Investigation of urban sprawl on the basis of remote sensing data--- A case study in Jiangning, Nanjing City, China

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Summary

The dissertation is continuing research on the project named "Sustainable Development by Integrated Land Use Planning (SILUP) ", which has been completed cooperatively by both Chinese and German research institutions, taking Jiangning District as a typical research area to recognize the spatial patterns, monitor dynamic change, measure distinct extents, analyze the driving forces and access impacts of urban sprawl based on the technology of Remote Sensing (RS), Geographic Information System (GIS) and so on.

Over the past 30 years, urban development in China has been remarkable. Land development and consumption have been out of control and kept expanding massively, especially to marginal areas of some metropolises. The undesirable growth patterns in Chinese cities appear to threaten the goal of sustainable development and impose some costs socially, economically and environmentally on households, firms and governments.

At present, the research on urban sprawl in China is still in a preliminary stage- the basic characteristics of urban sprawl are not explicitly defined and the understanding of its internal mechanisms has been maintained at the level of empirical theory. The dissertation deals with the existing literatures on the subject of urban sprawl, undertaking a thorough review in terms of similarities and differences, consensuses and disagreements among many researchers and publications by comparing definitions, indicators, causes and costs between the sprawl in Western countries and China. Looking at the example of the United States, urban sprawl occurred within a perfect market economic system. However, urban sprawl in many cities of China has emerged during a transition period of China's economy from a planned economic system to a market economic system. Is it appropriate to transfer the Western conceptualization of urban sprawl to China? To what extent can these results be applicable to China?

Therefore, it is urgent necessary to find ways to research urban sprawl in Chinese cities. Key questions should be answered: What is the exact definition of urban sprawl? How do we express the basic characteristics of urban sprawl explicitly? What are the internal mechanisms of urban sprawl? What are the driving forces and impacts of sprawl?

The objective of this dissertation is to structure a complete framework for areas in China which have similar development backgrounds as Jiangning, provide ideas of urban sprawl study in some developing countries which also have similar a development background with Jiangning and give references and ideas for comparative study on the problem of urban sprawl between areas in Western countries and China.

Summary

The main contents and conclusions include:

1. In the context of a spatial-temporal-based theory, this dissertation focuses on the spatial-temporal characteristics, measurement indicators, driving forces and impact assessment of urban sprawl.

Through a review of varying uses of definition, this dissertation seeks to define urban sprawl as a phenomenon of disordered construction of built-up areas in the process of spatial expansion due to urbanization of the urban fringe. Based on this definition, urban sprawl has to be considered within a temporal dimension in order to be understood as a process.

Remote sensing technology is indispensable for dealing with dynamic phenomenon and is a tool for determining the existence of urban sprawl. In addition, by applying the theory of landscape ecology to urban sprawl, the meaning and effects of urban sprawl can be better understood. Remote sensing and other technologies, such as GIS, can separately or in combination be applied on the study of urban sprawl. Based on spatial-temporal analyses, Cause-Impact model (CI model) is applied to analyze the impacts of urban sprawl.

2. Recognizing spatial pattern of urban sprawl. Using Landsat MSS/TM images, the built–up areas of four different years (1979, 1988, 1997 and 2003) were extracted from classified images. In order to improve the accuracy of classification, it was necessary to expand the original feature space based only on spectral feature. Combining classified images with three different landscape metrics including contagion, fractal dimension and shape index, the sprawl patterns were recognized.

3. Monitoring the dynamic change of urban sprawl. Based on classified images of four different years, the methodology of Shannon's entropy, change detection method, dynamic change rate of sprawl and variable clumping method were used to figure out the dynamic change of urban sprawl. The multi-dimensional indicators have been selected based on characteristics of sprawl. The calculation of integrated indicators was carried out using GIS. On the basis of the calculation results, the distinct extents of sprawl were identified.

4. Investigating the causes and impacts of urban sprawl. Through analyzing parameters of spatial-temporal characteristics and demographic-social-economic factors, the driving factors

of urban sprawl were investigated. Based on the driving forces, the Cause-Impact model is constructed to explain the impacts of urban sprawl.

5. The results of this dissertation show that non-agricultural lands have continued to grow by increasing amount, while displaying low efficiency and disordered spatial configuration, indicating a typical sprawling tendency. Three sprawling patterns are identified: random expansion at the urban fringe, scattered development of industrial land and leapfrog development of urban residential areas. The following specific sprawl features are identified: obvious fragmentation and irregularity of landscape; unadvisable pattern of land use growth with typical discontinuous development, strip development and leapfrog development; low density land use.

From 1979 to 1988, the phenomenon of disorder and scattered construction was obvious; from 1988 to 1997, sprawl was more significant in the process of suburbanization. Leapfrog development was significant from 1997 to 2003, which created a fragmented and broken landscape. During the first period, 1979-1988, the extent of urban sprawl was relatively low. This level continued to increase to a medium level of sprawl by 1997 and to a high level by 2003.

Driving forces including planning policy, population size and population composition, transformation of industrial structure and economic growth of development zone are the main reasons of urban sprawl. Excessive expansion imposes costs on development environmentally, economically and socially. The worst consequences of the excessive growth of the built-up areas are the smothering of agricultural and sensitive lands. Coupled with that is the pollution and dwindling of bodies of water and wetlands and the risk of flooding. Other costs such as increased air pollution, rising expenditure on transportation and rising motor accidents which come with sprawl are prevalent.

This dissertation intends to provide some cautions to decision-makers which they can use to implement good planning for the future development of Jiangning.

Zusammenfassung

Die Abhandlung ist, während die subsequential Forschung des Projektes Sustainable Development durch integrierte Flächennutzung-Planung (SILUP) nannte, die kooperativ von den chinesischen und deutschen Forschung Anstalten erfolgt worden ist und nimmt Jiangning Bezirk als der typische Forschung Bereich, um die räumlichen Muster, dynamische änderung des Monitors zu erkennen, mißt eindeutigen Umfang, analysiert die Antriebskräfte und die Zugang Auswirkungen der städtischen Ausbreitung basiert auf der Technologie der Fernabfragung (RS), des geographischen Informationssystems (GIS), des etc.

Über den letzten 30 Jahren ist städtische Entwicklung in China bemerkenswert gewesen. Landentwicklung und -verbrauch sind aus, die der Steuerung und gehaltener gewesen Erweiterung heraus, besonders zu den begrenzten Bereichen einiger Hauptstadt außer Betrieb sind. Die nicht wünschenswerten Wachstummuster der städtischen Ausbreitung in den chinesischen Städte scheinen, das Ziel der stützbaren Entwicklung zu bedrohen und etwas Kosten Haushalten, Unternehmen und Regierungen sozial, ökonomisch und umweltsmäßig aufzuerlegen.

Zur Zeit ist eine Forschung auf dem Gebiet einer städtischen Ausbreitung in China noch in einem einleitenden Stadium, haben die grundlegenden Eigenschaften der städtischen Ausbreitung keinen ausdrücklichen Ausdruck, und die Realisierung seiner internen Einheiten ist im Niveau von empiricism beibehalten worden. Die Abhandlung wird mit den vorhandenen literatures bezüglich der städtischen Ausbreitung fertig und nimmt sich einen vollständigen Bericht in ähnlichkeiten und Unterschieden ausgedrückt, übereinstimmung und Widerspruch unter vielen Forschern und Publikationen auf, indem sie zwischen Definitionen, Anzeigen, Ursachen und Kosten von Ausbreitung in den Westländern und in China vergleicht, die unterschiedliche Hintergründe in der städtischen Ausbreitung haben. Ein Beispiel von Vereinigten Staaten nehmend, trat städtische Ausbreitung mit einem Wirtschaftssystem des vollkommenen Marktes auf, jedoch ist städtische Ausbreitung in vielen Städte von China seit 1980 aufgetaucht. Dieses ist eine übergangsphase von Wirtschaft Chinas von einem geplanten Wirtschaftsystem zu einem Wirtschaftssystem des Marktes. Ist es möglich, die westliche Konzeptualisierung der städtischen Ausbreitung zu bringen? In welchem Ausmass diese Resultate nach China anwendbar sein können?

Folglich ist es dringend, Wege zu finden, auf städtischer Ausbreitung in den chinesischen Städte zu erforschen. Schlüsselfragen sollten beantwortet werden: Was ist die genaue Definition der städtischen Ausbreitung? Wie man die grundlegenden Eigenschaften der städtischen Ausbreitung ausdrücklich ausdrückt? Was sind die internen Einheiten der städtischen Ausbreitung? Was sind Antriebskräfte und Auswirkungen von Ausbreitung?

Die Zielsetzung dieser Abhandlung ist, einen kompletten Rahmen für Bereiche in China zu strukturieren, die ähnlichen Entwicklung Hintergrund mit Jiangning haben, zur Verfügung stellen einige Ideen der Studie der städtischen Ausbreitung für Bereiche in einigen Entwicklungsländern, die auch ähnlichen Entwicklung Hintergrund mit Jiangning und Hinweis für vergleichbare Untersuchung über das Problem städtischer Ausbreitung zwischen Bereichen in den westlichen Ländern und China haben.

Hauptinhalt und Zusammenfassungen schließen ein:

Zusammenfassung

1. Im Kontext einer räumlich-zeitlich-gegründeten Theorie, konzentriert die Abhandlung auf die räumlich-zeitlichen Eigenschaften, die Meßwertanzeiger, die Antriebskräfte und die Auswirkung Einschätzung der städtischen Ausbreitung.

Obwohl ein Bericht der unterschiedlichen Gebräuche von Definition, die Abhandlung eine Suche ist, zum der städtischen Ausbreitung als Phänomen des Störungaufbaus des aufgebauten Bereichs bei der räumlichen Expansion zu definieren wegen der Verfeinerung der städtischen Franse. Gegründet auf dieser Definition, muß städtische Ausbreitung innerhalb eines zeitlichen Maßes betrachtet werden, zwecks als Prozeß verstanden zu werden.

Fernabfragungtechnologie ist für das Beschäftigen dynamische Phänomene unentbehrlich und ist ein Werkzeug für die Bestimmung des Bestehens der städtischen Ausbreitung. Zusätzlich indem man die Theorie von Landschaftsökologie an der städtischen Ausbreitung, was städtische Ausbreitung ist und was Effekte der städtischen Ausbreitung sind, kann besser verstanden werden anwendet. Die Fernabfragung und andere Technologien, wie GIS, können in der Kombination für Anwendung auf der Studie der städtischen Ausbreitung separat oder sein. Gegründet auf räumlich-zeitlicher Analyse, wird Verursachen-Auswirkung Modell angewendet, um die Auswirkungen der städtischen Ausbreitung zu analysieren.

2. Erkennen des räumlichen Musters der städtischen Ausbreitung. Mit Landsat MSS/TM Bildern werden die aufgebauten Bereiche von vier unterschiedlichen Jahren (1979, 1988, 1997 und 2003) von eingestuften Bildern extrahiert. Um die Klassifikationgenauigkeit zu verbessern, ist es notwendig den ursprünglichen Eigenschaft Raum zu erweitern, der nur auf spektraler Eigenschaft basiert. Eingestufte Bilder mit drei unterschiedlichen Landschaftsmetriken einschließlich Ansteckung, fractal Maß und Formindex kombinierend, hilft es, Ausbreitungmuster zu erkennen.

3. Überwachung der dynamischen änderung der städtischen Ausbreitung. Gegründet auf eingestuften Bildern von vier unterschiedlichen Jahren, werden die Methodenlehre von Entropie Shannons, die änderung Abfragung Methode, die dynamische änderung Rate von Ausbreitung und die variable aufhäufende Methode verwendet, um dynamische änderung der städtischen Ausbreitung heraus darzustellen. Die mehrdimensionalen Anzeigen sind gründeten auf Eigenschaften von Ausbreitung vorgewählt worden. Die Berechnung der integrierten Anzeigen kann mit GIS durchgeführt werden. Auf der Grundlage von die Berechnung Resultate wird der eindeutige Umfang einer Ausbreitung gekennzeichnet.

4. Nachforschen der Ursachen und der Auswirkungen der städtischen Ausbreitung. Durch das Analysieren von Parametern der räumlich-zeitlichen Eigenschaften und der demographisch-Sozial-ökonomischen Faktoren, können die treibenden Faktoren der städtischen Ausbreitung nachgeforscht werden. Gegründet auf Antriebskräften, wird das Verursachen-Auswirkung Modell konstruiert, um die Auswirkungen der städtischen Ausbreitung zu erklären.

5. Die Resultate der Abhandlung zeigt, daß nicht landwirtschaftliches Land schnell wachsend mit der großen Menge, niedriger Leistungsfähigkeit und zerrütteten räumlichen der Konfiguration gehalten hat und eine typische ausbreitende Tendenz angezeigt. Drei ausbreitende Muster werden gekennzeichnet: nach dem zufall Expansion an der städtischen

Franse, zerstreute Entwicklung des industriellen Landes und leapfrog Entwicklung des städtischen Wohnbereichs. Die folgenden spezifischen Ausbreitungeigenschaften werden gekennzeichnet: offensichtliche Zerteilung und Unregelmäßigkeit der Landschaft; unadvisable Muster des Flächennutzungwachstums mit typischer unterbrochener Entwicklung, Streifenentwicklung und leapfrog Entwicklung; niedrige Dichte des Flächennutzungwachstums.

Von lagen 1979 bis 1988, das Phänomen der Störung und der zerstreute Aufbau auf der Hand; von ist 1988 bis 1997, Ausbreitung bei suburbanization bedeutender. Leapfrog Entwicklung ist bedeutend; von 1997 bis 2003, wurde das Land, mit dem Ergebnis einer defekten Landschaft zersplittert. Während 1979-1988 war der Umfang einer städtischen Ausbreitung verhältnismäßig niedrig. Während 1988-1997 erfuhr der Umfang einer städtischen Ausbreitung vom Zustand der niedrigen Ausbreitung zum Zustand der mittleren Ausbreitung. Während 1997-2003 erfuhr der Umfang einer städtischen Ausbreitung von der mittleren Ausbreitung zur hohen Ausbreitung.

Antriebskräfte einschließlich Planung Politik, Bevölkerung Größe und Bevölkerung Aufbau, Umwandlung der industriellen Struktur und Wirtschaftswachstum der Entwicklung Zone sind Hauptgründe der städtischen Ausbreitung. Übermäßige Expansion erlegt Kosten Entwicklung umweltsmäßig, ökonomisch und sozial auf. Die schlechtere Konsequenz des übermäßigen Wachstums der aufgebauten Bereiche ist das Ersticken der landwirtschaftlichen und empfindlichen Länder. Mit diesem verbunden die Verunreinigung und das Schwinden der Wasserkörper und -sumpfgebiete und die Gefahr der überschwemmung. Andere Kosten wie erhöhte Luftverschmutzung, steigende Aufwendung auf Transport- und Steigenmotorunfälle, die mit Ausbreitung kommen, sind überwiegend.

Die Resultate der Abhandlung beabsichtigen, einige Alarme zum Entscheidungstreffer zu geben, um die gute Planung für zukünftige Entwicklung von Jiangning zu bilden.

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1 Introduction

1.1 Background and problem formulation

Urban sprawl is defined the as "continuous expansion of big cities' marginal area, moreover, it always has strip of lands in the process of transformation from county to the city" (Gottman 1961). In the 20th century, urban sprawl has been a major problem in the process of urban development of Western countries. Most urban sprawl is considered to be of low-density expansion accompanied by a series of environmental and socio-economic issues.

Across cities and states of Europe and North America, there is a growing awareness of urban sprawl. Ewing (1997, 2002) characterized urban sprawl as "leapfrog land use patterns, strip commercial development along highways, and very low-density single-use developments –as well as by such indicators as poor accessibility of related land uses, and lack of functional open space." Galster et al. (2001) offered eight conceptually distinct and objective dimensions of land use which if present at low values and some combinations characterize sprawl. Hasse (2002) argued that urban sprawl is wasteful, inefficient and/or dysfunctional urban growth within the context of a landscape. Jaeger et al. (2010) proposed that urban sprawl is a phenomenon perceived in the landscape. The more heavily permeated a landscape is with buildings, the more sprawled the landscape. The more dispersed the buildings, the higher the degree of urban sprawl. The term "urban sprawl" can be used to describe both a state as well as a process.

To what extent can these results be applicable to China? Of fundamental importance is to compare the different backgrounds of urban sprawl between Western countries and China. Taking an example from the United States, urban sprawl occurred with a market economy system; however, since 1980 urban sprawl has emerged in many cities of China. This is a transition period of China's economy from a planned economy system to a market economy system. The emergence of the market economy in China has influenced spatial development significantly. The undesirable growth patterns in Chinese cities appear to threaten the goal of sustainable development and impose some costs socially, economically and environmentally on households, firms and governments.

What are the actual differences of urban sprawl between Western countries and China? Deng and Huang (2003) proposed that Chinese sprawl style is an unintended consequence of

political manipulation of land development on the urban fringe and urban sprawl, and that it requires a different definition and theoretical explanation of causes and consequences from those used in European countries and North America. The exact meaning of urban sprawl in the Chinese context remains largely unexplored; the term "urban sprawl" is used to describe inefficient patterns of urban expansion in China, as measured by the benchmark of monocentric urban structure. Bekele (2005) advanced the idea that urban sprawl for China is thus the disproportionate expansion of urbanized area. Wang and Gao (2005) concluded that the urbanization process has distinct characteristics in China and in Western countries, and that urban sprawl and urbanization in China are almost attendant. Li and Yang (2006) proposed that urban sprawl is rapid pie-style urban space spread. Urbanized land use expands rapidly associating with traffic congestion, green belt erosion by occupied farmland and other problems. Jiang et al. (2007) described the sprawl in China as rapid, low-efficient and disorderly growth of non-agricultural land towards peripheral areas; Qi and Lu (2008) gave the definition of "urban sprawl" as low-density, excessive spatial growth of cities. The agricultural lands in China were diminishing year by year with the rising level of urbanization. Moreover, the area of good-quality cultivated lands in the eastern part of the country has decreased. The loss of large amounts of cultivated land has been caused by overdevelopment of the real estate industry and the construction of various types of development zones. However, many key issues of urban sprawl in the Chinese context should still be settled. What is an appropriate definition of urban sprawl in the Chinese context? What is the explicit expression on the basic characteristics of urban sprawl? What are the internal mechanisms of urban sprawl? What are driving forces and impacts of sprawl in the Chinese context?

The following research has been based on the project named Sustainable Development by Integrated Land Use Planning (SILUP), which has been carried out cooperatively by both Chinese and German research institutions. The project SILUP aims to develop, improve and test methods and tools that allow a well- founded and balanced simultaneous consideration of both the socio-economic requirements and the necessary conservation and protection of natural resources in the course of the preparation and implementation of land use decisions, particularly in regard to transferring hitherto agricultural land to new purposes in development. The project of SILUP supplied a scientific basis for further study. This dissertation takes Jiangning District as a typical research area to analyze urban sprawl.

1.2 Research objectives

Three main research contents are proposed in Figure 1.1.

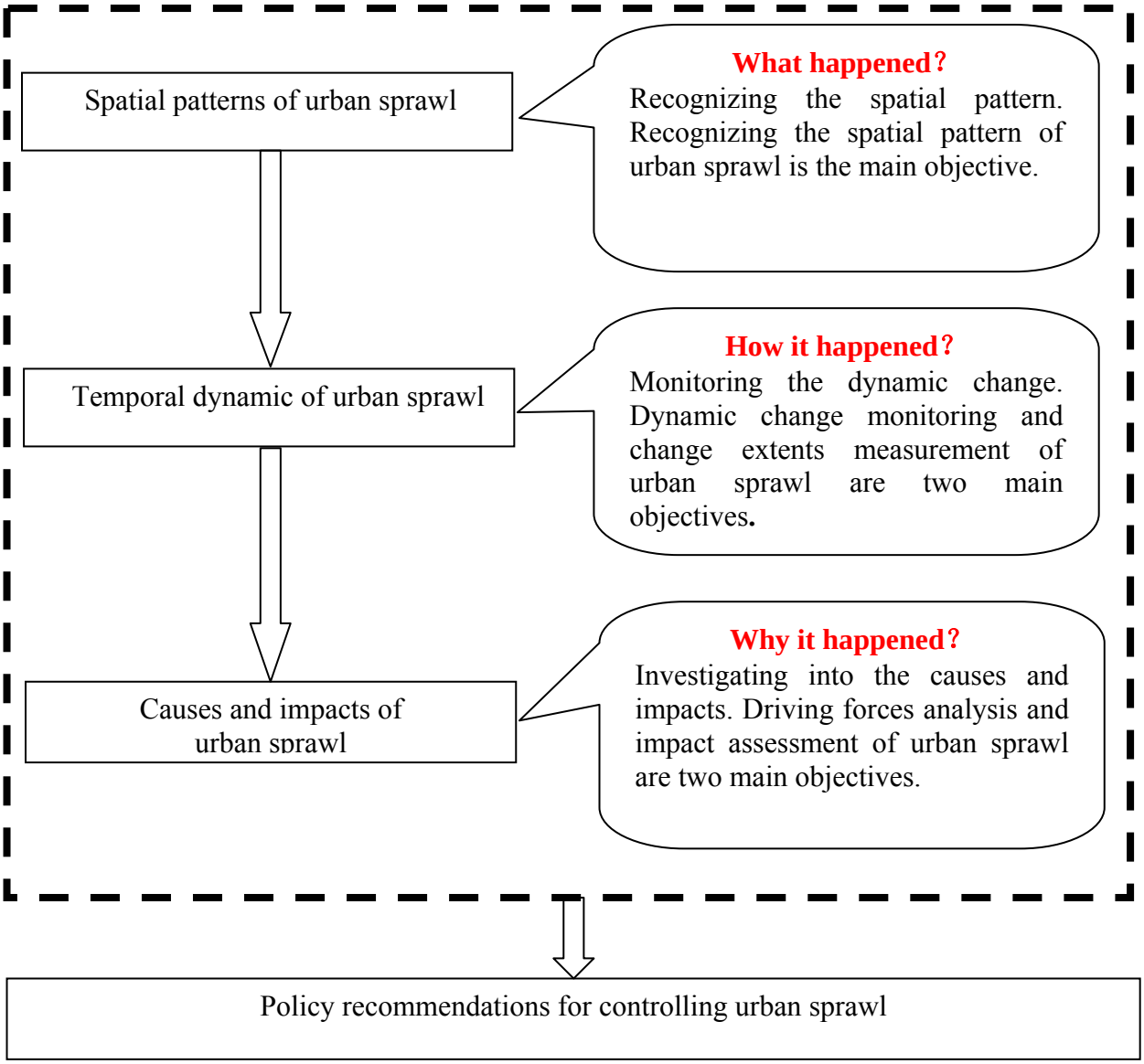

Figure 1.1 Main contents of research

The following is a list of primary results to be attained and of key questions to be answered throughout this work:

1. This dissertation deals with the existing literatures on the subject of urban sprawl, undertaking a thorough review in terms of similarities and differences, consensus and disagreement among many researchers and publications by comparing sprawl definitions, indicators, causes and costs between Western countries and China. Key questions: Is it possible to transfer the Western conceptualization of urban sprawl to China?

2. Recognizing the spatial pattern of urban sprawl. To recognize the spatial pattern of urban sprawl is the main objective. Using Landsat MSS/TM images, the built–up areas of four different years (1979, 1988, 1997 and 2003) were extracted from classified images, together with landscape metrics to recognize the spatial patterns of sprawl in Jiangning. Key questions: what are urban sprawl and its characteristics?

3. Monitoring the dynamic change of urban sprawl. Dynamic change monitoring and change extents measurement of urban sprawl have two main objectives. The multi-dimensional indicators had been selected based on characteristics of sprawl in China. The calculation of integrated indicators was carried out using GIS. On the basis of the calculation results, the distinct extents of sprawl were identified. Key questions: Which indicators can effectively measure sprawl in the specific Chinese situation?

4. Investigating the causes and impacts of urban sprawl. Driving factors analysis and impact assessment of urban sprawl are also main objectives of this research work. Through analyzing parameters of spatial-temporal characteristics and demographic-social-economic factors, the driving factors of urban sprawl were investigated. In addition, the impacts of urban sprawl were discussed based on the Cause-Impact model. Key questions: What are the specific Chinese driving forces and impacts of sprawl?

5. Based on above research results, some policy recommendations for controlling urban sprawl in Jiangning are proposed.

In all, three main objectives of the dissertation are listed below:

1. The dissertation intends to propose an idea of research on urban sprawl for Chinese areas which have similar development backgrounds through recognizing the spatial patterns, measuring the distinct extents and analyzing the driving forces and impacts of urban sprawl.

2. The dissertation intends to contribute some ideas of urban sprawl study for areas in some developing countries.

3. The dissertation intends to provide a reference for comparative study on the problem of urban sprawl between Western countries and China.

1.3 Research methodology

1. Remote sensing technology

Within a temporal dimension, urban sprawl can be understood as a process. This approach to urban sprawl focuses on spatial techniques in the present study. As Jat et al. state in their 2008 paper:" remote sensing technology is indispensable to deal with the dynamic phenomenon." It is also a tool for determining the existence of urban sprawl. Without remote sensing data, one may not be able to monitor and estimate urban sprawl effectively over a time period, especially for an elapsed time period (Jat et al. 2008). Using remote sensing for detecting urban change and urban sprawl, many scholars have made extensive research efforts for nearly three decades (Pathan et al. 1985; Yeh and Li 2001; James et al. 2001; Henry *et al*., 2001; McMahan *et al*., 2002; Burchfield et al. 2005; Sun 2007; Elena and Nancy 2007; Martinuzzi et al. 2007; Jat et al. 2008; Anne et al. 2008; Cheng and Lee 2008; Verzosa and Gonzalez 2010; Bhatta et al. 2010; Ujoh et al. 2010 and Tamilenthi et al. 2011). In this study, remote sensing classified images were used to extract the built–up area of four different years and for the analysis of the temporal change of the land cover.

2. Geographic Information System (GIS)

How to measure urban sprawl has also been a research challenge. Some research organizations (Sierra Club 1998; USA Today 2001; European Environment Agency 2006) have put forth their indicators for measuring urban sprawl, while many scholars focus more on establishing multi-dimensional indicators to measure urban sprawl based on GIS or descriptive statistical analysis (Fulton 2001; Lopez and Hynes 2003; Galster 2001; Hasse 2002; Hasse and Lathrop 2003). Remote sensing and other technologies, such as Geographic Information System (GIS), can be used separately or in combination for the study of urban sprawl (Yeh and Li 2001; Barnes et al. 2001; Epstein et al. 2002; Sudhira et al. 2004; Berkley 2005; Wolman et al. 2005; Huang et al. 2007; Yu et al. 2007; Sun *et al*., 2007; Iyer et al. 2007; Jat et al. 2008; Siedentop and Fina 2010; Adel and Feroz 2010). In this study, change extents of sprawl were figured out using integrated indicators based on GIS.

3. Landscape metrics

Landscape ecology evaluates the interaction between spatial and temporal patterns and ecological processes. A central hypothesis in landscape ecology is that the spatial arrangement of landscape affects ecological systems. Concern about urban sprawl is based on

the assumption that the spatial arrangement of urban development will have social, economic and environmental consequences over a range of temporal scales. It is better to understand what urban sprawl is and what its effects by application the theory of landscape ecology. Integrated remote sensing technology research on the spatial patterns of urban sprawl requires a combination of landscape perspectives for understanding. (Sudhira and Ramachandra 2007; Yu and Ng 2007; Wei 2008; Jat et al. 2008; Terzi and Kaya 2008; Furberg and Ban 2008; Zhang et al. 2008). In this study, sprawl patterns were recognized by combining remote sensing with landscape metrics.

4. Impact assessment model

Assessment of impacts of urban sprawl is also a subject for debate. Some scholars have given some ideas of impacts assessment. Deal and Schunk (2003) focused on the theoretical underpinnings and the practical application of an economic impact analysis sub-model developed within the Land use Evolution and Impact Assessment Modeling (LEAM) environment. The cost of urban sprawl was assessed in Kane County, Illinois by an application of this model. Hasse and Nuissl (2007) strived to assess the impact of urban sprawl on water balance and explored the repercussions of this impact upon the causation of and policies on urban sprawl. In this study, a Cause-Impact model (CI model) was applied to analyze the impacts of urban sprawl. The flowchart of methodology is shown in Figure 1.2.

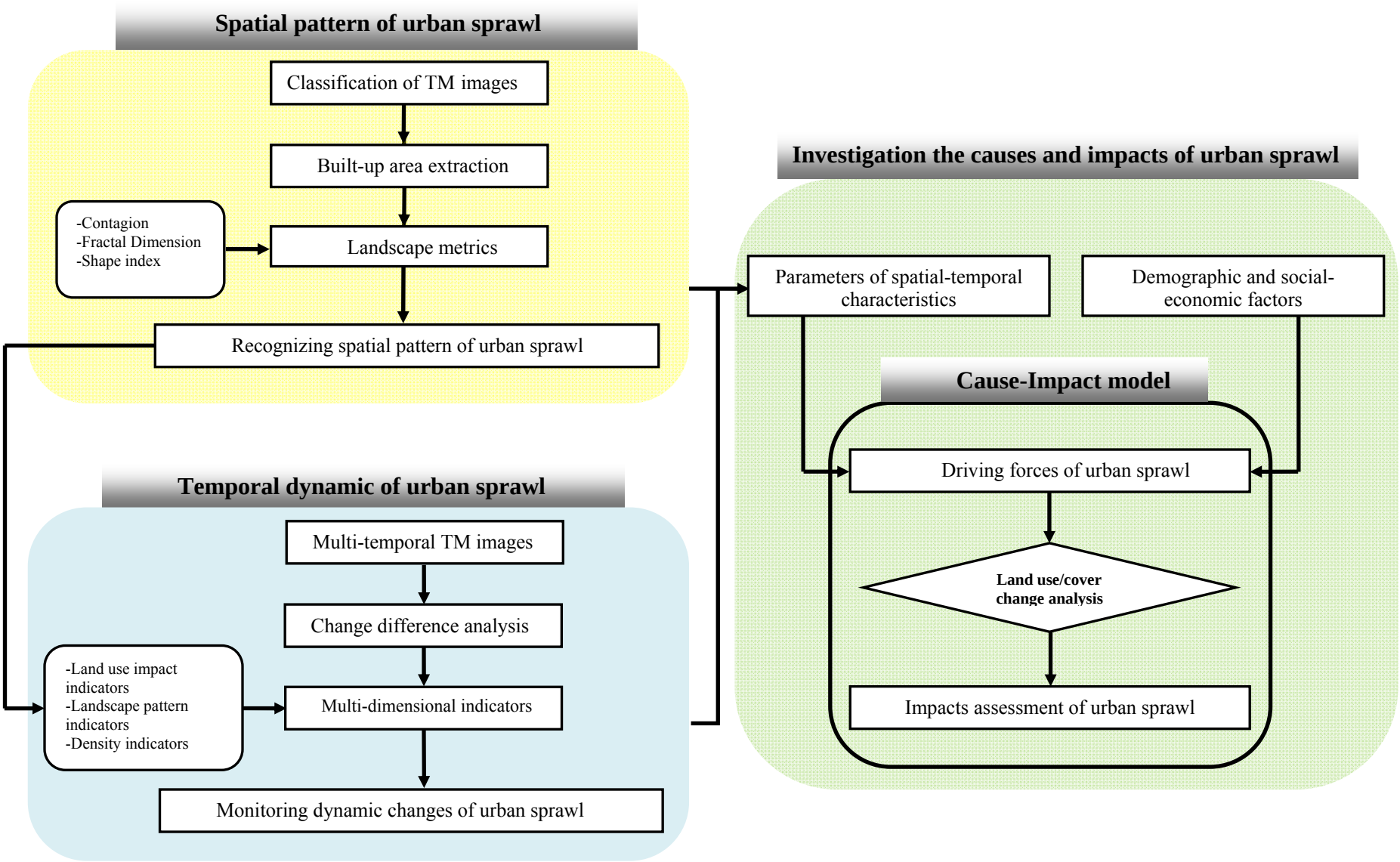

Figure 1.2 The flowchart of methodology

1.4 Construction of this dissertation

This dissertation is organized in 7 chapters as shown in Figure 1.3.

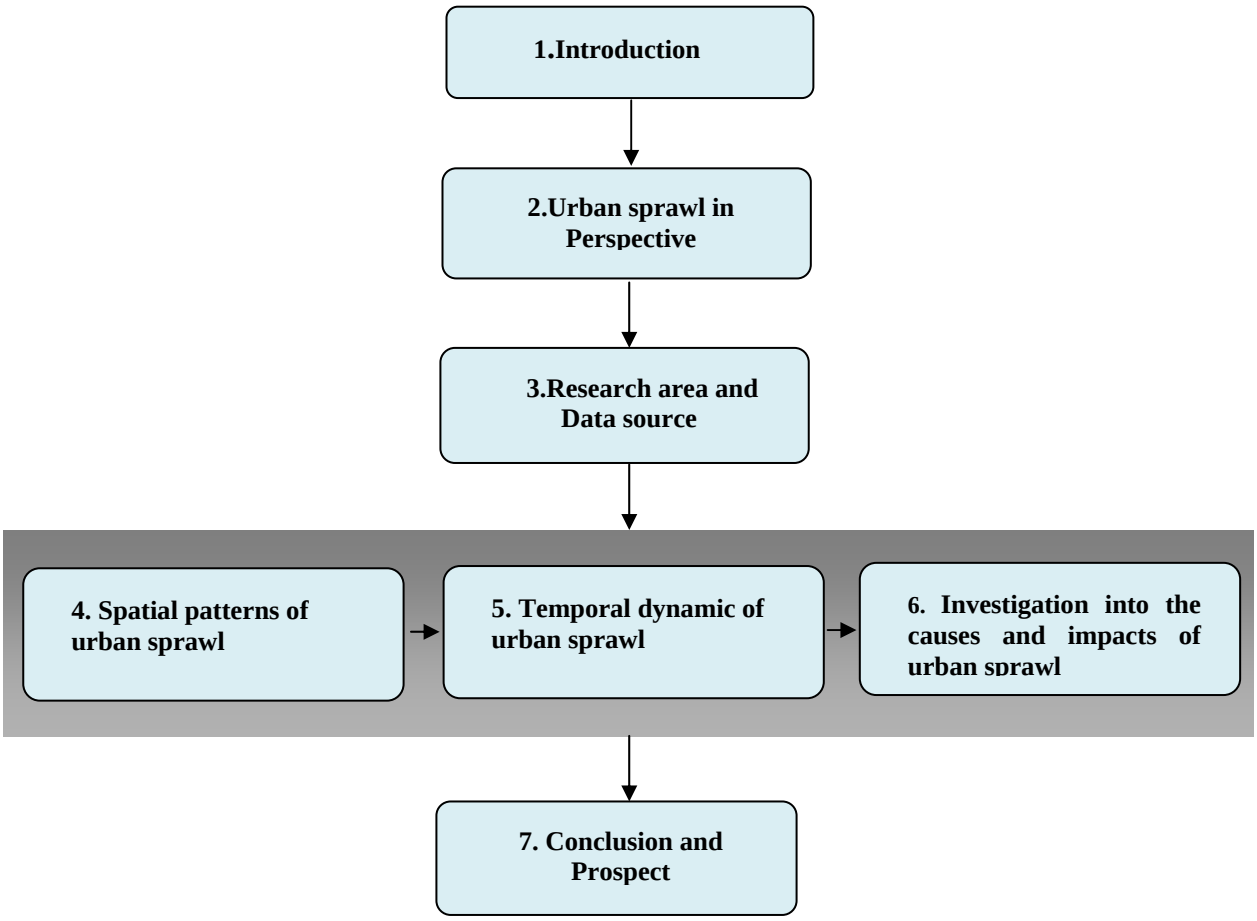

Figure 1.3 Chapters' arrangement of the dissertation

Chapter 1 - Introduction

Chapter 1 starts with background and problem formulation. Based on a list of primary results to be attained and of key questions to be answered throughout this work, three main objectives of the dissertation are described. Finally, the methodology of this work is proposed.

Chapters 2 – Urban sprawl in perspective

Chapter 2 provides a review of the existing research on urban sprawl in Western countries with regard to definition, indicators, causes and costs. In addition, an overview of the major issues of urban sprawl in China is presented. Summarizing and comparing urban sprawl are proposed in terms of similarities and differences, consensus and disagreement among researchers and publications between Western countries and China.

Chapters 3 - Research area and data source

After an introduction of the geographical situation, socio-economic development of the research area is described. Data source and image pre-processing are described after that.

Chapter 4, 5and 6 - Main contents

Chapter 4 highlights the identification of spatial pattern of urban sprawl. Taking Jiangning District as a research area, the built–up areas of four different years (1979, 1988, 1997 and 2003) were extracted from classified images using Landsat MSS/TM images, together with landscape metrics as a contagion index, fractal dimension index and shape index to recognize the spatial patterns of sprawl. The analysis result shows that non-agricultural land has kept fast growing with large amount and disordered spatial configuration, indicating a typical sprawling tendency. Three sprawl patterns are identified: randomly expansion at the urban fringe, scattered development of industrial land and leapfrog development of urban residential areas. The following specific sprawl features are identified: obvious fragmentation and irregularity of landscape; unadvisable pattern of land use growth with typical discontinuous development, strip development and leapfrog development; low density of land use growth; and other negative impacts on agriculture, environment and city life.

Chapter 5 focuses on the dynamic changes of Jiangning's urban sprawl, in particular focusing on dynamic change monitoring with change difference analysis and change extents measurement with multi-dimensional indicators. Based on the dynamic change analysis, the multi-dimensional indicators are selected to measure the extents of urban sprawl. The trend of urban sprawl is significant. From 1979 to 1988, The phenomenon of disorder and scattered construction was obvious in Jiangning. From 1988 to 1997, it was a period of rapid growth and fast urbanization in Jiangning. Sprawl is more significant in the process of suburbanization. Leapfrogging is significant because the development of Nanjing has shifted from the center to the southeast part. From 1997 to 2003, there was a period of great development in Jiangning. The construction of industrial parks, residential areas and university city caused the land in Jiangning to become fragmented and the landscape was broken up. Based on the dynamic change analysis, the multi-dimensional indicators were chosen to measure the extents of urban sprawl. The extent of urban sprawl was relatively low during 1979-1988; the extent of urban sprawl increased from a state of low sprawl to a state of

medium sprawl during 1988-1997; the extent of urban sprawl increased from medium sprawl to high sprawl during 1997-2003.

Chapter 6 analyzes the driving factors and the impacts of urban sprawl in Jiangning. Driving forces are found through analyzing spatial-temporal parameters and demographic-social-economic factors, mainly including planning policy, population size and population composition, transformation of industrial structure and economic growth of development zone. Based on analyzing driving forces, the Cause-Impact model is constructed to explain the impacts of urban sprawl. The excessive expansion imposes costs of development environmentally, economically and socially. The worse consequence of the excessive growth of the built-up areas is the smothering of agricultural and sensitive lands. Coupled with that is the pollution and disappearance of water bodies and wetlands and risk of flooding. Other costs which are prevalent with sprawl are increased air pollution, rising expenditure on transportation and an increase in traffic jams.

Chapter 7 - Conclusion and prospects

Chapter 7 contains conclusions on current work and prospects for future work. In conclusion, the major findings and some policy recommendations are discussed. In prospects, further work on urban sprawl with spatial techniques, policy formulations are proposed.

2 Urban sprawl in perspective

2.1 Research progress in western countries

2.1.1 Defining urban sprawl

Urban sprawl is one of the key issues today. Many western scholars have contributed to defining urban sprawl in different ways[1]. There are definitions and descriptions offered by Western scholars or organizations, and they vary in the subtle differences that can be found regarding to urban form, land uses, impacts and density. In terms of urban form, sprawl is the opposite of the idea of the compact city, with sprawl characteristics being "scattered" or "leapfrog" development. Linear urban forms, such as strip development along major transport routes, have also been considered as sprawl. The second element of the definition is the use of land use patterns to define sprawl. Spatial segregation of land uses, which means different land uses are intentionally disconnected or located at a large distance to each other, is most commonly used to define sprawl. However, sprawl cannot be defined clearly based only on urban form or land use. The third definition is based on the impacts of urban sprawl. Defining sprawl in terms of its cost is a common way of discussing the impacts of sprawl. In addition, there is a consensus that part of the definition of sprawl is low density.

The definitions of urban sprawl proposed by western scholars have been changing since the debate on urban land use change started after World War II. There are two main changes: firstly, urban sprawl was originally referred to neutrally, but scholars have increasingly referred to it derogatorily. Urban sprawl was only considered to be a spatial expansion of the city in the early stages. However, with global urbanization, most researchers believe that urban sprawl has given rise to a series of adverse consequences, such as environmental damage, economic inefficiency, social injustice and therefore non-sustainable development. Secondly, the definition of urban sprawl has increasingly been strengthened and improved. Urban sprawl was initially described as discontinuous development of urban space, and then further definitions have covered more descriptions of automobile dependency, single-use of land, low-density development and so on.

2.1.2 The indicators of urban sprawl

Measuring the extent of urban sprawl is a challenge for western scholars and research organizations. At present, considerable progress has been made in developing different

[1] Details regarding the definition of urban sprawl can be found in Appendix A.

indicators[2].

Indicators raised by western scholars or organizations for measuring urban sprawl can be grouped into three main categories: (1) indicators of spatial form, such as mixed use, accessibility, fragmentation, leapfrog and so on; (2) indicators of growth ratio, such as growth rate of population versus, growth rate of built-up area, etc.; (3) indicators of density, such as population density, housing density, employment density and so on.

It is also worth noting that a single indicator has been developed into multi-dimensional indicators by western scholars. Both single indicator and multi-dimensional indicators approaches have advantages and disadvantages. The single indicator is simple and easy to measure; however, difficult to reflect complicated characteristics of urban sprawl, which can be measured comprehensively using multi-indicators. Meanwhile, mass data and indicators selection are problems caused by the latter. Quantifying sprawl has been paid more and more attention to. In these studies, a whole city is always taken as an analysis unit when indicators are calculated, which reflect exactly the situation of sprawl in the city. The internal differences of sprawl in the city are difficult to depict.

2.1.3 The causes of urban sprawl

To fully understand what urban sprawl is, it is necessary to know its causes. With the in-depth study of urban sprawl, the studies on the causes of urban sprawl have gradually become an important focus for western researchers[3]. A good example of some of the scholarship is Downs, Dutton, Leroy and Carruthers. From their point of view, the internal mechanism of urban sprawl can be divided into different aspects like transportation, culture, markets and government: (1) Car traveling is a decisive factor leading to urban sprawl; after World War II, the automobile has become the transport technology that shapes the city. With this development, the flexibility and speed of transport are greatly improved, and low-density housing became more feasible and popular. Using an automobile became not so much a choice but a necessity (Newman and Ken worthy 1998). Therefore, the conditions mentioned above have provided advantaged preconditions for urban sprawl in automobile-based cities. As noted by Dieleman and Wegener (2004): "accessibility which can be prominently improved by efficient transport and sufficient infrastructure is an important element during

[2] Details regarding the indicators of urban sprawl can be found in Appendix B.
[3] Details regarding the driving forces of urban sprawl can be found in Appendix C.

urban sprawl." They also claimed that locations with good accessibility to workplaces, shops, educations and leisure facilities are more attractive for residential, industrial, office and retail development. A more dispersed settlement structure will form if accessibility in the entire metropolitan area is increased. (2) People's preference for a better environment and independent apartments; the cities in Western countries have had a long cultural tradition of residents desiring as much space (private and public) as possible to be planned into their urban environment (Newman and Kenworthy 1998). This is one of the most important forces for many residents to move to the outer districts of a city. After World War II, a happy family life style became based in the detached house with its own garden. (3) Urban sprawl is the spontaneous outcome under the market economy; the rapidly built suburbs in the interwar years (1918-1939) both in northern Europe and America can be easily explained by the theory which is proposed by Wassmer (2005) -if an urbanized area has greater acreage and population and its residents have more income, the agricultural land price and the commuting costs will be lower in the area; (4) Urban sprawl is a product of direct and indirect funding of developments by governments. In some countries, the governments also play an important role in the process of urban sprawl. The planning system and government policies are fundamental to encourage or prevent urban sprawl. Taking American as an example, the local governments are motivated to offer vacant land for commercial purposes because of the taxation generated by retail (Jiang Xiaolei 2009). In conclusion, urban sprawl can be regarded as the result of the combined effect of objective conditions and subjective wishes. As a natural phenomenon, suburbanization is a result of increasing incomes and population, transportation improvements, consumer choices, and the influence of competition for land in the urbanized from non-residential use.

In addition, the economic interpretation of urban sprawl has become an important part of the research since 1980. There are four different interpretations, including econometric analysis, Neo-classic Economics, land use regulation and the regulation schools of thoughts. In all, the causes of urban sprawl can be divided into three categories: (1) State and local fiscal policy.
Brueckner (2001a) explored that the property tax leads to sprawl by considering an urban area with a fixed population within a standard urban model. Owing to various subsidy programs from the finances of state and local governments, low-density development was encouraged. On the one hand, the federal income tax system can provide a substantial incentive for owner occupied housing; larger lots and homes are built due to lower effective price of housing services. On the other hand, public infrastructure is subsidized. McGuire and Sjoquist (2002)

conclude:"transportation is heavily subsidized not only mass transit but interstate highways, leading to a more extensive transportation network than may be efficient. Because of this act, longer commutes were encouraged due to the lower cost of transportation." Furthermore, property tax financing of infrastructure for new development results in an infrastructure price that is lower than the average across all properties. Less dense development and extending the urban fringe are encouraged since lands being developed on the fringe of urban areas command a lower price than in the more centralized and previously developed areas. (2) Market forces. In their conclusion, McGuire and Sjoquist (2002) wrote:"economists argue that the pattern of development and the amount of developed land are efficient and thus there should be no concern about sprawl as long as the land market is perfectly competitive." As Sjoquist stated in his 2003 book, "to the extent that market distortions exist, however, the pattern of development may be inefficient or the amount of urban lands developed may be excessive." Because of market benefits from the lands on the fringe of urban areas, the market price for lands on the urban fringe is too low and more lands will be converted from agricultural use to urban-development use. (3) Land use system and micro-regulation of land use. Government regulation of land use can influence on the urban sprawl. Suburban land use is dominated by zoning and subdivision ordinances that have substantial effects on land use. Large lots are required frequently when zoning and subdivision ordinances are put forward, which discourage multi-family housing and mandate large parking lots for commercial and retailing developments. In addition, the greater the number of local governments, the more difficult it is to adopt policies that might control sprawl because of the problems that arise in coordinating policies among a large numbers of jurisdictions.

2.1.4 The costs of urban sprawl

The alleged negative consequences of sprawl, environmentally, economically and socially, are usually captured under the term 'Costs of Sprawl' in most literature[4]. In reality, attempts to wrestle sprawl to the ground by its opponents have resulted in more research and literature on the negative consequences of sprawl than its benefits. The impacts of sprawl are one of the most hotly debated issues in the literature with sprawl often claimed as the cause of all the evils of modern urban life (Chin 2002).

Many scholars believe that sprawl is associated with the loss of environmentally fragile lands, reduced regional open spaces, increased air pollution, higher energy consumption and

[4] Details regarding the costs of urban sprawl can be found in Appendix D.

decreased aesthetic appeal of landscape. In addition to this, consensus can be achieved that urban sprawl places unnecessary strains on urban services, local finance and social structure and equity.

2.2 Research progress in China

2.2.1 Urban sprawl in China

China, as a developing country, has still a relatively low urbanization level. However, rapid growth of urbanized area with increasing rural–urban migration is a common process of urbanization. With the rapid development of China's cities, the level of urbanization increased from 17.9% in 1978 to 39.1% in 2002, shown in Table 2.1.

Table 2.1 China's urbanization level (%, in selected years)

Year	1978	1995	2002
Urbanization	17.9	29.0	39.1

Source: www.stats.gov.cn, data based on 2004

Because of urbanization, agriculture is less important in China's national economy. It is obvious that service jobs are increasing but farm jobs are decreasing, (Table 2.2).

Table 2.2 Composition of China's economy: by GDP and employment (in %)

Year	1978		1989		1997		2003	
Item	GDP	Employ ment	GDP	Employ ment	GDP	Employ ment	GDP	Employ ment
Primary	28.1	70.5	25.0	60.1	19.1	49.9	14.6	49.1
Secondary	48.2	17.3	43.0	21.6	50.0	23.7	52.2	21.6
Tertiary	23.7	12.2	32.0	18.3	30.9	26.4	33.2	29.3

Source: National Statistic Bureau of China, 2005

In 2006, the famous Chinese planner Lu Dadao pointed out that over the past decade the phenomenon of urbanization in China is seriously out of control, forming urban sprawl. This pattern of urban development is described as "making pie" in China: urban centers expand outward rapidly and agricultural land in semi-urban areas is quickly turned into urban land, which eventually leads to environmental degradation and traffic jams. Li and Yang (2006) proposed that urban sprawl in China is rapid pie-style urban space spread in this process and that urbanized land use expands rapidly, associated with this is traffic congestion, green belt eroded by farmland occupied and other problems; Jiang et al. (2007) described sprawl in China as rapid, low-efficient and disorderly growth of non-agricultural land towards

peripheral areas; Qi and Lu (2008) gave the definition of “urban sprawl” as low-density, excessive spatial growth of cities.

In China, the connotation of urbanization can be summarized in the following four aspects: 1) population urbanization mainly reflects the fact that peasants move from the countryside to cities or towns, including the proportion of urban population, urban population size, the population density in built-up areas; 2) economic urbanization mainly reflects the economic structure transition; 3) land urbanization mainly reflects the changes in the geographical landscape; 4) social urbanization mainly reflects the changes in lifestyle. The four aspects are interrelated but differentiated to reflect urbanization fully and accurately.

It is important to distinguish urban sprawl from "rational" or "normal" urbanization. The Chinese version of urban sprawl is indicated as the disproportionate expansion of the urbanized area. Although the Chinese context is quite different from the Western countries, there are two similarities in urban sprawl patterns. The first is the disproportionate conversion of farmland to urban uses. The second characteristic of the Chinese version of sprawl is scattered development at the urban fringe. The Western version also takes a form of development located on the edges of existing communities or leapfrogging into previously undeveloped areas. The Chinese version has some variations but retains the main feature of the dispersed development pattern. Various types of new development zones such as "High-tech Industry Park" and "Economic Development Zone" are often located in areas that were previously farmland. Low density and commercial strip developments are not characteristics of the Chinese version of sprawl, in contrast to the Western version of urban sprawl. In addition, central city decline resulting from negative impacts of urban sprawl is not a Chinese phenomenon. City centers are still booming in China, although statistics show that since 1982 they have been slowly losing their population (Zhou and Meng 1998).The main cause of population loss in city centers is the high price of housing. Not only are ordinary city residents forced to move away from central areas, but ordinary enterprises are often also forced to relocate to the municipal fringes due to the problem of finding affordable land in central areas.

New housing projects on the fringes have provided ordinary urban residents with better living conditions at the cost of longer commuting time, and the loss of cultivated land in peripheral areas (Zhang Tingwei 2000). In general, "richer" people prefer to live in suburban areas in Western countries, but the "poorer" have to move to fringe areas in Chinese cities. This is one

of the most important differences between the Chinese and Western versions of sprawl. As time goes on, many problems caused by urban sprawl in western countries have also appeared in China.

1) Loss of large amounts of cultivated land

In China, the agricultural regions are mainly located in the eastern part, where there is also rapid economic development. Built-up areas have been increasing in the eastern part because of rapid development, see in Figures 2.1 and 2.2.

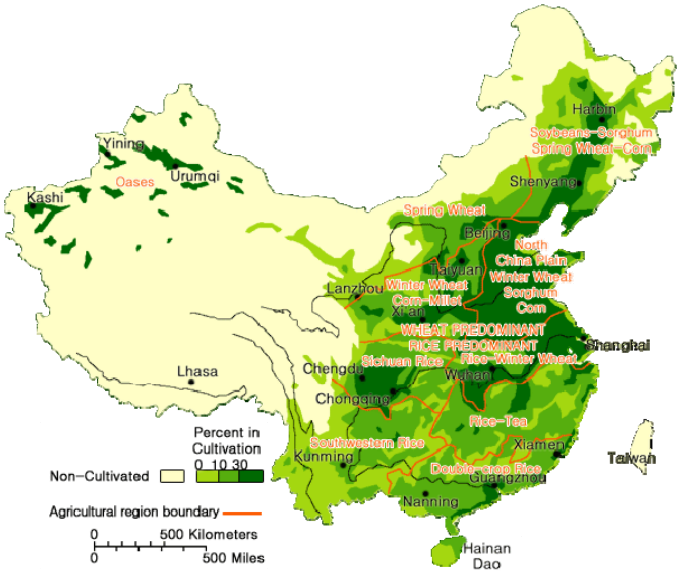

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Figure 2.1 Agricultural regions in China

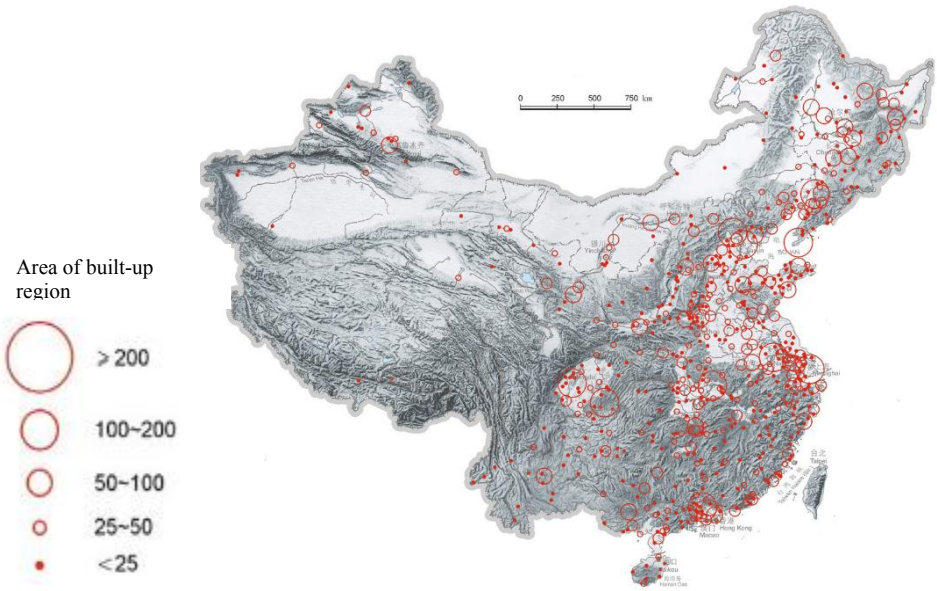

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Figure 2.2 Built-up region of cities in China (2000)

[5] Source: http://www.agritourschina.com/agriculturalregions.htm
[6] Source: http://course.bnu.edu.cn/course/cgeography/cn/html/7ziyuan/2ditu/img/p27-1.jpg

In the process of mass urbanization, land development and consumption, however, have been out of control and have kept expanding massively, especially to the marginal areas of some metropolises. The conflict among socio-economic development, resources, ecology and environment has become more serious. There has been a great loss of arable land in China since 1990. Only 140 million hectares of arable land were left in China in 1996 and that decreased further to 126 million hectares in 2002. That means that between 1996 and 2002, 14 million hectares of arable land had been nibbled away by urban sprawl, with an addition of 9.8 million hectares of cultivatable land from urbanization (the State Statistical Bureau, various years).

With the rising level of urbanization, cultivated lands in China have been diminishing year by year. During the period of 1987 to 2001, urban sprawl had engulfed 2.3 million hectares of arable land. This results in 34 million rural people losing their land. Furthermore, 1.566 million hectares of arable land were used for other purposes in 2000, among which 163,000 hectares were used for construction purpose, 763,000 hectares for reforestation, 578,000 hectares for agricultural restructuring, while 62,000 hectares were destroyed by natural disasters, 184,000 hectares through exploiting unused land, 66,000 hectares through reclaiming abandoned land and 42,000 hectares through land reconditioning.

With another government statistics of China's Ministry of Land and Resources, the area of arable land occupied by blind expansion of urban land accounts for 18.52% of the total misused land. Approximately18600 km^2 of land have been permanently converted to urban built-up area in the past decade, which is a serious problem to China, which has less than 10% of the world's arable land while needing to feed 20% of the world population. Furthermore, the reserve arable land resources are nearly used up while the expansion rate of city size is increasing (Jiang Xiaolei 2009).

In China, cultivated lands of good quality are mainly in the eastern part of the country, where urbanization is very prevalent. The change of cultivated lands in some regions of the east is shown in Table 2.3. In these regions, the loss of large amounts of cultivated lands is the consequence of disorderly development of built-up area mainly caused by over development of industrial parks and real estate.

Table 2.3 The change of cultivated land in some regions

Regions	Cultivated land (end of 2004) 1,000 hectares	Cultivated land (end of 2007) 1,000 hectares
Shanghai	315.1	259.6
Beijing	237	232.2
Jiangsu	4799	4763.8

Source: China Statistical Yearbook 2005, 2008

As the main population and urban areas are usually concentrated in the centre of the best arable land, the arable land has shrunk at an alarming rate of 0.3-0.4 million hectares per year, owing to increasing use of land for residential, industrial and urbanized purposes. Uncontrolled construction, excessive deforestation and reclamation have escalated the upward trend of urbanization, resulting in an unceasing disappearance of arable area.

Built-up areas in many major cities have increased by more than 50 % from 1985 to 2002, such as Beijing, Shanghai etc., shown in Table 2.4.

Table 2.4 The change of built-up areas and non-agricultural population in some major cities

Year		1988	1997	2003
Shanghai	the built- up area (km^2)	247	412	550
	non-agricultural population (ten thousand)	722.86	841.75	1024.99
Beijing	the built- up area (km^2)	391	488.13	1180
	non-agricultural population (ten thousand)	556.8	627.3	809.61
Guangzhou	the built- up area (km^2)	183	267	608
	non-agricultural population (ten thousand)	281.13	322.14	456.92
Nanjing	the built- up area (km^2)	128	177	447
	non-agricultural population (ten thousand)	202.25	229.85	372.39

Source: China Statistical Yearbook

2) The built-up area of cities grows much faster than the population

From 1990 to 1995, the built-up area has expanded at the yearly rate of 1015 km^2. There had been a lower population density in more than 400 cities, as compared with the national standard (10,000 people per km^2 of land). In cities with a population of less than 0.2 million, one resident occupied more than 142 m^2 of land on average. It is 1.91 times that in cities with a population of more than 0.5 million but less than 1 million and 1.62 times that in cities with a population of more than 1 million (Yao 2004).

From 1986 to 1996, the non-agricultural/urban population increased by 59.7%, whilst urban land use increased by 106.8%. The average area of land occupied by the urban population increased from 102 to 133 m^2. In the same period, the rural population only increased by 3%, up from 860 to 886 million, whilst the total area of land occupied by rural settlements increased from 8.1 to 16.5 million hectares. The average area of land occupied by the rural population increased from 97.7 to 195.5 m^2 (Yao 2004).

The growth rate of built-up areas in many metropolises is much higher than that of urban populations, see in Table 2.5. Some problems, such as traffic congestion and air pollution, are a threat to sustainable development.

Table 2.5 Changes of built-up area, population of four cities from 2001 to 2005

Items	Beijing	Shanghai	Guangzhou	Nanjing
Changes of built-up area (%)	0.11	0.11	0.09	0.25
Changes of population (%)	0.03	0.03	0.04	0.10

Source: China City Statistical Yearbook 2007

3) Large expanses of land use

The main reason of large expanses of land use is the construction of development zones and "University City"[7]. The establishment of many development zones has been associated with the fragmented conversion of agricultural land into urban use. This is particularly striking in metropolitan areas. University City in China is the outcome of the sped-up urbanization process, the change of the role played by the Chinese government in higher education and cooperation between enterprises and university. Some local governments lack of the means for construction of necessities and the basic conditions, leading to the bigger and bigger University City. For example, "Dongfang University City" in Langfang covers an area of 6.7 km^2; "Yuelushan University City" in Hunan covers an area of 44 km^2; the planned area of "Xianlin University City" in Nanjing is up to 70 km^2.

In 2000, there were more than 3,873 industrial development zones in China, in which 232 development zones were established under the approval of the central government and 1,019 development zones under the approval of the provincial governments. There are 3.6 million hectares of development zones, of which 43% remains idle. In 2002, another 0.2 million

[7] University City means new city in suburbs composed of one or more campuses. The layout of living areas and playgrounds is around the campus.

hectares of arable land was converted to industrial development zones, more than the average 0.163 million hectares from1996 to 2001. From 1992 to 1999, there were 0.3 million hectares of leased land. The total land tax revenue was about 100 billion Yuan. Moreover, out of the 1.33 million hectares of total idle land for industrial use in China, only 0.3 million hectares was reclaimed for urban construction from 1999 to 2002. (Yao 2004)

There are some points to explain: (1) the construction of development zones and University City has impacts on the order of land market, leading to oversupply of land; (2) in general, the land for University City construction has significant characteristics of large scale and inefficient land use; (3) the new development zones and University City are generally located in urban fringe or suburban areas, occupying a large amount of high-quality cultivated land.

4) Leapfrogging development

In China, the urban fringe has been regarded as area of rapid urbanization which can supply a large amount of land for urban development. Urban fringe is showing leapfrogging development because of transportation land extension, industrial land expansion and residential land spread. In this process, some serious problems, such as waste of land resource, irrational distribution of land use, ecological destruction and environmental pollution, has become increasingly prominent and have hindered the sustainable development of urban fringe(Feng 2010).

At present, Chinese scholars believe that the development of many cities is out of control. Disorderly urban construction leads to more and more conflict between socio-economic development and resources, ecology, and environment. However, there is lack of clear explanation of sprawl in China.

2.2.2 The indicators of urban sprawl

Compared to the sprawl of Western countries, it is mainly disorderly development of development zone in China. Some indicators are raised based on the urbanization of Western context, such as the share of detached houses, which are not suitable for measuring sprawl in China, which is in an initial practice phase. The nature of urban sprawl in China is different from Western countries, but some common characteristics are shared. Therefore, several indicators proposed by Western scholars, especially indicators of urban form, can be used as references. The research on measuring sprawl in China is inadequate, where indicators

proposed are mainly referred to as measurements of urban expansion and urban form. It is necessary to find a way that transfers specific characteristics of urban sprawl into measuring indicators. Some indicators have been proposed by Chinese scholars, see in Table 2.6.

Table 2.6 The indicators of urban sprawl

Sprawl indicators	Source
-The area or share of urban growth	Fan(1997)
-Intensity of annual growth	Liu et al. (2000); Xiao(2003); Chen *et al*. (2004)
-Elasticity of urban growth to population	Chen and Xu(2005)
-Shape index -Fractural dimension -Isolation index	Zhang et al. (2004); Zhu and Wang(2005); Yang et al.(2005)
-Density of built-up area	Huang (2006)
-Area -Shape -Discontinuous development -Strip development -Leapfrog development -Planning consistency -Horizontal density -Vertical density -Population density -GDP density -Agriculture impact -Open space impact -Traffic impact	Jiang et al.(2007)

2.2.3 Driving forces of urban sprawl in China

The economic value of land has been fully recognized in China since the transformation from planned economy to a market economy after reforms. All land-related policies are based on the understanding that land is a primary economic element and should generate revenue for the government. Land has become a main source of profit for all levels of real estate companies, villages, individual farmers, and government. As Zhang Tingwei stated in his 2000 paper:" the reforms have decentralized a considerable amount of decision power to localities and enterprises in the decision-making structure, which has significant impacts on land disposition, and ultimately on urban sprawl. Generating revenue from leasing land use rights and charging land use fees has become the most popular practice for local government since land is the most valuable "commodity"." Nowadays, there are three types of revenue from land in China including land tax, charges on land leasing and a variety of land use fees. Meanwhile, 15% to 20% of local revenue on average came from land leasing in recent years (Zhang Tingwei 2000). For urban sprawl, it is financially possible because most of the

revenue is spent on infrastructure improvement and extension projects. It is obvious that municipal governments acquire more land because of the growth of the urban population, the enormous demands for housing, and especially, increasing construction activities. While more farmland is being converted to urban uses, more investment is needed to develop infrastructure in new areas. With decentralization, local governments now have land use regulation power, which had previously been under the control of higher government (the central and provincial government) before the reform. County and village leaders prefer to "sell" their lands and to annex their municipalities to the central city because peasants in fringe areas surrounding the central city desire to become "urban residents". This decentralized land use power thus helps urban sprawl (Zhang Tingwei 2000). Through above discussion, it is easy to see that the causative mechanisms of urban sprawl in China are different from that of Western countries, which is mainly due to the industrial revolution. However, there are not so many research papers focus on the driving forces of urban sprawl with Chinese context, see in Table 2.7.

Table 2.7 Driving forces of urban sprawl in China

Driving forces of urban Sprawl	Source
-Land market -Local government's willingness to lease land as result of new tax revenue regulations -Decentralization process after China's economic reforms	Zhang Tingwei (2001)
-Increase in population and residents to improve the housing conditions increase the demand for housing space -Construction of development zones in major cities -The construction of University City -The construction of city ring expressway	Wang and Gao (2005)
-Demographic changes directly influence urban sprawl -Foreign direct investment -Transition of land use regulation	Deng Xiangzheng et al.(2005)
-The growth of urban population -Raise of income of urban residents -The gradual monetization of housing distribution	Li and Yang (2006)
-Rapid economic development -Worship of the governments GDP -Land use planning and urban planning has no binding effect -Some shortcomings of land management system -The impact of land system	Qing (2008)

-Dual mode of economic growth -The public finance system -Household registration system -Social security and assistance system -Land system reform lags behind	Chen (2009)

2.2.4 What urban sprawl is costing China

Deng, *et al*. (2004) asserted that the Chinese sprawl is an unintended consequence of political manipulation of land development at the urban fringe. The undesirable growth patterns of urban sprawl in Chinese cities appear to threaten the goal of sustainable development and impose some costs socially, economically and environmentally on households, firms and governments. However, the debate on the costs of urban sprawl in China seems to have gotten little attention in the literature, see in Table 2.8.

Table 2.8 The costs of urban sprawl in China

The costs of Sprawl	Source
-Reducing the land area devoted to agriculture and independence in food production	Olson(1996)
-Annual growth rate	Liu (2002)
-Social cost -Economic cost -Environmental cost	Duan (2006)
-Traffic jam -Green belt erosion -Farmland encroachment	Li and Yang (2006)
-A sharp reduction in arable land -Rapid expansion of urban land use -Urban construction land per capita higher -Road development and public transport facilities, lack of coordination	Qing (2007)

From the table 2.8, the impacts of urban sprawl can be divided into three different parts:

1) Sharp reduction of arable land resources; this point of view is also discussed in the costs of urban sprawl in Western countries. As a country with an enormous population, China should take care of the issue of food security. However, the cities' current high-speed expansion will not only affect the ability of China to remain self-sufficient in grain production, but also pose a threat to food security. 2) The serious whittling down of the urban land use efficiency and waste of tremendous city resources. As Jiang Xiaolei (2009) states :"the urbanization in most Chinese cities is boosted by property development since urban managers take the way of changing the function of land (such as sell arable land to real estate developers) to stimulate urban economic growth." Because of this irrational development model, it is significant that a large amount of land resources has been consumed and the demand for basic urban

infrastructure in city has been greatly increasing. Moreover, the proper urban spatial configuration has been disrupted and tremendous resources are wasted since urban development is more or less led by the individual projects without unified construction planning. 3) Increasing traffic problems. The urban residents increasingly rely on vehicles because of the ever-increasing commuting distance. As a result, the number of private cars has been growing quickly. At the same time, the environmental pollution in urban areas is getting worse due to increase the consumption of gasoline and other substantial energy.

2.3Summary and conclusion

By undertaking a thorough review, some analyses can be made:

1) The research on urban sprawl in Western countries is quite comprehensive, covering almost all aspects relating to definition, characteristics, quantitative measurements, causes, impacts and so on. In China, urban sprawl is a new subject being investigated. At present, the existing studies are only lessons learned from the theory and practice of Western counties and the literature review. Even if there is an empirical study, analysis is limited to the macro level. Therefore, in China, a lack of quantitative research and micro-level analysis of urban sprawl is a key issue.

2) Although research on urban sprawl is extensive in Western countries, it is necessary to analyze urban sprawl in an integrated system. Therefore, the characteristics, indicators, causes and impacts should be integrated into the research, which can help to completely understand urban sprawl, achieve logical consistency, moreover, provide a decision support for planning policy.

3) Despite having reviewed the principle research in Western countries, it is impossible to directly transfer their conceptualization of urban sprawl to China. Some differences are significant, such as population base, growth rate of urbanization, the basis of land ownership, market-orientation and so on. Therefore, my research carefully summarizes the development of research areas in order to highlight the urban sprawl in China.

3 Research area and Data source

3.1 Research area

3.1.1 Geographical situation and natural conditions

Jiangning District is situated in the middle part of Nanjing City, the capital of Jiangsu Province, the southern band of Yangtze River with the geographic location of 118°30´~119°25´E and 31°30´~32°00´N, shown in Figure 3.1. It includes 9 neighbourhoods after regulation in 2001. It had a total area of 1, 567 km².

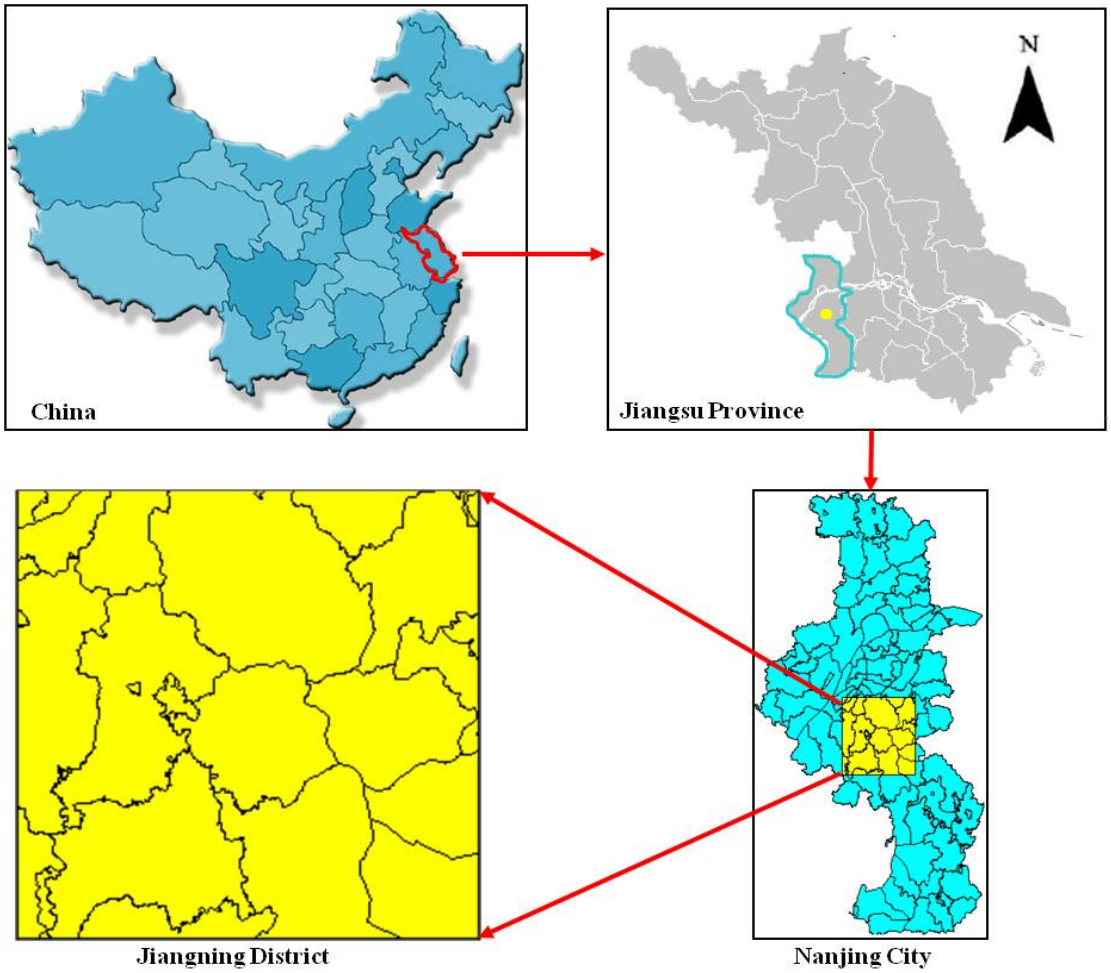


Figure 3.1 Location of Jiangning District

It is located in the Basin of Qinhuai River which is a tributary of the Yangtze River. The Qinhuai River and its tributaries form the surface water system and are the major sources of water supply for irrigation, industries and the population. The agricultural and forest area are the most important land resources in Jiangning District. For a long time, agriculture has been the pillar of its economy. Thus, cultivation has resulted in a substitution of secondary

vegetation and cultivated vegetation for the original pristine cover. The cultivated vegetation can be divided into five categories, shown in Table 3.1:

Table 3.1 Cultivated vegetation categories in Jiangning

Number	Cultivated Vegetation
1	Field crops
2	Vegetables
3	Managed Forest
4	Orchards
5	Afforest

The main parts of the soil are rice soil distributed in the lowland of Qinhuai River and Yangtze River, as well as some upland area. The secondary parts of the soil are yellow brown soils, which are distributed in the upland area. Due to human activities, the natural land cover has been replaced by the man-made forest and the agricultural plants. The lowland area is mainly cultivated agricultural plant (Lu and Chen 2000).

3.1.2 Socio-economic development

Before 1980, Jiangning was a traditional agricultural area, and in fact it was an important grain supply base for Nanjing. The rapid growth of rural enterprises started in 1980.The construction of economic and technical development zones accompanied by improved transportation facilities has resulted in remarkable changes in economic activities and in the pattern of land use (Ju 1998). The district is well connected to Nanjing, Shanghai and other major cities in the neighbouring provinces by national and provincial roads. The location condition of the county and its access to the outside world were substantially improved when the new International Airport in Lukou town was opened in July 1997. The new highway and the new railway connecting Nanjing to Shanghai have been used since 1997. These connections constitute important contributions to the improvement of the location's conditions.

Jiangning County became Jiangning District when administrative division adjustment was carried out in 2000. Because of this adjustment, the industrial structure of Jiangning has transferred primary industry into tertiary industry. The northern part experienced rapid growth of built-up areas due to constriction of Industrial and Economic Development Zones. The economic development in the southern part was boosted by the construction of Lukou airport.

3.2 Data source and image pre-processing

3.2.1 TM images and relative data

The remote sensing data is in a similar season, and is of better quality with no clouds, including Landsat MSS in 1979, Landsat TM in 1988, 1997 and 2003. The remote sensing data source is shown in Table 3.2:

Table 3.2 Remote sensing data

Name	Spatial Resolution (m)	Access Time
Landsat MSS	**57m**	**1979.08.06**
	28.5m	**1988.07.05**
Landsat TM	**28.5m**	**1997.10.18**
	28.5m	**2003.07.31**

The demographic data source is showed in Table 3.3:

Table 3.3 Demographic data

	1979	**1988**	**1997**	**2003**
Total population (Million)	**0.685**	**0.711**	**0.745**	**0.764**
Agricultural population	**0.67**	**0.655**	**0.637**	**0.43**
Non-agricultural population	**0.015**	**0.056**	**0.108**	**0.334**

The Social-economic data source shown in Table 3.4:

Table 3.4 Social-economic data

	1979	**1988**	**1997**	**2003**
GDP(million Yuan)		889	7584	16833
GDP per capita(Yuan)		1250	10180	22033
Tertiary industry (million Yuan)			1645	5560

3.2.2 Image pre-processing

3.2.2.1 Geometric correction of images

The Landsat MSS/TM data were used in the research. In order to facilitate extracting the surface information from the images, the data is corrected only after the geometric correction and a unified system of geographical coordinates is established. The method of second multi-directional and the nearest pixel resample method of the original images were used for geometric correction and fine registration, as shown in the sketch in Figure 3.2.

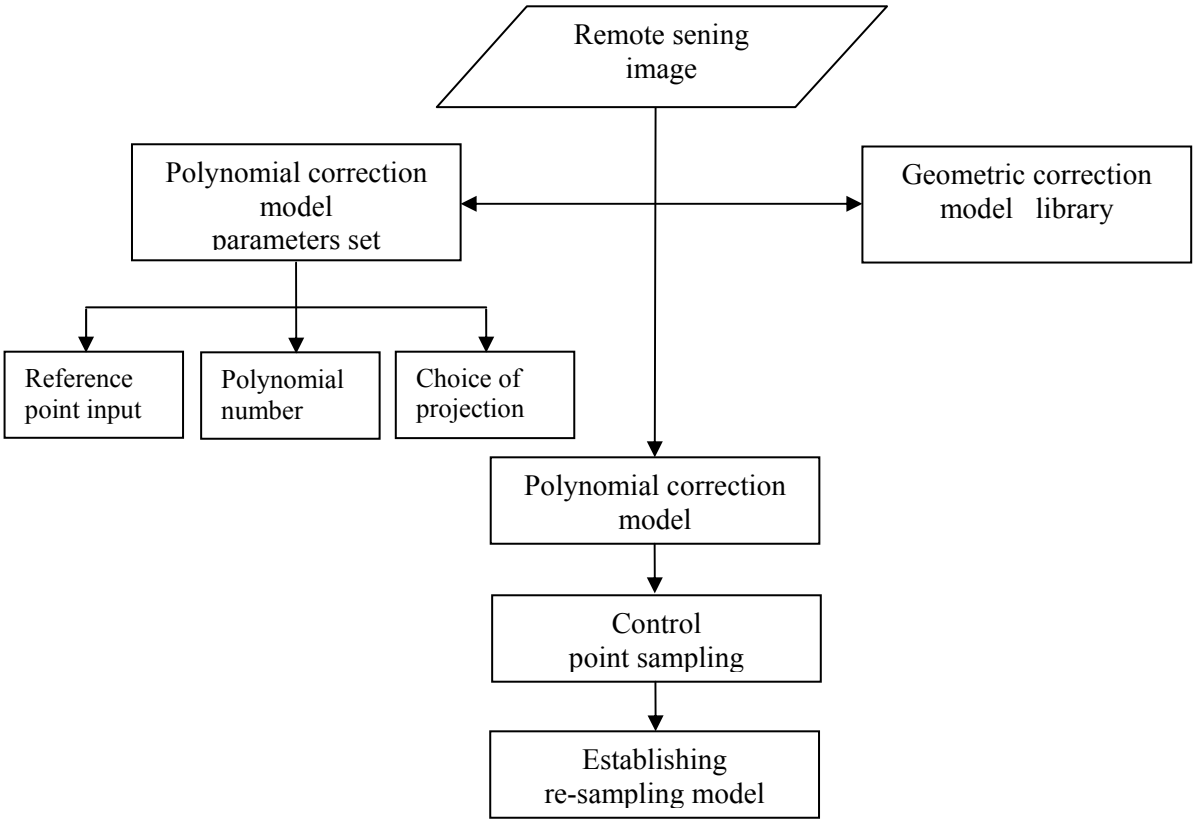


Figure 3.2 Geometric correction of images

3.2.2.2 Subset images

The original Landsat images covered the whole Nanjing City in 1979, 1988, 1997 and 2003, from which the sub images of Jiangning District were obtained, including mainly the construction of developing zones, University City and Lukou International Airport. That is an important factor of land use change, shown in Figure 3.3 and Figure 3.4.

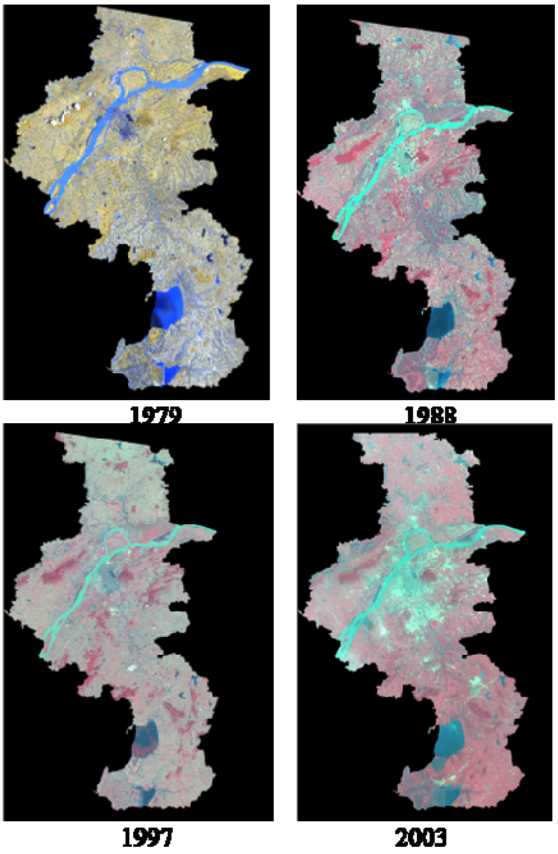


Figure 3.3 Original Landsat MSS/ TM images

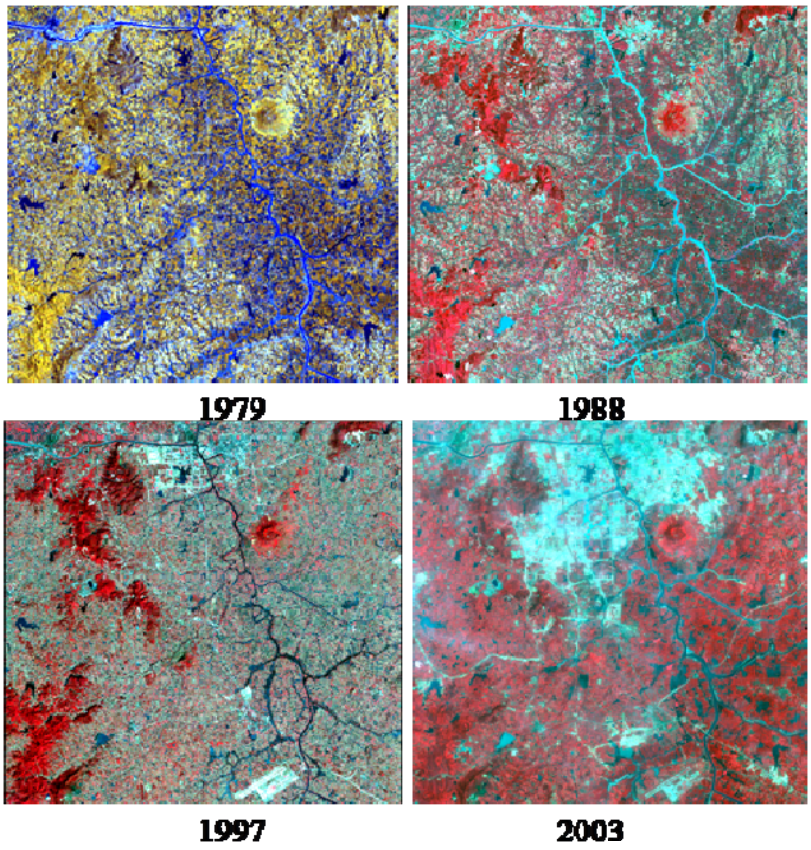


Figure 3.4 Sub-images from original images

4 Spatial patterns of urban sprawl

4.1 Characteristic information identification

4.1.1 Characteristics of land use/cover

As noted by Bhatta (2010):" in industrialized countries the future growth of urban populations will be comparatively modest since their population growth rates are low and over 80% of their population already live in urban areas. Conversely, developing countries are in the middle of the transition process, when growth rates are highest." The exceptional growth of many urban agglomerations in many developing countries is the result of a threefold structural change process: the transition away from agricultural employment, high overall population growth, and increasing urbanisation rates (Grubler 1994). The biggest challenge for science, engineering and technology in the 21st century is how to ensure adequate housing, sanitation and health, and transportation services in a habitable urban environment in developing countries. Sprawl is regarded as one of the potential threats for such development.

Four kinds of development are typical of urban sprawl, which reflect the summary of characteristics of sprawl made by Ewing in 2002. They are: leapfrog development[8], strip or ribbon development (commercial strip development)[9], low-density development[10] and single-dimensional development (single land use development). All of these forms contribute to the dependence on the automobile because the facilities of different functions in these kinds of cities are often located at greater than walking distance and outside of the scope of public transport.

Unlike careful planning for satellite towns based on the existing or planned public system, leapfrog development is the most costly with respect to providing urban services such as water and sewerage. In addition, the commercial strip development can be regarded as another kind of urban sprawl because the commercial strips are often away from residential districts and areas with other functions. Low-density development occurs accompany with the process

[8] Leapfrog development is a discontinuous pattern of urbanization, with patches of developed lands that are widely separated from each other and from the boundaries, albeit blurred in cases, of recognized urbanized areas. Source: http://chesapeake.towson.edu/landscape/urbansprawl/forms.asp

[9] Ribbon sprawl is development that follows major transportation corridors outward from urban cores. Lands adjacent to corridors are developed, but those without direct access remain in rural uses/covers. Over time these nearby “raw” lands might be are converted to urban uses as land values increase and infrastructure is extended perpendicularly from the major roads and lines. Source: http://chesapeake.towson.edu/landscape/urbansprawl/forms.asp

[10] Low-density sprawl is the consumptive use of land for urban purposes along the margins of existing metropolitan areas. This type of sprawl is supported by piecemeal extensions of basic urban infrastructures such as water, sewer, power, and roads. Source: http://chesapeake.towson.edu/landscape/urbansprawl/forms.asp

of suburbanization. Taking some instances of urban sprawl in different countries, sprawl is characterized by several land use patterns which usually occur in unison. Many cities of American are known as suburban sprawl, including the spreading outwards of a city and its suburbs to its outskirts to low-density, auto-dependent development on rural land, with associated design features that encourage car dependency. In the western of U.S., urban sprawl is reaching out across the landscape, the grassland is being carved up by roads and driveways for a small development of dispersed houses. Perhaps it will extend to the forest in the background in the next wave of development. In addition, housing subdivisions because of urban sprawl can be seen in Calgary, Alberta, Canada, in which are large tracts of land which entirely consist of newly-built residences. Such subdivisions may offer only a few places to enter and exit the development, causing traffic to use high volume collector streets. In monitoring urban sprawl of Melbourne, it is obvious that urban sprawl will push more houses into surrounding farmland in the next years, putting further pressure on stretched transport systems. Almost half of all new housing expected over the next decade will be built on fringes where there is little access to public transport.

Many scholars depicted the characteristics of land use/cover of urban sprawl. Galster et al. (2001) offered eight conceptually distinct, objective dimensions of land use that if present at low values and some combination, characterize sprawl. Some physical characteristics of sprawl are shown in Figure 4.1.

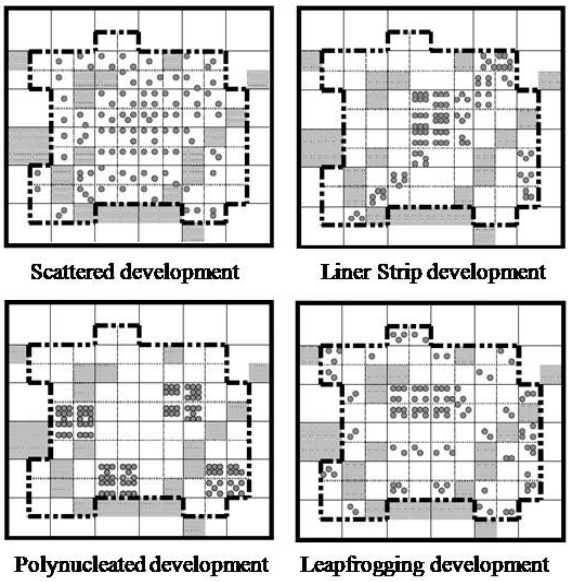


Figure 4.1 Some physical characteristics of Sprawl

Ewing et al. (2002) characterized urban sprawl as "leapfrog land use patterns, strip commercial development along highways, and very low-density single-use developments –as

well as by such indicators as poor accessibility of related land uses, and lack of functional open space", shown in Figure 4.2.

Low Density and Single Use Development

Uncentered Strip Development

Scattered and Leapfrog Development

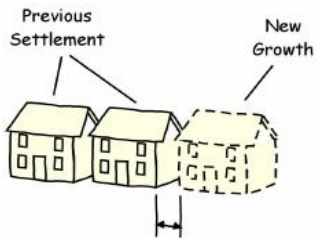
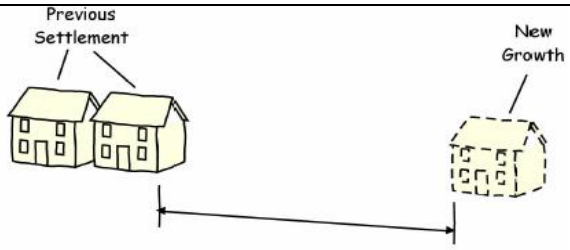
Sparse Street Development

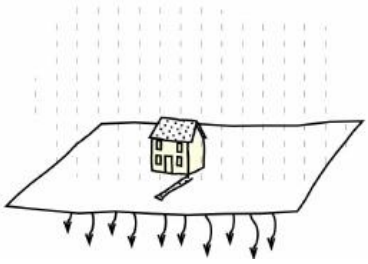
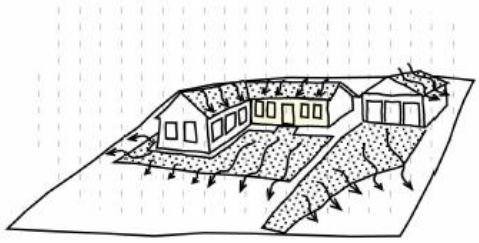
Figure 4.2 Sprawling development patterns

Source: http://www.smartgrowthamerica.org/documents/MeasuringSprawlTechnical.pdf

Hasse (2002) delineated twelve characteristic geospatial sprawl indices, like leapfrog development, segregated land use, increased per unit impervious surface etc., some of them are shown in Table 4.1.

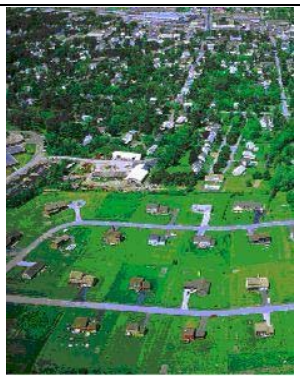
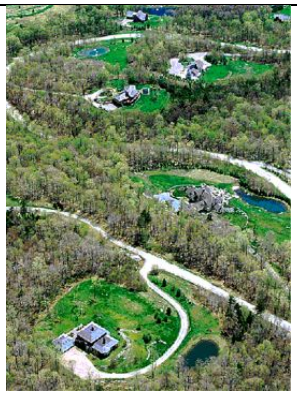
Table 4.1 Some characteristic geospatial sprawl indices (adapt from Hasse, 2002)

Leapfrog Development	
 Less sprawling	 More sprawling
Segregated Land Use	
 Less sprawling	 More sprawling

Increased per unit impervious surface	
	
Less sprawling	More sprawling

Anna (2003) put forward two characteristics of sprawl-one urban and the other rural. This does not mean that it is the only type of sprawl one might see. The description and pictures are shown in Table 4.2.

Table 4.2 The characteristics of urban sprawl and rural sprawl (adapt from Anna, 2003)

Discription	Pictures
-Leapfrog development -Commercial strip development -Low density residential areas -Large expanses of single-use development -Limited transportation alternatives -Lack of public open space	 Urban sprawl
-Seasonal or recreational homes -Low density residential areas -Inaccessible open space -Local economy may rely on seasonal residents and tourism -Conflict between residential and working lands may be increasing	 Rural sprawl

Siedentop and Fina (2008) presents a land transition model with three phases in Germany ("growth sprawl", "excessive sprawl" and "shrinkage sprawl"), shown in Figure 4.3. As they

state in their paper, "Growth sprawl" is annual growth rates of population and urbanised areas are positive with urban growth outpacing population growth and "shrinkage sprawl" shows a negative population development accompanied by a fall in urban growth rates."

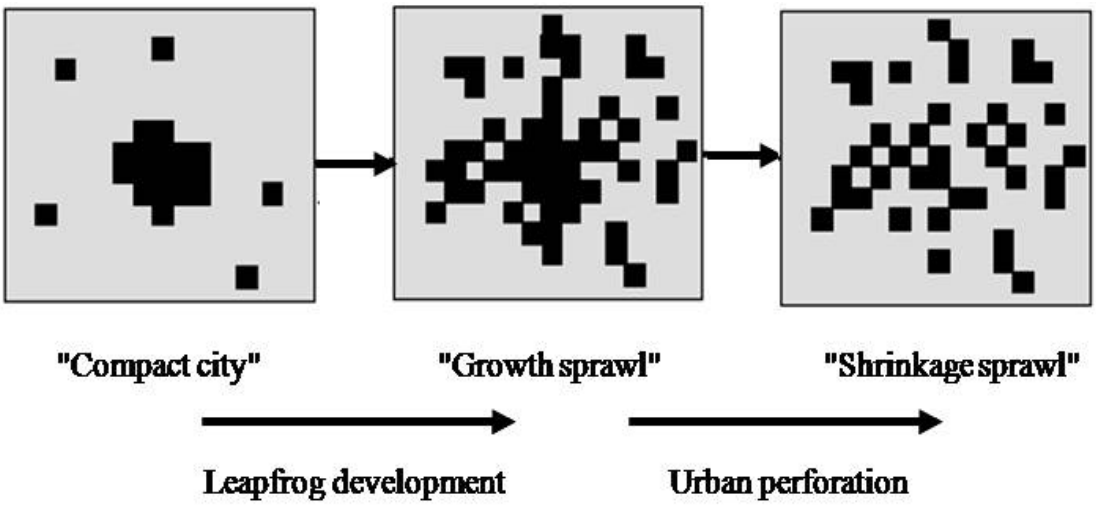


Figure 4.3 Pattern dimension of "Shrinkage sprawl"(adapt from Siedentop, 2008)

Li and Yang (2006) discussed that urban sprawl in China is rapid pie-style urban space spread. The concept map is shown in Figure 4.4. This figure shows the rapid pie-style urban space spread, with the boundary of the suburb expanding outward, at the same time, the city has been expanding to the suburb in out of control of urban planning. New construction land has always been concentrated in suburban areas.

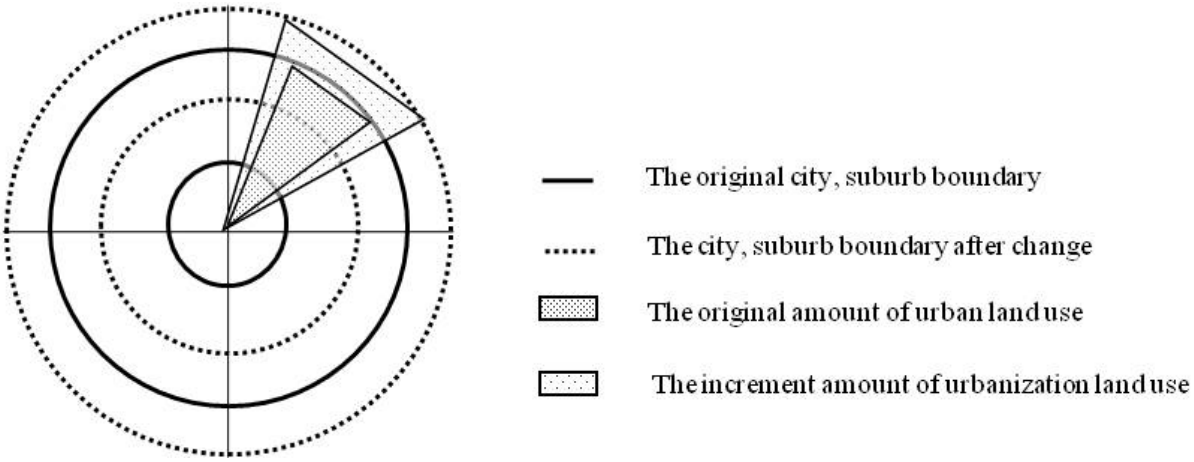
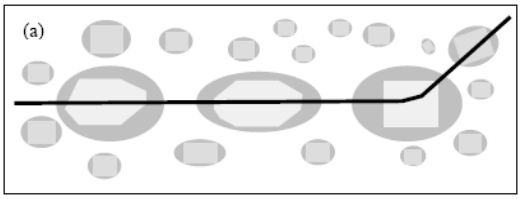
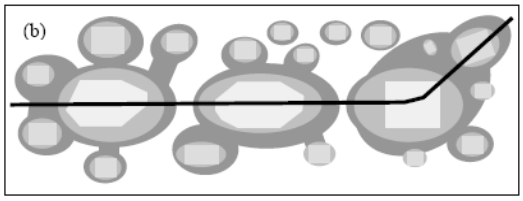
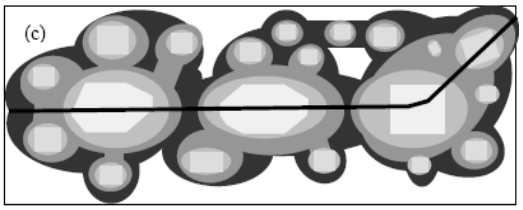


Figure 4.4 The concept map of urban sprawl of China's transition period (adapt from Li and Yang, 2006)

Ma et al. (2008) summarized urban sprawl patterns in the developed area of China, shown in Table 4.3.

Table 4.3 Urban sprawl patterns in the developed area of China at different stages since reform and opening-up (adapt from Ma et al., 2008)

Discription	Pictures
Some big cities benefiting from the preferential policy in the reform and opening-up environment firstly began to grow up at the initial stage, but their sprawls were unconnected to each other.	
With the development of economy and the establishment of suitable policies, more and more urban sprawls fused with their surrounding towns, industrial development zones or economic and technical development zones and others.	
The transportation axes are increasingly important in economic development and regional cities are establishing more explicit functional divisions. Gradually, some cities and/or towns were joined together and began to be fused into a big city group or an urban cluster.	

Initial city | **Initial town or economic and technical development zone** | **Sprawl area in the third stage**

Sprawl area in the first stage | **Sprawl area in the second stage**

4.1.2 Characteristics of built-up area

The built-up area refers to the area consisting of residential, commercial, and industrial complexes including paved ways, roads etc. Generally sprawl is ascribed to some type of development with implications such as loss of agricultural land, open space and ecologically sensitive habitats. Although an accurate definition of urban sprawl is debated, a general consensus is that urban sprawl is characterized by unplanned, uneven utilization and an increase in the built-up area along the urban and rural fringe or can be defined as "peripheral growth that expands in an unlimited and non-contiguous way outward from the solid built-up core of a metropolitan area" (Transportation Research Board 2002). The percentage of an area covered by impervious surfaces such as asphalt and concrete is a straightforward measure of development (Barnes et al. 2001). It can be safely considered that developed areas have

greater proportions of impervious surfaces, i.e. the built-up areas as compared to the less-developed areas, so that the built-up area is generally considered as a parameter for quantifying urban sprawl (Jat et al. 2008).

In this study, urban sprawl is defined as a phenomenon of disorder construction of built-up area in the process of spatial expansion due to urbanization of urban fringe[11]. Jiangning District has significant features of urban fringe, ranging from urban districts, urbanized areas and rural areas, shown in Figure 4.5.

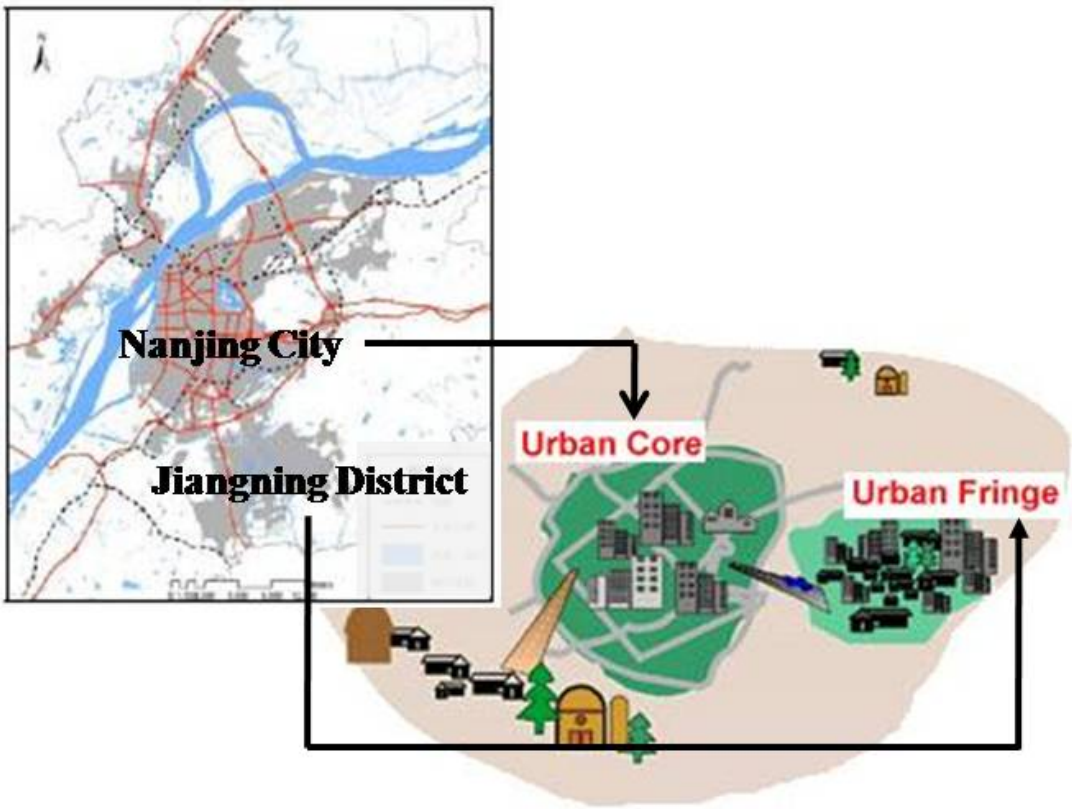


Figure 4.5 Schematic diagram of urban fringe

Source: PhD dissertation of Li Feixue and http://geodepot.statcan.ca

4.2 Characteristics information extrction

4.2.1 Land use/cover classification of TM images

The computer automatic identification classification of remote sensing image is based on the differences and changes of pixels in remote sensing images. It is the specific application of computer pattern recognition technology in the field of remote sensing, as well as an important content of remote sensing image processing. Remotely sensed datasets nonetheless

[11] Urban fringe: boundary area of a town or city, where new building is changing land use from rural to urban. It is often a zone of planning conflict. **(http://encyclopedia.farlex.com)**

have great potential for informing the planning process and monitoring and characterizing many urban patterns and processes (Paul 2003).

Whether object recognition or classification, the feature plays a significant role for the classification result. The feature space is a collection of multiple space elements in geographical space and image space of objects. Traditional remote sensing image analysis is only based on the spectral feature. The phenomenon of the same objects with different spectrums or different objects with the same spectrum is very common. For classifying an image, spectral feature alone cannot satisfy the classification accuracy. It is necessary to expand the original feature space to improve the classification accuracy.

In remote sensing image classification, statistical pattern recognition is the most common method. It is based on the spectral feature of an image. Statistical pattern identifies each observable pixel of the objects as a random variable subordinate to a certain distribution law. In the situation of multi-dimensional observation, the sum of each observable feature of the objects can be regarded as a random vector, and each random vector in a multi-dimensional feature space has a corresponding feature point. All feature points form a series of distribution groups in the feature space. The feature points in the same distribution group are considered to have similar features and are classified in the same category. Moreover, in order to achieve the feature points' classification results, it is important to find the boundaries of each distribution group or determine the conditional probability of any feature point in each group.

The spectral feature is usually reflected by the brightness of objects in the multi-spectral images. The brightness of objects displays with the different laws in each band of the image, which is the physical basis to distinguish different objects of image. In an ideal situation, each object within the same category should have the same brightness value. In other words, has the exactly same spectral response. The brightness value of objects within the same category always has a random error rate due to various external factors, thus the observable of the image brightness value is a random variable (x). As a result, the observable brightness value of objects within the same category in different image bands would constitute a multi-dimensional random vector (X), the equation is as follows:

$$X = [x_1, x_2, \ldots x_n]^T \qquad 4.1$$

n—the total number of bands of an image;

x_n—the brightness values of object in the n-band image

The band information is always constructed as a feature space in the multi-band remote sensing image classification. In the case of n bands, there is the feature space $X = (x_1, x_2 \ldots x_n)$.

Taking into account a certain correlation among the bands resulting in information overlap, the K-L transformation is carried out for images to reduce information redundancy. The K-L transformation can retain the key information, compress the amount of data, enhance and extract more visual effects of the new band data. The cumulative contribution rate of the first two transformed features attains 95% through calculating the contribution rate of their own values. The first two transformed features represent high-frequency and low-frequency components of the 7-band image, respectively, reflecting the edge of texture feature and the basic tone feature of the objects. The first two principal components, $PC_1$and PC_2, should be considered. Slope and aspect are considered as well in the topographic elements, and the topographic factor is $Z = (z_1, z_2)$.

In addition, texture feature, one of the important spatial features in remote sensing image, not only describes the distribution of every pixel in the image but also can be regarded as the high frequency of the image. It is clear that texture feature is a significant feature in the classification of remote sensing image. Texture features can be extracted based on Gray Co-concurrency Matrix, which is based on the notion that a texture can be characterized by measuring the distributions of pairs of gray levels (i, j) that are separated by a given distance d in a given direction θ. The frequency $P_{d,\theta}(i, j)$ is calculated by accumulating the occurrences of a pair of pixels that have grey levels (i, j) and separated by a distance d with direction θ, reflecting the spatial correlation of gray between any two points of an image. Texture features of an image can be reflected by measurement indexes such as mean、variance、homogeneity、contrast、 dissimilarity、 entropy 、second angle moment and correlation. According to many tests, the indexes of second angle moment, entropy, contrast and correlation are better to classify built-up areas.

The final expansion feature space is T = (X, PC, Z, Y), the description of the feature space shown in Table 4.4:

Table 4.4 Description of feature space

	Feature category	Feature serial number	Feature
X	Spectral Feature	**1**	TM_4
		2	TM_3
		3	TM_2
Y	Texture Feature	**4**	Second angle moment
		5	Entropy
		6	Contrast
		7	Correlation
Z	Topographical Feature	**8**	Slope
		9	Aspect
PC	Principal components Feature	**10**	PC_1
		11	PC_2

The technique sketch of image classification process is shown in Figure 4.6:

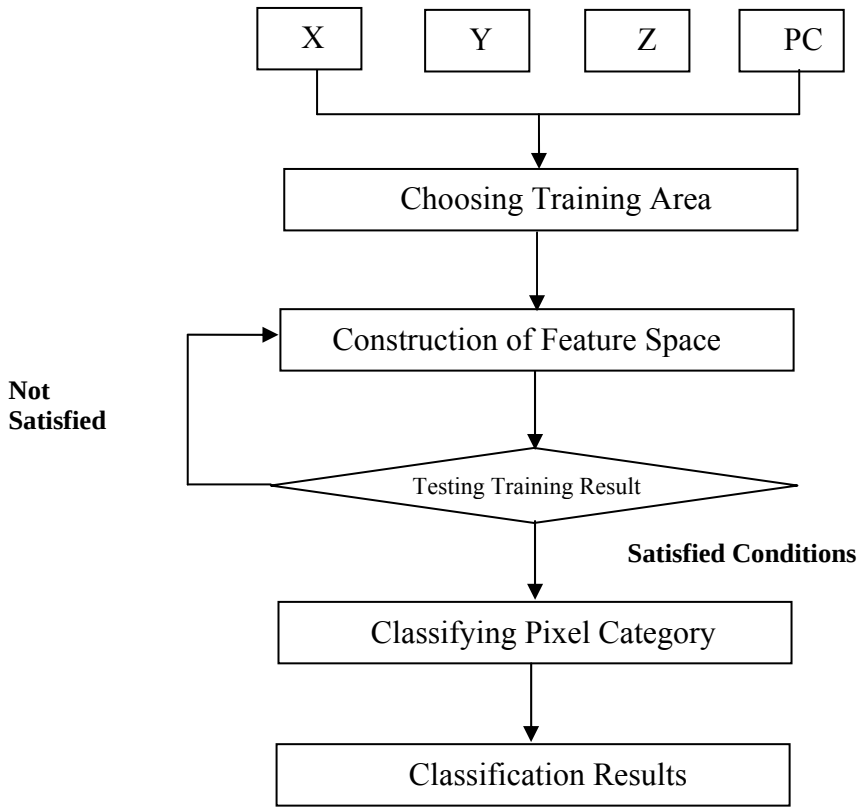


Figure 4.6 The process of image classification

4.2.2 Extracting built-up area from TM images

The built–up areas of four different years were extracted from the Landsat MSS/TM classified images, and is regarded as an indicator to monitor the dynamic change of urban sprawl. Figure 4.7 shows the procedure in extracting the built-up area from classified images.

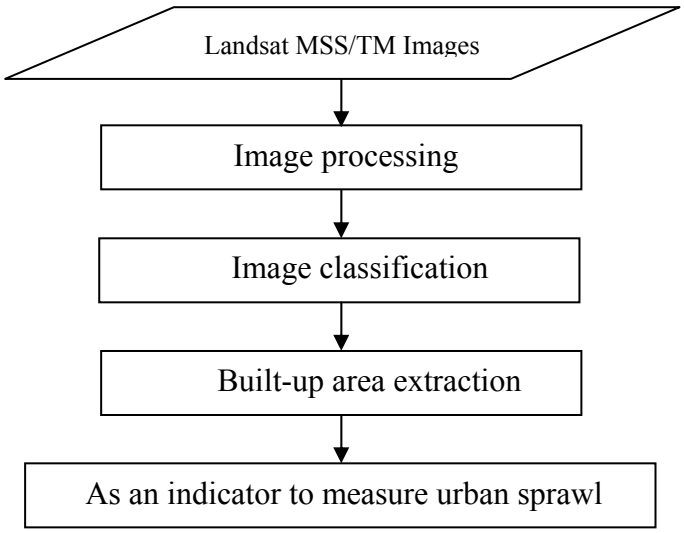


Figure 4.7 Procedure of built-up area extraction

Three types of land uses were obtained in the research area, which included the built-up areas, water areas and other areas (agricultural lands, ecologically sensitive and forest areas) as shown in the Figure 4.8.

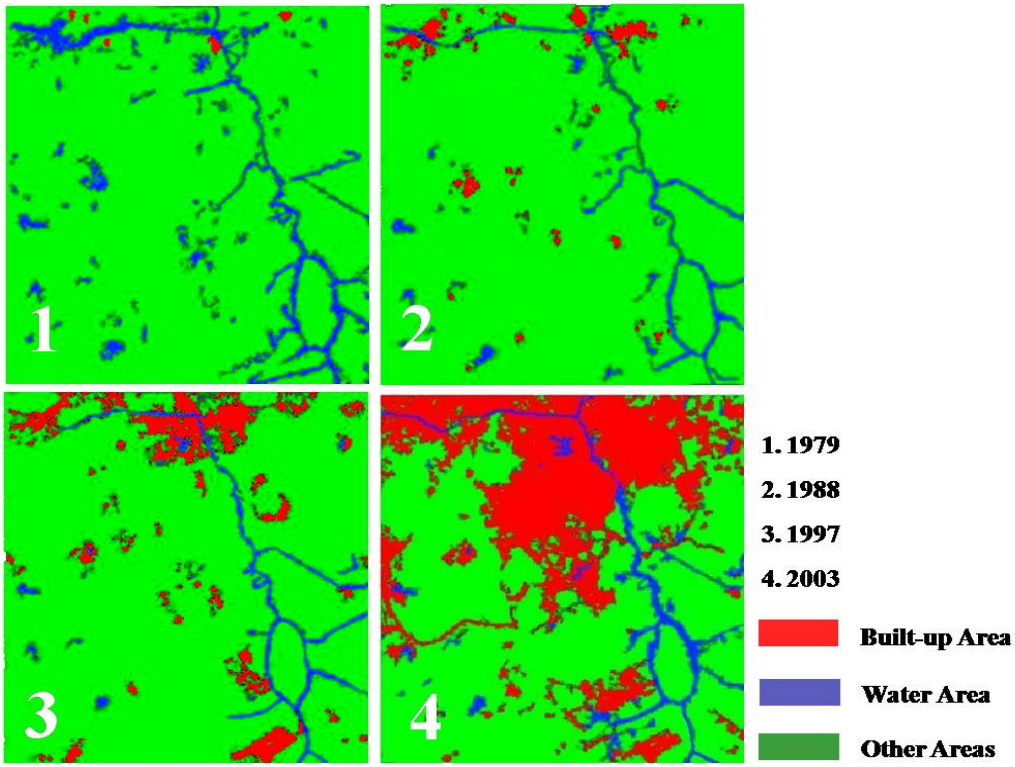


Figure 4.8 The classified images of research area

The results show a remarkable increase in the built-up areas from 1979 to 2003, depicting a scattered or leapfrog type of development pattern. The northern part of Jiangning experienced the largest increase in built-up areas due to Industrial and Economic Development Zones located there. The economic development in the southern part was boosted by the construction of the airport which was used on July 1, 1997.

Classification accuracy has an impact on follow-up study because the built-up area is one of the most important indicators to identify urban sprawl. The confusion matrix was used to evaluate classification accuracy. Classification accuracy is assessed based on not only spectral feature but also on other features, shown in Table 4.5 and Table 4.6. Comparing two results, the latter is higher, which indicates that the classification accuracy of remote sensing image can be improved by expansion feature space.

Table 4.5 Classification accuracy assessment with spectral feature

Land cover types	Built-up area	Water area	Other area	Total
Built-up area	63	11	33	107
Water area	15	80	0	95
Other area	0	0	239	239
Total	**78**	**91**	**272**	**441**
Classification accuracy: 80.91%	**Coefficient of Kappa: 0.7661**			

Table 4.6 Classification accuracy assessment with spectral feature and other features

Land cover types	Built-up area	Water area	Other area	Total
Built-up area	70	11	26	107
Water area	15	80	0	95
Other area	0	0	244	244
Total	**75**	**91**	**270**	**446**
Classification accuracy: 82.32%	**Coefficient of Kappa: 0.7831**			

From 1979 to 2003, urbanization has significantly changed the land use of Jiangning. The built-up area increased very quickly in the rural area. The proportion (%) of land use types in different periods obtained from classified images is shown in Table 4.7.

Table 4.7 Proportion (%) of land use types obtained from classified images

Land use types / Year	1979	1988	1997	2003
Built-up area	10	29.2	41.7	49.3
Water area	34.3	27.1	20	20.6
Other areas	55.7	43.7	38.3	30.1

A pictorial view of the land use changes over time, based on Table 4.9, shown in Figure 4.9.The excessive and unguided increase in the built-areas, especially in the northern part, has decreased the size of the water bodies and the wetlands, which used to occupy a significant portion of the total area, to almost insignificant portions.

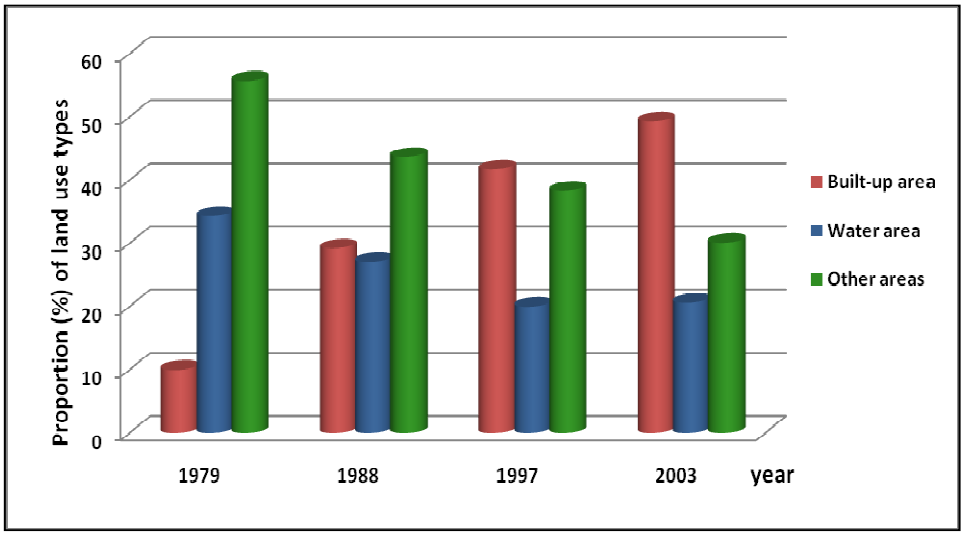


Figure 4.9 The chart of proportion (%) of land use types

The population in the region also influences sprawl. The proportion of the total population in a region to the total built-up area of the region is a measure to quantify sprawl. From 1979 to 2003, the growth rate of the built-up areas has outpaced that of the population growth rate, which indicates a clear case of sprawl in Jiangning, shown in Table 4.8.

Table 4.8 Growth rate of population and built-up area

Growth rate / Year	1979	1988	1997	2003
The growth rate of built-up area	0	65.8%	30%	15%
The growth rate of population	0	2.3%	5%	3.8%

4.3Landscape expression in spatial patterns

Landscape ecology evaluates the interaction between spatial and temporal patterns and ecological processes. A central hypothesis in landscape ecology is that the spatial arrangement of landscape affects ecological systems. For example, the distribution of vegetation responds to a combination of north-south gradients of temperature and east-west gradients of moisture (Turner et al. 2001). One of the main reasons why urban sprawl is a concern lies in the assumption that the spatial arrangement of urban development will have social, economic and environmental consequences over a range of temporal scales. By applying the theory of landscape ecology to urban sprawl, what is it and what its effects are can be better understood. In particular, using landscape ecology's tools allows us to store, manipulate and display spatial and temporal data at appropriate scales. It can provide finer grain data that include more information concerning urban sprawl. Landscape metrics or indices can be defined as quantitative indices to describe structures and patterns of a landscape. The change of built-up areas using only the remote sensing data can not reveal the real patterns of urban sprawl, thus landscape metrics are utilized to create quantitative measures of spatial patterns on a map or a remote sensing image.

Single landscape pattern metric cannot capture all the aspects of landscape characteristics; a suite of selected metrics may be useful in interpreting landscape change. There are a lot of landscape metrics; however, many of these metrics have shown high correlation with one another. A useful set of metrics to quantify landscape pattern should meet several criteria: (1) the metrics should be selected to answer a particular question or meet a particular objective; (2) the measured values of the metrics should be distributed over the full range of potential values and the behavior of the metrics should be known; (3) the indexes should be relatively independent of each other (Turner et al. 2001). In addition, the Environmental Protection Agency ranked the status of a number of landscape metrics and suggested that change in landscape patterns could be characterized by the three metrics of contagion, fractal dimension and dominance (Frohn 1998).

From classified images, the sprawling area in the north part of the city is more severe; sprawling areas also include the marginal area of the nearby suburbs, etc. These findings were tested through landscape metrics, which is necessary to quantify and determine spatial patterns of urban sprawl. Metrics for "sprawl" are scale dependent. A key question regarding urban sprawl is whether it is a result of population growth or land use planning decisions. The

relative contributions of these two factors complicate public perception of "urban sprawl" (Paul 2003). Before using the landscape metrics, the absolute size of population in urban area must be taken into account. The population size was 0.685, 0.711, 0.745 and 0.764 million in 1979, 1988, 1997 and 2003. In this study, contagion, fractal dimension and shape index were used to analyze the change of built-up areas.

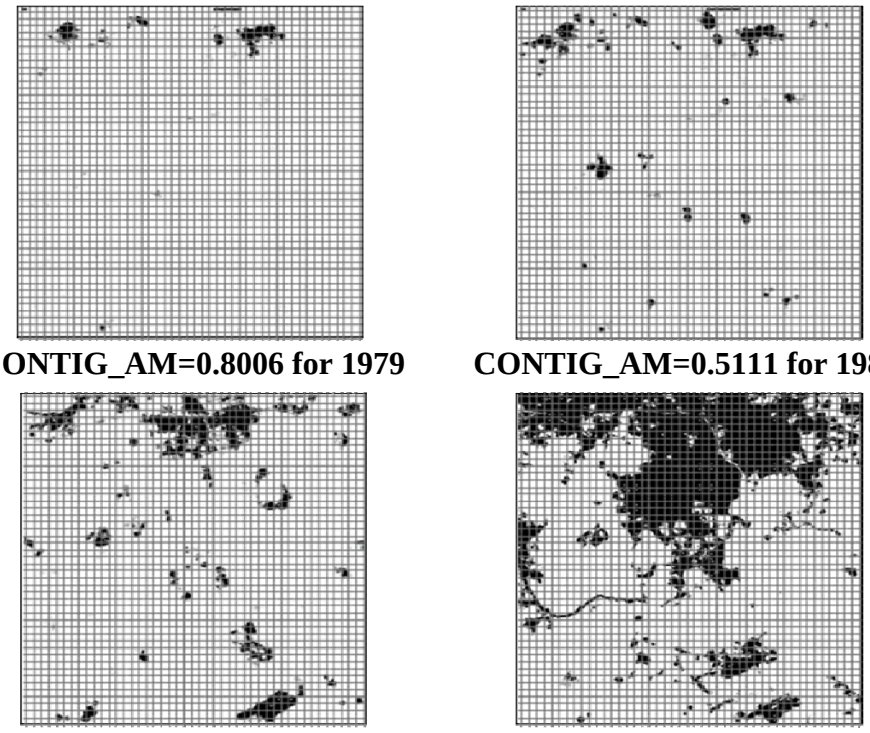
4.3.1 Contagion index

"Contagion" refers to the degree to which mapped attributes are clumped into patches of the same attribute class. Classical definitions of the contagion index (O'Neill et al.1988; Li and James 1993) consider the observed pairing of attributes on raster maps in comparison to the case of random pairing when attribute frequencies are equal. The contagion index is used often in literature despite the limitations of using single-valued indices to represent complicated map patterns. The index seems to be an effective summary of overall lumpiness on maps (Turner 1989). Contagion is used to detect changes in spatial clumping or aggregation of patches and the effects of spatial scale on landscape patterns. It is also used to analyze the relationship between land cover proportions and spatial pattern. Contagion is useful in capturing relatively fine scale differences in patterns that relate to the texture or graininess of the map. The description of contagion index is shown in Table 4.9.

Table 4.9 The description of contagion index

$$\frac{2\ln(t) + \sum_{i=1}^{t}\sum_{j=1}^{t}\left(\left(n_{ij}/N\right)\ln\left(n_{ij}/N\right)\right)}{2\ln(t)} \quad 4.2$$	
n_{ij} is the number of shared pixel edges between classes i and j and N is twice the number of total pixel edges since there is double counting of edges. *t is the total number of classes.*	
Description	*It is a measure of clumping or aggregation of patches, also used as an indication of the degree of fragmentation of landscape.*
Units	*Percent*
Range	*0.0<C<1.0* *Where contagion is low, urban areas can be said to be comprised of many small and dispersed patches of various land cover or land uses categories*

From Figure 4.10, the results showed the clumping change of built-up area in Jiangning.



CONTIG_AM=0.8006 for 1979 **CONTIG_AM=0.5111 for 1988**

CONTIG_AM=0.5007 for 1997 **CONTIG_AM=0.7002 for 2003**

Figure 4.10 Clumping change of built-up area

In 1979, the contagion index was very high because the range of built-up area was small; after 1979, the rapid expansion of urban land led to urban form mutation and the contagion index sharply decreased; from 1988 to 1997, the contagion index fluctuated less as extensive expansion made the urban compactness maintain a relatively stable trend; finally, from 1997 to 2003, the contagion index slightly increased due to gradual expansion of urban space, which means the new urban space is an expansion of exciting urban area into suburban areas because of a large number of new constructions, shown in Figure 4.11.

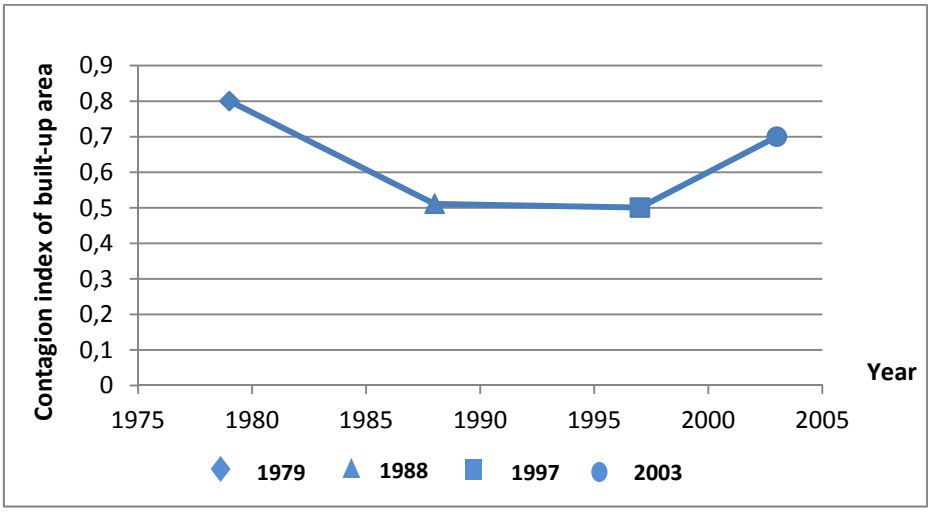


Figure 4.11 The change of contagion index of built-up area

4.3.2 Fractal dimension index

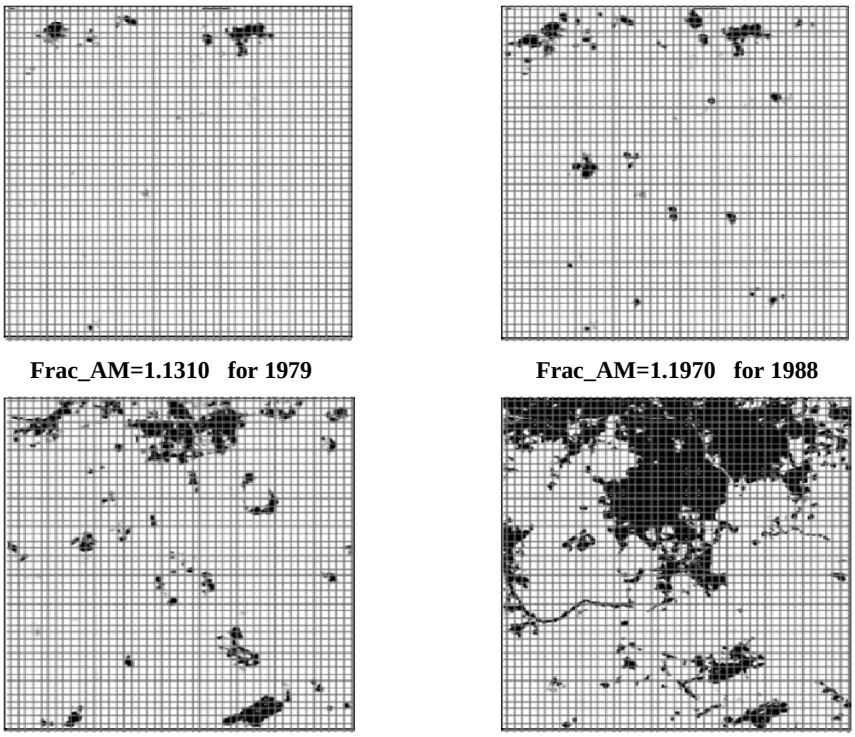
Urban sprawl is often rendered as an interaction interval between the developed regions, compact built-up areas and vacant lands, which shows the space filling with highly irregular and self-similarity. If an area is considered sprawling, its geometric configuration is irregular, scattered, and fragmented. One indicator to measure these configurations is fractal dimension. Increasing fractal dimension is evaluated as a reflection of sprawling process (Terzi 2008), the description of fractal dimension index is shown in Table 4.10.

Table 4.10 The description of fractal dimension index

$P = k A^{D/2}$ 4.3	
P=perimeter *A=area* *D=fractal dimension* *k=constant of proportionality*	
Description	*It is a measure of patch shape complexity.*
Units	*None*
Range	*$1 \leq F \leq 2$* *A fractal dimension greater than 1 for a 2-dimensional patch indicates a departure from Euclidean geometry. The value of F approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.*

In this research, fractal dimensions are used to analyze the changes in spatial configuration of built-up areas from 1979 to 2003. According to these results, we can draw some conclusions for the fractal analyses of Jiangning, shown in Figure 4.12.

Non-agricultural lands have kept growing fast by large amounts and with disordered spatial configuration, indicating a typical sprawling tendency. Obvious fragmentation and irregularity of landscape are significant due to unsuccessful enforcement of land use planning; unadvisable pattern of land use growth with typical discontinuous development and leapfrog development is also obvious; the sprawling area in the north part is larger than that in the south part, where there is relatively small influence by the development of Nanjing.



Frac_AM=1.1310 for 1979 **Frac_AM=1.1970 for 1988**

Frac_AM=1.3145 for 1997 **Frac_AM=1.4298 for 2003**

Figure 4.12 Changing shape complexity of built-up area

From Figure 4.13, we can see the fractal dimension increased significantly from 1979 to 2003. Rapid increase in fractal dimension can be interpreted as evidence of more severe sprawling areas, including the marginal area of the near suburbs.

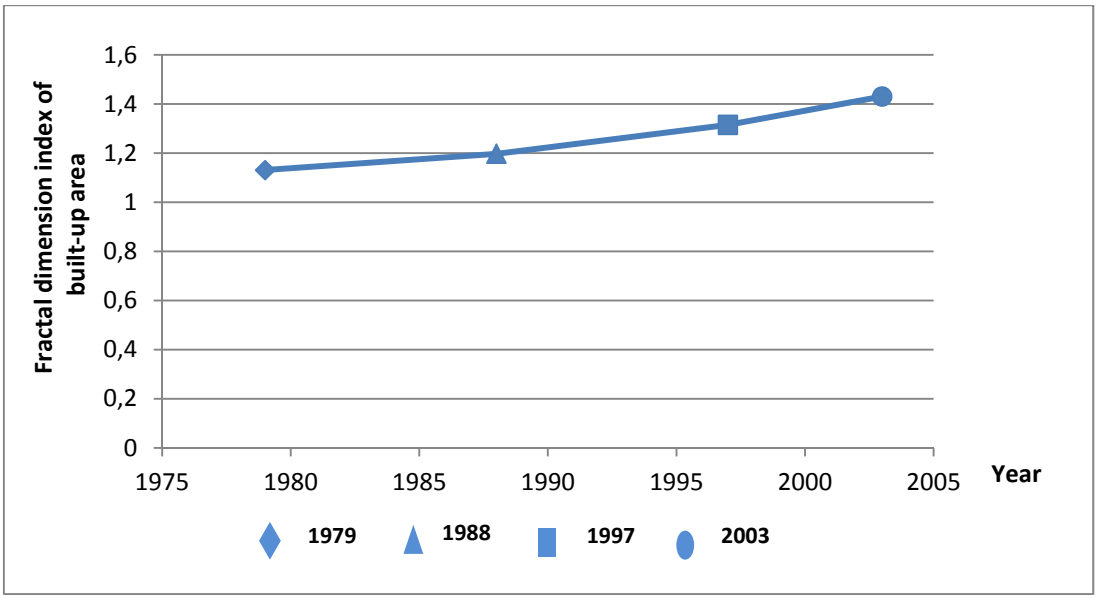


Figure 4.13 The change of fractal dimension index of built-up area

4.3.3 Shape index

Graphics of different shapes have a different shape index. The round shape has the smallest index, followed by a square, rectangle, star, H-shaped, line shape has the highest index. Lo, C.P. (1980) employed the Boyce-Clark shape index to study changes in the shapes of twenty-three Chinese cities between 1934 and 1974, and concluded that city shapes provide valuable clues to an understanding of the process of city growth. The description of fractal dimension index is shown in Table 4.11.

Table 4.11 The description of shape index

$$SBC = \sum_{i=1}^{n} \left\| \left\{ \left(r_i \Big/ \sum_{i=1}^{n} r_i \right) \cdot 100 - \frac{100}{n} \right\} \right\| \qquad 4.4$$	
SBC =*Boyce-Clark shape index;* r_i =*the Radius length from vantage point to perimeter of graphic* *n= the amount of radiation radius with same Angle difference*	
Description	*It is a measure of patch shape compactness.*
Units	*None*
Range	$SBC \geq 1, without\ limit.$ *SBC*=1*, when the patch is maximally compact and increases without limit as shape becomes more irregular.*

By calculating the shape index of built-up area, the change of shape compactness of built-up area is significant, shown in Figure 4.14.

There have been large-scale increases of built-up areas from 1988 to 2002. A large number of residential and public facilities were constructed as a strip-type development around the new airport and roads.

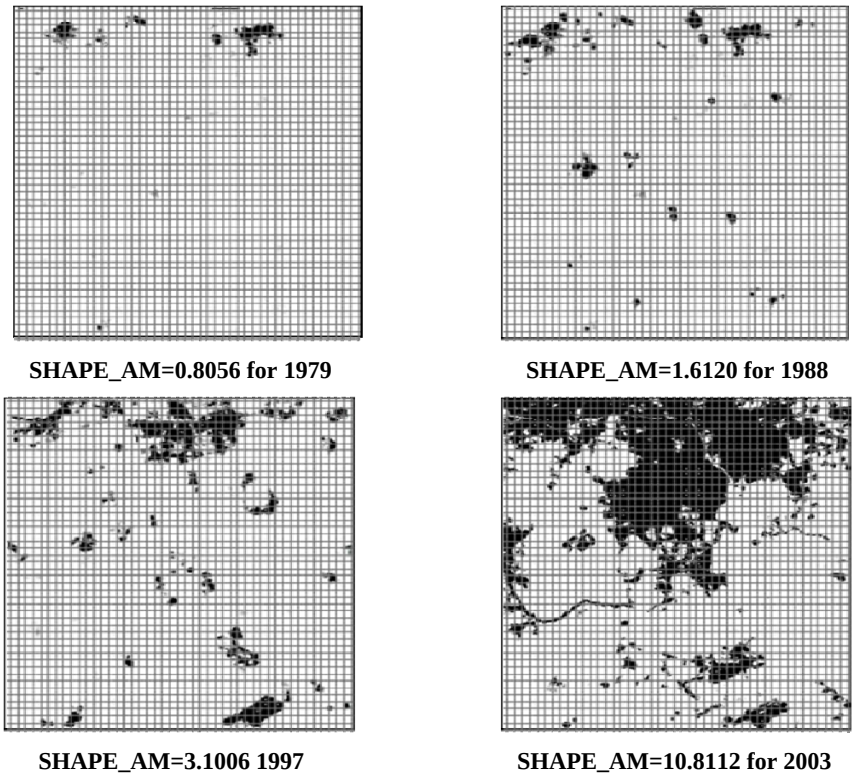


Figure 4.14 Changing shape compactness of built-up area

From Figure 4.15, it can be seen that the shape index of the research area increased from 1979 to 2003. At the beginning, the shape of the research area approximated a dot in a small circle. With the development, the shape index increased significantly.

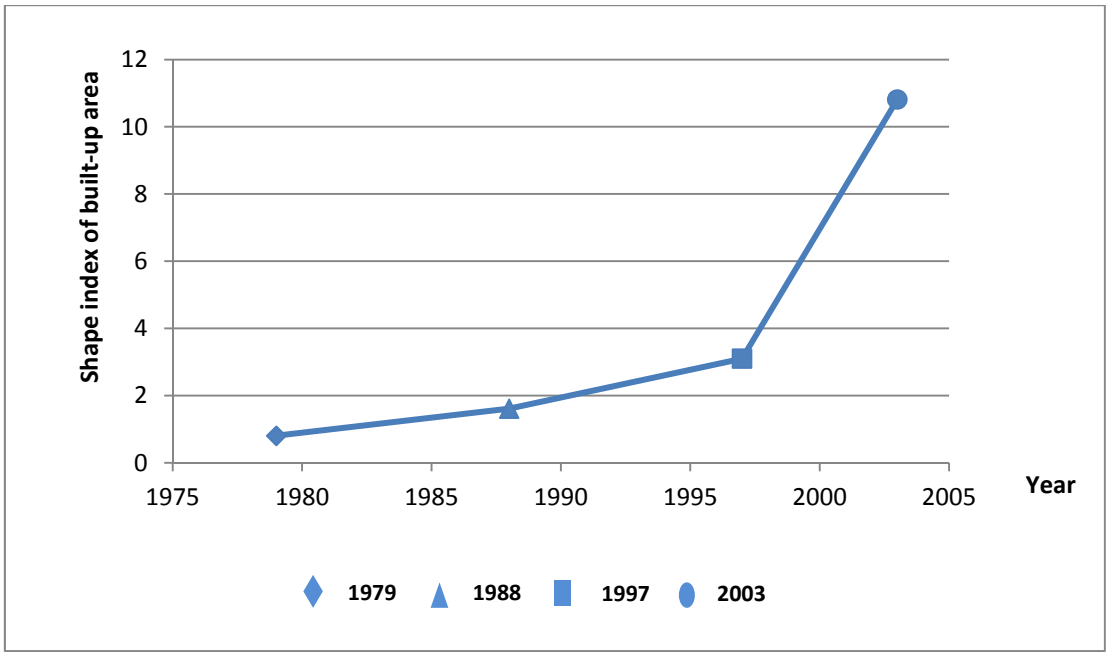
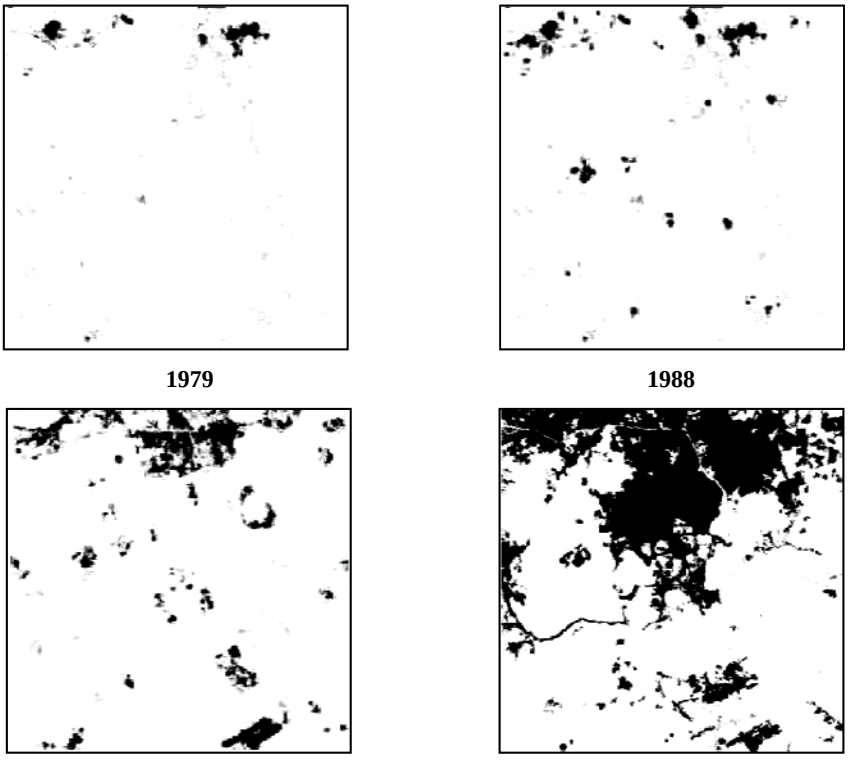


Figure 4.15 The change of shape index of built-up area

This chapter demonstrates that the application of remote sensing and landscape metrics are useful on recognizing the spatial patterns of urban sprawl. The characteristics of urban sprawl in Jiangning are listed as following:

1) Fast growth of built-up area

Figure 4.16 shows a remarkable growth of the built-up areas of Jiangning over the period. Areas of build-up that consume amounts of agricultural lands and forest lands are considered sprawling.



1979 **1988**

1997 **2003**

Figure 4.16 Fast growth of built-up area

2) Leapfrog development of built-up area

A scattered or leapfrog kind of development pattern is visible, as shown in Figure 4.17. In order to reduce land acquisition and development costs, development zone, residential areas, industrial parks are constructed away from the main city with the "leapfrog" growth patterns especially from1979 to 1998, which occupy a large amount of cultivated lands. Significant decreases in areas of cultivated lands is the typical negative impact caused by urban sprawl, resulting in severe separation of living and employment, increased traffic problems, automobile dependence and air pollution.

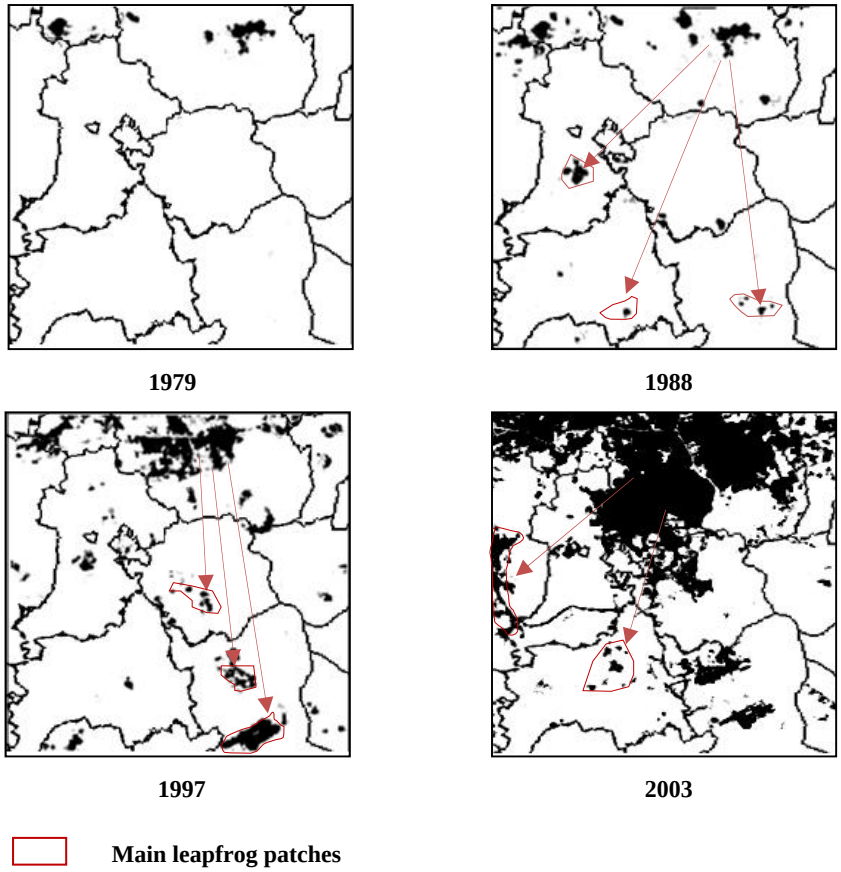


Figure 4.17 Leapfrog development in Jiangning

3) The obvious fragmentation and irregularity of landscape

Urban sprawl and "leapfrog" development patterns increasingly fragment the landscape, especially at the urban fringe. Landscape fragmentation has important consequences for biodiversity and ecosystems by altering ecological structure and function, resulting in changes in the provisioning of valuable ecosystem services. The impact of landscape fragmentation is the dispersal and population dynamics of plants and animals, the facilitation of the spread of invasive species or weeds, and the loss of scenic and recreational quality of landscapes due to noise, and the reduction in size and quality of recreation areas(Jaeger et al. 2008).

Before 1997, cultivated land was the dominant landscape type. The proportion of the built-up area has increased rapidly since 1997. The dominant landscape type changed from the cultivated land to the built-up area. Specifically, there was gradually increasing trend in built-up area from 1988 to 1997. And then, the built-up area developed blindly, contributing to the disorder and significant fragmentation of the landscape from 1997 to 2003, shown in Figure 4.18.

In addition, the road network is another major infrastructure system affected by development patterns. Transportation researchers have determined that land use influences the need for roads. Getting from one place to another usually requires travel along some form of transportation infrastructure, such as roads and highways, which for new developments is further from already established areas. The associated urban development that such road infrastructure attracts has transformed Jiangning's landscapes.

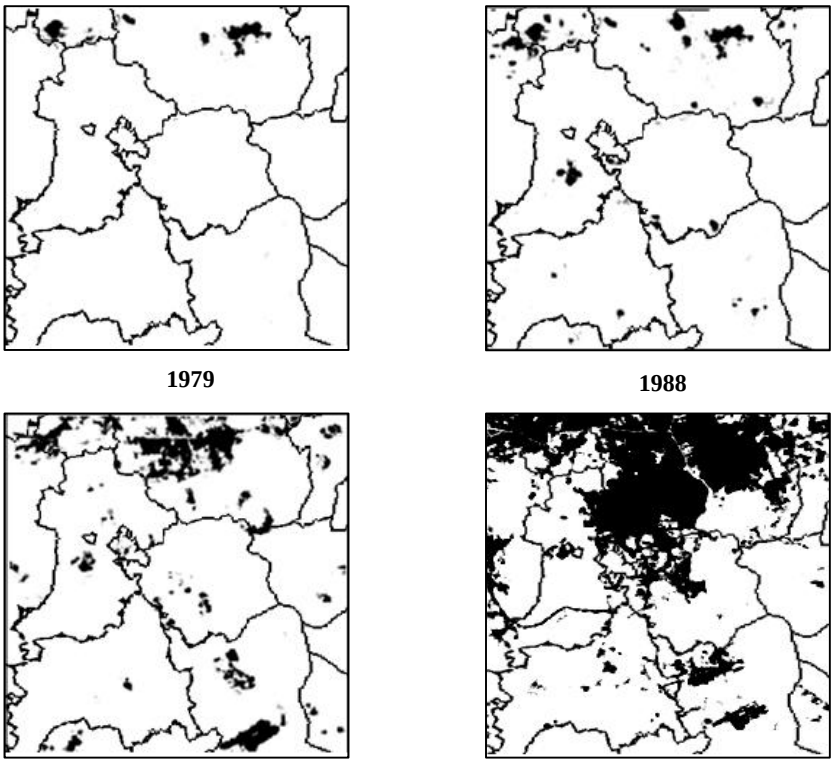


Figure 4.18 Fragmentation of built-up area

4.4 Summary

In China, the prominent land use change in urban fringe areas is the amount of agricultural lands replaced by various types of construction lands. Studying the landscape expression of the built-up area is very useful to determine sprawl patterns. Integrated remote sensing technology research on the spatial patterns of urban sprawl requires a combination of landscape perspectives of understanding. Three sprawl patterns are recognized in Jiangning: random expansion at urban fringe, scattered development of urban residential area and leapfrog development of industrial land. The following specific sprawl features are identified: the obvious fragmentation and irregularity of landscape; the unadvisable pattern of land use growth with typical discontinuous development and leapfrog development; the low density of land use growth and other negative impacts on agriculture, the environment and city life.

5 Temporal dynamic of urban sprawl

5.1 Dynamic change analysis

5.1.1 Change of land use/cover

The change of land use/cover patterns is a particular the phenomenon of urban sprawl. Spreading at the edges of city is explained by the construction rates; while restoration rates are increasing in the city centres, sprawling areas are the areas where the transformation on the agricultural land and new construction are at its peak.

Currently changing land use/cover in peri-urban areas in China is subject to different influences. On the one hand, authorities of land use planning at the regional level have been established to carry out planning for regional development; on the other hand, large national and international investors obtain construction permits very quickly. Peri-urban zones in China have gained economic importance and attract domestic as well as foreign investment. "Simply speaking, peri-urban areas are where the forces of globalization and localization intersect" (Webster 2002). As a consequence, agricultural communities are often forced to adjust to an urban or industrial way of life in a very short time. Moreover, informal housing and illegal land captures by migrants lead to uncontrolled construction activities and cause further dissipation of space (Veronika 2007). The pattern of land use near the city centre is highly fragmented and more spatially complex than in out-lying areas. There are two main points of suburbanization of Jiangning:

1) Urban fringe

On a closer inspection of the definition of "urban fringe" in China, one must define what the terms "city" and "rural" refer to. Cities are established with the approval of the central government. "Urban population" refers to a population living in areas under the jurisdiction of cities and towns. "Rural population" refers to a population living in counties - excluding those living in towns. Under this definition, the urban fringes cannot be identified in terms of the spatial dimension because urban population can be found in counties whilst rural population can also be found in cities. The term "urban fringe" refers to the counties neighboring a city because these counties are governed by the rural government. At the same time, these counties spatially connect urban infrastructure and facilities for urban expansion and agriculture land transfer for residential, commercial, industrial, trade, recreational, transportation and service.

The metropolitan area of Nanjing can be divided into urban core (Xuanwu, Baixia, Jianye, Gulou, Qinhuai and Xiaguan), rural fringe (Yu Huatai, Qixia, Pukou and the Dachang, the Luhe the County, the Jiangpu County and the Jiangning County) and rural core (Lishui and Gaochun County) (Yao 2004), as shown in Figure 5.1.

Based on the Nanjing City Overall Plan: 1991-2010 (NCOP), which was revised in 1997, the Nanjing municipality is divided into three levels: the planning area, the metropolitan area and the core city zone. The planning area refers to the whole administrative area covering a total area of 6,516 km^2. The metropolitan area comprises the urban districts (including the urban core) and parts of the Jiangning, Jiangpu and Liuhe Counties (urban fringe) with a total area of 2,753 km^2. The core city zone is bounded by the city ring road(s) and the southern part of the Yangtze River, covering an area of 243.83 km^2. The urban core is the most developed region with more than 60 % built-up area. The urban fringe of Nanjing is defined here as the metropolitan area between the urban core and the urban growth boundary (Yao 2004), as shown in Table 5.1.

Jiangning boarders Nanjing city to the east, west and north. The farthest point from Nanjing city is 46 km, the nearest point is 13 km, and the average spatial range is 27 km. The process of suburbanization is the cumulative growth of the Nanjing city through additions to its periphery.

Table 5.1 The Land use structure in Nanjing (1999)

	Municipality)		**Urban Fringe**		**Urban core**	
	Area (km^2)	Ration (%)	Area (km^2)	Ration (%)	Area (km^2)	Ration (%)
Arable Land	3491.41	52.31	1395.13	47.57	40.27	16.52
Forests	1625.05	24.27	689.18	23.50	40.23	16.50
Urban Land	1009.27	15.07	574.07	19.57	153.78	63.06
Water Area	571.11	8.53	274.51	9.36	9.55	3.92
Total	6696.84	100	2932.89	100	243.83	100

Source: Extracted from the Nanjing Municipal Construction Commission (1998)

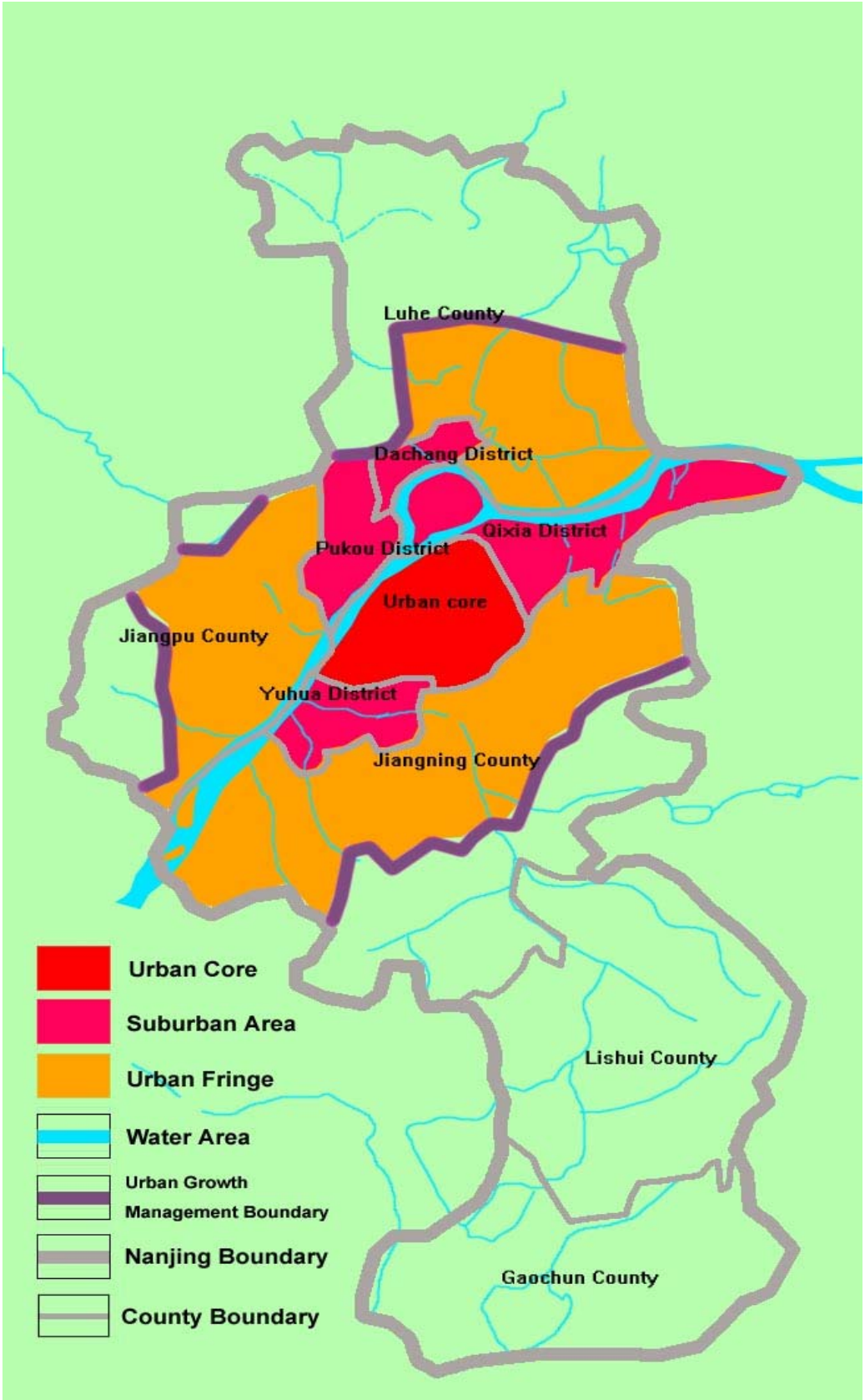


Figure 5.1 Urban Fringe in Nanjing

Source: Extracted from the Nanjing Municipal Planning Bureau（2000a)

2) Unstable county-city boundary

As urban fringe, the development of Jiangning has been affected by the urban expansion and administrative divisions' adjustments in Nanjing. For example, the built-up area in Nanjing extended from 42 km^2 in an early period to 144 km^2 in 1997. The city developed in size in all directions from 1979 to 2004, and urban land spread significantly. There were three adjustments in administrative divisions in Nanjing, which eroded land recourses near the outskirts. Jiangning is a leading area impacted by this change. Large-scale industrial parks and some low-density residential areas were built in Jiangning because of old city reconstruction, housing shortages, high rent prices, the rising cost of living service and relocation of the secondary industry in Nanjing. Dispersed land development in Nanjing is shown in Figure 5.2.

Owing to urban land reforms, vigorous expansion has been witnessed in the urban fringe of Nanjing. Massive amounts of land in Luhe County, Jiangpu County and Jiangning County has been exploited for economic development as well as infrastructure development (Wei 2001).In the urban fringe, urban population had increased from 223.0 million in 1984 to 261.2 million in 2002. The average yearly growth rate was 6% (Nanjing Municipal Statistic Bureau 2002). The built-up area in the urban fringe has increased from 402.3 km^2 to 574.5 km^2. The average yearly growth rate was 8%. There has been an increase in built-up area per capita and a decrease in the development density. The built-up area per urban population in this period had increased from 180.2 to 220.2 m^2 (Yao 2004), as shown in Table 5.2.

Table 5.2 Land development density in urban fringe of Nanjing (1978-2002)

Year	Built-up Area (km^2)	Urban Population (10000 persons)	Built-up Area per Urban Population (m^2)
1984	402.3	223	180.2
1988	435.1	226.3	192.7
1994	480.8	231.3	207.2
1997	520.4	234.9	222.1
2000	552.8	252.7	218.7
2002	574.5	261.2	220.2

Source: Extracted from the Nanjing Municipal Construction Commission (2002)

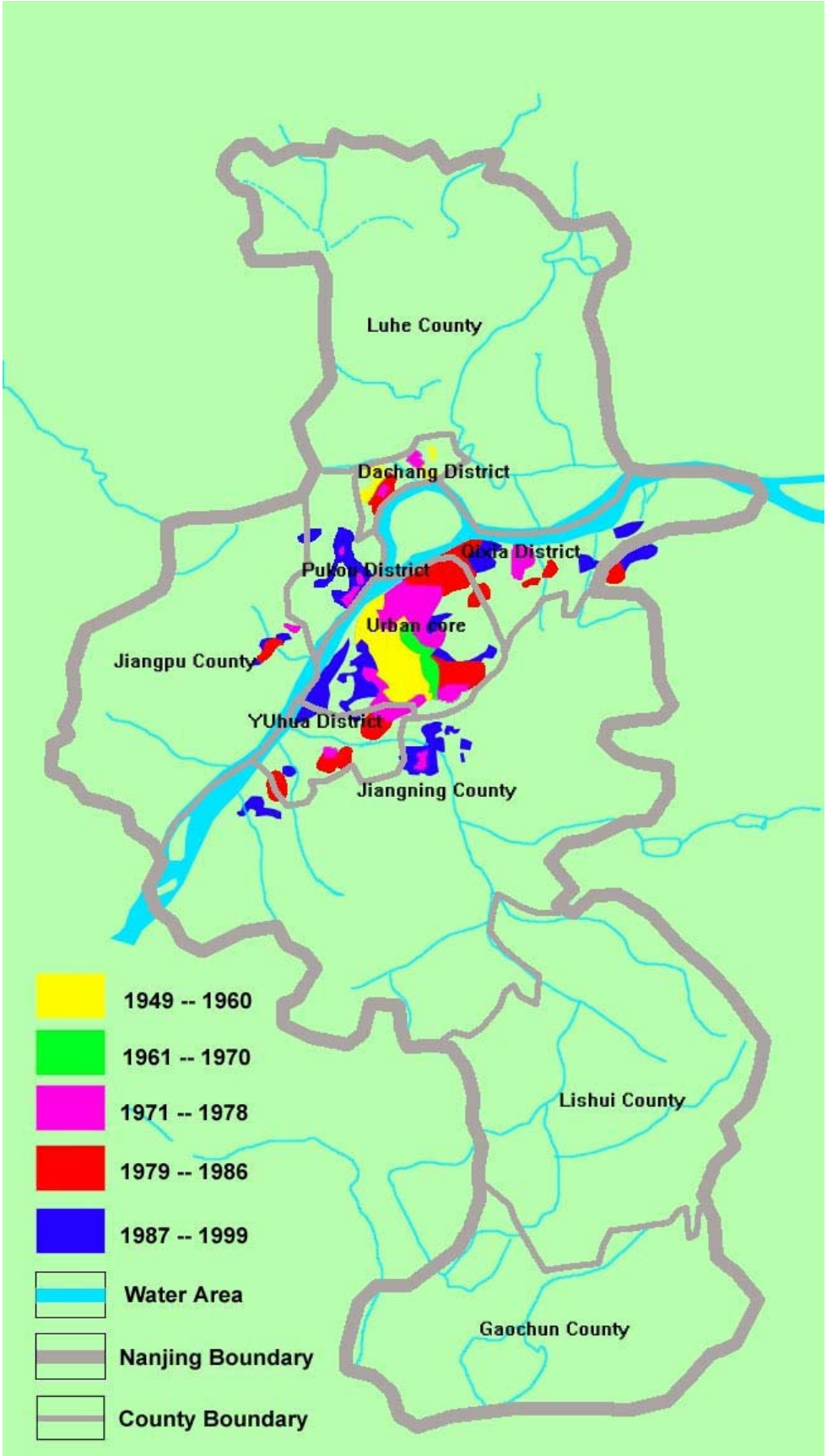


Figure 5.2 Dispersed Land Development in Nanjing

Source: Extracted from the Nanjing Municipal Planning Bureau (2000a)

5.1.2 Shannon's entropy analysis

Shannon's entropy[12] has been used to analyse urban sprawl (Yeh and Li 2001; Jat et al. 2007; Bailey 2009). The larger the value of Shannon's entropy, the higher the uncertainty of the information conveyed (Bailey 2009). High entropy is the most probable yet least predictable state that leads to disorder. Using Shannon's entropy, Yeh and Li (2001) measured urban sprawl for the first time, which is given as follow:

$$\mathrm{H_n} = -\sum_i^n \mathrm{p_i} \log\left(\frac{1}{p_i}\right) \qquad 5.1$$

Where

Pi = Proportion of the variable in the ith zone (proportion of built up area in each zone)
n = Total number of zones (number of zones in the research area)

The value of entropy ranges from 0 to log*n*. Value of 0 indicates that the distribution is very compact, while values closer to log*n* reveal that the distribution is much dispersed. Higher values of entropy indicate the occurrence of sprawl. Two types of thematic layers are needed for calculating the entropy value in different years, including the layer of administrative boundaries and the layer of built-up area, shown in Figure 5.3.

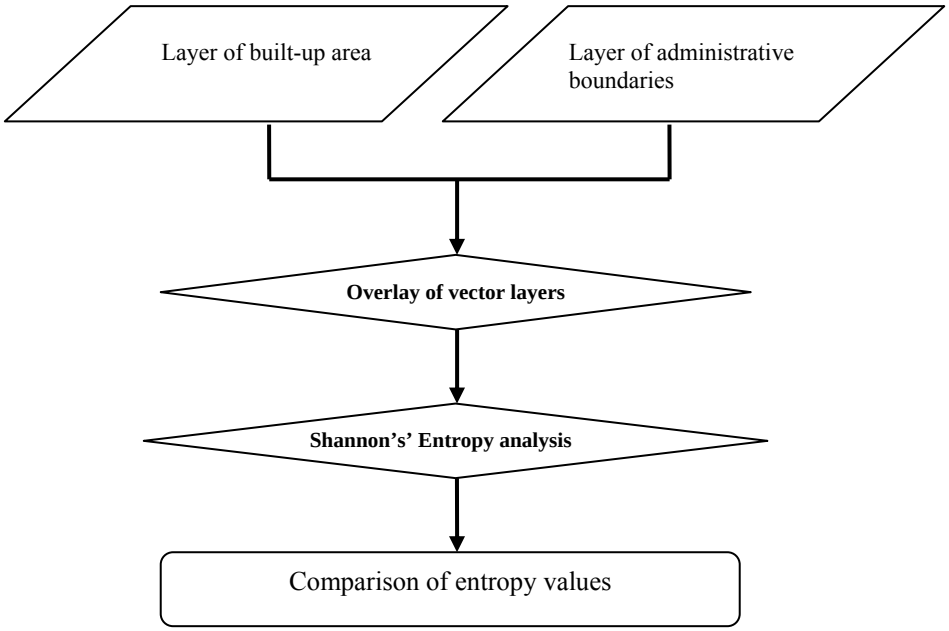


Figure 5.3 Shannon's' Entropy Analysis

[12] Shannon's entropy originated from information theory as a measure of uncertainty of conveyed information over a noisy channel, which is measure of the degree of dispersion or concentration of a random geographical variable (Verzosa and Gonzalez 2001)

The research area is divided into 13 zones based on the administrative boundaries of Jiangning. Entropy values have been calculated across all zones, and are summed-up to present the entropy for the research area. Shannon's entropy results for 4 years (1979, 1988, 1997 and 2003) are presented in Table 5.3:

Table 5.3 Shannon's entropy in different years

Year	Shannon's entropy
1979	0.4526
1988	0.8556
1997	0.7872
2003	0.8425

The dispersal of built-up areas will lead to an increase in the entropy value, which gives a clear idea to recognize whether land development is processing towards a more dispersed or compact pattern. Values for the years 1988, 1997, and 2003 were above 0.5, demonstrating dispersion of the built-up area, which is a sign of urban sprawl. Such high entropy values confirm that land development was spreading over the urban fringe and into the surrounding rural areas.

The relatively lower value of entropy in 1979 indicates a compact and homogeneous distribution of built-up area. The entropy value has decreased from 0.8556 in 1988 to 0.7872 in 1997, which is illustrated as the distribution of built-up area in 1988 being more dispersed than that in 1997. The entropy value has increased from 0.7872 to 0.8425 from 1997 to 2003, which shows a highly dispersed development from the core of the district. The values of entropy in 1988, 1997 and 2003 are closer to the upper limit of log13 (1.1139), reflecting a high rate of urban sprawl.

5.2 Dynamic change monitoring

5.2.1 Dynamic change of built-up area

In order to figure out change in the situation, the method of change detection was carried out. By overlapping time-series satellite imagery, rates of land conversion/consumption can be analyzed with great accuracy. The procedures involve: (1) classify image with 4, 3, 2 bands of Landsat TM, (2) perform post-classification (3) overlay with Layer of administrative boundaries (4) apply change detection with overlay and raster calculator. In this study, land

cover types were aggregated into two categories: built-up and non-built-up. Binary outputs were used to show the change from non built-up areas to built-up areas, where only change and non-change categories were differentiated. The procedure of change detection is shown in Figure 5.4:

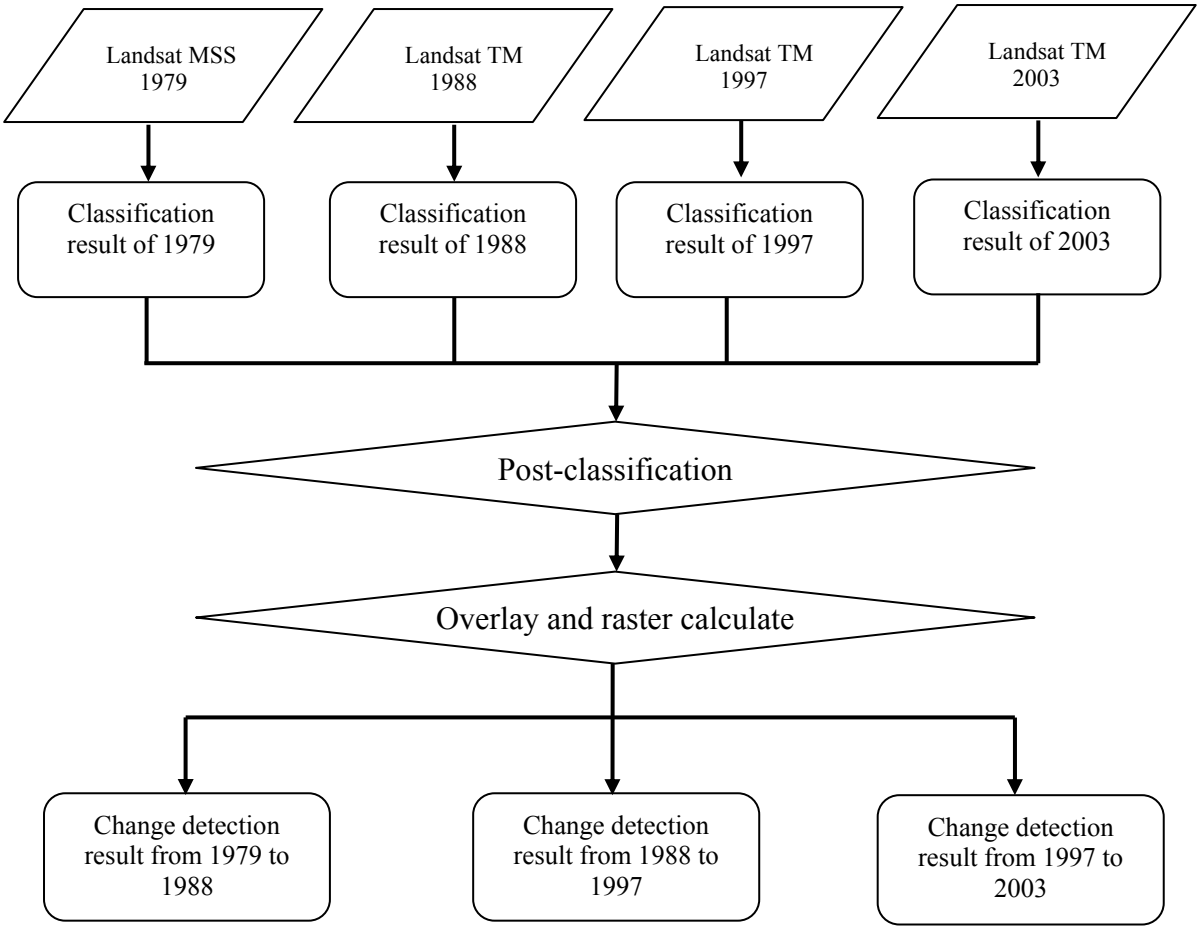


Figure 5.4 The procedure of change detection

Figure 5.5 presents the changing form of built-up area in Jiangning in different periods.

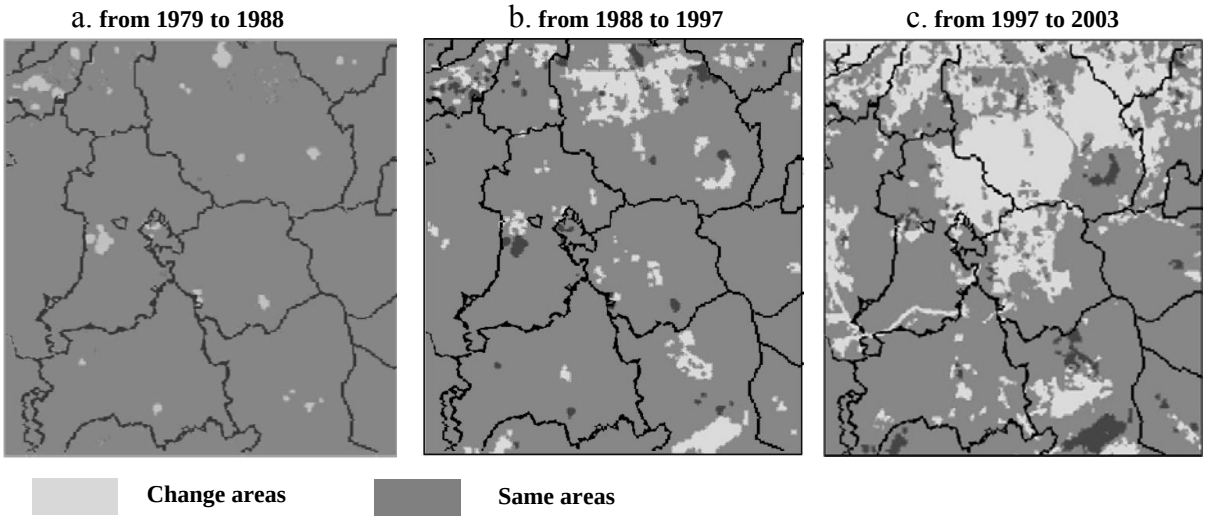


Figure 5.5 The range change of built-up area

Time-series analysis reflects the dynamic degree of spatial structure in different periods. The dynamic degree of spatial structure is an important indicator that can reflect the dynamic changes of urban spatial expansion. In this study, the formular of the dynamic change rate of sprawl was proposed:

$$DU = \frac{DB_{r2} - DB_{r1}}{DB_{r1}} \times \frac{1}{T_2 - T_1} \times 100\% \qquad 5.2$$

Where

DU is the dynamic change rate of urban sprawl for a period

T_1 , T_2 are specific years

DB_{r1} is total area of built up area in T_1

DB_{r2} is total area of built up area in T_2

A higher rate of dynamic change indicates A faster speed of sprawl. Table 5.4 shows the dynamic change rate of spatial structure in Jiangning:

Table 5.4 The dynamic change rate of sprawl in Jiangning

Year	1979	1988	1997	2003
Built –up area(km^2)	39.12	94.4	163.4	193.13
Net area(km^2)		55.28	69	29.73
The dynamic rate (%)		15.7	8.1	3.0

1) 1979 – 1988 Period

This was a period of development in Jiangning. Figure 5.5(a) illustrates the range change of built-up area during this period. Before 1980, it was a traditional agricultural area and an important grain supply base for Nanjing. Rapid growth of rural enterprises started in 1980, along with the construction of economic and technical development zones accompanied by improved transportation facilities have resulted in remarkable changes in economic activities and the pattern of land use. Scattered development was obvious. Due to lack of reasonable planning policies, the dynamic change rate of sprawl is highest during this period.

2) 1988 – 1997 Period

This was a period of rapid growth and rapid urbanization in Jiangning. Sprawl is more significant in the process of suburbanization. Figure 5.5(b) explains the range of change of the built-up area during this period. The white parts are change areas and and the gray parts experienced no change. It is very clear that leapfrog development in Jiangning was significant. The development focus of Nanjing has been shifted to the southeast part. The result of this

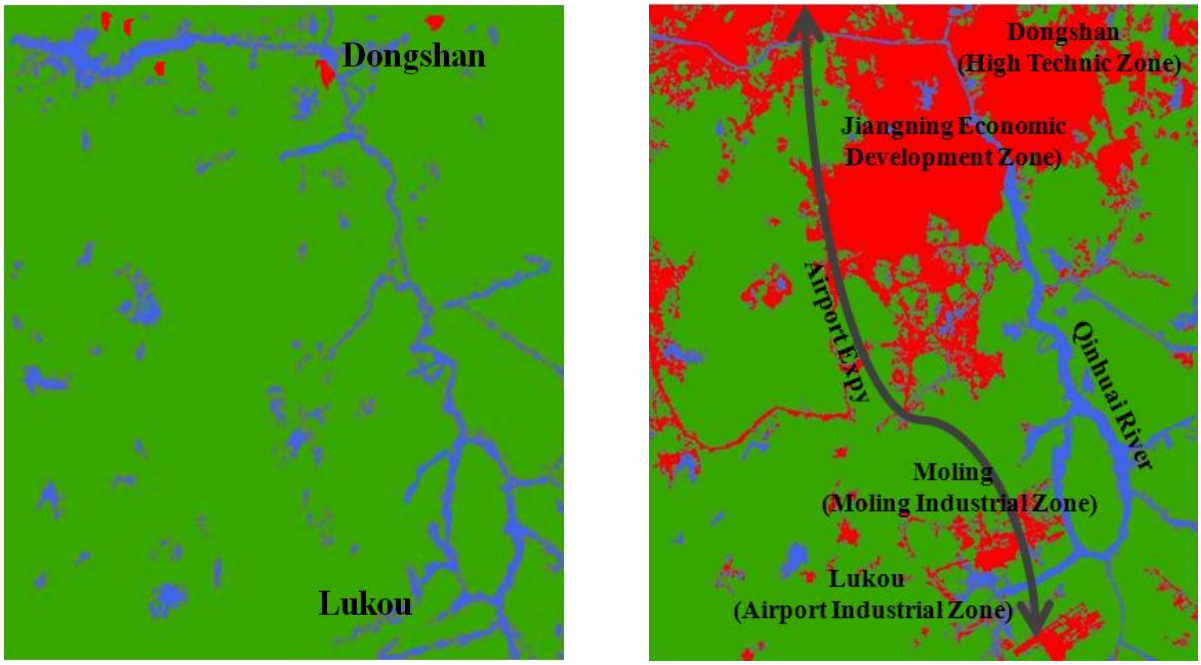
shift was that Jiangning became the new focus of development, changing from north to south due to the construction of the rural center, industrial parks and a new airport. In this period, land planning policy was playing an important role leading to the dynamic change rate of sprawl decreasing.

3) 1997 – 2003 Period

This was a period of vibrant growth in Jiangning. Figure 5.5(c) shows the range change of built-up area during this period. The stability of land use in Jiangning has become increasingly weakened and broken in recent years. Some farmers have more than once experienced the "land acquisition – demolition – house building – re-land acquisition – re-demolition" circle. The construction of industrial parks, residential areas and University City made the land fragmented. The combination of all kinds of architectural forms led to a broken landscape. In this period, the dynamic change rate of sprawl is lowest compared to the other two periods because land planning policy had more impacts on the development of Jiangning.

5.2.2 Dynamic change of land use/cover types in built-up area

The types of land use/cover have significantly changed because of sprawl in Jiangning. The maps of land use change, which come from the classification of Landsat TM images, is shown in Figure 5.6:



a. **The land use before development** b. **The land use after development**

Figure 5.6 The change of land use in Jiangning

Through comparison of land use/cover maps from 1988 and 2003, the main land use/cover types of built-up area and the composition ratio are presented in Table 5.5. The built-up area in Jiangning increased from 94.4 km^2 in 1988 to 193.13 km^2 in 2003, approximate doubling.

Table 5.5 The land use/cover types of built-up area and composition ratio

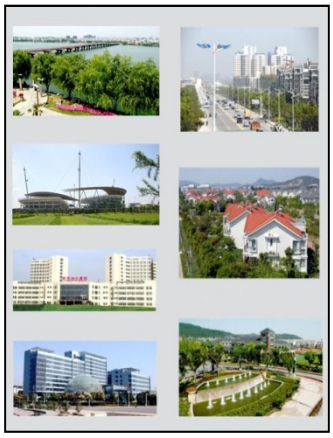
Year	Built-up area(km^2)	Residential land		Industrial land	
		Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
1988	94.4	50.46	53.5	20.34	21.5
2003	193.13	67.2	34.8	90.2	46.7

1) Industrial land

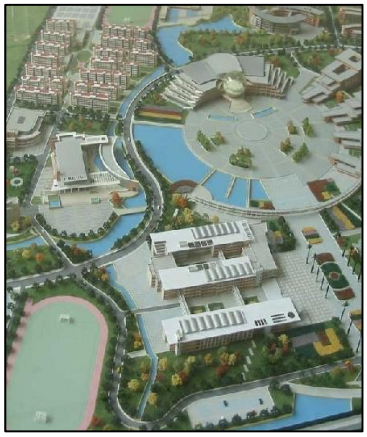
Since the middle of the 1990`s, with the rise of the "development zones", a large number of agricultural land was occupied by industrial land, which accounted for almost 60% of the acquisition of agricultural land. Taking Dongshan as a example, the establishment of Economic and Technological Development Zone started in 1992. Following this, the National Technology Park and Jiangning Mall were constructed in 1997 near Dongshan. Meanwhile, thirteen township industrial parks, eight professional markets and three trade markets were built in other areas. Apart from development zones, the construction of University City and Lukou International Airport were also important parts of indurstial land use, which led to land use change in Jiangning, shown in Figure 5.7.

Figure 5.7 Industrial land in Jiangning

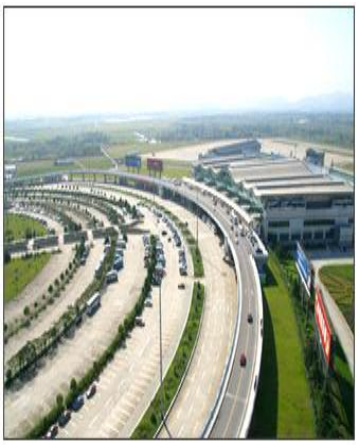
a. The Economic and Technological Development Zone



b. University City



c. Lukou International Airport



Source: http://hanyu.iciba.com/wiki/1488540.shtml; http://lou.1jiayuan.com/folder452/jiangning/2009-12-04/50047.html; http://www.zgppt.com/planeticket/jc/nkg.asp

2) Residential land

With the new roadways snaking out from Nanjing, the trend of residential suburbanization is more and more significant. The land around it was productive farmland, which became much more valuable as sites for new housing. The rapid expansion of housing into Jiangning wrought great changes of land use. In the metropolis circle of Nanjing, the neighborhoods of Dongshan, Moling and surrounding areas are important demographic, residential and industrial sub-centers. Since 1990's, housing construction has significantly increased except for the construction of the development zone. Real estate development has become a new economic highlight. After the qualitative analysis of industrial land and residential land, the spatial pattern of residential land and industrial land is quantified to test the development trend of the built-up area. Figure 5.8 is a flowchart of methodology for quantitative analysis on spatial distribution of industrial land and residential land. Variable Clumping Method (VCM) (Liu et al. 2002; Chen et al. 2006) is used to analyze differences in the spatial distribution of patches of different land use types. It is one of the methods in GIS spatial analysis, which can establish a buffer for a specified objective by a certain distance. Patches of land use are polygons in vector graphics. When a buffer analysis is carried out on polygons of a particular type of land use, and the distance between adjacent patches is less than twice the buffer radius, the buffers will be superimposed. A superposition area will form when the number of patches is large. If the buffer radii are constantly changing, then the number of superposition parts is also changing. The relation between the buffer radius and the number of superposition parts can quantitatively reflect the spatial pattern of patches of different land use types.

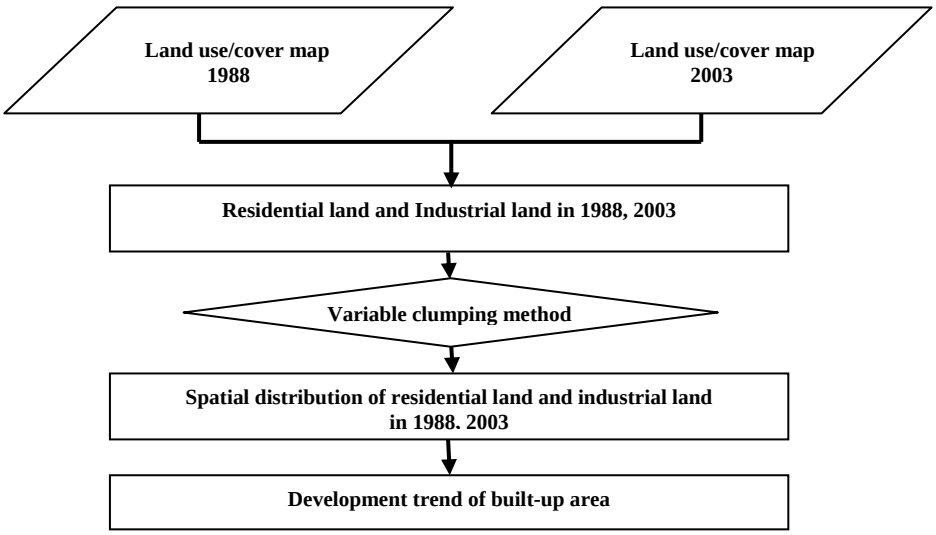


Figure 5.8 Quantitative analysis of spatial distribution of industrial land and residential land

A series of buffers were created based on successively incremental steps. The basic step is 30m, which is the spatial resolution of TM images. The results of analysis are presented in Figure 5.9, with the change of buffer radius on the X-axis and the change of superimposed patches number on the Y-axis. When the distribution of patches is highly concentrated, the peak of the VCM curve is inclined left. Inversely, when the distribution of patches is more dispersed, the peak of the VCM curve is inclined right. When patches distribute with a fixed distance, the curve peak will appear in the same fixed distance.

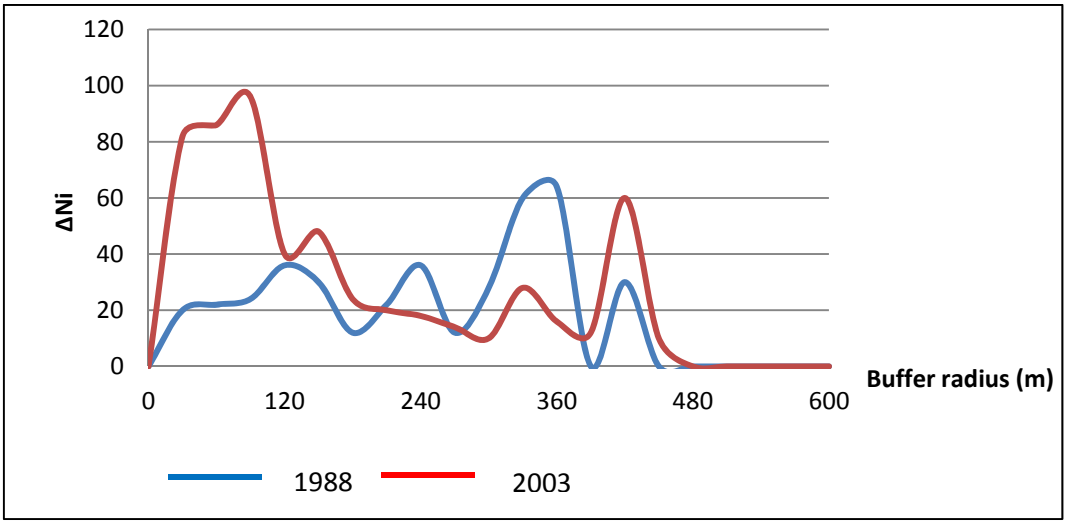


Figure 5.9 VCM curves of residential land and industrial land

In1988, multiple peaks of the VCM curve indicated scattered distribution of industrial land and residential land. In 2003, there are also multiple peaks, but the highest value of a peak is in the left, which means a relative concentrated distribution of part of the industrial land and residential land, and most of them were distribution. Comparing the VCM curves of these two years, the number of superimposed patches increased in close range and decreased in distant range, which indicates that the number of patches increased and the degree of landscape fragmentation intensified.

5.3 Change extents measurement

5.3.1 Multi-dimensional indicators selection

The indicators of urban sprawl used in western counties and China have some differences. Based on comparison, the principle characteristics of urban sprawl in China include the following:

1) Phase difference of urban sprawl

Since the 1950s, auto-oriented development has reinforced low-density, single-use development patterns, intensifying the trend of urbanized area spreading into undeveloped countryside. This spreading of development caused sharp reductions of arable land, inefficient use of urban land and the destruction of environmental resources, etc. Looking at an example from the United States, 60% of the metropolitan population lived in a city center in 1950, and by 2003, more than 60% of the metropolitan population lived in suburban areas. The urbanization rate reached 73.6% in 1970, which basically completed the process of urbanization. Sprawl can largely be equated with what the nation has called “suburbia” since at least the 1950s (Gillham 2002).

In China, the urbanization rate was only 7.3% in 1950 and reached 44.9% in 2007. The overall level of urbanization is low. It appears that population and industry were moving from city center to urban fringe due to the continuing development of Chinese cities. The agricultural land and natural landscape in suburban rapidly changed into non-agricultural land and urban landscape.

As we have seen, the phases of urban sprawl are different. In developed countries, sprawl can be defined throughout a region as suburbanization. However, urban sprawl appears attendant to the rapid growth of urbanization in China.

2) Population density difference

There is a different criterion of population density between Western countries and China. What is termed “low-density” in China is still high density in American. The definition of low density in the United States is 200-3,500 people per square mile; high density means more than 3,500 population per square mile. In China, the average population density in built-up area is about 25000-38000 people per square mile, which is far more than what is called high density in the United States.

3) Vibrancy of the city centre

The common point offered much research by western scholars in sprawl often leads to the " weakening of the central area" and even decline, while urban development in China shows the coexistence of both a "vibrant center "and "sprawling land use". There are some reasons to explain this difference: first, China is currently in the stage of accelerated development of

industrialization and urbanization, especially in coastal cities, which has attracted many workers from rural areas; second, most salaried person people prefer to live in the city center because of the more convenient public transport system; third, there is a certain gap between development of the city center in China and western countries. In China, the city center's development needs and potential are rather large, so many cities regard their city centers as business centers necessary to maintain contact with other cities, regions and even other countries, resulting in more a prosperous city center. Due to different backgrounds of sprawl, the selected indicators of sprawl in China are also different. How to select suitable indicators of sprawl in China is a big challenge. As we know, measuring "urban sprawl" is a daunting task. A clear and unique distinction requires justified rules weighing several components and indicators. Among these components, land-use development, environmental aspects and economic perspectives have to be considered (Guenter Haag 2002). The GIS-based tool relies on the assumption that sprawl is a multi-dimensional phenomenon which can be measured with a multiple-indicator approach. (Siedentop and Fina 2010). In order to better reflect the nature of sprawl, three-dimensional indicators were considered based on the actual situation of urban sprawl in Jiangning, The different indicators are grouped into 3 categories: 1) Land use impact indicators; 2) Landscape pattern indicators; 3) Density indicators. These indicators cover the different dimensions of sprawl corresponding with environmental, social and economic impacts of land use change to measure the extents of urban sprawl. Figure 5.10 depicts multi-dimensional indicators for change extents of urban sprawl.

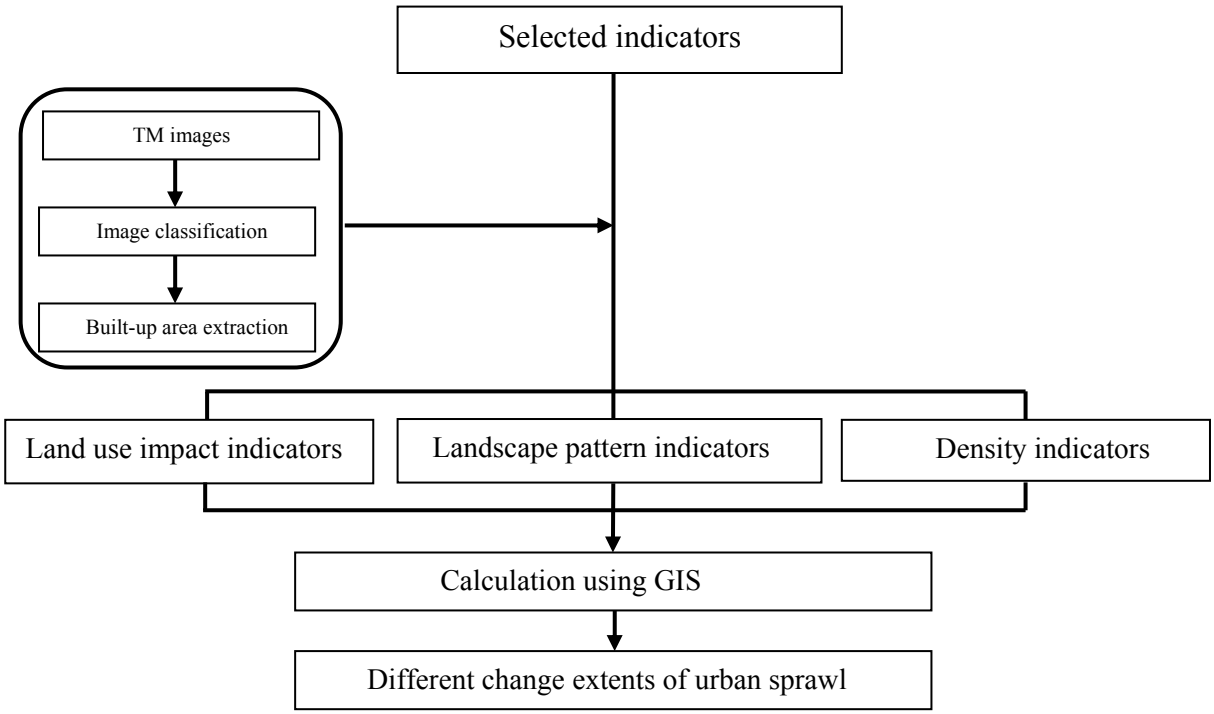


Figure 5.10 Multi-dimensional indicators for change extents of urban sprawl

In chapter 4, some characteristics of urban sprawl in Jiangning have been concluded. Based on these conclusions, the indicators ' measurement of urban sprawl is shown in Figure 5.11:

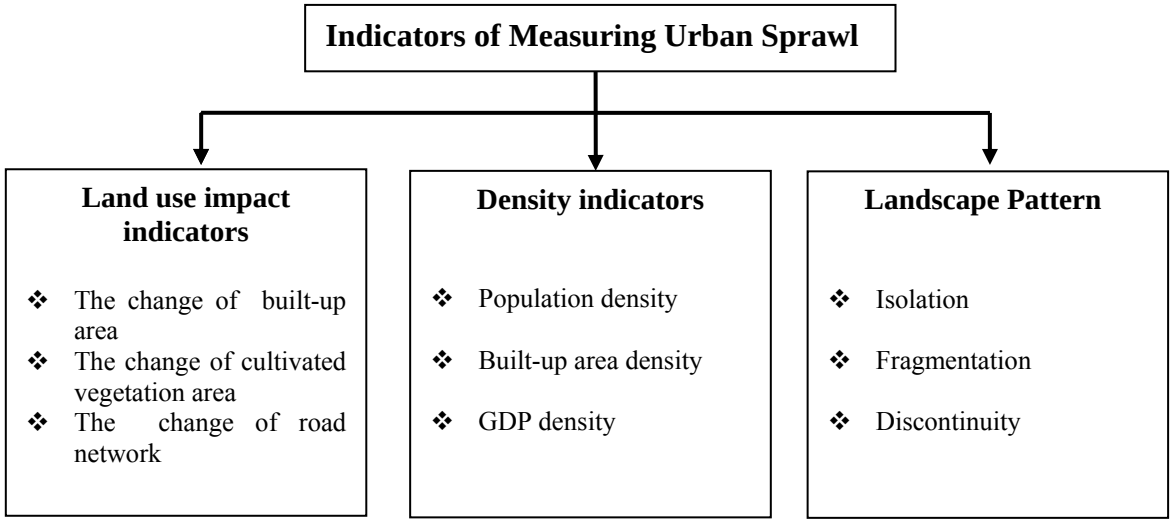


Figure 5.11 Indicators measurement of urban sprawl

5.3.1.1 Land use impact indicators

The rapid expansion of urban space brought about such a large turnover of high-quality farmland to be occupied that it resulted in a serious waste of land resources, and increased transport investment costs and commuting time. In order to illustrate more problematic overall trends of land use impacts attributable to urban sprawl, the land use impact indicator measures the degree to which new urban growth impacts important land resources. For this kind of indicator, some points should be considered:

- Areas of build-up that consume amounts of agricultural lands and forest lands are taken as sprawling.
- Areas of cultivated area that decreased significantly are the typical negative effects brought by urban sprawl.
- Road networks are indicators of human use. It requires more road network and consumes larger amounts of land because of sprawl.

The calculation of these indicators is shown as follows:

- The change of built-up area

The indicator of built-up area change measures the increase of built-up area created by new urban growth. The calculation of this indicator is:

$$BAC = \frac{\sum A_{di}}{\sum A_i} \qquad 5.3$$

Where:

BAC is Built-up Area Change

A_{di} is new urban growth in research area

A_i is the total area of research area

❖ The change of cultivated vegetation area

Areas of cultivated area that show significant decrease are the typical negative effects brought by urban sprawl. The indicator of cultivated vegetation area change measures the decrease of cultivated vegetation area due to sprawl. The calculation of this indicator is:

$$CVAC = \frac{\sum C_i}{\sum A_i} \qquad 5.4$$

Where:

CVAC is Cultivated Vegetation Area Change

C_i is the total cultivated vegetation area in research area

A_i is the total research area

❖ The change of road network

The indicator of road network change measures the increase of transport infrastructure area because of sprawl. The calculation of this indicator is:

$$RNC = \frac{\sum R_{di}}{\sum A_i} \qquad 5.5$$

Where:

RNC is Road Network Change

R_{di} is new road growth in research area

A_i is the total research area

5.3.1.2 Landscape pattern indicators

In order to determine the change in landscape caused by urban sprawl, the landscape pattern indicator represents a new analytical approach that could be especially appropriate for the identification and analysis of consequences of the ecological stressors due to sprawl. In chapter 4, three landscape metrics were used to analyze the change of built-up areas. For measuring the extent of urban sprawl. More metrics should be considered for this kind of indicator:

- Built-up area developed blindly causes the disorder of landscape functional differentiation, and significant fragmentation of the landscape.
- Isolation is related to the segmentation degree of urban land use - the larger the different types of land use area, the fewer the number of plots, indicating the lower urban land use segmentation and greater urban sprawl trends.
- This discontinuity is concerned with density only as a means of determining whether patches of growth occur at a significant distance from a previously existing built-up area.

The calculation of these indicators is shown as follows:

- Fragmentation

The indicator of fragmentation measures the degree of landscape fragmentation, reflecting the complexity of the landscape spatial structure. The calculation of this indicator is:

$$FRG = \frac{\sum n_i}{\sum A_i} \qquad 5.6$$

Where:

FRG is Fragmentation

n_i is The number of landscape patch i

A_i is the total area of landscape i

- Isolation

The indicator of isolation can be measured by the degree of contrast (i.e., the magnitude of differences in one or more attributes between adjacent patch types) between the focal habitat and neighboring patches. The calculation of this indicator is:

$$ISL = \frac{D_i}{\sum A_i} \qquad 5.7$$

Where:

ISL is Isolation

D_i is the distance index of landscape patch i

A_i is the total area of landscape i

- Discontinuity (leapfrog development)

The indicator of discontinuity can be measured by the patch distance to previous built-up area. The calculation of this indicator is:

$$DCT = \frac{O_i}{N_i} \qquad 5.8$$

Where:

DCT is discontinuity

O_i is the leapfrog distance for each new unit

N_i is number of new built-up area units

5.3.1.3 Density indicators

Density indicators are almost universally regarded as one of the essential components of sprawl, providing a measure of land consumption for new urban growth. For this kind of indicator, some points should be considered:

- Population density provides an opportunity to measure the efficiency of residential land use over time. It is determined by the amount of residential area per person and measures the extent to which the type of development is sprawling or compact (Terzi and Kaya 2008).
- Urban density can be accurately estimated for fully developed urban areas. The most reliable means of defining urban density is to measure the built-up area of cities.
- GDP density is a measure of economic activity by area. It is expressed as GDP per square kilometer and can be calculated by multiplying GDP per capita of an area by the population density of that area. Amongst other uses, it demonstrates the effects of geography on economy.

The calculation of these indicators is shown as follows:

- Population density

The population density can be measured by the number of people divided by the total area. The calculation of this indicator is:

$$PD = \frac{P_i}{\sum A_i} \qquad 5.9$$

Where:

PD is Population Density

P_i is the number of people

A_i is the total research area

- Built-up area density

The density of built-up areas can be measured by the population divided by the built-up area. The calculation of this indicator is:

$$BAD = \frac{P_i}{\sum B_i} \qquad 5.10$$

Where:

BAD is Built-up area Density

P_i is the number of people

B_i is the total area of built-up area

❖ GDP density

The GDP density can be measured by the value of GDP divided by the total area. The calculation of this indicator is:

$$GDPD = \frac{GDP_i}{\sum A_i} \qquad 5.11$$

Where:

GDPD is GDP density

GDP_i is the value of GDP

A_i is the total research area

The reliability of indicators should be considered. A reliability indicator is an evidential distinction that is linked probabilistically for a problem where performance is relatively strong or poor. In the study, the standard error is used to measure or estimate the standard deviation of the sampling distribution associated with the estimation method. The formula is:

$$\sigma = \sqrt{\frac{\varepsilon_1^2+\varepsilon_2^2+\cdots+\varepsilon_n^2}{n}} = \sqrt{\frac{\sum \varepsilon_i^2}{n}} \qquad 5.12$$

Where:

σ is standard error

$\varepsilon_{1,}\varepsilon_{2,} \ldots \ldots \ldots \varepsilon_n$ is error of n measured values.

Table 5.6 represents the reliability of variable estimates based on selected indicators for research area, which indicates that the standard errors of these indicators are low and means these indicators are reliable.

Table 5.6 The reliability of estimates based on selected indicators

Variables	standard error
The change of built-up area	0.017
The change of cultivated vegetation area(km^2)	0.003
The change of road network (m^2)	0.001
Fragmentation	0.014
Isolation	0.004
Discontinuity (leapfrog development)	0.008
Population density (person/km^2)	0.021
Built-up area density(person/ km^2)	0.015
GDP density(million Yuan/ km^2)	0.03

5.3.2 The distinct extents of urban sprawl

It is difficult to say which city will develop sprawl, but relatively easy to say that city is more or less sprawling than another or that a city is becoming more sprawling over time. In the previous section, each indicator provides a single-value characterization of sprawl, which can only measure more sprawling or less sprawling in Jiangning. It is important to tease out potential variations of sprawl in different periods, which are performed on all the indicators to distinguish the extent of sprawl in different periods. In order to compare levels of sprawl among different periods, a method of weighting all 9 measurement indicators is suggested. First, some thematic maps should be used: 1) raster maps of land use; 2) vector maps of built-up area boundaries; 3) vector maps of leapfrog area distribution. Second, the calculation and analysis can be carried out in ARCGIS 9.0 and FRAGSTATS 3.3 according to measurement indicators, and then the score of each period, which indicates the extent of urban sprawl, is attained.

1) Standardization of indicators

Different data types have different dimensions and numerical ranges, so it is very important to standardize the data. The method of standard deviation is used to carry out standardization, which is calculated as:

$$X'_{ij} = \frac{X_{ij} - \overline{X_i}}{\sigma_i} \qquad 5.12$$

Where:

X_{ij} is actual value

$\overline{X_1}$ is average value of indicator i

σ_i is standard deviation

2) The method of arithmetical average is used to calculate the composite score of urban sprawl in different periods. In order to more directly show the extent of urban sprawl, the comprehensive scores of different periods are converted to percentile scores, which is calculated as:

$$G_i = \frac{S_i - S_{min}}{S_{max} - S_{min}} \times 40 + 60 \qquad 5.13$$

Based on these two methods, the different extents of sprawl in different period can be calculated, shown in Table 5.7.

Table 5.7 The different extents of sprawl in different period

Indicators	Variables	1979-1988	1988-1997	1997-2003
Land use impact indicators	The change of built-up area	55.28	69	29.73
	The change of cultivated vegetation area (km^2)	13.31	32.14	48.76
	The change of road network (m^2)	30.25	60.24	110.66
Landscape pattern indicators	Fragmentation	55.95	107.24	187.73
	Isolation	21.71	39.56	2.56
	Discontinuity (leapfrog development)	0.1152	0.1344	0.1436
Density indicators	Population density (person/km^2)	11.1	33.5	88.9
	Built-up area density(person/ km^2)	16	20.3	21.3
	GDP density(million Yuan/ km^2)	0.00103	0.003	0.006
Composite score		34	52	76

From Table 5.7, some conclusions can be achieved:

1) Large-scale industrial parks and some low-density residential areas were developed in Jiangning because old city reconstruction, housing shortages, high rent prices, the rising cost of living service and a large number of relocations of secondary industries in the city centre. Because of this, the city has typical urban sprawl characteristics. The extent of urban sprawl is intensifying. The shape and complexity of built-up area, fragmentation of built-up area and agricultural land, and discontinuous development were more significant.

2) According to a composite score result, during 1979-1988, the extent of urban sprawl was relatively low. During 1988-1997, the extent of urban sprawl experienced increased from a

state of low sprawl to a state of medium sprawl. During 1997-2003, the extent of urban sprawl experienced went from medium sprawl to high sprawl.

5.4 Summary

The quantification and analysis of urban sprawl by means of the built-up area using remote sensing and demographic data indicate a significant growth and expansion of the built-up areas from 1979 to 2003, depicting a serious characteristic of urban sprawl. The dynamic component of sprawl has to be considered. Therefore, time-series analysis will be among the applied tools. Landsat MSS/TM data is conducive to analysis of the timing change of urban sprawl. The result indicates that the trend of urban sprawl in Jiangning is significant. From 1979 to 1988, the phenomenon of disorder and scattered construction was obvious in Jiangning; from 1988 to 1997, sprawl in Jiangning is more significant in the process of suburbanization. Leapfrog development is significant; from 1997 to 2003, the land in Jiangning became fragmented, resulting in a broken landscape.

6 Investigation into the causes and impacts of urban sprawl

6.1 Driving forces of urban sprawl

As concluded from EEA in 2006:" urban sprawl has an impact on almost all dimensions of our society. Sustainable urban planning strategies to combat urban sprawl can only be effectively specified when the forces driving urban sprawl are fully understood". To fully understand what sprawl is, it is necessary to know what its causes are. The causes of urban sprawl continue to be analyzed by many scholars. Generally speaking, the main causes of sprawl are poor land policies, population growth, rise in household income, subsidization of infrastructure investments and social problems in central cities.

Urban sprawl in Western countries can be regarded as the result of the development of a spontaneous market under the double guidance of long-term economic prosperity and the automobile revolution. However, urban sprawl in China is the result of economy transformation, indistinct property rights and so on. Zhang Tingwei (2001) proposed that three forces, including government force, market force and community force, were the dynamic mechanisms of Chinese urban spatial structure in 1990's. Deng et al. (2005) discussed that urban sprawl has been driven largely by demographic change, social and economic development, and the transition of land use regulation.

The driving forces of urban sprawl in Jiangning were presented in this dissertation. They can be subdivided into two major aspects: spatial-temporal parameters and social-economic-demographic factors. Spatial-temporal parameters involve discussing spatial pattern of land use and temporal cumulative effects. Social-economic-demographic factors focus on some key driving forces such as population growth and social-economic development. The framework is shown in Figure 6.1.

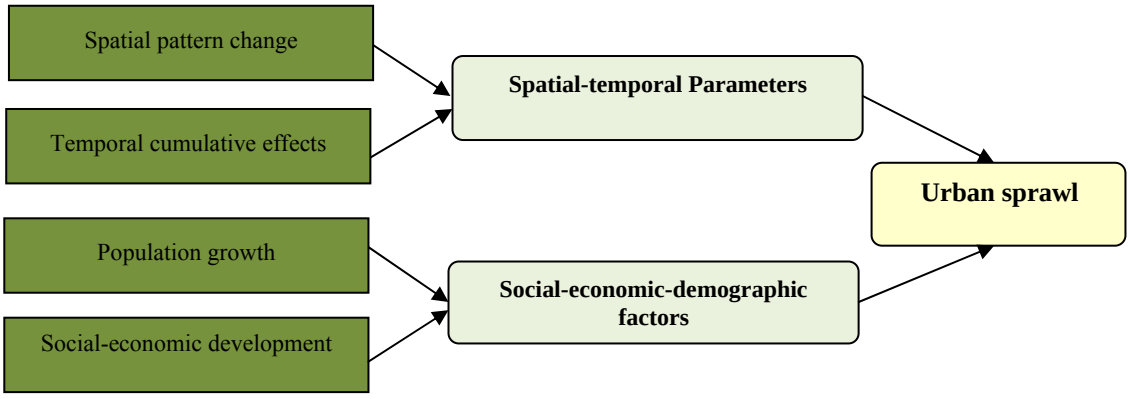


Figure 6.1 The framework of main driving forces

6.1.1 Spatial-temporal parameters

6.1.1.1 Spatial pattern of land-use change

As Deng et al. stated in their 2004 paper:" The inefficient spatial patterns of urban expansion, as demonstrated by the paradox of development zones and semi-urbanized villages, do point to the true meaning of 'urban sprawl'—inefficiency in spatial resource allocation on urban fringe. "

Since 1988, Nanjing has been experiencing urban spatial extension. Some construction projects scattered in the outskirts of the city. Rapid development in Nanjing is attributed to low price and regional transport in Jiangning, offering huge attraction to developers coming to exploit the arable land resources. As urban fringe area, urban space is enlarged because of the emergence of new constructions in Jiangning. Massive land has been exploited for economic development and infrastructure development. In the process of urban fringe land development, unreasonable land use and land consumption made spatial pattern of land-use change into disorder and decentralization, resulting in urban sprawl, shown in Figure 6.2.

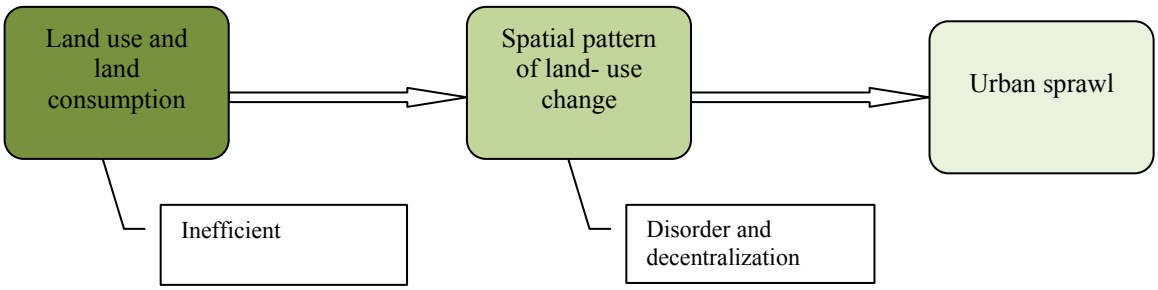


Figure 6.2 The spatial reason of urban sprawl

Taking Dongshan town as an example, it is a central area in Jiangning, where Economic and Technological Development Zone, University City and an exclusive residential district have been continuing to expand. At the same time, small towns have been greatly expanding to promote an omnibearing spread of space in rural areas with the rapid development of township enterprises. In addition, jobs will be provided by investors to the people affected by the land development. Therefore, urban fringe land development inevitably combines with rural industrialization and through the provision of employment it consequently reduces urban-rural disparities.

6.1.1.2 Temporal cumulative effects

Cities grow with or without planning, and develop landscape characteristics that persist through time, determining how they will function. Throughout the whole process, temporal

cumulative effects play an important role. Unreasonable land use and land consumption to some extent are caused by unreasonable land planning policy. As urban fringe, the land planning policy of Nanjing has direct impact on the land use and land consumption in Jiangning. Figure 6.3 indicates the temporal effect between land planning policy and land use and land consumption.

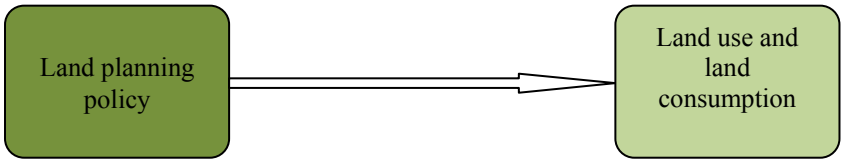


Figure 6.3 The temporal effect between land planning policy and land use and land consumption

T is time series

Based on the above analysis, there are four main reasons caused by land planning policy to explain sprawl in Jiangning:

1) Administrative division adjustment

For China, the rapid transformation of the economic system does not match the relative slow administrative management system. Administrative division adjustment has become the most effective way to promote the urbanization process because administrative division is the motivation and basis for development of local economy. In the Yangtze River region, the major cities have adjusted to administrative boundaries of urban areas. The most typical approach is to the annexation of surrounding county. Through transforming county into urban districts, the expansion of urban jurisdictions can be achieved. From the perspective of urban spatial development, the impact of this policy on urban sprawl is extremely significant. First of all, city centre has more space for development due to the expansion of the geographical range; second, the increase of hinterland will enhance the confidence of local government to further external expansion, resulting in inefficient use of land and drop of arable land, especially at urban fringe area. Jiangning County became Jiangning District when administrative division adjustment was carried out in 2000. On the one hand, this adjustment greatly promoted the re-layout of industry and re-construction of urban space structure; On the other hand, this change created problems of inefficient land use and the sharp reduction of arable land.

2) Land requisition system defects

In China, the consequences of urban sprawl are mainly inefficient development and use of land which results in a series of environmental problems. The reason is mainly the Chinese enclosure movement caused by land requisition system defects, which is "land-oriented" rather than "car-oriented" as in western countries. Land supply system has become more and more market-oriented with the economic development, leading to a big profit differential between low-cost of land requisition and high-yield land supply, which formed the basis of economic growth mode of land. For example, in Jiangsu province, the total fee for land requisition compensation for cultivated land is about 50,000-100,000 RMB per mu[13]. However, when agricultural land is transferred into construction land after land requisition, the selling price by government varied from hundreds of thousands to millions per mu. Therefore, the great benefits further encouraged the enclosure trend of local government and developers, intensifying the disorder expansion and shrinking the amount of cultivated land.

The level of agricultural land rent dropped from C_1 to C_2 due to instability in property rights of the agricultural land and lack of system guarantees; the Bid rent curve of urban industrial sectors shifted from L_1 to L_2 caused by distorted behaviors of government and developers, which formed a new growth boundary S2, resulting in excessive expansion and waste of land resources, shown in Figure 6.5.

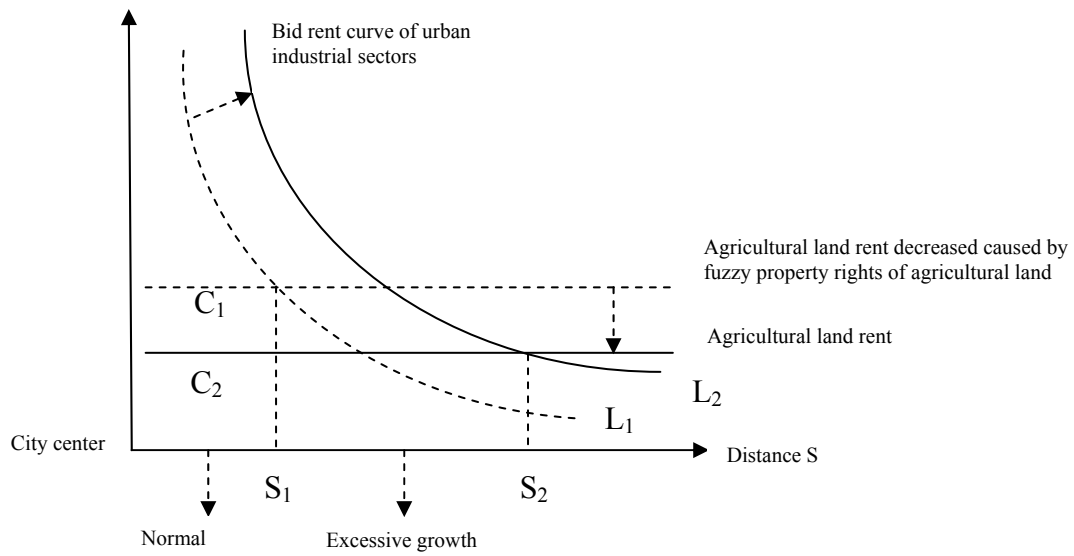


Figure 6.4 Land requisition system defect and urban sprawl (adapted from Feng Ke, 2010)

3) Industrialization policy

In China, the growing industrial zones within the city are being moved out of the city to the urban fringe areas because cheap building plot prices play an important role on the decision to

[13] **1 mu=666.7 m^2**

move industrial zoning out of the city. If urban sprawl is inefficient excess to the natural expansion of cities in the West, Chinese-style sprawl is the unintended consequence of political manipulation of land development on the urban fringe.

This situation could arguably be better understood as "industrial land-oriented sprawl" from the perspectives of scale. Ju (1998) concluded that the economic profitability of agricultural farming is in general much lower than that of industrial or other tertiary sectors under the pricing system. As a result, there is no economic motivation to maintain agricultural land. The amount of industrial land can promote urban development, which is under the control of zoning policies. The Nanjing Municipal Planning Bureau (NMPB), one of the agencies, is responsible for supervising urban fringe land development through examining and approving projects. It should provide favorable conditions to promote rural industrial development. From this perspective, NMPB is more likely to be less rigid in the enforcement of policies relating to urban land use zoning to favor urban fringe land development. The tight control over free-standing industrial development may be loosened for rural industrialization as well as the zoning policies previously laid down will be changed under such a policy. Moreover, legislation relating to the size of industrial land will also be less rigid.

Accordingly, industrialization policies were developed and the industrial sector has rapidly increased even though development zones are probably one of the biggest sources of wasted farmland. The establishment of industrial and economic zones in Jiangning is provided in Table 6.1 and Figure 6.5.

Table 6.1 Establishment of industrial and economic zones in Jiangning (adapt from Ju, 1998)

Item	Land Occupation(mu)
High Technic Zone	3000
Korean Ind. Zone	>1000
Motorbike Town	1000-2000
Lusheng Ind. Zone	4000-5000

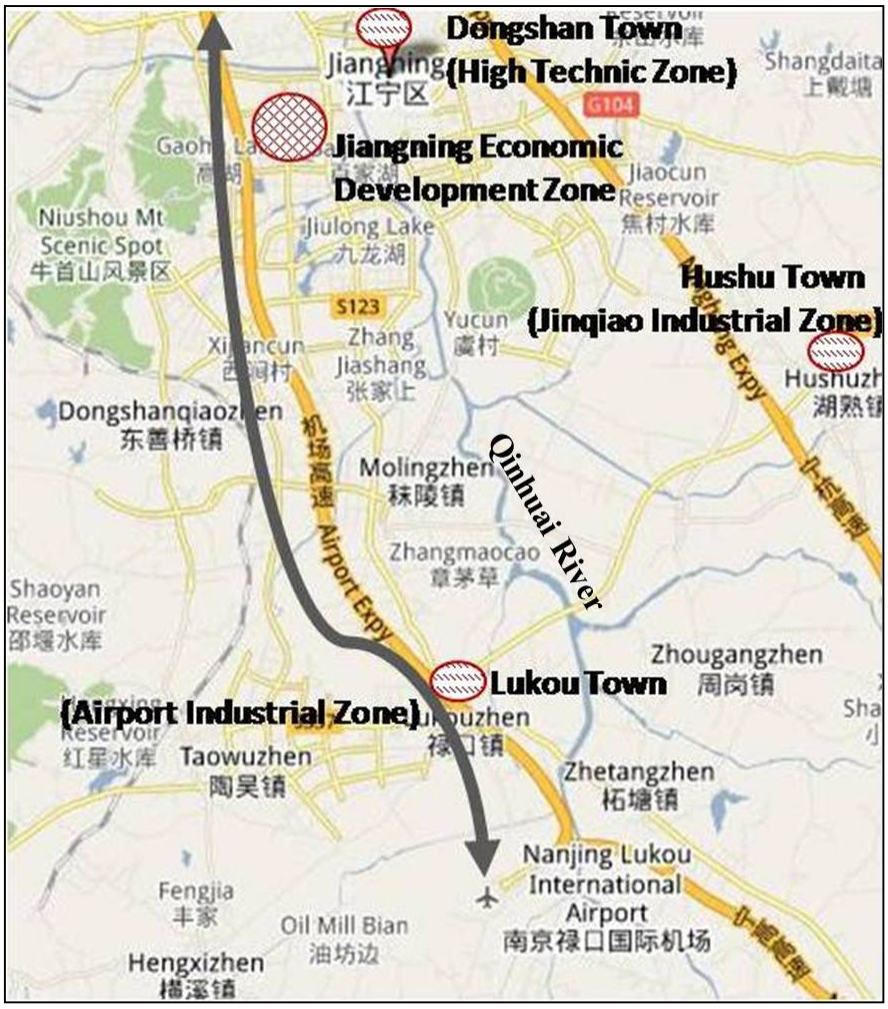


Figure 6.5 Economic and Industrial Zones in Jiangning District

❖ Transformation of industrial structure

Two phases of the process of urbanization in Jiangning are distinct: 1) Before 90's, it was the agricultural suburb despite entering the initial period of industrialization; 2) After 90's, the economic structure began to increasingly diversify. A new industrial area is now the main characteristic of Jiangning, instead of the agriculture suburbs. Industrialization is more and more significant which implies industrial development is the one of the most important reasons for urbanization, shown in Table 6.2:

Table 6.2 Industrialization in Jiangning (adapt from Zhu *et al.*, 2003)

	Year			Early period of industrialization	Intermediate period of industrialization
	1988	1992	1999	Annual rate of increase (%)	Annual rate of increase (%)
gross industrial output value(billion Yuan)	0.544	4.005	23.732	28.34	34.25
non-agriculture labor(ten thousand)	16.0	21.99	26.8	4.05	3.37

The involvement of private ownership, private entrepreneurship and foreign investments is significant because of the market-led reforms and the changing status of urban fringe land property right. It further involves the county governments in the urban fringe land use policy-making. Such involvement of new agencies has its effects on urban fringe land development. The effects mainly presented that a large amount of arable lands are needed. Furthermore, the first choice of private and foreign investment is urban fringe because of its attractive location.

Yao (2004) presented top priority of development shall continue to be given to tertiary industry according to the compendium of the 9th Five Year Plan of the Jiangning County (1996-2000). Especially for some tertiary industries such as specialized wholesale markets, transportation, tourism and retail enterprises, the geographical advantage of Jiangning is to put to good use. Comparing industrial structure in 1997 and 2003, the proportion of tertiary industry was rapidly increasing, shown in Table 6.3. As urban fringe, the development of tertiary industry benefited from its location. The real estate industry has become an important part to drive the development of tertiary industry and the most active part of economic growth. In addition, the information industry and other types of professional market developed rapidly because of the development of tertiary industry. At present, economic growth promoted the linear growth of development zones, industrial parks and transportation infrastructure. More lands should be invested when economy geared toward continuing growth, which can be regarded as an inner driving force of urban sprawl.

Table 6.3 Transformation of industrial structure in Jiangning

Year	GDP (billion Yuan)	Primary industry (billion Yuan)	Secondary industry (billion Yuan)	Tertiary industry (billion Yuan)
1997	75.84	11.72	47.66	16.45
2003	168.3	15.1	97.6	55.6

Data source: statistics of Jiangning

❖ Economic growth of development zones

In the early 90s, Chinese local governments set up a large number of development zones that are often large area and discontinuous from cities. Especially when considering the modes mass transportation in China, they can be characterized as leapfrog development at the macro-level. (Deng and Huang 2003). Although the first wave of development zones subsided in

mid-1990s, they continue to boom because of government initiative for economic development.

The Economic and Technology Development Zone was established in 1992 in Jiangning. In the process of urbanization, development zones have significant impact on economic growth. The purpose of developing economic zones is to open up new land for industrial production, particularly for high-tech industries. Land development within the zone is mainly for construction of luxurious hotels, villas, government offices, schools and universities. The area of economic and technology development zone is 25 km^2, economically active population is about 30,000, but financial revenue of economic and technology development zone account for 45.1% of total financial revenue of Jiangning District. However, a large amount of land in urban fringe were occupied and sold due to large-scale development zones. There are more "Development Zones", "Industrial Parks" and "University City", more construction lands are demanded.

4) The weakening of land use planning implement

In the process of planning of urban fringe land use, relevant laws and regulations in effect cannot be effectively put into force. Although power has been conferred by the central government upon local governments to manage affairs within their territories for the promotion of sustainable development, local governments often fail to ensure the implementation of these planning policies relating to urban fringe land use. Urban fringe land use governance in China is a bargaining process because municipal governments not only have been confronted over the land use in urban fringe but also has to coordinate the conflicts arising in the social conflicts in the governance of urban fringe land use. Yao (2004) indicated that the functions of land use planning institutions on urban fringe land use are paradoxical when they take the coordinating role in the policy conflicts and implementation of planning policies.

The role of NMPB is to favor the urban land market for the reinforcement of existing policies of rural development. Policies relating to zoning cannot be successfully implemented before making adjustments. The reason for the policy adjustment is that NMPB is working together with developers and rural agencies. NMPB fails to enforce land use regulations or policy framework for the operation of urban fringe land market or enhance the efficiency of urban fringe land use because the rural agency have a stake in its interests in urban fringe land

development projects. In addition, rural government and farmers try to bargain with the municipal planning agencies when municipal government prepares to control land use in urban fringe. It is obvious that the municipal governments have to protect the land resources and promote rural development at the same time. In order to attain the above two goals, land use policies originally laid down always have to be changed when there are conflicts between the policy of promoting rural development and control of the land use.

In all, urban sprawl in Western countries is mainly the result of spontaneous market forces in the market economy and the product of decisions by developers, businesses, individuals and government for their own interest. However, urban sprawl in China is difficult to explain reasonably using theory of urban expansion based on Western market-oriented land use. According to above analysis, urban sprawl in China has distinct "Chinese characteristics", which is the land system-oriented. Urban sprawl caused by frequency of administrative divisions' adjustment, low-cost land acquisition and disorder construction of the development zone presented "government failure". That means the role of government is limited in the process of market-led reform. Yao (2004) stated that:"the central governments often criticize municipal officials for failing to discharge their responsibility in preserving arable land. The rural communities often demand the municipal governments to promote rural economies. Developers complain that municipal governments are too bureaucratic in urban fringe land development". In other words, on the one hand, land use planning institutions are established to protect the interests of public through avoiding excess development in urban fringe. On the other hand, the pursuit of a market economy which promotes urban fringe development often clashes with the public interest.

6.1.2 Socio-economic-demographic factors

6.1.2.1 Demographic factors

Sprawling land use transformation patterns have close relationship with rapid population growth. In this part, two aspects were discussed as followed:

(1) Population size

(2) Population composition

❖ Population size

Change in land use can produce a change in quality of life for those living within the landscape. Population growth is the most significant factor affecting urban sprawl. As population size increases, so the amount of land was required for residential and commercial needs. The total population has been growing since 1979, shown in Figure 6.6. The demands for people have been changed due to living standards improvement, which brought the demand for housing. It is continuing to heat up that a number of agricultural lands have been transformed into construction land because real estate development.

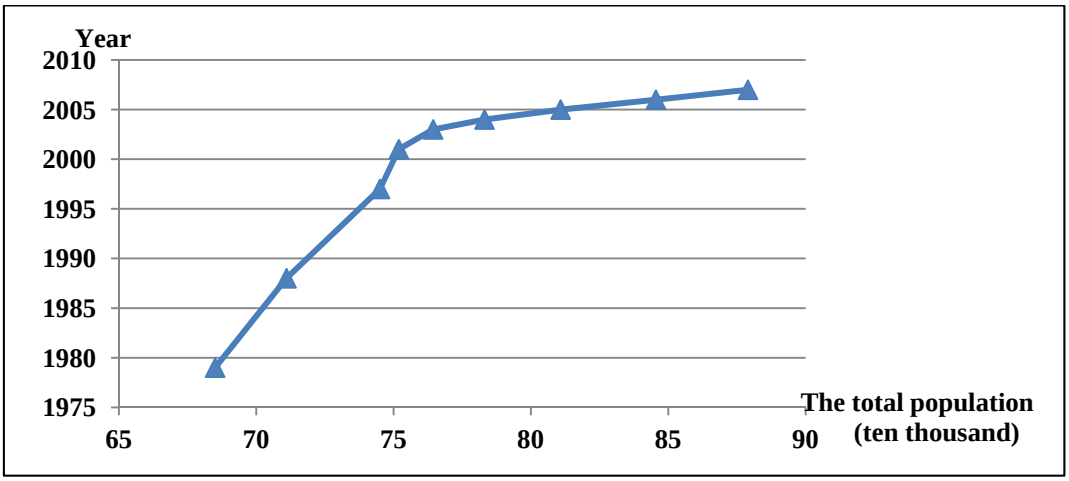


Figure 6.6 Population growth in Jiangning

❖ Population composition

It can be argued that population composition has affected the level of urbanization and has an impact on urban sprawl. Table 6.4 indicates the population composition. Accretion of non-agricultural population is 319,000 from 1979 to 2003, an increase of 95.5%. Certainly, the increase in non-agricultural population resulted in the demand for land use. Agricultural lands around were encroached rapidly in order to meet the requirements, which is the one of reasons of urban sprawl.

Table 6.4 Population composition in Jiangning

Year	Non-agricultural population	Agricultural population
1979	15,000	670,000
1988	56,000	655,000
1997	108,000	637,000
2003	334,000	430,000

According to conclusions from Bekele in his 2005 paper, there are three causes for increases in a country's urban population: 1) the natural growth rate; 2) the re-classification of rural settlements as they grow; 3) rural-urban migration. Migration was thought to be a process in which surplus labor was gradually withdrawn from the rural sector to provide needed manpower for industrial growth process. The high level of development zones brought a large number of non-agricultural employment opportunities, which is attractive for people who prefer to live in rural areas. Because of this, the real estate market in Jiangning is growing vigorously, leading to urban space expansion.

6.1.2.2 Socio-economic factors

The demand for urban sprawl is largely determined by both the facts of demographic and economic dynamics. It can be seen that the real reasons of the urban sprawl are dwelling dispersion and development of the economical functions. Global economic changes related to the development of the information and communication technologies effect the location dispersion of the population and the employment and causes urban sprawl (EEA 2006a). Sprawl in China is more a result of changing internal economic forces that brought previous urban economic activities into peripheral areas. Some socio-economic factors can help understand why sprawl appeared in Jiangning, mainly including land prices and housing preference.

- Land price

Uneven land reform is the key to understand Chinese-style urban sprawl; it is also the necessary condition to the paradox posed by development zones and semi-urbanized villages. With omnipresent political power and extremely cheap compensation to peasants, local governments can do almost whatever they want in converting rural land to urban land. The mighty power of eminent domain is no longer constrained by economic cost—market price of land. Furthermore, the big gap between urban land price which is determined by the market and rural land compensation, which is artificially low, generates great motivation for local government to develop urban land.

Land price is one of the most important factors to explain urban sprawl. According to "The Regulation of the People's Republic of China on Arable Land Occupation Tax" promulgated by the State Council in April 1987, arable land occupation tax should be levied on approved urban fringe land development in Nanjing (Tang 1992; Zhang 1997). Land occupation tax

becomes an important component of arable land occupation. Land occupation tax varies according to the arable land per capita, shown in Table 6.5. Given the artificially cheap price of rural land, local governments often enclose the best farmland for development zones in order to save on other costs. Almost 'free' rural land also inflates their desire, which results in more land expropriated than necessary.

Table 6.5 Land Occupation Tax in Nanjing

In Case of Arable Land per villager (*mu*)	Land Occupation Tax(yuan /*mu*)
<1	6600.0
1-2	5828.0
2-3	4329.0
>3	3330.0

Source: Extracted from the Nanjing Municipal Land Resources Bureau (1999c)

Absent the right to transfer or develop the land, the peasants can only build illegal shacks or lease their extra rooms to accommodate people like migrant workers and young urban couples. Inequality between the city and the countryside is not reduced. In this sense, peasants' rights over their land represent more efficient urban development and the demand for housing from migrants and urban residents. The result of their severely restricted rights is under-developed urban infrastructure, low density and leapfrogging of semi urbanized-villages.

❖ Housing preference

When urban development is sprawling gradually from the centre to the periphery, it fuses the surrounding towns and/or villages (i.e. rural-urban transformation), which in turn increases the area of urban sprawl in a short time. The house price and income are significant reasons for moving. Improving housing conditions and increasing the housing space are main reasons for people to want to move to more rural areas outside cities. This may partly be because housing prices are lower outside the urban areas, and that families can fulfil their desire for a bigger house than they would be able to afford in the city, as well as access to gardens or green areas in relation to housing. People who move to suburban areas want a change from household size and small housing units in the city. In addition, a lot of problems which exist in the city at present, such as less or a lack of green spaces, sports and playgrounds, as well as more expensive homes with less floor space to live well. There is a tendency that established couples move out of the inner city to more rural areas outside of urban areas, a tendency that is especially important for younger families with children. In "University City" in Jiangning,

people who work in university really want to live near the university because of transportation opportunities related to time, transport options and cost. An additional aspect associated with this is that people are able to settle in places that provide access to the positive aspects related to both the city and rural areas. From Table 6.6, the output value of construction and floor space under construction greatly increased.

Table 6.6 Output value of construction in Jiangning

Year	Output value of construction(billion Yuan)	Floor space under construction (m^2)
1997	1	1,240,000
2004	7.85	13,460,000

Data source: statistics of Jiangning

6.2 Impacts of urban sprawl

6.2.1 Model of assessing impact of urban sprawl

How to reflect the interconnection of environmental and socio-economic impacts caused by urban sprawl is still a subject for debate. Many scholars proposed their models to assess the impact of urban sprawl.

Kahn (1999) used economic models to address the impacts of sprawl from another angle: he attempts to measure the environmental damage associated with dispersion of development as represented by increases in automobile miles driven, home energy consumption, and land consumption; Hasser and Nuissl (2007) applied the conceptual framework of driving forces, pressure, state, impact and response (DPSIR-concept) to assess the impact of urban sprawl on water balance and explored the repercussions of this impact upon the causation of and policies on urban sprawl. Their study showed that the environmental impact of sprawl elicits only indirect repercussions in society; Koen et al. (2008) investigated the impact of uncontrolled urban growth ('sprawl') on air pollution and associated population exposure by means of a coupled modeling system dealing with land use changes, traffic, meteorology, and atmospheric dispersion and chemistry.

Sun and Cai (2008) explored environmental consequences of urbanization; long-term runoff and NPS pollution were assessed in Beijing, P.R.China. The assessment was based on land-use types, soil hydrology, and long term precipitation data. They used the environmental impact model L-THIA. The outcomes indicated that the area likely would be subjected to

impacts from urbanization on runoff and some types of NPS pollution. Urban sprawl will increase runoff volume considerably and significantly increase losses of COD and certain heavy metals such as Pb, Zn in runoff. The results of this study have significant implications for urban planning and decision making efforts to protect and remediate water and habitat quality in the Beijing area; Miriam and Albert (2010) examined the impact of urban sprawl, a phenomenon of particular interest in Spain, which is currently experiencing this process of rapid, low-density urban expansion. They discussed many adverse consequences which are attributed to urban sprawl though they were concerned primarily with the rising costs of providing local public services. They specified the empirical model including the cost model and the demand model used in analyzing the determinants of local public spending. The results indicated that low-density development patterns lead to greater provision costs of local public services; Chiara M. Travisi et al. (2010) analyzed empirically the intricate relationship between urban sprawl and commuting. Their modeling experiment highlights the effect of sprawl at the commune level, while taking into account the variability of communes across geographical location and level of polycentrism. Causal relationships between spatial developments and explanatory factors related to changes in urban density are analyzed using multivariate cross-section regression analysis and Causal Path Analysis (CPA).

6.2.1.1 The construction of the Cause-Impact model

The OECD (1993) proposed the Pressure-State-Response (PSR) model, which is based on a concept of causality: human activities exert pressures on the environment and change its quality and the quantity of natural resources (the "state" box). Society responds to these changes through environmental, general economic and sectoral policies (the "societal response"). The PSR framework tends to suggest linear relationships in the human activity-environment interaction, which divides indicators in three categories. PSR model can supply good background for the construction of Cause-Impact model (CI model).

In this dissertation, the CI model was put forward to obtain a deeper understanding of causes and impacts and help assess the impacts of urban sprawl concerning interrelationships between urban sprawl and environmental, socio-economic issues.
In more detail, the principal objectives of this model:

- An analysis of model drivers
- An analysis of land use change

- An assessment of impacts of urban sprawl on environment, society and economy

Figure 6.7 is concept of CI model.

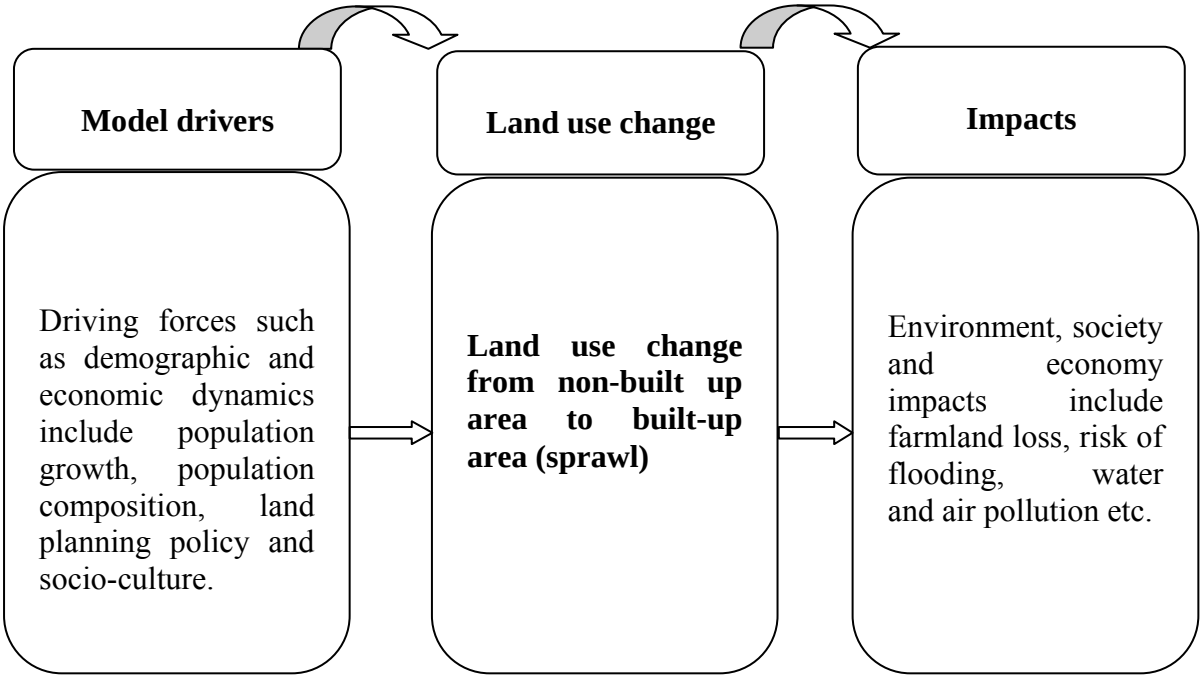


Figure 6.7 Cause-Impact model of urban sprawl

6.2.1.2 Model drivers

The fundamental CI model to capturing land use transformation dynamics begins with model drivers. Model drivers are considered driving forces, which contribute to urban land use transformation decisions. They also describe land use transformation probabilities, shown in Figure 6.8. In this figure, the inter relation between the different factors can be clearly presented. There are four transverse blocks including population, economy, planning policy and social culture. The small rectangles indicate the driving factors in each of these blocks. Some part of them is linked by arrows representing the relationship between them. For urbanization, the main factor is population composition and transformation of industrial structure. Meanwhile, transformation of industrial structure causes the change of population composition as well as the construction of development zones. Besides the transformation of industrial structure, land price is also an important influencing factor for the construction of development zones. Population is growing rapidly because of urbanization, which leads to real estate development. Moreover, real estate development has an impact on the characteristics of residential areas. There are two longitudinal blocks which indicate development situation and development pressure for land. Both of them are based on socio-economic needs, which directly result in the urban form change.

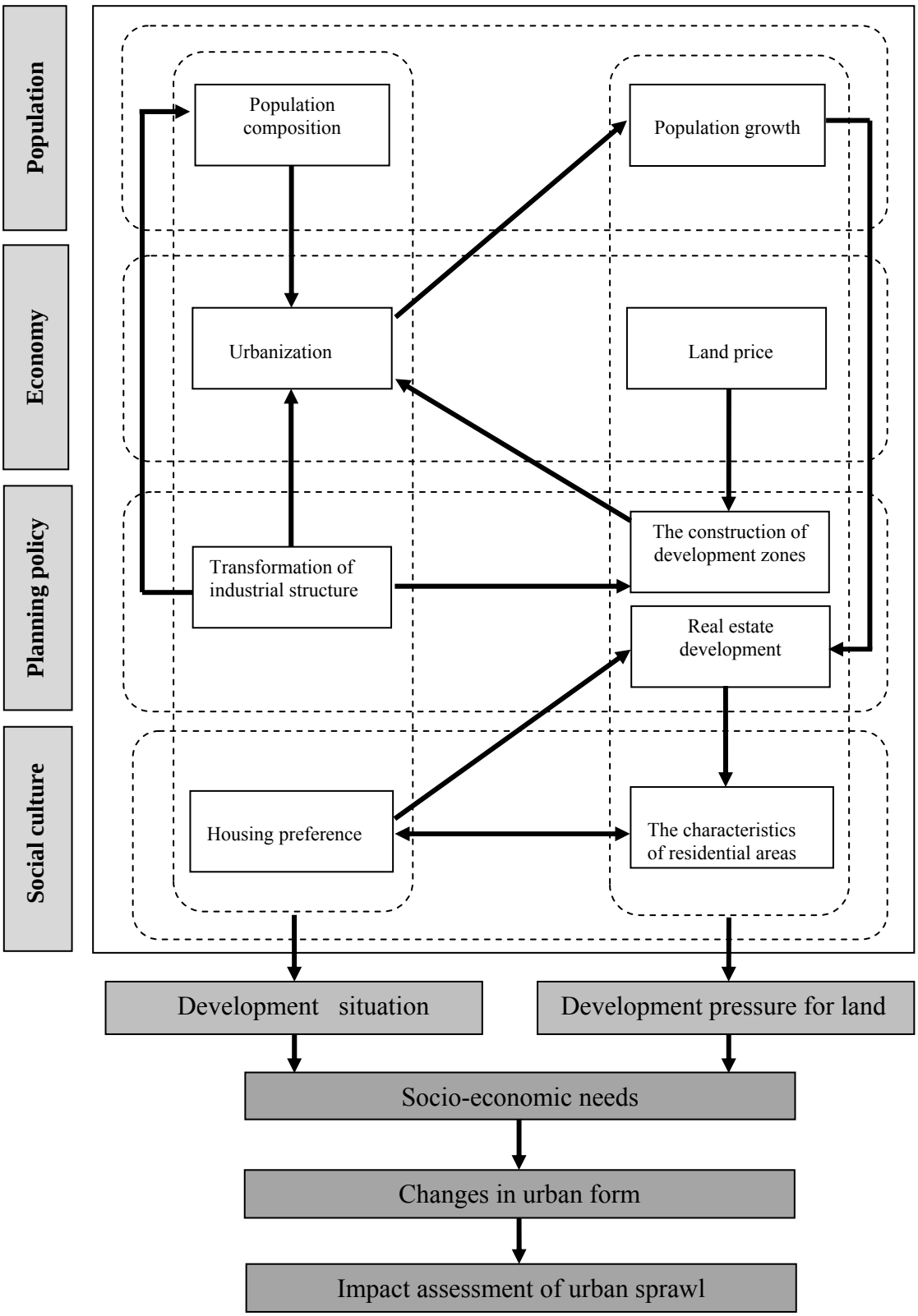


Figure 6.8 Model drivers of Cause-Impact model

6.2.2 Impact assessment of sprawl

The alleged negative consequences of sprawl, environmentally, economically and socially, are usually captured under the term 'Costs of Sprawl'. In reality, attempts to wrestle sprawl to the ground by its critics have resulted in more research into the negative consequences of sprawl.

(Mills 1981; Peiser 1989; Ewing 1994 1997; Gordon et al. 1997; Burchell et al. 1998; Brueckner 2000; Razin et al. 2000; Johnson 2001; Chin 2002; Allen et al. 2003; Hasse 2003; Carruthers et al. 2003; Bekele 2005; Eryilmaz et al. 2008; Miriam and Albert 2010).

With the movement from the inner city to the suburbs, sprawl causes a decline in the local revenues in the inner city while service requirements must be maintained or even improved (McKee, *et al*. 1972). The disappearance of the inhabitants and the fiscal imbalance leads to under-utilisation and the deterioration of the inner city and attendant infrastructure (Harvey *et al*. 1965). Sprawl is usually described by its critics as a network city. This implies more intense road construction culminating in high land consumption for roads (Litman 1997). Disputably, sprawl has several negative impacts on urban travel patterns (Torrens, *et al*. 2000).

6.2.2.1 Environmental impacts of urban sprawl

The impacts of urban sprawl on the environment can be divided into those that pose immediate human risk as opposed to those for which the associated human risk will not be fully known for years. These risks can also be divided into those that primarily affect the aesthetic appeal of an area as opposed to those that affect the viability of ecosystems (Johnson 2001). Sprawl has a considerable impact on ecosystems and other environmental resources (Barnes 2001). It is alleged to be associated with loss of environmentally fragile lands, reduced regional open spaces, increased air pollution, higher energy consumption and decreased aesthetic appeal of landscape (Margules, *et al.* 1992; Burchell, *et al.* 1998). Urban sprawl not only degrades environmental resources such as water quality, air quality (Centre for Watershed Protection 1995; Benfield, *et al*. 1999; Livingston, *et al*. 2003), but also limits or eliminates accessibility to natural resources such as agricultural lands, water etc. (Adelmann 1998; Barnes 2001; Hasse 2001).

In Jiangning, the serious consequence of the excessive growth of the built-up areas as seen from the classified images is the smothering of agricultural and sensitive lands. Coupled with that is the pollution and disappearance of water bodies and wetlands and risk of flooding. Other costs such as increasing air pollution, rising expenditure on transportation and rising motor accidents which come with sprawl are prevalent. The rate of growth in the built-up areas there is quite alarming in order to mitigate the negative effects of urban sprawl. The excessive expansion imposes costs on development environmentally, economically and socially. The costs of urban sprawl are showed in Figure 6.9.

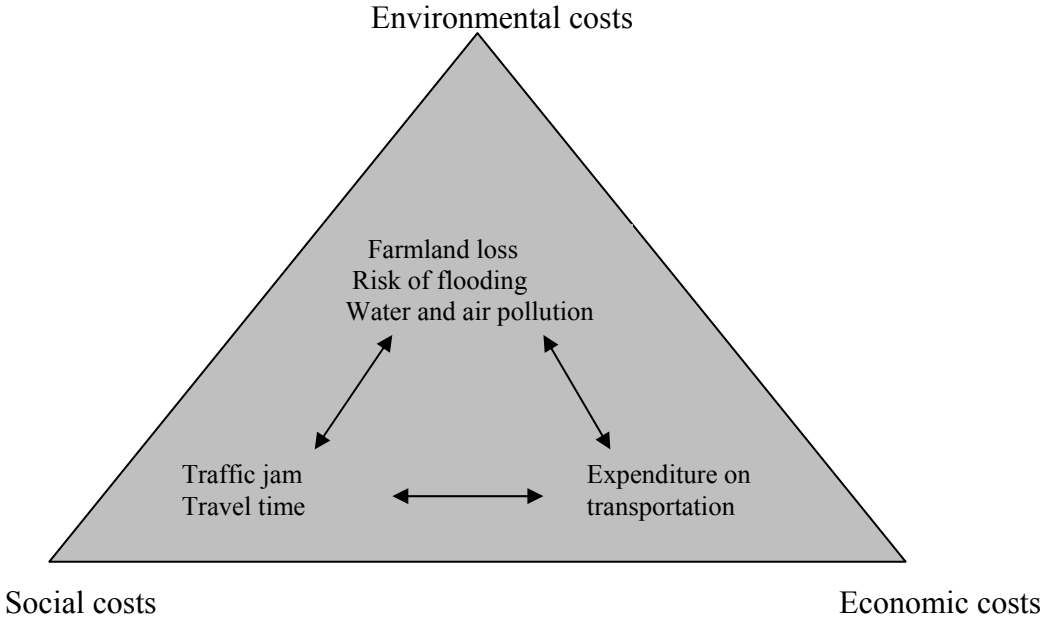


Figure 6.9 The costs of urban sprawl in Jiangning

The impacts of the potential changes in land use on the existing land use pattern and on the environment are at least conceived as follows:

❖ Loss of Fertile Cultivated Land

Land use in Jiangning has undergone major changes because of the rapid growth of non-agricultural land area since 1980. Changes in industrial structure are main reasons for land use change. By 1998, the total industrial output was 18.9 times the total agricultural, forestry, animal husbandry and fishery industry output. The construction of development zones and Lukou international airport are good explanations for industrial development, which also can be regarded as one of the most important factors led to land use change. Agricultural lands of high quality were significantly reduced in the plain area and the vegetation communities in hills were damaged due to the construction of development zones. However, reserved land resources for development and utilization are relative few, and reserved land resources for farming are less. In Jiangning, the degree of land use development is high. Such development patterns not only destroy fertile lands which could be sold, but also damage the landscape, shown in Figure 6.10. According to statistic, the reducing agricultural land mainly distributed in Dongshan (20%), Lukou (20%), Guli (10%) from 1990 to 1998 (SILUP Research Report 2002). Dongshan and Lukou town located on the both banks of Qinhuai River, where have the cultivated lands of the best quality in Jiangning. 90's, rural economic development and the rapid development of social undertakings, the arable land in research area continued to

decline to 5340 hectares. The end of 1995, per capita arable land area decreased to 0.072 hectares.

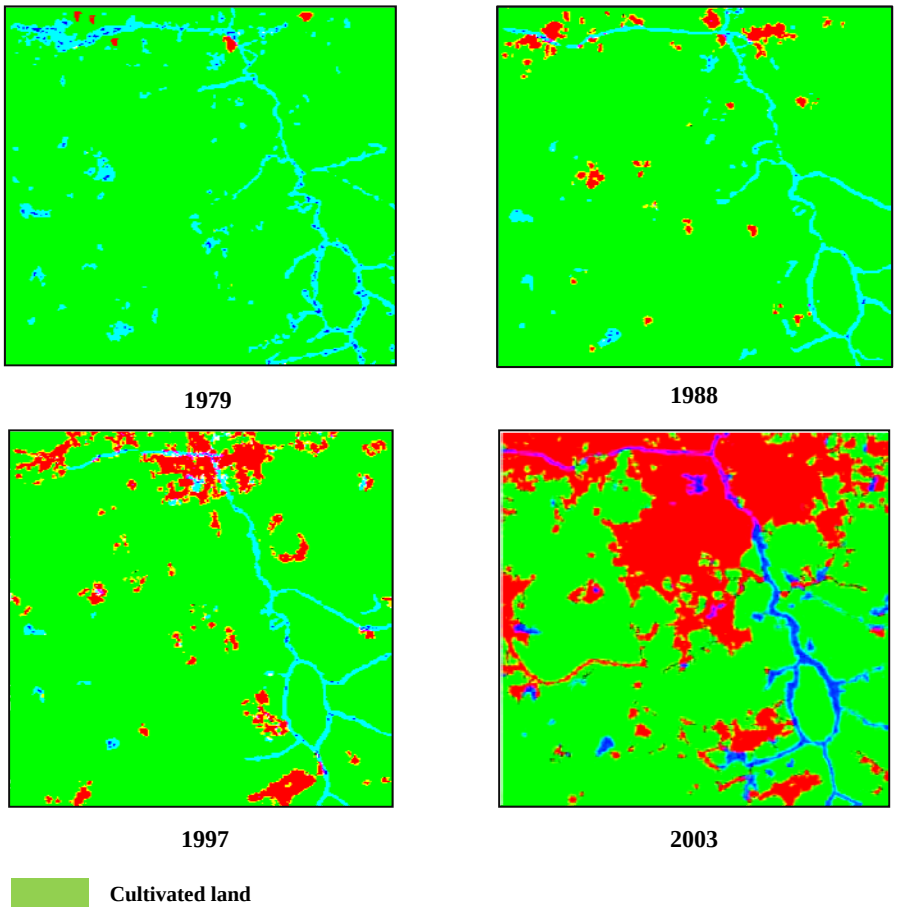


Figure 6.10 Cultivated land loss in Jiangning

❖ Increasing risk of flooding

The construction of infrastructure facilities, like Lukou International Airport, resulted in the filling-up of some drainage courses and alteration of the previous drainage system in Jiangning. The transformation of most fertile cultivated land along the banks of the Qinhuai River from traditional agriculture use into areas for development increases the potential for flooding as the flood plains of the Qinhuai River are converted into developed lands (Ju 1998).

❖ Water and air pollution

The evidence of sprawl presents the problem of increased automobile dependence which leads to significant air pollution. Air pollution and smog fall out to become water pollution. In addition, urban activities create water pollution directly, through land run-off of construction site erosion, fuel spills, oil leaks, paint spills, lawn chemicals, pet wastes and so on. Moreover, more water is consumed for lawn watering and other landscape activities, straining local water supply systems. The development of township and village enterprises has contributed to

industrialization and urbanization in Jiangning, which involve a lot of changes in land use as well as in the ways if exploitation of natural resources and has consequently created a host of environmental concerns. The industrial wastewater discharges into the environment has been increasing, shown in Table 6.7.

Table 6.7 Water and air pollution in Jiangning

Year	Industrial wastewater discharge(ten thousand tons)
2004	5027.9
2005	5036

Source: China's macro data analysis and mining system 2005

Ju (1998) stated: "the scattered distribution of economic activities and the resulting settlement structures make the control of pollution very expensive and therefore not affordable in many places". The deterioration of water quality and destruction of aquatic lives are serious problems for local people, particularly for those people who are completely depending on surface water for daily life activities. The water is not suitable for irrigation during certain periods due to the pollution by manufacturing firms upstream.

6.2.2.2 Socio-economic impacts of urban sprawl

Sprawl with its automobile dependency increases expenditure on roads, traffic services and parking facilities (Newman and Kenworthy 1998). The heavy expenditure by governments on road infrastructure will generate into increased tax burdens on businesses and households which makes it difficult for businesses to compete fairly on the international market. Newman and Kenworthy (1998) further claim that heavy automobile dependency can reduce regional economic development. Quite apart from the public cost of automobile dependency, households spend a greater chunk of their annual incomes on their cars, leaving very little money for other consumer goods (Litman, *et al*. 2002). A sprawling development is considered a toll on the time of suburban dwellers (Harvey, et al. 1965; Duany; et al. 2000; Sierra Club 2000). This is reflected in the amount of time suburban dwellers have to spend traversing vacant lands to meet their needs. Social structure and equity are deemed as problems of sprawl as people tend to be segregated on the lines of income and race (Batty, *et al*. 2003). Gordon and Richardson (1997) contend that in the United States, especially Southern California, the non-white population share in many suburban communities is quite high and sometimes the majority. Increased motorisation that comes with sprawl may lead to increased accidents and fatalities. The loss of lives and physical incapacitations flowing out of these accidents and fatalities may result in social outcomes which may not be desirable. The

socio-economic costs consequence of urban sprawl in Jiangning does not only affect the government, but also households and firms in the form of increased transportation, communication expenditure and levies. Social costs caused by urban sprawl are also very significant.

❖ Expenditure on transportation

Urban sprawl prompts the need for construction of more kilometers of roadways. Usually, the network infrastructure to new developments, further away from already established areas increases the infrastructure costs. Table 6.8 indicates the investment on road in 2001 and 2004.

Table 6.8 Road costs of different periods in Jiangning

Year	Investment on Road (Billion Yuan)
2001	0.310
2004	1.266

Source: http://jssn.xinhuanet.com

Sprawling business and home owners often fail to realize the long-term personal costs and risks of maintaining distant properties. As property taxes rise to cover service costs, and fuel costs increase for travel and heating large buildings, the owners' budgets may have trouble keeping up. Transportation costs for family members are much greater. Sprawl has the tendency to increase households' expenditure on transportation, thus reducing their expenditures on other needs. This generally leads to a reduction in the overall living standards of households. From Table 6.9, the average expenditure of households on transportation in Jiangning increased significantly from 2% in 1997 to 12% in 2003.

Table 6.9 Share of households' expenditure in Jiangning

Households' expenditure	1997	2003
Insurance	5%	5%
Education	18%	21%
Services	7%	9%
Housing	13%	20%
Food	30%	33%
Transportation	2%	12%

❖ Traffic jams and travel time

The city fringe, which is characterized by low-density and low mix of land use as well as scattered development, is often found to give rise to long-distance trips. In a compact, efficient city, travel times are often minimal, but sprawled cities take time to navigate. Suburban tract and country dwellers also spend more time maintaining large, empty residential properties: mowing the grass, plowing long driveways, raking leaves, weeding and so on. Urban sprawl has a great social cost in the Jiangning District. Because of increase of public transport resulting in traffic jam, change of public transit passenger volume becomes more and more significant, shown in Table 6.10. In addition, people are forced to spend more time commuting longer distances to reach their jobs, homes, schools and shopping areas. Urban sprawl, to a certain extent, affects people's welfare adversely; especially the poor.The current pattern of growth in Jiangning District imposes a tax or toll on the time of suburban dwellers as they would have to spend a much greater time travelling to take part in daily activities.

Table 6.10 Change of public transit passenger volume in Jiangning

Year	1996	2003
Public transit passenger volume(million person-trips)	2.85	18.12

Source: China's macro data analysis and mining system 2005

6.3 Summary

This excessive expansion imposes costs on development environmentally, economically and socially. The serious consequence of the excessive growth of the built-up areas as seen from the classified images is the smothering of agricultural and sensitive lands. Coupled with that is the pollution and dwindling of water bodies and wetlands and risk of flooding. Other costs such as increased infrastructure costs, increased air pollution, rising expenditure on transportation and traffic jam which come with sprawl are prevalent in the Jiangning District. In conclusion, the rate of growth in the built-up areas is quite alarming and requires serious policies to arrest the phenomenon in order to mitigate the negative effects of urban sprawl.

7 Conclusions and prospects

7.1 Conclusions

7.1.1 Major findings

The findings of this dissertation are:

1) Studying the landscape expression of built-up areas is very useful to determine sprawl patterns. Integrated remote sensing technology research on the spatial patterns of urban sprawl requires a combination of landscape perspectives of understanding. Three sprawling patterns can be recognized in Jiangning: random expansion at urban fringe, scattered development of industrial land and leapfrog development of urban residential area. The following specific sprawl features are identified: the obvious fragmentation and irregularity of landscape; the unadvisable pattern of land use growth with typical discontinuous development and leapfrog development; the low density of land use growth and other negative impacts on agriculture, environment and city life.

2) The dynamic component of sprawl has to be considered. Therefore, time-series analysis will be among the applied tools. In addition, GIS analysis can assist in identifying the extent of urban sprawl. The trend of urban sprawl in Jiangning is significant. From 1979 to 1988, the phenomenon of disorder and scattered construction was obvious in Jiangning; from 1988 to 1997, sprawl in Jiangning is more significant in the process of suburbanization. Leapfrog development is significant; from 1997 to 2003, the land in Jiangning became fragmented, resulting in a broken landscape.

3) The Cause-Impact model was put forward to obtain a deeper understanding of causes and impacts and help assess the impacts of urban sprawl concerning interrelationships between urban sprawl and environmental, societal and economic issues. The serious consequence of the excessive growth of the built-up areas is the smothering of agricultural and sensitive lands. Coupled with that is the pollution and disappearance of water bodies and wetlands and risk of flooding. Other costs such as increased infrastructure costs, increased air pollution, rising expenditure on transportation and traffic jam which come with sprawl are prevalent in the Jiangning District. The rate of growth in the built-up areas is quite alarming and requires serious policies to arrest the phenomenon in order to mitigate the negative effects of urban sprawl.

4) The Chinese version of urban sprawl is the disproportionate expansion of the urbanized area. Although the Chinese context is quite different from the Western countries, there are two similarities in urban sprawl patterns. The first is the disproportionate conversion of farmland to urban uses. The second is scattered development on the urban fringe. The Chinese version has some variations but retains the main feature of the dispersed development pattern. Despite having reviewed the principle research in Western countries, it is impossible to directly transfer their conceptualization of urban sprawl to China. Some differences are significant, such as population base, growth rate of urbanization, the basis of land ownership, market-orientation and so on.

7.1.2 Policy recommendations

In view of the severe loss of agricultural land owing to urban sprawl, there is a pressing need for enhancing the effectiveness of urban land use planning and implementing land-use planning policies and governance.

The current mode of planning operation is dedicated to the objective of resolving urban-rural conflicts through coordination. Strict land use planning control is characterized not only by land requisitioned in places between the urban and rural area but also by urban-rural inequality. Planning and land use policies are substantially affected by this objective. Urban-rural inequalities are obstacles to the implementation of urban fringe land use planning and result in an unrestrained development of land in urban fringe. While planning control of urban fringe land use may strengthen urban-rural inequalities, the municipal governments will have to change in planning commitments to favor policies promoting rural industrialization and urbanization and leading to an increase in the income of farmers. They may attach importance to the development of infrastructure in rural areas. Finally, the urban-rural interface may result in the implementation of policy in an informal manner and the deregulation of urban fringe land use.

This dissertation shows that a sustainable urban land development and reducing of urban-rural inequalities should be the objectives for further planning policy. The reduction of urban-rural inequalities and the provision of the institutional arrangements to transform the socialist principles underlying the bureaucratic management system into market principles remain the basic strategy of curbing urban sprawl. Land use policies should be designed by taking into consideration of urban-rural inequalities and the cost of planning implementation. To increase

the sense of responsibility of the local governments in carrying out centralized policies, mutual cooperation between governmental departments and urban-rural authorities are needed. Urban-rural cooperation is an important pre-requisite for the establishment of laws and regulations and standardization of urban fringe land use. Effective urban-rural communications and high standard of transparency and accountability should be established for the efficient operation of planning control. Urban-rural cooperation and integrated management may help promote regional development, achieve urban-rural equity and spatial and overcome the problem of over exploitation of resources.

A unified, coherent, transparent and representative land administration should be established to resolve the social conflicts. Otherwise, urban sprawl will not be curbed. To achieve a compact pattern of urban development, a comprehensive urban fringe land statutory framework has to be established. At the same time, the ability and accountability of the government in the governance of urban fringe land use should be strengthened for effective management of urban fringe land.

7.2Prospects

Taking Jiangning as research area, this study mainly discussed the spatial pattern, temporal dynamic change, driving forces and impacts of urban sprawl. Some issues still need to be discussed:

1) Quantitative study of urban sprawl goes into deep step by step, new technology and methods continue to emerge. However, how to form an objective criterion which can be universally accepted to evaluate reasonability of spatial pattern or spatial sprawl speed is an important research project.

2) The development of space technology like remote sensing and GIS provides a more effective and accurate means for investigating urban sprawl. How to combine these technologies much better for study of urban sprawl is also a hot spot of research in the future.

3) How to restrain urban sprawl in urban fringe in China is a further research topic, especially how to make a good land use policy to restrain this phenomenon is also very important.

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Appendix A: The definition of urban sprawl

Definition	Source
-Sprawl "on the one hand, the spilling over of urban-type buildings into the suburban and agrarian areas, and on the other hand, the disorganized growth of sporadic beginnings of settlements in agrarian regions separate farms, houses of farm workers, secondary occupation settlement as well as in early industrialized or commercially permeated areas where ironworks, foundries and mines served as starting points of such sprawling. In addition, the term is also applied to the unsystematic positioning of houses and groups of houses that are only temporarily occupied outside of closed settlement areas."	Akademie für Raumforschung und Landesplanung (1970)
-Compact growth around a number of smaller centres which are located at a distance from the main urban core is also classified as sprawl	Clawson and Hall (1973)
-Urban sprawl as "the scattering of new developments on isolated tracts, separated from other areas by vacant land."	Ottensmann (1977)
-Sprawl is continuous low-density development of urban fringe, low-density development along main high-way of suburban	Altshuler and Gomez-Ibanez (1993)
-Sprawl "process of the spilling-over of settlement areas and excessive use of open landscape by unsystematic, mostly weakly condensed extensions of settlement areas in the fringes of urban agglomerations."	Ermer et al. (1994)
-A working definition of urban sprawl "…unplanned, uncontrolled, and uncoordinated single use development that does not provide for a functional mix of uses and or is not functionally related to surrounding land uses and which variously appears as low-density, ribbon or strip, scattered, leapfrog, or isolated development. "	Nelson and Duncan (1995)
-Urban sprawl characterized as "leapfrog land use patterns, strip commercial development along highways, and very low-density single-use developments –as well as by such indicators as poor accessibility of related land uses, and lack of functional open space."	Ewing (1997)
-Sprawl: "the unchecked growth of settlements, taking effect in the area. The danger of sprawl in a landscape is particularly high in the fringe of the larges cities, not only through expansive residential building activities, but also through economic institutions that are expensive in areas. In recent time, sprawl particularly threatens attractive nearby recreational areas through increased building of weekend house."	Leser and Hubel-Fröhli (1997)
-Sprawl defined as expanding physical development, at decreasing densities, in metropolitan regions, where the	Burgess and Thomas (1998)

spatial growth exceeds population growth.	
-Sprawl: "low-density development beyond the edge of service and employment, which separates where people live from where they stop, work, recreate and educate- thus requiring cars to move between zones."	Sierra Club (1999)
-Sprawl: "a particular type of suburban development characterised by low-density settlements, both residential and non-residential; dominance of movement by use of private automobiles, unlimited outward expansion of new subdivisions and leapfrog development of these subdivisions; and segregation of land used by activity."	USHUD (1999)
-Sprawl is to be understood as the disturbance or destruction of the landscape and of ecosystems by spill-over development of settlements outside of closed built-up areas."	ARL & VLP(1999)
-Sprawl, is an unplanned, unsystematic, area-intensive outward growth mainly of city-type settlements into the rural space and is a consequence of progressive urbanization. The wish fir living in green places, for weekend house, quickly accessible shopping centres, cheap industrial areas, and transpiration infrastructure occupies much space, and if there are no conditions posed by regional planning and environmental protection, then construction will happen at places where it is cheapest. In this way, open spaces, recreational areas, and ecological compensation areas are lost, become dissected or downsized and lost their ecological and socio-economic functions."	Landscape Gesellschaft für Geo-Kommunikation (2000-2002)
-"Urban sprawl results from poorly planned, large scale new residential, commercial and industrial developments in areas previously not used for urban purposes."	Zhang (2001)
-Sprawl defined as land resources and measured it as the ratio of growth in land consumption to growth in population of the metropolitan area.	Fulton et al. (2001)
-Sprawl is used variously to mean the gluttonous use of land, uninterrupted monotonous development, leapfrog discontinuous development and inefficient use of land.	Peiser (2001)
-Sprawl is a pattern of land use in an urbanised area that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed used and proximity.	Glaster et al. (2001)
-Sprawl is the straggling expansion of an indeterminate urban or industrial environment into an adjoining countryside; the area of this advancement	The Oxford English Dictionary (2001)
-Urban sprawl is defined as" peripheral growth that expands in an unlimited and non-contiguous way outward from the solid built-up core of a metropolitan area"	Transportation Research Board (2002)

-Sprawl "the process in which the spread of development across the landscape far outpaces population growth. The landscape sprawl creates has four dimensions: a population that is widely dispersed in low-density development; rigidly separated homes, shops, and workplaces; a network of roads marked by huge blocks and poor access; and a lack of well-defined, thriving activity centres, such as downtowns and town centres. Most of the other features usually associated with sprawl-the lack of transportation choices, relative uniformity of housing option or the difficulty of walking- are a result of these conditions."	Ewing et al. (2002)
-Sprawl is defined as a pattern of urban and metropolitan growth that reflects low-density, automobile-dependent, exclusionary new development in the fringe of settled areas often surrounding a deteriorating city.	Squires (2002)
-Urban sprawl is wasteful, inefficient and or dysfunctional urban growth within the context of a landscape.	Hasse (2002)
-Sprawl defined as the difference between the percentage of a metropolitan area's population living in low density tracts200 to 3500 persons per square mile and the percentage living in high density tracts more than 3500 persons per square mile	Lopez and Hynes (2003)
-"Sprawl is low-density, leapfrog development characterized by unlimited outward extension. In the words, sprawl is significant residential or non-residential development in a relatively pristine setting. In nearly every instance, this development is low density, it has leaped over other development to become established in an outlying area, and its very location indicates that it is unbounded."	Burchell and Galley (2003)
-Sprawl from land use perspective such as the degree of compactness did not generate statistically significant results.	Wassmer (2005)
-Urban sprawl is a phenomenon that can be perceived in the landscape. The more heavily permeated a landscape by buildings, the more sprawled the landscape. The more built over and the more dispersed the buildings, the higher the degree of urban sprawl. The term urban sprawl can be used to describe both a state the degree of urban sprawl as well as a process increasing sprawl in a landscape.	Jaeger et al. (2010)

Appendix B: The indicators of urban sprawl

Sprawl indicators	Source
-Population moving from inner city to suburbs -Comparison of land-use and population growth -Time cost on traffic - Decrease of open space	Sierra Club (1998)
-Percentage of dwellings in single-unit detached houses -Population per square kilometre -Housing units per square kilometre	Razin and Rosentraub (2000)
-Change of population density -Change in urbanized land area	Emison (2001)
-Eight sprawl dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, proximity	Glaster et al. (2001)
-Amount of rural land that is lost to urbanization -Percentage growth in per capita land consumption	Kolankiewicz and Beck (2001)
-Average population density -Density of the median and the10th percentile tract -The Gini coefficient of tract gradients -Various forms of population density gradients -The regression fit of population density -gradients -The average and median distances between tracts and the CBD	Malpezzi and Guo (2001)
-The share of population beyond Standard Metropolitan Statistical Area	USA Today (2001)
-Residential density -Neighbourhood mix of homes, jobs, and services -Strength of activity centres and downtowns -Accessibility of street network	Ewing et al. (2002)
-Residential density -Mixture of residence -Employment and service facilities -Vitalization of inner city -Accessibility of road network	Smart Growth America (2002)

-Density -Leapfrog -Segregated land use -Regional planning inconsistency -High-way strip development -New road infrastructure inefficiency -Alternate transit inaccessistency -Community node inaccessibility -Loss of important land resources -Sensitive open space encroachment -Increased per unit impervious surface -Urban growth trajectory	Hasse (2002)
-Density of new urbanization -Loss of prime farmland -Loss of natural wetlands -Loss of core forest habitat -Increase of impervious surface	Hasse and Lathrop (2003)
-Decentralization -Job and population density	Glaeser and Kahn (2003)
- Sprawl index(SIi) SIi=(((S%i-D%i)/100+1))×50, where D%i = percentage of the total population in high-density census tracts i S%i = percentage of the total population in low-density census tracts i	Lopez and Hynes (2003)
-Change in urban land -Change in urban density	Anthony (2004)
-Metropolitan Density -Density variation -Shape -Composite Indexes of Metropolitan Sprawl -Diversity -Accessibility -Transportation Networks -Transportation infrastructure -Building design -Environmental context -Perceptions -Patches -Configuration	Knaap et al. (2004)
-Metropolitan size -Activity intensity -Distribution degree -Clustering extent	Tsai (2005)
-Low density urban growth outside the Urbanized area	Weber and Sultana (2005)
-Growth of built-up areas -Share of dense residential areas of all residential, areas and share of low density residential areas of all new residential areas -Residential density -Change in growth rates for population and built-up areas, available built-up area per person	European Environmental Agency (2006)

-Complexity -Centrality -Compactness -Porosity	Huang et al. (2007)
-Density metrics -Suburbanization metrics -Contiguity and openness metrics -Compactness metrics	Shlomo Angel et al. (2007)
-Size of built-up area and rate of change -Density of built-up areas and rate of change -Fragmentation, scatter(patch density and percentage change in patch density) -Population density	Schneider and Woodcock (2008)
-Fractality (fractal dimension)	Weith (2008)
-Population 1990 -Units of Impervious lands 1990 -Population per unit of impervious land (density by developed land) 1990 -Impervious land per capita 1990 -Population 2000 -Units of Impervious lands 2000 -Population per unit of impervious land (density by developed land) 2000 -Impervious land per capita 2000 -Change in units of impervious land 1990-2000 -Impervious lands % change 1990-2000 -Population change 1990 to 2000 -Population % change (1990-2000) -Population per unit of impervious land, % change 1990-2000 -Amount of impervious land units per new resident -Low Density Impervious Land as a % of Total Impervious (1990) -Low Density Impervious Land as a % of Total Impervious (2000) -Units of Resource (Agricultural/forest) lands 1990 -Units of Resource (Agricultural/forest) lands 2000 -Change in units of Resource (Agricultural/forest) lands -Resource lands % change 1990-2000 -Change in resource land units per new resident	http://chesapeake.towson.edu/landscape/urbansprawl/metrics.asp
-Gross population density -Net population density -Fractal dimension -Shape index -Gross leapfrog index -Net leapfrog index -Mean patch size (hectares) -Residential area -Industrial area -Public institutions land-use area -Mixed land use and malls -Tourism and recreation area -Special land uses	Frenkel and Ashkenazi (2008)

-Urban density -Change in urban density -New households per capita -Integration of new development into existing urbanised areas -Integration of new development in the public transport network -Effective share of open space -Jaggedness -Share of urbanised land -New consumption -Per-capita availability of open space	Siedentop and Fina (2010)

Appendix C: The causes of urban sprawl

Causes of urban sprawl	Source
-Independent decision-making of monopolistic competitors -Speculation of landholders -Natural terrain -Public regulation of government -The construction of transport facilities -Government's public policy -Collection of land development tax	Harvry (1965)
-Single family housing -Car ownership -The construction of the underlying plant -The existence of a large number of small local governments	Downs (1994)
-Lack of regional planning -Lack of neighbourhood design -Zoning and government policies -Specialization and standardization -Role of automobile and highways	Dutton (2000)
-Market forces -Market failure	Brueckner (2000)
-Socio-economic factors and land-use regulation related housing factors of urban communities	Zhang Tingwei (2001)
-Land ownership and use -Transportation patterns -Telecommunications technology -Regulations and standards	Gillham (2002)
-Fragmentation of local governments	Carruthers and Ulfarsson (2002)
-People's preference for low density housing -Lack of effective regional planning -City competition in the tax and employment -The decline in the quality of urban centre schools -Exclusive suburban zoning -The low price of gasoline -Federal funding of public transport	LeRoy (2003)
-Sectoral composition and transformation of the economy -Shift in the location of economic activity -Changes in land prices and housing costs -Changes in incomes, the distribution of incomes and spending patterns -Infrastructure investment, especially transport -Labour market structure -Demographic and household change -Lifestyle and behaviour -Migration, segregation and filtering -Public regulations: taxation and subsidies -Public regulations: land use planning and housing policies -Other agencies or managers -Quality of the inner city environment -Quality of landscape and townscape	Couch and Karecha (2003)

-General causes relating to the general drift of change in developed societies -Government policy, spatial planning related	Dieleman and Wegener (2004)
-Population growth -Rise in household income -Subsidization of infrastructure investments -Ineffective land use -Excessive growth -Social problems in central cities -Poor land policies	Bekele (2005)
-Employment centralization -A range of geographical variables -Political geography	Burchfield et al.(2005)
Macro-economic factors -Economic growth - Globalization - European integration Micro-economic factors -Rising living standards -Price of land -Availability of cheap agricultural land - Competition between municipalities Demographic factors -Population growth -Increase in household formation Housing preferences - More space per person - Housing preferences Inner city problems - Poor air quality - Noise - Small apartments - Unsafe environments -Social problems -Lack of green open space -Poor quality of schools Transportation -Private car ownership -Availability of roads -Low cost of fuel -Poor public transport Regulatory frameworks -Weak land use planning - Poor enforcement of existing plans - Lack of horizontal and vertical coordination and collaboration	EEA Report (2006)

-Population growth -Strong economy -Increasing household incomes -Fragmented municipal governments -Patterns of infrastructure investments -Public subsidization of infrastructure: the construction of roads and the provision of infrastructure using public money encourages development - 'White flight' from cities, and -Topographic barriers and other physical constraints upon development	http://chesapeake.towson.edu/landscape/urbansprawl/causes.asp
-Cheaper land and housing costs in the suburbs as compared to urban centers has lured many to settle in these areas. -There has been an increase in public spending for the development of infrastructure like roads, water and electricity in the suburbs than in existing urban centers, thus adding benefits to life in sprawls. -There has been an increase in commercial lending practices that favour suburban development. -Increase in family income of an average American has raised his living standard. Owning a car and paying for gas to transit from suburb to the city is affordable for many Americans. -Sprawls are characterized by low density populations and less traffic congestion. Therefore, even in the absence of any federal policies that would encourage growth of sprawls, these centres have proliferated due to the willingness of a growing number of people to live in sprawls, where they find life more calm and peaceful than in the cities. -Higher property and business taxes in the cities have pushed businesses to the suburbs where taxes are generally low.	http://www.buzzle.com/articles/urban-sprawl-causes-and-effects.html(2009)

Appendix D: The costs of urban sprawl

Costs of urban sprawl	Source
-Energy cost -Environmental impact -Capital cost -Operating cost	Real Estate Research Corporation (1974)
-Infrastructure costs -Public service costs -Transit -Vehicle miles travelled -Loss of resource lands -Energy consumption -Psychic and social costs -Impact on central cities -Infrastructure and operating efficiency -Transit	Ewing (1997)
-Economical resource allocation -Congestion -Open space and agricultural land -Energy glut -Density preference -Downtown impacts -Equity	Gordon and Richardson (1997)
-Public and private capital and operating costs -Transportation and travel costs - Land/natural habitat preservation -Quality of life -Social issues	Chin (2002)
-Eliminating agriculture lands -Spoiling water quality -Air pollution	Allen et al. (2003)
-Environmental costs -Visual effects -Personal effects -Economic effects	Bekele (2005)
-Increased and insufficient land use and energy consumption -Increased traffic congestion -Negative environmental effects, such as reduced air and water quality and loss of open space and other natural gases -Higher public costs for new facilities and services for the newly developed areas	Eryilmaz et al. (2008)
-Loss of community character -The decline of inner cities as people leave them for sprawled area -Loss of community spirit and values -Less leisure time; traffic congestion and longer commuting times -Over-crowded schools -Higher taxes -Higher costs of providing infrastructure, and	http://chesapeake.towson.edu/landscape/urbansprawl/causes.asp

adverse fiscal impacts on local governments -Ill-health due to air pollution generated by traffic -Reduced worker productivity; ugly, monotonous suburban landscapes -Loss of a sense of place -Marked spatial disparities in wealth between cities and suburbs; and -Land development patterns making the establishment and use of mass transit systems difficult	