the surrounding “urban field” (Bretagnolle *et al.* 2003).

As no two individual spaces are identical, similar urban activities can have vastly different results depending upon where they take place. Therefore, when geographic space is incorporated into an examination of a given urban system it will result in a wider variety of outcomes. For instance, while some urban activities impact small areas, others have ramifications that can influence other regions on an international scale. In the early 1960s, Brian J.L. Berry’s article “Cities as Systems within Systems of Cities” drew attention to the

different scales of urban systems (Berry 1964). Berry presents two general categories of urban systems that require examination in order to understand how to contend with the scalar impacts of urban activities: Systems of Cities and Cities as Systems.

1.1.2.1 Systems of Cities (Cities within National and Global Systems)

Cities are regionally and globally connected to each other through multiple connections and flows, such as goods, services, people, and knowledge (Friedmann and Wolff 1982). Thus, the network created by these interconnected cities is referred to as the Systems of Cities. With the progression of globalization, the web of connections linking countries to one another is expanding across both spatial and temporal scales. As Folke *et al.* (1997) say: “Everyone is now in everyone else’s backyard.”

Powerful cities can occupy a dominant position within their networks, and hence are called dominating cities. These dominating cities have privileges in terms of access to resources, and they usually dominate city networks at other cities’ expense. However, they also simultaneously play a key role in holding city networks together, because the time-space contraction has caused cities to be increasingly linked with each other and are impacting cities elsewhere at a larger scale (Piracha and Marcotullio 2003). In a national urban system, the dominating cities usually function as a “gateway” that controls the flow of information and goods. Not only do these cities interact with dominating cities in other countries, but they also heavily influence the national urban structure and the dynamics

within this structure. Cities also interact with each other based on geographical or invisible connections, which results in regional urban agglomerations or clusters; a city cluster usually has one dominating city, holding together a group of dependent cities that also develop a series of inter-dependencies with one another.

1.1.2.2 Cities as Systems (Ecosystem within a City)

The Cities as Systems perspective originated with the idea that a city was an organism with its own “metabolic” processes. One extremely important function of a city is its capacity to provide harmonious settings for both its “natural citizens” and “human citizens” (Fitzpatrick and La Gory 2000). Increasingly, an ecological approach has been adopted by researchers exploring urban issues, including the interactions between the citizens and the natural ecosystem.

The natural component of ecosystems within cities is analyzed through a focus on water, parks, wildlife species, vegetation coverage, and agriculture that exist within the city confines. In this aspect, urban ecology has been studied as a natural environment (Ditchkoff *et al.* 2006). More specifically, urban bio-ecology takes a city as a profoundly human-altered ecosystem, and studies the interactions between living things and their city environment (Douglas 1983).

Urban ecosystems differ from their natural counterparts only in so far as the degree of human influence on both the biotic and physical environment is exponentially greater in

urban ecosystems (Walbridge 1997). For example, this ecosystem is dominated by man-made features like buildings and roads. However, despite their profound impacts humans are often excluded from urban ecosystem studies. From an alternate viewpoint, the Chicago School has developed a series of sociological approaches that study a city's social and spatial organization, which can address the issues related to the anthropogenic impacts on urban ecological systems (Pickett *et al.* 1997).

1.1.3 Urban ecology: Understanding human-dominated ecosystems

Urban ecology is a subfield of ecology that focuses on the interactions between the natural and human components, as well as with their urban, or urbanizing, environment. In any given urban area there exists a series of complex interactions and feedback mechanisms between the social, biological and physical processes on which research in the field of Urban Ecology has begun to focus (Cao and Villeneuve 1998). Urban ecology studies the key drivers that cause the changes in human and biophysical environments and the interactions between social and biophysical agents on a landscape level.

Currently, the theories, concepts, and methods used in both the social and biological sciences are converging due to a reduction in the differences that separate the two. Basically, the convergences include the following three aspects: First, the hierarchical approach that is commonly used in the biological sciences is fast becoming a viable and popular alternative to the traditional reductionist approach in the study of sociocultural systems (Klijn and Haes

1994; O'Neill *et al.* 1989; O'Neill 1986; Wu and Loucks 1995). A hierarchy refers to a system of “different functional units that are linked, but operate on two or more scales” (Zipperer *et al.* 2000). More specifically, in an urban cluster a dominating city is at the top of the pyramid with the remaining cities existing on the lower levels. However, these cities interact with and influence one another across these levels. An urban system is a complex structure that can be simplified and better understood using a proper understanding of spatial and temporal hierarchies (Pickett *et al.* 1997). A second point of convergence, according to Grove and Burch (1997), is the “rejection of organismal and teleological explanations” for both sociocultural and biophysical systems, as social problems like racism have been improperly interpreted by such evolutionary and determinist methods. Finally, spatial heterogeneity⁴ is an increasingly significant component in the study of both sociocultural and biophysical systems (Alberti *et al.* 2003; Grove and Burch 1997; Pickett and Cadenasso 1995; Turner 2005). Heterogeneity is the measure of how different various parts of a landscape are from one another, under the idea that the influence of spatial heterogeneity on biotic and abiotic processes is essential to understand the dynamics of an urban system (Pickett and Cadenasso 1995).

⁴ Spatial heterogeneity “a complex mosaic of biological and physical patches in a matrix of infrastructure, human organizations, and social institutions” (Alberti *et al.* 2003, P. 1171).

1.1.4 Research direction

The development and dynamics of spatial heterogeneity, as well as the influence of spatial patterns on the processes in an urban system have already been studied on a conceptual level. Grove and Burch (1997) proposed an integrated urban ecosystem approach to address the spatial heterogeneity of urban ecosystems. Around the same time, Pickett *et al.* (1997) developed an ecosystem concept that included humans in the models used to understand the urban system. In this discussion, the role of spatial heterogeneity and organizational hierarchies in both the social and natural components of urban ecosystems were addressed. Zipperer *et al.* (2000) proposed a combination of the classical ecosystem approach and a patch-dynamic approach to account for and understand the full range of dynamics that are at play in urban and urbanizing ecosystems. For the purpose of this proposition these two approaches were defined as such: “The (traditional) ecosystem approach focuses on the magnitude and control of the fluxes of energy, matter, and species. The patch-dynamic approach focuses on the creation of the spatial heterogeneity within landscapes and how that heterogeneity influences the flow of energy, matter, species, and information across the landscape” (Zipperer *et al.* 2000).

Research questions that are related to environmental equity often arise in traditional urban ecosystem studies: “Is soil erosion linked to human erosion (e.g. declines in nutrition, employment, housing, family structure, norms)?” or, “Is environmental restoration

connected to urban revitalization?” Ultimately, spatial heterogeneity exists because patterns and processes of soil erosion, human erosion, environmental restoration, and urban revitalization are seldom equally disseminated across any given space. Questions such as, “What are the links between urban revitalization (e.g. changes in income or levels of employment) and environmental restoration (e.g. changes in vegetation structure, hydrologic discharge, soil erosion, or air quality)?” or, “Why do some areas decline socially, economically, and environmentally, whereas other areas remain the same or improve?” are often generalized as a more specific version of the question posed by Logan and Molotch (1987): “How are the fortunes of people tied to the fortunes of place?” Using a human ecosystem and landscape⁵ approach, the understanding of the conceptual relationships between ecological and social differentiation will help to address these types of questions.

The approach developed by Grove and Burch (1997) provides a good starting point in terms of how to integrate human ecosystem and landscape analyses with the idea that a human landscape approach may be understood as the study of the reciprocal relationships between spatial heterogeneity (pattern) and sociocultural and biophysical processes (Figure 1.2). According to Pickett (2001, P. 145),

⁵ Landscape is a mosaic of both biological and physical patches within a matrix of fundamental infrastructure, social and physical agents and order (Machlis *et al.* 1997). Here, landscape pattern refers to both the composition (e.g., the types of land cover) and configuration (e.g., spatial arrangement of patches).

“When human ecosystem and the landscape approaches are combined, human ecosystems types or patches are defined as homogeneous areas for a specified set of sociocultural and biophysical variables within a landscape. Analyses then focus on two issues: 1) the development and dynamics of spatial heterogeneity, and 2) the influences of spatial patterns on cycles and fluxes of critical ecosystem resources (e.g. energy, materials, nutrients, genetic and non-genetic information, population, labour, capital, organizations, beliefs, or myths).”

In this context, the new urban ecology seeks to answer the questions “who gets what, when, how, why, and where” in a given urban ecosystem. They attempt to do this through the identification of the key factors and structural dynamics that influence the biophysical and socioeconomic processes that occur within urban areas (Foster 2006).

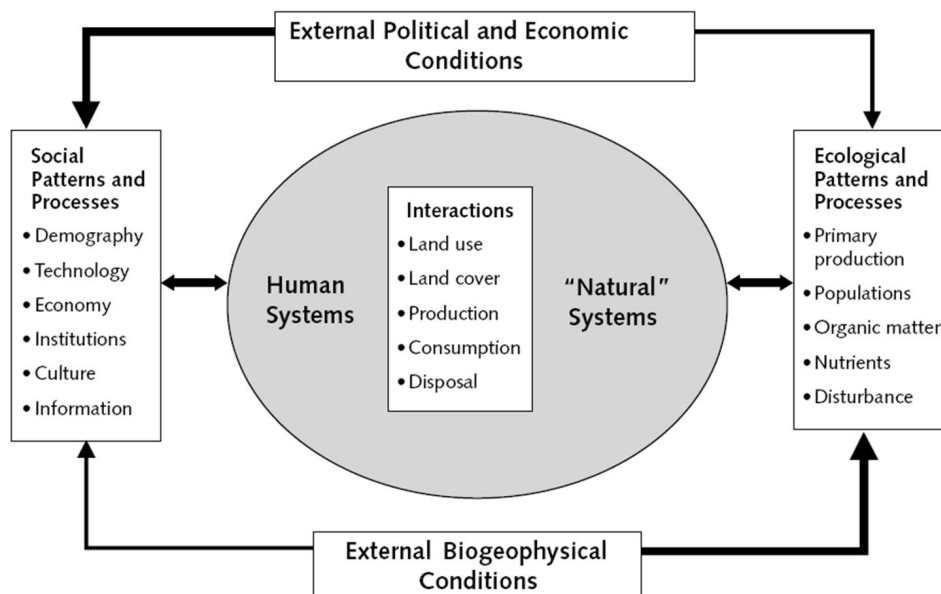


Figure 1.2 Conceptual framework of an integrated human ecosystem (Redman *et al.* 2004, P. 164)

In general, this thesis is designed to systematically study the relationship between socioeconomic and biophysical processes in an urban system at three different spatial scales. China's urban system will be analyzed empirically at the national, regional, and city levels. Efforts will be made to understand the interaction between human and natural factors, and the landscape patterns that result from this interactive process over time. Therefore, the main focus of this thesis is a temporal analysis of China's urban development at different spatial scales.

1.1.5 Urban development in China

China has been experiencing rapid economic growth for the past 30 years, and during this period the country has lifted half a billion people out of poverty – a remarkable achievement that no other nation has been able to accomplish at the same speed or scale. In the mid-1970s, China surpassed the United States to become the country with the largest urban population in terms of absolute numbers, but at the time China's urbanization rate was still only 18%. According to the most recent national census (National Bureau of Statistics of China 2011), China's urbanization rate reach the world average in 2010. Moreover, China in on the track of a steady urbanization over the long term and it is projected that nearly 70% of the population will be living in urban areas by 2045 (United Nations 2007). The speed of China's urbanization is and will be unprecedented in terms of the number, scale, and size of its urban expansion experience (Pannell 2002, 2003).

Therefore, a systematic study of China's urban development experience, and the unique features of this urbanization processes, is of high interest and reference value if we wish to understand and develop appropriate models and theories for explaining urbanization throughout the globe.

China is also currently transitioning from a centrally-planned economy to a market-oriented economy, which has led to additional important socioeconomic changes. Rural to urban and intra-city disparities are emerging as a consequence of China's urban and economic transition (Cao and Bergeron 2010). In addition, new housing allocation reforms are creating spatial or area-based marginalization, which further accentuates income and social inequalities. China has roughly 150 million rural migrants, commonly referred to as "floating populations," whose unique circumstance has contributed greatly to the problems of income disparity and urban inequality (Cao *et al.* 2000).

Overall, the institutional reforms initiated in 1978 have created a new mechanism for urban development in China. The emerging importance of marketization resulted in a fundamental change for the urbanization process, which the classic models of Western urbanization could be able to explain. To address the severe challenges concerning China's sustainable urban future, it is necessary to develop and examine a comprehensive overview of Chinese urban development.

China's urbanization has been on a continuous track of rapid development for the past few decades. In retrospect, there were drastic fluctuations in the magnitude of urban development up to the end of the 1970s, followed by a more stable period of development. However, China's development has not been evenly distributed: the urbanization rate of the eastern region is higher than that of the central region, and much higher than in the west. It wasn't until the late 1990s-early 2000s, that urban clusters began to emerge in China's eastern regions. In addition to these regional disparities, development was also uneven in terms of the size of cities. Since the mid-1990s, the policy of controlling the development of large cities has been gradually phased out, which has resulted in a significant increase in the number of larger cities. Overall, since the economic reforms that began in the late 1970s, China's cities have been gradually influenced by a market economy. In that sense, China's urban system is a hybrid product of a traditional planned economy and a market-oriented economy. Therefore, the study of such an urban system should enrich the literature of urban studies, which traditionally has been dominated by theories based in the experiences of Western cities. Furthermore, the application of Western theories to China's situation would help to develop a better understanding of the history and future trends of global urban development.

The existing literature concerning China's urban development can generally be placed into two categories: At the national scale, much attention has been focused on urban growth,

structural change, regional distribution or rank size distribution (Lin 2002; Pannell 2003; Qi 2002; Song and Zhang 2002; Wu and Yeh 1997), while the functional structure, the interaction mechanism among cities, and the relationship between socioeconomic and biophysical factors in the urban system has not been dealt with to the same extent. At the city scale, land cover change has been used to examine the morphological expansion of cities (Deng and Huang 2004; Gaubatz 1999; Xie *et al.* 2007), and the study of social spaces has also attracted a lot of recent interest (Gu and Shen 2003; Wu and Luo 1999; Wu 2008b; Xu *et al.* 1989a; Yeh *et al.* 1995b), but this approach is only in its initial stages. Moreover, the biophysical and socioeconomic factors have never been used in conjunction to explain the city system. Unfortunately, regional development has been overlooked in the study of China's urbanization. From the perspective of inter-city relations, the relationship between cities within a region is necessary for both cities and the surrounding areas within radius of their impact to achieve sustainable development. Moreover, the existing urban clusters in China lack an overall planning strategy that covers their urban and rural areas. Hence, there is a need to study cities at a regional scale in order to fill the gaps of knowledge that exist between the national and city scales.

1.2 Research questions and research scheme

1.2.1 Research questions

Despite the efforts made by researchers in the fields of Human Ecology and Urban Ecosystems (Grove and Burch 1997; Park *et al.* 1992; Shevky and Bell 1955), the reciprocal influences between human and physical landscapes continue to remain conspicuously absent in urban studies, and the substantial problem of how to integrate the influence of humans into the study of urban systems remains unsolved. Since cities cannot be explained simply by studying their components, an integrated framework encompassing both the socioeconomic and biophysical aspects of cities is required. Moreover, cities are “ecological entities” that are featured by unique patterns of behaviour, growth, evolution, and functions (Alberti *et al.* 2003; Grove and Burch 1997; Pickett *et al.* 1997). Therefore, taking both the human and physical factors in an ecological context into account would lead to a comprehensive understanding of the functioning of cities and the urbanization process.

China has stepped into an accelerated phase of urbanization, so it is important to understand the emerging spatial patterns of this urban transition. In order to study this process in China from an ecological perspective, several fundamental questions must be addressed:

- (1) For the national urban system, what are the spatial and temporal distribution patterns of cities, and how has the system of cities in China evolved over the last decades in regards to the socioeconomic and biophysical factors that shaped this change?
- (2) For a given regional urban cluster, how did the cities grow and expand within the regional urban system, and is there a way to study the expansion mechanism?
- (3) For a given city, how did the physical landscape pattern and social landscape pattern change simultaneously throughout the urbanization process, and is there any spatially statistical relationship between the evolution of these two patterns?

This thesis will try to answer the questions above by examining the urbanization process of China's urban system in the past three decades.

1.2.2 Research scheme

This research principally analyzes the post-reform urban development of China's urban system by using transformations in the pattern and structure of urban areas as a diagnostic tool. Since urban development is recognized as a complex set of processes that operate within the broader fabric of a society at different scales, these scales compose the hierarchical structure of an urban system. In this study, the concept of hierarchy will be used throughout and as such, the urban system is deliberately analyzed at three main scales (Figure 1.3):

(1) **Macroscopic Scale:** It is not possible to study China's urban system without knowing the history and context of its urbanization. Therefore, from a macroscopic view, the urbanization process in China since the 1950s will be introduced in order to illuminate the origins of China's modern urbanization patterns. At the top of the urban hierarchy is the national urban system. This system consists of a number of regional urban clusters and encompasses all the individual cities in a county (Figure 1.3). Based on connections such as the flow of capital and information, cities naturally agglomerate into regional clusters, with one or more cities acting as dominating nodes. Studies at the macroscopic scale try to derive the urban nodal structure, and urban pattern, based on the spatial interactions between cities. The research objective at the macro scale is to understand the complex economic, political, social, spatial, and demographic factors that drive urban development, and to assess the structure and pattern of China's urbanization process.

(2) **Mesosopic Scale:** The studies at the meso-scale focus on the relationship between cities in a given urban cluster. These cities develop based on a reciprocal relationship of both dependency and competition. Cities are connected to each other in two ways: the physical flow of goods and people, as well as the non-physical flows of information and capital (Figure 1.3). The research objective at this scale is to examine the socioeconomic

and biophysical contexts that delineate regional urban clusters, and simulate and project the urbanization process within an urban cluster.

- (3) **Microscopic Scale:** At the bottom of the urban hierarchy is an individual city, which is represented by a mixture of intensive land use and human activities scattered amidst both urbanized and undeveloped areas. At this scale, a city is considered as a functional entity with a high level of spatial and temporal heterogeneity (Figure 1.3) (Alberti *et al.* 2003). The objective at the micro-scale is to examine the relationships between socioeconomic and biophysical factors that influence the internal urban structure.

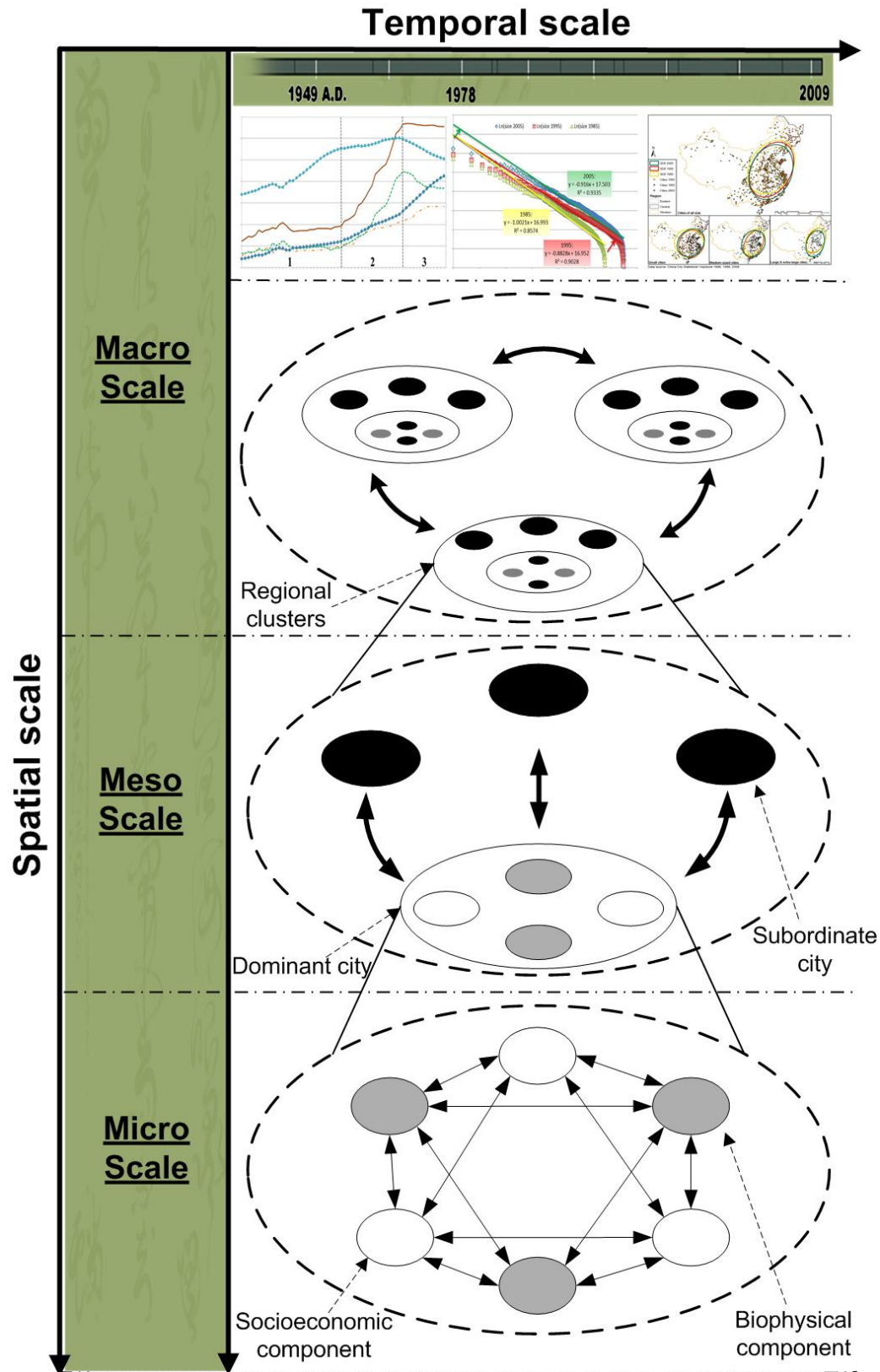


Figure 1.3 Conceptual framework of China's urban system, adapted from Coppack (1988)

The specific manner in which urban changes are spatially expressed is geographically and historically contingent. Moreover, urban feedback is usually phase-lagged, often by decades (e.g., urban growth triggered by a highway or subway development), which makes it indispensable to study urban changes over time (Alberti *et al.* 2003; Cohen 2004). Therefore, a temporal dimension is added to the three-tiered spatial hierarchy system. In essence, this research follows a top-down approach to reveal the patterns and structure of Chinese cities on both the spatial and temporal axis (Figure 1.3). A generalized process model of urbanization in China is also added to the end of the framework. China's urbanization is the result of both government-directed planning and a market-directed economy, which is driven by economic development as well as changes in the industrial structure. This model has the ability to represent the theories of hierarchy and spatial interactions that exist in the process of urbanization.

1.3 Methodology

Since a proper application of spatial hierarchy scales provides the key to simplifying and understanding the complexity of an urban system, the methodology of this thesis is also designed according to a hierarchical paradigm: Macro-scale, Meso-scale, and Micro-scale. A synthesized research framework for the whole thesis is presented below (Figure 1.4). At every scale, the research model and approaches will be discussed respectively.

1.3.1 Thesis framework

To summarize the methodology of this thesis, a composite theoretical framework is generated to include the study objects, research approaches, anticipated results, as well as the main sources of research data (Figure 1.4). In terms of spatial scale, the objects of study are China's national urban system, the JingJinJi urban cluster, and the city of Beijing, from the top down. For the temporal scale, the status of these three subjects in 1980s, 1990s and 2000s will be analyzed respectively. Since the scale of study ranges from general to specific, the methods and research data to be employed vary accordingly. In general, the data can be divided into socioeconomic (statistical) and physical (remote sensing and GIS) groups, which also cover a large temporal range. Figure 1.5 provides a detailed design of the methods and workflow at each scale.

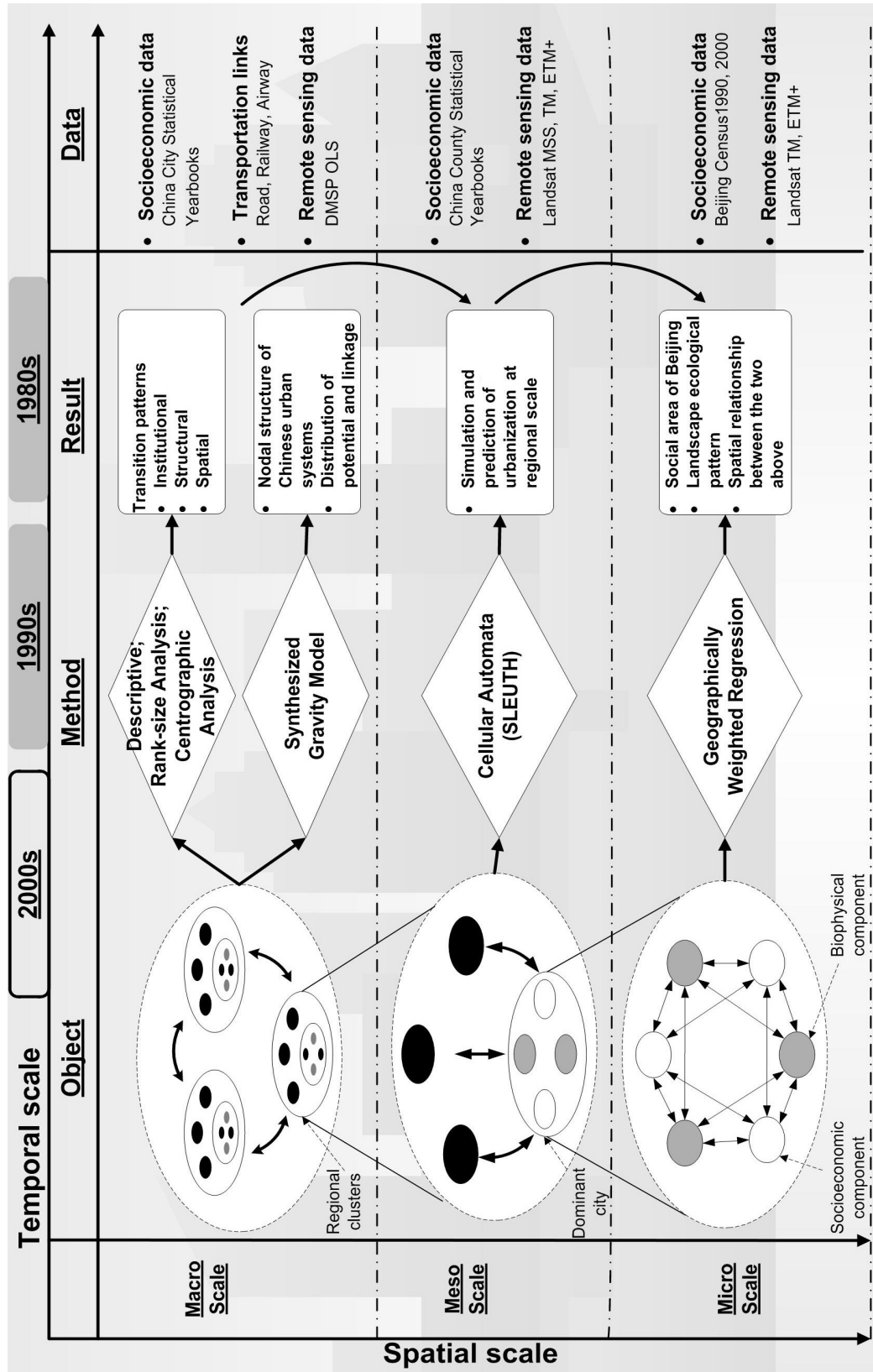


Figure 1.4 Theoretical framework to study China's urban system, partly adapted from Coppack (1988)

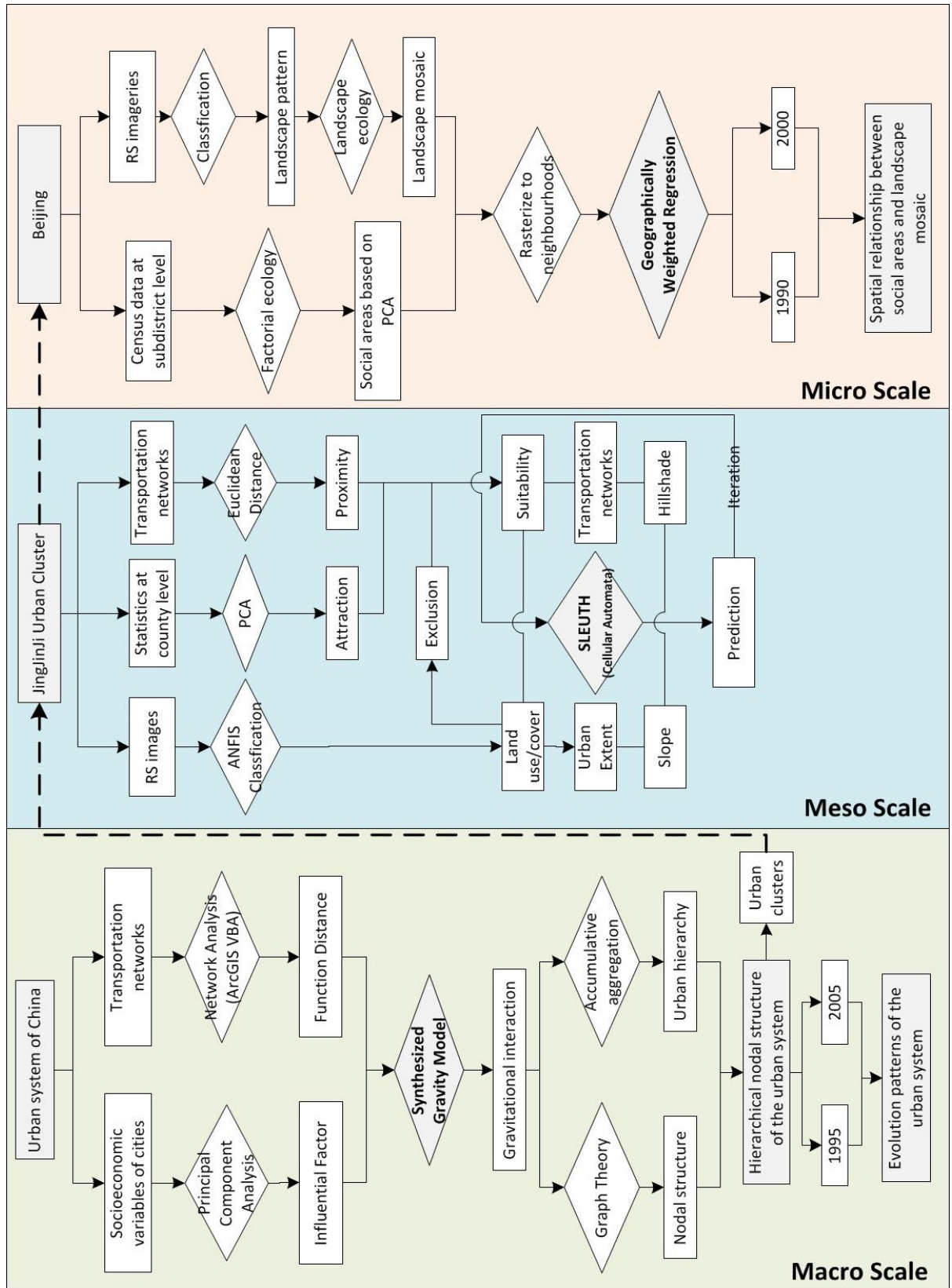


Figure 1.5 Flowchart of the methodology at different scales

1.3.2 National urban system – National scale (Macro scale)

The research at the national scale is composed of two parts. First, the challenges and opportunities in China's urban development are examined in a general context, and during this discussion the institutional barriers that impede China's urban development are addressed. Subsequently, the structural transitions of city-scaling and urban clusters are presented by employing Rank-size Analysis and satellite images. Then, the spatial distribution and transition patterns of China's urban system are analyzed using Centographic Analysis. The chapter endeavours to conduct a systematic and detailed analysis of the Chinese urban system that not only provides a better understanding of the current urban landscape, but also has far-reaching implications for planning, conceptualizing, and understanding future urban development in China.

Second, the urban hierarchy based on inter-city interactions is studied on the national scale. The purpose of this part is to investigate the socioeconomic development mechanism of China's national urban system. Efforts will be made to determine the nodal structure of China's urban system, the evolution of the nodal structure, and the relationship between this nodal structure and socioeconomic factors. In short, this part treats all of China's cities as a functional and geographic system, and aims at representing the evolution of the Chinese urban system quantitatively, spatially, and temporally.

The spatial interaction model will be the main method used to study the structure of China's national urban system. Instead of using a traditional Gravity Model based on urban population and linear distance between cities, the thesis proposes a Synthesized Gravity Model (SGM), which takes into account both socioeconomic and topographical factors to study the evolution of China's urban system since the 1990s. The Macro-Scale portion of the flowchart in Figure 1.5 describes the steps to build an SGM.

China's urban system is a hierarchical network consisting of around 600 cities of various sizes; a set of variables for each city is selected after removing the unrelated or collinear variables. Principal component analysis (PCA) is applied to reduce the dimensions of selected variables, and then the significant principal components are extracted. The factor score of each city is calculated for the first component using the regression method. The product of normalized variables and the coefficients of corresponding variables are summed up, and the final result serves as the Influence Factor to represent the composite "mass" of a given city.

Instead of using Euclidean Distance from the traditional Gravity Model, this model uses Function Distance as measured by travelling time. To determine the shortest traveling time between two cities in a transportation network, GIS Network Analysis tracks the quickest route by setting time as the impedance in different networks. Programming with ArcObjects and the Network Analysis module under the ESRI ArcGIS environment greatly

facilitates the complicated analysis needed to track the shortest distance between cities. Since cities are essentially nodes that are connected together by various transportation networks, the interactions within these different networks would differ depending on the Function Distance. These interactions are aggregated according to weight in order to generate one variable. The weight of each means of transportation is determined by their proportion of use in national traffic. Therefore, the Synthesized Gravity Model can be expressed as:

$$G_{mn} = R \cdot \frac{I_m \cdot I_n}{T_R^b} + W \cdot \frac{I_m \cdot I_n}{T_W^b} + A \cdot \frac{I_m \cdot I_n}{T_A^b}$$

$$= I_m \cdot I_n \cdot \left(\frac{R}{T_R^b} + \frac{W}{T_W^b} + \frac{A}{T_A^b} \right)$$

in which,

G_{mn} is the gravitational interaction between two cities m and n ;

I_m, I_n are the Influential Factors of city m and city n respectively;

R, W and A are the weights of gravitation of different transportation methods (Road, Railway, and Aviation);

T_R, T_W and T_A are the Function Distance of different transportation methods;

b is the distance exponent (the greater the value is, the greater friction the distance has) (Ewing 1974; Olsson 1970).

The cumulative measure of all the gravitational forces a city exerts on other cities is expressed as the Influential Potential (IP) variable. This (IP) variable is used in conjunction

with the number of heavy linkages a given city has with other cities to determine the hierarchy of cities. Graph Theory transfers empirical reality to a point-line graph by converting quantitative statistics to an easily identified chart (Tinkler 1979). This theory in combination with the gravity model provides an abstract representation of an urban system's hierarchy (Du 2000; Huff and Lutz 1995). Figure 1.6 represents the hypothetical interaction model of Chinese urban systems. A temporal analysis of the urban hierarchical nodal structure would answer the research questions posed at the macroscopic scale.

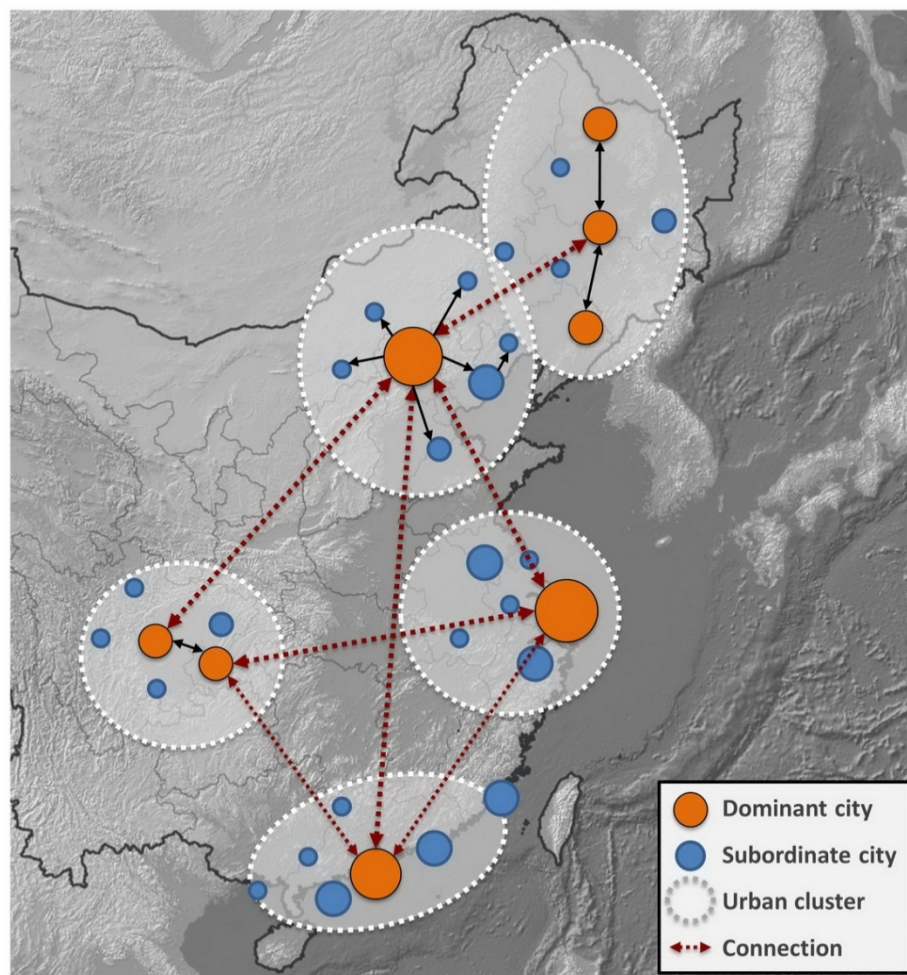


Figure 1.6 Hypothetical interaction patterns of China's national urban system

1.3.3 Regional urban cluster or subsystem – Regional scale (Meso-scale)

Today's metropolitan cities are sustained by a series of socioeconomic inputs that operate on regional scales; the influence of these metropolises is also required to support an urban field as defined as an area hundreds of times larger than the urban region (Alberti *et al.* 2003). Although the impacts of urban development are most noticeable at a local level, urbanization also results in environmental and socio-cultural changes on a regional level. Hence, the resources required by a city to continue urbanizing are dictated by its spatial organization and location, and thus the city's level of influence on the surrounding area. Though cities have long been understood to be local drivers of economic growth, their ability to influence urban development on the regional scale is not yet fully recognized (Alberti *et al.* 2003; Friedmann 1966; Pickett *et al.* 2001). As a transition between national scale and city scale studies, the examination of cities at a regional scale fills an important knowledge gap in the area of urban studies, and also helps to develop a better understanding of urban hierarchy.

Cellular Automata offers a unique and innovative approach to the study of urban systems and there has been a wide application of CA-based models to urban systems in urban studies. On the Meso-scale, the applicability of the CA-based SLEUTH model for regional urban growth pattern is studied through a focus on the JingJinJi Metropolitan Area (Beijing-Tianjin-Hebei). The SLEUTH model requires input data as layers of raster images:

Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade. The SLEUTH model was designed to incorporate only physical factors that shape urban development (Jantz *et al.* 2004). While urban settlements are the result of human activities in a physically restrained setting, once an urban settlement has been formed, it is the socioeconomic factors that play a substantial role in propelling urban growth. In order to incorporate socioeconomic factors into the SLEUTH model, the function of the Exclusion layer is extended in this research. Firstly, an Attraction layer is generated based on the socioeconomic and demographic factors that promote urban growth. Variables covering domains of demography, economy, industry and infrastructure are collected at county-level (counties, county-level cities, and city districts) units in JJJ Metropolitan Area. These variables are processed using Principal Component Analysis (PCA) to generate a comprehensive attraction index (the normalized value of the first component). Then variables including proximity to metropolitan centres and proximity to roads are calculated at a pixel level (30m*30m). By overlaying the Attraction layer, Proximity layer, and the Exclusion layer, a composite Suitability layer is created.

Based on urbanization state at several points of time in the history, the SLEUTH model is capable of simulating the urban development patterns both in the past and future. The model is implemented in two phases. In the Calibration Phase, five coefficients are calculated while the model is being implemented based on historical data, including the

Diffusion (Dispersion) Coefficient (DI), the Breed Coefficient (BR), the Spread Coefficient (SP), the Slope Resistance Coefficient (SR), and the Road Gravity Coefficient (RG). All these coefficients are used to define Urban Growth Rules in the urbanization process, and through these rules the factors that contribute to the urban change are unveiled. The Calibrating Phase also generates the fine coefficients that are used in the Prediction Phase to forecast urban growth in the future. This model allows for the projection based on user-configured scenarios to simulate future urban growth, and the comparison between the results of these scenarios has great implications for the interventions in the future urban planning.

By integrating socioeconomic factors into a modified SLEUTH model, the urban growth dynamics and patterns both in the past and future can be simulated and predicted (Figure 1.7), and the underlying drivers for this dynamics can be further explored within the regional context.

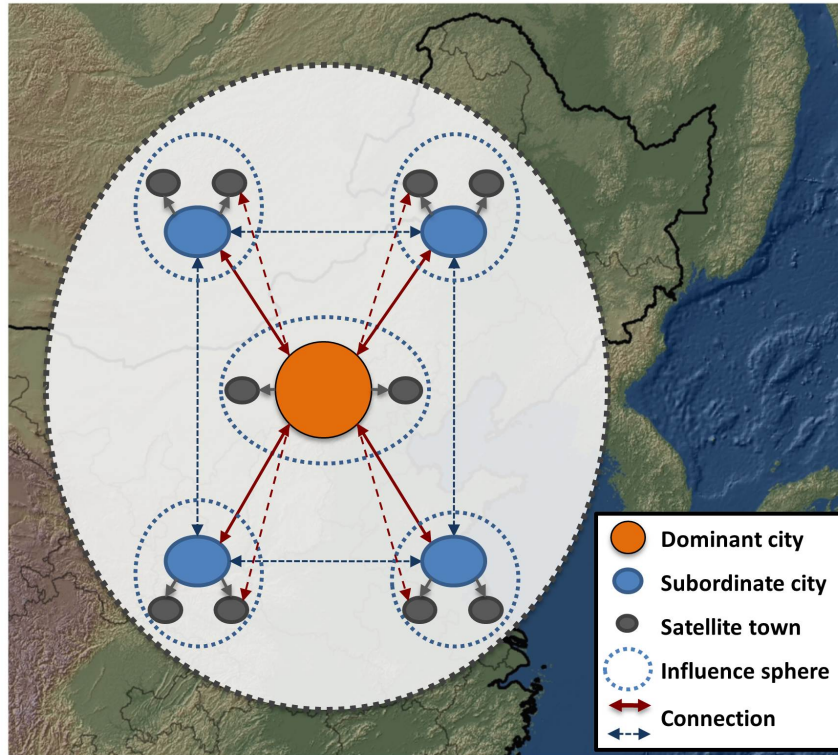


Figure 1.7 A conceptual model for a regional urban cluster

1.3.4 Urban ecological system – City scale (Micro-scale)

Although the relationship between urbanization and ecosystem dynamics have been theoretically explored (Collins *et al.* 2000; Grimm *et al.* 2000; Pickett *et al.* 1997; Pickett *et al.* 2001), the interactions between human and biophysical patterns and processes have never been explicitly represented, and neither have the feedbacks from these interactions. Moreover, most ecological studies represent urbanization as unidimensional and consider cities as homogeneous phenomena (Hobbs 1997; Turner 2005). However, urbanization is multidimensional and highly heterogeneous across time and space (Seto and Fragkias 2005; Weng 2007). The over-simplification or discrimination of the complex socioeconomic and

biophysical processes greatly limit the understanding of the complex dynamics in urban systems (Pickett and Cadenasso 1995).

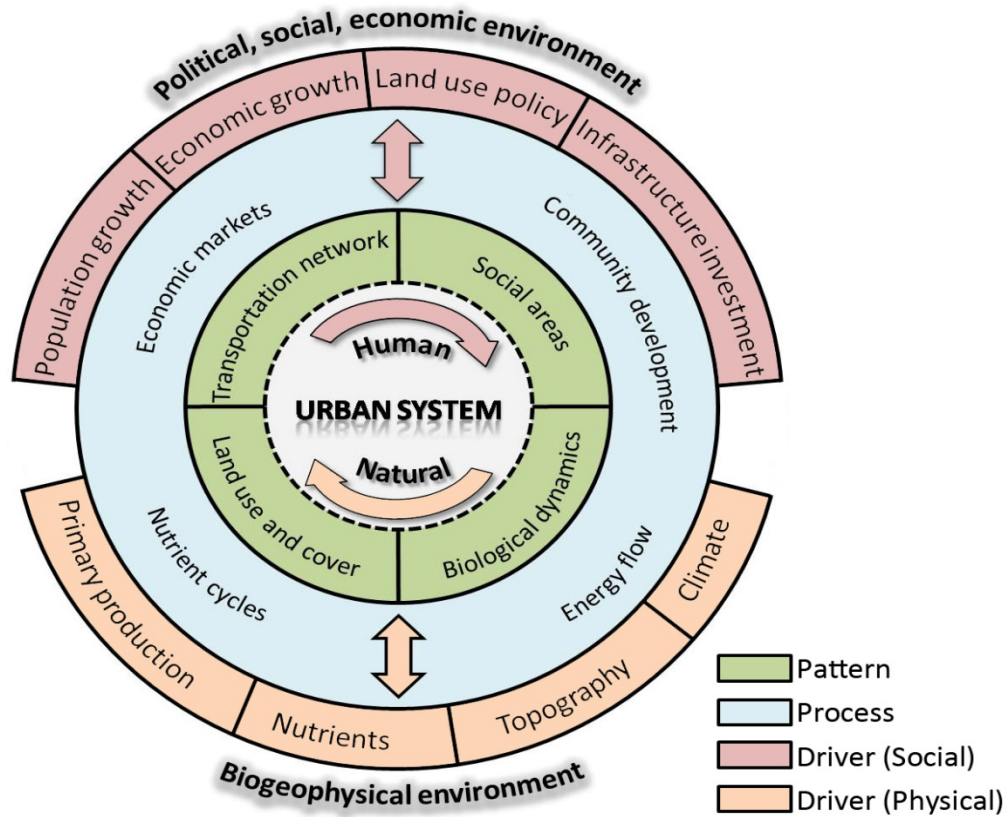


Figure 1.8 A conceptual model for the urban system of a city

Figure 1.8 is a proposed conceptual model that visually represents the links between human and biophysical drivers, patterns, processes, and the effects of urbanization. Both biophysical and human agents interactively work together to drive the composite urbanization processes, and a unique urban landscape pattern is formed as a result of this process.

Adopting the factorial ecology approach, the third part of the thesis aims to identify the factors that have shaped Beijing's urban landscape since the 1978 economic reforms. In conjunction with neighbourhood level census data from 1990 and 2000, PCA is used to identify the factors that are responsible for Beijing's internal social transformation over the past three decades. The principal components of the PCA are illustrated at the neighbourhood level as social areas.

The physical land use and cover maps are extracted by processing Landsat TM and ASTER remotely sensed images that have the same temporal span. A modified version of the Anderson scheme of land-use classification was adopted (Anderson *et al.* 1976). The classification scheme included: (1) high density urban land, (2) low-density urban land, (3) cultivated land, (4) shrub land, (5) forest land, and (6) water area. The supervised maximum likelihood classifier was used to produce the land-use/cover. Landscape patterns are derived based on the land-use/cover maps, with the ancillary sources such as transportation and Digital Elevation Model (DEM). Landscape metrics calculated from FRAGSTATS is used to quantify the structure and characteristics of landscape patterns.

Research in urban modeling suggests that the current physical landscape pattern is the outcome of a development process, and such a process is often controlled and constrained by both social and demographic activities. The relationship between the urban landscape pattern and social areas is explored using the geographically weighted regression (GWR)

technique. Unlike the linear regression technique that assumes that the relationship holds everywhere in the study area, GWR considers the spatial variable as non-stationary and allows the regression relationship to vary over space. Specifically, given a location “ u ” in space, its local regression model can be written as:

$$y(u) = \beta_0(u) + \beta_1(u)x_1 + \dots + \beta_n(u)x_n$$

in which,

$y(u)$ is the dependent variable;

$x_1 \dots x_n$ are the independent variables;

β_0 is the intercept and $\beta_1 \dots \beta_n$ are the coefficients.

To estimate the values of the coefficients and the dependent variable at location “ u ,” a geographic weighting scheme is applied to fitting by least squares. This weighting scheme is organized such that the data near location “ u ” are given a higher weight in the regression than data that is further away. As a result the regression determinant varies for different locations.

By analyzing both the 1990 and 2000 census data, the relationships between social areas and landscape patterns are compared temporally to examine the interactions between the human and biophysical processes.

1.3.5 Thesis structure

This thesis is presented in an article format that includes the following six chapters: an introduction chapter, four main chapters that consist of four articles formatted for peer-reviewed journals, and a conclusion chapter (Table 1.1). The hierarchical structure of the thesis makes it simple to divide the whole research into discrete parts that are based on the three spatial scales of study.

The detailed structure of the proposed thesis is shown below.

Table 1.1 Structure of the proposed thesis⁶

Chapter 1.
Introduction

Chapter 2.
Challenges Facing China's Urban Development in the New Era

Chapter 3.
Studying the Urban Hierarchical Pattern and Spatial Structure of China Using A Synthesized Gravity Model

Chapter 4.
The Spatiotemporal Transition of China's JingJinJi Metropolitan Area: Detection, Modeling, and Prediction

Chapter 5.
Urban Transformation of Beijing: Patterns and Process of the Landscape Change

Chapter 6.
Conclusion

Appendix
Technical Note: Use of Fuzzy Logics in Mapping Urban Areas from Landsat TM Imagery

⁶ Because this thesis has been completed in article form, each chapter has had to be adapted to the fit the standards of each academic journal or book chapter. As such, there are minor differences in formatting and also on focus. The core arguments, however, remain consistent with the research questions identified in this chapter.

1.4 Anticipated contributions

Urbanization has resulted in the massive transformation of natural landscapes, and in the process it has also contributed significantly to the proliferation of social issues such as urban poverty and social segregation (Cao 2010; Lo 2007; Polednak 1997; Sampson and Wilson 1995). Many studies have discussed the ecological method in conjunction with urban systems at the conceptual level (Grove and Burch 1997; Pickett *et al.* 2001; Zipperer *et al.* 2000), however, few have studied the landscape-level implications of the interactions between social and biophysical agents/elements. This thesis explores the complexity of interactions and feedback mechanisms that exist between social, biological, and physical processes, at the national, regional and city scales.

On a conceptual level, this research comprehensively studies the Chinese urban system. This systematic research not only presents an insightful view of China's urbanization at three spatial scales, but with a stratified research design it also sheds light on the urbanization mechanism of Chinese cities. The urban transition history and hierarchical structure at the national scale studies the urbanization context and consequences of China's political, social, and economic development. A regional urban cluster, such as the JingJinJi Metropolitan Area, is a component of the national system. Studies at the regional scale can further explore the urbanization process with more specified factors and constraints. Whereas a cluster is only a part of a larger whole, a dominating city is not solely a

component in an urban cluster; it is also a growth pole as this city's development can determine the overall structure of the cluster it belongs to. On one hand, the urban processes that are occurring at the higher levels of spatial scale provide a context for lower-level urban development. However, on the other hand, the higher-level urban patterns are an aggregation of lower level urbanization processes.

This thesis has also developed a series of methodological approaches that have the potential to further our understanding of the urbanization process in its entirety. These approaches, which include the Synthesized Gravity Model, Cellular Automata, Geographical Weighted Regression, etc., are employed to examine both the socio-economic and biophysical factors within an urban system, from different spatial and temporal scales.

In more concrete terms, in this thesis the SGM is tested and proven to be a feasible improvement on the traditional Gravity Model. SGM's improvement of the GM's results can be attributed to two basic aspects: (1) scale impacts, wherein Influential Factor was introduced to measure the accurate "mass" of a city, and (2) distance impacts, wherein Relative Distance based on network analysis is introduced to reveal the "distance decay" effect between cities. By incorporating the Principal Component Analysis and Network Analysis, the new model successfully overcomes the GM's limitations in terms of misrepresenting a city's influential strength, as well as its oversimplification of reality. The SGM can successfully discern and represent the hierarchy of China's urban system, as well

as its nodal structure. With this information an overall understanding of the Chinese urban system can be developed.

The CA-based SLEUTH is a grid-based simulating model, which has been widely applied and developed at the micro scale; however, it has seldom been incorporated into a regional study. Unlike the numerous methods and models developed for studies at the city scale, research at the regional scale only has access to a limited number of applicable models. The application of the SLEUTH model at the meso-scale in this thesis not only helps to develop a better understanding of the regional city systems' urbanization process, but it also contributes to the urban cluster modeling database on this scale. The SLEUTH model is able to determine which factors influence the development of the JingJinJi Metropolitan Area and to what degree, as well as project future growth scenarios, which is an invaluable tool for urban planners.

Landscape ecology has been used as a tool for studying the natural aspects of a given city, while Factorial ecology is often applied to studies of the social aspect. With the Geographically Weighted Regression, these two aspects are brought together to examine the quantitative relationships between socioeconomic and biophysical factors influencing urban development on a city scale. These two factors have a reciprocal relationship that sheds light on how the increasing complexity of Beijing's social space leads to the fragmentation of the city's physical space.

As far as China is concerned, this is the first time that the country's urban system has been thoroughly studied from the national to city level in one research. The application of Western theories that pertain to urban studies is examined in the urban system of China's market economy, and will contribute to the current literature on Chinese urban studies.

Chapter 2 Challenges Facing China's Urban Development in the New Era

2.1 Introduction

China's urbanization has been occurring at a rapid rate that is unmatched by any other country during the last few decades. Although China surpassed the United States to become the country with the largest urban population in terms of absolute numbers during the mid-1970s (Figure 2.1.A), its urbanization rate was barely 18% at the time. It was not until the beginning of the 1980s with the introduction of the open door policy and economic reforms⁷ that China experienced exponential economic growth which has allowed the country to urbanize rapidly over the last 30 years. As demonstrated by Figure 2.1.B, China's urbanization process has been in a stage of acceleration since the 1980s. According to the first report released by the 2010 National Census Office, 670 million people, which accounts for roughly 50% of the population, are living in cities and towns (National Bureau of Statistics of China 2011). This number is a 13.46 % increase from the number released in the 2000 census. As indicated in Figure 2.1.B, China faces steady and fast urbanization in the long run: 20% of the Chinese population is going to be urbanized, and the urbanization

⁷ When Deng Xiaoping came to power in 1977, a radically different development strategy was put in place. In a break with Maoism's isolationist tendencies, the Chinese government decided to integrate China's economy into the international market by adopting a development model that focused on the "production of exports."

rate can reach 70% between 2035 and 2045 (United Nations 2005, 2007). Despite the fact that China's urbanization rate only recently reached the world average of 50% (National Bureau of Statistics of China 2011), the speed of China's urbanization is unprecedented given its large population size; its cities are continuously expanding in terms of their number and spatial scale (Pannell 2002, 2003).

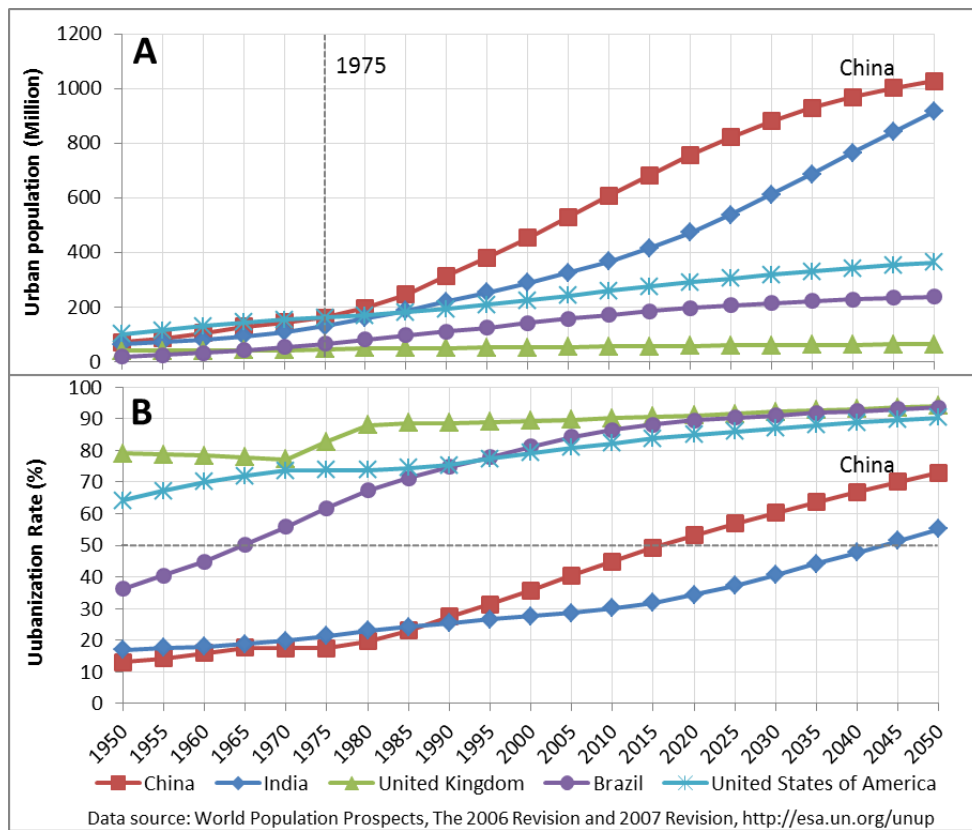


Figure 2.1 Urban population and urbanization rate of China and selected counties, 1950-2020

Although this astonishingly rapid urban growth is impressive, such a fast pace also presents various concerns. The Chinese government and policy makers continue to pursue an ever-increasing rate of development and to celebrate their success; however it is crucial that they pause to take into consideration the issues that are arising with the current state of

China's urbanization. In order to make urban growth sustainable in the future, China must look back on its urbanization path and ask some important questions. How have the political and economic systems been influencing urban growth? What patterns were generated as a result of the economic growth and reforms? Was the development evenly distributed spatially and temporally? What measures should be taken to pursue sustainable development at such a high speed? This chapter will attempt to address these questions.

By analyzing the historical evolution of the cities in China, and the context under which it took place, the unique dynamics of urban development in China can be appreciated. The first section of this chapter introduces China's urbanization process since the 1950s in order to reveal the origins of the country's modern urbanization patterns. This is followed by a discussion of institutional barriers that impede its urban development. Subsequently, the structural transitions of city scaling and urban clusters are studied by employing Rank-size Analysis and satellite imagery, including an analysis of the challenges that accompany these changes. After reviewing these challenges, the spatial distribution and transition patterns of China's urban system are analyzed using Centographic Analysis. This chapter endeavours to conduct a systematic and detailed analysis of the Chinese urban system that not only provides a better understanding of the current urban landscape, but also has far-reaching implications for conceptualizing, understanding, and planning future urban developments in the China.

2.2 Challenges and opportunities for China's urban development

China's political and economic regimes have undergone a complicated development process since the establishment of the People's Republic of China (PRC) in 1949. Various studies have been conducted in an attempt to delineate the stages of urbanization in China (Chen 2008; Kamal-Chaoui *et al.* 2009; Lin 2002; Pannell 2002), but despite their divergent findings, the underlying fact is that cities in China have undergone a number of distinct phases of expansion, contraction, stagnation, and acceleration over the past six decades. Based on variations in the number and population of cities, the contemporary history of China's urbanization since 1949 is divided into three stages for the purpose of this study (Figure 2.2): the Pre-reform Phase (1949-1978), the Revival Phase (1979-1996), and the Transition Phase (1996-present). In order to present a comprehensive view of China's urban development, its course is discussed from institutional, structural, and spatial perspectives.

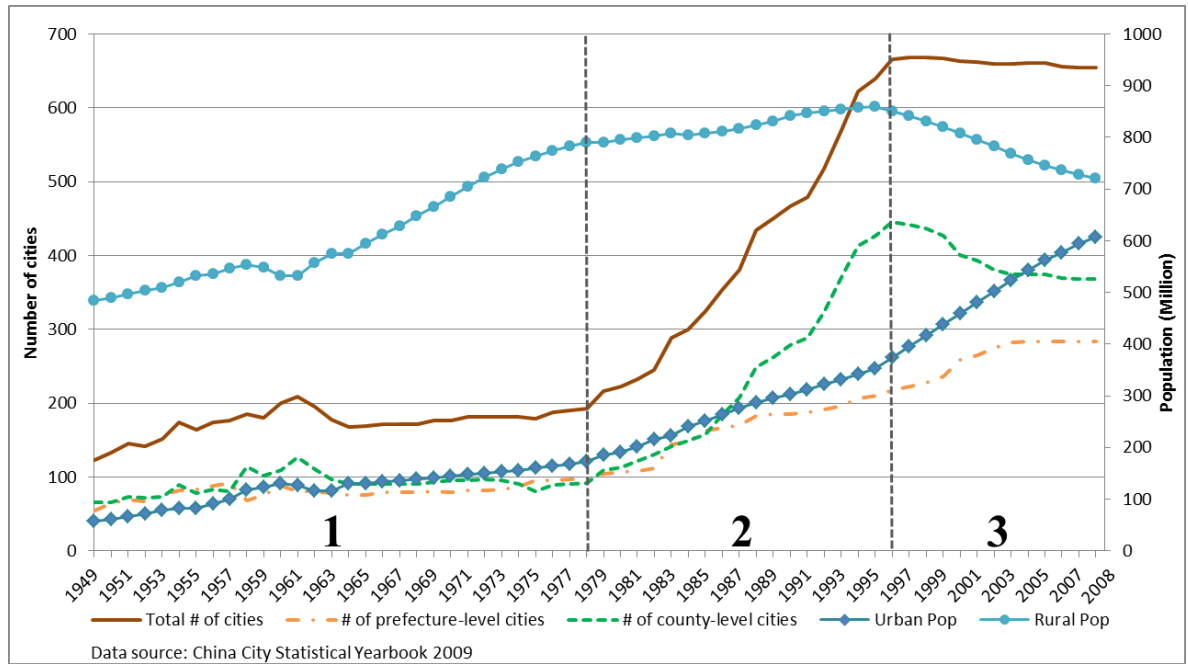


Figure 2.2 Urban development phases of China⁸

2.2.1 Drivers behind the institutional transition

2.2.1.1 Pre-reform phase (1949-1978)

⁸ There are three administrative types of cities in China: 1) provincial-level municipalities (PLMs); 2) prefecture-level cities (PLCs); and 3) county-level cities (CLCs). In addition, administrative towns are today also considered “urban” settlements. PLMs (currently including Beijing, Shanghai, Guangzhou and Chongqing) report directly to the central government. A province is usually divided into a number of prefectures, which are administered by PLCs, and these PLCs report to provincial governments. Counties in a prefecture are subordinated to the governing PLC, and a county is centred at and administered by a town. A CLC is actually a town that meets the criteria for a statutory city.

Up to 1982, “urban population” referred to the total population of cities and towns. In the 1990s, urban population included (1) all residents of urban districts in provincial and prefectural-level cities; (2) resident population of “streets” (*jiedao*, 街道) in county-level cities; (3) population of all residents’ committees in towns. Since 2000, urban population is composed of: the population in City Districts with an average population density of at least 1,500 persons per square kilometer, other population in sub-district units and township-level units meeting criteria such as “contiguous built-up area”, being the location of the local government, or being a Street or having a Resident Committee (Liu *et al.* 2003).

The Pre-reform Phase consists of the Rehabilitation period (1949-1952) and the First Five-Year Plan (1953-1957), during which Chinese leadership under Mao Zedong⁹ embarked on an intensive economic reform program that was designed to emulate the Soviet model, which was essentially based on heavy industry. It was remarkably successful in terms of urban development, and the urbanization rate grew steadily from 10.64% in 1949 to 15.39% in 1957. However, since heavy industry is not as labour-intensive as light industry, less rural labour was used, and therefore urbanization did not keep pace with industrialization.

During China's three-year "Great Leap Forward"¹⁰ (*da yuejin*, 大跃进)" campaign (1958-1960), which followed the 1st Five-Year Plan, large-scale migration from the countryside to urban areas took place. Consequently, the number of cities increased dramatically from 176 in 1957, to 209 in 1961 and the urbanization rate reached 19% in 1960, which remained a record until 1980 (Lin 2002). However, the "Great Leap Forward" was unrealistic and turned out to be a catastrophe. From 1959-1961, China suffered a widespread famine that resulted in millions of deaths (Yang 2008) that significantly decreased the rural population between 1958 and 1960 (Phase 1 in Figure 2.2).

⁹ Mao Zedong (1893-1976), known as the founder of the People's Republic of China, ruled the country from its establishment in 1949 until his death in 1976.

¹⁰ The Great Leap Forward was a new economic development strategy proposed by the Chinese government in 1958 that sought to meet the following objectives: the grain and steel production would both be doubled within one year, however the Chinese government underestimate the importance of capital and high technology to realize these objectives.

Due to the influx of rural labour and the proliferation of newly designated cities, the demand for financial assistance from the government to urban areas increased dramatically, and in order to ease its burden the central government launched an Economic Readjustment plan in 1962. As a result of various adjustments, such as the elimination of some cities and the enforcement of the Household Registration¹¹ (*hukou*, 户口) system, the number of cities dropped from 209 in 1961 to 169 in 1965, and the urban population decreased to 18% (Lin 2002). By means of strictly controlling the population and resources, the Chinese government was able to stabilize the urbanization rate for much of the following decade and to shape the country's urban system.

The Cultural Revolution¹² (*wenhua da geming*, 文化大革命) (1966-1976) was a period of widespread political and social upheaval that resulted in nation-wide chaos and economic instability. Economic and urban development in China was frozen for over a decade (Phase 1 in Figure 2.2) with the exception of cities in the central and western regions that were developed for military and national security interests. In 1978, the introduction of an open door policy and economic reform marked the end of Mao's regime and ushered in a new era of economic and urban revival.

¹¹ Since the end of the 1950s, la Chine established a household registration system in urban and rural areas called *hukou*. It acts as a tool of public control by limiting the population's geographic mobility.

¹² The Cultural Revolution, which occurred from May 1966 to October 1976, was initiated and directed by Mao Zedong. This movement represents the continuation of the Maoist re-conquest of China. However, in reality, Mao wanted to do away with his political opposition.

2.2.1.2 Revival phase (1979-1996)

In 1979, Mao's pragmatic successor, Deng Xiaoping¹³, earnestly began a process of economic reform that was aimed at generating sufficient surplus to finance the modernization of China's economy. The first part of this economic reform involved the introduction of a Household Responsibility System (HRS – *jiating lianchan chengbao zerenzhi*, 家庭联产承包责任制). China's HRS applied to agricultural land and implemented production quotas for households that allowed them to market the surplus production of their individual plots as opposed to farming for the collective. Ultimately, the adoption of the HRS successfully motivated farmers and greatly raised productivity, but it also created a large number of surplus rural labourers. With the relaxation of the restrictions prohibiting farmers from migrating to urban areas, rural labourers were encouraged to migrate to small towns in order to establish, or join, industries owned by townships and villages (Town and Village Enterprises, TVEs – *xiangzhen qiye*, 乡镇企业). The subsequent growth of TVEs brought about a period of prosperity in small towns, which played an important role in urban development. In conjunction with the loose control over the designation of urban areas, rural development and reforms provided impetus for the upgrading of towns into cities and also the expansion of small cities (Hsu 1994; Lin 2002). From 1978 to 1996, the number of cities in China more than tripled, increasing dramatically

¹³ Deng Xiaoping (1905-1997) was the architect of China's open door policy and economic reforms. These policies were implemented in China at the end of the 1970s, and profoundly transformed Chinese society over the following decade.

from 193 to 666. County-level cities were the primary drivers of this astounding urban growth, compared to their prefecture level counterparts (Phase 2 in Figure 2.2). According to Table 2.1, the population residing in small urban areas (less than 0.2 million) accounted for a mere 13% in 1980, but then soared to around 21% in the early 1990s. China’s national urbanization policy in the 1980s emphasized, “controlling the big cities, moderating development of medium-sized cities, encouraging growth of small cities,” played a significant role in controlling the number and population of the country’s cities (Table 2.1).

Table 2.1 The variation of the ranking scale of China’s cities

Year	Total # of cities	Metropolitan		Extra-large		Large		Medium		Small	
		Pop≥2 Million		2>Pop≥1 Million		1>Pop≥0.5 Million		0.5>Pop≥0.2 Million		Pop<0.2 Million	
		#	Pop %	#	Pop %	#	Pop %	#	Pop %	#	Pop %
1975	184	5	23.4	8	15.3	25	24.1	52	22.0	95	15.1
1980	223	7	26.7	8	12.3	30	24.6	70	23.5	108	13.0
1985	324	8	24.8	13	14.6	31	19.4	94	24.5	178	16.8
1990	467	9	22.9	22	18.7	28	12.6	117	24.2	291	21.5
1995	640	10	19.8	22	15.1	43	14.8	191	28.8	374	21.4
2000	665	13	22.4	22	14.5	54	15.5	220	28.9	352	18.5
2005	661	22	30.1	32	14.7	83	18.9	227	23.6	297	12.8
2007	656	23	31.7	35	15.2	82	17.7	233	23.4	283	11.9

Data source: The Compilation of 50 Years’ Urban Statistics of New China; The Compilation of the Demographic Statistics of China 1949-1985; China City Statistical Yearbook 2001, 2006; China Population and Employment Statistics Yearbook 2008

China’s economic reforms were carried out through a series of actions that were undertaken simultaneously. First, China introduced an “Open Door” policy in the spring of 1979 that began to allow and encourage direct foreign investment and international trade to spur its economy. Second, recognizing the economic and geographic advantages of the

coastal cities, China set up four Special Economic Zones¹⁴ in 1979: Shenzhen, Zhuhai, Shantou, and Xiamen, with Hainan making the list in 1988 (Cao *et al.* 2000). Then, inspired by the rapid development of these zones, China designated 14 open coastal cities in 1984 and 13 open border cities in 2000 (Figure 2.3), all of which were given the autonomy to act as experimental sites for attracting foreign investment and testing the roles of free market forces. By the late 1980s, the “Special Economic Zones” policy had generated rapid development in the selected open coastal cities, thus triggering the first wave of renewed urban construction and urbanization (Kamal-Chaoui *et al.* 2009). After beginning to integrate its economy internationally, China also endeavoured to transform its economy from a socialist one with sole macro-control to a market-driven one with government intervention.

¹⁴ The Special Economic Zones (SEZ) were created during the period of economic reform at the end of the 1970s. They were intended to function as experimental zones of rapid economic growth, and incentives like tax reduction or exemption were introduced to attract foreign investment and technology.

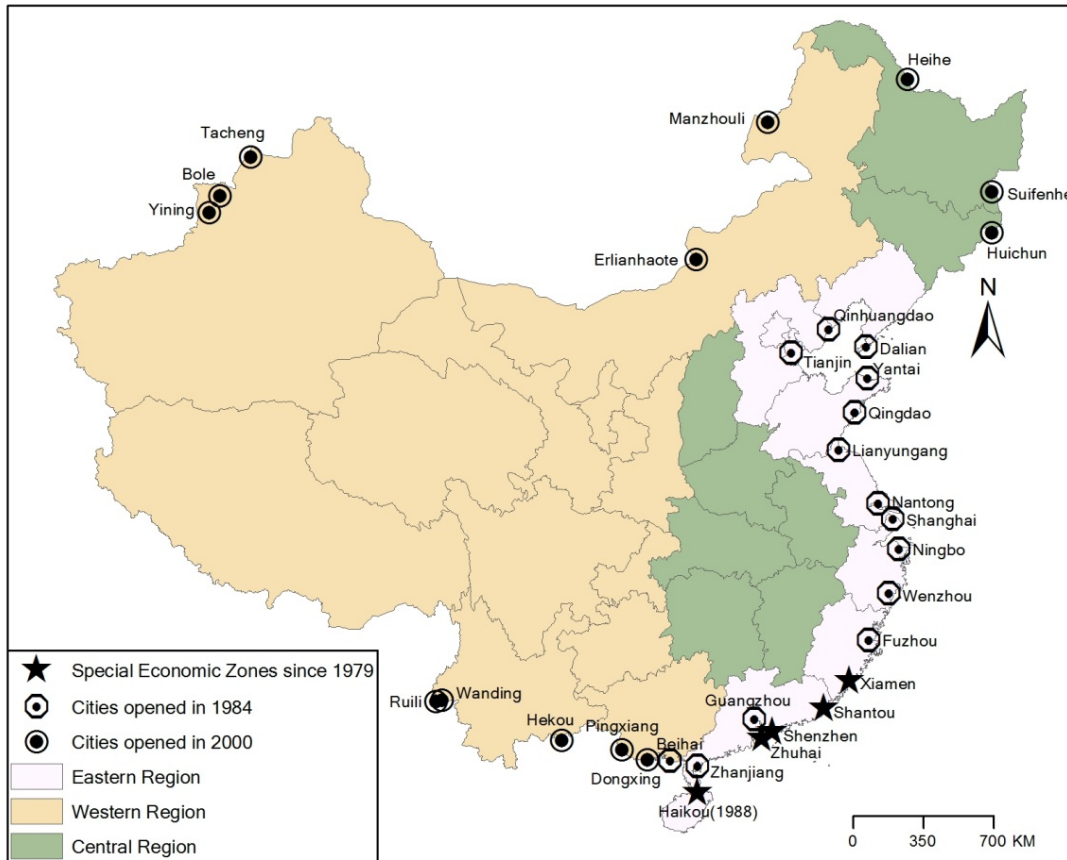


Figure 2.3 Open cities in China since 1979

In 1979, the Chinese government implemented the Birth Planning Policy in an attempt to alleviate social, economic, and environmental problems. Although the “One Child Policy¹⁵” has been controversial due to concerns over its negative social consequences (Merli and Raftery 2000), it has successfully curbed excessive population growth. By

¹⁵ The economic reforms of the late-1970s accelerated and encouraged the implementation of a population policy. Despite a substantial downward trend in the birth rate, China’s population continues to rise. In 1980, the “One Child Policy” was instated to encourage couples to limit their families’ size. The policy has been suggested as a possible cause for the gender imbalance in China, as increased female infanticide (spontaneous or forced abortion) based on gender preference (mostly to boys) has been attributed to this policy. Moreover, as the one-child policy steps into the second generation, one adult child has to provide support for his or her two parents and four grandparents. The so called “Four-Two-One” problem leaves the older generation with more dependency on retirement funds and the younger generation with more financial and moral pressure.

managing China's population growth, the government has avoided exacerbating social issues, such as slum development, the demand for social services (health, education, law enforcement), and strains on the ecosystem from the overexploitation of arable land and high volumes of waste. As a result of the Birth Planning Policy's adoption as well as increased rural-urban mobility, the annual growth rate of the rural population was much smaller than in previous decades and the absolute number of rural residents plateaued in 1995 (Phase 2 in Figure 2.2).

With the relaxation of state control and the operation of the spontaneous forces brought on by market reforms, the period of economic revival (1979-1996) witnessed the expansion of small and medium-sized cities (from 1979 to 1996, the number of small cities increased from 32 to 141, while the number of medium cities increased from 128 to 436). At the same time, agricultural restructuring and rural industrialization greatly raised productivity and increased the standard of living for most of the Chinese population, which generated support for further development.

2.2.1.3 Transition phase (1996-present)

Starting with the 9th Five-Year Plan (1996-2000), China entered into a new transitional phase that continued with the 10th Five-Year Plan (2001-2005) and 11th Five-Year Plan (2006-2010). Economic reform continued, however, China's policies toward

urbanization and the configuration of the urban system have been in transition from the old system of status designation to a newer, migration-based structure.

The different levels of governments have played a crucial role in the development of the urban system throughout its evolution. Until recently, two of the most important factors in shaping urban growth had been politics and public policy (Small 2002; Song and Zhang 2002). However, since the adoption of Opening and Reform policies at the end of the 1970s, the importance of the government's role has gradually diminished due to the relaxation in attitude towards the establishment of cities¹⁶ (Yeh and Xu 1996). Urban growth during the Revival Period owed much to the designation of cities at the county level (Phase 2 in Figure 2.2). This resulted in a massive increase in urban population through the urban household registration system (*hukou*) simply because of the promotion of many towns to city-status. The population residing in small cities accounted for 13% of the national urban population in 1980, however, this increased to 21% in 1995 (Table 2.1 and Figure 2.4). Essentially, the increased urbanization of this period was propelled by the designation of new cities.

¹⁶ Population size as well as economic and defense concerns were the main criteria for granting city status. Since being a city means being qualified for more fiscal autonomy and more investment in public facilities, many towns strive to upgrade into cities. It is also a strategy to grant a unqualified town a city status in order to attract foreign investment.

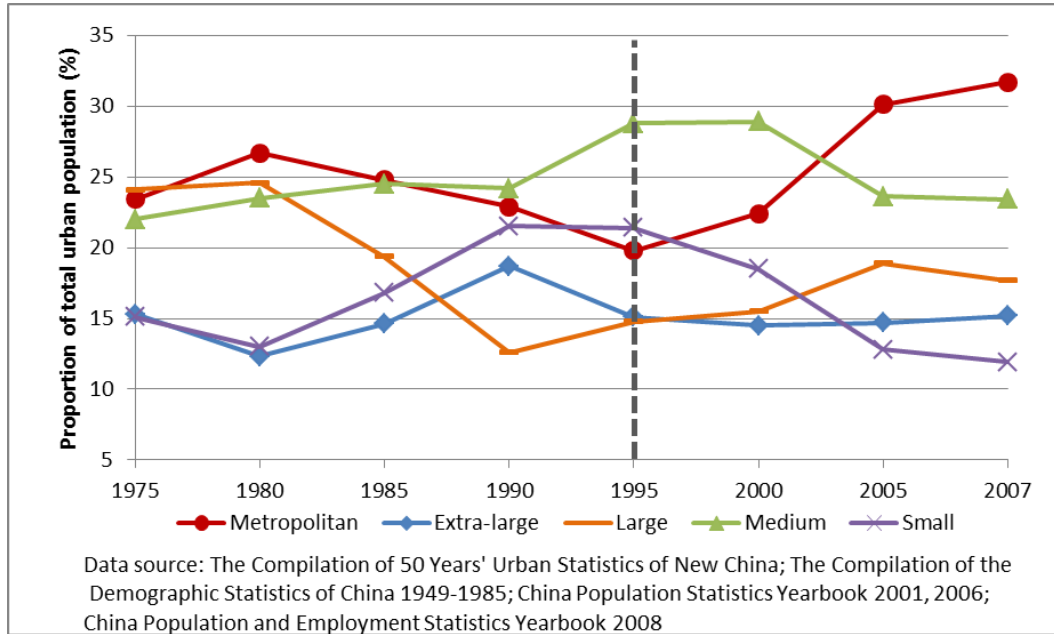


Figure 2.4 Distribution of urban population among cities at different scales

In the mid-1990s, the Chinese government began to shift its emphasis from “encouraging the development of small cities” to “a coordinated development of large, medium, small cities and small towns” (Kamal-Chaoui *et al.* 2009). Consequently, from the late-1990s onwards policy makers moved from designating new cities towards *in situ* growth due to urban migration. As illustrated by Figure 2.2, although the urban population was growing at an extraordinary speed after 1995, the total number of cities remained stable at around 650. In a parallel phenomenon, the rural population was diminishing at a continuous, rapid, rate for the first time in China’s history. This reduction of the rural population was mainly caused by rural to urban and inter-city migration, rather than by the transformation of villages to towns. Given that larger cities have better access to resources and investment, which in turn creates a more vibrant job market, and better facilities and

infrastructure it is unsurprising that many people left the countryside for urban areas. Consequently, the number of people residing in metropolitan areas swelled from 20% in 1995, to 32% in 2007 (Figure 2.4). The urban density also shifted dramatically due to massive urban migration, growing from 323 people per square kilometers in 1995, to 870 in 2005 (Figure 2.5).

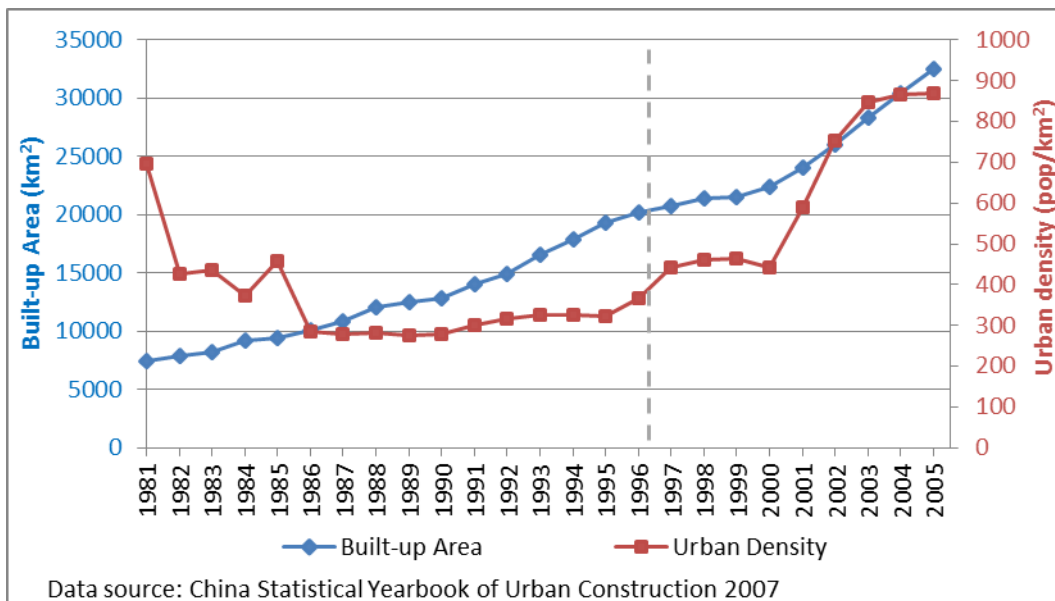


Figure 2.5 Urban built-up area and urban density, 1981-2005

2.2.1.4 Institutional barriers resulting in pseudo-urbanization

Although China has achieved remarkable success by continuously reforming urban policies, institutional barriers still exist that impede further urbanization to keep pace with the urban growth.

2.2.1.4.1 Dual social structures of urban and rural development

In China, an official distinction exists between the rural and urban populations due to the *hukou* system, which assigns every Chinese person to a specific locality and was originally designed to promote industrial and urban development (Chen 2008). To achieve this end, those who lived in urban areas were given special benefits such as lifelong employment, health care, housing, and pensions. This increase in funding to urban centres created a significant disparity in the living conditions between rural and urban areas. For example, people residing in urban areas have on average 11 years of education, as opposed to 6.6 years of education in rural areas (Yusuf and Saich 2008). The rural workers that do get jobs in cities send many of their wages back to their families in the countryside, and these remittances substantially help to alleviate poverty in the area. However, these workers are considered to be temporary and leave the cities in the off-season in order to work on their farms. Therefore, as the *hukou* system continues to restrict permanent transfers, it also continues to perpetuate the inequality between rural and urban areas (Chen *et al.* 2011).

Education is the primary way in which individuals can facilitate a *hukou* change and since education is more readily available in urban centres, rural workers are stuck in a “Catch-22” (Wu and Treiman 2007). Statistically, permanent immigrants are associated with high education, usually university level, and urban destinations, whereas temporary migrants are associated with lower education and rural origins (Yusuf and Saich 2008). Therefore, rural residents are marginalized in terms of education and job opportunities.

Furthermore, those living in urban areas with a rural *hukou* cannot access education in the urban areas, and making it improbable that their children will experience any occupational mobility (Wu and Treiman 2007). In order to provide better options for the children of rural migrant workers, migrant children's schools need to be established and incorporated into the larger educational system (Yusuf and Saich 2008).

The size and speed of migration had long lagged behind the level of economic and industrial development. Until recently, most rural-urban migration has taken place in the more developed, urban regions of China and this has perpetuated regional disparities (Cao and Bergeron 2010). Although migrant workers are technically considered to be urban dwellers, they are living in an inferior situation compared to the regular urban population due to the fact that they are denied access to the social welfare benefits that only come with an urban *hukou*. Therefore, this special phenomenon of urban development is termed "pseudo-urbanization".

2.2.1.4.2 Public Housing: price and accessibilities

Since the 1990s, the Chinese government has established adequate housing as one of its main priorities (Chen *et al.* 2011). Currently, there exists a multilevel housing program that attempts to provide housing to families and individuals from all income brackets. Low-rent housing is public housing provided by the government for low-income families, affordable commodity housing is a joint project between the government and developers

that sells houses to low-income families at a subsidized price, and the price restriction (ordinary) commodity program caters to middle-income families who have the funds to purchase a house at market values (Song 2010). Unfortunately, as China has begun to move from a welfare-based housing system to a market-based one, the prices of ordinary commodity housing have risen drastically and now even middle-income families can barely afford to purchase them, opting instead for housing at the lower levels. Yan (2009) indicated that, “China’s property price to income ratio is estimated at 15 in 2007, much higher than the ‘reasonable level’ of 3-6 recommended by the UN”. Furthermore, as welfare housing is not a lucrative market, developers overwhelmingly focus on providing ordinary level housing at market prices. The proportional representation of affordable housing in China has dropped from 16.6% in 1999, to 5.1% in 2008, which has left approximately 10 million people with urban *hukou* facing housing difficulties (Yan 2009). Ultimately, there is a shortage of affordable housing in China across all income brackets.

One of the main contributing factors to unreasonably high prices is that developers in China have an uncommonly high profit margin in the housing development sector at 27-30%, whereas in most countries, this profit is about 2% (Tsou *et al.* 2008). This high profit margin is due to the lack of available land, as well as lack of development and infrastructure tax fees. Furthermore, issues with the Housing Provident Fund (HPF) and mortgages contribute to people’s inability to afford housing. For example, the HPF is only

available to employed workers and there is still a sense of discomfort amongst the Chinese about debt, thus a low percentage take advantage of readily accessible loans (Tsou *et al.* 2008; Wang 2001). Also, there is a decided lack of interest by municipal governments in providing low-income housing, inconsistent funding from the central government, and a shortage of suitable housing to be used as low-rental housing, all of which contribute to the lack of affordable housing in China (Wu 1996).

The shortage of affordable housing in China also directly affects rural migrants who do not have an urban *hukou*. As it stands, this system is used as criteria for housing and those with an urban *hukou* have exclusive access to public housing (Tsou *et al.* 2008; Wang 2001). Since they cannot register for public housing, rural migrant workers have an impermanent living situation. Therefore, the majority collect in areas where rent is cheap, transportation is readily available, and job opportunities exist in abundance. These areas have come to be known as “villages within cities,” and are generally inferior areas with poor infrastructure and security (Yamaguchi and Shinya 2010). In conclusion, despite the government’s efforts to provide adequate housing for all citizens, reforms have not been able to keep pace with the rapidity of urbanization and those from low-income families have the most difficulty in finding appropriate housing in Chinese cities.

2.2.1.4.3 Discrimination of social security system

In pre-reform China, the state was a provider of social welfare: all citizens worked collectively and then the state equally distributed benefits among the population (Cao *et al.* 2000). However, after the economic reforms, state dependents became viewed as burdens and China began to move towards a market-based system in which people with a substantial income have excellent access to housing, education, and health. Conversely, the majority of the population remains in need of social services. Therefore, the distribution of the available services is unequal, for example, only 1.7% of the unemployed receive relief from the civil affairs department with 20-30% receiving compensation from their work unit (Kochhar 2010).

Originally, China had a two-tier system of social welfare in which a state-work unit collaboration provided assistance, whereas social services in rural areas were provided by communes and brigades (Zhao and Li 2006). Due to this division, public goods are delivered to a region based on the number of *hukou* holders, not the actual population. This system was chosen because local governments are unwilling to share goods with non-*hukou* holders due to their inadequate funding. As a result, rural migrant workers living in urban areas suffer from lack of access to social security benefits. To summarize, social security is more readily available to those living in urban areas, but they are still largely reserved for those with a good income. Rural areas suffer from a lack of funding and those with a rural

hukou living in urban areas are denied access due to the government's unwillingness spend the money necessary to keep track of their locations (Kochhar 2010).

2.2.2 Urban structural transition

As a result of the economic and urban reforms, the structure of China's urban system has also experienced a significant transition. A Rank-size Analysis of the urban system reveals that smaller cities are increasing in size; however, the overall structure remains unbalanced due to the extraordinarily large number of small cities. This emergence of urban clusters provides both opportunities and challenges for urban development in this new era.

2.2.2.1 Evolution of scaling distribution: Upgrade of smaller cities

Land and housing reforms in the late 1990s were two major progressions in China's economic restructuring that led to the flourishing of the land and housing markets (Ding 2003). Due to the massive inflow of migrants, cities grew both in terms of size and scale. During the past two decades, the development of Chinese cities has been evolving along two distinct patterns, as can be seen in the Rank-size distribution diagram of Chinese cities (Figure 2.6). From 1985 to 1995, small and medium-sized cities grew substantially in size. As shown in Figure 2.6, the distribution of high-ranking cities converges during this time, whereas the distribution of low-ranking cities remains distinct, which means that there was substantial growth in the size of smaller cities. As indicated in Table 2.1, the number of

small and medium-sized cities more than doubled from 1985 to 1995, and the proportion of urban residents in these cities also increased from 41.3% to 50.2%.

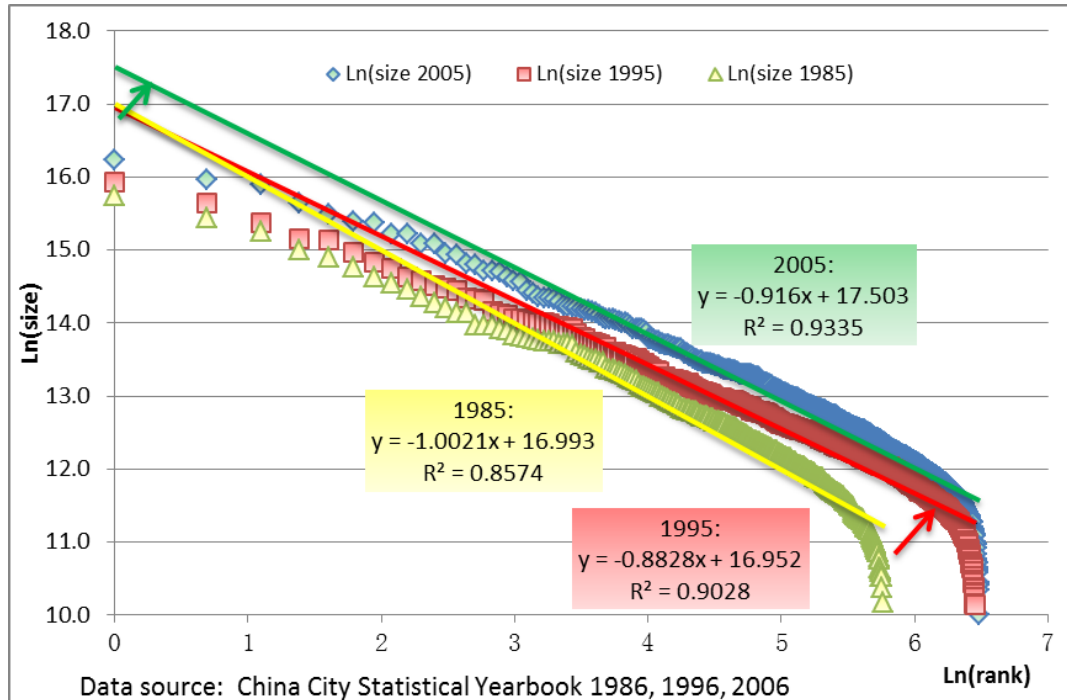


Figure 2.6 Rank-Size Distribution of Chinese cities in 1985, 1995, and 2005¹⁷

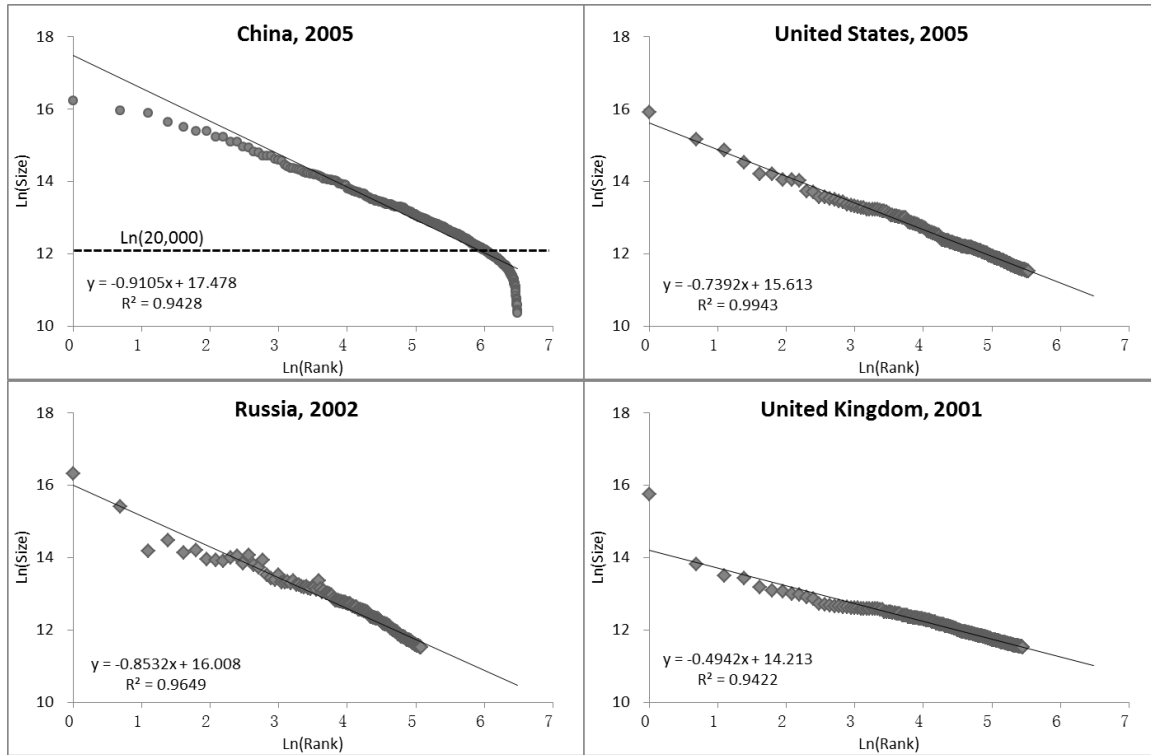
Conversely, the expansion of large cities, and the upgrading of small cities dominates the statistics from 1995 to 2005. In Rank-size distribution, lower-ranked cities remain clustered on the diagram during this decade, whereas higher-ranked cities shifted more thus indicating an increase in the size of larger cities (Figure 2.6). The data shown in Table 2.1 reinforces the existence of this trend. From 1950 to 2005, the number of lower-ranked cities

¹⁷ The Rank-Size Distribution diagram is drawn following these steps: 1) Take the largest city in a country and give it the ranking number 1; take the second largest and give it the ranking number 2; keep on doing this for the rest of the cities, or possibly selecting cities exceeding a certain size. 2) Calculate the natural logarithm of the rank and of the city size (population) and plot the resulting data in a diagram, and then a log-linear pattern can be drawn.

did not vary whereas the number of higher ranked cities nearly doubled. These higher-ranked cities include metropolitan areas, extra-large, and large cities, with the proportion of urban population living in these areas increasing by 10% in 10 years.

2.2.2.2 Unbalanced structure of the urban system

According to Table 2.1, small cities accounted for more than 60% of the total number of cities in China in 1995. In the same year, medium-sized cities comprised another 30% of the total, leaving only 10% for larger cities. However, only approximately half of the urban population resided in small and medium-sized cities in the 1990s. Although many smaller cities began to expand and upgrade their status, their number and population remain excessively large, thus distorting the structure of China's urban system. In comparison to other countries, the linear relationship between the natural logarithm of the city rank and size in China is not as apparent due to the curled tail for small cities (Figure 2.7). However, as shown in Figure 2.7, if the small cities (dots below the $\ln(20,000)$ line) in China were excluded from the examination of the rank-size relationship, a remarkable log-linear pattern would emerge. Therefore, the overabundance of small cities has resulted in the imbalance of city size distribution.



Data Source: China City Statistical Yearbook 2006; U.S. Census Bureau, www.census.gov; <http://population.mongabay.com/>

Figure 2.7 Rank-Size diagrams of cities with population of over 100,000 in China, US, Russia and UK

The development of small cities is an inevitable phenomenon in China's urbanization processes since it is traditionally an agricultural country with a massive rural population. There is a surplus rural population of 200 million and such an enormous amount of excess labour has created an overwhelming demand of employment that cannot be met by large cities alone (Cao *et al.* 2000). Small cities, as well as towns, act as a link between rural and urban life by transporting technology, culture, and economic benefits to rural areas, thus helping to coordinate a more balanced development (Cao *et al.* 2005). However, the development of too many small cities would inevitably lead to a series of socioeconomic problems. For instance, small cities are less efficient in terms of the production of goods:

they produce less while consuming more energy than large cities. In addition, a small city's ability to absorb surplus rural labour declines more quickly over time than a large city, until it eventually reaches a saturated state when it can no longer offer economic benefits to new rural migrants (Kamal-Chaoui *et al.* 2009). Also, small cities' lack of economic advantages makes it difficult for them to attract investment and consequently increase in size. Moreover, small cities are generally sparsely distributed over space without fully functional infrastructure and management systems. A common issue that can be observed in most small cities is the waste of land due to the lack of urban planning and administration (Song and Zhang 2002).

What has caused the structural distortion of China's urban system? Aside from the fact that China is an agricultural country with the largest population in the world, the government's urban policies have also been a major contributing factor. Since the 1980s, China's urban development policy has been continually encouraging the growth of small cities, which has resulted in many undersized cities and significantly distorted the city-size distribution ratio. In giving small cities and towns priority for the allocation of financial resources, the government has facilitated the development of TVEs and increased the number of established towns. Fortunately, in recognition of the uneven nature of China's urbanization, the central government has suspended the designation of new cities since 1997. As indicated in Figure 2.2, the number of county-level cities even began to decline after

1997 due to the fact that some small and middle-sized cities either evolved into large cities themselves, or agglomerated with nearby large cities to form districts.

2.2.2.3 Emergence of urban clusters

Although the number of cities in China remained stable, they have continued to expand in terms of their size due to rural-urban migration over the last decade. Due to increased mobility within the urban system, connections between cities have been established and reinforced: large cities attract the flow of material, capital, and labour, and play a leading role within the region. As a result of the formation of these connections, urban clusters or city strips dominated by metropolitan cities have gradually taken shape.

Using remote sensing images to present real observations of urban development has a long history (Anderson *et al.* 1976; Gillanders *et al.* 2008). Instead of using imagery captured by traditional sensors during the day, this study selected imageries that were collected at night by the Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS). In comparison to GIS-based methods like interpolations, population dots, or urban density, the night-time light images have a greater ability to depict urban areas in terms of their density and boundaries. Consequently, DMSP OLS images are often used to depict the extent of urban settlement in a specific area (Elvidge *et al.* 2001; He *et al.* 2006a; Henderson *et al.* 2003). Using a thresholding technique (Imhoff *et al.* 1997; Lo 2001), the stable lights data sets of 1995 and 2006 were selected and processed for

examining urban cluster development, and the resulting patterns are mapped in Figure 2.8. The dark areas on the map represent large urban cores and the colour become lighter in more remote areas since the nightlight illumination diminishes with the increasing distance from the urban core.

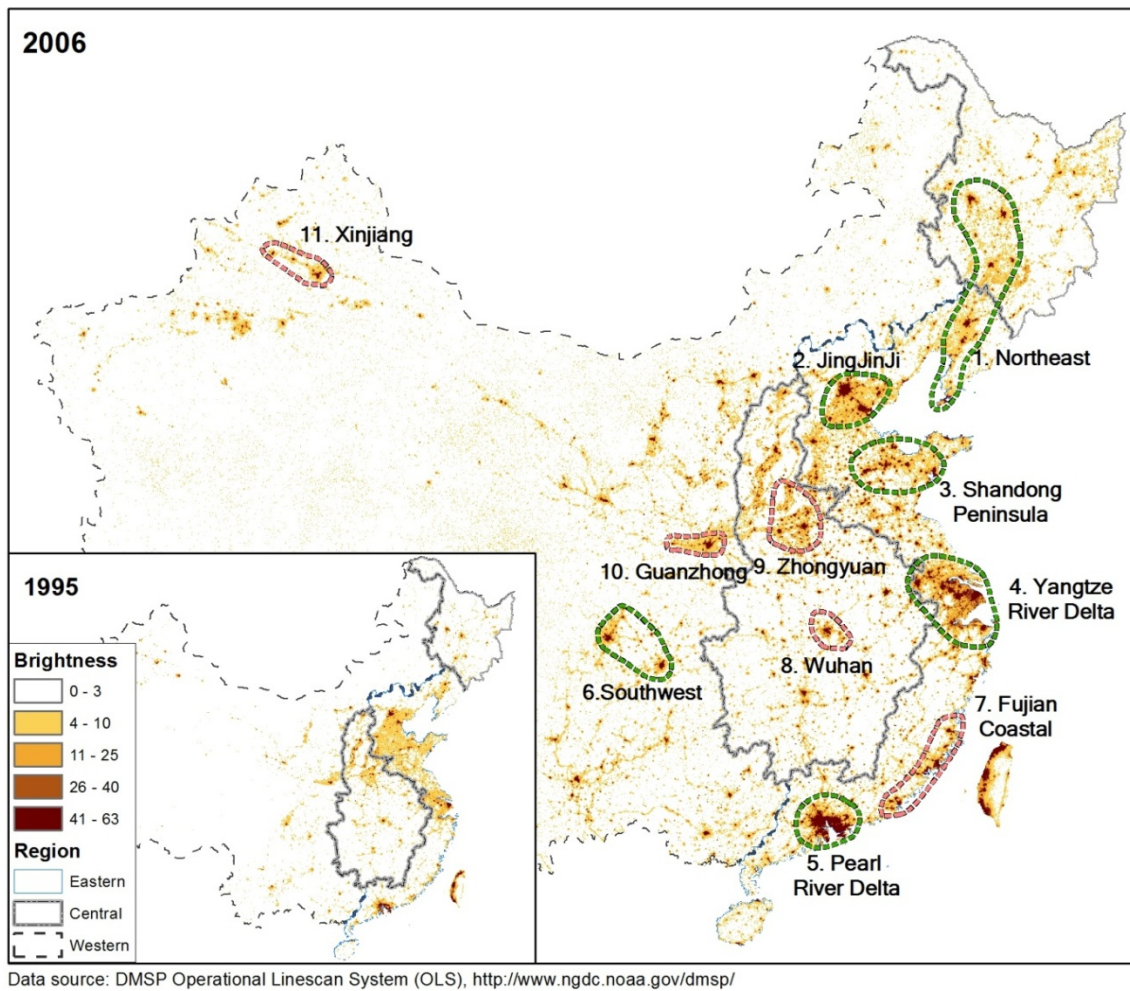


Figure 2.8 Urban clusters identified from DMSP night-time light images

Urban clusters in China are usually found in the plains, deltas, and industrial districts (Yeh and Xu 1996). The comparison of maps in Figure 2.8 demonstrates the emergence of major urban clusters between 1995 and 2005 as detailed below.

(1) **Northeast urban strip (Haerbin-Shenyang-Dalian)**. This region spreads from Haerbin in the north to Dalian in the south. Cities in the region include Changchun, Jilin, Anshan, Fushun, Benxi, and Liaoyang, most of which are characterized by heavy industry.

(2) **JingJinJi urban cluster (Beijing-Tianjin-Hebei)**. Beijing and Tianjin are the dominant cities in this cluster, while other important cities of this region include Tangshan and Tanggu. Certain cities like Shijiazhuang and Handan in southern Hebei province were recently incorporated into this cluster to enhance its competitive strength.

(3) **Shandong Peninsula urban cluster**. This newly developed cluster is dominated by Jinan and Qingdao, and Yantai is the major port in the region. Due to its abundance of agricultural, forestry, and fishery products, and its proximity to Korea and Japan, it has experienced rapid development since the implementation of economic reforms and the open door policy.

(4) **Yangtze River Delta urban cluster (Nanjing-Shanghai-Hangzhou)**. This cluster is dominated by Shanghai with Nanjing and Hangzhou acting as supporting cities. Other notable cities within the cluster include Wuxi, Suzhou, Changzhou, Ningbo, and Nantong. The Nanjing-Shanghai-Hangzhou-Ningbo railway, the Grand Canal, and the Yangtze River connect these cities to one another by facilitating travel and communication.

(5) **Pearl River Delta urban cluster.** Guangzhou and Hong Kong are the major cities in this urban cluster. However, Shenzhen, Dongguan, and Foshan continue to grow in size and importance with the massive inflows of migrants.

(6) **Southwest urban cluster.** This is the largest urban cluster in western China and its dominant cities, Chongqing and Chengdu, are strong enough to function as major growth poles. Other important cities within this cluster include Nanchong, Zigong, Mianyang, and Yibin.

Based on the information provided by the DMSP OLS imagery, light has also been shed on the emergence of new urban clusters, which include: the Fujian Coastal urban cluster (#7 on Figure 2.8), the Wuhan urban cluster (#8), the Zhongyuan urban cluster (#9), the Guanzhong urban cluster (#10), and the Xinjiang urban cluster (#11), most of which are still in the preliminary stages of development. The majority of these eleven clusters are situated either in deltas or on plains that have abundant natural resources and a long history of development. Furthermore, they have a high population density and are known for different agricultural or industrial production specialities. Since they are located along the coast or important transportation lines and are more accessible to the world market, the economic reform and open policy period have been beneficial to their growth and prosperity. In addition to the increasing development of existing cities, new cities are beginning to emerge in established urban clusters. For example, Dongguan, Shenzhen, and Zhuhai are

gaining importance in the Pearl River Delta, and Changzhou continues to expand in the Yangtze River Delta (Song and Zhang 2002; Yeh and Xu 1996; Zhao *et al.* 2003; Zheng *et al.* 2009).

2.2.2.4 Challenges facing China's urban system

2.2.2.4.1 Inconsistent definition of cities and towns, and urban population

The status of a city has practical importance for its own development and its residents: once an urban place is recognized as a designated city, it is entitled to a greater allotment of financial resources and its residents gain access to better public facilities and social services. However, the criteria for city and town designation and official urban population definition have changed frequently since the 1950s, making the data and statistics concerning urban studies inconsistent and difficult to compare longitudinally. Chen (2008) and Liu *et al.* (2003) summarized the history of the definition of cities and towns in detail.

Basically, the early official criteria from the 1950s to the 1970s for the designation of cities and towns were based on an urban region's population and administrative status (Liu *et al.* 2003). More specifically, areas with a clustered population of more than 100,000 could be a city and those with a population of less than 100,000 could obtain the "designated city" status if they meet certain requirements like industry or mining. The criteria were further altered based on the proportion of non-agricultural population when a need to increase or decrease the number of cities is required. Since the mid-1980s, Gross

National Product (GNP) was included in the definition system to make the criteria more complex. The current definition of cities and towns was adopted in 1993, and the scale of the non-agricultural population remains the most important factor for China when designating cities. Various requirements in the minimum size of non-agricultural population, GDP, the share of the tertiary industry, local financial revenues, and level of urban infrastructure were specified, making the definition system extremely complicated and confusing (Liu *et al.* 2003).

Unfortunately, the criteria for designating cities and towns are frequently changing as is the official definition of the urban population, making it increasingly difficult to accurately assess China's urban population and urbanization level. According to Ma and Cui (1987), Chinese authorities such as State Council Population Census Office, Ministry of Public Security, and the National Bureau of Statistics published eight types of official statistical data relating to the urban population. The figure generated by Chen (2008) (reproduced in Figure 2.9) clearly depicts the discrepancy among the four most frequently used type of data.

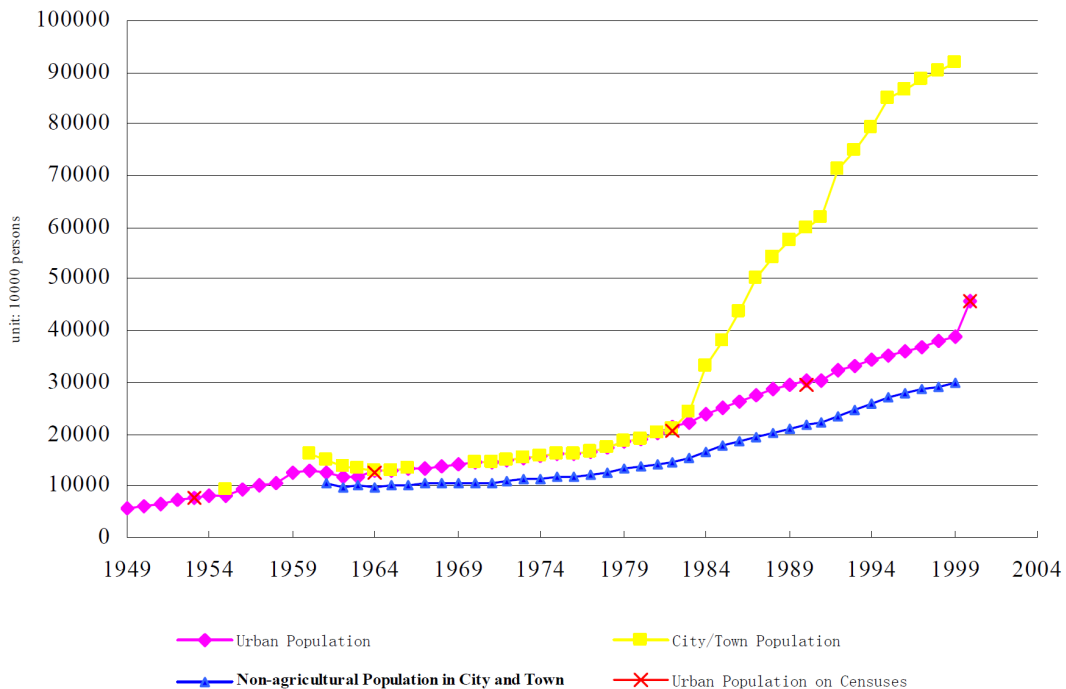


Figure 2.9 Comparison of urban population from different statistical criteria, by Chen (2008)

The statistics on urban populations have consistently been adjusted according to the national censuses of 1953, 1964, 1982, 1990 and 2000. However, the data for years other than these five census years is only available at the national scale, and thus, studies conducted at the provincial-level or city-level cannot use it without distorting it through statistical or mathematical estimations. For example, a city/town population is based on the 1982 census definition and it includes all of the population residing in designated cities and towns, thus this data cannot be used to reflect the urbanization process under the frequently changed administrative/statistical designation system. Non-agricultural population refers to the population considered to be urban according to the household registration system and it is not influenced by the fluctuating designation system of cities. It is preferred by academics since it is consistent and comparable along the temporal and spatial scale. However, it is

often criticized for its underestimation of the rapid growth of urbanization since it does not include the migrant workers and rural-urban migrants who do not have an urban household registration (Zhao and Li 2006).

In summation, the changing definition of cities and towns has a significant impact on the reported number of cities and towns. However, a complicated definition system also makes it difficult to accurately examine the development speed since it is obscured by the quantity of urban areas. Furthermore, the primary sources for official statistics on China's urbanization have caused confusion and misunderstanding due to their lack of consistency.

2.2.2.4.2 Identifying and planning the role of urban clusters

Since the mid-1990s, China's urbanization has been characterized by the fact that large cities are the principal sources of urbanization, and as a result more urban clusters are emerging across the country (Chen 2008). In order to recognize this reality, the central government has begun to gradually alter its urbanization plan to encourage the expansion of large cities. In 2001, the 10th Five-Year Plan was promulgated to conceive a "coordinated development of large, medium, small cities and small towns" that focused on the development of large cities (Kamal-Chaoui *et al.* 2009). The 11th Five-Year Plan, launched in 2006, explicitly stated that "making megalopolises as the leader, exerting the functions of central cities and forming several new megalopolises with less land utilization, more

employments, strong element concentration ability and rational population distribution” was China’s top priority (Kamal-Chaoui *et al.* 2009), as displayed in Figure 2.8.

In this context, it becomes crucial to properly plan the growth of urban clusters and maximize their leading role in strengthening rural-urban linkages. However, since China lacks experience in developing urban metropolises, it is extremely challenging to plan for their growth. Most of the current urban clusters are in their preliminary stages, and incorporated cities usually share physical or economic links. At the same time, China unfortunately also lacks a comprehensive system or a master plan that is designed to coordinate the development of its cities. For example, the JingJinJi urban cluster is one of the earliest metropolises, and Beijing and Tianjin are the dominant cities of this region. Due to its political status as the capital city of China, Beijing’s development has always received precedence, and a concessive relationship has slowly replaced its once collaborative relationship with Tianjin and other surrounding cities. Ultimately, the development of Tianjin has been impeded by the “shadow effect” of Beijing.

Therefore, to effectively utilize urban clusters as a viable catalyst for urban development, the barriers to the implementation of this strategy must be mitigated. First, efforts should be made to use comprehensive development planning strategies to create an integrated system of urban development approaches that links all the growth-generating elements of an urban cluster. This is challenging to put into practice because local

municipalities within each cluster still depend on internal revenue allotments from the central government, and continue to independently make development plans. To change the status quo, the central government and local authorities will have to involve themselves in the cluster's policies, plans, and programs, in order to design economic policies and coordinate economic resources.

Secondly, urban sector programs should be considered in a cluster's development strategy. The leading city in an urban cluster is usually comprehensive in its economic makeup, with a robust tertiary industry, and subordinate cities should identify with a specific service that it can uniquely provide. For example, by taking into consideration the advantages and disadvantages of various types of cities some can be targeted for heavy industry, some for logistics, and some for tourism and recreation. Ideally, the integrated development of city cluster would use urban infrastructure and services as the skeleton, and economic and social interrelationships as the lifeblood to achieve a sustainable level of development (Choe and Laquian 2008). Moreover, specific policies such as special economic zones, industrial parks, and other development enclaves should be properly employed in pursuing additional opportunities and attracting external investments.

2.2.3 Spatial transition

China's urban system has not only experienced a structural transition, but also a significant spatial transition with regard to the distribution of cities and the urban development patterns.

2.2.3.1 Spatial distribution

When the People's Republic of China was founded in 1949, it consisted of one hundred and twenty three cities and an urban population of fifty eight million (Lin 2002). More than half of these cities were located on the eastern coast, and the population of this region was more than twice that of the central and western regions combined. The rehabilitation and reconstruction of the national economy in the 1950s accelerated the pace of industrialization and urban development, leading to the expansion of existing cities and creation of new ones, most of which are located in North-Eastern and Northern China.

Prior to the economic reforms of the late 1970s, the central government emphasized urban development in the central and western parts of China for reasons of national security. Consequently, a large number of coastal industries were relocated to inland areas through administrative measures, resulting in a relatively even urbanization pattern (Hsu 1994). In the post-reform era, however, the government's priority shifted back to developing the eastern coast, which directly led to the uneven nature of China's urbanization pattern. China's implementation of an open policy has altered its previous emphasis on promoting

urban and economic development in the western and central regions. As a result, new cities have begun to emerge in the eastern and coastal regions since 1978. In 1985, the number of cities in Eastern China was roughly equal to the number of cities in Western China (102 vs. 105 as seen in Table 2.2). Ten years later in 1995, the number of cities in Eastern China increased significantly to 273, while the number of western cities only increased to 152. Due to the emphasis placed on western development by the central government after 1995, the growth rate of western cities has begun to accelerate, though the disparity between the east and west is still significant (Table 2.2).

Table 2.2 Chinese cities by region in 1985, 1995 and 2005

Region	1985		1995		2005	
	Count	Pop (Million)	Count	Pop (Billion)	Count	Pop (Billion)
East	102	56.32	273	99.61	263	161.13
Centre	117	36.68	215	62.71	227	84.22
West	105	25.26	152	37.84	171	54.67
Sum	324	118.25	640	200.16	661	300.02

Data source: China City Statistical Yearbook 1986, 1996, 2006

2.2.3.2 Transitional patterns

Centrographic Analysis is a spatial statistics tool that can be used to track the growth of many cities which consist of urban systems while monitoring their movement. More specifically, this tool creates standard deviational ellipses to summarize the spatial characteristics of geographic features, and the statistics provided can give useful insights into the central tendency, dispersion, and directional movement patterns. A common way of measuring the trend for cities is to record the geographic centre (or the centre concentration)

of cities, which can be used to reveal movement patterns. This tool also calculates the standard distance for the X and Y directions, and these two measurements define the axes of an ellipse encompassing the distribution of all cities. By examining the X and Y standard distance and the rotations of the ellipses, the Centographic Analysis tool allows the users to examine if the distribution of cities is elongated or rotated, and hence has a particular pattern of orientation (Cao and Zhao 2003).

The standard deviation ellipses in Figure 2.10 and the corresponding attributes in Table 2.3 demonstrate and measure the spatial expansion and movement tendencies of the Chinese cities over the past two decades. Compared to the ellipse of 1985, that of 1995 moved to the southeast, rotated counter clockwise (-4°), and its area shrank, indicating that the distribution of cities exhibited a south-eastern trend during this decade (Table 2.3). In other words, the cities along the south-eastern coast were growing much faster than cities in other regions of China, thus pulling the gravity centre of development to the southeast. From 1995 to 2005, the ellipse moved south and west and its cover area expanded, meaning that cities in the southwest were expanding relatively faster, drawing the gravity of urban development in that direction (Table 2.3). As indicated on the map for small cities in Figure 2.10, small cities were more widely scattered, but were becoming concentrated after 1995. Since 1985, medium-sized cities in central and western China have been growing substantially, which is revealed by a diminishing standard distance in the Y axis and an

increasing distance in the X axis (Table 2.3). After 1995, large and extra-large cities in the south were expanding at an exceptionally rapid rate, pulling the ellipse south by a considerable amount (Figure 2.10).

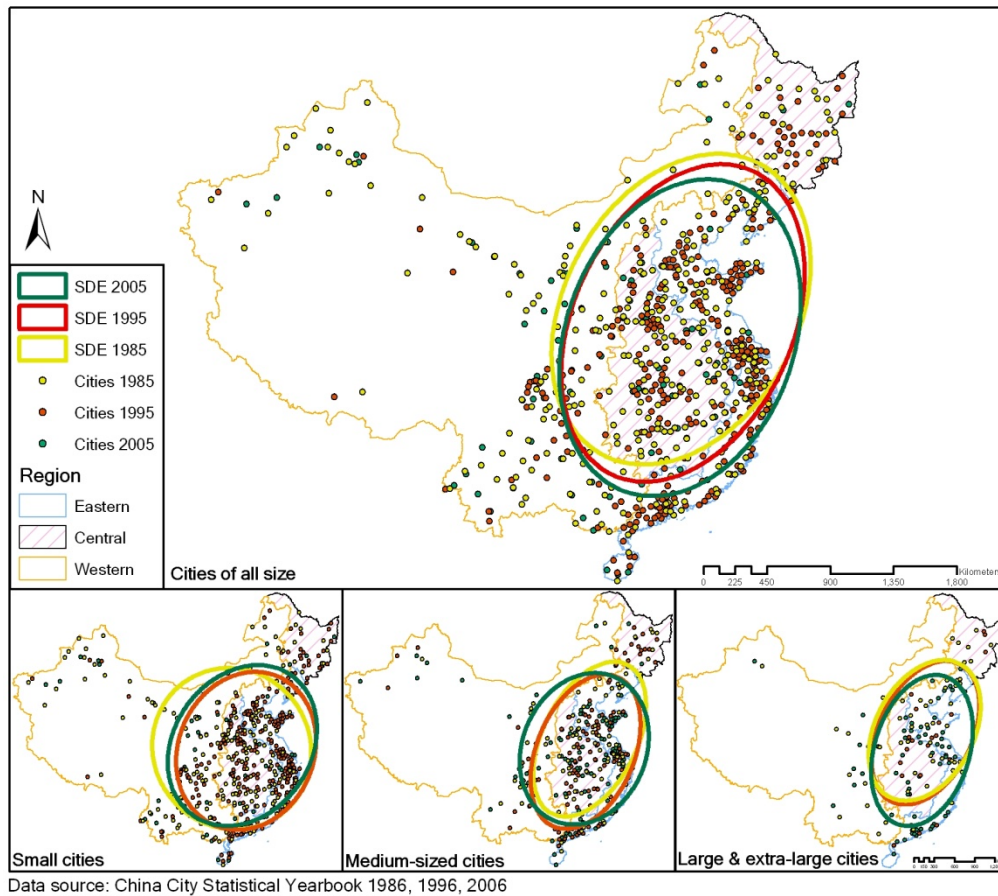


Figure 2.10 Standard deviation ellipses of Chinese cities in 1985, 1995, 2005

Table 2.3 Parameters about the standard deviation ellipses of Chinese cities

Value	Number	CentreX	CentreY	XStdDist	YStdDist	Rotation	Area
1985	323	940861	3816121	828378	1174853	29°	3057283
1995	640	954207	3717840	778614	1189260	25°	2908845
2005	661	933607	3613212	811814	1160069	20°	2958446

2.2.3.3 Challenges of eliminating spatial disparity and inequality

In China, there is a great disparity between the development of cities in the west and the development of cities in the east (Cao and Bergeron 2010). For example, in the mid-1980s the ratio of cities in the eastern, central, and western regions was 1:1.15:1.03. By 2005, the rapid development of eastern cities shifted the ratio to 1:0.86:0.65 (Table 2.2). In spite of increased urbanization, the inequality between the coastal and inland areas is continuing to grow in all aspects.

China's entry into the World Trade Organization (WTO) in 2001 brought about the prospect of international trade and communication. Economic prosperity is concentrated in large coastal cities due to their better access to international investment and world markets, and their urban development has accelerated economic progress (Choe and Laquian 2008). In addition, the "trickle down" effect of these large cities' success stimulates the development of small cities surrounding them, which is usually a significant contribution in the early stages of urbanization. However, most of the large cities (83%), with an urban population over 5 million, are located in the eastern and central regions, whereas the western region only contains a small number of large cities. Moreover, large inland cities are lagging behind large coastal cities which possess high human capital and relatively good consumer amenities (Lall and Wang 2010).

Since the inland areas are already at a disadvantage in terms of geographic location, access to resources, and the quality and quantity of human capital, it is extremely challenging to narrow the socio-economic gap between urban development in the east and that in the west. Urban development policies, plans, and programs in both regions should be given equal importance to minimize inequities and growth imbalances. Special measures should be devised to prevent the marginalization of inland areas in economic and social activities by giving them access to, and control over, economic resources. The opening of new SEZs served as a good example: Tacheng, Bole and Yining in Xinjiang were opened as SEZs in 2000 to promote the economic links to Central Asia (Figure 2.3). In addition, the urban policy making process for each city should take into consideration its position in the urban hierarchy (systems of cities) and geographic advantages, so that a specifically tailored plan can be implemented to meet its urbanization challenges (Lall and Wang 2010).

2.3 Targeting a sustainable urban development

As this research has demonstrated, Chinese cities have witnessed significant transformations in terms of their institutional and spatial structures. The transition of Chinese cities into participants in the global market reflects the urban transition process of the developing world (Wu 2005). The urbanization experience of other developed and developing countries can also help to direct China's urban future. For instance, international experience indicates that manufacturing is often concentrated in metropolises as economic development begins, then diffuses to other cities, and eventually leads to increased specialization and division of labour between small and large urban centres (Lall and Wang 2010). China's economic prosperity relies heavily on manufacturing industry, and consequently large coastal cities have a disproportionate concentration of manufacturing companies, as opposed to financial services. This indicates that China is still in the early stages of industrialization and economic development, and will therefore undergo substantial structural changes in the near future as its development progresses.

China's urban growth is a substantial achievement that has attracted the world's attention. However, in addition to the challenges of its institutional "enigma," imbalanced structure, and spatial inequality, the socioeconomic gap between the urban and rural populations has continued to widen. To decrease this discrepancy the Chinese government will have to adopt certain reforming measures, such as social security and welfare reform,

and ensure that the proportions of rural and urban investment are equalized through increased rural investment.

Despite the fact that China's cities are expanding by encroaching on agricultural land, they are not yet fully prepared for the massive influx of rural migrants that comes with urbanization. The high speed of urban construction without proper planning and administration has caused a series of reoccurring urban issues such as traffic congestion, a lack of affordable housing and social infrastructure, the degradation of the environment, and an overall decline in the quality of life. How to confront these challenges while maintaining its fast pace of urbanization has become one of the most difficult challenges for China's urban planning administration.

Chapter 3 Studying the Urban Hierarchical Pattern and Spatial Structure of China Using A Synthesized Gravity Model

3.1 Introduction

Any movement over space that results from a human process can be broadly encompassed by the term spatial interactions (Haynes and Fotheringham 1984). Spatial interactions determine the connections and influences between locations by evaluating the flow of human capital, resources, or information in geographic space. The Gravity Model (GM) is the most well-known and widely used method for studying spatial interactions (Ashtakala and Murthy 1988; Haynes and Fotheringham 1984; Isard 1998). The GM is based on a gravitational attraction formula as defined by Newton's law of physical gravity. In essence, the attraction between two objects is positively proportional to their mass and inversely proportional to their separation distance, as in the equation proposed by Stewart (1948) to define the "demographic force" between two places¹⁸.

¹⁸ According to Stewart (1948), the "demographic force" between a place i and a place j can be expressed as :

$$G_{ij} = g(P_i P_j / d_{ij}^2)$$

where P_i and P_j are populations at places i and j respectively; d_{ij} is the distance between places i and j , and g is a constant to be determined empirically.

The universal popularity of the GM stems from both theoretical and practical considerations (Haynes and Fotheringham 1984). It has been modified and applied to a variety of fields that include, but are not limited to, transportation, marketing, retailing, migration, and urban analysis (Chen 2009; Davies 1979; Isard 1998; Karemera *et al.* 2000). In general, studies on aggregate flows of human interactions, such as migration and traveling, almost always rely upon the GM (Hua and Porell 1979). For instance, Ashtakala and Murthy (1988) developed a set of gravity models to represent province-wide commodity flows in Canada, and these gravity models were calibrated using an optimization technique that employs a power function and a regression analysis. In a different scenario, Karemera *et al.* (2000) used a modified GM based on immigration regulations to examine how political, economic, and demographic factors influence migration flows to North America. Chen (2009) optimized the traditional GM to integrate the temporal dimension and this optimized model is capable of studying the spatial processes of cities using a time-lag parameter and time functions.

The increasing application of the GM to study geographical phenomena (Chen 2009; Du 2006; Jin *et al.* 2004) has established its potential for studying spatial interactions between cities. In spite of this, critics have raised concerns about the model's over-simplification of reality: the inadequacy of using population to represent a city's "mass" and the inaccuracy of using direct distance to reflect the distance decay effect (Ewing 1974;

Haynes and Fotheringham 1984; Hua and Porell 1979; Isard 1998). A Synthesized Gravity Model (SGM) that integrates socioeconomic and topographical factors is developed in this research to compensate for the above shortcomings.

China has experienced rapid economic growth since the 1990s (Cao and Bergeron 2010), and the urbanization of China has attracted the attention of both Chinese and Western scholars. Numerous quantitative models have been developed and tested in an attempt to explain the size and role of individual cities in a specific urban system (Leung *et al.* 2000; Skinner and Henderson 1999; Tian *et al.* 2005; Wu and Martin 2002); however, some questions still remain unanswered. First, little is known about the nodal hierarchy of the national urban system of China. Since most of the previously conducted studies have concentrated on aspects of the functional structure and distribution of cities (Lin 2002; Song and Zhang 2002; Tian *et al.* 2005), the study of urban linkages and interactions has largely been overlooked. Moreover, rather than investigating the socioeconomic factors and mechanisms of urban systems, more attention has been paid to category classification of cities (Ma 2002; Yeh and Xu 1996). In addition, a large number of models have been developed that study cities from a political or an economic perspective, but most of these lack a spatio-temporal dimension and in-depth analysis of the hierarchical interactions among cities (Logan and Molotch 1987; Stone 1989, 1993). It is necessary, therefore, to

concentrate on the functional structure and the mechanisms of interaction among cities in an urban system on a spatio-temporal dimension.

The Synthesized Gravity Model (SGM) developed in this research is applied to study the spatial interactions and evolution of China's urban system since the mid-1990s. Principal Component Analysis (PCA) and Network Analysis are employed to determine the synthesized Influential Power (IP) of cities and also the cities that are influenced. To better understand the evolution patterns of China's urban system, Graph Theory¹⁹ is employed to build the hierarchy of China's urban system based on the SGM results. Special attention is given to the spatial interactions between cities, the nodal structure of China's urban system, and the evolution of its hierarchical structure.

¹⁹ Graph theory is the study of graphs the represent relations of mathematics. In urban studies, intercity flows can be analyzed by specifying certain properties of the relations between cities and accepting the point-line abstraction of graph theory (Nystuen and Dacey 1961).

3.2 Methodology

The research is carried out in steps as depicted in Figure 3.1. First, the SGM is developed by integrating the PCA and Network Analysis results. The theory and criteria are then specified to identify the nodal and hierarchical structure of an urban system. At last, these steps are applied to China's urban system in both 1995 and 2005, to unveil the urban structure and urban transition patterns.

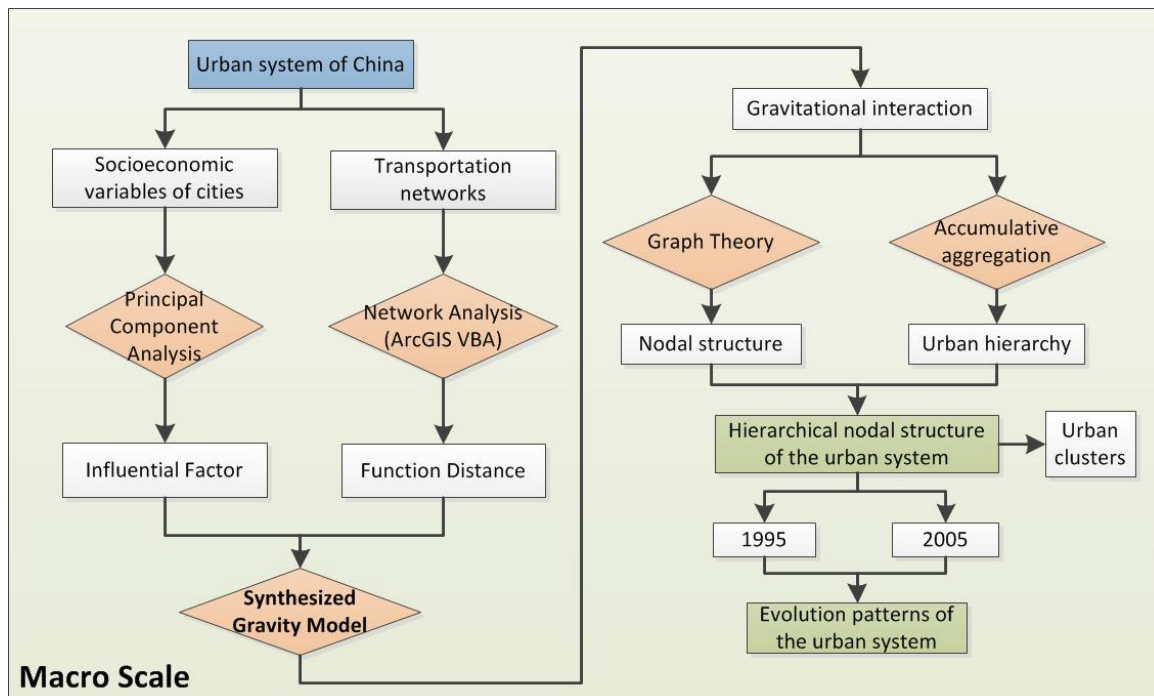


Figure 3.1 Flowchart of the methodology

3.2.1 Building the Synthesized Gravity Model

The classic gravity equation as derived from physics is limited in two manners. First, while population is a widely-used variable for representing the size of a city, it is not a variable that is capable of fully reflecting the influence of the city. As illustrated in Figure

3.2.a, city A and city B are of the same population and distance to city C. According to the traditional gravity model, city A and city B should exert the same influence on city C as the mass and distance are the same. However, if city B is a more dynamic city and located in a more favorable environment (such as better infrastructure and employment, easier access to resources and investments), the influencing power of city B would exceed that of city A. Thus, population alone is not sufficient to adequately represent the influence of a city; a more comprehensive variable is required to accurately measure the “mass” of a city. For example, in the economic gravity model that is used to study migration, factors such as unemployment rate, real estate markets, and relative wage are often employed to produce composite scores to replace the traditional “mass” variable of population (Lowry 1966; Yin 2005).

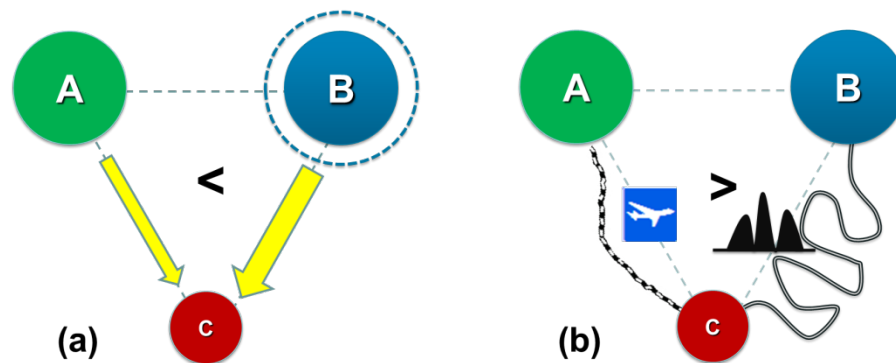


Figure 3.2 Schematic illustrations about influence between cities

In this study, a more vigorous and composite variable, the Influential Factor (IF), is developed to substitute population as “mass” in the SGM. The IF encompasses a large number of socioeconomic variables that account for different facets of urban formation. It is

a single index that represents a distillation of these variables to best describe a city's competitiveness and influential power. The calculation of the IF is as follows:

- (1) A set of variables for each city is selected by removing unrelated or multi-collinear variables. Variables are selected based on their ability to represent a city's competitiveness and the city's links with other cities (Dou *et al.* 2000; Hair *et al.* 2005; Wang and Shen 2002).
- (2) Principal component analysis (PCA) is applied to reduce the dimensions of selected variables. Principal components are then extracted based on eigenvalues (greater than 1). The factor score of each city is calculated by multiplying the standardized data matrix and the factor loading matrix. Since the first component accounts for as much of the variability in the data as possible, the normalized factor score of the first component is used as the IF, which represents the composite "mass" of a city.

The second drawback in the traditional GM is that the simple direct distance between two cities does not accurately reveal the distance decay effect in realistic space. Cities are connected by a variety of networks through which they interact with one another. The revolution in transport and communications technologies has immensely changed the relative positions of cities and towns. The term "time-space contraction" or "time-space convergence" describes this progressive reduction of travel time between two locations (Bretagnolle *et al.* 2003). At the inter-urban scale there is an apparent contraction between cities that are connected with faster transportation modes (cities become closer to each other

because of the increasing communication speed). As illustrated in Figure 3.2.b, city A and city B are of the same population size and same linear distance to city C, and accordingly exert the same gravitational pull on city C according to the traditional GM. City A and city C are connected by railways as well airlines, but city B and city C are only linked by a winding road across mountainous terrain, which means that the travel time between city A and C would be much shorter than that between city B and C. Hence, a more accurate measurement of travel time is required to appropriately reflect the relative distance between cities. To obtain a realistic measurement, variables such as time, cost of trip, topography, and/or other attributes of the route from one city to another must be taken into account (Chen 2009; Hua and Porell 1979). Function Distance (FD) as measured by travel time is developed in this paper to replace the direct distance variable in the traditional gravity model.

To determine the shortest travel time between two cities in a multimodal transportation network, the GIS Network Analysis is employed to find the quickest route by setting time as the impedance. Since cities are nodes that are connected by various transportation networks, the interactions within different networks vary depending on the FD. In other words, there are a total of three different kinds of gravitational interactions between two cities based on the three available means of transportation: road, railway, and aviation. Although waterways also function as an important means of transport in areas

along major rivers and coasts, they were not included since these routes are not overly prevalent in China, and there is also a lack of sailing data. Programming with ArcObjects and the Network Analysis module under the ESRI ArcInfo environment greatly facilitates the analysis that is required to determine the shortest distance, and therefore, the Function Distance is calculated as:

$$T_i = \frac{S_i}{V_i} \quad 1$$

in which,

T_i stands for the Function Distance (travel time);

S_i stands for the shortest distance travel by the i^{th} transportation method;

V_i stands for the mean velocity of the i^{th} transportation method.

The weight of each means of transportation is determined by its proportion of use in national traffic, and then this is used to aggregate these interactions to generate one variable. For example, road transportation accounts for 53% of the total traffic, and road gravity represents 53% of the total gravity. Therefore, the Synthesized Gravity Model can be expressed as:

$$\begin{aligned} G_{mn} &= R \cdot \frac{I_m \cdot I_n}{T_R^b} + W \cdot \frac{I_m \cdot I_n}{T_W^b} + A \cdot \frac{I_m \cdot I_n}{T_A^b} \\ &= I_m \cdot I_n \cdot \left(\frac{R}{T_R^b} + \frac{W}{T_W^b} + \frac{A}{T_A^b} \right) \end{aligned} \quad 2$$

in which,

G_{mn} is the gravitational interaction between two cities m and n ;

I_m, I_n are the Influential Factors of city m and city n respectively;

R, W and A are the weights of gravitation of different transportation methods (Road, Railway, and Aviation);

T_R, T_W and T_A are the Function Distance of different transportation methods;

b is the distance exponent (the greater the value is, the greater friction the distance has) (Ewing 1974; Olsson 1970), which is assigned a constant value of 1.5²⁰.

3.2.2 Delineation of the nodal and hierarchical structure

The GM solves the problems of quantifying spatial interactions and interpreting the spatial behavior of various economic sectors that the Central Place Theory and Core Periphery Theory fail to address (Hua and Porell 1979). Despite these benefits, the GM still lacks the ability to account for a crucial element in any urban system: its hierarchy. Although Camagni and Salone (1993) claim that urban hierarchies have become less pertinent as an analytical tool due to developments in communication and transportation networks, it is widely accepted that traditional hierarchies remain the most abstract and consistent representation of the structure of urban systems (Camagni and Salone 1993; Huff

²⁰ The determination of the value of b is also a field receiving much attention, and a widely used method is regression based on flows of commodity, information, and population, such as long-distance calls and migration (Ewing 1974; Olsson 1970); since the emphasis of this paper is placed on the “mass” and “relative distance”, a value of 1.5 is determined from practice based on the premise that the influential regions of the top hierarchical cities do not overlap in space (Du 2000).

and Lutz 1995). In this case, the derivation of an urban hierarchy that incorporates elements of the GM becomes a challenge in urban system studies.

Graph Theory has been proven to be an efficient tool for accurately revealing and depicting the nodal relationship in a hierarchical system (Davies 1979; Dematteis 1997; Du 2000; Gu and Pang 2008; Nystuen and Dacey 1961; Tinkler 1979). This theory makes a proper transfer from empirical reality to a point-line graph; from quantitative statistics to an easily identified chart (Tinkler 1979). In combination with gravity models, this theory provides an abstract representation of the hierarchy of urban systems (Du 2000; Huff and Lutz 1995).

Regardless of its size, every city exerts a “gravitational pull” on all other cities. It is not realistic to connect every city by a line since this would result in an indecipherable illustration. However, a connection can be made to link an individual city to the city that exercises the strongest gravitational pull on it. In this case, cities are then only linked by the strongest interaction, and Graph Theory can take advantage of this to accurately illustrate the urban structure. Therefore, for a specific city m , the first step is to loop through the whole set of cities to determine the maximum gravity and create links between these cities with a line. With the assistance of VBA ArcObjects in the ESRI ArcInfo environment, this procedure is executed following the equation below:

$$G_m^{\max} = \text{Max}(G_{m1}, G_{m2}, G_{m3}, \dots, G_{mi}) \quad 3$$

in which,

G_m^{\max} is the maximum (strongest) gravitational pull that city m exerts;

$\text{Max} ()$ calculates the maximum gravity between city m and all other cities.

In order to demonstrate the inherent hierarchy of an urban system, the scale of cities based on IF must also be identified. When identifying cities' places according to the IF scale, a city that exerts a stronger influencing power and influences more cities is deemed to be of greater importance. The Influential Potential (IP) measures this influencing power, which is a cumulative measurement of all gravitational forces that a city exerts on other cities. The equation is expressed as:

$$G_m^P = \sum_{i=1}^n (G_{mi}) \quad 4$$

in which G_m^P is the IP of city m ; and G_{mi} is the gravity that city m has on city i .

The hierarchy of cities is determined by the Influential Potential and the number of strongest linkages with other cities. Based on experience and previous publications (Dematteis 1997; Du 2000; Du 2006; Gu and Pang 2008), the cities are categorized into four scales (Table 3.1).

Table 3.1 Delineation of city levels

Hierarchy	Influential Potential
3	$\{L^T \geq 20\}$ or $\{L^T \geq 10 \ \& \ G^P \geq (G_M^P + 3 G_S^P)\}$
2	$\{20 > L^T \geq 10\}$ or $\{10 > L^T \geq 5 \ \& \ (G_M^P + 3 G_S^P) > G^P \geq G_M^P + 2 G_S^P\}$
1	$10 > L^T \geq 5 \ \& \ G^P < G_M^P + 2 G_S^P$
0	$L^T < 5$

Note: L^T is the total number of largest linkages a city has; G_M^P is the mean of the influential potentials of every city, and G_S^P is the standard deviation of these potentials.

3.3 Applying the SGM to China's urban system

The urban function at the national level has been largely characterized by the spatial interaction of cities (Du 2000). Applying the SGM to China's urban system can elucidate the evolution of its hierarchical structure, as well as the relationships between its spatial structure and the socioeconomic factors that have been influencing its development.

Supported by previous studies (Dou *et al.* 2000; Sit 1999; Wang and Shen 2002) and statistical theories on sampling adequacy (Hair *et al.* 2005), 13 variables (Table 3.2) covering the fields of demography, economy, as well as urban infrastructure, are selected from the statistics yearbooks for all Chinese cities (640 cities in 1995 and 661 cities in 2005). Eventually, three components were identified through the PCA in 1995 (Table 3.2), which explain 72.05% of the total variance in the 13 variables (Table 3.3). Three components were also extracted using the data of 2005 (Table 3.2), which account for 69.57% of the total variance in the 13 variables (Table 3.3). The contribution of each variable varies across the three components in both periods (Table 3.2).

Table 3.2 Rotated component matrix in 1995 and 2005

Variables in 1995	Component			Variables in 2005	Component		
	1	2	3		1	2	3
GDP	.948	-.190	-.081	GDP	.961	.010	.043
Non-agricultural Population	.931	-.211	.001	Employed Population	.951	-.025	.013
Investment in Assets	.905	-.201	-.061	Non-agricultural Population	.937	-.035	.016
Urban Built-up Area	.886	-.084	.000	Urban Built-up Area	.910	-.022	.033
Foreign Investment Used	.857	-.170	-.018	Foreign Investment Used	.902	.022	.085
Employed Population	.846	-.348	-.132	Average Wage	.533	.282	.144
Average Wage	.532	.449	-.138	Percentage of GDP from Secondary Industry	.077	.857	.086
Percentage of Employment in Secondary Industry	.437	.689	-.258	Percentage of Employment in Secondary Industry	.174	.832	.138
Percentage of GDP from Secondary Industry	.275	.640	-.604	Percentage of Employment from Tertiary Industry	-.068	-.774	-.118
Road Area Per Capita	.256	.547	.360	Percentage of GDP from Tertiary Industry	.279	-.641	.012
Forest Coverage Rate	.222	.294	.090	Green Area Per Capita	.057	-.003	.819
Percentage of GDP from Tertiary Industry	.305	.112	.822	Forest Coverage Rate	.203	.205	.687
Percentage of Employment from Tertiary Industry	.353	.333	.704	Road Area Per Capita	-.063	.083	.681

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

Data source: China City Statistical Yearbook 1996, 2006

Table 3.3 Total variance explained in 1995 and 2005

Component	1995			2005		
	Eigenvalue	% of Variance	Cumulative %	Eigenvalue	% of Variance	Cumulative %
Component 1	5.09	39.12	39.12	4.80	36.91	36.91
Component 2	2.24	17.22	56.34	2.57	19.76	56.67
Component 3	2.04	15.71	72.05	1.68	12.91	69.57
KMO Adequacy	0.809			0.796		

Component 1 accounts for as much of the variability in the data as possible (39.1% in 1995 vs. 36.9% in 2005), and it interprets a city's influential capacity mainly according to economic strength, population size, and the rate of employment. These variables are the most significant of those used to measure a city's competitiveness and dynamics, and they contribute most to Component 1. Cities with high Component 1 scores are the largest cities, and they are also the most competitive in terms of economic development, thus attracting more investment and in turn investing more in urban development (Table 3.4). Since the major contributors to the Component 1 remained relatively constant from 1995 to 2005, they provide consistent information throughout the analysis. Therefore, the factor score of Component 1 is the most suitable variable to be used as a composite index to replace population in the GM (Table 3.2).

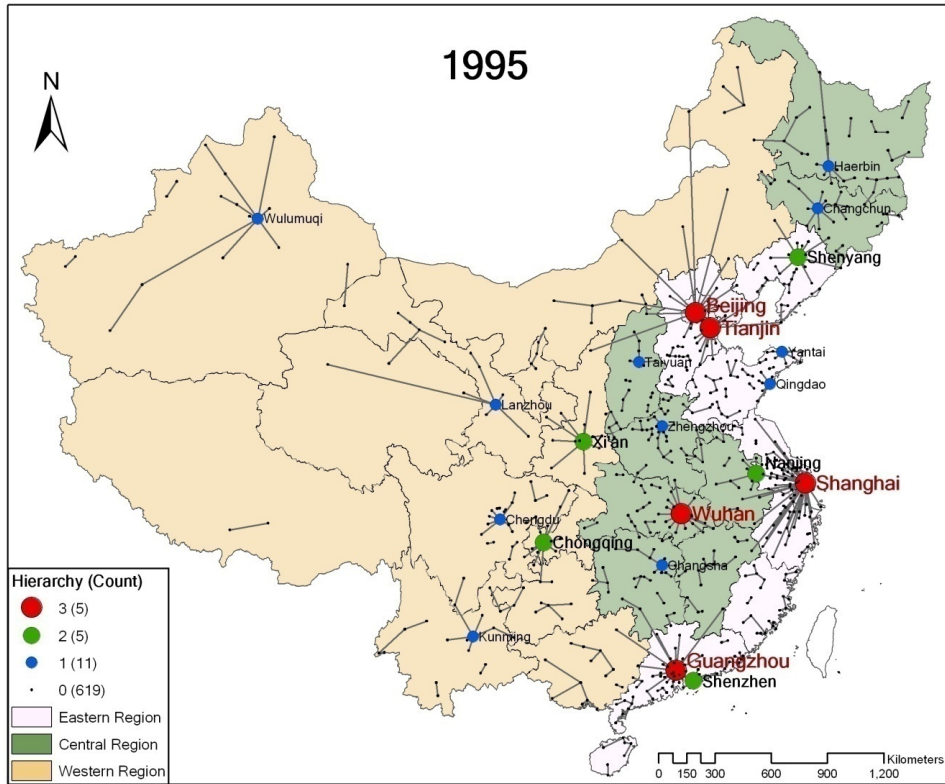
Table 3.4 Cities with highest scores of the principal components in 1995 and 2005

Rank	1995						2005					
	Component 1		Component 2		Component 3		Component 1		Component 2		Component 3	
	City	Value	City	Value	City	Value	City	Value	City	Value	City	Value
1	Shanghai	1.00	Kalamayi	1.00	Suifenhe	1.00	Shanghai	1.00	Yima	1.00	Lianjiang	1.00
2	Beijing	0.55	Daqing	0.99	Erlianhaote	0.99	Beijing	0.89	Kalamayi	0.94	Sanya	0.90
3	Tianjin	0.51	Dongying	0.89	Zhuhai	0.77	Guangzhou	0.53	Jinchang	0.92	Weihai	0.85
4	Guangzhou	0.41	Zhuhai	0.82	Haikou	0.74	Tianjin	0.47	Jiayuguan	0.89	Changshu	0.81
5	Wuhan	0.35	Ma'anshan	0.82	Wanding	0.72	Shenzhen	0.47	Huozhou	0.87	Gaomi	0.74
6	Shenyang	0.31	Jiayuguan	0.80	Jining	0.68	Nanjing	0.33	Daqing	0.87	Qufu	0.72
7	Chongqing	0.29	Panjin	0.79	Kashi	0.64	Wuhan	0.33	Dongying	0.85	Rizhao	0.68
8	Shenzhen	0.27	Shiyan	0.78	Hailaer	0.63	Dongguan	0.31	Jinjiang	0.85	Anqiu	0.67
9	Dalian	0.24	Shenzhen	0.78	Yingtang	0.58	Chongqing	0.31	Jiexiu	0.85	Laixi	0.67
10	Nanjing	0.22	Foshan	0.77	Heihe	0.57	Shenyang	0.30	Panjin	0.85	Zhongwei	0.66

Component 2 and Component 3 in the 1995 analysis describes cities by industrial sector (Table 3.2). Component 2, accounting for 17.22% of the total variance, draws information from the secondary industry, which means that cities with higher Component 2 scores are predominantly manufacturing-cities that feature industries such as coal, oil, minerals, and the production of electronics (Table 3.4). The profit gained from these industries enables the cities to invest in the construction of infrastructure, including the paving of roads or urban afforesting and greening. Component 3 accounts for the least variance (15.71%) among the three components, and the cities with high Component 3 scores are those featuring tertiary industries, such as the tourism resorts of Haikou and Zhuhai. Due to the underdevelopment of tertiary industries in China in the mid-1990s, a large number of cities with higher Component 3 values are not well known.

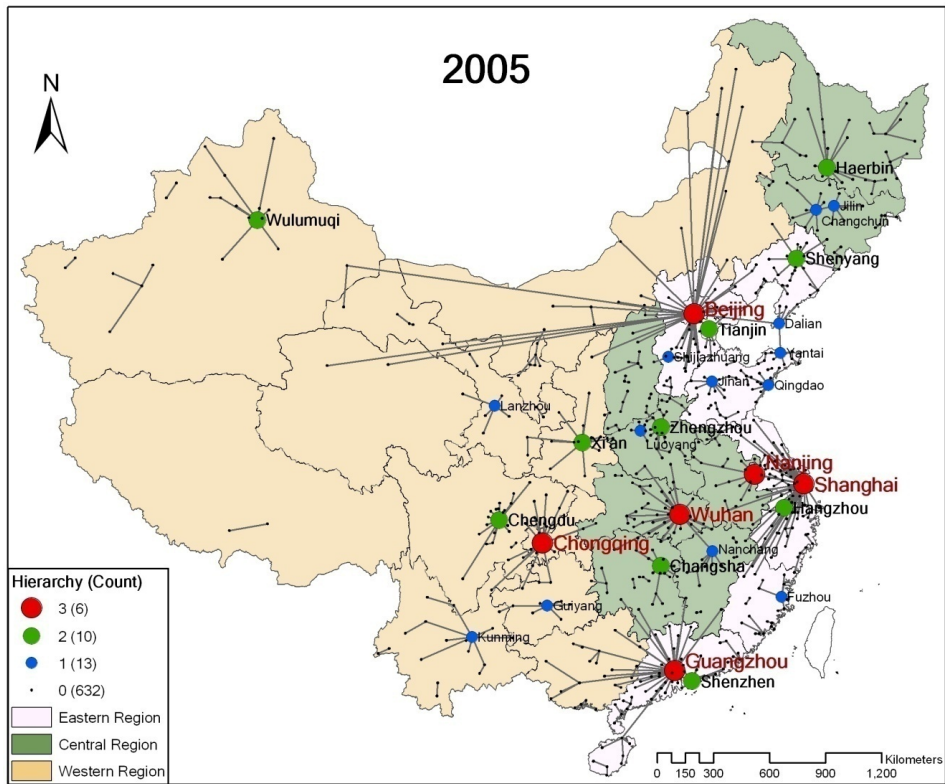
In the 2005 analysis, Component 2 scores now include information on both secondary and tertiary industries (Table 3.2). The analysis shows that the cities with higher Component 2 values (positive) are those which are heavily dependent upon the secondary industry, while the cities with lower values (negative) are those that rely on the tertiary industry. Component 3 in 2005 provides reference to the construction of infrastructure, and most of the cities with higher values are tourist cities that attach importance to the natural environment's maintenance and the city's appearance (Table 3.4).

Once the steps taken to determine the hierarchical structure covered in the previous section are completed, the urban hierarchies of Chinese cities in 1995 and 2005 are categorized into four levels (3 to 0 from the highest to the lowest), based on the IP and number of strongest linkages a city retains (Figure 3.3 and Figure 3.4).



Data source: China City Statistical Yearbook 1996; China Urban Construction Statistical Yearbook 1996

Figure 3.3 Hierarchical structure of Chinese cities in 1995



Data source: China City Statistical Yearbook 2006; China Urban Construction Statistical Yearbook 2006

Figure 3.4 Hierarchical structure of Chinese cities in 2005

3.4 Findings and discussions

The nodal and hierarchical structure of China's urban system experienced great change between 1995 and 2005: 1) More urban clusters have emerged since 1995; 2) the interactions between cities in urban clusters varies case by case and unhealthy interactions have led to unbalanced urban development in the JJJ urban cluster; 3) the urban development in China is not even over the space: the development in the west and central of China is lagged, but disparity between the inland and coastal cities has been reduced.

3.4.1 Evolving urban clusters

A group of cities that are dominated and influenced by one or more megalopolises will usually agglomerate based on their geographical and/or socioeconomic interactions, resulting in regional urban clusters. Certain prosperous areas in China, such as the Pearl River Delta (PRD) and the Yangtze River Delta (YRD), have consistently been the location of urban clusters throughout the country's modern history. These areas have high levels of urbanization and involve rural labour in non-agricultural activities. Since the 1980s, China's economic reforms and the open door policy have reaccelerated the development of these previously established urban clusters (Skinner and Henderson 1999; Yeh and Xu 1996), and further economic development has also led to the emergence of new urban clusters as demonstrated by the spatial connections illustrated in Figure 3.4. Additionally, the number

of cities at the higher levels of the hierarchy (level 3 and 2) is increasing substantially, reinforcing the existing interactions or forming new spatial connections.

The hierarchical structure of the urban system clearly demonstrates the pattern and evolution of urban clusters through its notable “hub and spoke” interactions and nodal connections (Figure 3.3 and Figure 3.4). In 1995, Beijing, Tianjin, Shanghai, Wuhan, and Guangzhou were identified as cities at the top of the hierarchy. Another five large cities, Shenyang, Xi’an, Nanjing, Chongqing, and Shenzhen are delineated as cities at the second level, and 13 more cities are included in the third level. Apparently, the connections in the 1995 urban system are relatively weak, and so the “hub and spoke” pattern can only be vaguely discerned in several regions. Therefore, the influencing power of cities with a higher IP was only able to affect cities within a short distance, and even metropolitan cities were found to have only a small number of strong links to cities within a relatively short distance. However, the considerable number of cities functioning as nodes fosters the development of urban clusters, and the pattern has started to emerge in the areas surrounding Beijing, Shanghai, and Guangzhou.

China’s urbanization entered a new phase of development after 1995 (Figure 3.5): the number of cities remained stable, but those previously established cities continued to expand, mainly due to rural-urban migration. With the increasing mobility within China’s urban system, the connections between cities have been strengthened. Bigger cities attract

flows of material, capital, and labour, and play leading roles in their surrounding regions. For instance, Nanjing and Chongqing have functioned as nodal cities since 2005, whereas they did not in the 1995 analysis, and six additional cities (Haerbin, Zhengzhou, Hangzhou, Changsha, Chengdu and Wulumuqi) have been added to the second level. Urban clusters or city strips, dominated by nodal cities at the top and second levels of the hierarchy, have taken shape, and the “hub and spoke” pattern can be clearly discerned in these regions.

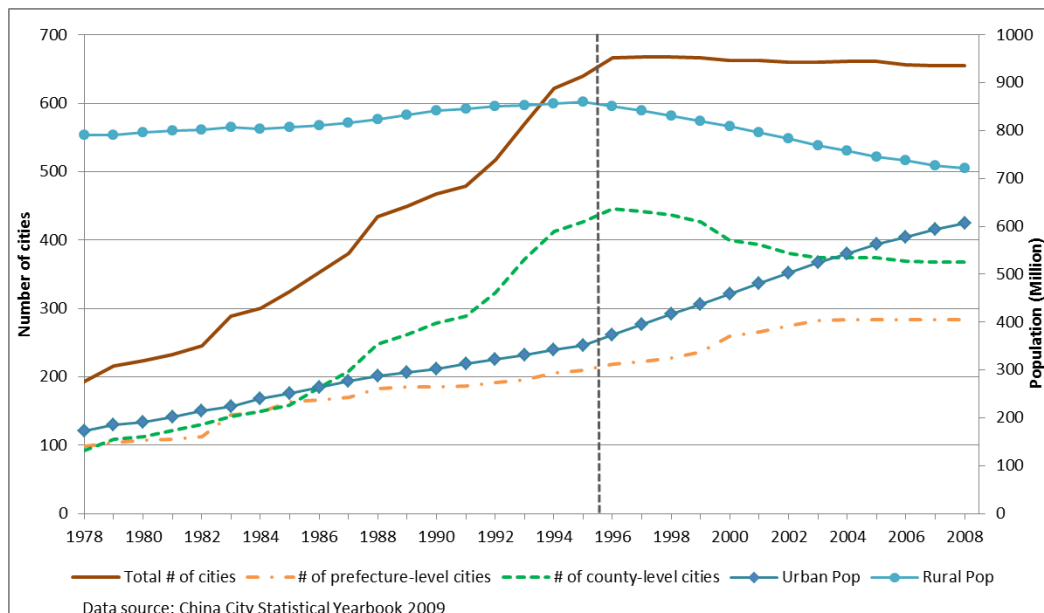


Figure 3.5 Urban development of China since 1978

In order to consolidate the results of the Synthesized Gravity Model to examine the evolution of urban clusters, remote sensing images are used to present real observations of the urban development. Instead of using images captured by traditional sensors during daytime, this research uses the images that are collected at night by the Defense Meteorological Satellite Program’s Operational Linescan System (DMSP OLS). Due to its

ability to capture city lights, DMSP OLS imagery has been widely used to detect and analyze the extent and density of urban settlements (Elvidge *et al.* 2001; He *et al.* 2006a; Henderson *et al.* 2003). Compared to GIS-based methods, like interpolations population dots or urban density, the nighttime light images have a higher fidelity for depicting the urban areas in terms of density and boundaries²¹ (Figure 3.6). Clusters are usually found in the plains, deltas, and industrial districts (Yeh and Xu 1996). The comparison of Figure 3.3 and Figure 3.4 reveal this same pattern for China's urban clusters in 2005, and these major clusters are: (1) the Northeast urban strip (Haerbin-Changchun-Shenyang-Dalian), (2) the JingJinJi urban cluster (Beijing-Tianjin-Tangshan), (3) the Shandong Peninsula urban cluster, (4) the Yangtze River Delta (YRD) urban cluster (Nanjing-Shanghai-Hangzhou), (5) the Pearl River Delta urban cluster, and (6) the Southwest urban cluster. Four other emerging urban clusters are the Fujian Coastal urban cluster, the Wuhan urban cluster, the Zhongyuan urban cluster, and the Guanzhong urban cluster, most of which are still developing and have only preliminarily taken shape. The majority of these ten clusters are situated either in deltas or on plains with abundant natural resources and a long history of development. They have a high population density and are each famous for the production of different agricultural or industrial goods. These urban clusters are booming in the economic reform and open policy period because they are located along the coast and are

²¹ The magnitude of the lights from urban areas is reflected by the pixel value of the DMSP OLS image: the higher the image value, the stronger the magnitude, thus indicating a higher residential density.

more accessible to the world market. In addition to the further development of existing cities, new cities are beginning to emerge within these clusters; for example, Dongguan, Shenzhen, and Zhuhai in the Pearl River Delta, and Changzhou in the Yangtze River Delta (Song and Zhang 2002; Yeh and Xu 1996; Zhao *et al.* 2003; Zheng *et al.* 2009). Light has also been shed on the emergence of new urban clusters; for example, the development of provincial capitals like Jinan, Zhenzhou, Changsha, Wulumuqi, and Kunming, has created the potential for new urban clusters.

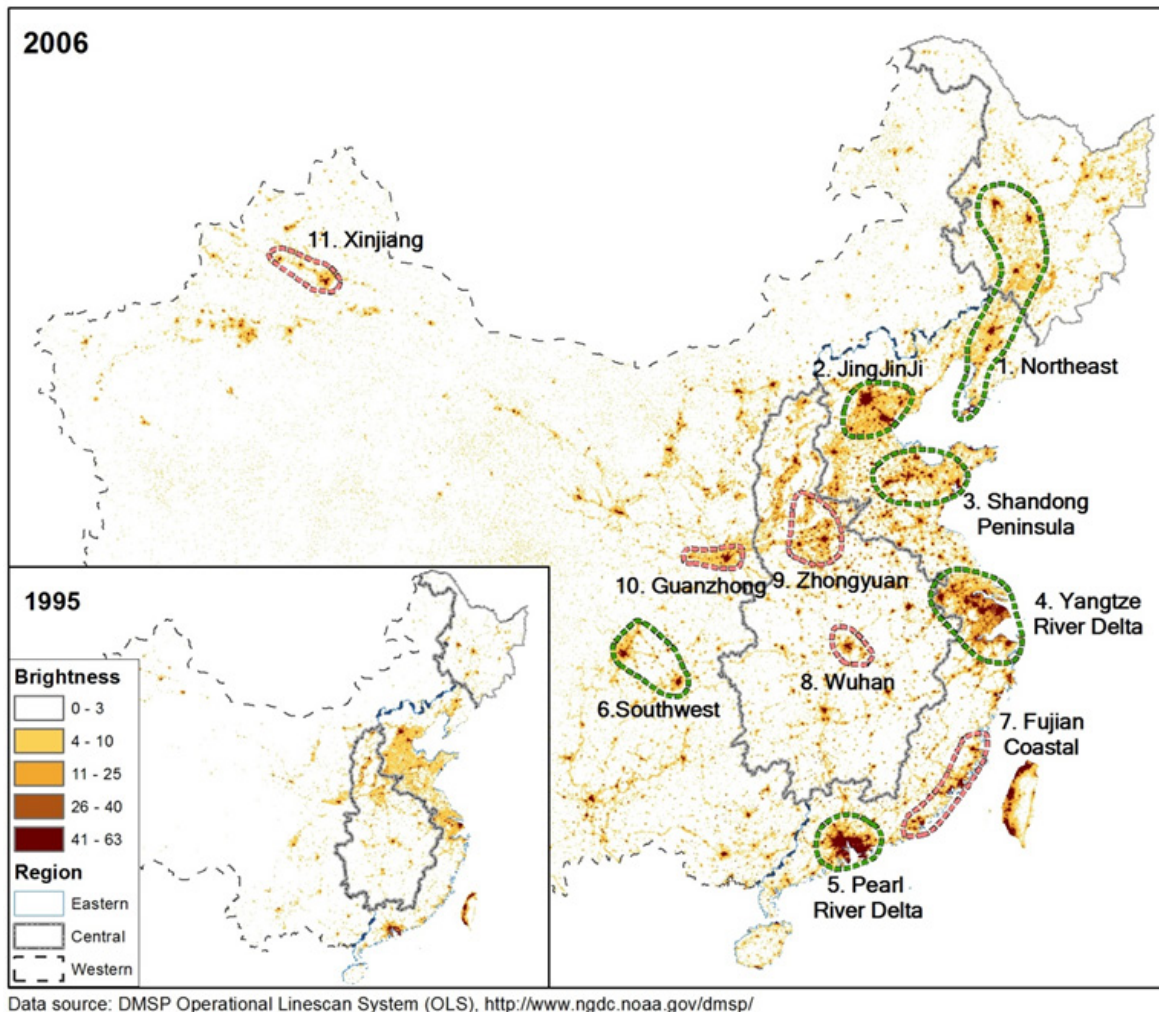


Figure 3.6 Urban clusters discerned from the DMSP nighttime light images

3.4.2 Unbalanced development within urban clusters

Urban systems evolve spatially and temporally as the social, economic, technological, and geographical conditions that exert an influence on them change (Du 2000; Huff and Lutz 1995). Consequently, the evolution of the urban system is driven by the socioeconomic development of the cities that exist within its boundaries. A new pattern of the spatial structure of urban systems is a composite result of both the development of individual cities and the interactions between them. In other words, a fast-growing city absorbs resources

from neighbouring competitors, thus impeding its rivals' development. In the meantime, the fast-growing economy provides a regional "econiche" to benefit subordinate cities. The Yangtze River Delta urban cluster and JingJinJi urban cluster serve as two unique examples.

As the largest city in China, Shanghai dominates the Yangtze River Delta, which includes Nanjing and Hangzhou among its major cities. The manufacturing industry of Shanghai has been relocated from the city proper to other cities, and as a result the development of Shanghai both depends upon, and also spurs, the development of surrounding cities. Moreover, the convenient transportation between Shanghai and other cities makes the urban cluster compact and dynamic. Therefore, the complementary development mechanism in the Yangtze River Delta urban cluster encourages the sustainable growth of all its cities. From 1995 to 2005, Nanjing became a top-level nodal city, and the strongest linkages to it increased from 8 to 11; Hangzhou was promoted to a second-level nodal city, and the strongest linkages to it increased from 3 to 6 (Table 3.5). Both cities have gained essential positions in the urban subsystem as the number of strongest linkages and IF values continue to increase (Figure 3.7).

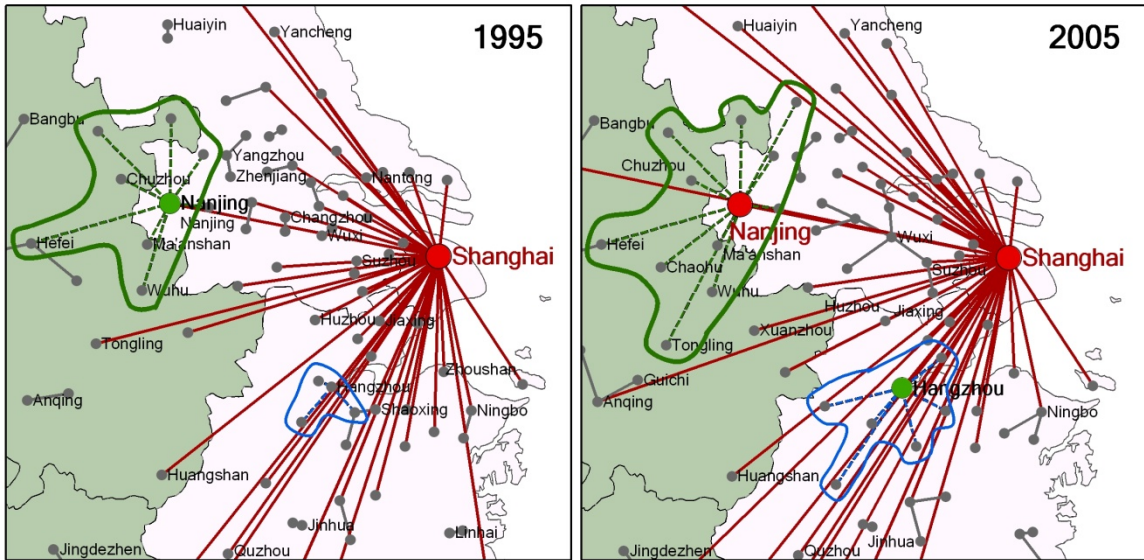


Figure 3.7 Evolution of the Yangtze River Delta urban cluster

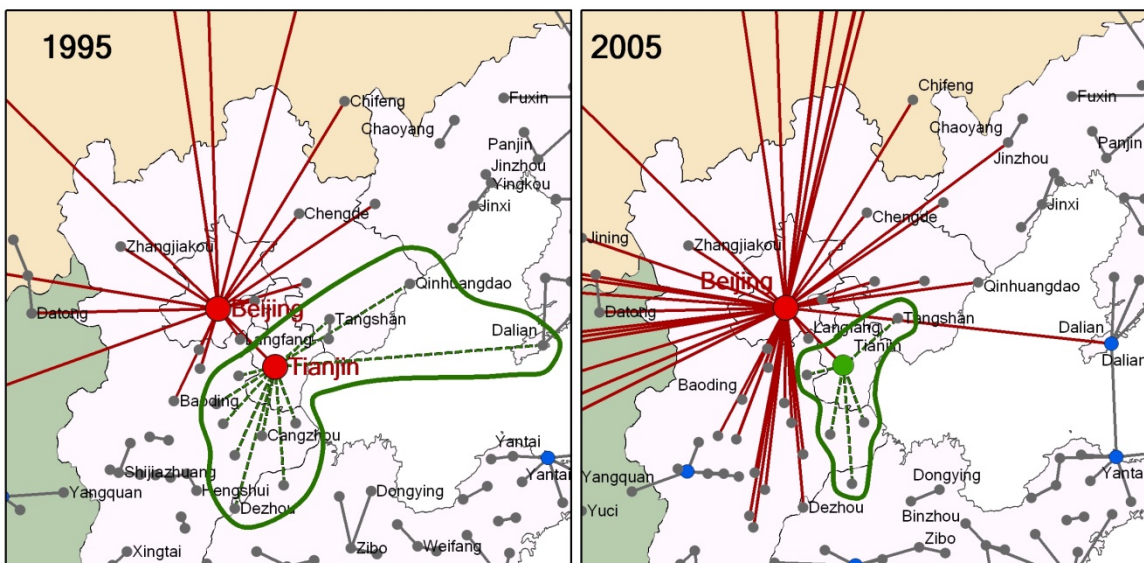


Figure 3.8 Evolution of the JingJinJi urban cluster

Table 3.5 Variation of largest linkages and influential factor

Urban cluster	City	Linkages		Influential factor	
		1995	2005	1995	2005
Yangtze River Delta	Shanghai	43	44	1.00	1.00
	Nanjing	8	11	0.51	0.47
	Hangzhou	3	6	0.15	0.27
Jingjinji	Beijing	18	45	0.55	0.89
	Tianjin	11	5	0.22	0.33

However, the development of the Jinjinji cluster has contrasted sharply with the experience in the Yangtze River Delta. As the dominant city in the cluster, Beijing's development has been prioritized due to its political status as the capital city of China. Beijing's position of privilege did not allow for other cities to compete, and the collaborative development relationship between Beijing and its neighbouring cities was replaced by a concessionary one. Although the gap between Beijing and Shanghai has been narrowed (1 vs. 0.55 as indicated by IF in 1995; and 1 vs. 0.89 in 2005), the difference between Beijing and Tianjin has continued to grow since 1995 (0.55 vs. 0.22 in 1995; and 0.89 vs. 0.33 in 2005) (Table 3.5). Tianjin's development has been substantially hindered by the "shadow effect" created by Beijing's rapid growth, and as a result Tianjin has seen losses in its number of strongest interaction linkages (Figure 3.8). Beijing's number of strongest linkages increased from 18 in 1995 to 45 in 2005; while the number of cities with strongest linkages to Tianjin was reduced from 11 in 1995 to 5 in 2005, due to Beijing's dominance of the region (Table 3.5).

3.4.3 Uneven spatial development

The change in spatial distribution of the cities and connections between Figure 3.3 and Figure 3.4 reveals another important phenomenon: cities in the central and western regions have been developing at a rapid rate over the past two decades.

Prior to the 1980s, the urban development of the inland provinces in Central and Western China was prioritized for national defense reasons. A large number of coastal industries were relocated to inland areas through administrative measures, resulting in a relatively even urbanization pattern. In the post-reform era, however, the central government shifted its priority to the east coast, leading to a largely asymmetrical urbanization pattern. The spatial distribution of cities varies by size and region (Figure 3.3 and Figure 3.4). Cities in Eastern China monopolized the top of the hierarchy in both 1995 and 2005, Eastern China also witnessed the greatest growth in third-level cities (Qingdao and Yantai in 1995, Qingdao, Yantai, Jinan, Dalian, Shijiazhuang and Fuzhou in 2005), and Central China's second-level cities grew the most rapidly (No cities in 1995; Zhengzhou, Haerbin, Changsha in 2005) (Table 3.6).

Table 3.6 Chinese cities by hierarchy and region in 1995 and 2005

Hierarchy	Eastern (count)		Central (count)		Western (count)	
	1995	2005	1995	2005	1995	2005
3	4	4	1	1	0	1
2	3	4	0	3	2	3
1	2	6	5	4	4	3
0	264	249	209	219	146	164
Sum	273	263	215	227	152	171

Meanwhile, the gaps between cities in terms of their respective IF strengths have been steadily decreasing. The newly developed IF variable in the SGM has proven to be a more comprehensive factor than population as it reflects the complex and multidimensional quality of the urban structure, performance, and dynamics. For example, Shenzhen ranks 10th in 1995 according to non-agricultural population, which is one third of the non-agricultural population of Nanjing; however, when factors such as GDP, foreign investment, and average wage were taken into consideration, Shenzhen moves up to eighth in 2005 (Table 3.7). Another city from the southeast of China, Dongguan, is introduced to the top ten in 2005. By 2005, Dongguan ranks 8th in terms of non-agricultural population, while Shenzhen continues to climb, settling in the fifth position. The superior location of the southeast coastal region of China attracts both inland and foreign capital, thus creating a sound environment for urban, economic, and social development. For example, three cities in the top-ten list of 2005, namely Guangzhou, Shenzhen, and Dongguan, are located in the southeastern coastal region of China, and all three have been climbing the ranks at different speeds for the past 10 years (Table 3.7). Another discernible phenomenon is that the gap

between influential factors has been narrowed from 1995 to 2005. Standardizing the IF (setting the city with the largest value as the reference with value 1) can help to explore the relative difference between the values of two cities' influential factors (Table 3.7).

Table 3.7 Comparison between the ranks of influential factor and non-agricultural population

Rank	1995			2005		
	City	IF	Non-agricultural population (Rank)	City	IF	Non-agricultural population (Rank)
1	Shanghai	1.000	8338 (1)	Shanghai	1.000	11284 (1)
2	Beijing	0.545	6194 (2)	Beijing	0.887	8554 (2)
3	Tianjin	0.507	4743 (3)	Guangzhou	0.532	4826 (5)
4	Guangzhou	0.414	3167 (6)	Tianjin	0.473	5324 (3)
5	Wuhan	0.348	3758 (5)	Shenzhen	0.467	1819 (10)
6	Shenyang	0.312	3800 (4)	Nanjing	0.329	4105 (8)
7	Chongqing	0.286	2753 (7)	Wuhan	0.326	5031 (4)
8	Shenzhen	0.272	748 (10)	Dongguan	0.311	4595 (7)
9	Dalian	0.244	1881 (9)	Chongqing	0.307	4776 (6)
10	Nanjing	0.218	2260 (8)	Shenyang	0.304	4101 (9)

Data source: China City Statistical Yearbook 1996, 2006

3.5 Conclusion

Chinese cities have undergone a pronounced transformation in terms of spatial structure and hierarchical patterns since the 1980s. The development of China's cities in the context of marketization and globalization reflects the transition process of cities in the developing world (Wu 2005). This comprehensive study of Chinese cities as a functional and geographic system quantitatively, spatially, and temporally, was able to analyze and present the development and evolution of the urban system. The transformation of the Chinese urban system has been closely associated with and influenced by the urban policies implemented by the Chinese government. From the beginning of the 1980s to the mid-1990s, the Chinese government placed a considerable amount of emphasis on the development of small and medium-sized cities and took a series of administrative measures to control the growth of large cities. However, since the Tenth Five-Year Plan (2001-2005), the government's urbanization policy has been modified to the "coordinated development of large, medium, small cities and small towns", and more attention has been paid to the development of large cities (Chen 2008). Accordingly, the pattern of China's urban system since 1995 has been characterized by the emergence of urban clusters. The scaling distribution and spatial distribution reveal an "upward" (upgrading of smaller cities) and "westward" (coastal to inland) movement that is aimed at eliminating disparities within the Chinese urban system. The Eleventh Five-Year Plan launched in 2006, has declared the government's intent to cement the position of megalopolises as leaders of the urban system,

whereby they are expected to exert the functions of central cities and help in the formation of several new megalopolises. Meanwhile, the development within urban clusters has also experienced its fair share of challenges, such as the unbalanced growth found in the JingJinJi urban cluster. Regional urban planning is required to coordinate the interactions between cities in a hierarchy. To conclude, the analysis of the Chinese hierarchical urban system that this thesis has conclusively undertaken not only provides a better understanding of the current urban landscape, but also has far-reaching implications for planning, conceptualizing, and understating future urban developments.

The Synthesized Gravity Model has proven to be a feasible way to optimize the traditional Gravity Model. These improvements consist of two basic adjustments: (1) Influential Factor was introduced to measure the accurate “mass” of a city, and (2) Relative Distance based on network analysis is introduced to reveal the “distance decay” effect between cities. The first adjustment is made to reflect the fact that cities with large influential factors, or “masses,” tend to generate and attract more activities than cities with small ones. In the second, the SGM analysis compensates for the fact that the farther apart cities are in terms of relative distance, the less they interact with one another (Haynes and Fotheringham 1984).

By incorporating the Principal Component Analysis and Network Analysis, the new model successfully overcomes the traditional GM’s problem of being unable to accurately

reflect a city's influential strength, as well as its oversimplification of reality. The gravitational relationships among cities help to distinguish the hierarchical structure and nodal distribution of urban clusters, which explains the interaction mechanism underlying the evolution of the urban system.

Potential improvements can be made to ameliorate the Synthesized Gravity Model. First, due to the lack of available socioeconomic data in China, only 13 variables were selected to derive the comprehensive influential factor. However, a selection of additional variables covering more aspects of the urban influential power would produce a more accurate depiction of reality. Second, in the Synthesized Gravity Model, as shown in Equation 2, the values of R , W and A were determined from the proportion of people and goods transported by different methods, and all the cities were analyzed using a general set of values for a specific year. Suppose that cities were given separate weights based on individual situations, the accuracy of the measurements of interactions would be improved. To conclude, the Synthesized Gravity Model overcomes some limitations associated with the traditional gravity model, and it can be used as a prototype for the development of a new type of model in the same "family."

Chapter 4 The Spatiotemporal Transition of China's JingJinJi Metropolitan Area: Detection, Modeling and Prediction

4.1 Introduction

Since the mobility of people and goods extends the influence of cities well beyond their borders, it is inadequate to study a city in isolation without taking its relationship to the surrounding area into consideration (Semboloni 1997). Studying the development of a group of cities that are closely connected sheds light on the crucial role of cities in the structuring of urban space (Cohen 2004).

Following the implementation of economic reforms and an open door policy in the late 1970s, China's cities have been increasingly influenced by a market economy. Today, China's urban system is a hybrid product of a traditional planned economy and the market system. Therefore, the study of such an urban system would be a significant contribution to the field of urban studies, which continues to be dominated by Western-oriented theories. Furthermore, the application of such theories to China's urban development would also help to better understand the historical, present, and future trends of urban development.

The studies on China's urban development falls into two general categories in terms of scale: the city level and the national level. In regards to the former, the morphological

expansion of cities has been studied extensively by detecting and observing changes in land cover (Deng and Huang 2004; Gaubatz 1999; Xie *et al.* 2007), and, the study of social spaces within cities has also attracted a great deal of interest (Gu and Shen 2003; Wu and Luo 1999; Wu 2008b; Xu *et al.* 1989a; Yeh *et al.* 1995b). More attention, however, has been paid to urban growth, structural change, regional distribution, and rank size distribution in studies conducted on the national scale (Lin 2002; Pannell 2003; Qi 2002; Song and Zhang 2002; Wu and Yeh 1997). Despite these extensive investigations at both the micro (city) and macro (national) level, the functional structure, the mechanism of interaction among cities, and the relationship between socioeconomic and biophysical factors in the urban system have largely been ignored.

While the two previously discussed areas of study of urban China (city and national level development) have been widely examined, regional development has been largely overlooked. Although urban clusters are emerging and developing at a rapid rate in China, the existing urban clusters lack an overall development strategy that encompasses both their urban and rural areas (Clarke *et al.* 1997). Urban clusters are usually distinguished by the spatial interactions between cities, but the growth processes and patterns within a cluster are not often included in urban studies. Healthy inter-city relations, the relationship between cities within a region, are essential for cities and the areas that fall within the radius of their impact to achieve sustainable development (Dou *et al.* 2000). Hence, there is need to study

cities at a regional scale in order to complement studies conducted on the national and local city scales.

Located in the north of China, the JingJinJi Metropolitan Area is one of the largest urban clusters in China's urban hierarchical structure (Han 2013). It has a prolonged history, and as a result it is generally considered to be characteristic of China's urban development. The development of urban patterns is mainly due to geographical and historical factors, and since the patterns that reflect these factors are usually phase-lagged, often by decades (e.g., the development brought about by the construction of a new highway), the study of urban change over time is crucial (Alberti *et al.* 2003; Cao *et al.* 2005; Cohen 2004). This study of the JingJinJi Metropolitan Area's urban development focuses on answering the following questions: At a regional scale, how does the JingJinJi Metropolitan Area develop in relation to the surrounding area? What specific processes and patterns are discernible in this area's urban development? How can its expansion mechanism be accurately represented, simulated, and projected as a potential development pattern for other urban areas?

Regional scale studies focus on the relationships between cities in any given urban cluster that has developed based on reciprocal interactions of dependency and competition. These relationships connect cities in two ways: the physical flow of goods and people, and the non-physical flow of information and capital. To depict the evolution of an entire system, a Cellular Automata (CA) based model can be used. The CA is a dynamic model to

study space and time as discrete units, and space is often considered as a regular lattice of two dimensions, which evolves along the third dimension of time (Batty 2003; Clarke *et al.* 1997; White and Engelen 1993). Due to its ability to represent nonlinear, spatial, and stochastic processes (Ward *et al.* 2000), the CA model is extremely useful in urban studies. This research employs a CA model, SLEUTH, to simulate the urbanization process, present transition patterns, and predict future development patterns within the JingJinJi Metropolitan Area of China.

4.2 Research methodology

4.2.1 JingJinJi Metropolitan Area

The JingJinJi Metropolitan Area (JJJ) has played a significant role in promoting the economic development of northern China. The study area is located between the latitudes of 38°05'N and 41°04'N, and the longitudes of 115°14'E and 118°54'E. It consists two megacities Beijing and Tianjin at the province administrative level, two large cities Tangshan and Baoding, and 11 smaller cities from Hebei province, covering a total area of 64,022 km², with a total population of 94.32 million (Figure 4.1). There are 73 county-level units in the area, including counties, county-level cities, and city districts of municipalities. The JJJ is dominated by Beijing and Tianjin: Beijing is the capital city of China with an area of 16,300 km² and a population of 19.62 million as of 2010. Tianjin is one of the largest cities in North China with an area of 11,700 km² and a population of 12.99 million in 2010. Hebei province has an urbanization rate of 37.70%, while Beijing and Tianjin have much higher levels of urbanization (83.62% and 72.11%, respectively) in comparison to the national average of 49.95% (2010).

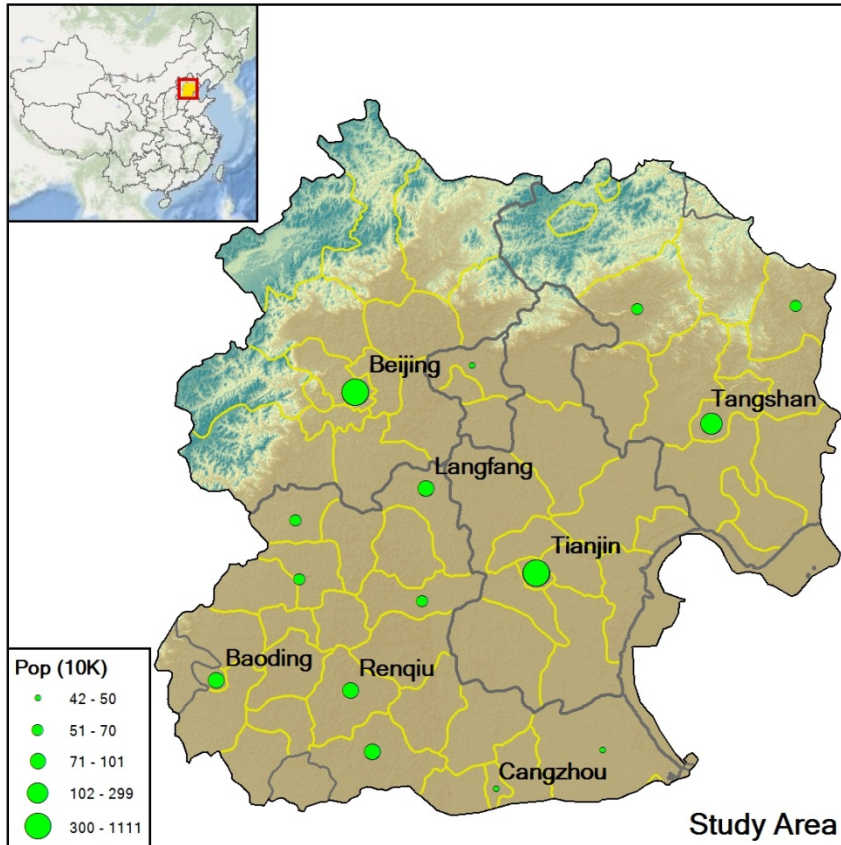


Figure 4.1 Study area of the JingJinJi Metropolitan Area

4.2.2 Data acquisition

To conduct a temporal analysis of the study area, five sets of remote sensing images from 1978, 1984, 1992, 2000, and 2009 were obtained. Each set of images is composed of 6 scenes (1978) or 4 scenes of Landsat images (1984 to 2009) that cover the entire study area (Figure 4.2). Images captured from Landsat sensors (Multispectral Scanner System (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+)) are selected for their relatively consistent spatial and spectral resolution (Jensen 2005).

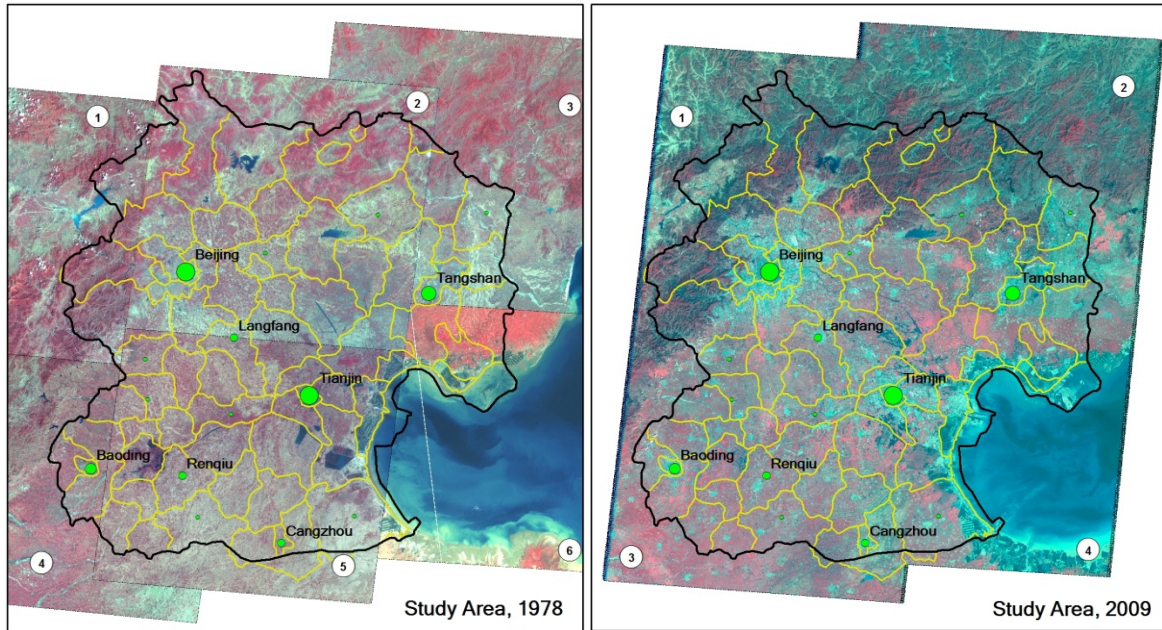


Figure 4.2 Landsat TM mosaics of 1978 and 2009

Since at least 4 scenes of Landsat TM or 6 scenes of Landsat MSS images are required to cover the entire study area, the mosaicking of multi-date images is unavoidable because of the minimum 7 days overlap between neighbouring scenes (Landsat Project Science Office 2009). The number of scenes and acquisition date of each scene is indicated in Table 4.1. For the areas where cloud-free coverage is not available, the scenes that are closest to the anniversary date are selected to minimize the variation of environmental factors (Jensen 2005).

Table 4.1 Acquisition date for each scene

Scene ID	Path /Row	1978 (Landsat 2/3 MSS)	Path /Row	1984 (Landsat 4 MSS)	1992 (Landsat 5 TM)	2000 (Landsat 7 ETM+)	2009 (Landsat 5 TM)
1	131/32	1977/7/4	123/32	1984/8/16	1992/9/7	2000/4/30	2009/9/22
2	131/33	1979/9/4	122/32	1984/9/10	1992/7/30	2000/5/25	2009/9/15
3	132/32	1978/9/10	123/33	1984/8/16	1991/6/17	2000/5/16	2009/9/22
4	132/33	1979/5/29	122/33	1984/9/10	1993/6/15	2000/5/25	2009/8/30
5	133/32	1978/9/20					
6	133/33	1979/9/6					

All Landsat scenes were processed by the United States Geological Survey (USGS) using the Standard Terrain Correction (Level 1T) method. This Level 1T processing includes radiometric correction, systematic geometric correction, and precision correction by using ground control points (GCP) and digital elevation models (DEM) to correct parallax error due to local topographic reliefs (Roy *et al.* 2010). Prior to the Level 1T processing, any pixels with a digital value of 255 are identified as “saturated” since they exceed the sensor’s detection limit and therefore do not provide useful data for subsequent analysis. Furthermore, the areas covered by clouds are also identified, which generally coincided with the location of the “saturated” pixels. Therefore, a NO DATA “mask” is applied to each band to exclude all areas with “saturated” pixels or cloud coverage (Landsat Project Science Office 2009).

4.2.3 The CA-based SLEUTH model

Cellular Automata (CA) modeling was developed with the explicit purpose of representing emergent properties that originate from sets of simple behavioural rules operating over a cell-based pattern (Pinto and Antunes 2007). Therefore, the CA-based model's usefulness derives from its capacity to combine subsystems, revealing the emergence of large-scale patterns from the interactions of local elements (Torrens 2000). It works interactively with space, time, and system attributes, where a change in one element has profound effects on its neighbours along the spatial and temporal scales. For example, a conversion from agricultural land to built-up land at a location may have a significant influence on its neighbours being converted to built-up areas in the near future. Essentially, CA allows users to simultaneously model configuration and function with pattern and process.

CA offers a unique and innovative approach to the study of urban systems and there has been a wide application of CA-based models to urban systems in the field of urban studies. Factors such as urban growth and sprawl, segregation and gentrification, population dynamics and mobility, and land use evolution process and history can all be examined using CA (Clarke *et al.* 1997; O'Sullivan and Torrens 2000; Pinto and Antunes 2007; White and Engelen 1997). As such, this extensive method gives researchers valuable insight into the development of urban systems. CA models consist of five essential elements: cells

arranged evenly on grid, states of the cells, neighbourhoods, transition rules, and time, all of which are explained in detail by Project Gigalopolis (2012).

As one of the widely used CA models in urban studies, SLEUTH's name comes from an acronym that is derived from the model's required inputs of image data: Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade. SLEUTH runs under the UNIX system or the UNIX environment built in Windows (such as Cygwin using a GNU C compiler), and it is composed of the urban growth model (UGM) and the land cover deltatron model (DLM), which is optional. Once the inputs are properly prepared, SLEUTH's functionality is verified, then the model is calibrated, and changes are predicted based on calibration results. Five coefficients are calculated while the model is being implemented, including the Diffusion (Dispersion) Coefficient (DI), the Breed Coefficient (BR), the Spread Coefficient (SP), the Slope Resistance Coefficient (SR), and the Road Gravity Coefficient (RG). All these coefficients are used to define urban growth rules specified by the model, as described in the following paragraphs. The values of these coefficients range from 0 to 100, where 100 represents the highest possibility that new urban growth will abide by these growth rules.

One of SLEUTH's main tasks is to interpret dynamic urban growth with four growth rules (Jantz *et al.* 2004). The first rule, spontaneous growth, is defined by the Diffusion Coefficient, and this growth simulates the process of urban growth in a new area, without

being affected by established urban areas and infrastructures. The Dispersion Coefficient effectively limits how often a particular cell is selected to apply spontaneous growth law (being urbanized without neighbour's influence), and it also defines the overall outward dispersive nature of distribution.

The second rule, new spreading centre growth, is measured by the Breed Coefficient, and it defines the likelihood that a spontaneous occurrence of urban growth will develop into a centre of further growth. The Breed Coefficient defines the probability of an urbanized cell to evolve into a new urban core and start its own growth cycle (new spreading center) during the spontaneous growth phase. Additionally, the Breed Coefficient is used in the road-influenced growth phase to determine the possibility of urban expansion alongside a road.

The third rule, edge growth, is defined by the Spread Coefficient, and it estimates the extent to which urban growth has moved outwards from the city, and also how much urban infilling has occurred. The Spread Coefficient defines the probability that a cell in a spreading centre will trigger the development of another neighbouring cell, and therefore it controls how much diffusive expansion occurs outwards from urbanized areas.

The fourth rule, road influenced growth, is measured by the Road Gravity Coefficient, and it represents the tendency of new settlements to develop along existing transportation lines. The Road Gravity Coefficient defines the maximum distance over which each road

can influence the probability that new urban growth will occur. Finally, The Slope Resistance Coefficient determines likelihood of a settlement extending up steeper slopes, which represents the restricting influence of steep slopes on development, and it functions in all the previous four rules. Users can also define an Exclusion layer, which specifies areas that cannot be developed, such as water or reserved parks.

In an urban growth simulation, time units are referred to as a growth cycle. For the purposes of this research a growth cycle corresponds to a one year period. These four growth rules can be visualized as five steps in a growth cycle (Figure 4.3).

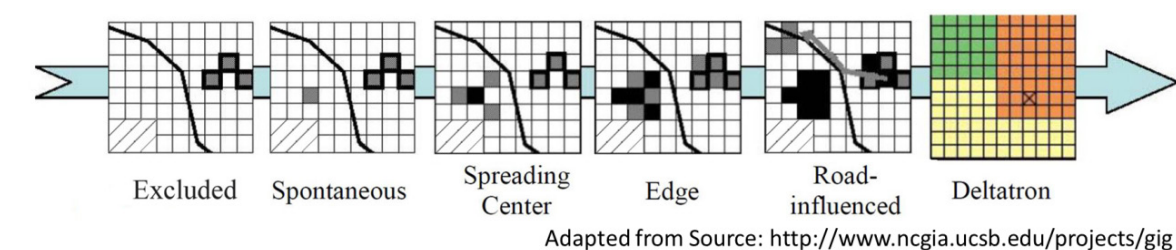


Figure 4.3 The behavior rules of a growth cycle year

4.2.4 Incorporation of socioeconomic data into the SLEUTH model

While urban settlements are the result of human activities in a physically restrained setting, once an urban settlement has been formed, it is the socioeconomic factors that play a substantial role in propelling urban growth. The traditional SLEUTH model only incorporates physical factors that shape urban development (Jantz *et al.* 2004) and its failure to include socioeconomic factors severely limits its usefulness, both in terms of simulating

historic growth patterns and in predicting future scenarios of where the new urban growth is going to take place.

In order to incorporate socioeconomic factors into the SLEUTH model, the function of the Exclusion layer is extended in this research. The Exclusion layer in the SLEUTH model was originally designed to be a binary layer to exclude those land cover types that are not suitable for urban use (a value of 1 means suitable and 0 means otherwise). Areas where urban development is restrained or impossible, such as open water bodies or reserved park space, are simply ignored in the growth model. In order to incorporate socioeconomic variables, firstly, an Attraction layer is generated based on the socioeconomic and demographic factors that promote urban growth. Variables that encompass demography, economy, industry, and infrastructure are collected for the 73 county-level (counties, county-level cities, and city districts) units in the JJJ Metropolitan Area. As county-level statistics from provincial yearbooks are not as abundant as those found in the census, 17 variables are finally used based on previous studies (Dou *et al.* 2000; Sit 1999; Wang and Shen 2002) and the requirements for sampling adequacy (Hair *et al.* 2005) (Table 4.2). These variables are processed using Principal Component Analysis (PCA) to generate a comprehensive attraction index (the normalized value the first component, valued from 1 to 100): the areas with higher values are more attractive for potential urban growth, and vice versa. Then, variables that include a proximity to metropolitan centers and roads are

calculated at a pixel level (30m*30m). These two variables are then reclassified to a standardized scale of 1 to 100 and combined into a Proximity layer that indicates a location's development potential. For example, areas closer to metropolitan cities are more likely to be urbanized due to the demand for housing close to urban centres. By overlaying the Attraction layer, the Proximity layer, and the Exclusion layer, a composite Suitability layer is created. The pixel value of this Suitability layer indicates the possibility that a certain area of land will become urban.

Table 4.2 Socioeconomic factors included in the SLEUTH model

Domain	ID	Variables
Demography	1	Population Density
Economy	2	Urban Employment Rate
	3	Average Wage of Staff and Workers
	4	Gross Domestic Product (GDP) Per Capita
	5	GDP Growth Index
	6	Share of Primary Industry's Product in GDP
Industry	7	Share of Secondary Industry's Product in GDP
	8	Share of Tertiary Industry's Product in GDP
	9	Gross Industrial Output (GIO) Per Capita
	10	Share of GIO from Domestic Funded Enterprises
	11	Share of GIO from Enterprises Funded by Hong Kong, Macao and Taiwan
	12	Share of GIO from Foreign Funded Enterprises
Infrastructure	13	Investment in Fixed Assets Per Capita
	14	Local Expenditure Per Capita
	15	Local Revenue Per Capita
	16	Number of Beds in Health Care Institutions per 1000 people
	17	Number of Certified Doctors and Nurses per 1000 people

4.2.5 Data input preparation

Urban layers were derived from the reclassification of detailed land cover classified maps. An adaptive-neural-based fuzzy inference system (ANFIS) is applied to classify Landsat TM, ETM images to map land cover for the following years in the JJJ urban area: 1978, 1984, 1992, 2000, and 2009. More details of this classification method can be found in the appendix of this thesis. A modified version of the Anderson land-use classification scheme is adopted (Anderson *et al.* 1976). The classification scheme included: (1) Urban land, (2) Agricultural land, (3) Forest land, (4) Barren land, (5) Wet land, and (6) Water.

The land cover maps are further converted into binary urban/non-urban layers to depict the JJJ Metropolitan Area's profile.

Transportation layers are derived from the visual image interpretation and on-screen digitization of the satellite data and the thematic transportation maps from different periods. The Slope layer is created from the ASTER Global Digital Elevation Model (GDEM), which is subsequently transformed to percent slope. All values beyond 100% in the slope layer are changed to 100 and the layer is then re-sampled to a 30 m resolution using the bilinear algorithm. The Hillshade layer is also created from the same GDEM for the study area.

The Suitability layer is a composite of three separate layers. The Attraction and Proximity layers are calculated as stated in last section, and the Exclusion layer encompasses any sites that cannot be developed: water bodies, wetlands, historical sites, airports with a 1 km buffer, railway stations, and local green spaces. These spaces within the JJJ Metropolitan area were identified and classified from satellite images, as well as thematic maps.

All these input data required for SLEUTH's calibration are clipped to the same boundary, and then converted to raster grids of 30m*30m in grayscale gif format. Table 4.3 lists the data requirements and generation methods for the SLEUTH model.

Table 4.3 Data requirement and generation methods

Input layers	Data requirement	Extraction methods
Slope	One Slope map in percentage rise	Generated from ASTER Global Digital Elevation Model
Land use	At least two land use maps were required for the model. Five land use maps were used to increase the calibration accuracy	Classification from Landsat images of 1978, 1984, 1992, 2000, and 2009
Urban extent	At least four periods of urban extent for calibration. This research employed five.	Extracted from Landsat images through image classification
Transportation	At least two road networks. This research employed five roads networks maps	Transportation maps, updated with Landsat images
Hillshade	Background for display purpose	Generated from ASTER Global Digital Elevation Model
Suitability (Attraction & Exclusion & Proximity)	One layer showing the areas that are more likely to be developed and cannot be developed	Overlay of rasterized from vector of protected areas and multi-criteria evaluated result

4.2.6 Dynamic spatial modeling

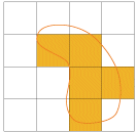
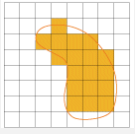
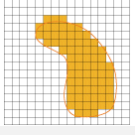
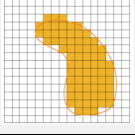
The SLEUTH model operates under the assumption that the way in which a region has developed in the past will to some extent determine how it will continue to develop in the future. As such, the SLEUTH model uses past developmental patterns to shed light on probable future changes in the study area’s urban development (Clarke *et al.* 1997). The model is implemented in two phases: the Calibration Phase and the Prediction Phase. During the calibration phase, SLEUTH replicates historical trends and patterns in urban development to “tune” the coefficients. During the prediction phase, the growth rules controlled by the calibrated coefficients are employed to project the future in a probabilistic

way. In order to forecast future change, urban growth during a given historical period must be accurately simulated during the calibration phase. To ensure accuracy, the model is calibrated by fitting simulated data to real historical data collected from the study area. In the case of the JJJ Metropolitan area, this procedure was completed using a large number of Monte Carlo iterations in three steps: Coarse, Fine, and Final (Jantz *et al.* 2004).

Table 4.4 describes the process of determining the BR coefficient. The other four coefficients (DI, SP, SR and RG) follow the same process and only the range and increment values differ after the Coarse step. The Coarse calibration step applies the widest range of coefficients (0-100), a large step value (25) for incrementing the coefficients, and the lowest spatial resolution through a resampling of the images to 1/4 of the original size (120 m). Each coefficient has the possibility of being assigned a value from these five: 0, 25, 50, 75, or 100, therefore, the combination of the five coefficients will be $5*5*5*5*5=5^5=3125$. Each combination will also be run the number of Monte Carlo times. When the Monte Carlo value is set to 2 in the Coarse step, the model will run $3125*2=6250$ interactions for a complete Coarse calibration. By using the fit statistic (usually the Leesalee value) that is generated during the model run, the results of the coarse calibration step are evaluated, producing a narrower range of coefficients in the best-fit set (Project Gigalopolis 2012). In the Fine calibration step, the range for each coefficient is further narrowed, and the increment size, the number of Monte Carlo iterations, and image resolution are all increased

to improve the results of this modeling process. The Monte Carlo iterations are run with a half resolution (60m) for input data in accordance with SLEUTH's standard calibration method. In the Final step, the best-fit results of the Fine step are used, again the ranges of possible coefficients are narrowed down, and Monte Carlo iterations are run for full-resolution (30m) inputs.

Table 4.4 Calibration process for the Breed Coefficient in SLEUTH model

Step	Resolution	Coefficient value range	Increment Step	Coefficients used for iterations	Monte Carlo Iterations
Coarse		1-100	25	0; 25; 50; 75; 100	4
Fine		70-85	5	70; 75; 80; 85	8
Final		82-82	1	82	10
Predict		82-82	1	82	100

4.3 Results and discussion

4.3.1 Result of the Calibration Phase

Coefficient values are constantly altered throughout the implementation of the SLEUTH model due to its self-modification process. Therefore, the coefficients that are the best calibrated by the stop date are selected, and their use ultimately produces a single set of stop date coefficients that allow for the initialization of the forecasting process. During the SLEUTH's running there is a certain amount of random variability and the most reliable set of coefficients can be selected for the forecasting process by using the averaged results of more Monte Carlo iterations. As shown in Table 4.4, the best coefficient values of final Monte Carlo iterations with one step increment are used to derive an average for each coefficient. Table 4.5 presents the calibration phase's results for modelling the JJJ Area, as well as the coefficients that were used during the prediction process.

Table 4.5 The optimum of the coefficient set through calibration phases

Coefficients	Calibration Phase			Prediction Phase
	Coarse	Fine	Final	
Diffusion	12	8	7	7
Breed	85	95	94	94
Spread	100	95	95	95
Slope	25	24	22	22
Road gravity	60	75	84	85

The JJJ area's high spread coefficient (95 from the final phase) represents the likelihood that urbanization will continue to occur outwards from the existing urban centre's

outskirts. Moreover, the breed coefficient for this area is also quite high (94), which indicates that there is a high probability that new urban centres will be established. Both this probability of new urban centres and the likelihood of spreading are responsible for the majority of the dispersive urban growth in the JJJ Metropolitan Area. Meanwhile, the road gravity factor is also quite high (84), which shows that road networks attract a substantial amount of urban growth. However, Table 4.5 also indicates a large increase in the Road gravity coefficient between steps: in the Coarse step the value is lower, whereas it is higher by the Final step. This discrepancy is caused by the fact that the details of transportation lines are lost when the layer is resampled to a coarse resolution (120m or 60m).

Slope resistance is low (25 from the final phase), demonstrating that topography is not a significant limiting factor for urban development. With the exception of the mountainous terrain to the north and west of the JJJ, there are no spatial constraints for the city's development across the North China plain. Lastly, the JJJ area is an urban cluster with long history of human settlements that features a large number of cities as well as numerous small towns and villages. These established settlements have higher probability of future urbanization as demonstrated by the high Breed and Spread coefficients, while the low diffusion coefficient (7) indicates the low probability that new urban centres will be established through spontaneous growth.

4.3.2 Land use/land cover change during the Calibration Phase

Land use/land cover change focuses on the nature of urban growth and the changes of other land use/cover types that necessarily accompany this process. In the context of this research, the process of urban expansion in the JJJ Metropolitan area is analyzed by extracting the spatial distribution of the urban use/urban cover classes from each map in the time series. Then, the GIS minimum dominate overlay method effectively summarizes the changes that have occurred in urban areas. The GIS method is uniquely suited to this task because it maps urban land use in the 1970s as a point of reference, and then overlays this representation with the time sequence: the net addition in the following time period. By assigning a unique colour scheme to each year's net addition on the overlaid map, the progression of urban growth in the study area is visually presented, thus allowing for a statistical summary of urban expansion for each period.

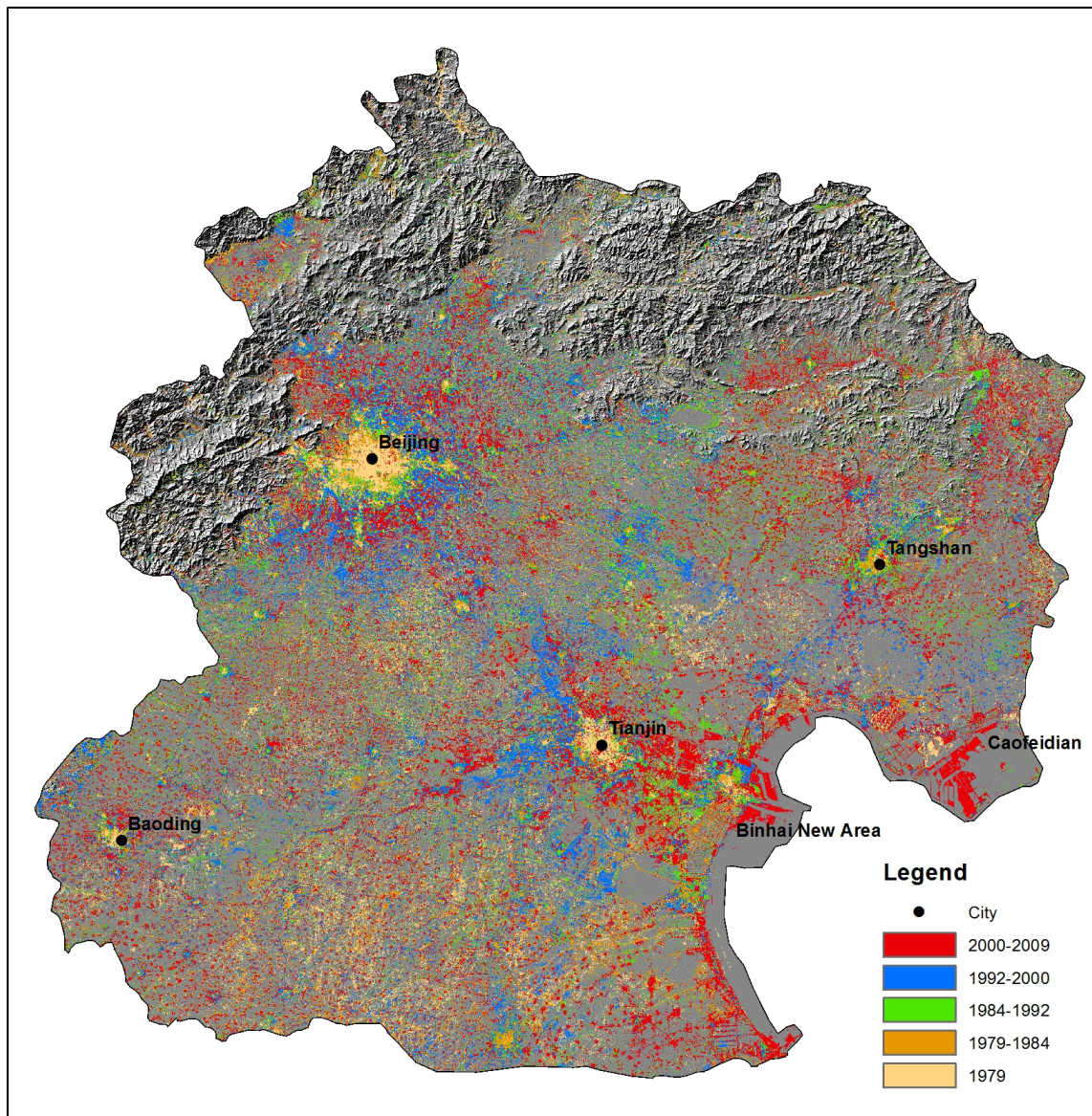


Figure 4.4 Urban expansion from 1978 to 2009

Figure 4.4 shows the spatial trends of urban expansion within the JJJ Metropolitan Area. Between 1978 and 1984, the annual urban growth rate was relatively slow at 106 km² per year, and during this period the majority of new urban development took place in the areas surrounding large cities. The pace of urbanization accelerated from 1984-1992, doubling its rate to 213 km² per year, which led to an additional 1705 km² of built-up areas.

In 1978, only 8% of this region could be considered urban (Table 4.6), and most of the newly developed land was located in the regions around highly developed cities, like Beijing, Tianjin, Tangshan, and Baoding.

Table 4.6 Land and land cover statistics for the JingJinJi Metropolitan Area

Land use/cover	1978		1984		1992		2000		2009	
	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%
Urban land	5325	8.0%	5963	9.0%	7668	11.6%	9856	14.9%	12590	19.0%
Cropland	36154	54.5%	35563	53.6%	33908	51.1%	32120	48.4%	29963	45.2%
Forest land	19471	29.3%	19216	29.0%	19061	28.7%	18534	27.9%	18179	27.4%
Bare land	576	0.9%	704	1.1%	652	1.0%	821	1.2%	695	1.0%
Wetland	1367	2.1%	1298	2.0%	1206	1.8%	815	1.2%	473	0.7%
Water	3039	4.6%	2863	4.3%	3286	5.0%	4062	6.1%	4399	6.6%
Seashore	431	0.6%	754	1.1%	580	0.9%	153	0.2%	62	0.1%
Total	66362	100.0%	66362	100.0%	66362	100.0%	66362	100.0%	66362	100.0%

The nature of urban change was analyzed by representing land conversion using a two-way cross-tabulation (a matrix analysis) that assigns a unique class to each coincidence between any two input layers. This assignment process captures the different combinations of change, such the conversion from farm land to urban land. Although there are a total of 36 possible combinations for each period due to the given number of land use and land cover classes, in order to focus on the process of urbanization, only combinations that involve conversion from non-urban to urban land were selected (Table 4.7).

According to Table 4.7, JJJ's urbanization began to take off after 1992. Between 1992 and 2000, its growth rate reached 273 km² per year, and 14.9% of the total study area was urbanized (Table 4.7). Much of the growth in the 1990s took place in small towns and cities as a direct result of the Chinese government's two Five-Year plans (the Eighth and Ninth Five Year Plans of 1991-1995 and 1996-2000 respectively). These Five-Year plans strictly controlled the development of large cities, and encouraged the growth of small cities between 1990 and 2000 (Kamal-Chaoui *et al.* 2009). As indicated by Figure 4.4, the urban growth in the 1990s (blue) was largely distributed along major roads and railways and at a distance from large cities.

Table 4.7 Land use and land cover conversion statistics

Land use/cover		Land conversion statistics			
Year A	Year B	1992-2000		2000-2009	
		Area(km ²)	%	Area(km ²)	%
Cropland	Urban	3516	45.9%	5658	44.9%
Forest land	Urban	534	7.0%	381	3.0%
Bare land	Urban	272	3.5%	429	3.4%
Water	Urban	477	3.2%	971	7.7%
Wetland	Urban	20	0.3%	11	0.1%
Seashore	Urban	6	0.1%	48	0.4%

Since the early 2000s, urban development in the JJJ Area has featured a higher urbanization speed and a more centralized pattern, resulting in 19% of the area being urbanized (Table 4.7). During this time large cities have also regained prominence for fast spatial sprawl. The early stage of suburbanization began to take shape in these cities due to growing automobile ownership and ever-increasing cost in inner-cities. Another noticeable

change in the spatial patterns is the emergence of developed areas along the coastline (Figure 4.4). China's entry into the World Trade Organization in 2001 brought about increased international trade and communication with the rest of the world. As the need for major ports for exporting and importing goods continues to increase, the capacities of China's harbours are being rapidly expanded to accommodate fast-growing business. Caofeidian, which used to be a small unpopulated island located 80 kilometres south of Tangshan, is being quickly converted into a gigantic economic development zone through land reclamation (Figure 4.4). Caofeidian had been slated to become China's largest steel production base by 2010 and the area was expected to have a population of 300,000 by 2010 (<http://www.caofeidian.us/>). Binhai New Area in Tianjin is also being developed as a new Special Economic Zone in Northern China, functioning as the Pudong New Area in Shanghai. While robust industrial economies require raw materials like salt, which is obtained by evaporating sea water, the production of sea salt in this method led to an increase in built-up areas along the coastline. Although the areas of sea shores distinguished from remote sensing images varies due to the timing (affected by the sea tide), the areas that were converted to built-up surfaces increased significantly in the past decades (Table 4.6).

4.3.3 Scenarios of the Prediction Phase

Following the model's successful calibration, the prediction mode uses the average values (Table 4.5), the full resolution data (30m), and the final Monte Carlo iterations (100)

to simulate the JJJ Metropolitan Area's potential future growth until 2050. Researchers have the potential to explore the possible consequences of policy changes by altering the composition of SLEUTH input layers and coefficients that produce future simulations. In this study, three scenarios are designed for the JJJ Metropolitan Area to maximize SLEUTH's practical application potentiality. The first scenario, the Status Quo (SQ) scenario, assumes that the JJJ Area's status quo would be maintained, and future growth would correspond with historical growth trends. Second, in the Environmental Protection (EP) scenario, various environmental considerations, such as the protection of farmland, limits future expansion. Third, the Balanced Growth (BG) allows for urban growth that is based on historical growth tendencies, but that is controlled to eliminate development disparity throughout the whole region. Xiang and Clarke (2003) suggest three criteria for defining and applying each set of acceptable scenarios: plausible unexpectedness, informational vividness, and cognitively ergonomic design. The application of these criteria to the three scenarios used in this study demonstrates the modeling method's usefulness, and also provides a coherent context for city planners' use.

In the SQ scenario, the state of growth based on historical development trend is maintained. This scenario can be applied without altering the coefficient values that affect urban growth rules or the input layers. The diffusion, breed, spread, slope resistance, and

road gravity coefficients are set at 7, 94, 95, 22, and 85 respectively, which are the best fit values from the Calibration Phase.

In the EP scenario, input layers and coefficients are modified to meet the requirements of a future forecast. Since this scenario is designed to protect environmentally sensitive land covers in the JJJ area, these land covers can be included in the Suitability input layer to increase their resistance to further urban development (Oguz *et al.* 2007). JJJ's fast urbanization has led to the loss of large amounts of valuable agricultural land. Since farming is considered to be the most substantial Chinese industry, the protection of agricultural land has always been included in the regional development plan. To achieve this goal, agricultural land is extracted from the 2009 land cover maps, and included in the Suitability Layer with low values. Forestland is in a similar situation and is also included, but with slightly higher values. The coefficients are also altered to inhibit environmentally costly growth and promote environmentally friendly development (Leao *et al.* 2004). As spontaneous growth tends to take place on agricultural lands close to transportation lines, the value of the Diffusion coefficient is reduced; urban growth on steeper terrain instead of plains can also reduce the loss of agricultural land, thus the value of Slope resistance is further reduced to encourage development on these steeper areas. The final set of coefficients for the DI, BR, SP, SR and RG used in the prediction is 1, 94, 95, 10, 85.

The third scenario, BG, is designed to plan a sustainable development scheme in the JJJ area. As discussed in the previous chapter of this thesis, Tianjin's development has been greatly affected by Beijing's "shadow effect." In the context of Beijing's unchallenged dominance in this urban cluster, planning measures are required to reach a balance between urban and economic growth in the JJJ Area. These measures would promote Tianjin's development and their outcomes can be predicted using the SLEUTH model. To achieve this, Tianjin's administrative territory is extracted and manually assigned a high suitability value. This factor is integrated into the Suitability Layer to forecast the urban development future of Tianjin, as well as the whole JJJ area. The same coefficients as in the SQ scenario are used to maintain a consistency with historical developmental tendencies and potential future growth patterns.

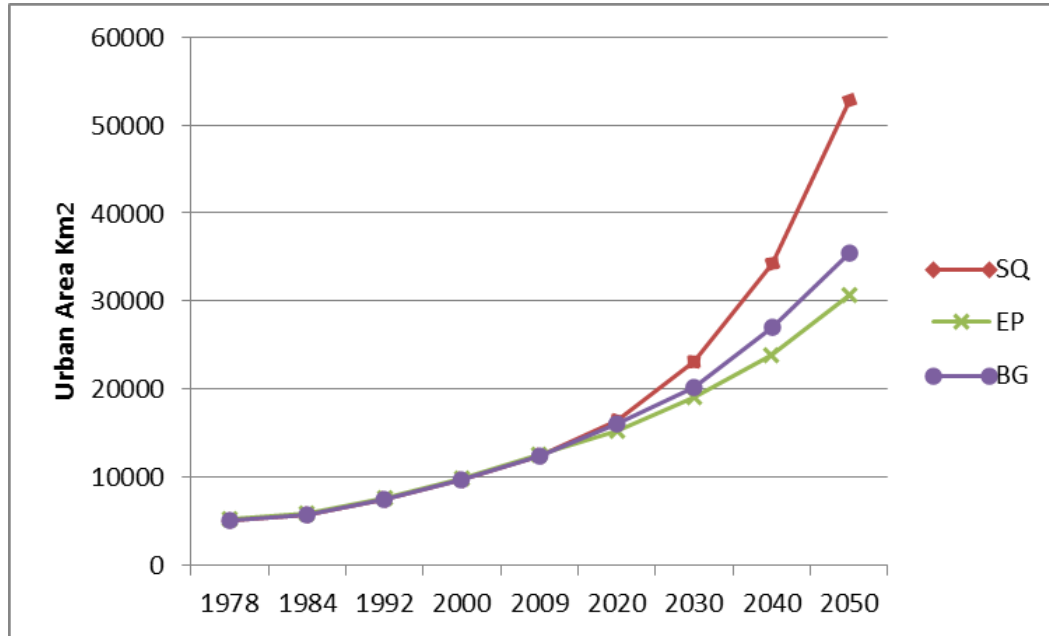


Figure 4.5 The urban area of the JJJ up to 2050 under three scenarios

Figure 4.5 compares the results of these three scenarios for urban future predictions.

The SQ scenario assumes that there are no further limiting factors to urban expansion in the future. The area of the region expanded about 200% from 2009 to 2050 with only 2.7% of urbanization occurring in unsuitable areas with regards to slope. This scenario shows the highest expansion causes degradation of land and its natural resources. The EP scenario shows the smallest increase in future expansion as compared to historical growth. Under this scenario, the city area expanded 40% from 2009 to 2050 with a larger proportion occurring in unfavourable areas such as, barren lands and steeper areas. This form of urban expansion is demonstrative of compact city growth that saves thousands of hectares of land from development. It is predicted that urban area in the third scenario will cover approximately 35688 km² by 2050, an 80% increase in size. The growth rate of Tianjin is slighter higher than Beijing (1.12:1), to reduce the disparity of these two megacities.

However simple they may be, these scenarios are based on JJJ's past urban development, and are therefore approximations since urban development is partly controlled not only by the Master Plans that control regional land use planning, but also by the upper boundaries set by municipalities. In reality, a mixture of land use planning, municipality controls, and in some cases unharnessed real estate development, is shaping the development of some of the major cities and towns. These factors create a complex situation in which defining accurate scenarios is quite difficult. Hence, except for academic researching purposes, the three scenarios presented in this study serve only as a general reference to help city managers forecast the possible outcomes of development plans and policies through the conduction of "what-if?" experiments.

4.4 Driving forces of JJJ's urban growth

It is difficult to determine trends for land cover and land use, as well as of social, economic, and demographic characteristics, since they are constantly in flux. These spatial structures are inherently unstable, and their continuous exposure to external phenomena makes them subject to frequent change. In the context of JJJ, the dynamics of urban transition can attribute to the following four factors: Urban policies, Industry restructuring, Rural-urban migration, and the Reclassification of urban boundaries

4.4.1 Urban policies

The regional urban development of the JJJ area is inescapably influenced by urban policies that were formulated and renewed every 5 years and implemented at a national scale.

Since the introduction of the economic reforms and open door policy in the 1980s that integrated China into the world economy the series of Five-Year Plans that control China's development has continued to direct its urbanization. These Five-Year Plans are government policies that determine the focus of urban development and set goals for where and how future growth will take place. From 1978 to 1988, the Chinese government declared that the objectives of its urbanization strategy were: "controlling the large cities, moderating development of medium-sized cities, encouraging growth of small cities" (National Development and Reform Commission 2012). As indicated on Figure 4.4, the

urban growth between 1979 and 1984 were widely distributed over space, due to the encouraged development of small cities and towns.

By the 1990s China had begun to enjoy the benefits of participating with the global market. Its coastal cities attracted large amounts of foreign direct investment (FDI) stimulated China's economy and prompted further urbanization. Over the next decade China continued to implement this strategy during the Eighth (1991-1995) and Ninth Five Year Plans (1996-2000), but strengthened their control over the growth of large cities. One of the measures taken by the central government to promote the development of smaller cities was to end the local government's reliance on the inter-governmental transfer of funds. Consequently, local governments were able to make land leasing a principle source of revenue and this resulted in the revitalization of inner-city areas, as well as increased suburbanization. At the end of these two plans the Chinese government was faced with the issue of regional disparities, as well as gaps between urban and rural areas. The urban growth between 1980s and 2000, as indicated by blue and green areas on Figure 4.4, are found to be surrounding the two megacities (Beijing and Tianjin) in the JJJ area, and the growth in medium and small cities, or even rural areas, are not discernible on the map.

The transition from tenth Five Year Plan (2001-2005) to the Eleventh Five Year Plan (2006-2010) is about the change of emphasis of urban development, from a city and town-based urbanization to a metropolitan urbanization. As a result, the attention was

focused on the development of metropolitan regions, especially along the eastern coast. According to Figure 4.4, the decade after 2000 was the most dynamic development phase for the JJJ area, and the whole region has experienced great urban growth, especially surrounding the megacities and along the coastline.

Currently, the Twelfth Five Year Plan (2011-2015) has recognized that, the income gap between rural and urban areas is a social that needs to be resolved. As such, this Five-Year Plan has made it a priority to promote a more balanced urban development.

4.4.2 Industry restructuring

The Modernization Theories developed in the 1950s posited that urban development in less developed countries would follow the European or American style. According to this developmental approach, cities in JJJ area should undergo an economic transition along a “continuum of progress from a traditional rural society toward a modern urban industrialized one” (Knox and Pinch 2006). Although the socialist marketism with Chinese characteristics differs greatly from capitalism, the development and industrialization steps share common characteristics.

The development of the two mega-cities, Beijing and Tianjin, has been characterized by a transition from centralization to decentralization. The increasing environmental and economic pressures induced the centrifugal movement of secondary industries. Heavy industry and manufacturing sectors were relocated to suburban areas and more land became

available for service sectors. The outward movement of heavy industries led to the exodus of employed or related residents. Meanwhile, the soaring housing price and the revitalization of inner cities also forced the suburbanization of residents.

As explained in the Core-Periphery model, economic growth in one region would trigger strong demand for sustenance and economic necessities that local producers could not satisfy. This demand would create the opportunity for investors in peripheral regions to establish a local capacity to meet the demand. Due to the Agglomeration Diseconomy in inner cities (Knox and Pinch 2006), entrepreneurs would take advantage of the cheaper land and labor in the hinterland. If this spread effects is strong enough to be trickled down to the peripheral areas to stimulate their growth, these regions can develop an upward spiral of cumulative causation. A growth pole is formed with the urban core and its periphery, which is usually characterized by a key industry whose economic influence causes linked industries to develop in the vicinity, As this key industry expands, there is an increase in the output of employment, related investments, new technologies and new industrial sectors. However, because of the theory of Scale and Agglomeration Economies near the growth pole, regional development is usually unbalanced (Knox and Pinch 2006). Meanwhile, the “trickle-down” of innovations and investments usually take decades. In the short-term, this strategy has more negative than positive effects. More specifically, the hinterlands will suffer because industries will overwhelmingly choose to locate themselves in the growth

center. The hinterland effects that dominate the early years of the growth center policy is also called the “shadow effect:” large cities expand at the expense of smaller ones, much as a larger tree can stunt the growth of the ones below it by blocking their access to sunlight (Evans 1985). In the JJJ area, Beijing is the dominant city and its development has long been prioritized due to its political status as China’s capital city. Due to this political privilege, other cities were unable to compete with Beijing, and the collaborative development relationship between Beijing and its surrounding cities became a concessive one. Essentially, the spreading effect of Beijing’s development was outweighed by the siphoning effect.

4.4.3 Rural-urban migration

Natural growth, rural-urban migration, international migration, and the reclassification of urban boundaries are the main contributing factors to urban growth. In the case of the JJJ Metropolitan Area, rural-urban migration is the most significant factor influencing its continued urban development.

Prior to the economic reforms, China’s overall development strategy relied on secondary industry, which had a low labour absorption rate, fewer opportunities for urban employment, and consequently lower levels of urbanization (Lin and Chen 2011). Such a reduction in urban employment inevitably results in an increased number of agricultural workers, and this saturation of the agricultural market results in a drop in agricultural wages,

ultimately increasing urban-rural inequality (Cao *et al.* 2000). It is this disparity between the living conditions in urban and rural areas that prompts those born in the countryside to migrate to urban centres, like Beijing, in the hopes of securing employment and a better standard of living.

However, the issue of rural-urban migration in China is a difficult one. While the *hukou* system makes it extremely difficult for rural residents to establish themselves in urban areas, China's one-child policy has led to little or no natural growth in urban centres, and so these mega-cities depend on such migration to further their development (Qi 2002). Statistics on Beijing's growth patterns put this situation into perspective: Beijing's natural growth has remained steadily at zero since 2001, and according to the 2000 census, migrants accounted for 24.4% of the population, 46% of whom were rural migrants according to Cao *et al.* (2011). Furthermore, without this influx of rural migrants Beijing's population will decrease from 10.5 million to 9.8 million between 2000 and 2030. However, if Beijing chooses to relax its migration policies, then its population could reach 21.2 million by 2030 (Cao *et al.* 2011). In summation, the future growth of JJJ's cities is largely dependent upon encouraging rural migrants to seek employment in its urban centres. Some of the challenges that these cities will have to endure in order to continue attracting rural migrants include: social and labour segregation, income disparity, incomplete welfare

system and housing system, and migration barriers like the *hukou* system and migrant children's access to education.

4.4.4 Reclassification of urban boundaries

Reclassification of urban boundaries is another factor contributing to the JJJ Area's urban growth, in terms of both population and spatial size. Owing to the prevalent measure to promote urbanization since 1983, many counties have been allowed upgrade their status to that of a city or to agglomerate into metropolitan cities. In order for this reclassification to occur, counties must meet the specific requirements enacted by a revised State Council directive in 1986. For instance, a county with a total population of less than half a million would qualify for city designation if it has a town with a nonagricultural population of at least 100,000 and an annual output of at least 300 million yuan (Cao *et al.* 2011). Prior to this State Council directive only the town would have been reclassified as a city, but with its implementation the entire county can now be reclassified. As these newly designated cities were upgraded from the county level, they contain vast rural areas and accordingly a large rural population in their proper.

Beijing has 18 administrative units including Districts, whose residents are all counted as urban population, and Counties, only a small portion of whose residents have non-agricultural *hukou* and thus counted as urban population. In 1992, eight of the 18 units are counties, and the rural population accounts for 32.1% of Beijing's total population. By

2009, six of the counties have been incorporated in the urban boundary of Beijing, leaving only two as counties and accounts for 4.2% of the total population. This expansion of administrative urban boundaries exists in every large cities in the JJJ metropolitan area.

4.5 Conclusions

To further their development, today's metropolitan cities depend upon a series of regional-level socioeconomic inputs, while at the same time their influence is also required to support the surrounding urban field. Since an urban field is defined as an area hundreds of times larger than the physical urban region itself, the way in which these modern metropolises interact with their surrounding regions has an impact on a quite extensive area (Alberti *et al.* 2003). Therefore, while the changes that accompany urban development are most noticeable on a local level, urbanization also leads to environmental and socio-cultural changes on a regional level. The reciprocal nature of this relationship between metropolises and their outlying regions can be summarized as such: a city's need for resources to develop is affected by its spatial organization and location, as well as its degree of influence on the surrounding region. While these large cities have long been recognized as drivers of local development, their importance on a regional scale has often been overlooked (Alberti *et al.* 2003; Friedmann 1966; Pickett *et al.* 2001). As such, this study of cities at a regional level has taken this knowledge gap into consideration to establish a more complete understanding of China's urban hierarchy.

In this research, the SLEUTH model was successfully calibrated for the JJJ Metropolitan Area using historical data from 1978 to 2009. As the traditional SLEUTH model is limited in its analytical capabilities due to its reliance on physical factors such as

land cover and terrain data to model urban growth, this study of the JJJ Metropolitan Area developed a method that also includes socioeconomic data. The role of socioeconomic factors in determining the course of urban development is extremely important and to account for this, a composite indicator is statistically derived from 17 variables related to the study area's demography, economy, industry and infrastructure. This indicator, together with other variables indicating the region's attractiveness and resistance to future urban development, is incorporated into the SLEUTH model to improve its accuracy. As illustrated in the calibration phase of this model, the JJJ area's urban growth over the past few decades was characterized by a dynamic and sprawling pattern, and this tendency will continue in future urban development scenarios. In addition, the speed of urbanization is not even across the study area, since larger, existing cities and coastal area are more prone to future urban development.

SLEUTH's ability to predict future urban growth was demonstrated by the projection of three future growth scenarios that were used to evaluate the potential consequences of continued urbanization. While these scenarios have a unique importance to developers and planners, it must be noted that urban growth is a complex process that is also affected by population increase, the construction of infrastructure, and other related socioeconomic factors. Furthermore, in the case of the JJJ Metropolitan Area, development is not only controlled by land use planning, municipal decisions, but also by the particular development

environment in China. Despite the SLEUTH model's heightened ability to analyze urban development patterns, it is limited because it only considers road networks when determining the effects of infrastructure on urban expansion. While the results generated by SLEUTH and other models are approximations, SLEUTH's accurate modelling method produces scenarios that are extremely useful for comparing potential consequences.

Finally, this research brought to light the extremely useful link between GIS and the CA for maximizing the results of SLEUTH's application. With the combined use of GIS and CA, the input data was more easily prepared for modeling in a raster based GIS environment and the model's results were then more easily imported into the same GIS environment for visualization. As this model is readily available for the efficient projection of different development scenarios it serves as a support tool for city planners during the decision making process.

Chapter 5 Urban Transformation of Beijing: Patterns and Process of Landscape Change

5.1 Introduction

The studies on urban social structure have been conducted extensively on Western cities. The three classic models, identified as Concentric Zone model by Burgess (1925), Sector model by Hoyt (1939), and Multile-nuclei models by Harris and Ullman (1945), have laid the foundation for the analysis of urban social spatial structure. With the emergence of factorial ecology in urban geography in the 1960s, factor analysis provided a new method to study urban social structure. From empirical studies of North American cities, following the Chicago School's ecological approach (Davies and Barrow 1973; Foggin and Polèse 1977; Murdie 1969; Timms 1971), researchers found that the social space was dominated by three main factors (dimensions) represented by socio-economy, family, and ethnicity. It is argued that each of the three dimensions takes on a particular spatial pattern reflecting the models mentioned above: socio-economic status—sector model; family status—concentric model; ethnic status—multiple-nuclei model (Shevky and Bell 1955). With the advance of urbanization, deurbanization and revitalization of the inner city, the classic mosaic of neighborhoods in central cities has become blurry as the traditional stratum of social, ethnic, and family status have been fragmented by new lifestyles and

urban behaviors. Therefore there are limitations to the factorial ecology approach, namely in the lack of social inequality, social exclusion, and also with the increasing in environmental issues (Knox and Pinch 2006).

Urban socio-spatial theories based on western cities may have limited implications on the same field in developing countries, especially China, where the fast urban and economic developments are making fundamental changes to its cities (Zhao 2011). Cities in China have been growing at unprecedented rates. The economic reform initiated in 1978, particularly following the land reform of 1987 and the housing reform in the 1990s, raised the curtain for China's development. With the sustained and steady economic liftoff since the 1980s, China's urbanization has stepped into an accelerating stage (Han 2013). According to the 2010 national census of China, 51% of the Chinese are living in urban areas. Despite the impressive speed and scale of growth, China's distinctive processes of urbanization have created unique land patterns and posed new challenges. For instance, over-urbanization, in which cities are growing more rapidly than the level of jobs and housing that they can sustain, has been a pressing problem for China. The internal structure of cities is also experiencing phenomenal changes. Cities are being spatially compartmentalized into residential segments: Luxury residence and apartment complexes are populated by "nouveau riche" from dynamic formal sector of the economy, with well-paid jobs and higher social status; these contrast sharply with the squatter and cottage

areas of people working in informal sectors of economy, who lack formal education and training and thus the opportunity to escape from a vicious circle (Knox and McCarthy 2005).

Apart from the old socialist development scheme in the 1950s or 1960s, China's recent dynamic socioeconomic and political environment has given distinctive forms and growth mechanism to its cities (Gaubatz 1999). The rapid physical and socio-economic developments of Chinese cities have been attracting increasing attention, from not only Chinese scholars but also international urban researchers (Chan 1994; He *et al.* 2006b; Kirkby 1985; Ma and Hanten 1981; Sit and Dong 1985; Small 2002; Yusuf and Wu 1997). Previous research concerning Chinese urban growth mostly fall into the following two groups: studies on the socio-economic structure based on census and annual statistics data; and studies on the physical morphology based on remotely sensed imagery.

In the first group, economists and sociologists have described cities as self-organizing systems in which emergent bottom-up processes create distinct neighbourhoods and unplanned demographic, socioeconomic clusters (Kitchen and Williams 2009; Knox and Pinch 2006). Among those pioneers in exploring Chinese urban social ecology, Small (2002) sums up an introduction of the China urban development concerning migration, urban growth rate and patterns. Zhao *et al.* (2003) depicted the dominance of large cities in terms of population, foreign direct investment and employment availability. Lo (1975, 1986, 2005)

has worked on the evolution of the social structures of Hong Kong over a span of 4 decades, revealing a structural evolution from a concentric-sector pattern to a multi-nuclei pattern; Yeh *et al.* (1995a), Wu and Yeh (1999), Xu *et al.* (1989b) have taken Guangzhou city as a case study and employed Principal Components Analysis (PCA) and cluster analysis to unveil the socio-spatial patterns using socio-economic data. Researches from a physical perspective have studied biophysical processes and patterns of urban land cover patches, as well as species configuration and habitat alternation (Cheng and Masser 2003; He *et al.* 2008; Riitters *et al.* 1995). However, as physical and social factors work simultaneously to shape urban development, neither the social nor the natural domain can explain how an integrated human and ecological systems function and evolve at various levels (Alberti *et al.* 2003). The implications of the interactions between social and physical agents at a landscape-level have seldom been explored.

This paper makes an attempt to integrate both these social and physical agents to study the city of Beijing. The research aims to answer questions about how patterns of human and biophysical responses emerge from the interactions between human and biophysical processes of cities and how these patterns in turn affect the formation of urban landscape. With the assistance of temporal analysis, this study investigates formal hypotheses about how these processes interact over time and space in Beijing.

5.2 Methodology

5.2.1 Study Area - Beijing as a city

Beijing, a metropolis in Northern China, is one of four provincial level municipalities in China. As China's capital city, Beijing has cultural, political, and historical importance, but in the last century Beijing has also taken on industrial and economic significance that makes its development worthy of study (Li *et al.* 2007; Sit and Dong 1985). As Beijing develops into a global city by attracting foreign investment, building a world-class financial centre, and hosting the 2008 Olympic Games, its developmental patterns have become a point of interest (Wei 2005). This concept of the global city is often defined and examined in terms of developed Western cities, however as an emerging Asian city Beijing's historical development has been unique, which affects its urban development.

The old Beijing Municipality in the 1950s was composed of only its urban core and immediate suburbs. The urban area was confined in the old city wall, which is now the 2nd Ring Road (Figure 5.1)²². The urban area of Beijing has been greatly extended since the economic reforms of the 1980s. Its urban expansion has been accompanied by the construction of a series of ring roads and a fully branched network of subways, and the loss of farmland and forest land, which were transformed into commercial or residential districts (Li *et al.* 2007).

²² From core to periphery, the ring roads are labeled as the 2nd, 3rd, 4th, 5th, and 6th Ring Road, and the construction year for each ring road is shown on Figure 5.4.a.

The administrative system of Chinese cities is generally described as a hierarchy, composed of one major urban core and a series of subsequent lower-level rural territories. The Beijing Municipality comprises 18 administrative sub-divisions, which are county-level units governed directly by the municipality (second-level divisions). Of these, 16 are districts and 2 are counties. Figure 5.1 shows these divisions, where Xicheng (1), Dongcheng (2), Xuanwu (3), and Chongwen (4) are at the center of Beijing, comprising the Urban Core. The region composed of Shijingshan (5), Haidian (6), Chaoyang (7), and Fengtai (8) is referred to as the “Inner Suburb.” The following six districts, Mentougou, Changping, Shunyi, Tongzhou, Fangshan, and Daxing, encompass the more distant suburbs and satellite towns, constituting the “Outer Suburb” of Beijing. The other two districts, Huairou and Pinggu, and the two counties, Miyun and Yanqing, are located further out in semirural and rural areas, which are not included in this research. Therefore, the study area of this research covers Beijing’s 14 districts excluding the four northernmost districts and counties (Figure 5.1).



Figure 5.1 Administrative divisions of Beijing

5.2.2 Research Design

A city is a product of both human and natural processes, which runs on social and physical drivers within a matrix of political, social, economic and biophysical environments.

Figure 5.2 is a proposed conceptual model that links human and biophysical drivers, patterns, processes, and effects of urbanization for the study of a city. Both human and

biophysical agents interactively work together to drive the urban socioeconomic and biophysical processes, and as a result of this integrated process, a unique urban landscape pattern is formed. Specifically, this model aims at addressing (a) what patterns emerge for both natural and developed land, (b) how these patterns influence urban functions and human behaviours (c) how biophysical and human processes operate as feedback mechanisms, and (d) what forces drive urban development patterns.

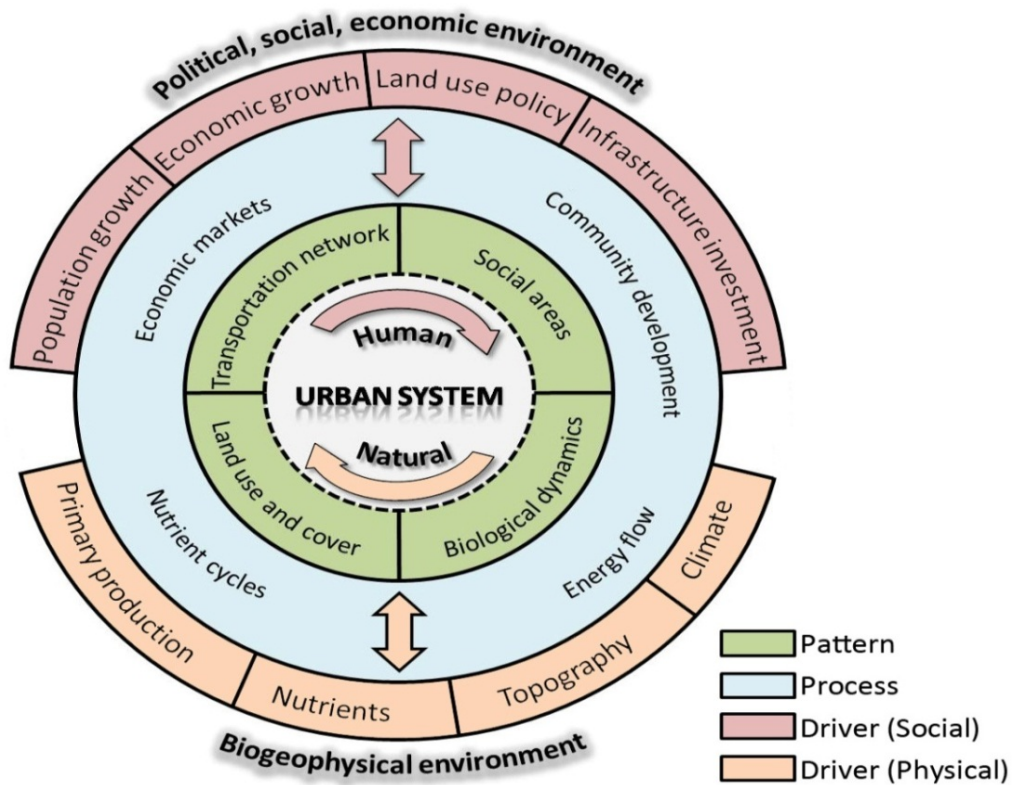


Figure 5.2 Conceptual model of Beijing as an urban system

The objective of this paper is to focus on understanding the interpretation of the economic, social and political “blueprints” that give shape and character to Beijing. Given

these considerations, the framework for this research is structured as shown in Figure 5.3: The study is carried out in three steps: the first studies the social aspect of Beijing, and the second focuses on the physical aspect, then the results of these two aspects are integrated into the third step which examines the relationship between them.

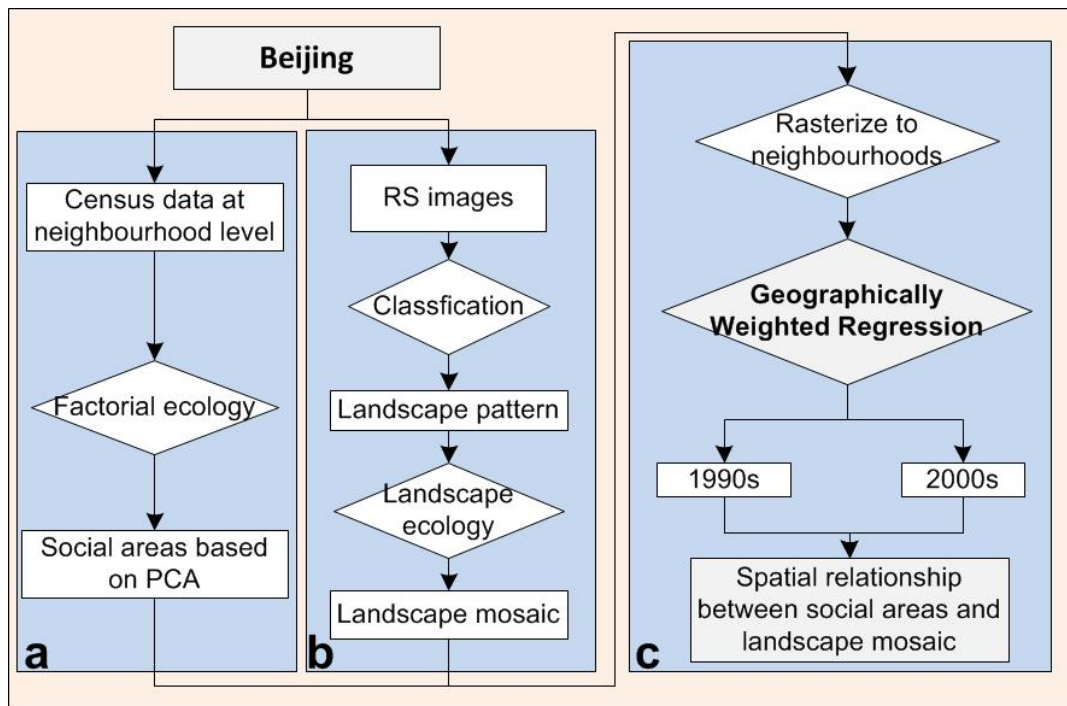


Figure 5.3 Flowchart of the methodology

5.2.2.1 Factorial ecology of Beijing – Social aspect

Adopting a factorial ecology approach, the first step aims to identify the factors that have shaped Beijing’s social landscapes in 1990 and 2000 (Figure 5.3.a). Neighbourhood-level data is collected from Census 1990 and 2000 of Beijing. Because of changing census methodology, the 1990 census omits data about ethnic groups and housing conditions, resulting in fewer variables as compared to the 2000 census. All the data has

been normalized to percentage or density over areas. However, because there is correlation among some variables, and due to inefficiency in mapping each variable individually, a technique is required to either remove highly correlated variables, or represent the data file using a smaller number of uncorrelated factors (Ferguson and Cox 1993).

Factor Analysis is often employed in data reduction process to parsimoniously identify a small number of factors to explain most of the variance in the original data file, which is usually composed of a much larger number of variables (Hair *et al.* 2005). The Principal Components extraction method is adopted in the factor analysis to condense the dimension of the data file²³. Usually, a small number of components are calculated to represent the most variation in the original variables. Each component represents one major socio-economic aspect of the data file, such as family structure or social status, which can be further mapped to illustrate their spatial patterns. For this study, Principal Component Analysis (PCA) is used to identify the factors (principal components) and give them scores relative to their importance for Beijing's internal social transformation in the 1990s and 2000s at the neighborhood level (Cao and Villeneuve 1998).

²³ The principal component extraction procedure starts by identify the first component that explain as much variance in the input variables as possible through a method of linear combination of these variables. It then seeks for the second component that accounts for as much of the remaining variation as possible. The second component should not have correlation with the first component. This procedure continues in this way until the set Eigenvalue is reached or the number of components found is the same as original variables (Hair *et al.* 2005).

5.2.2.2 Landscape ecology of Beijing – Physical aspect

Figure 5.3.b depicts the second step in the methodology of this paper. The physical land use and cover maps are extracted by processing Landsat TM remotely sensed images that have the same temporal span (1990, 2000 and 2009). For this process, a modified version of the Anderson land-use classification scheme was adopted (Anderson *et al.* 1976), including: (1) Urban land, (2) Agricultural land, (3) Forest land, (4) Barren land, and (5) Water. The supervised maximum likelihood classifier was used to produce the land-use/cover pattern. Landscape patterns are derived based on the land-use/cover maps with ancillary sources such transportation and Digital Elevation Model (DEM).

Transportation infrastructure plays a significant role in determining the extent of urban sprawl, and Beijing's ring roads are the city's most important commuter routes. A buffer zone that is delineated by centre lines between the ring roads and boundary of the research area is designed to examine the long-term trends in urban development as it spreads outwards from these roads over the past three decades. Since the ring roads were built during different periods (Figure 5.4.a), the influence of their construction can be investigated by temporal and spatial comparison of the urban growth in different zones. Meanwhile, since the urban expansion of Beijing is not spatially uniform, a pie-shaped zone of eight directions is designed to measure the magnitude of urban sprawl over the different sectors by landscape metrics (Figure 5.4.b).

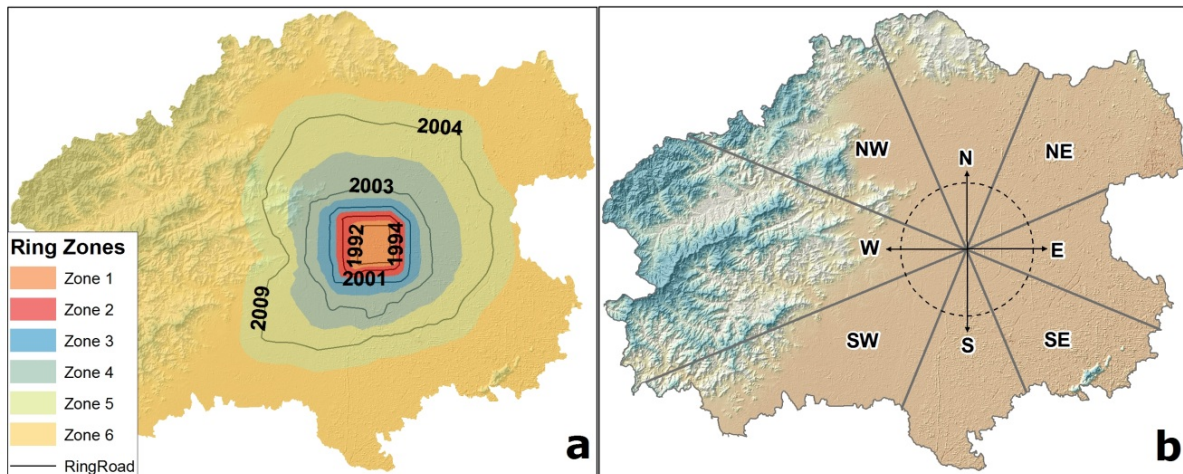


Figure 5.4 Zoning maps of the study area

While landscape ecology has produced hundreds of landscape metrics, many of them are highly correlated (Riitters *et al.* 1995) and it is possible to adequately represent the complex patterns of urban transformation with a single metric. Hence, to obtain an accurate representation of urban evolution, a collection of metrics must be compared across time and space. It is best practice to use the fewest uncorrelated metrics to adequately represent land cover classes, patch compactness and fragmentation, as well as landscape shape complexity. The methodology employed by Riitters *et al.* (1995) is used as a guide to select the most appropriate composite of four metrics, namely the percentage of landscape (PLAND), number of urban patches (NP), Landscape shape index (LSI), and Perimeter-Area Fractal Dimension (PAFRAC).

5.2.2.3 Spatial regression analysis of the social ecology and landscape ecology

For the third step in this research a regression method is used to examine the relationship between the social and physical patterns of Beijing, as show in Figure 5.3. The

social and physical landscape patterns change simultaneously throughout the urbanization process, but is there any spatially statistical relationship corresponding to the evolution of these two patterns? Research in urban modeling suggests that the current physical landscape pattern is the outcome of a development process, and such a process is often controlled and constrained by both social and demographic activities (Alberti *et al.* 2003). In fact, the process of suburbanization driven by socioeconomic development fragments forests, agricultural land, removes native vegetation, and demands increased mobility with an intensive transportation infrastructure (Riitters *et al.* 1995). Such landscape and environmental changes may eventually reduce the quality of life in suburban areas and may lead to more development in farther locations.

It is difficult to run traditional (non-spatial) regression, such as ordinary least squares (OLS) regression, on spatial data due to two reasons (Scott and Pratt 2009): First, spatial autocorrelation exists among spatial features since features close to each other tend to be more homogeneous than features that are distant. Spatial distance, or location information, are usually overlooked in nonspatial regression methods and this often leads to overcount type of bias. Second, regional variation is inherent to spatial data. The non-stationary characteristic of spatial processes means that spatial process varies in different areas of a study area.

Spatial regression methods, geographically weighted regression (GWR) technique for example, are able to capture spatial variations in regression analysis, as well as providing diagnostics on spatial relationships among the variables involved (Fotheringham *et al.* 1998). Unlike the linear regression technique that assumes that the relationship is constant throughout space, GWR considers the spatial variable as non-stationary and allows the regression relationship to vary over space. In the process of urbanization, for example, the processes that caused urban land use/cover change are not stationary everywhere, but GWR is able to count this spatial variation into determining the causal factors for this change.

5.3 Results and analysis

As the research methodology indicates, the study of Beijing is implemented in three steps. First, the social landscape patterns are identified through the method of factorial ecology; Second, the physical landscape patterns are represented using landscape metrics; Third, the spatial and statistical relationships between social and physical landscape patterns are examined using the GWR.

5.3.1 Social landscape of Beijing

The factors that have shaped Beijing's social landscape since the 1978 economic reforms are best revealed through social areas, which are generated from factor analysis (PCA method) of the study area. Through the support of previous studies (Dou *et al.* 2000; Sit 1999; Wang and Shen 2002), and statistical theories on sampling adequacy (Hair *et al.* 2005), the 29 variables listed in the 1990 statistical yearbook and the 41 variables listed in the 2000 statistical yearbook, are selected.

5.3.1.1 Modeling results

In order to run a valid factor analysis, all variables and observations are guaranteed to satisfy the six requirements of PCA (Child 2006; Ferguson and Cox 1993): 1) Variables included in the analysis from both 1990 and 2000 are all numerical ones and standardized; 2) The ratio of observations to variables is greater than 5; 3) The correlation matrix for the variables must contain more than 2 correlations of 0.30 or greater; 4) Variables with

measures of sampling adequacy less than 0.50 are removed; 5) The overall measure of sampling adequacy by Kaiser-Meyer-Olkin are higher than 0.50; 6) The Bartlett test of sphericity is statistically significant. The overall performance of the models for 1990 and 2000 is summarized in Table 5.1.

Table 5.1 Overall performance of analysis

Year		1990	2000
Observations (No. of Neighbourhoods)		254	267
Variables		29	41
Factors (Components)		5	8
% of variance explained by factors above		85.28%	79.31%
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.715	.801
Bartlett's Test of Sphericity	Approx. Chi-Square	14433.86	23776.31
	df	406	861
	Sig.	*	.000

Factors with Eigenvalues greater than 1.0 are extracted from PCA results. The 1990 model extracted five factors, which explain 82.90% of the total variance (Table 5.2). The 2000 model, however, explains 79.31% of the total variance of using eight extracted factors. Since the last two factors of 2000 account for a smaller portion of the variance and are mostly extracted from one or two individual variables, they are excluded from the analysis and only the first six components are selected to represent the social areas of Beijing in 2000.

Table 5.2 Variance explained by components

Factor	1990			2000		
	Eigenvalue	% of Variance	Cumulative %	Eigenvalue	% of Variance	Cumulative %
1	10.67	36.79	36.79	8.99	21.41	21.41
2	3.99	13.75	50.55	6.52	15.52	36.93
3	3.70	12.75	63.30	6.02	14.34	51.27
4	3.09	10.64	73.94	4.37	10.41	61.68
5	2.60	8.96	82.90	2.62	6.23	67.91
6				1.81	4.31	72.22
7				1.53	3.63	75.86
8				1.45	3.45	79.31

As demonstrated in Table 5.3 the first factor accounts for the largest amount of variability among all factors, followed by lower order factors with diminishing explanatory power. Though the number of factors increased by 2 in the 2000 census (6 factors in 1990 and 8 in 2000), the overall explanatory power was reduced in 2000, measuring 82.9% and 79.22% respectively (Table 5.3). This suggests that the urban mosaic has become more complex when comparing between 1990's and 2000's, and therefore more difficult to interpret with limited variables. In 1990, the first factor, representing the most dynamic urban population with couple-type family structure and tertiary sector jobs, explained more than one third (36.79%) of the variance. In 2000, however, a similar factor in which higher education has played a bigger role accounts for approximately one fifth of the variance (21.41%) (Table 5.3). In addition, the change of the industry's structure has also led to the transformation of social space in the city: The second factor in 1990, which represents the population working in the heavy industry sector, downgraded to the sixth factor in 2000,

while temporary population (floating or seasonal workers) emerges as the second largest factor. Except for the industry of employment, the social space of 1990 is remarkably related to family structure. For example, the first factor features couple-without-children family type and the second factor is labeled as couple-with-one-child type. The third factor, on the other hand, refers to those large families with three or more generations living together, and the fourth factor refers to single elderly people living alone. The social areas of 2000 have become more mobile, where population with high mobility accounts for 14.34% of the total variance. Since detailed ethnic variables are not available in 1990, ethnic groups are not identified as a factor in 1990, but they explain almost 10% of the total variance for 2000 as the fourth factor, which is defining the social space of Beijing.

Other than the changes in the composition and order of the factors between 1990s and 2000s, the spatial distribution of these factors has also shown unique patterns, which are discussed respectively in the following sections.

Table 5.3 Component matrix of the factor analysis, 1990 & 2000

	1990	% of Variance	2000	% of Variance
Factor 1 Tertiary industry workers		36.79	Highly-educated with better jobs	21.41
Houseworker as Non-working %		-.92	Public Owned House, Rent or Bought	.86
Non-agricultural population %		.90	Higher Education %	.83
Retired %		.84	Non-Agricultural Population %	.83
Occupation in Government %		.84	Basic Education %	-.81
Occupation in Professional/Technical %		.80	Employment in Tertiary Industry, Quality of Life Service %	.77
Occupation in Clerical Workers %		.79	Retired %	.75
Illiteracy rate %		-.78	Illiterate Rate %	-.69
Disabled %		-.76	Age group 0-14 %	-.64
Age group 0-14 %		-.74	Employment in Primary Industry %	-.58
Age group 15-64 %		.73	Population Density	.58
Occupation in Primary Industry %		-.72	Employment in Tertiary Industry, Production %	.55
Higher education %		.70		
Family of 1 generation %		.65		
Four persons family %		-.64		
Two persons family %		.62		
Divorce Rate %		.55		
Occupation in Sales %		.54		
Factor 2 Secondary industry workers		13.75	Temporary population in poor living environment	15.52
Occupation in Production & Transportation Facility %		.85	Housing, Poor Condition	.83
Three persons family %		.71	Average Floor Space of Building	-.77
In-coming population %		.41	Family of 1 Generation %	.70
			Family Size	-.69
			Family of 4 Generations %	-.67
			Employment in Tertiary Industry, Circulation %	.66
			Family_3 Generation %	-.62
			Average Rooms of Household	-.62
			Temporary Resident %	.58
			Divorce Rate	.58
			Unemployment Rate	.57
Factor 3 Large families		12.75	Population with high mobility	14.34
Family of 3 generations %		.91	Housing, Low Rent Apt. or House	.87
Five persons and over family %		.88	Population Mobility	.81
Family of 4 generations %		.82	Age group 0-14 %	.80
Five persons family %		.64	One Member Family 15-64 %	.76
			One Member Family 65 and Over %	-.75
			Age group 65 and Over %	-.72
Factor 4 Aged population living alone		10.64	Ethnic minorities	10.41
Age group 65 and Over %		.84	Nationality, Zhuang	.85
One person family %		.76	Nationality, Uygur	.82
Family of 2 generations %		-.61	Nationality, Mongolian	.82
			Nationality, Korean	.72
			Nationality, Manchu	.60
			Nationality, Tibetan	.56
Factor 5 Unemployed		8.96	People with Public Administration jobs	6.23
Unemployment Rate %		.84	Employment in Tertiary Industry, Public Administration Service %	.56
Basic education %		-.76	Nationality, Hui	.54
Factor 6			Secondary industrial workers owing properties	4.31
			Housing, Medium House or Apt Owner	.85
			Employment, Secondary Industry %	.49
Total		82.90		72.22

5.3.1.2 Social space of Beijing, 1990

The social mosaic has also been substantially transformed geographically, and the spatial variation can be revealed by mapping out the score of each factors.

The first factor represents tertiary industry workers live in the Urban Core (Figure 5.5.1) who are mainly from small-sized families and have relatively higher education background. Since both members of the families have a job in the tertiary department, they are better off in terms of living conditions. However, divorce rate is relatively high for these two-person families without children (Table 5.3).

The second component features workers in the secondary industry, such as people working in Production & Transportation Facilities (Table 5.3). Most of these people live in the Inner Suburban areas and they tend to live in three-member families (Figure 5.5.2), typically two parents with one child, as the nationally enforced birth-control policy has been in effect for a decade. Since secondary industry workers' houses in the 1990s were usually provided by their work units²⁴, the location of their residences are close to their working places.

²⁴ Before the housing reforms in the mid-1990s, housing for urban residents was provided by Danwei (working units) for free. However, the residents could continue living at the same place after the reforms if they paid a small commission fee to obtain usage rights.

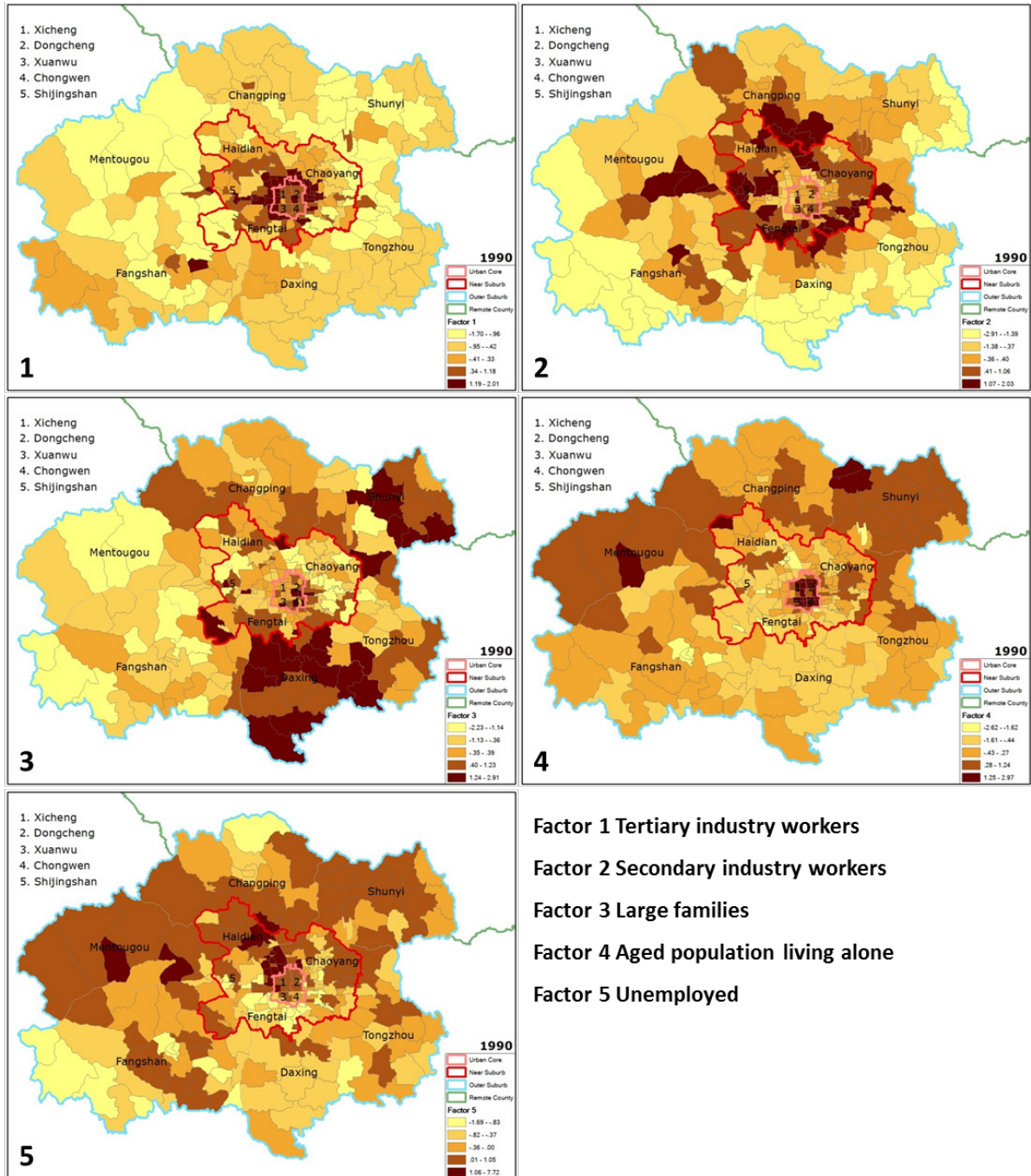


Figure 5.5 Social space of Beijing, 1990

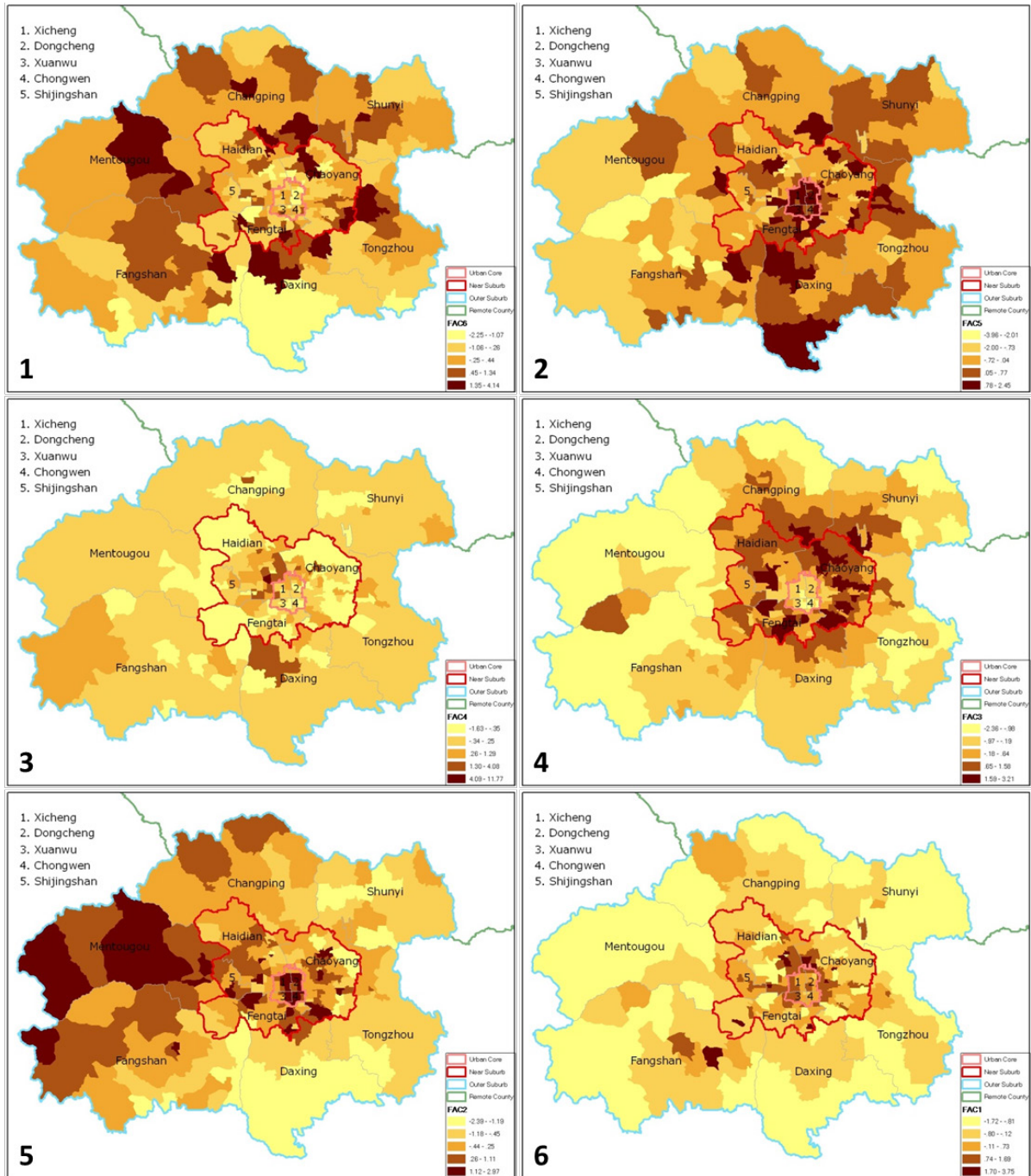
The third component refers to the population living in larger families with four members or more (Table 5.3). As the birth-control policy was only implemented in the beginning of the 1980s, by the 1990s there still remained a large proportion of families with two or more children. They are mostly located in the Outer Suburban areas, especially the southern districts like Daxing and Tongzhou, where agricultural population accounts for a larger proportion (Figure 5.5.3).

The fourth component, however, represents a special social group, elderly population aged over 65 (Table 5.3). These people were mostly unemployed and therefore do not include the retired population who are categorized in the first factor. They are mainly located in the Northern Outer Suburban areas and some areas in the Urban Core (Figure 5.5.4). Essentially there are two groups of people that make up this component in these two areas, older former farmers in the Outer Suburban areas, and older people that have always lived in the Urban Core.

The last component represents population with higher unemployment rate. It appears that lack of basic or higher education is one of the main contributors to this high rate (Table 5.3). This category of population is largely distributed in the north of Beijing, especially the Outer Suburban areas (Figure 5.5.5). The makeup of this population is typically younger people from farming families that have stayed in the area.

5.3.1.3 Social space of Beijing, 2000

The first component of 2000 represents highly-educated people with better jobs in the tertiary industry (Table 5.3). This population lives in the transition zone of the Urban Core and the Inner Suburban areas, mostly in Haidian, Chaoyang, Xicheng and Xuanwu districts (Figure 5.6.1). Higher education plays a more important role in 2000. Due to the fierce competition in the job market, education level is usually highly related to social status, especially in a highly populated megalopolis where labor force is oversupplied. In addition, the Chinese government enacted a series of educational and economic policies to promote people's investment on higher education in the mid-1990s. As a result, a large number of colleges and universities were established during that time, and the proportion of highly educated population increased greatly.



Factor 1 Highly-educated with better jobs
Factor 3 Population with high mobility
Factor 5 People with Public Administration jobs

Factor 2 Temporary population in poor living environment
Factor 4 Ethnic minorities
Factor 6 Secondary industrial workers owing properties

Figure 5.6 Social space of Beijing, 2000

The second component represents temporary population in poor living conditions, usually migrants with a small family size and high unemployment rate. As the education level for this population is relative low, it is difficult for them to find jobs other than in Circulation or Transportation (Table 5.3). The divorce rate for this group of people is relatively higher. They mainly live in the Urban Core and some neighbourhoods in the Inner Suburb (Figure 5.6.2). The social space is quite scattered, but all of the neighbourhoods host residences with inferior conditions, such as smaller floor space and shared facilities. While this component was prominent in 2000, the 1990 census did not include the measurement because the temporary population was much smaller and still a new phenomenon.

The third component represents population with high mobility (Table 5.3). These people are usually of working age, in a single-member family, renting a low-rent apartment to live in the Inner Suburb areas (Figure 5.6.3). This is a relatively new phenomena likely resulting from post-1978 policies, including the One Child Policy and the gradual marketization of the work force.

The fourth component represents ethnic minorities, and is newly measured in 2000 (Table 5.3). Ethnic minorities are not widely distributed in Beijing, mainly concentrated in several districts like Haidian, Changyang and Daxing (Figure 5.6.4). Again, because mobility increased after the initiation of reforms in 1978, and particularly during the 1990,

the presence of minorities increased by the time of the 2000 census enough to make this the fourth largest component.

Components five and six are the least important components, each accounting for less than 10% of the variance. Since Beijing is the political center of China, those people with jobs in Public Administration services, as well as the Hui Minority, consist the fifth component, and they tend to be located in the Urban Core (Figure 5.6.5). Though there is a measure for minorities (as seen in component four), the Hui minority has a long standing presence in Beijing, and as such as been included separately in the fifth component. The last and least important component is composed of Secondary industrial workers owning properties; they tend to live in the Outer Suburb and along the boundary of the Inner Suburb (Figure 5.6.6). While this factor is measured as the second largest factor in 1990 and these people were living in the Inner Suburban areas, it is the relocation of heavy industry of Beijing that has resulted in the exodus of this group of population.

5.3.2 Landscape ecological analysis

Social areas represent stratified dimensions of the urban population's characteristics and behaviors, where people of similar living standards, occupations, ethnic background, and life-style tend to be grouped together but segregated from others (Knox and McCarthy 2005). A landscape ecology approach, on the other hand, employs a series of metrics to describe the physical footprint of the urban space, as a result of development of social areas

and also as a basis to predict future social space. Based on the method described in section 5.2.2.2, selected landscape metrics are calculated from FRAGSTATS and used to quantify the structure and characteristics of landscape patterns (McGarigal *et al.* 2002).

5.3.2.1 Landscape metrics over time and space

As the process of urbanization is usually non-reversible, the built-up area increases and the landscape evolves as urban growth continues. This section will use four indicators: PLAND, NP, LSI, and PAFRAC to measure and assess landscape changes.

The Percentage of Landscape (PLAND) measures landscape composition by quantifying the proportional abundance of urban patch type in a given landscape (McGarigal *et al.* 2002). Since the PLAND's measurements are relative, it is more appropriate to measure the composition of an urban landscape than a class area when comparing landscapes of varying sizes. Figure 5.7.a and Figure 5.7.b illustrate PLAND metrics over time and space, respectively. According to Figure 5.7.a, Zone 1 and 2 were saturated for further urban development by 1990. This is reflected by their minimal variation in PLAND values since the 1990s. Zone 1 encompasses the whole Urban Core and Zone 2 covers the Inner Suburb areas surrounding the Urban Core, hence both of these zones are highly populated with a long history of urban development. The second ring road built in 1992 and the third ring road built in 1994 were previously used as the “backbone” of transport system before suburbanization was initiated in Beijing. Zone 3 was also largely

(77.8%) urbanized by 1990, and this development reached a saturation point (85%) by 2000. Zones 4 and 5 have benefited the most from increased suburbanization. Urban sprawl spread at extraordinary speed towards the outer districts of Beijing, and this tendency was further accelerated by the construction of both the fifth (built in 2004) and sixth (built in 2009) ring roads, as well as the rapidly increasing prevalence of private vehicles. Zone 6, however, encompasses remote rural areas that are still largely covered by forests and agricultural lands. In addition, urban development's outward spread did not progress isotropically (evenly in all directions). As indicated by Figure 5.7.b, the eastern sector has experienced the greatest urban development, while the growth in the western and northwestern sectors was heavily constrained by the mountainous terrain. In a general pattern, the gap between the PLAND lines of 1990 and 2000 is larger than that between 2000 and 2009 in both Figure 5.7.a and Figure 5.7.b. This indicates that the decade before 2000 experienced a more rapid rate of urban growth than the decade following 2000.

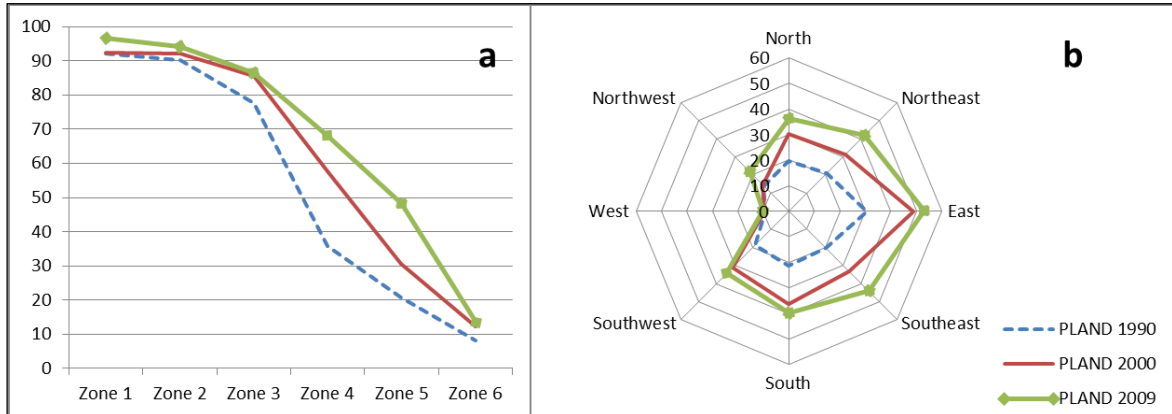


Figure 5.7 The PLAND metric over time and space

The Number of Urban Patches (NP) metric is a measure of discrete urban areas in a landscape. As such, a decrease in NP would be observed if urban areas expand and amalgamate together, but an increase is expected during periods of rapid, spontaneous urban development where new urbanized areas emerge (commonly seen in the early stage of urbanization) (McGarigal *et al.* 2002). Figure 5.8.a shows that Zones 1, 2, and 3 all have a low variation in the number of urban patches over time due to the fact that in these zones built-up areas tend to be clumped together to form larger urban regions. However, Zones 4, 5 and 6 all experienced a noticeable decrease in their NP metric between 1990 and 2000, indicating an expanding sprawl pattern based on existing urban centers. The rural Zone 6, however, has an increasing number of urban patches after 2000, indicating that small urban village areas were rapidly developing in remote areas at this time. In terms of directional sectors, as the urban areas in the southern and southwestern sectors were highly scattered with large numbers of patches in 1990, they experienced a large scale urban in-filling between 1990 and 2000, resulting in a great reduction in the NP metric. Although the

eastern (East, Northeast and Southeast) sectors grew faster than other sectors, their NP metric's variance is substantially less noticeable due to the agglomeration of urban patches.

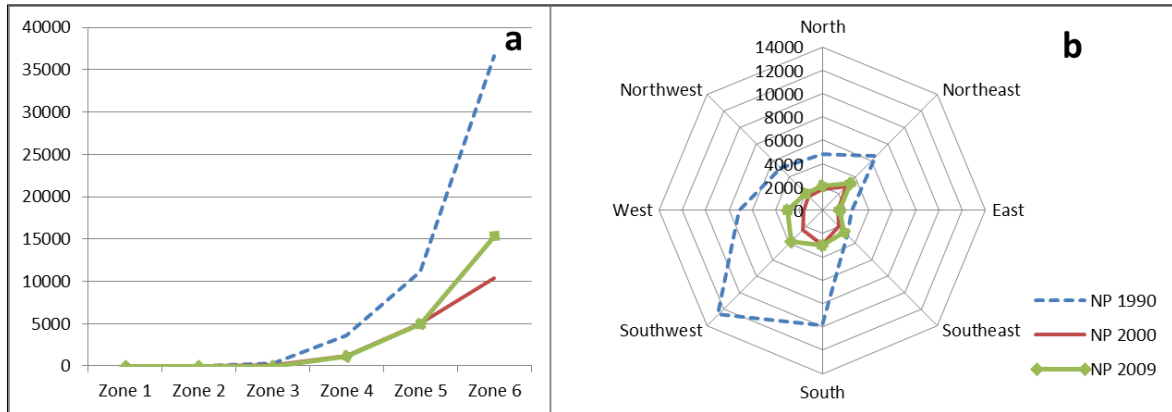


Figure 5.8 The NP metric over time and space

The Landscape Shape Index (LSI) measures the total length of edge (or perimeter) of urban patches divided by the minimum length of urban patches' edge possible for a maximally aggregated state. This state can only be theoretically reached when all the patches are dissolved into one single patch (McGarigal *et al.* 2002). The LSI is a simple measure of class clumpiness. Its value declines as urban areas agglomerate and boundaries dissolve, and a large value indicates a highly fragmented landscape with complicated edges. The LSI provides more information about a class's edge or perimeters than does the NP, thus reflecting the patch complexity in the landscape. According to Figure 5.9.a, the LSI decreases from 1990 to 2000, especially in the outer zones (Zone 3 to Zone 6), which confirms that the urban patches have merged, thus reducing the total edges of all patches. There is a small increase in the LSI values from 2000 to 2009, showing that the urban

landscape has become more fragmented since 2000. The LSI shows a similar pattern in almost all directions, although the decline rate in the south and west far exceed the other directions between 1990 and 2000.

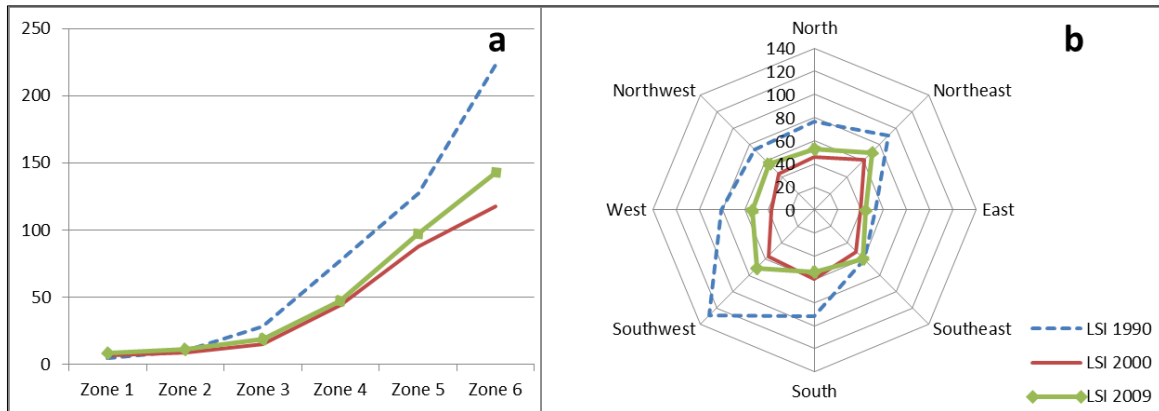


Figure 5.9 The LSI metric over time and space

The Perimeter-Area Fractal Dimension (PAFRAC) measures the patch shape complexity of the whole landscape. All types of land cover classes (Built-up, Forest, Agriculture, etc.) are included in this landscape-level index to show the zone’s fractal dimension. To calculate PAFRAC, the number 2 is divided by the slope of regression line, which is obtained by “regressing the logarithm of patch area (m^2) against the logarithm of patch perimeter (m)” (McGarigal *et al.* 2002). Essentially, the PAFRAC has a value ranging from 1 to 2. It approaches 1 when the landscape is composed of simple perimeters such as squares and circles, and approaches 2 when the patches in the landscape have shapes with highly complex, plane-filling perimeters. A PAFRAC value deviating further from 1 indicates a larger departure from a Euclidean geometry (regular square or circles) and a

stronger patch shape complexity. As shown in Figure 5.10.a and Figure 5.10.b, from 1990 to 2000 there is a drop in the PAFRAC value for every zone and in all directions, meaning that the patches were becoming more regular and less complicated in terms of perimeters due to expanding growth pattern of the urban areas. Since 2000, however, the PAFRAC values have increased somewhat, indicating that the overall complexity has increased and the landscape has become more fragmented.

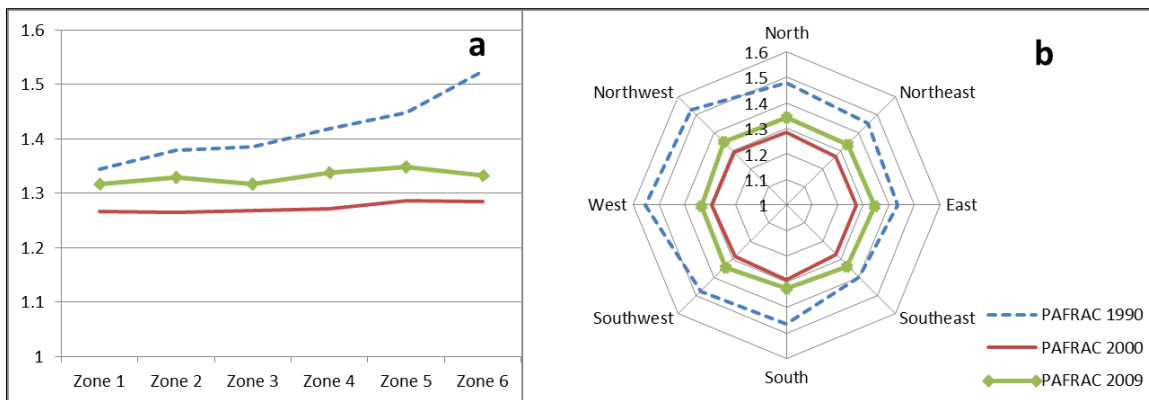


Figure 5.10 The PAFRAC metric over time and space

5.3.2.2 Landscape change patterns

The analysis of PLAND, NP, LSI and PAFRAC show that the landscape change of Beijing due to urbanization between the 1990 and 2000s demonstrates the following characteristics:

- 1) The Urban Core and inner strip surrounding the Urban Core (Zone 1 and Zone 2) were saturated before 1990 and lacked space for further surface developments. As such, intensification or vertical development, such as high-rise buildings, and the

revitalization of the old downtown are the only options available to meet the growing need for space in the Urban Core.

- 2) Suburbanization is playing a leading role in expanding Beijing's development. It is taking place at an extraordinary rate, quickly converting non-urban land into built-up areas. However, this process has slightly slowed down since the 1990s, and continues to slowly decline.
- 3) While Beijing is suburbanizing outwards in all directions (a growing pancake pattern), the rate of growth is uneven and varies depending on a number of factors including topographic restrictions and the construction of new roads. The eastern suburbanization (Chaoyang, Tongzhou) is largely characterized by outwards growth from existing urban centres, while towards the south (Fengtai, Fangshan, Daxing), new urban areas are being established, and the space between them slowly being filled up.
- 4) Fragmentation (irregularity and complexity) of the whole landscape decreases in the decade of 1990-2000 due to the early-stage development pattern, and fragmentation increases in the later decade due to more complex growing pattern.

Landscape fragmentation due to urbanization, transportation infrastructure, and other human development poses a threat to environmental integrity (Girvetz *et al.* 2008).

Meanwhile, urban fragmentation can also reflect the phenomenon of increasingly differentiated societal and spatial polarization within cities, which represent a threat to social cohesiveness on a political-planning as well as on a subjective-perceptive level (Deffner and Hoerning 2011).

5.3.3 Spatial Regression Analysis

While the social and physical landscapes of Beijing have been explored through the methods of factorial ecology and landscape ecology respectively, the relationship between the above two landscapes remains unanswered. The GWR incorporates the data's spatial structure into the estimation of the regression model's parameters and shows how these estimates vary across space. It also serves as an analytical tool to examine variations in the relationship between variables over geographic and data space (Scott and Pratt 2009). A common approach to regression analysis is to identify the best OLS model possible before moving to the GWR. In this study, relationships between the dependent variable, urban physical landscape change, and the independent variables, social factors, are modeled using both the stepwise OLS regression and the GWR.

5.3.3.1 Results and performance of the OLS regression

In total, eight OLS regression models are constructed, four for 1990 and four for 2000, each performed with one of the four landscape metrics, PLAND, NP (PD), LSI and PAFRAC, to investigate the relationships between social factors and the landscape metrics.

Since the value of NP varies greatly among neighbourhoods of different size, we substitute the Patch Density (PD) for the NP in the regression. The PD has the same basic utility as the NP as an index, except that it is a standardized variable that counts number of patches on a per unit area basis to facilitate comparisons (McGarigal *et al.* 2002).

For both 1990 and 2000, much of the variations in the dependent variables of the PLAND and the LSI can be explained by social factors (Table 5.4 and Table 5.5). As shown in Figures 5.4 and 5.5 83% of the PLAND's variation in 1990 and 73% in 2000 can be modeled by a linear relationship between this landscape index and corresponding significant social factors. However, the relationships between the PD and the PAFRAC and social factors cannot be modeled linearly as well as the previous two (by R^2 in Table 5.4 and Table 5.5). Therefore, we will take the PLAND and the LSI to investigate the relationships between social and physical landscape in the following steps.

The coefficient for each explanatory variable reflects both the strength and type of relationship the explanatory variable has to the dependent variable. The PLAND has a positive relationships with the first three factors in 1990 (the larger the value of factors, the larger value of PLAND), while in 2000 it has positive relationships with factors 1 to 5 and negative with factor 6. The LSI, on the other hand, has negative relationships with all explanatory variables in both 1990 and 2000 (Table 5.4 and Table 5.5).

Table 5.4 OLS regression models in 1990

	Dependent Variables			
	PLAND	PD	LSI	PAFRAC
	Coefficient	Coefficient	Coefficient	Coefficient
Intercept	48.57 *	4.40 *	14.01 *	1.39 *
Factor 1	28.67 *	-2.08 *	-6.90 *	-0.07 *
Factor 2	14.40 *	-1.04 *	-3.80 *	-0.03 *
Factor 3	10.33 *	-1.41 *	-4.81 *	-0.01 *
Factor 4		0.62 *	1.70 *	
Factor 5		-0.57 *		
No.	254	254	254	225
AICc	2120.06	1383.85	1730.70	-543.86
R ²	0.83	0.39	0.63	0.51
Joint Wald Statistic	2556.63 *	203.90 *	663.46 *	213.88 *
Koenker (BP) Statistic	48.45 *	39.52 *	23.36 *	8.37 *
Jarque-Bera Statistic	31.92 *	924.44 *	852.91 *	5.00
Spatial Autocorrelation (Moran's I) Summary				
Moran's Index:	0.25	0.45	0.37	0.39
z-score:	10.81 *	19.97 *	16.35 *	14.83 *

* Statistically significant at the 0.05 level.

Table 5.5 OLS regression models in 2000

	Dependent Variables			
	PLAND	PD	LSI	PAFRAC
	Coefficient	Coefficient	Coefficient	Coefficient
Intercept	55.551*	1.705*	8.193*	1.272*
Factor 1	19.627*	-.514*	-3.741*	-.011*
Factor 2	10.103*	-.709*	-3.461*	-.012*
Factor 3	11.161*		-1.143*	
Factor 4	5.603*	-.210*	-.735*	
Factor 5	12.180*		-.791*	-.013*
Factor 6	-2.484*	-.141*		.007*
Factor 7				.006*
Factor 8		.211*		
No.	267	267	267	239
AICc	2290.19	759.72	1384.00	-893.47
R ²	0.73	0.48	0.74	0.24
Joint Wald Statistic	1364.692*	280.818*	720.854*	70.999*
Koenker (BP) Statistic	21.179*	4.924	30.893*	27.108*
Jarque-Bera Statistic	19.415*	33.531*	66.391*	42.386*
Spatial Autocorrelation (Moran's I) Summary				
Moran's Index:	0.332	0.201	0.205	0.096
z-score:	15.151*	9.237*	9.425*	4.040*

* Statistically significant at the 0.05 level.

The Joint Wald Statistic is a measure of overall model statistical significance (ESRI 2012; Hair *et al.* 2005). The null hypothesis for this test is that the explanatory variables in the model are NOT effective. For a 95% confidence level, p-values (probability) are smaller than 0.05 both in 1990 and 2000, indicating that they are statistically significant models.

5.3.3.2 Assessment of spatial stationarity

The Koenker (BP) Statistic (Koenker's studentized Breusch-Pagan statistic) is a measurement to determine whether the independent variables have a consistent relationship to the dependent variable in the model both in geographic and data space (ESRI 2012). When there is consistent relationship in geographic space, the spatial processes are stationary and behave the same across the study area. When the model is consistent in data space, there is no heteroscedasticity in the model and changes in explanatory variable would not lead to the variation in the relationship between dependent and explanatory variable (Hair *et al.* 2005). The model would have heteroscedasticity if the predictions were more accurate for some locations than they were for other locations. The null hypothesis for this test is that the model is stationary. With a 95% confidence level, the PLAND and the LSI both have a p-value (probability) smaller than 0.05 in both 1990 and 2000 (Table 5.4 and Table 5.5), indicating that there is statistically significant heteroscedasticity or the dataset has nonstationarity.

The Jarque-Bera statistic indicates if the residuals (the observed/known dependent variable values minus the predicted/estimated values) are normally distributed (ESRI 2012). The Spatial Autocorrelation (Moran's I) tool on the regression residuals can also tell if they are spatially random. The values of the Jarque-Bera statistic and Moran's I index from both Table 5.4 and Table 5.5 indicate that the residuals of 1990's and 2000's OLS regression models are not normally distributed. The OLS regression model is misspecified if the

residuals are clustered (abnormal distribution), and the inclusion of spatial variables such as the proximity to urban centres could improve the performance. Given that there is significant heteroscedasticity among the variables, Geographically Weighted Regression (GWR) analysis is suitable for modeling the relationships. Corrected Akaike Information Criterion (AICc) can be used to compare OLS regression models with GWR models (ESRI 2012), and the model with the smaller AICc is considered a better fit with the observed data.

5.3.3.3 Results and performance of the GWR

The previous stepwise OLS regression models provide solid assistance in determining explanatory variables for the GWR. According to the diagnostics of the OLS regressions in 1990 and 2000 (Table 5.4 and Table 5.5), two dependent variables, the PLAND and the LSI, are more representative in defining the relationships between physical and social mosaics. The GWR was run on these two dependent variables and the independent variables determined from the OLS regression models, and the results are listed in Table 5.6.

Table 5.6 GWR results for PLAND and LSI in 1990 and 2000

Variable	PLAND		LSI	
	1990	2000	1990	2000
ResidualSquares	22730.74	31946.72	7056.07	1506.30
AICc	1980.21	2136.90	1651.12	1318.84
R ²	0.93	0.89	0.80	0.85

The AICc is a measure of model performance and is helpful for comparing different regression models. Taking into account model complexity, the model with the lower AICc value provides a better fit to the observed data (Yu 2006). The AICc is not an absolute measure of goodness of fit but is useful for comparing models with different explanatory variables as long as they apply to the same dependent variable. If the AICc values for two models differ by more than 3, the model with the lower AICc is held to be better (Kupfer and Farris 2007). Comparing the the GWR's AICc value to the OLS regression's AICc value is one way to assess the benefits of moving from a global model to a spatial regression model. The values of AICc from Table 5.6 are significantly smaller than those from Table 5.4 and Table 5.5 (ex. AICc for GWR's PLAND 1990 as 1980.21 vs AICc for OLS's PLAND 1990 as 2120.06), which indicates that the GWR proves to be a better method to explain the relationships of landscape metrics and social factors.

Meanwhile, the higher values of R² also confirm a measure of goodness of fit (Table 5.6). A larger proportion of dependent variable variance has been accounted for by the GWR models: The model for the PLAND in both 1990 and 2000 has improved by 10% or more in terms of the R² values. In 1990, the R² increased from 0.83 in the OLS regression

model to 0.93 in the GWR model; in 2000, R^2 increased from 0.73 to 0.89. LSI has a similar degree of increase in the values of R^2 .

5.3.3.4 Coefficient surfaces of the GWR models

The coefficient surface of the GWR model shed light on the regional variation in the model's explanatory variables, which help to better understand the spatial pattern of interactions between the landscape metrics and social factors. Mapping the coefficients on a surface clearly presents the location and magnitude of the variation in these coefficients. Understanding of this variation can also inform policies at different scales: those variables that have strong variation in the coefficients across the space are important for local policies, while those variables with constant coefficients over space are important for region-wide policies (Scott and Pratt 2009).

Figure 5.11 shows the coefficient surface of the WGR model for the PLNAD in 1990. In 1990, three factors (Tertiary industry workers, Secondary industry workers, and Large families) play significant roles in determining the urbanized areas in each neighbourhood. The coefficient surface for factor 1 (Tertiary industry workers) shows a concentric zonal pattern. The lowest values are centered at the Urban Core as this area was already highly developed and the increase in this factor would lead to only minor growth of the urban area in these neighbourhoods. The highest values are found at the transition zone from the Inner Suburb to the Outer Suburb, where the fastest suburbanization was taking place in the 1990s.

The surfaces for factor 2 (Secondary industry workers) shows a sectoral pattern and the higher values are located in eastern sectors as these neighbourhoods are characterised by a higher proportion of employment in secondary industry. The industry workers in Chaoyang, Shunyi, and Tongzhou together accounted for 30% of the total industry workers of Beijing in 1990 (Beijing Municipal Bureau of Statistics 1991). Factor 3 (Larger families) shows a multiple nuclei pattern and the nuclei are located in Haidian, Chaoyang and Fengtai districts.

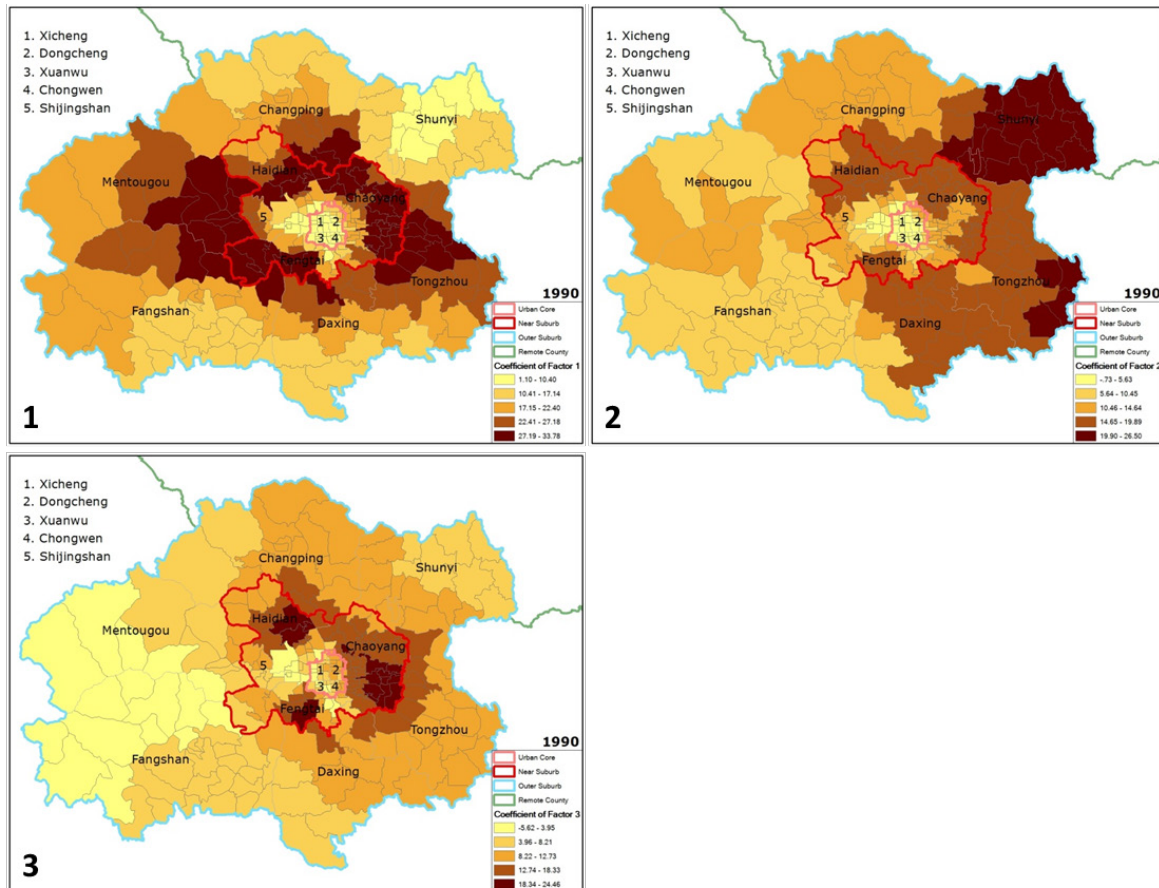


Figure 5.11 Coefficients of PLAND's GWR model, 1990

As the city of Beijing became more urbanized in 2000, the number of factors that determine the spatial expansion increased and the spatial patterns of factors also become more complex (Figure 5.12). The regression model for PLAND determines six factors in 2000, and these factors exhibit nuclei, strip and sectoral patterns respectively as demonstrated in Figure 5.12. As one of the districts with fastest growing speed, the north-eastern Haidian District stands out as a region that has higher values in most factors due to the following reasons: Haidian District is famous for the high-tech and electronics industry, one of the fastest growing industries in the 2000s. Zhongguancun, known as “China’s Silicon Valley”, acts as a major centre in electronics- and computer-related industries, as well as pharmaceuticals-related research. Meanwhile, most of the universities of Beijing are located in Haidian District, including the most prestigious universities in the country. University students are from all across China and account for a large portion of the registered population in this area, which is reflected in a more dynamic pattern with higher mobility.

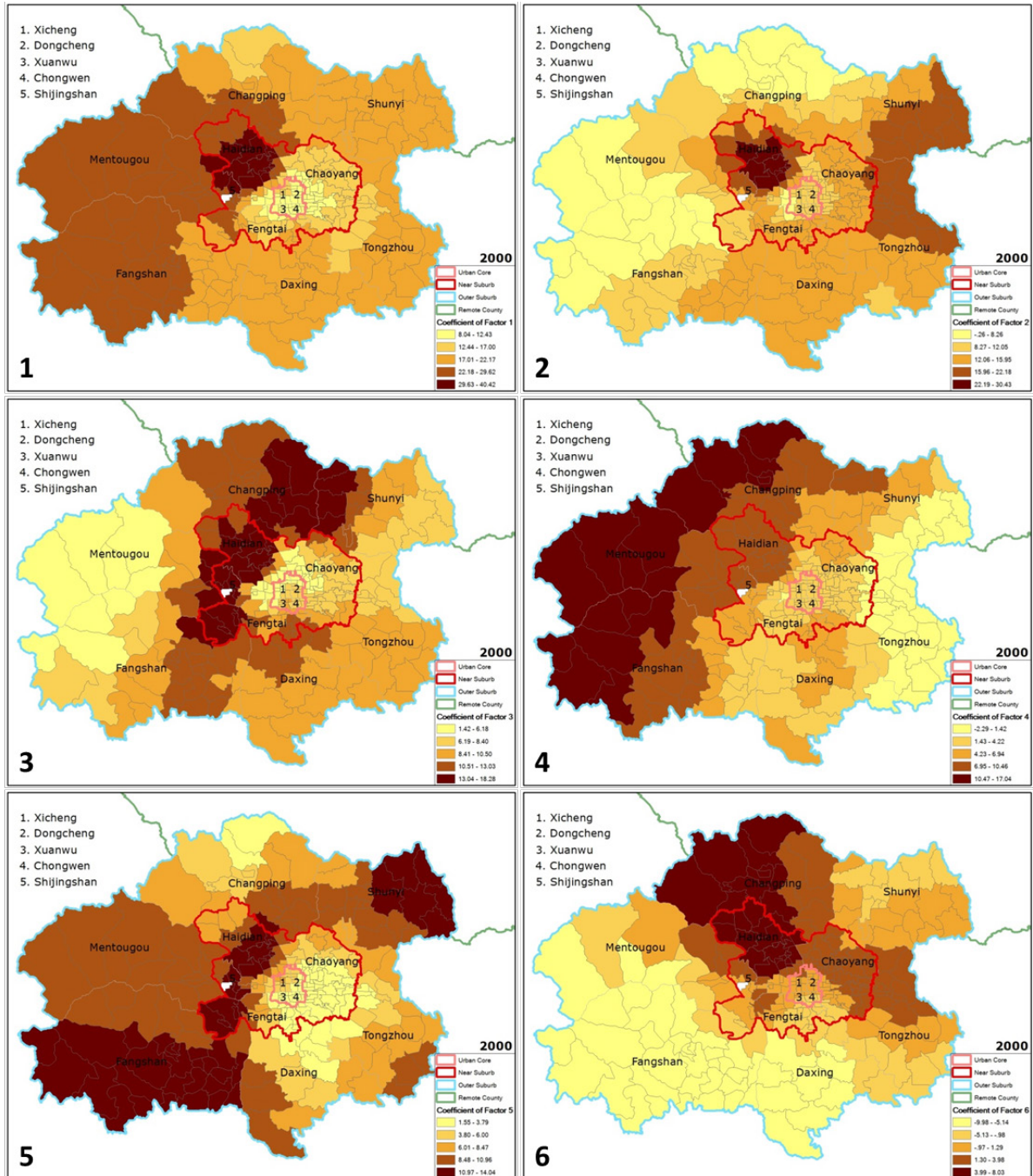


Figure 5.12 Coefficients of PLAND's GWR model, 2000

5.4 Discussion and conclusion

Both the urban social space and landscape patterns have changed dramatically in the past decades. Not only has the number of factors that shaped the social mosaics changed, but also the nature of the factors has experienced a big transition. Meanwhile, the relationship between the social and physical spaces has also undergone a substantial change, both in the magnitude of influence among different factors and in the patterns of spatial variation of these factors. The methodology in this paper is able to examine the two together to better understand their interaction. The transition patterns can be generalized in the following aspects: 1) Suburbanization has become the primary phenomena in Beijing's urban growth, 2) Urban space has become more dynamic in terms of use and social segregation is becoming evident 3) Relocation of the secondary industry has greatly transformed urban space, 4) The development of satellite towns governs Beijing's urban future.

5.4.1 Suburbanization of Beijing

The massive suburbanization (including Inner Suburb, Outer Suburb, and Periphery) of Beijing has shaped both the social and physical landscapes. In terms of urban social areas, the first and largest factor that explains the urban mosaic in 1990 is mainly located in the Urban Core. In 2000, however, the first factor expands into the Inner Suburban areas. Meanwhile, this social change has greatly influenced physical landscape. According to the

regression results in Table 5.4 and Table 5.5, factor 1 remains the largest explaining factor both in the 1990s and 2000s. Not only are the built-up areas sprawling outward, but also the physical appearance in terms of shape or fractal dimension has been significantly transformed.

To demonstrate this finding, based on yearbook data from 1980, 1990, 2000, and 2005, the population difference of each neighbourhood is calculated for the past decades. Together with statistics since the 1980s, the population shift pattern between 1990 and 2000 is clearly demonstrated in Figure 5.13: the downtown population move out from the Urban Core to the Inner Suburb, and the Inner Suburban areas also attract people from the Outer Suburbs or periphery. The proportion of population living in the Urban Core has been decreasing from 26.7% in 1980 to 16.6% in 2005. The Inner Suburb, however, had a proportion of 30.6% in 1980, but this number increased to 45.9% in 2005. The Outer Suburb's proportion of urban population slowed dwindled from 29.8% to 27.7% (Figure 5.13).

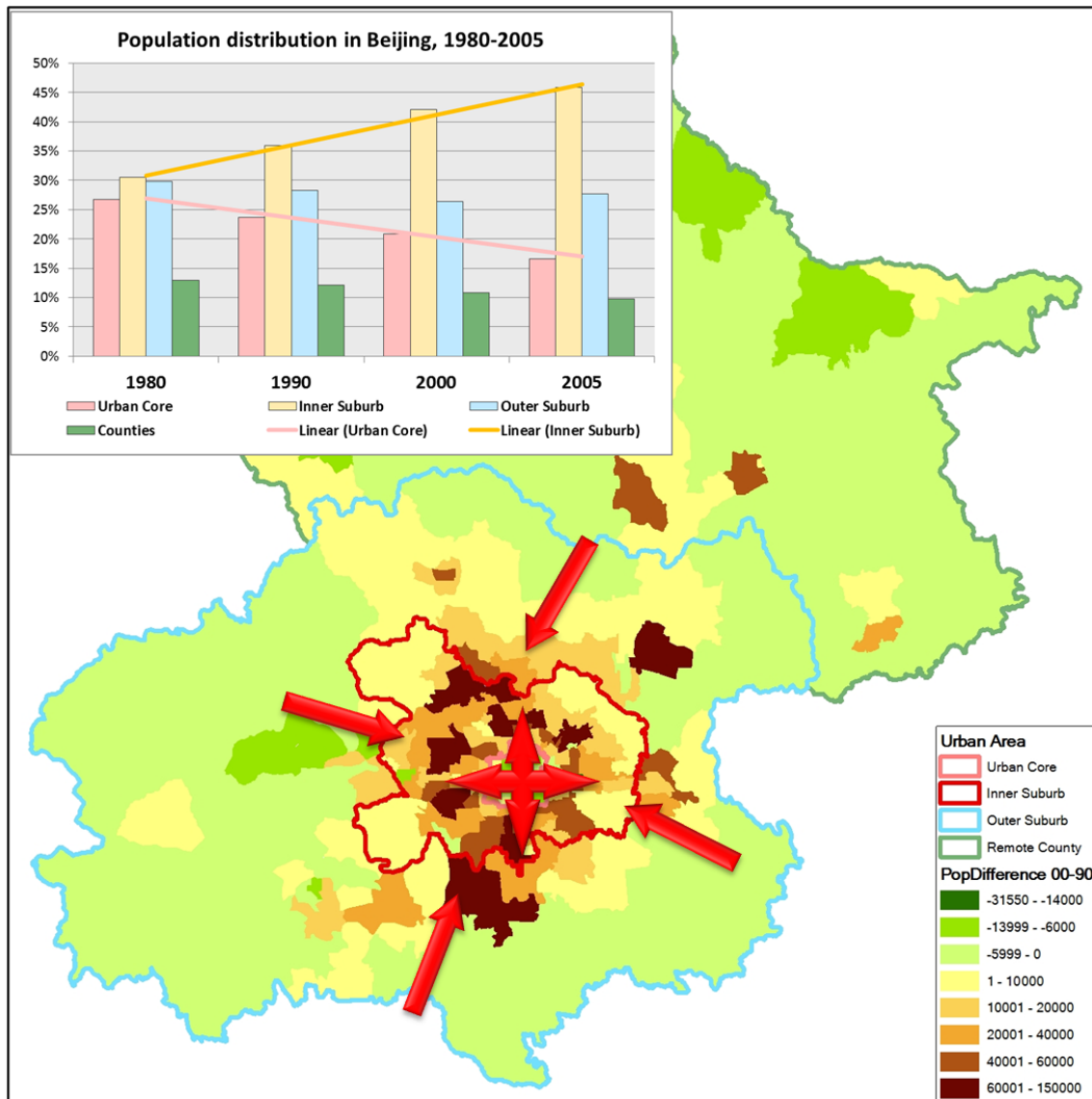


Figure 5.13 Population shift of Beijing since the 1980s

The internal structure of cities, also interpreted as the physical manifestation of the prevailing social structure, explicitly reflects the implementation of the economic environment, public policies, and development plans (Yeh and Wu 1995). Chinese cities' patterns were strongly influenced by the socialist ideology and highly centralized planned economic system before reforms in 1978, which introduced a more market-oriented

economy known as the “socialist market economic system” (Yeh and Wu 1995). The transition from the centralized planning of Socialist continues to the more market-based system of Western industrialized countries greatly contributed to the change of internal structure of Beijing. Such a transition was especially noticeable since the implementation of housing reforms of the 1990s and real estate development afterwards²⁵. Besides, the development of transportation system (ring roads, subway, and bus lines) facilitates daily commute, and the lower housing cost in suburbs triggers the centrifugal movement of population from the downtown core. Meanwhile, the city keeps being developed, and better job opportunities and living conditions attract labourers from the rural areas. This centripetal movement is channelled to the suburb areas for the same reason of lower cost of living that motivates the centrifugal movement.

As a consequence of urban expansion, there is an increased demand for converting the non-urban land to built-up areas (Zhao 2011). To address issues of high land prices and development costs, an over populated city center, and excessive pressure on the historic city core, Beijing’s Master Plan was designed to last until 2020. It is meant to accommodate population and employment growth, reduce land use and infrastructure inefficiencies that are caused by Beijing’s history of reliance on physical design and architectural principles in

²⁵ In the centrally planned system of the 1950s and 60s housing was a redistributive good that was considered to be a part of state welfare. However, in the newly emerging market economy, housing began to be treated more as a private good as the government cooperated with private investors to provide adequate housing, thus reducing their share of responsibility (Cao *et al.* 2000).

its development. It focuses on balancing environmental protection with economic development by protecting the fragile mountain ecosystems to the north and west, and promoting development in the northern and eastern regions. Also, it aims to protect cultural, historic, and environmental areas, as well as strengthen development along the north-south and east-west axes using culture and social identity as the foundation for this spatial structure (Ding *et al.* 2005).

5.4.2 Urban dynamics and social segregation

Eliminating inequality is a fundamental principle of socialist ideology, and China attempted to build a classless society without the segregation or disparity in the pre-1978 era. Nevertheless, social areas and differences still existed due to differing abilities to allocate housing for their workers. However, since the economic reforms of 1978 and the housing reforms of the 1990s, social differences have become more discernible in space, which is determined more by social status.

Social segregation by area is the result of the characteristics of the housing market, the actions of the planning authorities, and unequal social status. According to the social landscapes discerned from PCA results, the most prominent change between the urban mosaic of 1990 and 2000 is that by 2000 temporary population in poor living conditions became the second largest factor and population with high mobility became the third (Table 5.3). These two factors together also account for 21% of the physical landscape change in

2000s (Table 5.5). As China's capital city, the growth and development of Beijing has been encouraged for decades by a series of government policies and the distribution of resources, and as such, it is an economically competitive metropolis. It is the disparity between the living conditions in urban and rural areas that prompts those born in the countryside to migrate to urban centres in the hopes of securing employment and a better standard of life. While the *hukou* system makes it extremely hard for rural residents to establish themselves in urban areas, China's one-child policy has led to little or no natural growth in urban centres, and so these mega-cities depend on this rural-urban migration in order to further develop (Cao *et al.* 2011). Statistics on Beijing's growth patterns put this situation into perspective: Beijing's natural growth has remained steadily at zero since 2001, and according to the 2000 census, migrants accounted for 24.4% of the population, 46% of which were rural migrants (Cao *et al.* 2011).

Despite the need for rural migrants, urban centres like Beijing continue to make life challenging for those who do make the move. The case of the Zhejiangcun (Zhejiang village) migrant enclave illustrates these difficulties. Zhejiangcun developed in the 1980s when migrants from Wenzhou established a community on Beijing's "urban-rural transition belt" where rural collective ownership allowed them to actually benefit from their rural *hukou* (Jeong 2011). In practice, the people living on this land rented it to the migrants, or constructed separate living facilities. This alliance provided migrants with a place to live,

and the local residents with an important source of income. However, since the 1990s Beijing has converted this area's residents' *hukou* classification to urban, thus depriving them of the land use rights that allowed this alliance to flourish. As such, this "urban-rural transition belt" is no longer a safe haven for new rural urban migrants: this area is now a business center and high-end residential district as a result of large-scale real estate projects supported by the Beijing government (Jeong 2011). Although this conversion gave the present residents access to guaranteed employment and monetary compensation for both the land and rental housing, they also lost access to future profits and the ability to help new rural migrants establish themselves in Beijing.

In addition to this governmental exclusion, rural migrants also face a high degree of social exclusion that further complicates the migration process. According to Zhan (2011), 63% of rural migrants to Beijing reported discrimination based on their non-local and peasant origins, and also spoke of the difficulty of making urban friends. Also, governmental officials are more prepared to provide services to urban residents and local schools regularly charge illegal extra registration fees for the children of rural migrants (Zhan 2011). As a result, rural migrants tend to interact with people from the same region of origin and this segregation results in an exclusion from the profitable social networks that exist within an urban centre. Ultimately, the social and legal exclusion that rural migrants face in cities pose significant deterrents to moving, but urban centres depend on said

migrants in order to continue to grow and develop. The relationship between urban residents, urban governments, and rural migrants is both complicated and symbiotic since both need one another to generally improve the country's living conditions.

In summation, the future growth of China's cities is largely dependent upon encouraging rural migrants to seek employment in urban centres. In order to continue attracting rural migrants to sustain itself, Beijing will have to mitigate problems such as social and labour segregation, income disparity, incomplete welfare system, and migration barriers like the *hukou* system.

5.4.3 Relocation of the secondary industry

The second social space in 1990 features workers in the secondary industry, however, this factor dropped to the 6th social space in the 2000s. This transition reflects the important role of secondary industry in Beijing before the 1990s and also the result of the relocation of the secondary industry out of the inner urban areas.

Before the 1980s, Socialist development schemes were heavily involved in the city's planning by government directly supervising the process. Because production activities such as industry and transport were valued over non-production activities such as storage and finance, the secondary sector played a key role. Meanwhile, the growth and development of the retailing of consumer goods was restricted (Sit 1999). Starting from the economic reforms of the 1980s, the focus of Beijing's development moved from an

industrial center to a political and cultural one, emphasizing its greatness in the areas of social order, morality, culture, technology, and education (Sit 1995).

A distinguishing feature of the pre-reform Chinese cities is the organization of the cities through “self-contained” communities based on work units (Lo 1980). Based on historical background and socialist ideology, urban planning after the 1950s was strictly controlled to give emphasis on the development of industry. The industrial sector was given priority to choose the most suitable land and resources (Yeh and Wu 1995). Unlike land use in Western cities, where the residential and industrial zones are separated, housing usually forms an internal part of the industrial zone because work units are responsible for providing housing for their workers (Yeh *et al.* 1995a). Therefore, an industrial enterprise would be at the core, surrounded by residential areas and social services like shopping, elementary education, and recreation to support the community. Since collective land usage was free in China, industries tended to claim more land resources than they needed, which mainly led to the urban sprawl at that time (Yeh and Wu 1995). As a result of booming industrialization, the new built-up, low density, peripheral areas and the continuously built-up, highly intensified old urban core have constructed an outstanding urban landscape (Pannell 1977).

Throughout the 1980s and 90s the tendency towards decentralization, marketization, and globalization continued to be deemed as Beijing’s development goal. To accomplish

this, the city focused on the peripheries while industrial land was converted to tertiary use, leading to an increase in urban expansion (Zhao 2011). According to Figure 5.14, the portion of employment in the secondary industry has been decreasing since 1990. In the factorial ecology analysis, heavy industry is the third largest factor in 1990, but becomes the sixth in 2000. This is the result of the outward movement or suburbanization of heavy industries. In the 1990s, residential suburbanization accelerated with many new forms, which induced industrial suburbanization and also quickened its step.

Figure 5.14 Industry structure by employment in Beijing

5.4.4 Towards sustainable urban development

This research employs factorial ecology to extract the social space of Beijing and applies landscape ecology to extract the physical pattern of Beijing, for the past three decades. Spatial regression model is used to investigate and quantify the relationships

between the social and physical landscapes. In the end, urban policies and development plans that caused the urban transition are discussed to conclude the research.

Due to the combination of market forces, resource allocation, and industrialized cooperation, megacities have continued to expand. Urban sprawl is inherently unsustainable as it destroys fragile farmlands and decreases food production. This has undoubtedly created serious problems for China's population, including excessive pressure on housing, environmental issues, insufficient infrastructure, and public safety. A full understanding of a city's expansion patterns from both social and physical perspectives helps to capture the development mechanism, and the investigation of the causal relationship between these patterns also sheds light on the mitigation policies required for sustainable urban development.

Chapter 6 Conclusion

6.1 Review of findings

Approximately one fifth of the world's population lives in China and over the last three decades China has been urbanizing at a rate that is unmatched by any other country in terms of both its scope and speed. In the mid-1970s China surpassed the United States as the country with the largest urban population, though its urbanization rate at the time was barely 18%. A few years later at the end of the 1970s, with the introduction of an open door policy and economic reforms, China experienced an exponential economic growth that has allowed the country to rapidly urbanize over the last 30 years.

Recently China has surpassed the world's average urbanization rate of 50%, and does not show any signs of slowing down. Its massive population and quick urbanization rate aside, China is also unique in terms of its socio-political system and historical-cultural context: it is a hybrid of government planning and market forces. Since it encompasses a large part of the global population and has had a vastly different urbanization experience than that of Western countries, around which most theories are based, studying China's urbanization is an opportunity to contribute to the field of urban studies in an unprecedented manner. This thesis adapts Western theories of urbanization to China's situation by developing new models and concepts that are also widely applicable.

As China's urban experience has been so unlike that of Western countries, it is essential that its current urban development be studied in a historical context. This thesis pays close attention to the factors controlling China's urbanization over the years: governmental policies have always played a significant role in determining the focus of China's urban development, but since the introduction of economic reforms China's urbanization has become increasingly driven by market forces. Furthermore, the Chinese government's focus for urban planning has changed over time, which has directly affected its path of urbanization. China's evolution of urban planning is usually represented in four distinct periods, but this thesis divides China's modern history of urban development into three periods that better reflect the reality of how this process occurred: Pre-reform, Revival, and Transition.

Since urbanization occurs across both space and time, this thesis systemically examines the formulation of the Chinese urban system spatio-temporally. We used a top-down, hierarchical approach to investigate the relationship between the socioeconomic and biophysical processes within this urban system. Previous approaches have focused exclusively on the physical processes, and to meet this challenge of combining the social and physical aspects we developed new methodologies at each level of study. In general, we found that the urban processes occurring at the higher levels of the spatial hierarchy provide

a context for lower-level urban development. However, at the same time, these higher-level urban patterns are the aggregation of lower level urbanization processes.

On a conceptual level, this thesis contributes to the existing literature in the field of urban studies by combining the spatio-temporal dimension and the hierarchical approach. Not only does it provide insight into China's urbanization at three spatial scales, but it also presents an analysis of the formulation of the Chinese urban system over time. Since China's political, social, and economic development has played a significant role in the country's urbanization history, the effects of these were studied at the national scale: the objectives of China's Five Year Plans have had a profound effect on the size of cities being developed and where new growth is concentrated. It was determined that the current focus on megalopolises is spurring the expansion of urban clusters, such as the JingJinJi Metropolitan Area, which functions as a component of this national system. Whereas a cluster is only a part of a larger whole, a dominating city is not solely a component in an urban cluster; it is also a growth pole. A dominating city's development can determine the overall structure of the cluster it belongs to. Furthermore, few have studied the landscape-level implications of the interactions between social and biophysical elements on a city-scale. Using this method of analysis it was found that China's high speed of urbanization is not always accompanied by proper planning and this results in a series of social problems for cities since the balance between natural and human factors is not being

maintained. This thesis fills this gap by exploring the complexity of interactions and feedback mechanisms that exist between social, biological, and physical processes at the national, regional, and city scales, thus providing future planners with a valuable tool.

At the national level study of China's urban system, the Synthesized Gravity Model has proven to be a feasible improvement on the traditional Gravity Model that only uses physical characteristics in its analysis. SGM's improvement of the GM's results is twofold: (1) scale impacts, wherein Influential Factor was introduced to accurately measure the "mass" of a city, and (2) distance impacts, wherein Relative Distance based on network analysis is introduced to reveal the "distance decay" effect between cities. By incorporating the Principal Component Analysis and Network Analysis, the new model successfully overcomes the GM's limitations: more specifically its inability to represent a city's influential strength, as well as its oversimplification of reality. Thus, this thesis was able to more accurately measure the interactions between cities and better represent the reality of China's urban system.

Although it was formulated for China, the SGM is widely applicable because its variables can be adjusted for urban systems around the world. The results of the SGM's application in this thesis are as follows: it discerned the hierarchy of the urban system and revealed the nodal structure within this hierarchy, both of which can be generally categorized as interactions between cities within an urban system. First, the SGM revealed

the hierarchy of China's urban system based on an extensive index that more accurately represents reality. With the development of advanced transportation and communication networks, the distance between cities has decreased, and SGM takes this contraction of time and space into consideration. Due to China's rapid urbanization, this contraction is a significant factor in how its developing cities influence one another, and this thesis has restructured the GM to account for it. Second, the SGM is capable of determining how cities group together and why: the SGM revealed a nodal structure in China's urban system, which is a dominant phenomenon that will continue into the future. Finally, the SGM's application found that urban development is occurring unevenly in China. New growth is found disproportionately in the east of China while the west is still quite rural, and this development is happening in clusters as opposed to uniformly.

Due to the prevalence of these urban clusters, this thesis then focuses on the JJJ Metropolitan Area to study how this process has been taking place. The Cellular Automata-based SLEUTH model is a grid-based simulating model, which has been widely applied and developed at the micro scale; however, it has seldom been incorporated into a regional study such as this one. Unlike the numerous methods and models developed for studies at the city scale, research at the regional scale has access to only a limited number of models. Therefore, the application of the CA model to the JJJ Metropolitan Area greatly expands the urban cluster-modeling database for this scale by providing further research

projects with a wider variety of tools to examine the regional-level interactions within an urban system.

The SLEUTH model is limited as it only considers physical variables in simulation and predicting urban growth. By integrating socioeconomic factors into a modified CA-based SLEUTH model, the urban growth dynamics and future development scenarios of an area can be simulated and predicted more thoroughly. This thesis used a PCA index to determine which factors influence the development of urban clusters, and then GIS aggregated different methods to determine potential directions for future development. The CA-based SLEUTH model is uniquely suited for this task because it is able to calibrate based on historical trends of urban development, thus presenting more realistic future simulations. This technique was applied to the JJJ Metropolitan Area to determine which factors have had the strongest influence on its development, and to represent this quantitatively. In the JJJ Metropolitan Area we found that the following three factors were particularly strong. First, its high spread coefficient is demonstrative of the fact that this area's urbanization is mainly occurring outwards from its existing urban areas and urban cores. Second, the breed coefficient for this area is also quite high, which indicates that there is a high probability that new urban centres will be established. Finally, the high road-gravity factor shows that road networks attract a substantial amount of urban growth, and thus significantly influence the study area's development patterns. This probability of

new urban centres and the likelihood of spreading are both responsible for the majority of the dispersive urban growth seen in the JJJ Metropolitan Area. Based on this information, three potential future growth scenarios were projected under different environmental and development conditions, which demonstrated the effect that these factors can have on urban development. The application of the CA-based SLEUTH model in this thesis confirms that four factors play an essential role in the formulation of the JingJinJi Metropolitan Area's urban growth mechanism: urban policies, industry restructuring, rural-urban migration, and reclassification of urban boundaries.

The Micro-scale study of Beijing is conducted from two perspectives: the social and physical since these factors combine to influence a city's growth. From a social perspective, the factorial ecology approach is adopted to identify the social landscape patterns and the factors that have shaped Beijing's social landscapes in 1990 and 2000 respectively. In the comparison between 1990's and 2000's social areas, it was discovered that the urban system has become increasingly complex and more difficult to interpret with limited variables. While the 1990 model extracted five factors, which were able to explain 82.90% of the total variance of the 29 variables used, the 2000 model only was able to explain 72.22% of the total variance of 41 variables, despite using six extracted factors. In addition, industry, family structure, and migration have played significantly different roles in structuring urban space between 1990 and 2000. For example, the population working in heavy industry was

the second most important factor in 1990, but by 2000 its influence had decreased, and it dropped to sixth, while the temporary population (floating or seasonal workers) emerged as the second largest factor. The social space of 1990 is closely linked to family structure, while the social areas of 2000 have become more mobile: populations with a large degree of mobility account for a larger variance.

From a physical perspective, Beijing's landscape patterns were extracted by processing remotely sensed images that have the same temporal span as the social studies. We used four landscape metrics to describe the landscape patterns in terms of their composition, shape, complexity, and fragmentation. A buffer zone that is delineated by centre lines between the ring roads and the research area's boundaries was designed to examine the long-term trends in urban development as it continues to spread outwards from these roads as it has been doing over the past three decades. Furthermore, as Beijing's urban growth is not isotropic, a sectoral zone was also designated to identify the pattern of urban sprawl over different sectors using landscape metrics. Results show that Beijing's suburbanization process was greatly influenced by the ring roads, but that it has not been progressing at an even pace in every direction. This new urban growth has resulted in the increased spatial complexity and fragmentation of Beijing's physical landscape.

Finally, the relationship between the social and physical landscapes was quantitatively defined using the Geographically Weighted Regression technique, which determined that

there is statistically significant heteroscedasticity with the data, and that a strong relationship exists between the physical landscape (measured by landscape metrics) and social landscape (measured by factor scores of the PCA). This relationship has become more complex: three social factors accounted for 93% of the increased fragmentation of Beijing's physical development in the 1990s; however, six social factors were only able to explain 89% of the total variance in the 2000s. More specifically, the GWR model demonstrates how the coefficient of each factor has changed over space and time.

In general, a study with this kind of specificity has never been conducted before, and such a detailed examination of the interactions between the social and physical landscapes contributes new theories and methods to existing the research on urban studies, especially in terms of China. As far as China is concerned, this is the first time that the country's urban system has been thoroughly studied from the national to city level in one research. The adjustment of Western theories of urban development to better suit China's unique context has allowed for a more comprehensive and accurate study of China's urban system. As such, these improved models will contribute to the current literature on Chinese urban studies.

6.2 Limitations of this thesis

The Synthesized Gravity Model for the national scale study overcomes many of the limitations associated with the traditional Gravity Model. However, there are potential improvements that can be made to ameliorate the model. First, due to the lack of available socioeconomic data in China, only 13 variables were selected to derive the comprehensive influential factor. However, a selection of additional variables covering more aspects of the urban influential power would produce a more accurate depiction of reality. Second, in the equation of the Synthesized Gravity Model, the values were determined from the proportion of people and goods transported by different methods, and all cities were analyzed using a general set of values for a specific year. If cities were given weights based on their individual situations, the accuracy of the interactions' measurements would be improved.

During the forecasting process of the SLEUTH model at the regional level, the future scenarios were based on the historical development patterns and the current reality. However, there are unpredictable factors that could affect the future growth of an urban cluster. For example, the construction of a new railway would bring economic opportunities to the cities that would influence their future development. Since it is impossible to predict where such a railway would be built, its influence on the surrounding area cannot be factored into these future simulations.

Although socioeconomic variables are included in the SLEUTH model to represent an area's attraction/resistance (probability of conversion to urban land), this probability is only a hypothesis that might differ from reality. For example, an event of national importance, like the Olympics, prioritizes the development of a certain region, which otherwise might not have been urbanized to the same degree. These sorts of factors are difficult to include in an attraction/resistance layer analysis.

For the city-level analysis, the variables that were collected have been evolving over time, and some variables from the 2000s do not have corresponding indicators from the 1990s. Therefore, it is difficult to tell if the social areas we detected in the 2000s existed in the 1990s, and if they did, what changes have occurred over the past decade. For example, information about areas' ethnic composition was collected in the 2000s and it was determined that ethnicity was a factor influencing social areas. However, since such information was unavailable in the 1990s, it was not possible to temporally compare this factor.

In addition, landscape metrics were calculated on a neighbourhood level, but the size of neighbourhoods varies greatly: neighbourhoods in the downtown core are much smaller than those on the city outskirts. Unfortunately, the area and shape of a neighbourhood can bias the calculation index due to the "edge effect." This bias can be eliminated if a consistent spatial unit (such as a square of 5km x 5km) was adopted to calculate the

landscape metrics, which is not realistic in this thesis. Since social information was collected according to neighbourhood boundaries, it would ultimately result in a greater margin of error if these factors were divided into 5km x 5km squares.

6.3 Future research directions

The systemic study of China's urban system conducted in this thesis has the potential to be applied to urban clusters other than the JingJinJi Metropolitan Area. We used four factors to determine how the JJJ Area has been developing to project how it would continue to develop under various circumstances. Since each cluster follows a unique development path, the application of the CA-based SLEUTH model to another cluster would reveal the factors that influence its growth patterns. For instance, Beijing is in the JJJ Area and its development has been given special attention due to its political status as China's capital. However, the Haerbin-Shenyang-Dalian urban cluster is characterized by heavy industry, thus its urban development history will be vastly different than that of the JJJ Area, as will any future growth projections. On the other hand, the Shandong Peninsula urban cluster is a case study for how the economic reforms, the open door policy, and China's integration into the global economy have affected the country's urban development. It is close to Korea and Japan, and produces an abundance of agricultural, forestry, and fishery products that can be exported from its busy port cities. The Yangtze River Delta (YRD) urban cluster is also worth a detailed study since it is dominated by Shanghai, which is a very Westernized city. These three clusters are found on China's highly developed eastern coast, but emerging urban clusters from the Southwestern China would also be of interest for future research. As China moves to rectify the discrepancy between its eastern and western regions, more urban clusters are beginning to develop. The Southwest urban cluster is dominated by Chongqing

and Chengdu, and it remains to be seen how much new growth these cities can generate in this undeveloped area. Within the scope of this thesis it was only possible to study the JJJ Area in detail, but future research in this field has an abundance of varied and unique urban clusters in China. Further study on any of these urban clusters, and the factors that have driven, and continue to drive, their development would contribute to a more thorough understanding of China's complex urban system.

On the city level this kind of further research would also be of great value. As previously mentioned, the government has always prioritized Beijing's development because of its political status as the capital, and its influence on surrounding cities has been extremely high. China also has many influential cities whose development has not been driven by macro-level projects, such as Shanghai, Guangzhou, and Urumqi. Shanghai is a Western style city that is at odds with the majority of China's cities and a study of its urban development could illuminate how historical factors contribute to a city's future development. Guangzhou dominates the Pearl River Delta urban cluster, but Shenzhen is expanding at a rapid rate with Hongkong and Macau growing on the outskirts of this urban cluster. Studying Guangzhou's development under the pressure and opportunities that exist in such a complex environment would shed light on the relationship between dominating cities and the others in the urban cluster. Finally, Urumqi in the northwest of China is home to one of China's indigenous populations and it is in one of the most underdeveloped areas

of the country. An examination of Urumqi's social space would shed light on the effect that ethnic divisions can have on a city's development, as well as proximity to other urban areas. This thesis have developed new methodologies that are uniquely suited to the study of China's complex urban system, and by applying them to a greater number of urban clusters and cities an even more comprehensive understanding of this system could be developed.

Appendix

Technical Note: Use of Fuzzy Logics in Mapping Urban Areas from Landsat TM Imagery

7.1 Introduction

Remotely sensed medium-resolution (between 10 to 100 m spatial resolutions) and multispectral imagery (e.g., Landsat and ASTER) has typically been applied to identifying urban areas or discriminating residential, industrial, and commercial zones in an urban landscape (Chander *et al.* 2009; Kahya *et al.* 2010). Accurate image classification results are a prerequisite for further applications; however, producing a satisfactory classification image from medium-resolution imagery is not a straightforward task. Factors contributing to this difficulty include the availability of suitable images for the desired time, ancillary and ground reference data, as well as the variables and classification algorithms selected to run the classification (Lu and Weng 2005). It has been proven that a combination of ancillary data and spectral features can significantly improve the classification performance (Coburn and Roberts 2004; Stefanov *et al.* 2001). Out of the variety of ancillary data including texture, context and basemaps like transportation network, the digital elevation

model (DEM) has been proven to be the most efficient data for improving classification accuracy in an urban context (Lu and Weng 2005).

Multiple spectral imageries provide various dimensions of information on the land features; however, high input dimensions also cause a critical problem of space- and time-consumption in the processing procedures like land cover classification (Wang *et al.* 2007). Therefore, reducing the dimensions of data without losing much information would contribute to the effectiveness of remote sensing classification. Several methods have been adapted to transform multispectral bands, such as band ratios and vegetation indices like Normalized Difference Vegetation Index (NDVI), Tasseled Cap Transformation, and Principal Component Analysis (PCA) (Bannari *et al.* 1995). Compared to other transformations, which use predefined linear equations on a number of selected channels, PCA employs a statistical procedure to convert all applicable data channels into several principal output channels. This procedure explores inter-band correlation and the decorrelation of multi-band imagery to minimize data redundancy and correlation between bands.

As it is not usually possible to control the availability of a desired image, classification algorithms are often used to improve the classification accuracy. Conventional methods for classifying multispectral remote sensing imagery such as parallelepiped, minimum distance from means, and maximum likelihood, only utilize spectral information

and consequently have limited success in classifying urban multispectral images (Jensen 2005; Shackelford and Davis 2003). Besides, urban landscapes are typically composed of features with similar spectral signatures, and this makes mixed pixels a common problem, especially for medium-resolution imagery. However, conventional classification methods are based on crisp classifications, i.e., each pixel can only be classified as one class in the classifying process. Therefore, the mixed pixel problem results in the low accuracy of land cover classification of urban areas (Lu and Weng 2005).

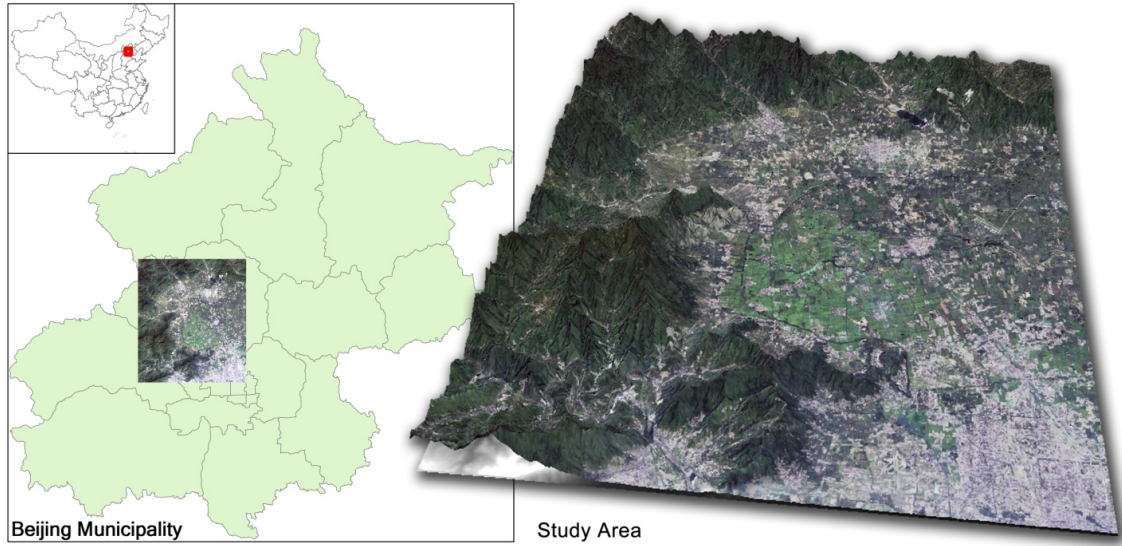
Fuzzy logic, also synonymous with the theory of fuzzy sets, is a theory that relates to the classification of objects with imprecise boundaries. Owing to the advantages of fuzzy logic in defining ambiguity, fuzzy logic is able to process an input space to an output space through a mechanism of if-then inference rules. Fuzzy logic techniques in the form of approximate reasoning offer powerful reasoning capabilities for decision support and expert systems (Kulkarni 1998). Fuzzy classification techniques allow pixels to have a probability of belonging (membership) in more than one class, and through this membership the imprecise nature of the data is better represented.

In this paper, DEM is included as ancillary data, and several transformations including NDVI, Normalized Difference Built-up Index (NDBI), and PCA are employed to provide a better represented dataset with distinctive characteristics. A fuzzy logic-based hierarchical classification method that incorporates both spectral and spatial information is

then developed. Meanwhile, the maximum likelihood classifier (MLC) and knowledge-based expert system are also applied to provide comparison references. This fuzzy expert system turns out to be able to produce a substantial increase in classification accuracy of urban land cover maps compared to the traditional maximum-likelihood and expert system classification approach.

7.2 Methodology

This research applies an expert system approach to a portion of urban land cover of Beijing, China (Figure 7.1). An area covering a variety of land cover types and terrains is selected, so that the classification system can be tested in a more general context. The study area occupies approximately 1859 km², which is located in the districts of Haidian and Changping in the northwest of Beijing city. The major body in the area is a flat landscape with urban built-up and agricultural land, surrounded by mountainous terrain in the north and west. Urban and suburban development of the study region has proceeded at a rapid rate with widespread conversion of adjacent, undeveloped regions, and agricultural lands to residential and commercial uses. These districts have been ranked as the fastest growing regions in the Beijing since 1990. The primary motivation for this work is to conduct historical land cover classification, and monitor and plan future land cover change using the remotely sensed imageries as a basis.



7.3 Data processing and atmospheric correction

The sequence shown in Figure 7.2 was carried out to pre-process Landsat imagery and this imagery was used to derive land cover features by selected classification methods.

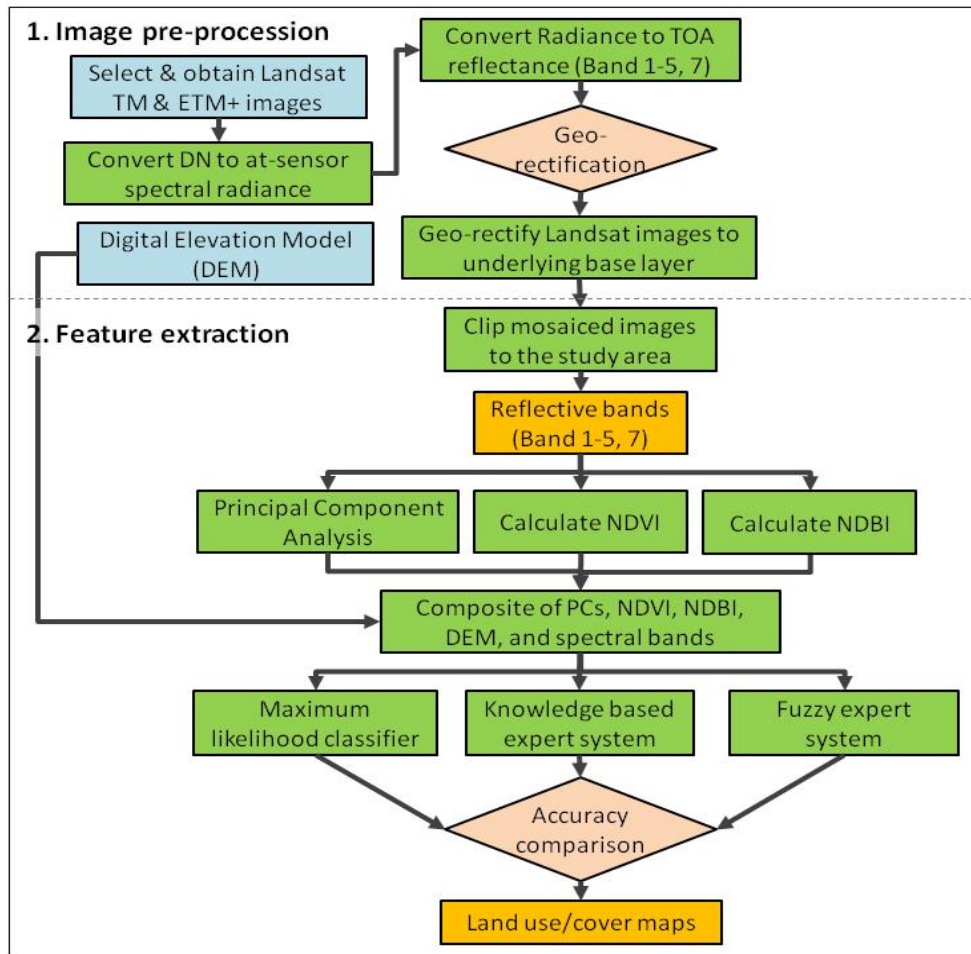


Figure 7.2 Flowchart of Landsat image processing

From the data pre-processing emerges the composite dataset from the result of previous steps: principal components, NDVI, NDBI, and/or apply the NO DATA masks to create final raster dataset with the maximum available data coverage.

7.4 Supervised maximum likelihood classification

Multispectral classification is the process of sorting pixels into a number of individual classes based on their reflective or transformed values. An example of a classified image is a land cover map, showing features like urban, vegetation, bare land, water, etc. Supervised

Classification is a term used to refer to a wide variety of feature extraction approaches; however, it is traditionally used to identify the use of specific decision rules and classifiers such as Maximum Likelihood, Minimum Distance, and Mahalanobis Distance.

A supervised classification of the Landsat data was performed using the Maximum Likelihood Classifier (MLC) algorithm. All the composite bands (except DEM) were used in this process. Since this research is urbanization-related study of the regional scale, the definition of land cover classes were adopted from Anderson *et al.*'s (1976) Land Use And Land Cover Classification System. Based on the land use and land cover situations, five types of land cover classes were distinguished in the classification scheme: built-up land (BL), Wood land (WL), Farm land (FL), water (WA), and barren land (BL).

Training areas for the land cover classes were selected with the assistance of ancillary geological, land use, and field data. Both the Jeffries-Matusita and Transformed Divergence separability were measured to ensure that the selected training areas for the land cover types are statistically separate. The statistics of training areas were calculated for each class and are presented in Figure 7.3.

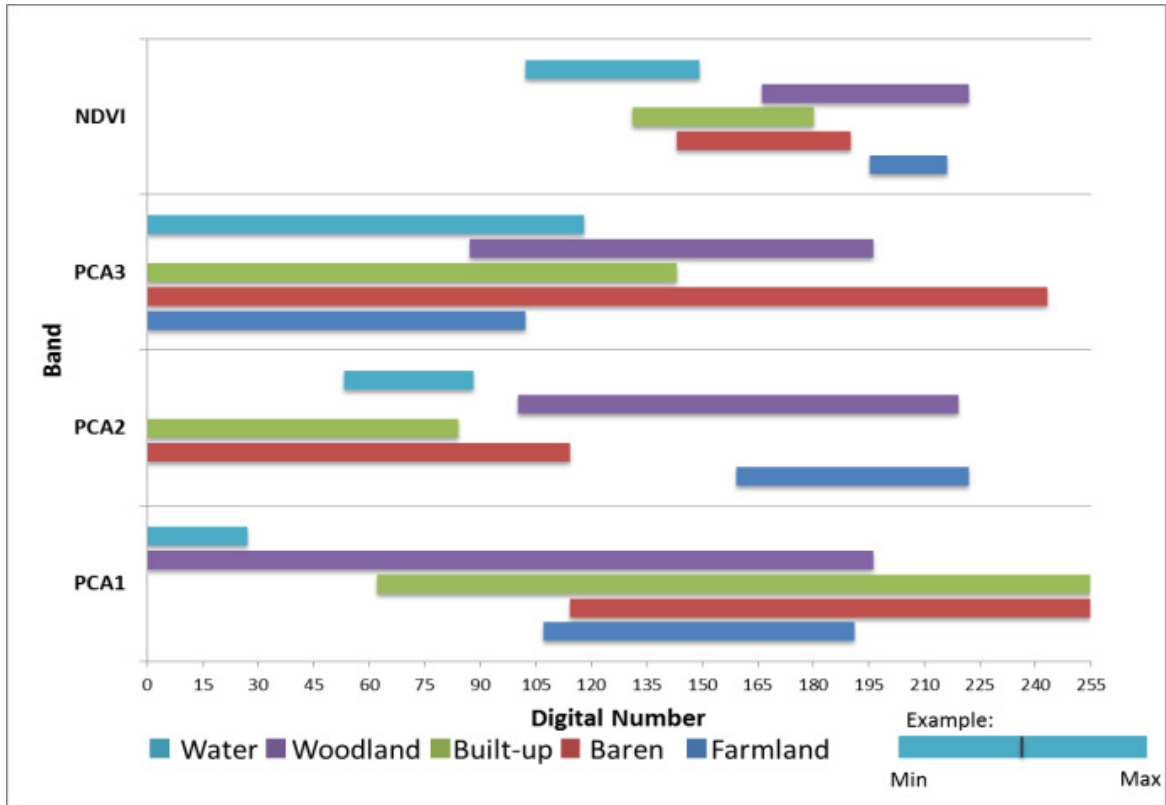


Figure 7.3 Statistics of training areas

7.5 Knowledge-based expert system

One of the major disadvantages of these techniques is that they are all per-pixel-based classifiers. Each pixel is treated in isolation to determine which feature or class it belongs to. Ancillary data that the human visual interpretation system takes for granted such as context, shape and proximity, are usually not incorporated. Expert knowledge-based classification, however, overcomes the limitations described above, by setting up a decision tree of conditions and defining variables based on raster imagery, vector layers or spatial models.

The applications of expert system or knowledge-based algorithm in the remote sensing classification fall into two categories: 1) Expert system was used to improve the

accuracy after the conventional pixel-based classification method, such as the Maximum Likelihood Classifier (MLC) was applied. It is also referred to as post-classification refinement, in which a set of low level constituent information gets abstracted into a set of high level informational classes. In such applications, ancillary data, including band ratios, textures, land cover maps, administrative boundaries, were usually incorporated into conventional and afterward expert system classifications (Kahya *et al.* 2010). 2) In the other kind of applications, expert system was directly used to conduct the classification: rule sets or decision trees were designed firstly based on expert knowledge or training experiments; a hierarchical system of IF-THEN rules were then applied to extract the results (Lawrence and Wright 2001; Wang and Jamshidi 2004). Modern methods like Neural Networks and Fuzzy Logics were usually incorporated into the expert system to get improved performances.

In essence, an expert classification system is a hierarchy of rules, or a decision tree, that describes the conditions under which a set of low level constituent information gets abstracted into a set of high level informational classes. A rule is conditional statement, or list of conditional statements, about the variable's data values and/or attributes that determine an informational component or hypotheses. Multiple rules and hypotheses can be linked together into a hierarchy that ultimately describes a final set of target informational classes or terminal hypotheses. Based on the knowledge of NDVI and NDBI, the

multi-band image can be segmented in a hierarchy of input and output. To achieve a higher accuracy in classifying the land cover, principal component and DEM are also incorporated into the decision system (Figure 7.4).

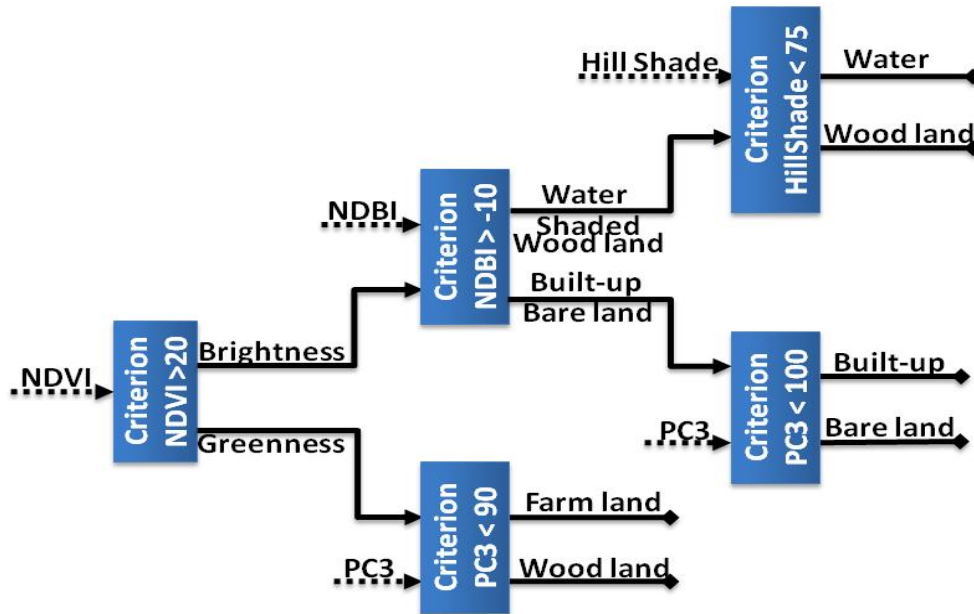


Figure 7.4 Multi-criteria decision tree of the expert system

7.6 Fuzzy logic classifier

Membership function, a mathematical function that defines the degree of an element's membership in a fuzzy set, is the core of fuzzy logic applications (Zadeh 1965). In terms of the application of fuzzy logic to image classification, two ways to define membership functions have been widely adopted:

- 1) Use predefined membership function based on prior knowledge or data exploration.

Membership functions are defined using prior knowledge such as results from

supervised classification, and the fuzzy logic inference rules are constructed and tested through the simulation of classification procedure.

2) Adaptive neuro-fuzzy inference system (ANFIS) is a neuro-adaptive learning technique developed in MATLAB. Rather than choosing the parameters for a given membership function arbitrarily, these parameters could be determined so as to tailor the membership functions to account for more variations in the data (MathWorks 2010). There are two methods that ANFIS learning employs for updating membership function parameters: Backpropagation for all parameters (a steepest descent method); and a hybrid method consisting of backpropagation for the parameters associated with the input membership functions, and least squares estimation for the parameters associated with the output membership functions

The Fuzzy Inference System (FIS) contains both the model structure, (which specifies such items as the number of rules in the FIS, the number of membership functions for each input, etc.), and the parameters, (which specify the shapes of membership functions).

Since the model structure used for ANFIS is fixed, the model is prone to overfit the data on which is it trained, especially for a large number of training epochs. The checking data, which is used to cross-validate the fuzzy inference model, is important for learning tasks for which the input number is large, and/or the data itself is noisy. When the checking data option is used with ANFIS, the model parameters that correspond to the minimum

checking error are returned at each training epoch. The FIS membership function parameters computed when both training and checking data are loaded are associated with the training epoch that has a minimum checking error (MathWorks 2010).

As a result, the training error decreases, at least locally, throughout the learning process. Therefore, the more the initial membership functions resemble the optimal ones, the easier it will be for the model parameter training to converge. Human expertise about the target system to be modeled may aid in setting up these initial membership function parameters in the FIS structure.

In section 2.2, we have defined the five land cover classes to be separated. Normally, it is hard to achieve good performance with only two or three input bands, especially for the similar classes without big differentiation in most spectral bands. To discriminate the similar classes, we have introduced non-spectral bands, PC bands, NDVI, NDBI and DEM. For the fuzzy classifiers discussed above, it is assumed that an input band is partitioned by m membership functions, then n input bands will consist of $n^m \times 5$ rules for the classification process, so that the classification complexity increases exponentially with the rising number of input bands. In this study, each input is partitioned using 3 membership functions, and the number of rules needed would be $3^6 \times 5=3645$, and the time required for the classification would be unreasonable. A hierarchical structure is proposed to solve the problem (Figure 7.5).

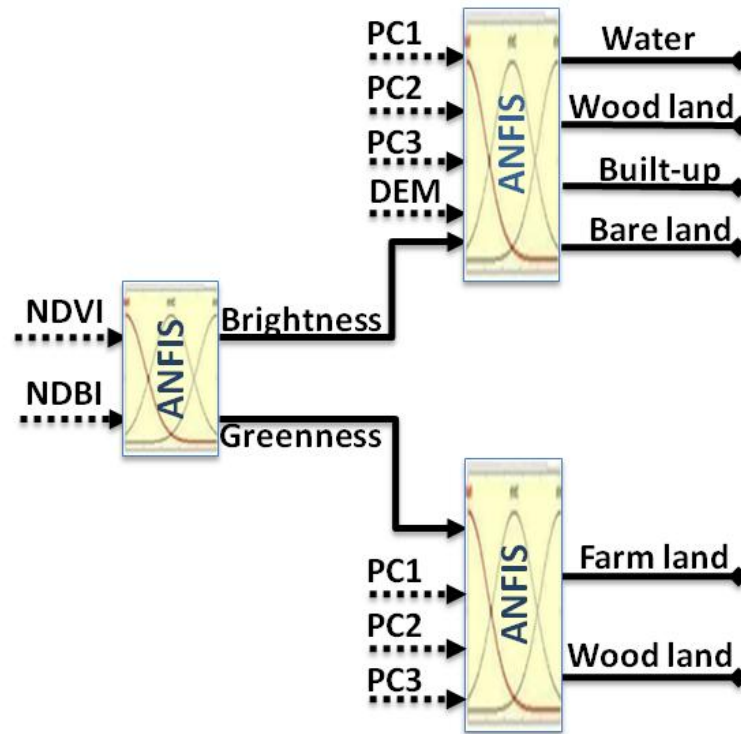


Figure 7.5 Hierarchical structure of the fuzzy expert system

The hierarchical structure simplifies multi-class one-level classification to gradual levels of classification. In the first level, all the land cover classes are separated into two groups based on the characteristics of NDVI and NDBI. For each group, it is further divided to sub-groups in the next level through the additional band inputs. For the group classification, additional input bands are selected based on observing the signature data and consulting geographical experts.

7.7 Result

Figure 7.6 presents the results of land cover classification of the study area by applying three different classifiers. The results of the accuracy assessment for the three classifiers are presented in Table 7.1.

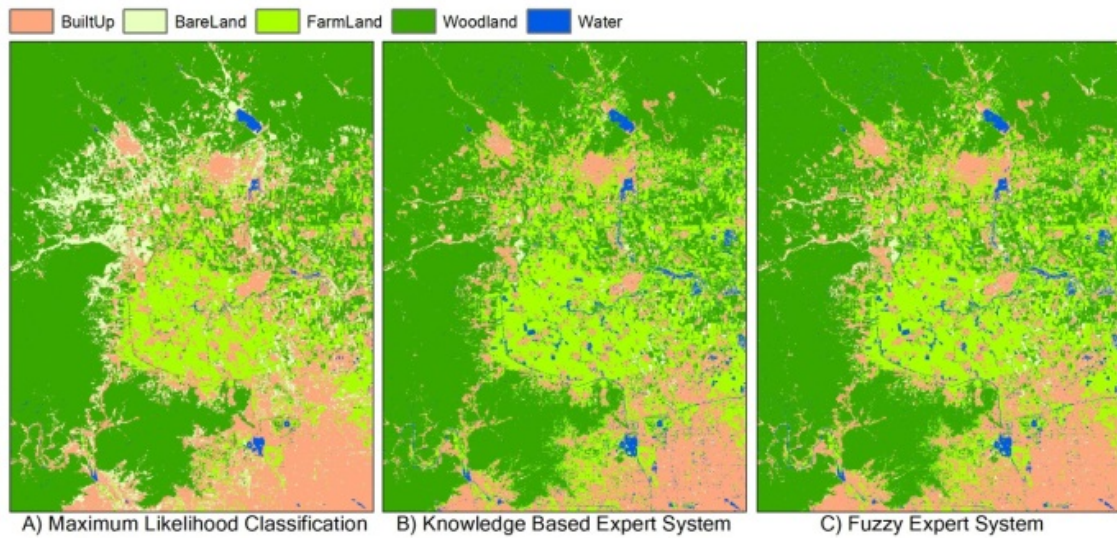


Figure 7.6 Land cover classification results

Table 7.1 Error matrix of the classification from Landsat TM data

	Reference Data						
Maximum Likelihood Classification	Classification	Built-up	Water	Woodland	Farmland	Bareland	Row Total
	Built-up	66	12	1	7	6	92
	Water		46	1			47
	Woodland	1	1	53	9		64
	Farmland				30		30
	Bareland	13		6	7	24	50
	Column Total	80	59	61	53	30	283
	Overall Accuracy = 77.39%	K _{hat} = 71.23%					
Knowledge Based Expert System	Classification	Built-up	Water	Woodland	Farmland	Bareland	Row Total
	Built-up	48	1				49
	Water	1	47	2			50
	Woodland	7	1	57	4	2	71
	Farmland	5	5	1	48		59
	Bareland	19	5	1	1	28	54
	Column Total	80	59	61	53	30	283
	Overall Accuracy = 80.57%	K _{hat} = 75.73%					
Fuzzy Expert System	Classification	Built-up	Water	Woodland	Farmland	Bareland	Row Total
	Built-up	59	1	1	1	1	63
	Water	1	52	2			55
	Woodland	6	1	57	5	2	71
	Farmland	3	2		46	1	52
	Bareland	11	3	1	1	28	42
	Column Total	80	59	61	53	30	283
	Overall Accuracy = 84.70%	K _{hat} = 80.66%					

7.8 Discussion and Conclusion

Land cover classification of urban areas has been problematic due to the heterogeneity and small spatial size of the surficial materials, which leads to significant sub pixel mixing.

This problem becomes exacerbated when discrimination of multiple classes is necessary. Instead of using the multi-spectral bands as the main input of classification, this study utilizes the Principal Component bands, NDVI, NDBI, as well as the DEM as the major feedings into the classification system. Three kinds of classification system, namely Supervised Maximum Likelihood Classifier, Knowledge-based Expert System, and Fuzzy Expert System, are implemented separately to examine the accuracy differences. The results presented here demonstrate the usefulness of satellite imagery for urban land cover mapping and some of the shortcomings of conventional classification techniques such as maximum likelihood. It was found that maximum likelihood classification of high-resolution multispectral imagery over urban areas produced significant amounts of misclassification errors between spectrally similar classes such as Road and Building classes.

For the supervised classification system, NDVI and NDBI, especially NDBI, enables built-up areas to be mapped at a higher degree of accuracy and objectivity in comparison with supervised classification based on multispectral bands. The absence of training samples from the mapping makes subjective intervention from the human analyst redundant. This means that the same results can be derived regardless of the analyst or how many times the mapping is repeated. The redundancy also considerably expedites the mapping process that can be accomplished by direct subtractions of original spectral bands. Through the arithmetic manipulation of TM bands and simple recoding of the intermediate images,

NDBI does not require complex mathematical computation. It is concluded that the proposed NDBI is much more effective and advantageous in mapping general built-up areas than the maximum likelihood method. It can serve as a worthwhile alternative for quickly mapping urban land (Zha *et al.* 2003).

In the Knowledge-based Expert System, the arbitrary selection of training areas or signatures can be avoided. In this process, the confusion error is usually generated to compromise the final result. Although the building of If-Then rules at the very first step needs expertise and abundant knowledge on the spectral signature of different land covers, it is relatively efficient and also provides a higher accuracy than the traditional supervised classification system. Additionally, once the system is constructed, it can be easily applied to images of a similar geophysical environment or images of the same location over different time periods.

Finally, the hierarchical fuzzy classification method proves to be the most accurate method to classify the data by utilizing both spectral and spatial information. The classification accuracies of the fuzzy classifier were approximately 7% greater than the maximum likelihood in terms of overall accuracy, and 9% greater in terms of K_{hat} accuracy. Accordingly, there were significant decreases in the number of misclassifications between spectrally similar classes. Further work is needed to improve the performance of the fuzzy classifier in dense urban areas and to produce even more detailed urban land cover maps by

identifying features such as roads, business areas, and residential areas. An image segmentation approach combined with morphological feature operators may be used to further improve upon the results presented here.

References

- Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C. and Zumbrunnen, C. (2003) Integrating humans into ecology: opportunities and challenges for studying urban ecosystems, *BioScience* 53(12):1169-1179.
- Anderson, J. R., Hardy, E. E., Roach, J. T. and Witmer, R. E. (1976) *A Land Use and Land Cover Classification System for Use With Remote Sensor Data*. Washington: United States Government Printing Office.
- Antrop, M. (2004) Landscape change and the urbanization process in Europe, *Landscape and Urban Planning* 67(1-4):9-26.
- Ashtakala, B. and Murthy, A. S. N. (1988) Optimized gravity models for commodity transportation, *Journal of Transportation Engineering* 114(4):393-408.
- Bannari, A., Morin, D., Bonn, F. and Huete, A. R. (1995) A review of vegetation indices, *Remote Sensing Reviews* 13(1):95 - 120.
- Beijing Municipal Bureau of Statistics (1991) *Beijing Statistical Yearbook-1990*. Beijing: China Statistics Press.
- Berry, B. J. L. (1964) Cities as systems within systems of cities, *Papers in Regional Science* 13(1):147-163.
- Bretagnolle, A., Daudé, E. and Pumain, D. (2003) *From theory to modelling: urban systems as complex systems*. 13th European Colloquium on Quantitative and Theoretical Geography, Lucca, Italy: September 8-11, 2003.
- Burchell, R. W. and Mukherji, S. (2004) Costs of sprawl 2000, *TR News*(229):16-21.
- Burgess, E. W. (1925) The growth of the city, in Park, R. E. and Burgess, E. W. (eds.) *The city*. Chicago: Chicago University Press, pp. 47-62.
- Camagni, R. P. and Salone, C. (1993) Network urban structures in Northern Italy: elements for a theoretical framework, *Urban Studies* 30(6):1053-1064.
- Cao, G. Y., Chen, G., Pang, L. H., Zheng, X. Y. and Nilsson, S. (2011) Urban growth in China: past, prospect, and its impacts, *Population & Environment*:1-24.
- Cao, H. and Villeneuve, P. (1998) La localisation des garderies dans l'espace social de l'agglomération de Québec (Social Space and Daycare Centers in the Quebec Metropolitan Area), *Cahiers de Géographie du Québec* 42(115):35-65.
- Cao, H., Zhao, Y. and Losier, S. (2000) Le projet urbain de Pudong à Shanghai offre-t-il un développement durable pour la globalisation de la Chine? (Does the Pudong Urban Project in Shanghai Have a Sustainable Future?), *Les Annales de la recherche urbaine* 86:92-100.
- Cao, H. and Zhao, Y. (2003) The Application of Centographic Analysis to the Study of the Intra-urban Migratory Phenomenon in the Greater Moncton Area in Canada, 1981-1996, *Romanian Review on Political Geography* V(1):16-25.

- Cao, H., Chouinard, O. and Dehoorne, O. (2005) De la périphérie vers le centre : l'évolution de l'espace francophone du Nouveau-Brunswick au Canada (From the Periphery to the Center: Evolution of the French-Speaking Community in New Brunswick in Canada), *Annales de Géographie* 642:115-140.
- Cao, H. (2010) Urban–rural income disparity and urbanization: what is the role of spatial distribution of ethnic groups? a case study of Xinjiang Uyghur Autonomous Region in Western China, *Regional Studies* 44(8):965-982.
- Cao, H. and Bergeron, S. (2010) *Disparités régionales et inclusion des minorités : Les défis de la Chine de l'après Jeux Olympiques de Beijing (Regional Disparity and Minority Inclusion: The Challenges of China after Beijing 2008 Olympic Games)*. Québec: Presses de l'Université du Québec.
- Chan, K. W. (1994) *Cities with Invisible Walls: Reinterpreting Urbanization in Post-1949 China*. Oxford, New York: Oxford University Press, USA.
- Chander, G., Markham, B. L. and Helder, D. L. (2009) Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors, *Remote Sensing of Environment* 113(5):893-903.
- Chen, J., Guo, F. and Wu, Y. (2011) One decade of urban housing reform in China: Urban housing price dynamics and the role of migration and urbanization, 1995-2005, *Habitat International* 35:1-8.
- Chen, Y. (2009) Urban gravity model based on cross-correlation function and Fourier analyses of spatio-temporal process, *Chaos, Solitons and Fractals* 41(2):603-614.
- Chen, Z. (2008) *Urbanization and Spatial Structure Evolution of Urban System in China: IDE-JETRO*, available online at <http://www.ide.go.jp/>.
- Cheng, J. and Masser, I. (2003) Urban growth pattern modeling: a case study of Wuhan City, PR China, *Landscape and Urban Planning* 62(4):199-217.
- Child, D. (2006) *The Essentials of Factor Analysis*. London: Continuum Intl Pub Group.
- Choe, K. and Laquian, A. (2008) *City cluster development: toward an urban-led development strategy for Asia*. Mandaluyong City, Philippines: Asian Development Bank.
- Clarke, K. C., Hoppen, S. and Gaydos, L. (1997) A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area, *Environment and Planning B* 24:247-262.
- Coburn, C. and Roberts, A. (2004) A multiscale texture analysis procedure for improved forest stand classification, *International Journal of Remote Sensing* 25(20):4287-4308.
- Cohen, B. (2004) Urban growth in developing countries: a review of current trends and a caution regarding existing forecasts, *World Development* 32(1):23-51.
- Collins, J. P., Kinzig, A., Grimm, N. B., Fagan, W. F., Hope, D., Wu, J. and Borer, E. T. (2000) A new urban ecology: modeling human communities as integral parts of

- ecosystems poses special problems for the development and testing of ecological theory, *American Scientist* 88(5):416-425.
- Coppack, P. M. (1988) The Evolution and Modeling of the Urban Field, in Coppack, P. M., Russwurm, L. H. and Bryant, C. R. (eds.) *Essays on Canadian Urban Process and Form III: The Urban Field*. Waterloo, Ontario: Department of Geography, University of Waterloo, pp. 5-27.
- Cui, G. (1990) The processes, characteristics and tendencies of urban development in China, *GeoJournal* 21(1-2):25-32.
- Davies, W. K. D. and Barrow, G. T. (1973) A comparative factorial ecology of three Canadian prairie cities, *The Canadian Geographer* 17(4):327-353.
- Davies, W. K. D. (1979) Urban connectivity in Montana, *The Annals of Regional Science* 13(2):29-46.
- Deffner, V. and Hoerning, J. (2011) *Fragmentation as a threat to social cohesion? A conceptual review and an empirical approach to Brazilian cities*. International RC21 Conference, Amsterdam.
- Dematteis, G. (1997) Globalisation and regional integration: the case of the Italian urban system, *GeoJournal* 43(4):331-338.
- Deng, F. F. and Huang, Y. (2004) Uneven land reform and urban sprawl in China: the case of Beijing, *Progress in Planning* 61(3):211-236.
- Ding, C. (2003) Land policy reform in China: assessment and prospects, *Land Use Policy* 20(2):109-120.
- Ding, C., Song, Y. and Knaap, G. (2005) *Growth Scenarios for Beijing 2020: Technical Report on the Beijing's 2020 Comprehensive Plan Revision Process*. Lincoln Institute of Land Policy.
- Ditchkoff, S., Saalfeld, S. and Gibson, C. (2006) Animal behavior in urban ecosystems: Modifications due to human-induced stress, *Urban Ecosystems* 9(1):5-12.
- Dou, W., Li, G., Gan, Y., Wang, L. and Yang, K. (2000) Urban competitive pattern and its changes in China, *Chinese Geographical Science* 10(2):105-112.
- Douglas, I. (1983) *The Urban Environment*. London: Edward Arnold.
- Du, G. (2000) Using GIS for analysis of urban systems, *GeoJournal* 52(3):213-221.
- Du, G. (2006) Spatial structure of urban systems in developing countries: a case study of China, *Journal of Nanjing University (Natural Sciences)* 42(3):225-241.
- Elvidge, C. D., Imhoff, M. L., Baugh, K. E., Hobson, V. R., Nelson, I., Safran, J., Dietz, J. B. and Tuttle, B. T. (2001) Night-time lights of the world: 1994-1995, *ISPRS Journal of Photogrammetry and Remote Sensing* 56(2):81-99.
- ESRI (2012) Interpreting OLS results. Available at http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/Interpreting_OLS_results/005p00000030000000/. Retrieved on March 7, 2012.

- Evans, A. W. (1985) *Urban Economics: An Introduction*. New York: Basil Blackwell Oxford.
- Ewing, G. O. (1974) Gravity and linear regression models of spatial interaction: a cautionary note, *Economic Geography* 50(1):83-88.
- Ferguson, E. and Cox, T. (1993) Exploratory factor analysis: a users' guide, *International Journal of Selection and Assessment* 1(2):84-94.
- Fitzpatrick, K. and La Gory, M. (2000) *Unhealthy Places: The Ecology of Risk in the Urban Landscape*. New York: Routledge.
- Foggin, P. M. and Polèse, M. (1977) *The social geography of Montreal in 1971*. Toronto: Centre for Urban and Community Studies, University of Toronto.
- Folke, C., Jansson, A., Larsson, J. and Costanza, R. (1997) Ecosystem appropriation by cities, *Ambio* 26(3):167-172.
- Foster, S. R. (2006) The City As An Ecological Space: Social Capital and Urban Land Use, *Fordham Law School Occasional Papers in Regional Science* Paper 5.
- Fotheringham, A. S., Charlton, M. E. and Brunson, C. (1998) Geographically weighted regression: a natural evolution of the expansion method for spatial data analysis, *Environment and Planning A* 30:1905-1927.
- Friedmann, J. (1966) *Regional Development Policy: A Case Study of Venezuela*. Cambridge, Massachusetts: MIT press.
- Friedmann, J. and Wolff, G. (1982) World city formation: an agenda for research and action, *International Journal of Urban and Regional Research* 6(3):309-344.
- Gaubatz, P. (1999) China's urban transformation: patterns and processes of morphological change in Beijing, Shanghai and Guangzhou, *Urban Studies* 36(9):1495-1521.
- Gillanders, S. N., Coops, N. C., Wulder, M. A. and Goodwin, N. R. (2008) Application of Landsat satellite imagery to monitor land-cover changes at the Athabasca Oil Sands, Alberta, Canada, *Canadian Geographer* 52(4):466-485.
- Girvetz, E. H., Thorne, J. H., Berry, A. M. and Jaeger, J. A. G. (2008) Integration of landscape fragmentation analysis into regional planning: a statewide multi-scale case study from California, USA, *Landscape and Urban Planning* 86(3):205-218.
- Grimm, N. B., Grove, J. M., Pickett, S. T. A. and Redman, C. L. (2000) Integrated approaches to long-term studies of urban ecological systems, *BioScience* 50(7):571-584.
- Grove, J. and Burch, W. (1997) A social ecology approach and applications of urban ecosystem and landscape analyses: a case study of Baltimore, Maryland, *Urban Ecosystems* 1(4):259-275.
- Gu, C. and Shen, J. (2003) Transformation of urban socio-spatial structure in socialist market economies: the case of Beijing, *Habitat International* 27(1):107-122.

- Gu, C. and Pang, H. (2008) 基于重力模型的中国城市体系空间联系与层域划分 (Study on spatial relations of Chinese urban system: gravity model approach), *地理研究* (*Geographical Research*) 27(1):1-12.
- Haddad, L., Ruel, M. and Garrett, J. (1999) Are urban poverty and undernutrition growing? Some newly assembled evidence, *World Development* 27(11):1891-1904.
- Hair, J. F., Black, B., Babin, B., Anderson, R. E. and Tatham, R. L. (2005) *Multivariate Data Analysis (6th Edition)*. Upper Saddle River: Prentice Hall.
- Han, R. (2013) Challenges facing China's urban development in the New Era, in Cao, H. and Paltiel, J. (eds.) *Facing Twenty-First Century China: Domestic and International Dynamics from a Multidisciplinary Angle*. Ottawa: University of Ottawa Press. (Accepted).
- Harris, C. and Ullman, E. (1945) The nature of cities, *Annals of the American Academy of Political and Social Science* 242:7-17.
- Haynes, K. E. and Fotheringham, A. S. (1984) *Gravity and Spatial Interaction Models*. NewburyPark, CA: Sage Publications.
- He, C., Li, J., Chen, J., Shi, P., Pan, Y., Zhuo, L. and Toshiaki, I. (2006a) The urbanization process of Bohai Rim in the 1990s by using DMSP/OLS data, *Journal of Geographical Sciences* 16(2):174-182.
- He, C., Okada, N., Zhang, Q., Shi, P. and Li, J. (2008) Modelling dynamic urban expansion processes incorporating a potential model with cellular automata, *Landscape and Urban Planning* 86(1):79-91.
- He, S., Li, Z. and Wu, F. (2006b) Transformation of the Chinese city, 1995-2005: Geographical perspectives and geographers' contributions, *China Information* 20(3):429-456.
- Henderson, M., Yeh, E. T., Gong, P., Elvidge, C. and Baugh, K. (2003) Validation of urban boundaries derived from global night-time satellite imagery, *International Journal of Remote Sensing* 24(3):595-610.
- Hobbs, R. (1997) Future landscapes and the future of landscape ecology, *Landscape and Urban Planning* 37(1-2):1-9.
- Hoyt, H. (1939) *The Structure and Growth of Residential Neighborhoods in American Cities*. Washington DC: Federal Housing Administration.
- Hsu, M. L. (1994) The expansion of the Chinese urban system, 1953-1990, *Urban Geography* 15(6):514-536.
- Hua, C. and Porell, F. (1979) A critical review of the development of the gravity model, *International Regional Science Review* 4(2):97-126.
- Huff, D. L. and Lutz, J. M. (1995) Change and continuity in the Irish urban system, *Urban Studies* 32:155-173.

- Imhoff, M. L., Lawrence, W. T., Stutzer, D. C. and Elvidge, C. D. (1997) A technique for using composite DMSP/OLS "city lights" satellite data to map urban area, *Remote Sensing of Environment* 61(3):361-370.
- Isard, W. (1998) Gravity and spatial interaction models, in Isard, W., Azis, I., Drennan, M., Miller, R., Saltzman, S. and Thorbecke, E. (eds.) *Methods of Interregional and Regional Analysis*. Vermont, USA: Ashgate Publishing Company, pp. 243-279.
- Jantz, C. A., Goetz, S. J. and Shelley, M. K. (2004) Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore-Washington metropolitan area, *Environment and Planning B* 31(2):251-271.
- Jensen, J. R. (2005) *Introductory Digital Image Processing: A Remote Sensing Perspective (3rd Edition)*. Upper Saddle River, New Jersey: Prentice Hall.
- Jeong, J. H. (2011) From illegal migrant settlements to central business and residential districts: Restructuring of urban space in Beijing's migrant enclaves, *Habitat International* 35:508-513.
- Jin, F., Wang, F. and Liu, Y. (2004) Geographic patterns of air passenger transport in China 1980-1998: imprints of economic growth, regional inequality, and network development, *The Professional Geographer* 56(4):471-487.
- Kahya, O., Bayram, B. and Reis, S. (2010) Land cover classification with an expert system approach using Landsat ETM imagery: a case study of Trabzon, *Environmental Monitoring and Assessment* 160(1):431-438.
- Kamal-Chaoui, L., Leman, E. and Zhang, R. (2009) Urban trends and policy in China, *OECD Regional Development Working Papers* 2009/1.
- Karemera, D., Oguledo, V. I. and Davis, B. (2000) A gravity model analysis of international migration to North America, *Applied Economics* 32(13):1745-1755.
- Kirkby, R. J. R. (1985) *Urbanization in China: Town and Country in a Developing Economy, 1949-2000 AD*. New York: Columbia University Press.
- Kitchen, P. and Williams, A. (2009) Measuring neighborhood social change in Saskatoon, Canada: a geographic analysis, *Urban Geography* 30(3):261-288.
- Klijn, F. and Haes, H. (1994) A hierarchical approach to ecosystems and its implications for ecological land classification, *Landscape Ecology* 9(2):89-104.
- Knox, P. and Pinch, S. (2006) *Urban Social Geography: An Introduction*. New Jersey: Prentice Hall.
- Knox, P. L. and McCarthy, L. M. (2005) *Urbanization: An Introduction to Urban Geography, 2nd Edition* New Jersey: Prentice Hall.
- Kochhar, G. (2010) Market and migrants: Redefining China's urban social welfare system, *China: An International Journal* 8(2):193-219.
- Kulkarni, A. D. (1998) Neural-Fuzzy Models for Multispectral Image Analysis, *Applied Intelligence* 8(2):173-187.

- Kupfer, J. A. and Farris, C. A. (2007) Incorporating spatial non-stationarity of regression coefficients into predictive vegetation models, *Landscape Ecology* 22(6):837-852.
- Lall, S. and Wang, H. G. (2010) *China Urbanization Review: Balancing Urban Transformation and Spatial Inclusion*. The World Bank.
- Landsat Project Science Office (2009) Landsat-7 Science Data User's Handbook. Available at http://landsathandbook.gsfc.nasa.gov/handbook/handbook_toc.html. Retrieved on December 12, 2009.
- Lawrence, R. and Wright, A. (2001) Rule-based classification systems using classification and regression tree (CART) analysis, *Photogrammetric Engineering and Remote Sensing* 67(10):1137-1142.
- Leao, S., Bishop, I. and Evans, D. (2004) Simulating urban growth in a developing nation's region using a cellular automata-based model, *Journal of urban planning and development* 130:145.
- Leung, Y., Mei, C.-L. and Zhang, W.-X. (2000) Statistical tests for spatial nonstationarity based on the geographically weighted regression model, *Environment and Planning A* 32(1):9-32.
- Li, L., Dray-Novey, A. and Kong, H. (2007) *Beijing: From Imperial Capital to Olympic City*. New York: Palgrave Macmillan.
- Lin, G. C. S. (2002) The growth and structural change of Chinese cities: a contextual and geographic analysis, *Cities* 19(5):299-316.
- Lin, J. Y. and Chen, B. (2011) Urbanization and urban-rural inequality in china: a new perspective from the government's development strategy, *Frontiers of Economics in China* 6(1):1-21.
- Liu, S., Li, X. and Zhang, M. (2003) *Scenario Analysis on Urbanization and Rural-Urban Migration in China*. Institute of Geographic Sciences and Natural resources Research, Chinese Academy of Sciences, Beijing.
- Lo, C. (1975) Changes in the ecological structure of Hong Kong 1961-1971: A comparative analysis, *Environment and Planning A* 7:941-963.
- Lo, C. (1980) Shaping socialist Chinese cities-model of form and land use, *China: Urbanization and National Development*, Leung, CK, and Ginsburg, N., eds., pp130-155, *Research Paper*.
- Lo, C. (1986) The evolution of the ecological structure of Hong Kong: implications for planning and future development, *Urban Geography* 7(4):311-335.
- Lo, C. (2005) Decentralization and polarization: contradictory trends in Hong Kong's postcolonial social landscape, *Urban Geography* 26(1):36-60.
- Lo, C. P. (2001) Modeling the population of China using DMSP operational linescan system nighttime data, *Photogrammetric Engineering and Remote Sensing* 67(9):1037-1047.

- Lo, C. P. (2007) The application of geospatial technology to urban morphological research, *Urban Morphology* 11(2):81-90.
- Logan, J. R. and Molotch, H. L. (1987) *Urban Fortunes: The Political Economy of Place*. Berkeley, CA: University of California Press.
- Lowry, I. (1966) *Migration and Metropolitan Growth: Two Analytical Models*. San Francisco, CA: Chandler Pub. Co.
- Lu, D. and Weng, Q. (2005) Urban classification using full spectral information of Landsat ETM Imagery in Marion County, Indiana, *Photogrammetric Engineering & Remote Sensing* 71(11):1275-1284.
- Ma, L. J. C. and Hanten, E. W. (1981) *Urban Development in Modern China*. Boulder, Colo.: Westview Press.
- Ma, L. J. C. and Cui, G. (1987) Administrative changes and urban population in China, *Annals of the Association of American Geographers* 77(3):373-395.
- Ma, L. J. C. (2002) Urban transformation in China, 1949 - 2000: a review and research agenda, *Environment and Planning A* 34:1545-1569.
- Machlis, G. E., Force, J. E. and Burch, W. R. J. (1997) The human ecosystem. I. The human ecosystem as an organizing concept in ecosystem management, *Society and natural resources (USA)* 10:347-368.
- MathWorks (2010) *Fuzzy Logic Toolbox™ 2 User's Guide*. Natick, MA: The MathWorks, Inc.
- McGarigal, K., Cushman, S. A., Neel, M. C. and Ene., E. (2002) FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at <http://www.umass.edu/landeco/research/fragstats/fragstats.html>. Retrieved on March 12, 2010.
- Merli, M. G. and Raftery, A. E. (2000) Are births underreported in rural China? Manipulation of statistical records in response to China's population policies, *Demography* 37(1):109-126.
- Montgomery, M. and Hewett, P. (2005) Urban poverty and health in developing countries: household and neighborhood effects, *Demography* 42(3):397-425.
- Murdie, R. (1969) *Factorial Ecology of Metropolitan Toronto, 1951-1961: An Essay on the Social Geography of the City*: University of Chicago, Dept. of Geography.
- National Bureau of Statistics of China (2001) *China Statistical Yearbook-2001*. Beijing: China Statistics Press.
- National Bureau of Statistics of China (2008) *China Statistical Yearbook-2008*. Beijing: China Statistics Press.
- National Bureau of Statistics of China (2011) Major Figures of the Sixth National Population Census, 2010. Available at

- http://www.stats.gov.cn/tjfx/jdfx/t20110428_402722253.htm. Retrieved on January 7, 2012.
- National Development and Reform Commission (2012) Five Year Plans. Available at <http://baike.baidu.com/view/29796.htm#8>. Retrieved on March 13, 2012.
- Nystuen, J. and Dacey, M. (1961) A graph theory interpretation of nodal regions, *Papers in Regional Science* 7(1):29-42.
- O'Neill, R., Johnson, A. and King, A. (1989) A hierarchical framework for the analysis of scale, *Landscape Ecology* 3(3):193-205.
- O'Neill, R. V. (1986) *A Hierarchical Concept of Ecosystems*. Princeton, New Jersey: Princeton University Press.
- Oguz, H., Klein, A. and Srinivasan, R. (2007) Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Houston-Galveston-Brazoria CMSA, *Research Journal of Social Sciences* 2:72-82.
- Olsson, G. (1970) Explanation, prediction, and meaning variance: an assessment of distance interaction models, *Economic Geography* 46:223-233.
- Pannell, C. W. (1977) Past and present city structure in China, *Town Planning Review* 48(2):157-172.
- Pannell, C. W. (2002) China's continuing urban transition, *Environment and Planning A* 34:1571-1589.
- Pannell, C. W. (2003) China's demographic and urban trends for the 21st century, *Eurasian Geography and Economics* 44(7):479-496.
- Park, R. E., Burgess, E. W. and McKenzie, R. D. (1992) *The City: Suggestions for Investigation of Human Behavior in the Urban Environment*. Chicago: University of Chicago Press.
- Pickett, S. T. A. and Cadenasso, M. L. (1995) Landscape ecology: Spatial heterogeneity in ecological systems, *Science* 269(5222):331-334.
- Pickett, S. T. A., Burch, W. R., Dalton, S. E., Foresman, T. W., Grove, J. M. and Rowntree, R. (1997) A conceptual framework for the study of human ecosystems in urban areas, *Urban Ecosystems* 1(4):185-199.
- Pickett, S. T. A. (2001) Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Area", *Annual Review of Ecology and Systematics* 32.
- Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C. and Costanza, R. (2001) Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas, *Annual Review of Ecology and Systematics* 32(1):127-157.
- Pinto, N. N. and Antunes, A. P. (2007) Modeling and urban studies: an introduction, *Architecture, City, and Environment* 2(4):471-485.

- Piracha, A. L. and Marcotullio, P. J. (2003) *Urban Ecosystems Analysis: Identifying Tools and Methods*. United Nations University Institute of Advanced Studies, Jingumae, Tokyo.
- Polednak, A. P. (1997) *Segregation, Poverty, and Mortality in Urban African Americans*. New York, USA: Oxford University Press.
- Project Gigalopolis (2012) SLEUTH urban and land use change model. Available at <http://www.ncgia.ucsb.edu/projects/gig/index.html>. Retrieved on November 23, 2011.
- Qi, W. (2002) *Review and tendency on the Chinese urbanization and city development*. Regional Training Workshop on Knowledge Infrastructure for Good Governance, Hangzhou, People's Republic of China: November 5-8, 2002.
- Redman, C. L., Grove, J. M. and Kuby, L. H. (2004) Integrating social science into the long-term ecological research (LTER) network: social dimensions of ecological change and ecological dimensions of social change, *Ecosystems* 7(2):161-171.
- Riitters, K. H., O'Neill, R. V., Hunsaker, C. T., Wickham, J. D., Yankee, D. H., Timmins, S. P., Jones, K. B. and Jackson, B. L. (1995) A factor analysis of landscape pattern and structure metrics, *Landscape Ecology* 10(1):23-39.
- Roy, D. P., Ju, J., Kline, K., Scaramuzza, P. L., Kovalsky, V., Hansen, M., Loveland, T. R., Vermote, E. and Zhang, C. (2010) Web-enabled Landsat Data (WELD): Landsat ETM+ composited mosaics of the conterminous United States, *Remote Sensing of Environment* 114(1):35-49.
- Sampson, R. and Wilson, W. (1995) Toward a theory of race, crime, and urban inequality, *Crime and Inequality*:37-54.
- Scott, L. and Pratt, M. (2009) An introduction to using regression analysis with spatial data. Available at <http://www.esri.com/news/arcuser/0309/files/why.pdf>. Retrieved on August 30, 2011.
- Semboloni, F. (1997) An urban and regional model based on cellular automata, *Environment and Planning B* 24(4):589-612.
- Seto, K. C. and Fragkias, M. (2005) Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics, *Landscape Ecology* 20(7):871-888.
- Shackelford, A. K. and Davis, C. H. (2003) A hierarchical fuzzy classification approach for high-resolution multispectral data over urban areas, *Geoscience and Remote Sensing, IEEE Transactions on* 41(9):1920-1932.
- Shevky, E. and Bell, W. (1955) *Social Area Analysis: Theory, Illustrative Application, and Computational Procedures*. Palo Alto, California: Stanford University Press.
- Sit, V. F. (1995) *Beijing: The Nature and Planning of a Chinese Capital City*. New York: John Wiley & Sons.

- Sit, V. F. S. and Dong, L. (1985) *Chinese Cities: The Growth of The Metropolis Since 1949*. Oxford, New York: Oxford University Press.
- Sit, V. F. S. (1999) Social areas in Beijing, *Geografiska Annaler: Series B, Human Geography* 81(4):203-221.
- Skinner, G. W. and Henderson, M. (1999) *A hierarchical regional space model for contemporary China: analyzing the urban hierarchy*. Geoinformatics' 99 Conference, China Data Center, University of Michigan: 20 June 1999.
- Small, K. A. (2002) Chinese urban development: introduction, *Urban Studies* 39(12):2159-2162.
- Song, J. (2010) Moving purchase and sitting purchase: Housing reform and transition to homeownership in Beijing, *Housing Studies* 25(6):903-919.
- Song, S. and Zhang, H. (2002) Urbanisation and city size distribution in China, *Urban Studies* 39(12):2317-2327.
- Stewart, J. Q. (1948) Demographic gravitation: evidence and applications, *Sociometry* 1:31-58.
- Stone, C. (1989) *Regime Politics: Governing Atlanta, 1946-1988*. Lawrence: University Press of Kansas.
- Stone, C. (1993) Urban regimes and the capacity to govern: a political economy approach, *Journal of Urban Affairs* 15(1):1-28.
- Tian, G., Liu, J., Xie, Y., Yang, Z., Zhuang, D. and Niu, Z. (2005) Analysis of spatio-temporal dynamic pattern and driving forces of urban land in China in 1990s using TM images and GIS, *Cities* 22(6):400-410.
- Timms, D. W. G. (1971) *The Urban Mosaic: Towards a Theory of Residential Differentiation*. Cambridge: Cambridge University Press.
- Tinkler, K. J. (1979) Graph theory, *Progress in Human Geography* 3(1):85-116.
- Tsou, J. Y., Yu, H. and Cecilia, H. H. S. (2008) Challenges for the Implementation Strategy of Affordable China Housing. Available at http://policydialogue.org/files/events/Tsou_Yu_Cecilia_challenges_implementation_housing.pdf. Retrieved on March 20, 2011.
- Turner, M. G. (2005) Landscape ecology in North America: past, present, and future, *Ecology* 86(8):1967-1974.
- United Nations (2005) World urbanization prospects: the 2005 revision. Available at <http://www.un.org/esa/population/publications/WUP2005/2005wup.htm>. Retrieved on January 28, 2009.
- United Nations (2007) World urbanization prospects: the 2007 revision. Available at <http://esa.un.org/unup>. Retrieved on January 28, 2009.
- United Nations (2010) World urbanization prospects: the 2009 revision. Available at <http://esa.un.org/unup>. Retrieved on January 28, 2011.
- Walbridge, M. R. (1997) Urban ecosystems: editorial, *Urban Ecosystems* 1(1):1-2.

- Wang, G. and Shen, J. (2002) A study of the urban comprehensive competitiveness of cities at prefecture level or above in China (中国地级以上城市综合竞争力研究), *FUDAN Journal (Social Sciences)* (复旦学报(社会科学版)) 3:69-77.
- Wang, Y., Jamshidi, M., Neville, P., Bales, C. and Morain, S. (2007) Hierarchical Fuzzy Classification of Remote Sensing Data, in Nikravesh, M., Kacprzyk, J. and Zadeh, L. A. (eds.) *Forging New Frontiers: Fuzzy Pioneers I*. Berlin / Heidelberg: Springer, pp. 333-350.
- Wang, Y. P. (2001) Urban housing reform and finance in China, *Urban Affairs Review* 36(5):620-645.
- Ward, D. P., Murray, A. T. and Phinn, S. R. (2000) A stochastically constrained cellular model of urban growth, *Computers, Environment and Urban Systems* 24(6):539-558.
- Weng, Y. (2007) Spatiotemporal changes of landscape pattern in response to urbanization, *Landscape and Urban Planning* 81(4):341-353.
- White, R. and Engelen, G. (1993) Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land-use patterns, *Environment and Planning A* 25(8):1175-1199.
- White, R. and Engelen, G. (1997) Cellular automata as the basis of integrated dynamic regional modelling, *Environment and Planning B: Planning and Design* 24(2):235-246.
- Wu, F. (1996) Changes in the structure of public housing provision in urban China, *Urban Studies* 33(9):1601-1627.
- Wu, F. and Yeh, A. G.-O. (1997) Changing spatial distribution and determinants of land development in Chinese cities in the transition from a centrally planned economy to a socialist market economy: a case study of Guangzhou, *Urban Studies* 34(11):1851 - 1879.
- Wu, F. and Yeh, A. (1999) Urban spatial structure in a transitional economy: the case of Guangzhou, *China Journal of the American Planning Association* 65(4):377-394.
- Wu, F. and Martin, D. (2002) Urban expansion simulation of Southeast England using population surface modelling and cellular automata, *Environment and Planning A* 34:1855-1876.
- Wu, F. (2005) The city of transition and the transition of cities, *Urban Geography* 26(2):100-106.
- Wu, J. and Loucks, O. L. (1995) From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology, *Quarterly Review of Biology* 70(4):439-466.
- Wu, J. (2008a) Toward a landscape ecology of cities: beyond buildings, trees, and urban forests, in Carreiro, M. M., Song, Y. C. and Wu, J. (eds.) *Ecology, Planning, and Management of Urban Forests*. New York: Springer, pp. 10-28.

- Wu, Q. and Luo, J. (1999) The progress in urban social spatial differentiation study of China, *Chinese Geographical Science* 9(3):206-212.
- Wu, W. (2008b) Migrant settlement and spatial distribution in metropolitan Shanghai, *The Professional Geographer* 60(1):101-120.
- Wu, X. and Treiman, D. J. (2007) Inequality and equality under Chinese socialism: The Hukou system and intergenerational occupational mobility, *American Journal of Sociology* 113(2):415-445.
- Xie, Y., Fang, C., Lin, G. C. S., Gong, H. and Qiao, B. (2007) Tempo-spatial patterns of land use changes and urban development in globalizing China: a study of Beijing, *Sensors* 7:2881-2906.
- Xu, X., Hu, H. and Yeh, A. G.-O. (1989a) A factorial ecological study of social spatial structure in Guangzhou, *Acta Geographica Sinica* 44(4):385-399.
- Xu, X., Hu, H. and Yeh, C.-O. (1989b) A factorial ecological study of social spatial structure in Guangzhou, *Acta Geographica Sinica* 44(4):385-399.
- Yamaguchi, Y. and Shinya, M. (2010) *Affordable Housing for Rural Migrant Workers in Urban China*. Welfare Asia 4th Conference, Taipei, Taiwan.
- Yan, H. (2009) Welfare Housing Programs in China. Available at <http://www.eai.nus.edu.sg/BB485.pdf>. Retrieved on January 28, 2011.
- Yang, D. T. (2008) China's agricultural crisis and famine of 1959-1961: A survey and comparison to Soviet Famines, *Comparative Economic Studies* 50(1):1-29.
- Yeh, A. and Wu, F. (1995) Internal structure of Chinese cities in the midst of economic reform, *Urban Geography* 16:521-554.
- Yeh, A., Xu, X. and Hu, H. (1995a) The social space of Guangzhou City, China, *Urban Geography* 16:595-621.
- Yeh, A. G.-O., Xu, X. and Hu, H. (1995b) The social space of Guangzhou City, China, *Urban Geography* 16:595-621.
- Yeh, A. G.-O. and Xu, X. (1996) Urbanization and urban system development in China, in Lo, F. and Yeung, Y. (eds.) *Emerging World Cities in Pacific Asia*. Tokyo - New York - Paris: United Nations University Press.
- Yin, H. (2005) 对城市吸引区范围界定的理论分析 (A theoretic analysis of ascertaining the Cities' Gravitation-Regions), *财经研究 (Journal of Finance and Economics)* 11:108-114.
- Yu, D. L. (2006) Spatially varying development mechanisms in the Greater Beijing Area: a geographically weighted regression investigation, *The Annals of Regional Science* 40(1):173-190.
- Yusuf, S. and Wu, W. (1997) *The Dynamics of Urban Growth in Three Chinese Cities*. Oxford, New York: Oxford University Press.
- Yusuf, S. and Saich, T. (2008) *China Urbanizes: Consequences, Strategies, and Policies*. Washington, D.C.: World Bank Publications.

- Zadeh, L. A. (1965) Fuzzy sets, *Information and Control* 8(3):338-353.
- Zha, Y., Gao, J. and Ni, S. (2003) Use of normalized difference built-up index in automatically mapping urban areas from TM imagery, *International Journal of Remote Sensing* 24(3):583 - 594.
- Zhan, S. (2011) What determines migrant workers' life chances in Contemporary China? Hukou, social exclusion, and the market, *Modern China* 37(3):243-285.
- Zhao, L. and Li, J. (2006) *China reforming the Hukou system: Reducing discrimination against the rural population*. EAI Background Brief No. 284.
- Zhao, P. (2011) Managing urban growth in a transforming China: evidence from Beijing, *Land Use Policy* 28(1):96-109.
- Zhao, S. X. B., Chan, R. C. K. and Sit, K. T. O. (2003) Globalization and the dominance of large cities in contemporary China, *Cities* 20(4):265-278.
- Zheng, Y., Chen, T., Cai, J. and Liu, S. (2009) Regional concentration and region-based urban transition: China's mega-urban region formation in the 1990s, *Urban Geography* 30(3):312-333.
- Zipperer, W. C., Wu, J., Pouyat, R. V. and Pickett, S. T. A. (2000) The application of ecological principles to urban and urbanizing landscapes, *Ecological Applications* 10(3):685-688.