Spatial Process of Urbanization in Kathmandu Valley, Nepal

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Abstract

Urbanization is a complex spatial process that converts rural land uses to urban uses, and causes various impacts on ecosystem structures, functions, dynamics, and the livelihoods of human beings. Kathmandu Valley, the most populous metropolitan region in Nepal, has been rapidly urbanizing since the 1980s. Due to the urbanization pressure, the valley has been facing serious environmental consequences in recent years. Therefore, the quantification of the spatial process of urbanization is essential for the monitoring and assessment of the changing environment of the valley. This research aims to investigate the spatial pattern of urbanization since the 1960s and identify the driving factors of urbanization. Remote sensing, geographic information systems, spatial metrics, analytic hierarchy process, and fieldwork techniques were applied in order to prepare time series land use maps, interpret spatial pattern changes, and analyze the urbanization process.

A highly dynamic spatial pattern of urbanization is observed in the valley. The urban built-up areas, which are used as an indicator of urbanization, had a slow trend of growth in the 1960s and 1970s but have grown rapidly since the 1980s. Prime agricultural land in the valley floor has been changed to urban/built-up areas. Shrubs and forest landscapes in rural areas mostly changed into agricultural uses, while half of the land in the valley has remained agricultural. Nominal land use transitions between the other land use types in the valley were also noticed. The urbanization process of individual uncontrolled housing practices has developed fragmented and heterogeneous land use combinations in the valley, but urban growth has gradually become more synchronized in recent decades.

However, a refill type of development process in the city core and immediate fringe areas has shown a decreasing trend of the neighborhood distances between the different land uses, and an increasing trend of physical connectedness, which indicates a higher probability of homogenous landscape development in the upcoming decades.

The dynamic pattern of urbanization, particularly for the last decade, has been greatly influenced by seven driving factors: physical conditions, public service accessibility, economic opportunities, land market, population growth, political situation, and plans and policies. These factors have played important but different roles in the core, fringe, and rural areas. Among these factors, economic opportunities in the core, population growth in the fringe, and the political situation in the rural areas are identified as the highest impact factors of urbanization. The physical conditions factor has had the least effect in the core and fringe areas as compared to its role in the rural areas. The role of public service accessibility gradually decreased from city core to rural area. Due to the lower land availability in the city core, the land market factor had less of a role in the core compared to the fringe and rural areas. The plans and policies factor is evaluated as less effective in all thematic areas.

This empirical analysis revealed the spatial process of urbanization in the valley, which is an important reference for the urban and regional planners in Nepal and other less developed countries. Furthermore, the research results form an important data source for predicting urban growth dynamics and scenario analysis.

Keywords: Land Use Change, Analytic Hierarchy Process, Spatial Metrics, Driving Factor Modeling, Hybrid Method, Urban Remote Sensing, LULC, GIScience.

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Abbreviations

AHP	Analytic Hierarchy Process
AWMPFD	Area Weighted Mean Patch Fractal Dimension
CBS	Central Bureau of Statistics
CONTAG	Contagion
DoR	Department of Road
ED	Edge Density
ENNMN	Euclidian Nearest Neighbor Distance Mean
GIS	Geographical Information System
GPS	Global Positioning System
HMGN	His Majesty's Government of Nepal
ICIMOD	International Centre for Integrated Mountain Development
IDM	Industrial District Management
IUCN	The World Conservation Union
KVTDC	Kathmandu Valley Town Development Committee
LPI	Largest Patch Index
LULC	Land use and land cover change
MoF	Ministry of Finance
NPC	National Planning Commission
PD	Patch Density
PDA	Personal Digital Assistant
RS	Remote Sensing
SHDI	Shannon's Diversity Index.
UNEP	United Nation Environment Program

Chapter One

Introduction

1.1 Background and problem statement

Urbanization has become a major trend worldwide in recent years. In 1920, the urban population made up 14% of the world, and reached 25% in 1950 (Weber and Puissant, 2003). Currently, 50% (3.3 billion) of the world population lives in urban areas (United Nation, 2008). Rapid urbanization is an ongoing dynamic process, and is the most dominant phenomenon in all developing countries (Thapa *et al.,* 2008). The urbanization rate in Nepal is among the highest in Asia and the Pacific (ADB/ICIMOD, 2006). The number of urban centers in Nepal grew from 10 to 58 between the years 1952 and 2001, while the urban population increased from 0.2 million to 3.2 million, a sixteen-fold increase in the same period. As of 2001, 14% of the country population lived in urban areas, which is expected to be double by the 2010s (CBS, 2001; Sharma, 2003). Continuous migration from rural areas to urban areas largely contributed to the rapid urbanization in Nepal.

Usually, urbanization refers to the proportion of the population of a country that lives in cities (UNESCO, 1973; Sharma, 2005). In some studies, however, it has been referred to as a process of spatial diffusion (Lewis and Maund, 1976; Herbert and Thomas, 1982). The concept of urbanization may vary from discipline to discipline, author to author and region to region; hence, in this study, I have defined urbanization as *a territorial and socioeconomic process that causes a general transformation of landscape patterns over time*. More precisely, the spatial process of urbanization can be considered as the observable transformation of the spatial pattern of land use and land cover, such as the transformation of agricultural and forest land uses into built-up surfaces or the gradual transformation of rural landscape into urban landforms. The time-space relationship plays an important role in understanding the spatial process of urbanization.

As a city grows, the increasing concentration of population and economic activities demands more lands be developed for public infrastructure (roads, water facilities, and utilities), housing, and industrial and commercial uses. These processes are often driven by the development plans and policies of a particular region (Seto and Kaufmann, 2003; Abdullah and Nakagoshi, 2006). Migration, urban sprawl, agriculture, and forest patterns also often contribute to the landscape changes. Understanding the spatial process of urbanization and the mechanisms that drive the dynamic process is fundamental to increasing the effectiveness of managing the environmental sustainability.

The transformation of rural landscape to urban landscape has caused various impacts on ecosystem structure, function, and dynamics (Antrop, 2000; Mesev, 2003; Weng, 2007). Persistent dynamic land use change processes are expected to accelerate in the next several decades. Worsening conditions of crowding, housing shortages, insufficient infrastructure, and increasing urban climatological and ecological problems require consistent monitoring of urban regions (Miller and Small, 2003; Thapa and Murayama, *in press*).

Understanding the causes and consequences of urbanization processes to explore the extent and location of future landscape changes is very important. Landscape change is often seen as a function of socio-economic and biophysical factors that are referred to as the driving factors of land use change (Turner II *et al.*, 1990). The driving factors that influence the magnitude and extent of land use change are often related to the functioning of local and national markets, policy, and demographic conditions.

However, monitoring of land use changes is needed to understand and predict the dynamic process of land use patterns at different times. This was traditionally limited due to labor intensive fieldwork that is often unable to reveal the spatial pattern of landscape changes and environmental consequences that occurred in a given time period. Significant technological advancement in data acquisition and analysis techniques in recent years has made it easier to analyze the spatiotemporal dynamics of landscape changes (Nelson, 1983; Tang *et al.,* 2005; Thapa and Murayama, 2008a). Remote sensing (RS) data coupled with fieldwork information and geographic information systems (GIS) have been recognized as effective tools in quantitatively measuring spatial patterns and their changes over relatively large geographic scales (Nelson, 1983, Frohn, 1998; Petit *et al.,* 2001; Longley, 2002; Murayama, 2004; Thapa *et al.*, 2007a). Remotely sensed images from airborne and satellite sensors provide a large amount of cost-effective, multi-spectral, and multi-temporal data to monitor landscape processes and estimate biophysical characteristics of land surfaces (Herold *et al.,* 2003; Miller and Small, 2003; Carlson, 2003; Thapa and Murayama, *in press*). GIS technology provides a flexible tool with which to store, analyze, and model the digital data for the detection of change (Murayama, 2004; Thapa and Murayama, 2008b).

As the result of population growth and migration from rural to urban areas, urbanization has been recognized as a critical process in metropolitan areas of Nepal. Moreover, Kathmandu Valley, which is the most populous metropolitan region in the country, has been facing rapid urbanization over the last three decades (Sharma, 2003). As of 2001, it had a total population of 1.5 million, where two-thirds lived in urban areas (14% of the total land in the valley). Such urbanization pressure led to a population influx, an increase in motorized transport, air, water and noise pollution, energy consumption, a loss of agricultural land, and a reduction in biological diversity in the valley. Eventually, it has altered the land use patterns over time in the valley. Consequently, more and more agricultural lands and forest lands have been converted into urban areas and human settlements over the past few decades (Haack and Rafter, 2006; Thapa *et al.*, 2007b; Thapa and Murayama, 2008a).

Quantifying land use patterns, analyzing the changes over time, and identifying the causes of changes are essential for monitoring the spatial process of urbanization and environmental consequences in the Kathmandu valley. There is a lack of scientific studies focused on spatiotemporal changes in Nepal due to the lack of spatially consistent databases over time (HMGN/UNCTN, 2005; Haack and Rafter, 2006). Therefore, an integration of fieldwork, RS, GIS, and AHP techniques is proposed to summarize and interpret the spatial patterns of land use changes over time, the associated environments, and the driving factors of the pattern changes in the valley.

1.2 Research objective

The main purpose of this research is to investigate the spatiotemporal process of urbanization and the driving factors that encouraged the transformation of Kathmandu Valley landscape over time by incorporating modern geographic tools and techniques. In particular, the main focus of the research is the mapping and interpretation of the spatial patterns of land uses from the 1960s to 2000, and the investigation of the factors that played key roles in the urbanization process in the last decade. Kathmandu, located in a bowl shaped valley, is interesting case to study as it consists of topographic constraints for horizontal urban expansion but faces rapid urbanization, having an annual urban population growth rate of 5.2%. It is the main political and administrative center, a major tourist gateway, and an economically strategic location in Nepal. High population growth, dramatic land use changes, and socioeconomic transformations have brought the paradox of rapid urbanization and environmental consequences to the valley (Thapa *et al.,* 2008). Along with new developments within the city fringes and rural villages, shifts in the natural environment and newly developed socioeconomic strains between residents are emerging. Such rapid demographic and environmental changes and weak land use planning practices in the past decades have resulted in environmental deterioration, haphazard landscape development, and stress on the ecosystem structure (UNEP, 2001; HMGN/UNCTN, 2005; ADB/ICIMOD, 2006; Thapa and Murayama, 2008a).

1.3 Review of previous studies

This study focuses on the spatial process of urbanization rather than the socioeconomic process of urbanization. The spatial process of urbanization brings changes in the spatial patterns of land use and land cover, which act differently in space at different scales over different time periods. Therefore, the study heavily relied on land use and land cover change to synthesize the spatial process of urbanization in Kathmandu. Furthermore, remote sensing, as a major source of data for mapping the spatial patterns of land use and land cover, is considered. A brief review of some relevant references related to remote sensing based mapping, spatial patterns and processes, land use and land cover changes, and the driving forces of these changes is presented in the following sections.

Remote sensing of urbanization. Remote sensing has long been used to map urban growth and urban morphology, and implies the mapping of the form, land uses, and density of urban areas, each having an associated shape, configuration, structure, pattern, and organization of land use (Johnsson, 1994; Carlson, 2003; Miller and Small, 2003; Lillesand *et al.*, 2008). Sometimes simply mapping an urban or non-urban dichotomy is important; sometimes detailed morphologic mapping is needed, where the positions of buildings and roads or the extraction of the three-dimensional topographical aspects of urban areas are needed (Thapa and Murayama, *in press*). Satellite imagery has the unique ability to provide synoptic views of large areas at a given time, which is not possible using conventional survey methods. The process of data acquisition and analysis through GIS is very fast as compared to conventional methods.

Recent advances in remote sensing technologies and the increasing availability of high resolution earth observation satellite data provide great potential for acquiring detailed spatial information to identify and monitor a number of environmental problems in urban regions at desirable spatiotemporal scales (Carlson, 2003; Miller and Small, 2003; Thapa *et al.*, 2007). Transitions in architecture and building density, vegetation, and intensive socioeconomic activities at the block level in cities often transform the urban landscape to become more heterogeneous (Cadenasso *et al.*, 2007). Therefore, the urban environment represents one of the most challenging areas for remote sensing analysis due to the high spatial and spectral diversity of surface materials (Herold *et al.*, 2002; Maktav *et al.*, 2005; Thapa and Murayama, 2007). In recent years, a series of earth observation satellites has provided abundant data at high resolutions (0.6-2.5 m; QuickBird, IKONOS, OrbitView, SPOT, and ALOS) to moderate resolutions (15-30 m; ASTER, IRS, SPOT, and LANDSAT) for urban area mapping (Thapa and Murayama, *in press*). Remote sensing data from these satellites have specific potential for detailed and accurate mapping of urban areas at different spatiotemporal scales. The high resolution imagery provides data for monitoring urban infrastructures, whereas moderate resolution imagery can provide synoptic measures of urban growth, surface temperature, and more. A wide range of urban remote sensing applications from both sensors is currently available (Carlson and Arthur, 2000; Batty and Howes, 2001; Miller and Small, 2003; Maktav *et al.*, 2005; Thapa and

Murayama, 2007; Gatrell and Jensen, 2008). These include quantifying urban growth and land use dynamics, population estimation, life quality improvement, urban infrastructure characterization, monitoring land surface temperature, air quality, vegetation, and topographic mapping.

Despite advances in satellite imaging technology, computer-assisted image classification is still unable to produce land use and land cover maps and statistics with high enough accuracy (Lo and Choi, 2004; Thapa and Murayama, 2007). Image analysis techniques are evolving rapidly, but many operational and applied remote sensing analyses still require extracting discrete thematic land surface information from satellite imagery using classification-based techniques (Prenzel and Treitz, 2005). Several image classification techniques, from automated to manual digitization, can be found in the literature (Lo and Choi, 2004; Ozkan and Sunar-Erbek, 2005; Prenzel and Treitz, 2005; Carvalho *et al.*, 2006; Nangendo *et al.*, 2007; Thapa and Murayama, *in press*). However, these studies have spanned a broad range of land-surface types and sensors. Different image classification methods use data from different satellite sensors to determine how the organization of information inherent to the classification scheme influences classification accuracy and the representation of the earth surface in thematic meaning. Wang (1990), Johnsson (1994), Zhang and Foody (2001), Lo and Choi (2004), and Thapa and Murayama (*in press*) argued that the heterogeneity and complexity of the landscape in urban regions, for example, suburban residential areas forming a complex mosaic of trees, lawns, roofs, concrete, and asphalt roadways, require land use and land cover classification techniques that combine more than one classification procedure to improve remote sensing-based mapping accuracies.

Land use and land cover change studies. A theoretical understanding of the processes that lead to the spatial pattern of land use has been provided by researchers from different disciplines for many years. Looking back to the history of land use studies, J. H. von Thünen first developed a basic analytical model between markets, productions, and distances in the 1820s to analyze agricultural land use patterns in Germany (von Thünen, 1826). However, understanding of urban land use patterns started in the early 20th century. Among the most well known urban land use studies in this early period, three different descriptive models (the concentric zone model, sector model, and multiple nuclei model) dominated the geography literature (Alonso, 1964; Campbell, 1998; Briassoulis, 2000). The concentric zone model was developed by Earnest Burgess based on land values and bid-rents in Chicago in the 1920s (Burgess, 1925). An important feature of this model is the positive correlation of the socio-economic status of households with distance from the CBD (Central Business District): more affluent households were observed to live at greater distances from the city center (Kates *et al.,* 1990; Campbell, 1998). Following the Burgess model, in the 1930s, Homer Hoyt revised the concentric zones by considering the influence of the transportation system, which is known as the sector model (Hoyt, 1939; Campbell, 1998). He found that cities tend to grow in a sector fashion originating from the CBD along the major transportation routes. The multiple nuclei model was developed by Harris and Ullman (1945), who considered the CBD as the major center of commerce. However, they suggested that specialized cells of activity would develop according to the specific requirements of certain activities, different rent-paying abilities, and the tendency of economic activity to cluster together (Campbell, 1998; Briassoulis, 2000).

These models were developed to generalize the patterns of urban land use found in early U.S. cities. In general, these classic spatial models provide basic concepts about the zone and sector that continue to have useful roles in organizing city structure and testing general theories in urban geography. Whatever the detailed functional characteristics of a city, its internal spatial structure will be organized around the concentration of employment opportunities, service facilities, and their associated land uses (Herbert and Thomas, 1982). Due to the complex structure and function of a city in the real world, the early classic models became unrealistic for representing and predicting land use patterns and dynamics. This prompted the need for a more spatially explicit model with more detailed real geographic data. Consequently, with the advancement of computer assisted geographic technologies, new methods are being used in land use change studies as well as to model dynamic urbanization processes.

In recent years, the computer age per se, land use change has been considered as a complex, dynamic process that links natural and human systems. It has direct impacts on soil, water, and the atmosphere, and is thus directly related to many environmental issues of global importance (Overmars and Verburg, 2005; Koomen and Stillwell, 2007). The large-scale deforestations and subsequent transformations of agricultural land in the tropics are examples of such land use changes (Angelsen and Kaimowitz, 1999; Nelson *et al.,* 2001; Walsh *et al.*, 2001; Lambin *et al.,* 2003). In the course of land use change studies, some researchers have focused on urbanization from the perspective of either economic geography (Krugman, 1999) or from a more technology-driven perspective that focuses on the interaction of land uses through cellular automata models (Torrens and O'Sullivan, 2001; White and Engelen, 2000; Wu, 1999; Clarke and Hoppen, 1997; Batty and Howes, 2001; Herold *et al.,* 2003; Dietzel *et al.,* 2005; Torrens, 2006; Zhao and Murayama, 2006). In practice, many processes that influence land use change interact and lead to complex patterns, depending on the local cultural, socioeconomic, and biophysical context at different spatial scales (Lambin *et al.,* 2001).

At a wider prospective, land use change is also an important factor in the climate change cycle, and the two are interdependent; changes in land use may affect the climate while climatic change will also influence future land use patterns (Dale, 1997; Watson *et* *al.,* 2000). Therefore, land use and land cover change (LULC) research has received much attention during the past decade because of the pivotal role of LULC in many urgent issues like global climatic change, food security, soil degradation, and biodiversity deterioration (Lambin *et al.,* 2001).

LULC research involves many disciplines because it operates at the interface of the natural and human sciences (Lambin *et al.*, 2001). LULC is the result of the complex interaction of behavioral and structural factors associated with demand, technological capacity, social relations, and the nature of the environment. A theory of land use change, therefore, needs to conceptualize the relation between the driving forces and land use change, relations among the driving forces, and human behavior and organization.

Different disciplinary theories can help us to analyze aspects of land use change in specific situations. The synthesis of these theories is essential, but the paradigms and theories applied by the different disciplines are often difficult to integrate, and the specific research results do not easily combine into an integrated understanding of LULC. To date, researchers have not succeeded in integrating all disciplines and the complexity of the land use system into an all-compassing theory of land use change (Verburg *et al.,* 2004). Conclusions drawn from disciplinary LULC studies can vary substantially between disciplines, which implies that the complexity of the land use system as a whole is not completely understood.

From a geographical discipline, LULC studies have been carried out mainly at the national and sub-national level, using available geographic information from maps, census data, and remote sensing. These data have been used to construct driving factors of land use change that are used to explain the locations of these changes (Serneels and Lambin, *et al.,* 2001; Nelson *et al.,* 2001; Pontius and Schneider, 2001). These studies often lack explicitness about processes and human behavior. The drivers used are proxies for the processes that determine land use change. The identified relations between land use change and the projected driving factors are valid at the regional level and do not straightforwardly translate into the determinants of LULC at small scales, such as the block level or even the household level. The strength of this geographical approach is its spatial explicitness, which helps to explain land use patterns and can be directly used in geographical modeling approaches (Pontius and Schneider, 2001; Pijanowski *et al.,* 2002). However, this approach contrasts with the approach of the social sciences, which generally conduct micro-level studies aimed at understanding people-environment relations (Turner, 2003; Gatrell and Jensen, 2008). Socioeconomic studies often focus on the household level to gain insight into the factors that influence land use decisions. These studies provide information about decision-making processes and human behavior. However, they do not incorporate a spatial component.

Determinants of the urbanization process. The land use process is a nonlinear dynamic change that includes many related ecologic, geographic, economic, and social factors and interrelations (Zang and Huang, 2006). The spatial configuration of land use is an important determinant of many ecological and socioeconomic processes (Lambin *et al.,* 2001; Hietel *et al.,* 2005; Mottet *et al.,* 2006). Land use change is usually driven by a variety of forces which relate differently to one another in different spatial and temporal settings.

Basically, we can consider two main categories for land use change drivers: biophysical and socioeconomic. The biophysical drivers include characteristics and processes of the natural environment such as weather and climate variations, landforms, topography, geomorphic processes, volcanic eruptions, soil types and processes, drainage patterns, and the availability of natural resources (Verburg *et al.,* 2004). The socioeconomic drivers comprise demographic, social, economic, political, and institutional factors and processes such as population and its change, industrial structure and its change, technology and technological change, families, the market, various public sector bodies and related policies and regulations, values, community organization and norms, and property regimes (Briassoulis, 2000). It should be noted that the biophysical drivers usually do not cause land use change directly. They mostly cause land cover changes that, in turn, may influence the land use decisions of land owners/managers (e.g., no farming on marginal lands) (Mottet *et al.,* 2006). In addition, land use changes may result in land cover changes that, then, feedback on land use decisions, perhaps causing perhaps additional land use changes.

An improved understanding of land use change is considered to be a requirement for the global assessment of urbanization processes in mountain landscapes with reference to their various functions, including biodiversity, aesthetics and cultural heritage, and production levels. Thus, this understanding will contribute to the development of management strategies and policies to restructure or prevent further decline in the environmental value of mountain agriculture. Given the complexity of human/nature systems and the scale dependency of land use change drivers, the need for approaches that integrate socioeconomic and biophysical drivers are now widely recognized (Liu, 2001; Lambin *et al.,* 2001; Verburg, *et al.,* 2004). At present, case studies are important for gaining an understanding of the complex relationships between the social and natural systems that drive landscape and land resource change (Naveh, 2001; Lambin *et al.,* 2003; Almida *et al.,* 2003; Bray *et al.,* 2004; Antrop, 2005; Hietel *et al.,* 2005; Tian *et al.,* 2005). A range of methods, from econometric to probabilistic, is used to understand the land use change drivers in many urban regions.

Understanding the driving factors of land use changes is an important aspect for modeling future land use scenarios. However, this research focused on exploring the driving factors of land use change in Kathmandu Valley with the people participatory approach. The participation of local people in the decision making process in order to understand the processes of their surrounding environment is very important. Modeling the driving factors, including people's perceptions, and deriving a thematic meaning of the land use change process has been a challenging topic for many years, as a range of drivers plays different roles at different scales in a particular place. Most of the driving factors are interlinked with each other. The driving factors should be dealt with as multi-criterion problems, as there are different levels of relations between the factors. In practice, more than one criterion should be considered while making decisions and when measuring the weight of the driving factors. To solve the multi-criterion problems analytically, Saaty (1980) introduced the Analytic Hierarchy Process (AHP) method, which has a sound mathematical foundation, in 1976. Since then, it has been widely used in several socioeconomic and engineering applications (Banai-Kashani, 1989; Malczewski, 1999; Kauko, 2004; Thapa and Murayama, 2008b).

The AHP method is a general theory of measurement that derives ratio scales from both discrete and continuous paired comparisons in multilevel hierarchic structures. These comparisons may be taken from actual measurements or from a fundamental scale that reflects the relative strength (Saaty, 1980, 1989). It has been applied to a variety of prediction and multi-criteria decision problems. AHP works in a nonlinear framework, carrying out both deductive and inductive thinking, taking several factors into consideration simultaneously, allowing for dependence and feedback, and making numerical tradeoffs to arrive at a synthesis or conclusion (Saaty, 1996; Saaty and Vargas, 2001). Furthermore, the AHP provides a multi-criteria decision support method that uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the respondents/users (Kauko, 2004; Thapa and Murayama, 2008b).

Urbanization in Nepal. The first official census in Nepal was held in 1952-1954. Data on urbanization are available since that time. Frequent changes in definitions and urban political territories, and the incorporation of new ones in Nepal, often complicate the study of urban areas (Basyal and Khanal, 2001; Sharma, 2003). In the 1970s, the regional development strategy was adopted, and a series of north-south growth corridors and growth centers were identified to concentrate development efforts in order to achieve full economic development and encourage the agglomeration of the economy, which resulted in important contribution to urbanization (Shrestha *et al.*, 1986; HMGN, 1991; IUCN, 1999; Pradhan and Perera, 2005).

With an urban population of nearly 14%, Nepal is one of the least urbanized countries in the world (Pradhan, 2004). This is much less than the Philippines (53%), Myanmar (26%), Cambodia (20%), and Bangladesh (17%) (Portnov *et al.*, 2007). In the last five decades, the national population increased by 2.8 times, whereas the urban population increased by 16 times. The urban population growth has accelerated since the 1980s (Sharma, 2003). In the 1990s, the rate of urbanization (6.6% per annum) was among the highest in the Asia Pacific Region (ADB/ICIMOD, 2006), higher than in Sri Lanka (2.2%), India (2.9%), Pakistan (4.4%), Bangladesh (5.3%), and Cambodia (6.2%) (Portnov *et al.*, 2007). The high growth rate of the urban population is due to natural growth, migration, the designation of additional municipal towns, and the expansion of municipal towns amalgamating rural areas (Pradhan, 2004).

Kathmandu is the most populous metropolitan region in the country (Thapa *et al.*, 2008). The region has faced population influxes in different time periods. The urban population has increased from 196777 to 995966 in the last five decades (Sharma, 2003).

A very high increase was observed in the 1990s. Recently, Kathmandu accommodated 31% of the total urban population of the country. The increase of population in Kathmandu valley has decreased the amount of agricultural land and brought new farming systems. Rapid urbanization and the introduction of new agricultural technology have encouraged the valley's farmers to change their farming patterns from traditional (low value crops) to new crops (high value crops) (Shrestha, 2006; Haack and Khatiwada, 2007). Until 1990, the urban area was limited to within the ring road, which is almost equal to the Yamanote Rail Line of Tokyo in length (Kobayashi, 2006). Furthermore, the urbanization was confined to the ring road area due to accessibility to commercial areas and residents moving away from the crowded urban core.

In the 1980s and 1990s, the urban growth of Kathmandu generally occurred in the north-south direction. This was mainly due to the fact that much of the easily accessible land had already been consumed and the land bordering on the west was undulating and difficult to develop, whereas the international airport impeded expansion to the east (ICIMOD, 2007). The space between Kathmandu and Bhaktapur had been filling up with low-density ribbon development (Thapa and Murayama, 2008a). This process has continued until the present.

The challenges and opportunities in Kathmandu have attracted people from different parts of the country. The migration of qualified and well-off people has made it the most competitive city in the country, and has helped in its prosperity (Thapa *et al.*, 2008). Significant increases in movement to the valley from other areas in Nepal over the last several years have occurred as a result of political turmoil and unemployment in the rural areas. This migration, coupled with natural population increases, has caused tremendous population growth in the valley (Haack and Rafter, 2006).

Chapter Two

Kathmandu Valley: Geography and Urban Development Initiative

2.1 Geographical setting

Kathmandu Valley, a river basin, forms the core of Nepal's most populous metropolitan region. The valley has been important economically, administratively, and politically for hundreds of years. Physiographic boundaries formed by the complex topography play an important role in allocating development resources. Therefore, the valley is delineated based on the watershed boundaries, which were derived from 20-meter digital elevation point data (ICIMOD/UNEP, 2001). The valley is situated between 27°31′55″ to 27°48′56″ North latitude and 85°11′11″ to 85°31′52″ East longitude (Figure 2-1). The valley is composed of five municipal urban centers (Kathmandu, Lalitpur, Bhaktapur, Kirtipur, and Madhyapur Thimi), in addition to 97 surrounding villages. The study area covers 684 km^2, and the urban centers make up only 14% of the land.

The elevation in the valley ranges from 1,100-2,700 meters above the sea level, and forms complex topography within a small geographic area. Half of the study area has slopes of less than 5 degrees, while more than 20% of the land has slopes greater than 20 degrees. This tectonic valley is a Tertiary structural basin covered by fluvial and lacustrine sediments, and encircled by mountains on all sides (Pradhan, 2004). The climate of the valley is sub-tropical cool temperate. The maximum and minimum temperatures in 2003 were 29.7°C in May and 2°C in January, respectively, whereas annual average rainfall was 1,740 mm; these represented the greatest temperature and rainfall of the past decade (CBS, 2005). Most of the precipitation occurs between June and August as a result of southeast monsoon winds. Some rainfall occurs during the winter, brought by trade winds from the northwest (HMGN, 1969). Annual average humidity in the valley is 75%.

The valley is drained by the Bagmati river system. The river system is the main source of water for drinking and irrigation in the valley (Thapa *et al.*, 2008). There are two landform units in the valley: the alluvial plains along the rivers, and the elevated river terraces, locally called '*tars*'. In the city core area, the slopes are very low (less than 1 degree), and the soils have a predominantly loamy and boulder texture (Haack and Khatiwada, 2007). Historically, the valley used to be considered highly productive agricultural land. Major crops cultivated in the valley include rice, wheat, maize, potatoes, mustard, and a number of oil seeds (Photo 2-1). A large variety of vegetables are increasingly grown throughout the year, providing fresh products to the urban population (Bohle and Adhikari, 2002).

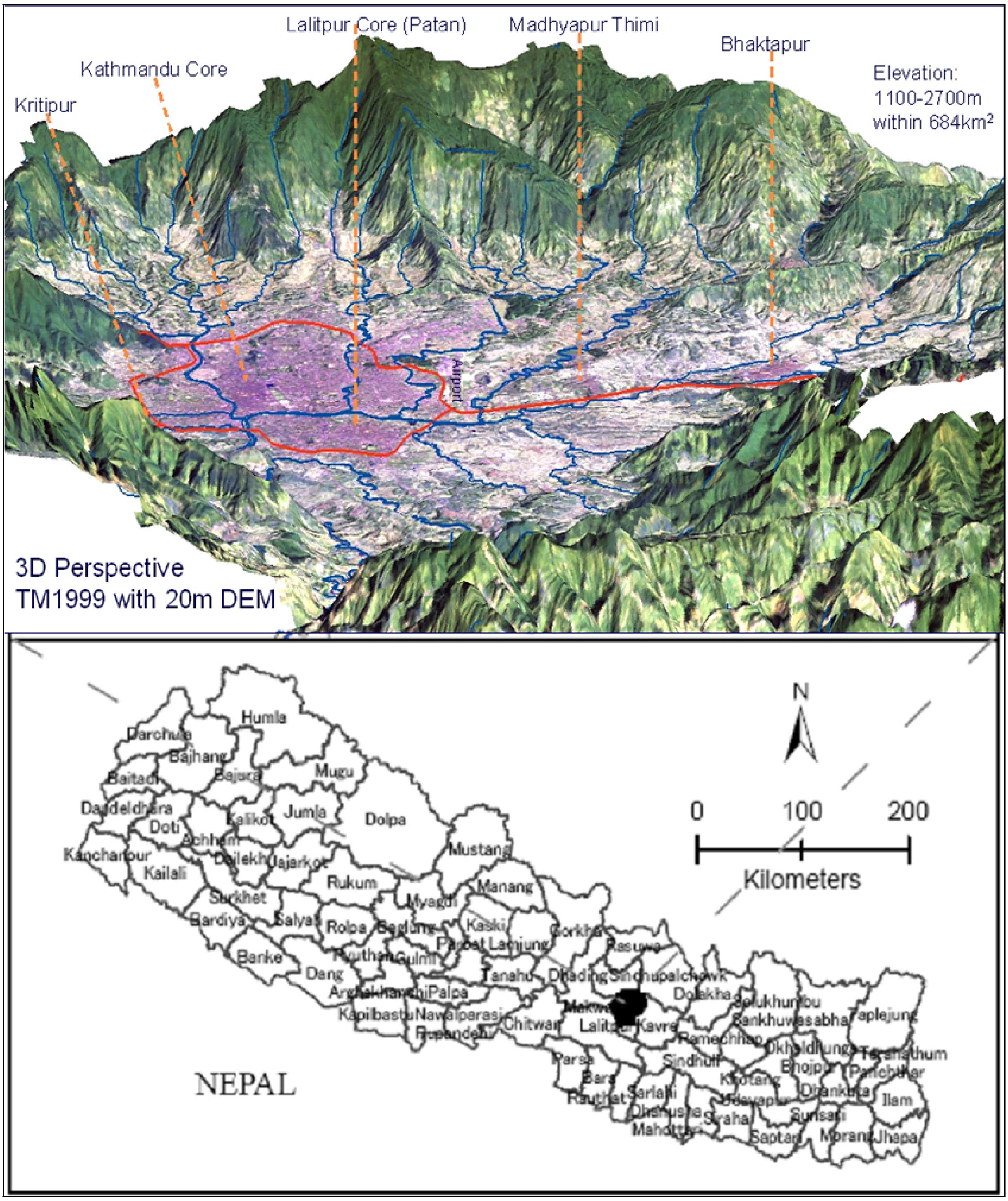

Figure 2-1: Study area – Kathmandu Valley.

Data source: ICIMOD/UNEP (2001); LANDSAT TM (1999.11.04)

Photo 2-1: Agriculture landscape in Kathmandu Valley.

Photo by the author.

Note: Kathmandu Valley is one of the most productive agricultural regions in Nepal. The soil contains high nutrition for agriculture. Most of the valley floor, and much of the terraced valley walls, are intensively cultivated. Due to easy access to the market center and high demand of perishable goods in the urban area, farmers are encouragingly growing cash crops (Bohle and Adhikari, 2002).

2.2 Demographic pattern

Kathmandu valley became accessible to people from other parts of the country and the foreigners beginning in the 1950s. The construction of highways and air service, along with improving developmental activities and trades with India and Tibet, led the rapid urban development in the valley (Shrestha *et al.*, 1986; Thapa *et al.*, 2008). Due to economic opportunities and urban facilities, Kathmandu became the center of attraction for people from all parts of the country and adjacent neighboring countries (Photo 2-2). Currently, 1.5 million people live in the valley (CBS, 2001), of which 66% are in urban areas (i.e., 98 km^2, 14% of the total land). As a result, the annual growth rate of the urban population in the valley has accelerated from 1.3% in 1952 to 5.2% in 2001. The total urban population in the valley was 0.2 million in 1952-1954, and had increased by 5 times by 2001 and is expected to reach 2.6 million by 2031 (Figure 2-2).

The average population density in the valley is 2,300 persons/km^2; however, it varies by settlement in the range of 70-13,000 persons/km^2 (Figure 2-3A). The valley floor is densely populated, with more than 6,000 persons/km^2. A lower population density is observed at greater distances from the city core, and is mostly composed of villages located at higher elevations. Fringe villages adjacent to the urban areas have faced rapid population growth, having increased by more than 100% in the last decade. However, some remote villages in the valley have experienced depopulation.

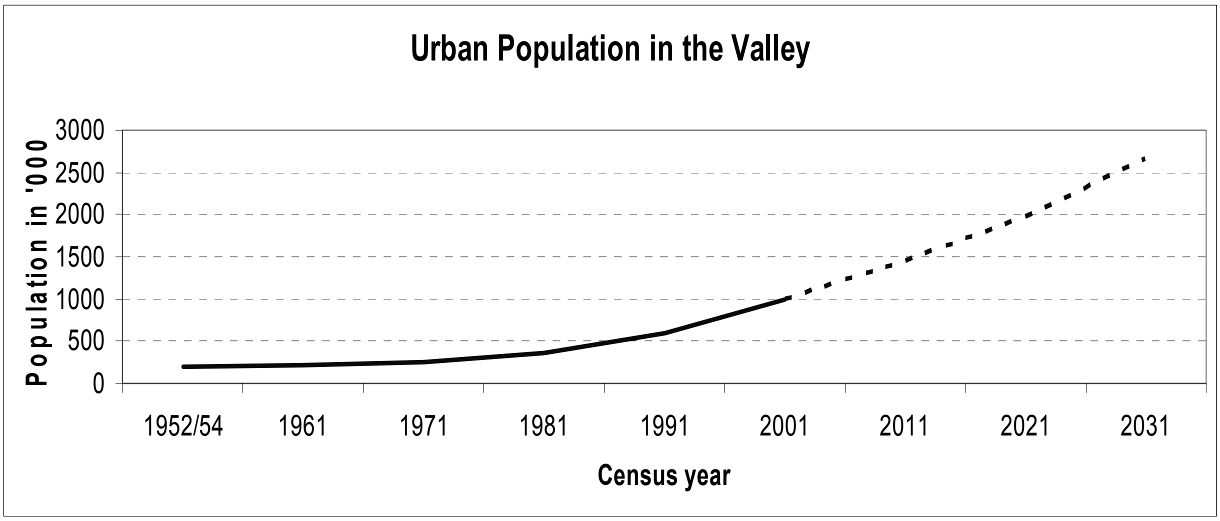

Figure 2-2: Urban population in Kathmandu Valley.

Data source: CBS http://www.cbs.gov.np/.

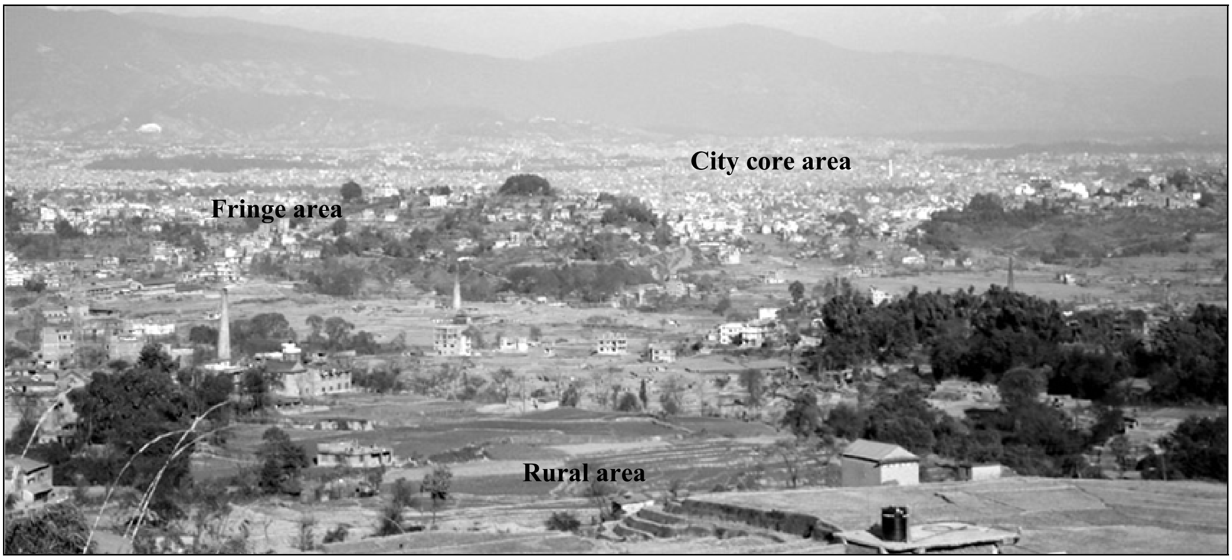

Photo 2-2: Kathmandu Valley landscape.

Photo by the author.

Note: The photograph shows rural agriculture villages, fringes and city core areas. Hillocks in the fringes are being urbanized rapidly.

The challenges and opportunities of Kathmandu have attracted people from different parts of the country. Almost 32% of the total population is migrants from other parts of the country. Migration within the valley, from rural areas to urban fringes, has also occurred, but data on this are unavailable. Almost every village has migrants, but higher concentrations are observed in close proximity to the urban areas (Figure 2-3B).

CBS (2004) reported that the reasons for migration in the valley include ‘family reasons’ (54%), ‘looking a job’ (18%), an ‘easier lifestyle’ (14.2%), ‘education/training’ (9.1%), ‘natural disasters’ (0.6%), ‘political reasons’ (0.3%), and ‘other purposes’ (3.8%). In Nepal, most women have to go to their husband’s house after marriage, which might be considered as the major factor for migration due to ‘family reasons’ in Kathmandu.

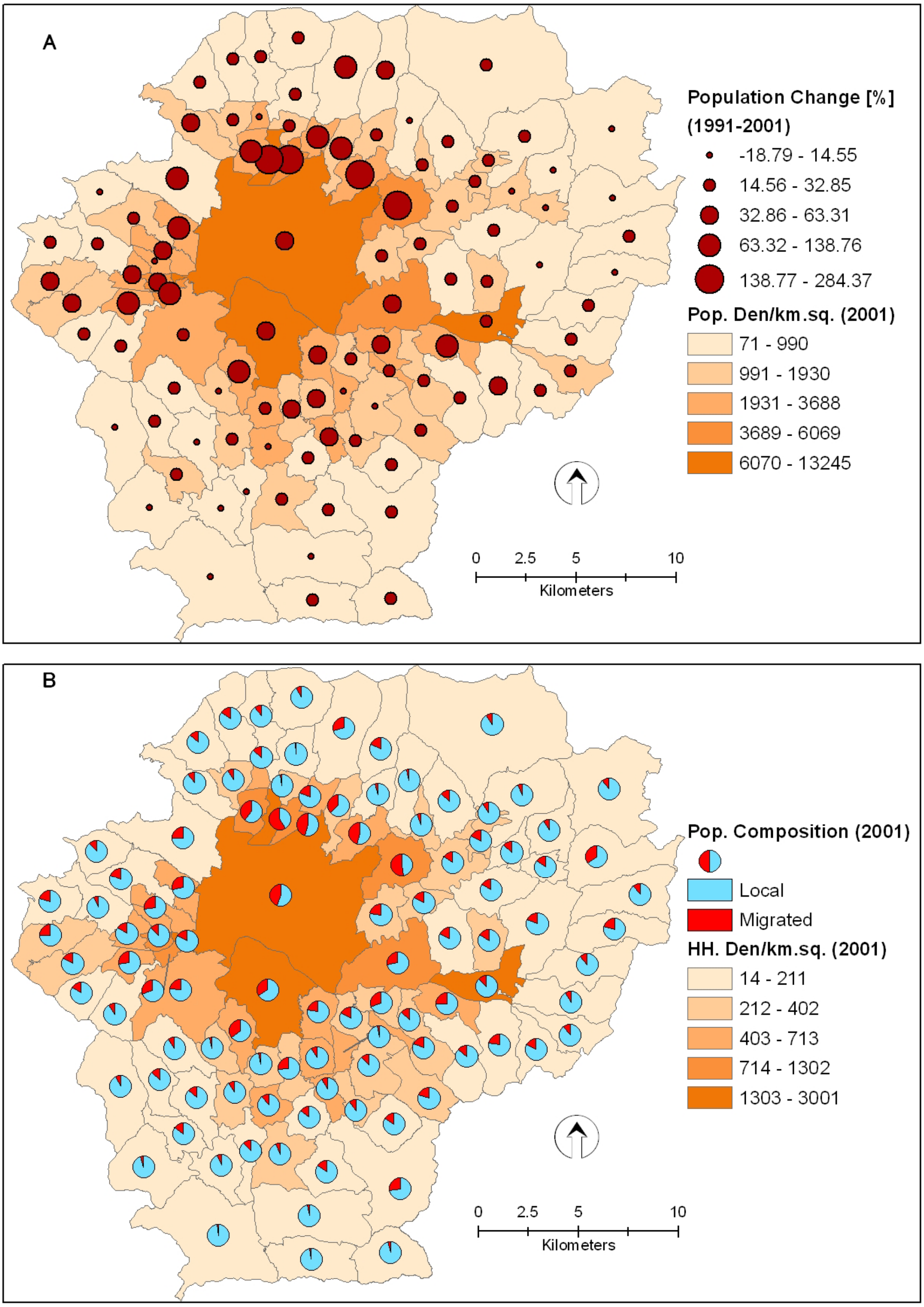

Figure 2-3: Population characteristics in Kathmandu Valley

Data source: CBS, (2001); ICIMOD/UNEP (2001).

2.3 Economy and employment pattern

Migration of qualified and well-off people has made Kathmandu the most competitive city in the country, and has helped in its prosperity. According to the population census of 2001, 44% of the total population in the valley is economically active, and the remainder was considered inactive, including children (CBS, 2001). The majority of the active population, as compared to the inactive population, is largely distributed in the fringes and rural areas (Figure 2-4A). The population of the city core area is evenly divided between active and inactive. The valley seems to be agriculture oriented, with 53% of the total households (212,971) involved in this sector (CBS, 2001).

Figure 2-4B shows that a large proportion of the households with non-agricultural activities is concentrated in the urban core and in some adjacent villages located in the north and north-east areas. They mostly involved in manufacturing, trade/business, transportation, and other services. However, the spatial pattern suggests that the majority of the households scattered in and around the metropolitan fringes is engaged in agricultural activities. In these areas, the farmers grow rice, wheat, maize, beans, mushrooms, vegetables, a variety of fruits including bananas and oranges, and raise cattle and poultry as livestock. New types of services have been emerging, such as internet/cyber parlors, computer services, photocopying, communications, call centers, and tourism-related business in the valley (MoF, 2005; ICIMOD, 2007).

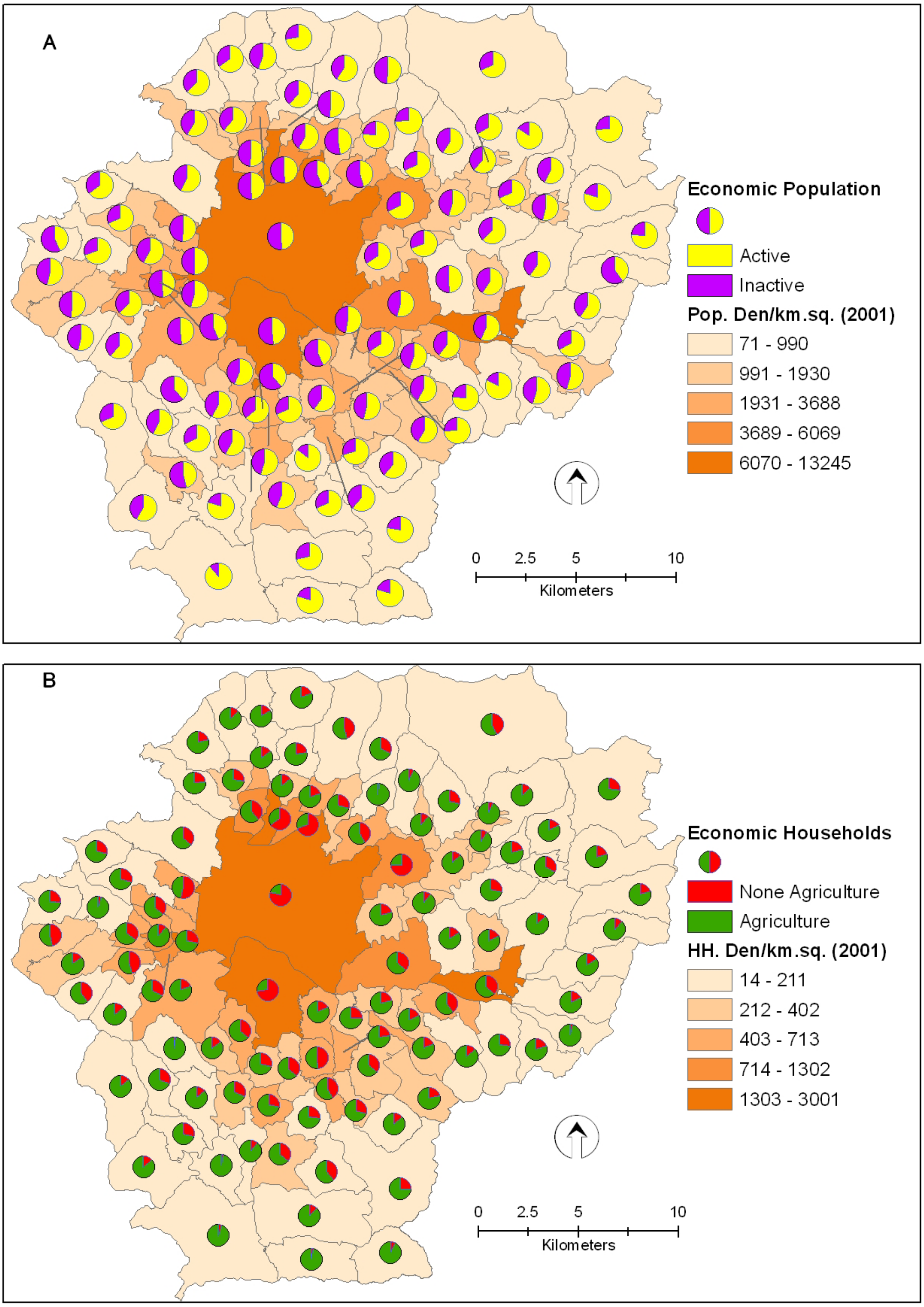

Figure 2-4: Economic characteristics in Kathmandu Valley

Data source: CBS, (2001); ICIMOD/UNEP (2001).

Both manufacturing and cottage industries have developed in the valley. Manufacturing industries include food processing and beverages, home appliances, garments and carpets, bricks and construction materials, and machinery. Three industrial estates, Balaju, Patan, and Bhaktapur, were established in 1960, 1963, and 1979, respectively. A total of 237 industries registered in these estates provide employment to 6,022 people (IDM, 2007).

Apart from these estates, more than 500 industries, providing an additional 50,000 jobs, are scattered near the major highways in the valley, especially the Tribhuvan Highway and Araniko Highway (Thapa *et al.,* 2008). The carpet industry is concentrated in and around the Swayambhu and Boudha areas. Brick kilns (Photo 2-3) are mostly concentrated in the southern part of the urban region in close proximity to the ring road. Often the laborers are seasonal migrants from the hills of Nepal. About 30,000 people were estimated to be employed in brick production in the valley in 2001 (Haack and Khatiwada, 2007). A significant number of jobs are also provided by tourism sector industries, agriculture and forestry industries, construction, administration, trade, health, and education (Gautam *et al.*, 2004).

Due to market globalization, rapid development in information technology, and high income received from labor exports in the last decade, the per capita income of Kathmandu has increased from NRS 24,084 (US$ 437) in 1996 to NRS 45,816 (US$ 705) in 2004 (CBS, 2004)[1]. The per capita income of the Kathmandu has remained higher than other urban areas (US$ 209 in 1996 and US$ 391 in 2004) in the country.

[1] US$ was computed @55 NRS in 1996 and @65 NRS in 2004.

Photo 2-3: Brick factories in Kathmandu Valley

Photo by the author.

Note: Most of the housing structures in the valley are built by bricks. Many brick factories can be seen around the urban periphery of Kathmandu. The bricks are made from the rich valley soils, the same soils used for agriculture. The brick kilns are intense in several locations of the Valley and have an interesting pattern of using the same lands for bricks during the dry season and then conversion to rice during the wet, summer monsoon months (Haack and Khatiwada, 2007), an interesting seasonal land use pattern.

2.4 Urban development initiatives

Construction of the Tribhuvan Highway in the 1950s, linking the region to India, and the Araniko Highway to China in the 1960s (DoR, 2004) increased commercialization and external influences in Kathmandu. These roads also enabled people from outer regions to migrate into Kathmandu. Nepal's first and only international airport was constructed in 1949, and flights to some Indian cities started in the late 1950s, helping to attract more people around the world to Kathmandu. Along with the establishment of infrastructure, which allows easy access to the city, the agglomeration of rural settlements of the valley into the city began in the early 1960s (Ranjitkar and Manandhar, 1981; Thapa *et al.,* 2008).

A planned development effort was started in Nepal after the abolition of the Rana regime, although the first development agency was established in 1935 (NPC, 2002). A planning approach to development in Nepal began in 1956 with the formulation of the First Plan (1956-1961). Ten periodic plans have been executed, and the Eleventh Plan is currently being implemented. A first physical development plan of Kathmandu valley was finalized in 1969 to accelerate the urban development process of the valley (HMGN, 1969). The plan aimed to preserve the historical and cultural heritage, guide urban development through land use planning, and enhance population densification in fringe areas. The plan adopted the multi-nucleated regional growth strategy with linkage of dispersed settlements in the valley, continuation of existing growth tendencies of the Kathmandu-Patan complex, and the bipolar development of Bhaktapur by reinforcing transportation linkages and expanding settlement. The government promulgated a Town Development Implementation Act in 1972 to implement the plan. The Kathmandu Valley Town Development Committee (KVTDC) was formed under this act in 1976 in order to assign overall responsibility of planning and regulating urban growth in the Kathmandu valley.

In 1976, the Kathmandu Valley Town Development Plan (KVTDP) formulated three broad zoning concepts: Zone A as the city core (Kathmandu and Lalitpur), Zone B as the fringe areas, and Zone C as planned settlements in rural villages of the valley. The plan prepared by the KVTDC led to the construction of a ring road (27.8 km) around the Kathmandu and Lalitpur municipalities in the late 1970s that significantly assisted the urbanization process in the rural areas in the city periphery. Later, the KVTDC launched two programs, the guided land development and land-pooling schemes. In order to cope with rising issues and problems caused by the rapid urbanization trend in the valley, the KVTDP was revised in 1984, and was renamed the Kathmandu Valley Physical Development Concept (KVPDC). In this plan, major focuses were given to transportation facilities, protection of arable land, and the improvement of the environment (HMGN, 1991).

The government prepared a Structural Plan of Kathmandu Valley in 1987 aimed at providing guidelines for the physical development of metropolitan Kathmandu through 2010. Zoning was proposed to preserve agricultural lands and environmentally sensitive areas. Because the political situation changed in 1990, this plan was not implemented (ICIMOD, 2007).

In 1991, the Kathmandu Valley Urban Development Plans and Programs was prepared, which made various strategic recommendations related to land use, the environment, infrastructure, financial investments, and intuitional aspects of the urban development in the valley (HMG, 1991). Urban expansion was focused on greater Kathmandu (Kathmandu and Lalitpur) extending past the ring road and the present municipal boundaries. The government published the Environment Planning and Management of the Kathmandu Valley in 1999. This document focused on the analysis of existing ecological and environmental problems in Kathmandu valley and possibilities of limiting the growth of Kathmandu through secondary adjoining towns (Adhikari, 1998; IUCN, 1999).

In 2002, the KVTDC prepared a Long Term Development Concept for Kathmandu Valley (*Kathmandu Uptyakako Dirghakalin Bikas Avadharana - 2020*), which is the latest planning document for the next 20 years. This plan focuses on developing Kathmandu as the central city core, Lalitpur and Bhaktapur as sub-city cores; surrounding satellite market centers (Gokarna, Thimi, Kritipur, and Harisiddhi as towns, Thankot, Tokha, Snkhu, Lubhu, Chapagaon, and Pharping as traditional settlements, and Nagarkot and Saibu Bhaisepati as nucleated centers (KVTDC, 2002). Local municipal governments, including Kathmandu Metropolitan, Lalitpur Sub-Metropolitan, Bhaktapur Municipality, Kirtipur Municipality, and Madhyapur Thimi Municipality, are also involved in designing and implementing urban development plans at the local level (Pradhan and Perera, 2005).

Chapter Three

Methodology in Land Use Mapping and Modeling of Driving Factors

3.1 Data collection strategy

Because of the lack of temporal and spatially consistent datasets for the valley, multi-temporal satellite images with high resolution (CORONA, SPIN, and IKONOS) to moderate resolution (LANDSAT MSS and TM) were processed to identify the temporal changes in landscape patterns since the 1960s. The high resolution images are only available for limited areas in the valley; therefore, most care was given to the LANDSAT MSS and TM images. Because of the mountainous terrain and topographic complexity in the study area, the elevation data was also considered as an important source of information. The data collected through interviews and site observations during the course of fieldwork were also used. A detailed list of the data used in this study is shown in Table 3-1.

In addition to using the data prepared by different agencies, two fieldwork sessions (March-April 2007 and December 2007-January 2008) were conducted to acquire first hand data required for the research. Most of the essential data for improving mapping accuracies and investigating driving factors of spatial changes were collected through the fieldwork (Appendix I). Landscape observations, meetings with experts, and AHP structured interviews (Appendix II) were conducted in the valley.

A PDA (Personal Digital Assistant) with a built-in GPS (Global Positioning System) equipped with a data entry form and navigation map and a handheld digital camera were used for collecting the geographic data, and recording perspective views of the locations for laboratory analysis. More than two hundred geographic locations, represented by points and polygons and their corresponding attributes, were collected in the field, representing core, fringe, and rural areas. The data represent both homogeneous and heterogeneous landscape environments in the study area. The GPS coordinates and photographs of each location were used for updating the land use maps.

Table 3-1: List of database used in this research

Data types	Year	Resolution/scale	Sources
Satellite imageries			
CORONA	1967.02.05	1 Meter	USGS
LANDSAT MSS	1976.10.28	57 Meter	University of Maryland
LANDSAT TM	1989.10.31	30 Meter	University of Maryland
SPIN-2	1991.xx.xx	2 Meter	USGS
LANDSAT TM	1999.11.04	30 Meter	University of Maryland
IKONOS	2000.xx.xx	1 Meter	GeoEye, Space Imaging
QuickBird	2007.xx.xx	0.6 Meter	Google Earth
Aerial photographs	1979, 1981, 1992, 1998	-	Survey Department, Nepal
Vector layers			
Spot height (points)	1995	20 Meter	ICIMOD/UNEP (2001)
Land cover map	1978	-	ICIMOD/UNEP (2001)
Land use map	1995	1:25000	ICIMOD/UNEP (2001)
Road map	2000	-	ICIMOD/UNEP (2001)
Paper maps			
Cadastre	2002	1:500	Survey Department, Nepal
Socioeconomic data			
Population census data	1991, 2001		CBS (1991,2001, 2004)
Ancillary data: Literatures, geographic references, observation and interview	2007.03-04 2007.12-2008.01	-	Kathmandu fieldworks

3.2 Land use mapping

The study mostly relies on satellite data and fieldwork data. The satellite data are in image form and contain many details, but not in an objective thematic setting. Therefore, a series of processing steps is needed to transform those data into meaningful thematic information. In this research, remote sensing, GIS, and fieldwork approaches were applied to prepare the thematic land use maps for the years 1967, 1978, 1991, and 2000.

Geometric correction. Accurate registration of multi-spectral remote sensing data is essential for analyzing the land use and land cover conditions of a particular geographic location (Jensen, 2005; Thapa and Murayama, 2007). The geometric rectification process was carried out for all satellite images, including aerial photographs, using a road network map in the local projection system (i.e., UTM WGS 1984). Sufficient ground control points were selected to rectify the images. A first-order polynomial linear transformation function was used with an acceptable root mean square error (less than 1 pixel) on each satellite image.

Ground reference data. In image analysis, ground reference data play important roles in determining information classes, interpreting decisions, and assessing the accuracy of the results. Substantial reference data and a thorough knowledge of the geographic area are required in this stage. In this study, sufficient data were collected from the fieldwork and higher resolution imagery acquired from airborne and space-borne sensors, as well as city planning maps and other documents (see Table 3-1). Using all of these data, detailed ground reference data of the study area were prepared for land use class scheming, image classification, and subsequent accuracy assessments.

Land use class scheming. The classification scheme provides the framework for organizing and categorizing information that can be extracted from image data (Thapa and Murayama, 2007). A proper classification scheme includes classes that are both important to the study and discernible from the data on hand (Anderson *et al.*, 1976). Image enhancement, contrast stretching, and false color composites were created to improve the visual interpretability of the image by increasing the apparent distinctions between the features. Knowledge-based visual interpretation, texture, and association analysis were performed at the preliminary stage. Furthermore, field survey data, aerial photographs, high resolution satellite images, and city planning documents were carefully analyzed while preparing the classification scheme.

A color composite evaluation with multiple bands was applied to each LANDSAT satellite image of the study site. For example, the false color composite (Bands 4, 3, and 2 as Red, Green, and Blue, respectively) clearly shows the water bodies in black, rice paddy fields in pink, vegetation in dark red, and urban surface materials as light blue. It was difficult to distinguish dry farm land and exposed field in the false color images, but this is distinguishable in another false color combination (Bands 7, 5, and 2 as Red, Green, and Blue, respectively). Identification of asphalt surfaces in the images is easier, but the association of this surface type in the study area makes it difficult to consider it as an indicator of the urban land use pattern (Thapa and Murayama, *in press*). Most of the roads are made of asphalt, and are associated with residential, business, and industrial areas. After analyzing all the information collected so far, only twelve types of land uses were considered for mapping, i.e., *agricultural areas, forest, shrubs, open space, water, built-up areas, industrial areas, roads, airport, institutional areas, government secretariat area,* and *royal palace*. The last six land uses cover nominal spaces in the valley; therefore, these land uses were merged into an *urban/built-up area* category (Table 3-2) for detailed quantitative assessment purposes. However, all twelve legends were mapped in the land use maps.

Table 3-2: Land use type and corresponding descriptions

Land use type	Descriptions
Shrubs	Shrubs, grass and pasture lands
Forest	All types of forest
Water	Rivers, lakes and ponds
Urban/Builtup area	Road, industrial areas, airport, administrative and institutional areas, palaces, and compact settlements.
Open space	Park, playground and golf course
Agricultural area	Paddy field, vegetable and fruits farms, dry farmlands

Mapping. Although remote sensing has been widely applied in determining where, how much, and what kinds of landscape changes have occurred, considerable uncertainty continues to exist in the quality and scope of spatial data for landscape models. In particular, we need more standardized and improved mapping methods for incorporating multiple data sources in topographically constrained areas to analyze spatial patterns, dynamics, and causes.

Mapping techniques that combine more than one procedure, often called hybrid mapping approaches, improve the accuracy of remote sensing based land use and land cover maps (Lo and Choi, 2004; Lillesand *et al.*, 2008; Thapa and Murayama, *in press*). These approaches provide better results than using only a single approach (Kuemmerle *et al.,* 2006; Thapa and Murayama, 2008a). Therefore, a hybrid approach was developed for Kathmandu valley, considering the data and topographic constraints (Figure 3-1).

An unsupervised approach with the ISODATA clustering technique was applied to obtain different land use clusters of similar spectral pixels in the MSS and TM images. This preliminary interpretation reduced the artificial errors and selected the most appropriate clusters for further processing. According to the land use classification scheme specified in Table 3-2, the supervised approach with the maximum likelihood parameter was run to improve the accuracy of the land use classification for the images for all three dates (1976, 1989, and 1999). At least 20 areas of interest for each class were created for editing signatures and comparing the error matrices. The image classification accuracy was performed by evaluating the overall classification accuracy using geographically referenced datasets. Four measures (producer's, user's, and overall accuracy, and the K_{hat} statistic) of accuracy assessment were computed to evaluate the accuracy of the thematic maps (see Appendix III for details).

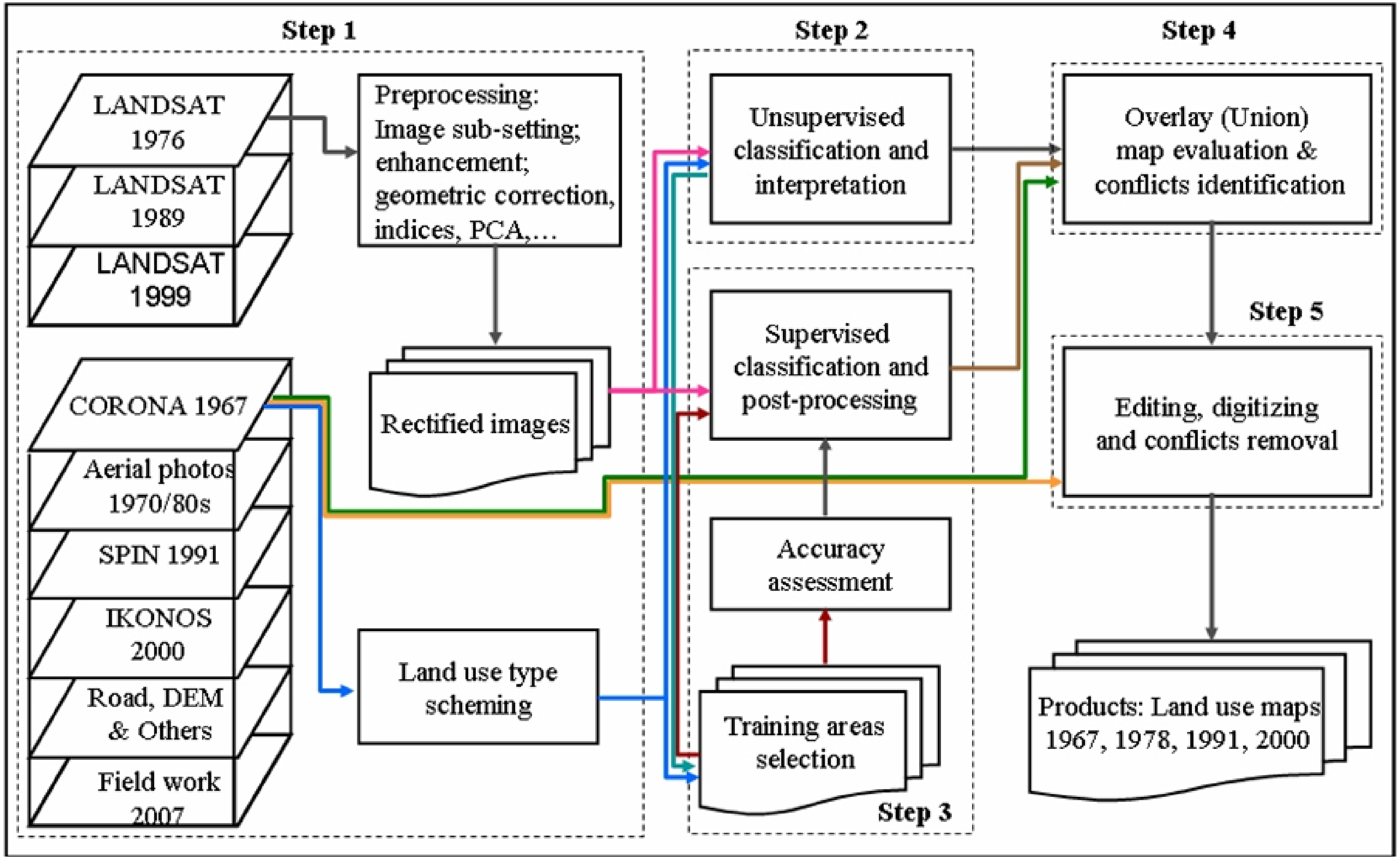

Figure 3-1: Hybrid scenario for land use mapping from remote sensing images.

Because of the complex topography in the valley, land use types are closely related to altitude and slope and have some specific distribution rules. Confusion areas were detected mostly between the water areas and shadows of mountain areas; bare lands, brick factories, and construction sites; and golf course and shrub lands. The areas of confusion were further verified with DEMs and slope data, road data, the 1978 land cover map, high resolution imagery, including CORONA (1967), SPIN (1991), IKONOS (2000), aerial photographs acquired at different time periods, and fieldwork information to determine the appropriate land use type (see Table 3-1). Editing and digitizing were carried out to resolve all the confusion and conflicts that occurred in each map. This process helped to improve the accuracy of the mapping. After updating the maps, the reference year of each map was changed to 1978, 1991, and 2000, respectively. The CORONA image was manually digitized to prepare the land use map for 1967.

3.3 Investigating spatial pattern changes

The land use transition matrix is a useful tool that has been widely accepted in land use change analysis (Tang *et al.,* 2005; Yu and Ng, 2006; Xiao *et al.,* 2006). Three land use transition layers for the years 1967-1978, 1978-1991, and 1991-2000 were prepared for the detailed land use change pattern analysis in the valley.

A set of landscape metrics were selected to measure and monitor the landscape fragmentation, land use complexity, proximity, dominancy, and diversity (Table 3-3). The selected metrics are patch density (PD), largest patch index (LPI), edge density (ED), area weighted mean patch fractal dimension (AWMPFD), Euclidian nearest neighbor distance mean (ENNMN), cohesion (COHESION), contagion (CONTAG), and Shannon's diversity index (SHDI). These metrics can reflect their conceptual basis and describe the composition and configuration of landscape pattern changes in the valley.

Table 3-3: Description of spatial metrics used in this study

Metrics	Description	Units	Justification
PD	PD equals the number of patches of a specific land cover class divided by total landscape area.	No./ 100 ha.	A measure of fragmentation
ED	The sum of the lengths of all edge segments involving a specific class, divided by the total landscape area multiplied by 10000.	Meters/ ha	A measure of fragmentation
LPI	The area of largest patch of the corresponding class divided by total area covered by that class, multiplied by 100.	Percent	A measure of dominance
ENNMN	The distance mean value of all patches of a land use to the nearest neighbor patch of the land use based on shortest edge-to-edge distance from cell centre to cell centre.	Meters	A measure of isolation/ proximity
AWMPFD	It describes the complexity and fragmentation of a patch by a perimeter-area ratio. Lower values indicate compact form of a patch. If the patches are more complex and fragmented, the perimeter increases representing higher values.	None, range: 1-2	A measure of fragmentation and complexity
COHESION	Approaches 0 as the portion of the landscape comprised of the focal class decreases and becomes increasingly subdivided and less physically connected.	None, range: 0-100	A measure of physical connectedness
CONTAG	Contagion index describes the fragmentation of a landscape by the random and conditional probabilities that a pixel of patch class is adjacent to another patch class. It measures to what extent landscapes are aggregated or clumped.	None, range: 1-100	A measure of fragmentation and the degree of aggregation
SHDI	Shannon's diversity index quantifies the diversity of the landscape based on two components: the number of different patch types and the proportional area distribution among patch types.	Information	A measure of patch diversity

Source: McGarigal et al. (2002)

The metrics were computed for each land use map at the class and landscape levels. Metrics at the class level are helpful for understanding landscape development, while those at the landscape level provide relatively general information on the assessment (O'Neill *et al.*, 1988; Jaeger, 2000; Turner *et al.,* 2001; Herold *et al.,* 2003; Torrens, 2006; Thapa and Murayama, 2008a). All these metrics were calculated using the FRAGSTAT software (McGarigal *et al.,* 2002).

3.4 Modeling of driving factors using AHP

Driving factors are usually correlated, and it is possible that one factor can affect another directly or indirectly through several factors in the urbanization process (Turner *et al.*, 1990; Naveh, 2001; Verburg *et al.*, 2004; Zhang and Huang, 2006). However, these factors are difficult to understand without reference to the relationships between the factors that affect the land use changes. To understand the process of urbanization in the valley, Saaty's (1980) analytic hierarchy process (AHP) was selected, as it can model an expert's decision collected through interviews and provides rigorous quantitative measures to describe the relationships between the factors.

AHP is one of the best known comparative ratings of the importance of various factors, which are extracted from stakeholders and then analyzed to produce a set of consensus weights using a fairly common form of matrix algebra (Banai-Kashani, 1989; Goodchild, 2006). The technique is based on a pairwise preference comparison of elements (attributes or alternatives), and results in a comparison matrix where the relative importance of each element or factor is determined numerically. The technique also has a scientific basis where the consistency of the driving factor evaluation can be judged. Kauko (2004) argued that most of the classical multi-attribute modeling approaches are based on the assumption of explainable utility functions, but the AHP does not assume that the evaluator is able to express his or her overall elicitation of the problem as one function. Instead, the AHP is based on the assumption that the relevant dominance of one attribute over another can be measured by a pairwise comparison of preferences, systematically made on each level of a hierarchy of factors (Saaty, 1980; Banai-Kashani, 1989; Ramanathan and Ganesh, 1994; Malczewski, 1999).

In using AHP to model a problem, one needs a hierarchical structure to represent that problem, as well as pairwise comparisons to establish relations within the structure (Saaty, 1980). The AHP has been used with absolute or relative types of comparisons to derive ratio scales of measurement (Saaty, 1993; Canada *et al.,* 1996; Malczewski, 1999; Thapa and Murayama, 2008b). In absolute comparisons, alternatives are compared with a standard in one's memory that has been developed through experience. In relative comparisons, alternatives are compared with pairs according to a common attribute. The relative measurement w_i, $i = 1,\ldots, n$, of each of n elements is a ratio scale derived by comparing the elements in pairs with the others. In paired comparisons, two elements i and j are compared with respect to a property they have common. The smaller i is used as the unit and the larger j is estimated as a multiple of that unit in the form $(w_i/w_j)/1$, where an estimate of the ratio w_i/w_j is taken from a fundamental scale of absolute values between 1 and 9 (Table 3-4). The numbers are used to represent how many times the larger of two elements dominates the smaller with respect to a property or criterion they have in common. It is possible to estimate the value between 1 and 2 as 1.1, 1.2, …1.9 if the comparisons scale requires a more precise value.

AHP allows combinations of group judgments and satisfies the reciprocal property for the group in comparing two items in the AHP (Ramanathan and Ganesh, 1994). In this case, one must use the geometric mean rather than the arithmetic mean during linearly combined multiple responses (Aczel and Saaty, 1983; Harker, 1989; Saaty, 1996). Aczel and Roberts (1989) studied possible ways for combining individual judgments into a group judgment and found them to be meaningful statements involving the merged functions.

One of the strengths of the AHP is to measure the degree of consistency present in the subjective judgments made by the decision maker (Aczel and Saaty, 1983; Ramanathan and Ganesh, 1994; Canada *et al.,* 1996; Thapa and Murayama, 2008b). Judgmental consistency is concerned with the transitivity of preference in the pairwise comparison matrices. The AHP includes a measure of consistency for the individual comparison matrix of the decision problem. The consistency ratio CR is an approximate mathematical indicator of the consistency of pairwise comparisons. Saaty (1980) suggested that a consistency ratio less than or equal to 0.10 is acceptable in the decision making process. Lower consistency ranges improve the accuracy. Furthermore, if the consistency ratio of an individual matrix or the entire hierarchy is found to be unacceptable, the decision maker should review the judgments made and look for intransitivity (Canada *et al.,* 1996; Saaty and Vargas, 2001).

In this research, an AHP based fieldwork data modeling framework was developed to evaluate the driving factors of urbanization in the valley for the last decade (Figure 3-2). This model evaluates the consistent weight of each factor through pairwise comparisons (Saaty, 1980; Thapa and Murayama, 2008b). The model questionnaires in the AHP framework are attached in Appendix II. Considering the characteristics of the metropolitan landscape, the valley is further divided into three thematic areas, including the *core, fringe* and *rural* areas. Key criterions adopted to select the respondents were that he/she must have at least a bachelor’s degree of education, have long term residential experience in the valley, and have knowledge about the landscape changes. Furthermore, each key respondent was made aware of the three thematic areas using a map. Each respondent was requested to evaluate the factors for these three areas simultaneously and independently.

Table 3-4: The AHP scale and matrix process

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Source: Saaty (1980)

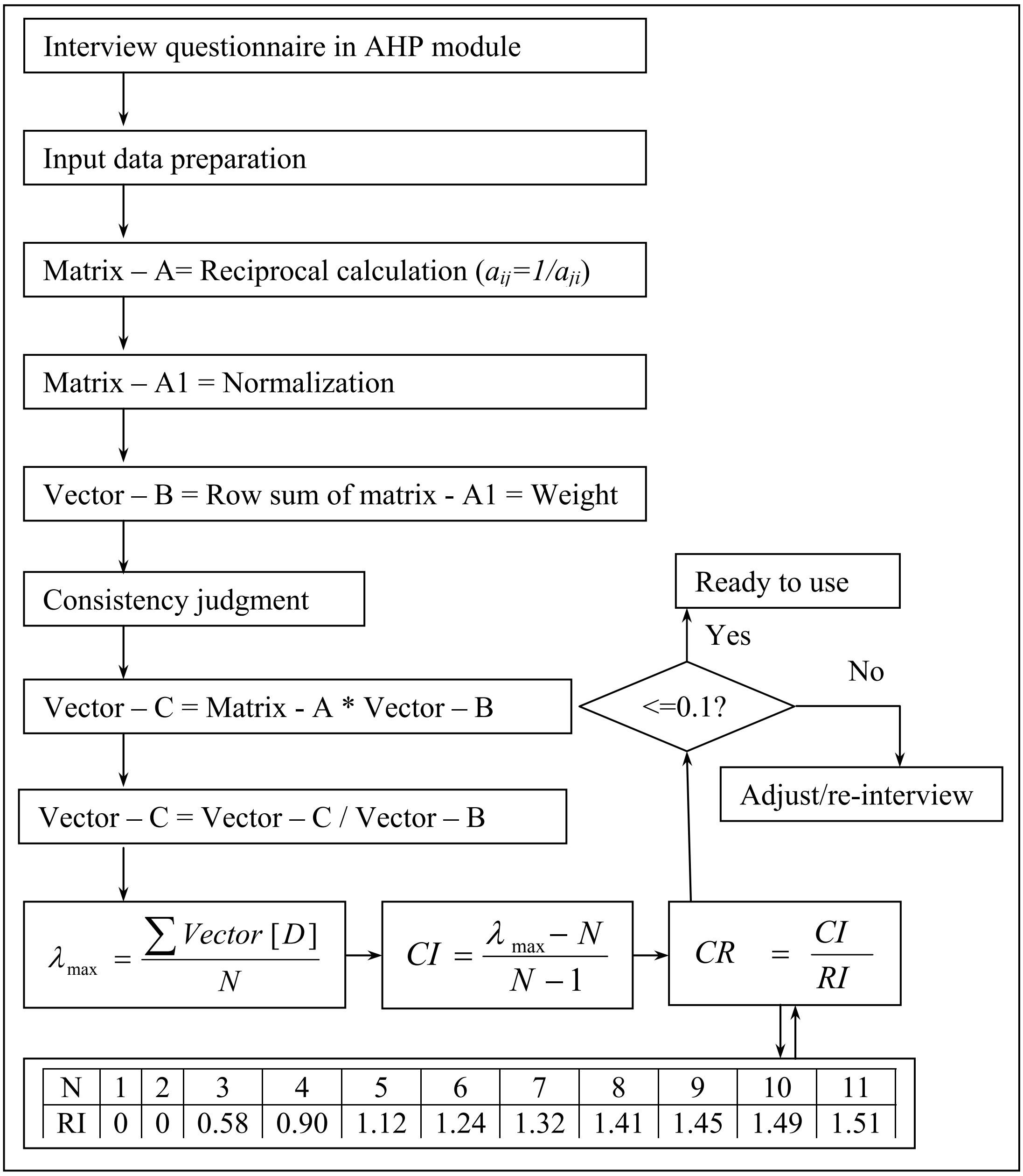

Figure 3-2: Modeling of driving factors in AHP framework.

Chapter Four

Land Use Changes in Kathmandu Valley

4.1 Land use patterns in the valley

Land use statistics and transition matrices are important information to analyze the temporal and spatial changes of land use, and examine the driving forces behind those changes. Figures 4-1, 4-2, 4-3, and 4-4 show the four land use maps for the years 1967, 1978, 1991, and 2000. The urban/built-up areas in the valley had a noticeable increase, from 3% (2,010 ha) of the total land in 1967 to 14% (9,717 ha) in 2000, showing a promising spatial process of urbanization with consistent (5%) growth in 1991 and 2000 (Table 4-1). However, an opposite trend in shrubs (13,563 ha) and forest (15,800 ha) lands was observed, where half of the shrubs land changed to another class by 2000, including a significant disappearance between 1978 and 1991. Similarly, the forest lost 4% of its land over the three and a half decades. However, after gaining a small area in 1978, the forest lost land area in later years.

Agricultural lands still cover half of the valley, but its area has increased and decreased in different time intervals. The agricultural land decreased slightly by 1978, but increased to 56% of the total land by 1991, and had again decreased to 54% in 2000. Only 2% of the total land in the valley is covered by water. A few manmade ponds and the Bagmati river system are the major components of the water coverage. Because water covers a small area, only a nominal pattern of change was found for water. Similarly, the availability of open spaces for recreation and sports purposes in the valley is observed to be very low.

The landscape of Kathmandu valley is diverse and complex and comprises both homogeneous and heterogeneous surface features, which causes problems with the spectral variability in the satellite image data. Assimilating the spectral and radiometric properties of image data is more important than the spatial resolution in improving the accuracy of computer assisted land use and land cover classification (Thapa and Murayama, *in press*). Aggregating the detailed remotely sensed surface characteristics into thematic information always contains some degree of errors, which is further justified by the accuracy assessment process. An acceptable accuracy in supervised image classification, i.e., more than 80%, was achieved in each map (see Appendix III for detailed accuracy assessment results). Therefore, the hybrid technique was used to optimize the maps (Thapa and Murayama, 2008a). According to the hybrid method used in this study, the final land use maps were revisited for conflict removal/digitization process, and corrected as well as possible to minimize the accuracy error. Thus, the final output maps had better accuracies. However, the accuracy still depends on the limited high-resolution data coverage and other data sources. The resulting land use maps in this study may still contain some unavoidable minor errors regardless of these efforts.

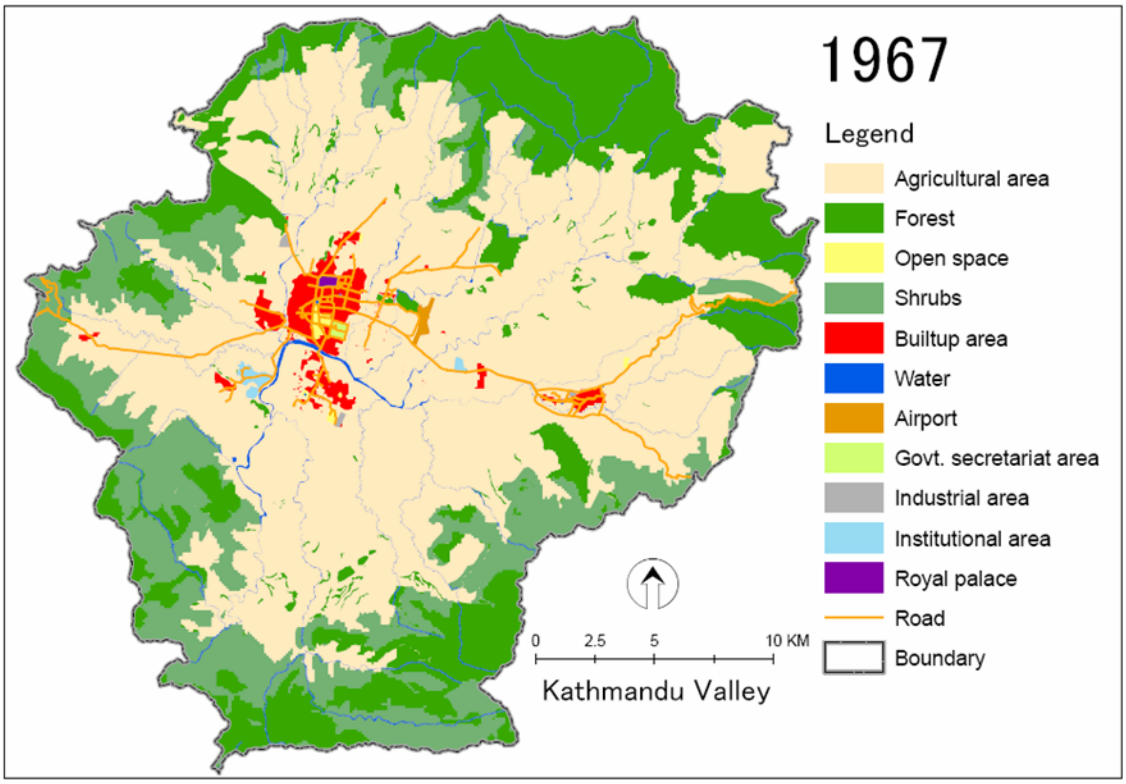

Figure 4-1: Land use map (1967).

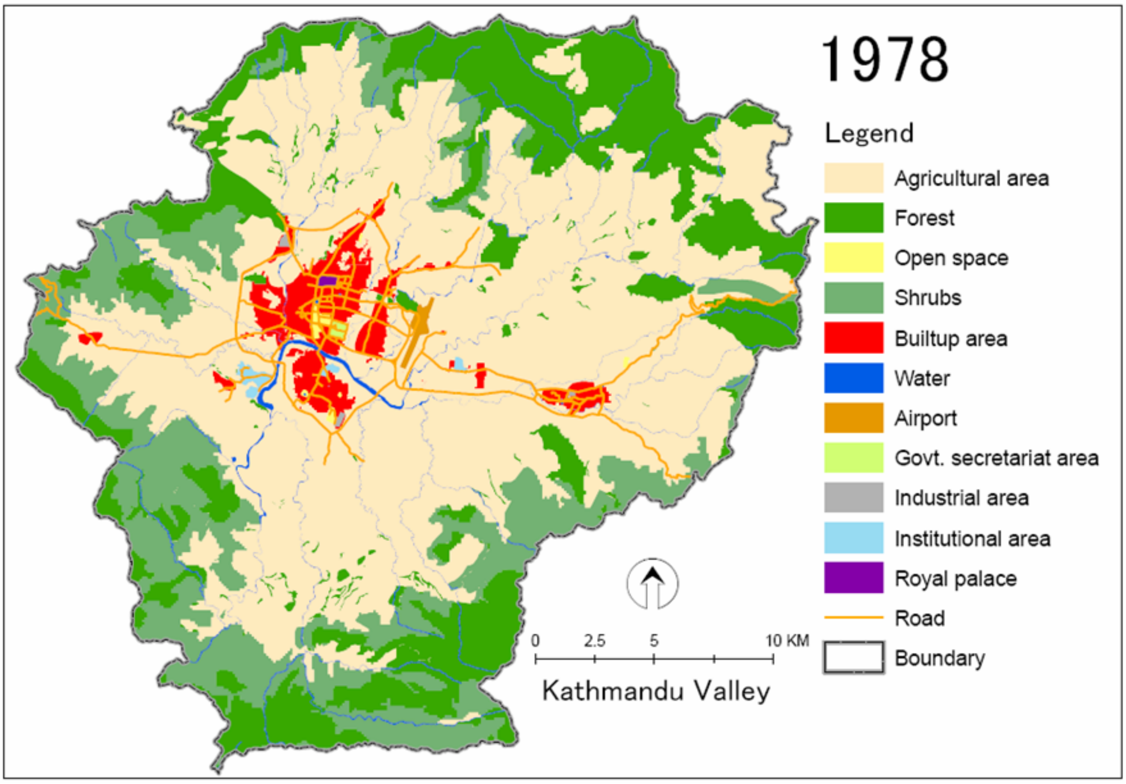

Figure 4-2: Land use map (1978).

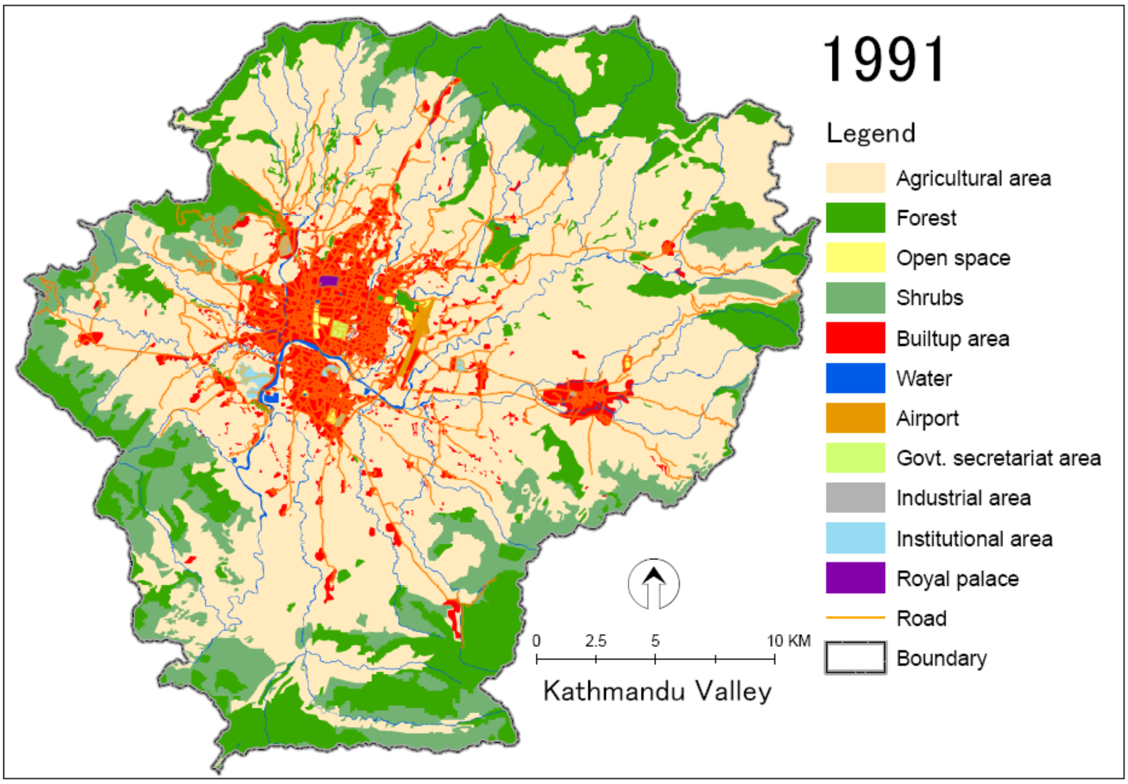

Figure 4-3: Land use map (1991).

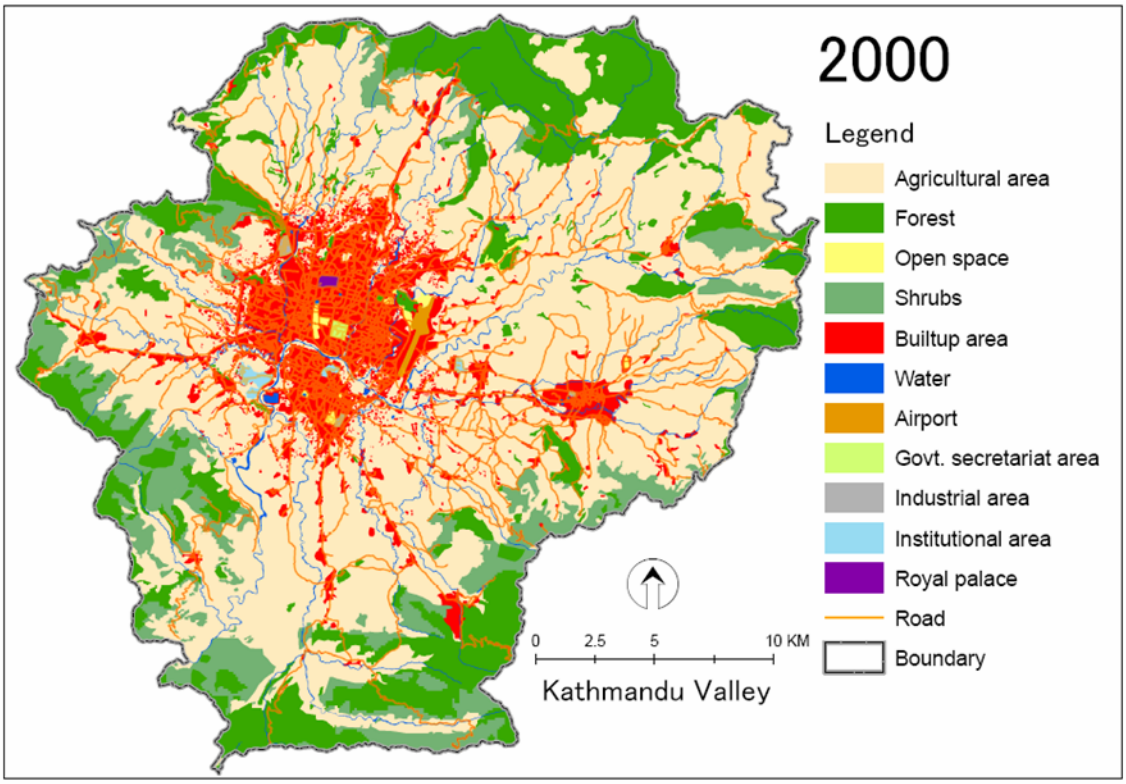

Figure 4-4: Land use map (2000).

Table 4-1: Land use statistics

Year	1967		1978		1991		2000	
Land use type	Hectare	%	Hectare	%	Hectare	%	Hectare	%
Shrubs	13563	19.81	12124	17.71	8129	11.87	7150	10.44
Forest	15800	23.08	16311	23.83	13887	20.29	13301	19.43
Water	1337	1.95	1380	2.02	1341	1.96	1266	1.85
Urban/builtup area*	2010	2.94	3362	4.91	6313	9.22	9717	14.19
Open Space	100	0.15	95	0.14	135	0.20	171	0.25
Agricultural area	35649	52.07	35186	51.40	38652	56.46	36854	53.83
Total	68458	100.00	68458	100.00	68458	100.00	68458	100.00
Classification accuracy+		-		80.66		84.44		83.33

*Aggregation of builtup area, airport, govt. secretariat area, industrial area, institutional area, royal palace, and road.

+The classification accuracy was assessed for each classified image during the supervised classification process (see Appendix III for the details). The Corona image was digitized where no accuracies assessment is required.

4.2 Land use changes

A rough LULC analysis can be done from high resolution satellite data without processing. Figures 4-5 to 4-7, for example, are based on images acquired by earth observation satellites at different time periods over the past four decades. These figures very clearly illustrate the typical pattern of LULC around Kathmandu, or in other words, the urbanization process in Kathmandu. They show the radical transformation of the landscape pattern in the Baneswor area, southeast of the city core, in recent years. In 1967, the area was agricultural land (Figure 4-5), where very few small houses are observed along the road.

This predominantly rural agricultural landscape gradually changed to a peri-urban landscape with increasing human settlement in the 1970s and 1980s. Roads were extended eastward. This can be observed in Figure 4-6, where built-up space can be seen to have spread southeastward from the northwest and the main road. This can be thought of as a spatial diffusion of urbanization outward from the city core. In the image, some housing units can be seen standing alone in the agricultural fields, which is evidence of the start of land fragmentation and indicates a lack of control by urban planning. This pattern of growth reflected the weakness of the earlier plans and programs formulated in the 1970s and 1980s, which often lacked any micro-scale visions for development in the city periphery.

By 2000, lands abutting the main road were almost all occupied by housing units. Until 2000, no more space for agriculture can be observed (Figure 4-7). Almost all spaces have been transformed into built-up areas. Plots are seen to be even further subdivided, and it remains the case that no patterns of planned housing development can be observed. Similar cases are found in other areas of the city periphery. However, a few private builders have started planned housing developments in the city periphery in the late 1990s.

Figure 4-5: Kathmandu Valley floor - Baneswor area, 1967.
Source: CORONA Satellite Image.

Figure 4-6: Kathmandu Valley floor - Baneswor area, 1991.
Source: SPIN Satellite Image.

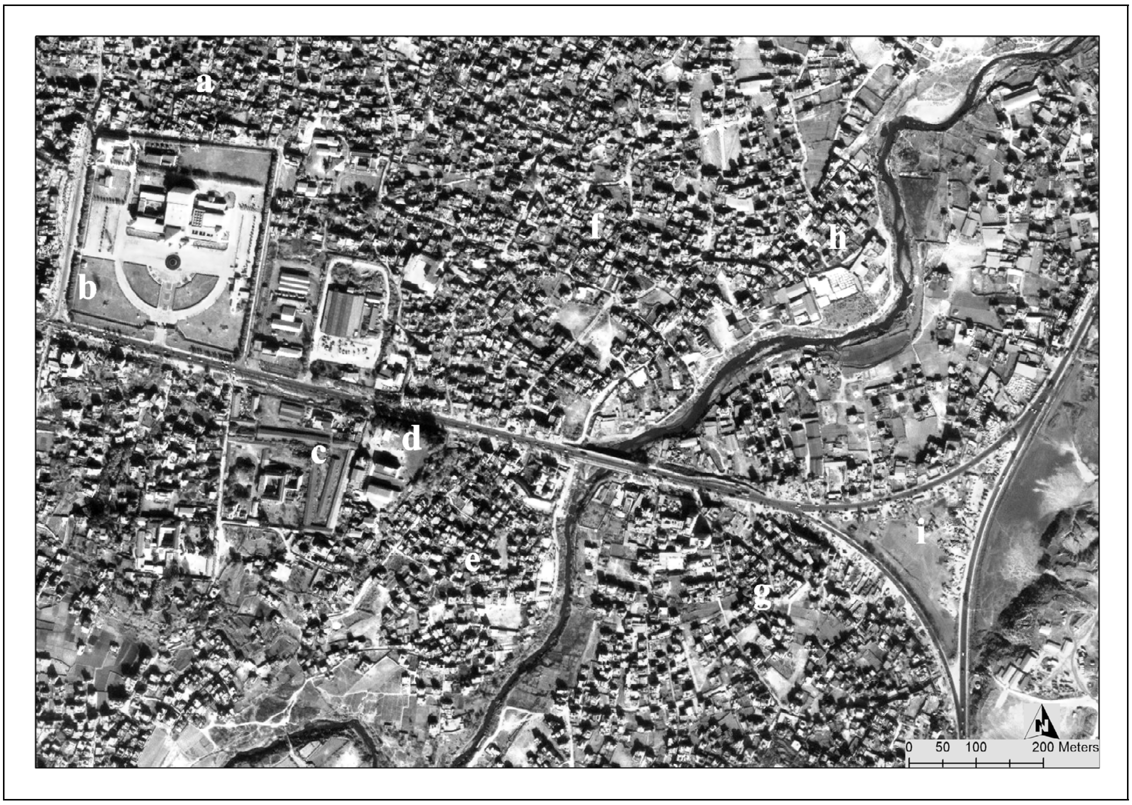

Figure 4-7: Kathmandu Valley floor - Baneswor area, 2000.
Source: IKONOS Satellite Image.

Although these three figures show the results visually, more quantified results about the LULC are needed for understanding the urbanization process for further decision making in resource management and planning. Therefore, landscape transition maps and matrices were prepared for the three time periods: 1967-1978 (Figure 4-8 and Table 4-2), 1978-1991 (Figure 4-9 and Table 4-3), and 1991-2000 (Figure 4-10 and Table 4-4). The maps demonstrated significant landscape transitions during the study period. Most of the agricultural lands in the valley floor and near existing built-up areas were transformed into urban/built-up lands, whereas shrubs and forest lands were converted into agricultural lands elsewhere in the rural periphery.

Three major land use transitions during the period of 1967-1978 were observed. The agricultural lands (1.96% of the total land) in the valley floor, mostly in close proximity to the road and existing built-up periphery, were converted to urban/built-up areas. In the southwestern mountain landscape, much of the shrubs lands were converted to forest lands, while in the northeastern area the forest areas changed to agricultural lands. The transitions between the other land uses were found to be very nominal during this period.

A ring road around the existing urban core was built during this period. This road significantly enhanced the urbanization process in later decades, which can be easily discerned during the years 1978-1991 (Figure 4-9). The agricultural lands near the road began to be transformed to urban/built-up areas. During this period, a significant amount of agricultural land (3.9%) was changed to urban built-up lands, with urbanization following the road networks and existing built-up peripheries. In the meantime, the other land uses also contributed to the urbanization process at lower rates. Large proportions of shrubs (5.3%) and forest (3.8%) lands were transformed into agricultural land in the surrounding rural mountain areas in the valley. This can be observed mostly in the northeastern border of the valley, and may be due to conversion of agricultural lands to built-up areas in the urban fringes, which forced the farmers to migrate in vicinities in one hand. On the other hand, due to road expansion and market accessibility to rural areas, farmers were encouraged to develop agricultural activities in the rural hills and had encroached on the nearby shrubs and forest lands.

The land use transition continued in 1991-2000. A different phenomenon of land conversion is observed in this period as compared to the earlier time period. The transformation of agricultural land into urban/built-up areas was escalated (4.4%), but the transformation of the other land uses into agricultural lands remarkably decreased. However, agricultural encroachment on shrubs lands still continued at slow rate as compared to earlier. Forest (0.36%) and shrubs (0.19%) lands were also changed to built-up areas as a result of the expansion of rural roads in the 1990s.

Figure 4-11 shows the transition of urban built-up areas over the other land uses as a whole for the last four decades, which makes the spatial patterns of urbanization clearer. The spatial pattern of urban growth is observed at different forms at different scales in different places. Larger clusters away from the urban areas can be discerned until 1978. The start of agglomeration between the urban patches is noticed in the 1990s. Refill development connecting the several urban fringe patches and more heterogeneous landscape development in the existing built-up periphery can be observed by 2000.

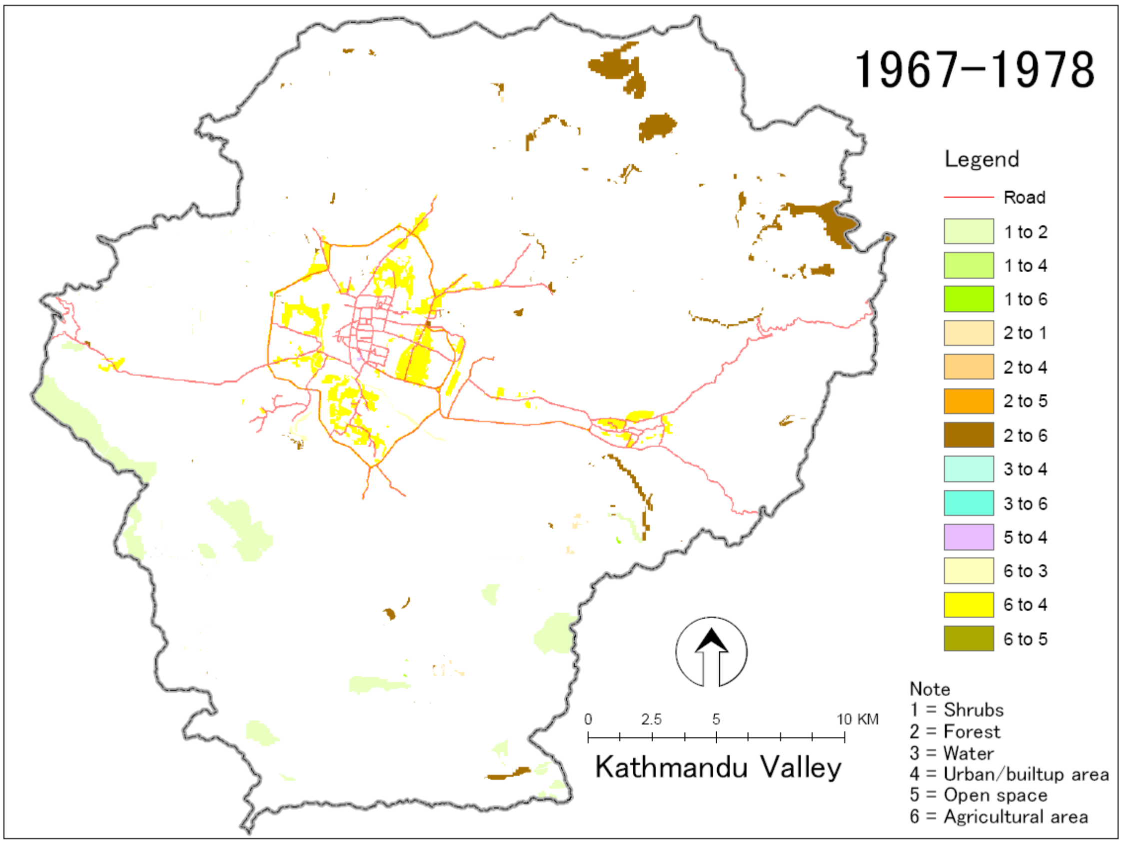

Figure 4-8: Land use change (1967-1978).

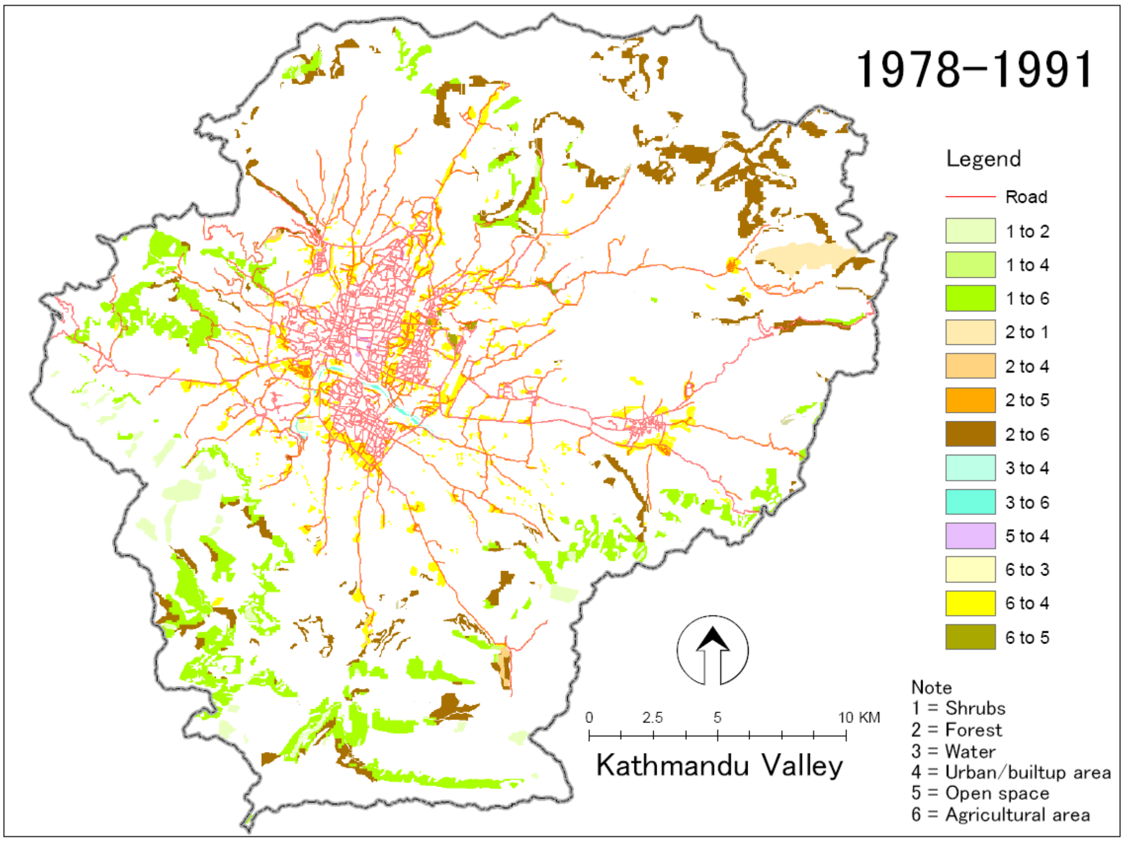

Figure 4-9: Land use change (1978-1991).

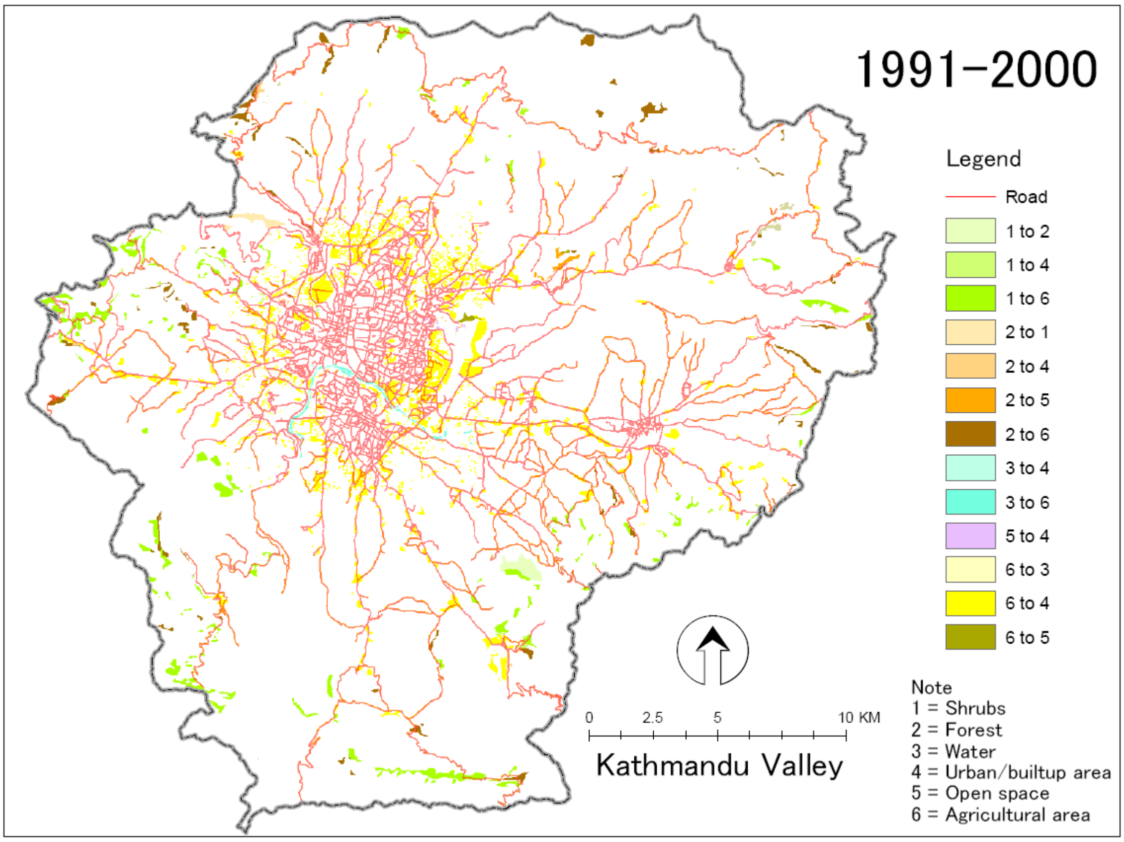

Figure 4-10: Land use change (1991-2000).

Table 4-2: Land use transition in percentage (1967-1978)

1967	1978 Shrubs	Forest	Water	Urban /builtup area	Open space	Agricultural area	Total
Shrubs	17.68	2.13	0.00	0.00	0.00	0.01	19.81
Forest	0.03	21.70	0.01	0.01	0.00	1.33	23.08
Water	0.00	0.00	1.95	0.00	0.00	0.00	1.95
Urban/builtup area	0.00	0.00	0.00	2.93	0.00	0.00	2.94
Open space	0.00	0.00	0.00	0.01	0.14	0.00	0.15
Agricultural area	0.00	0.00	0.06	1.96	0.00	50.05	52.07
Total	17.71	23.83	2.02	4.91	0.14	51.40	100.00

Table 4-3: Land use transition in percentage (1978-1991)

1978	1991 Shrubs	Forest	Water	Urban /builtup area	Open space	Agricultural area	Total
Shrubs	11.41	0.89	0.00	0.13	0.00	5.27	17.71
Forest	0.46	19.32	0.00	0.21	0.03	3.81	23.83
Water	0.00	0.00	1.92	0.04	0.00	0.06	2.02
Urban/builtup area	0.00	0.00	0.00	4.90	0.00	0.01	4.91
Open space	0.00	0.00	0.00	0.03	0.10	0.00	0.14
Agricultural area	0.00	0.07	0.04	3.90	0.07	47.32	51.40
Total	11.87	20.28	1.96	9.22	0.20	56.46	100.00

Table 4-4: Land use transition in percentage (1991-2000)

1991	2000 Shrubs	Forest	Water	Urban /builtup area	Open space	Agricultural area	Total
Shrubs	10.35	0.12	0.00	0.19	0.00	1.21	11.87
Forest	0.08	19.23	0.00	0.36	0.04	0.57	20.29
Water	0.00	0.00	1.84	0.03	0.00	0.09	1.96
Urban/builtup area	0.00	0.01	0.00	9.19	0.01	0.01	9.22
Open space	0.00	0.00	0.00	0.02	0.18	0.00	0.20
Agricultural area	0.01	0.07	0.01	4.40	0.02	51.95	56.46
Total	10.44	19.43	1.85	14.19	0.25	53.83	100.00

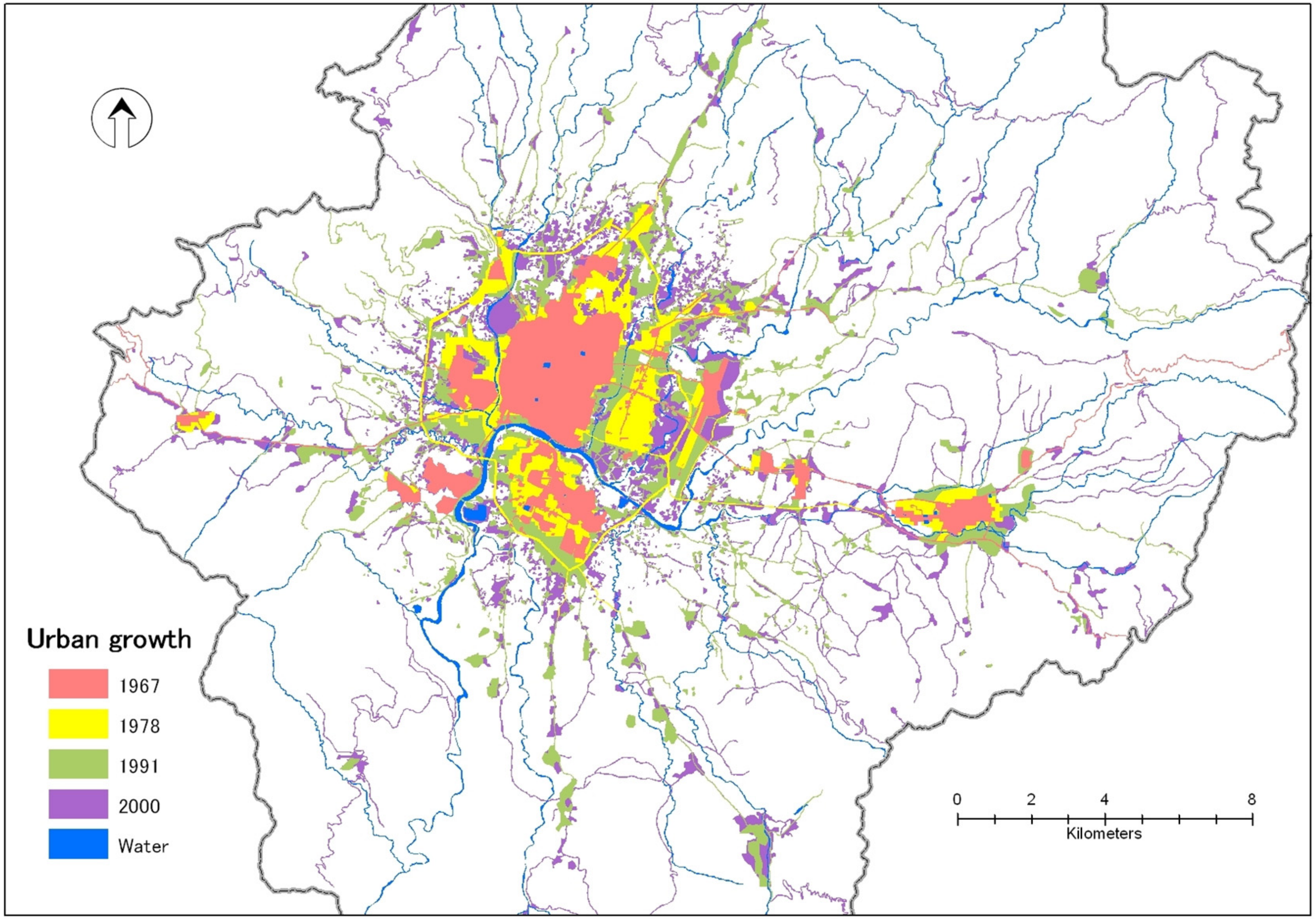

Figure 4-11: Spatial patterns of urbanization in Kathmandu Valley.

4.3 Landscape fragmentation and heterogeneity analysis

Planners and policy makers are normally concerned about the negative effects of landscape fragmentation and heterogeneity development. There are two processes that can result in these effects, namely the reduction of the total amount of land with a specific land use (decrease in size), and the breaking up of land use into smaller patches (increase in isolation of the land use patches). This process will also be followed by an increase in the total amount of edges in some cases. Agricultural expansion in the rural areas, urban development, and transportation infrastructure development in the valley over time are regarded as the main processes that influence landscape fragmentation and heterogeneity development.

Table 4-5 shows the results of the selected spatial metrics at the class and landscape level for the years 1967, 1978, 1991, and 2000. At the landscape level, the patch density (PD) in the valley increased from 0.86 in 1967 to 1.99 in 2000. The number of new patches in the landscape significantly increased since 1991. The increase of PD often leads to increased edge density (ED), as it creates new edge segments in the patch. The ED almost doubled in the whole study period, increasing steadily in the 1980s and 1990s after a small increase in the 1970s. Edge density often increased while land use fragmentations occurred due to land use changes. In the valley, it is observed mainly in the urban built-up areas, and the agricultural area particularly increased in the 1980s and 1990s, as shown by the figures of PD and ED. However, the dominance index (LPI) slightly improved in 1991 but decreased in 2000. The land use compactness of the urban/built-up areas in the valley floor and the expansion of agricultural activities into shrubs and forest lands, forming larger patches in the landscape in the 1980s and 1990s (Figures 4-9 and 4-10), can be commonly observed.

Table 4-5: Landscape metrics at class and landscape levels for different time period

Year	Class	PD	ED	LPI	ENNMN	AWM PFD	COHE SION	CON TAG	SHDI
1967	Shrubs	0.06	7.94	8.58	486.10	1.196	99.52		
	Forest	0.28	11.58	11.02	273.91	1.186	99.36		
	Water	0.31	14.12	0.31	87.40	1.358	95.85		
	Urban/builtup area	0.06	4.79	2.81	126.30	1.328	99.33		
	Open space	0.01	0.29	0.08	1678.16	1.139	94.30		
	Agricultural area	0.14	21.92	51.84	338.17	1.301	99.95		
Landscape level		0.86	30.32	51.84	247.76	1.256	99.76	60.91	1.189
1978	Shrubs	0.07	8.17	7.18	445.02	1.202	99.48		
	Forest	0.25	11.90	10.38	281.12	1.185	99.37		
	Water	0.32	14.13	0.25	86.71	1.342	95.54		
	Urban/builtup area	0.03	5.97	4.90	68.46	1.329	99.59		
	Open space	0.01	0.27	0.08	1680.55	1.132	94.01		
	Agricultural area	0.17	23.09	48.06	305.24	1.291	99.92		
Landscape level		0.86	31.77	48.06	243.29	1.253	99.72	59.55	1.226
1991	Shrubs	0.18	8.95	3.07	225.65	1.170	98.74		
	Forest	0.21	11.57	8.20	357.51	1.182	99.21		
	Water	0.41	14.15	0.15	83.50	1.313	93.48		
	Urban/builtup area	0.23	18.58	8.89	159.60	1.393	99.70		
	Open space	0.02	0.50	0.04	665.96	1.129	91.92		
	Agricultural area	0.24	35.73	53.69	192.39	1.330	99.94		
Landscape level		1.29	44.74	53.69	192.04	1.286	99.78	58.05	1.209
2000	Shrubs	0.21	9.48	1.94	203.22	1.171	98.35		
	Forest	0.24	13.52	7.29	297.77	1.199	99.19		
	Water	0.52	14.04	0.09	82.50	1.294	91.33		
	Urban/builtup area	0.53	33.92	13.70	102.06	1.426	99.78		
	Open space	0.02	0.60	0.05	594.60	1.139	93.16		
	Agricultural area	0.47	46.48	45.42	125.23	1.347	99.91		
Landscape level		1.99	59.02	45.42	142.40	1.310	99.77	54.78	1.254

Note: See Table 3-3 for detail descriptions on the selected metrics.

A significant amount of agricultural lands, i.e., 4.4%, was transformed into urban/built-up area during the period 1991-2000 (Figure 4-11), which reduces the proximity (ENNMN) of the neighboring land use patches. The ENNMN decreases across the whole study period. The expansion of urban/built-up areas in the existing built-up periphery in the valley floor and agricultural encroachment near shrubs and forest lands in the rural areas could be the main causes of the ENNMN decline in the 1990s.

The AWMPFD increased slightly, reporting the degree that the shapes of the patches became more complex in later years. This may be due to road network expansion towards the rural areas in the 1980s and 1990s. A decreasing trend is observed in CONTAG, which shows the growing dispersion and fragmentation of the urban/rural landscape in the valley. The physical connectedness of the land use in 2000 improved as compared to 1967, but it faced some increases and decreases in the 1970s and 1980s, as shown by the COHESION index.

The diversity of land uses in the valley also increased. Construction of additional bridges over the rivers and the expansion of urban/built-up areas over the agricultural land in fringe areas and the beyond in the valley played key roles in increasing the heterogeneity of the landscape. However, the construction of commercial complexes and planned residential developments in the valley floor increased in recent decades, but their impacts on improving the homogeneity at the landscape level is nominal. A temporal reduction of the contagion (CONTAG) and an increase of the patch diversity (SHDI) presented a clear picture of increasing the landscape heterogeneity in the valley.

At the class level metrics, changes in the PD of all land use classes are observed, except in the forest land cover. The PD of urban/built-up and water areas had remarkable changes in the 1980s and 1990s. The proportions of these land uses are small in the valley as compared to the other major land uses. Due to the inconsistent widths and linear character of the rivers, construction of additional bridges over the rivers in the later decades might have influenced the increase in the PD of water areas. The increase of PD in urban/built-up areas is a result of the urbanization process that occurred rapidly in the 1990s. The population influxes into the valley floor increased the demand for new housing, subsequently creating new built-up areas in the city fringes that segmented the existing agricultural lands in the later years. This process also increased the PD and ED of urban/built-up areas, including agricultural areas. The ED of agricultural land remained higher than that of other land uses. However, this dominancy could cause higher ED values, as shown by the LPI. A noticeable change is observed in the ED and PD of agricultural and urban/built-up land uses correlating each other in the 1980s and 1990s. The trend of unordered individual housing development in the valley floor, especially in the fringe areas (e.g., Figure 4-6) in the corresponding decades enhanced the fragmentation and the heterogeneous landscape development.

A gradual increase in LPI is found for the urban/built-up land use type. The increasing intensity of building and other infrastructure in the core area in the 1990s (Figure 4-7), for example, increased the LPI of the urban built-up area. In the same time-frame, the LPI of agricultural land decreased significantly, showing a tremendous urbanization pressure over the agricultural lands, as observed in Figure 4-10. The urbanization process over agricultural land is a global trend. However, the LPI of other land uses decreased. The expansion of urban infrastructure abutting the land between the built-up areas and surrounding areas in the valley floor in the later decades (Figure 4-11) is the main cause of the improvement of the dominance index of the urban/built-up areas.

Adding new urban structures in agricultural spaces creates new patches, eventually fragmenting the land in both categories and reducing the proximity (ENNMN) between the neighboring patches of similar land uses. This occurred mostly in the agricultural land in the valley. A decreasing trend is observed over the whole study period. It is true that when urbanization activities occur in agricultural land, for example the development of road networks, open spaces, or even individual buildings, it creates a patch for the infrastructure itself and divides the agricultural lands into two patches. This process decreases the ENNMN of agricultural land patches, creating several patches within close proximity. Interestingly, a decrease of ENNMN for urban built-up areas in the 1970s shows that the urbanization process was confined mostly in the margins of the existing built-up areas. In the 1980s, ENNMN increased, which shows the start of the urbanization process away from the city core, i.e., rural areas (Figure 4-11). The distance (ENNMN) between the patches of open space significantly decreased in 1991 and 2000. This was due to expansion of existing open spaces and the addition of new open spaces such as golf courses in the valley.

The AWMPFD always remained higher in water areas as compared to the other land use types, reflecting the complex shape of the rivers. This is somewhat natural, as rivers pass through complex mountain topography in the valley. The shape complexity of urban/built-up lands significantly increased in later decades. Expansion of roads into rural areas could be a cause of this. The agricultural land still has simple shapes compared to the other land uses in the valley, although the trend of shape complexity has gradually increased. Based on the COHESION index, the agricultural land use has a higher degree of physical connectedness than the others. The degree of physical connectedness of urban/built-up areas also gradually increased over time. Abutting the lands between the urban structures in close proximity to roads, especially in the city core and fringe areas, could be a result of the increase.

4.4 Micro-scale case study: the Kalanki area

To understand the overall urbanization process at the local level, a detailed micro-scale case study was conducted. An immediate urban frontier, Kalanki (Figure 4-12), was selected based upon its land use change characteristics, strategic location, and accessibility. It is located along the north-west junction of the Prithwi Highway and the Ring Road in the Kathmandu valley. The area has had road accessibility since the early 1960s, and all outbound transportation vehicles (east-west Nepal and India) pass through Kalanki. Strategically, this area is relatively more important than the other urban frontier areas in the valley. After analyzing the land use changes at the valley level, this area was found to have had rapid changes and has experienced the spatial diffusion process of urbanization as an urban frontier. Considering these facts, this area is worth examining in order to understand the character of urbanization as a detailed case.

The micro-scale case study covers an area of 93,947 m^2. The data sources for this study are cadastral (property) map, aerial photographs, and fieldwork (2007). Paper cadastral maps and aerial photographs from 1981 and 1998 were scanned and geometrically rectified into the real world coordinate system. Similarly, the SPIN (1991) and QuickBird (2007) images were also geometrically rectified. Each element (building, road, and farm land) in the maps was digitized for land use change analysis at the parcel level. A detailed field survey was conducted using the semi-structured interview questionnaires (Appendix IV). Using the field work information and the source image data, four land use maps were derived for the years 1981, 1991, 1998, and 2007. These land use maps are very detailed, and contain information at a scale of 1:500. Three analyses were carried out: land use change, functional land uses in 2007, and pull factors that contributed to the recent urbanization process in the area.

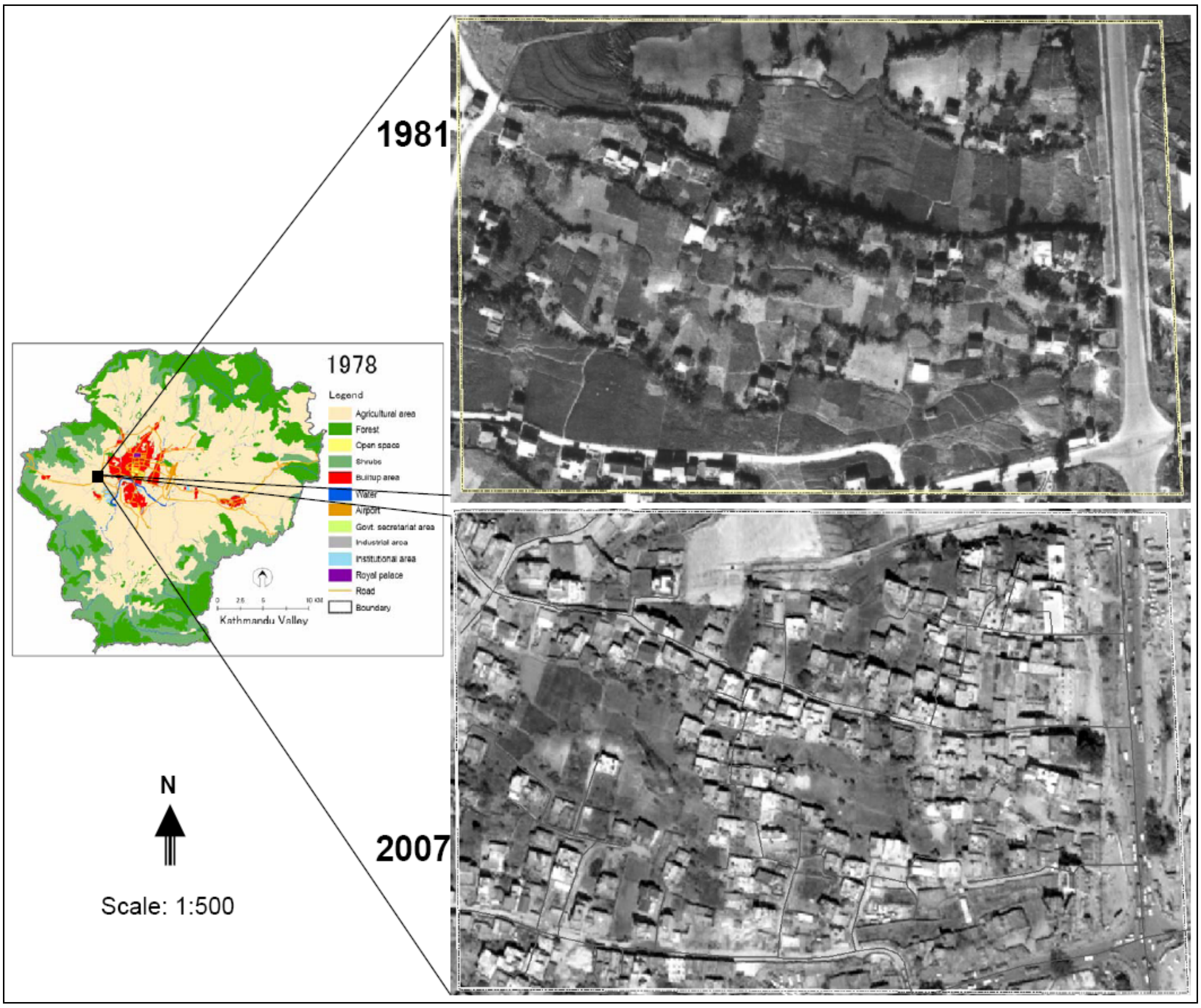

Figure 4-12: Micro study area - Kalanki.

Source: Aerial Photograph (top-right: 1981) and QuickBird Pan Image (bottom-right: 2007).

Land use pattern change in the Kalanki area. Although it is derived from raw images acquired by aerial survey in 1981 and earth observation satellite in 2007, Figure 4-12 very clearly illustrates the typical pattern of land use change in the Kalanki area. In 1981, the area was almost all agriculture land. Very few houses are observed along the tertiary road. The built-up space is seen to have spread outward from the main road. This predominantly rural agricultural landscape gradually changed to fringe landscape with increasing human settlement in the 1980s and 1990s, which can be observed in the Figure 4-13. By 2007, lands abutting the main road were almost all occupied by housing units. The trend of spatiotemporal changes observed in the last 27 years shows a great deal of urban densification in the frontier areas of the valley, which plays an important role in improving the homogenous landscape in the future.

Radical transformation of the landscape pattern has been experienced in Kalanki in recent years (Table 4-6). Agricultural land in the area accounted for 82% of the land area in 1981, and decreased gradually in different time periods. However, the agricultural dominancy no longer exists by 1998 (Figure 4-14). Since then, the other land uses, i.e., urban built-up area, have dominated the urban frontier. More than two-thirds of the land was occupied by the other land use types (excluding roads) in 2007, which shows the rapid transition of agricultural land use to other purposes.

Figure 4.15 illustrates the functional land uses in the area in 2007. All together, a mixture of eight types of land uses was identified during the fieldwork. Small scale business, schools, and temples are also existed in the area, but these functions have nominal proportional coverage (Figure 4-16). Residential areas are observed as most prevalent, and cover a majority of the land (39%) as compared to other functional land uses. However, the area still preserved the residential and agricultural area, which can exceed 60% of the land.

Table 4-6: Land use changes in Kalanki area

Year	Agricultural land		Other land*	
	Area m^2	Area [%]	Area m^2	Area [%]
1981	62398.57	82.10	13608.36	17.90
1991	49687.02	65.37	26319.91	34.63
1998	37289.26	49.06	38717.67	50.94
2007	23580.43	31.02	52426.50	68.98

*Road exclusion.

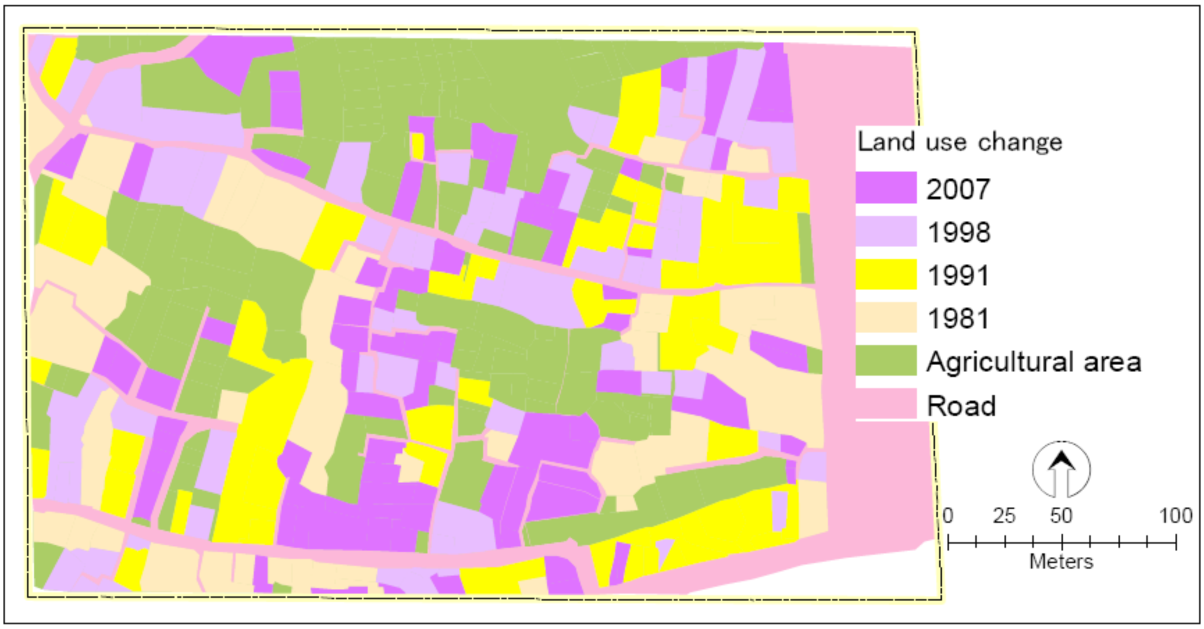

Figure 4-13: Land use change in Kalanki area (1981-2007).

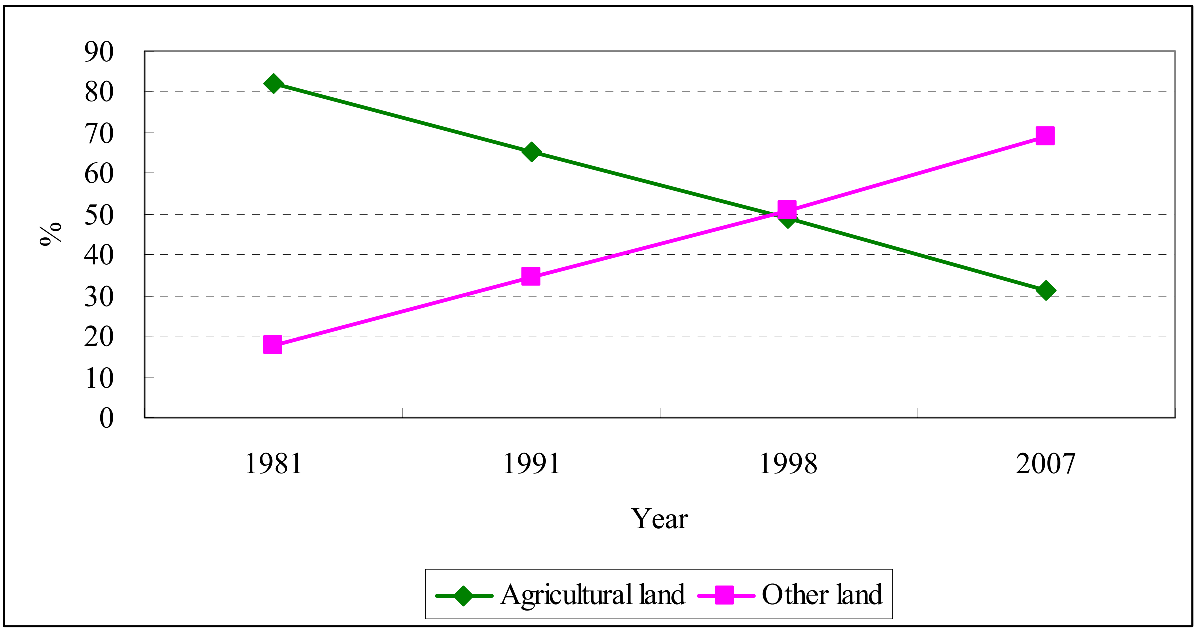

Figure 4-14: Transformation of agricultural land use in Kalanki area.

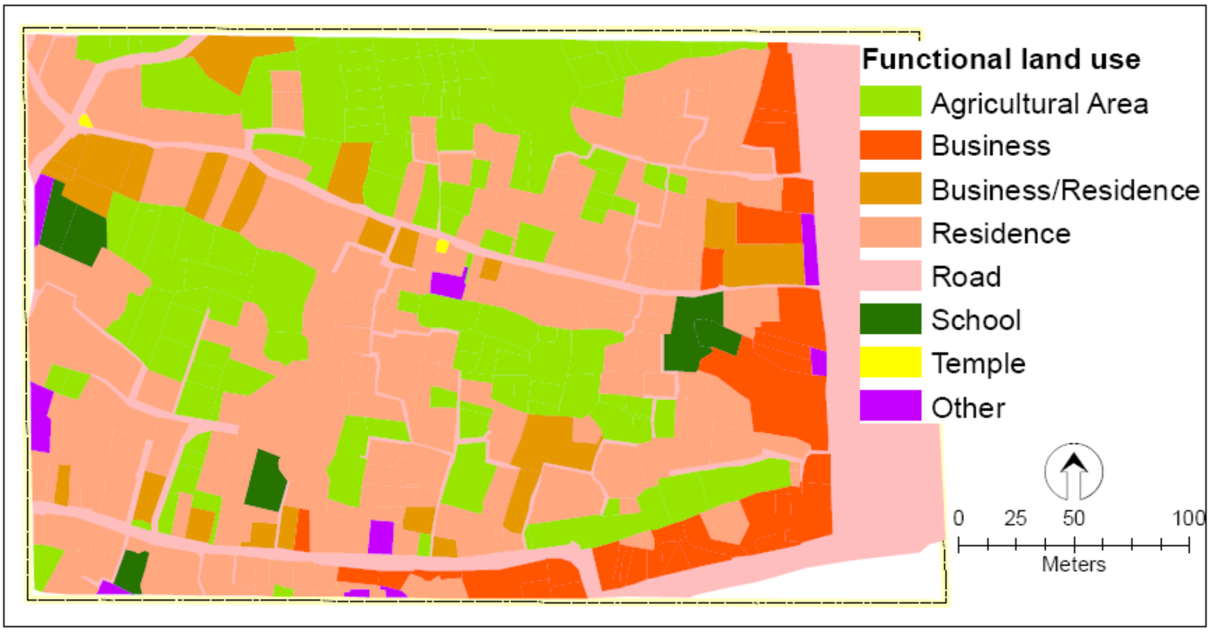

Figure 4-15: Functional land use in Kalanki area (2007).

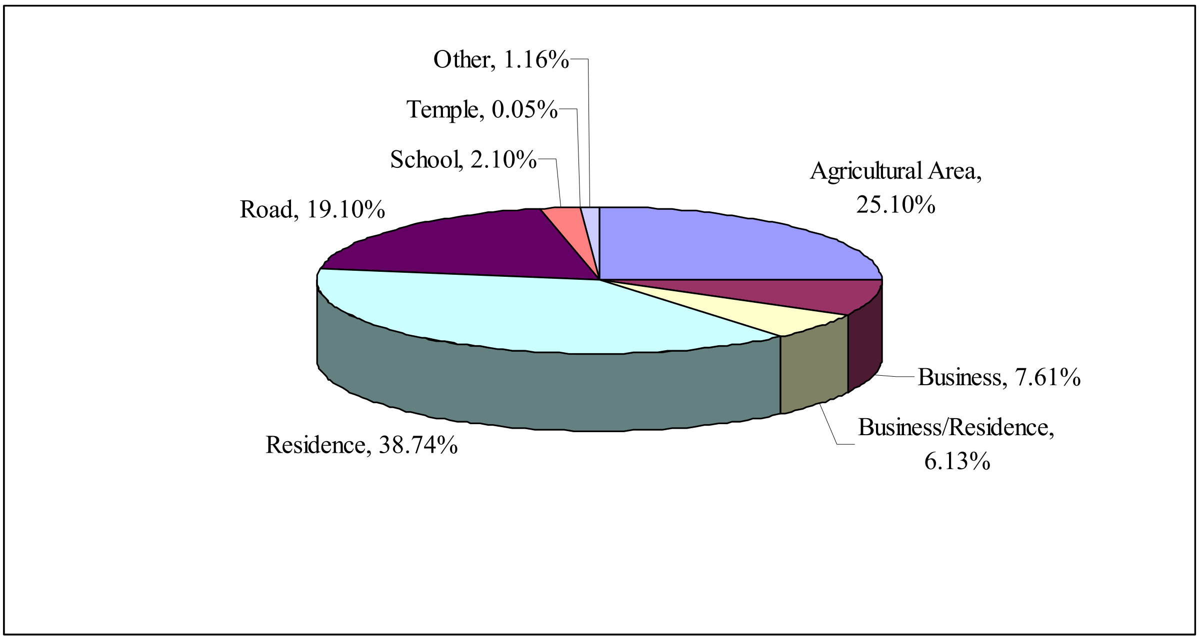

Figure 4-16: Representation of functional land use in Kalanki area (2007).

Driving factors of land use changes in the Kalanki area. The study area had 268 houses in 2007. Each house was visited during the field work (Figure 4-17). The owners from 47% of the houses were available to respond to the queries (Appendix IV). Most of the people in the business area were either unavailable or did not know details, as they were temporary migrants. Among the respondents, 57% of the houses were owned by migrants, while the others belonged to local residents. The owners of the agriculture areas were also local. An interesting clustered pattern was observed among the migrant houses: one migrant would bring another as a kind of social network, and they mostly use the land for residential purpose.

Figure 4-18 synthesizes the reasons behind that have ultimate relation to land use change in the area. The majority of the respondents (20%) claimed that they were there because of inherited land, a continuation of ownership from parents and grandparents. Some of them replied that it is the most accessible place and were unwilling to leave their birth place, while some argued that they still maintain their lifestyle and had no economic reason to sell the inherited land and migrate somewhere else.

The second major reason is business. The Kalanki area along the ring road and the interaction of the highway is also a small business hub. Retail, service, and restaurant types of business flourish in the area. Some respondents said that their businesses are in the area or somewhere else in the valley, but that they live there. The employment opportunities are the main reason for 16% of homeowners. This does not mean that there are many employment opportunities in Kalanki. Most of the economic activities are confined in the core area, which is very accessible from the Kalanki area.

Kathmandu is a center for higher education in the country. A range of academic campuses from engineering, medical sciences, social sciences, business sciences, and even top high schools are situated in the valley. Kalanki has good access to motor roads.

Therefore, education and road accessibility accounted for 11% and 5% of the total respondents, respectively.

Some people (11%) found the land cheaper than in the other urban frontier areas in the valley while they were migrating. Now, however, the land is very expensive for new migrants. 10% of the total respondents argued that they migrated to Kalanki due to family members and friends, or a social network. Some of the respondents explained that they had been working in the valley for a long period of time. In the early stage of their living in Kathmandu, they found their colleagues living comfortably in Kalanki, who played key roles in land negotiations with local owner to obtain a cheaper price, allowing them to live there. Some respondents replied that their relatives facilitated their migration there.

However, very few people (4%) highlighted peace and safety reasons due to conflict in the country. Some people responded that the purpose for them being there is not clear or were afraid to respond. This study enhances the in-depth understanding and synthesizes the situation in urban frontiers of Kathmandu. Similar stories can be observed elsewhere in the valley.

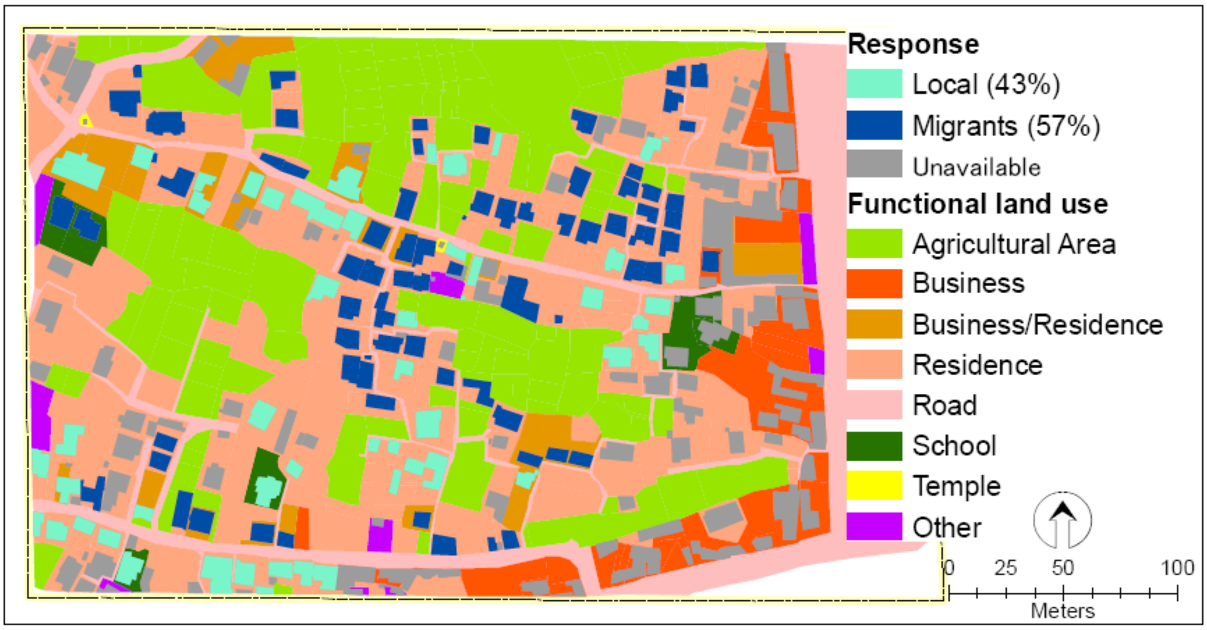

Figure 4-17: Housing survey, Fieldwork (2007).

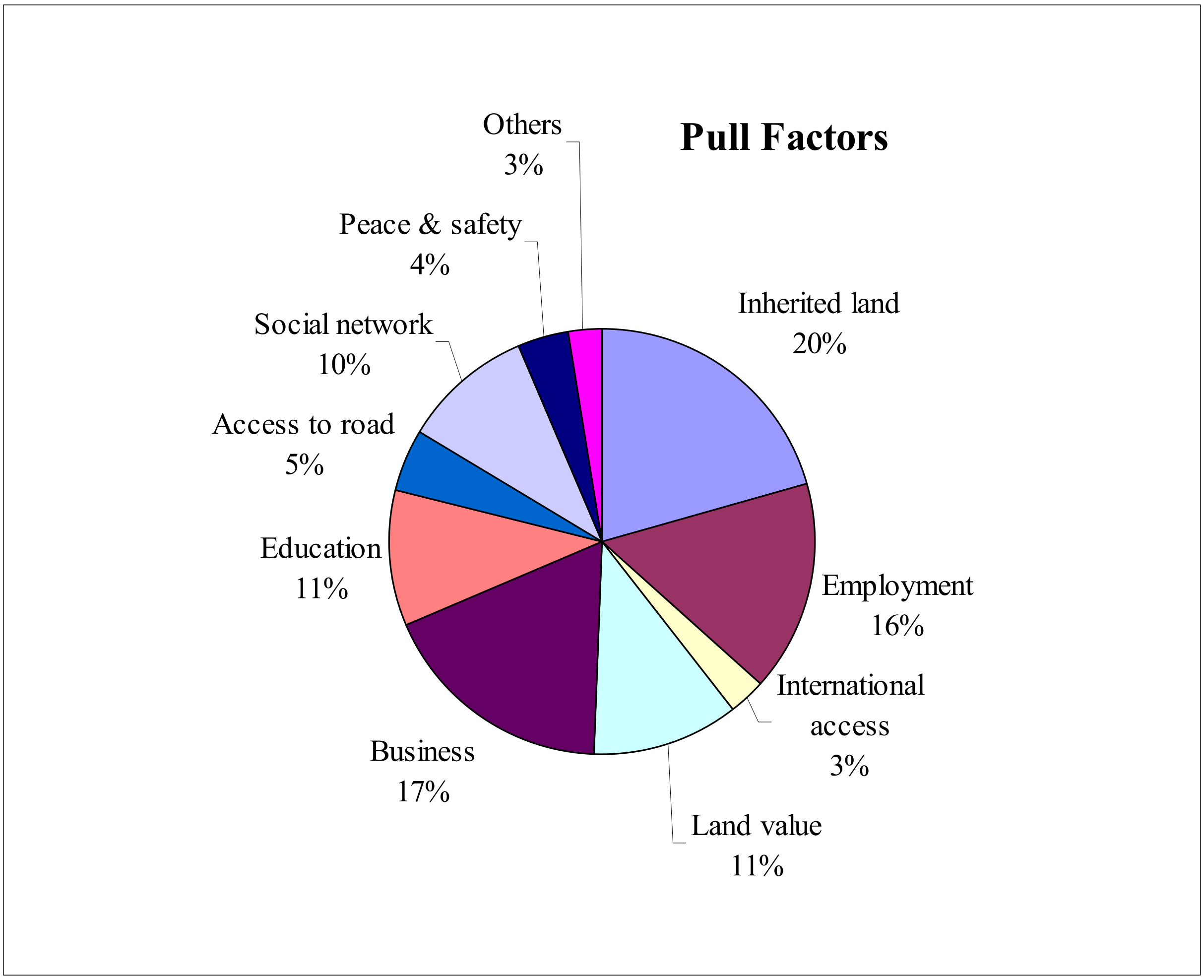

Figure 4-18: Driving factors of land use change in Kalanki area.

4.5 Spatial pattern of urbanization: A conceptual observation in Kathmandu Valley

A conceptual map (Figure 4-19) based on the research results can be used as an overview of the urbanization pattern in the valley. The figure synthesizes the spatial diffusion of urbanization in the valley acting at different times, scales, and distances. In the mountainous area (M) and river basin (R), certain accessible directions are the preferred axes of spreading and certain types of impacts may reach much further then initiate new secondary centers of urbanization. The letters and numbers in the following descriptions refer to the urbanization features in the figure.

A hierarchical network of central sites forms the initial settlement pattern (A, B, C, D, E, and F). The size of a central site depends on its geographical location within the settlement pattern and reflects its unique history. Around the main city (A), smaller ones are connected by a highway (G) and small road (r). The main city shows different stages of urban growth (1, 2, 3, 4, 5), absorbing small nearby rural settlements (s) at different time periods. It exhibits stages of development from a square medieval town (1), which was developed during the 12th–18th centuries (Thapa *et al.*, 2008). Until the middle of the 20th century, factories and new housing spread (2) to its periphery, and small rural settlements (s) were gradually transformed into urban forms.

The highway (G) opened the access to other towns, villages, and even beyond the valley by connecting many settlements in the 1960s. The opening of the ring road (Rr) in 1970s provided more access to the smaller towns in the valley and reduced the traffic in the core area. These roads encouraged the population influx (m) from the countryside and enhanced the urban agglomeration stretching between the urban regions to 3, 4, and 5 in the 1980s, 1990s, and 2000s, respectively. This process eliminated the urban boundary between the city areas A and B in the south. Traffic congestion in the city center caused the creation of new economic zones in the outer urban fringe, where easy access by transportation infrastructure was possible (e). In the meantime, some brick factories (b1) located near the city center were closed. Most urban structures in the valley are built of bricks. Due to very high demand, the brick factories are reestablished elsewhere in the valley on rural agriculture land (b2) with suitable soil for brick production.

More heterogeneous settlement patterns (H) were developed, causing severe fragmentation of the agricultural land. Due to the urban growth process, some of the fragmented landscape in the early fringe areas has undergone refill development, enhancing homogeneity (h). Residential housing, commerce, and agriculture create a complex mixture of different land uses and functions that characterizes this highly dynamic zone in the outer urban fringe (5). When good traffic connections (Rr) are available towards the main employment centers, well-planned residential areas developed in the fringes (p). The main access roads form the most important attractors and generate different forms of ribbon-urbanization in the valley. Roads leading to the rural countryside might develop a looser form of open residential housing (6).

In smaller towns (C), characteristics of the inner urban fringe are limited or missing, and residential and industrial development characteristics for the outer urban fringe developed immediately around the initial center. Improvement of the roads (r) made rapid access to some remote rural villages (E, F) possible. In some cases, this resulted in the development of exurbs (D). In addition, the rural roads became attractors for new settlements for recreation and leisure (7).

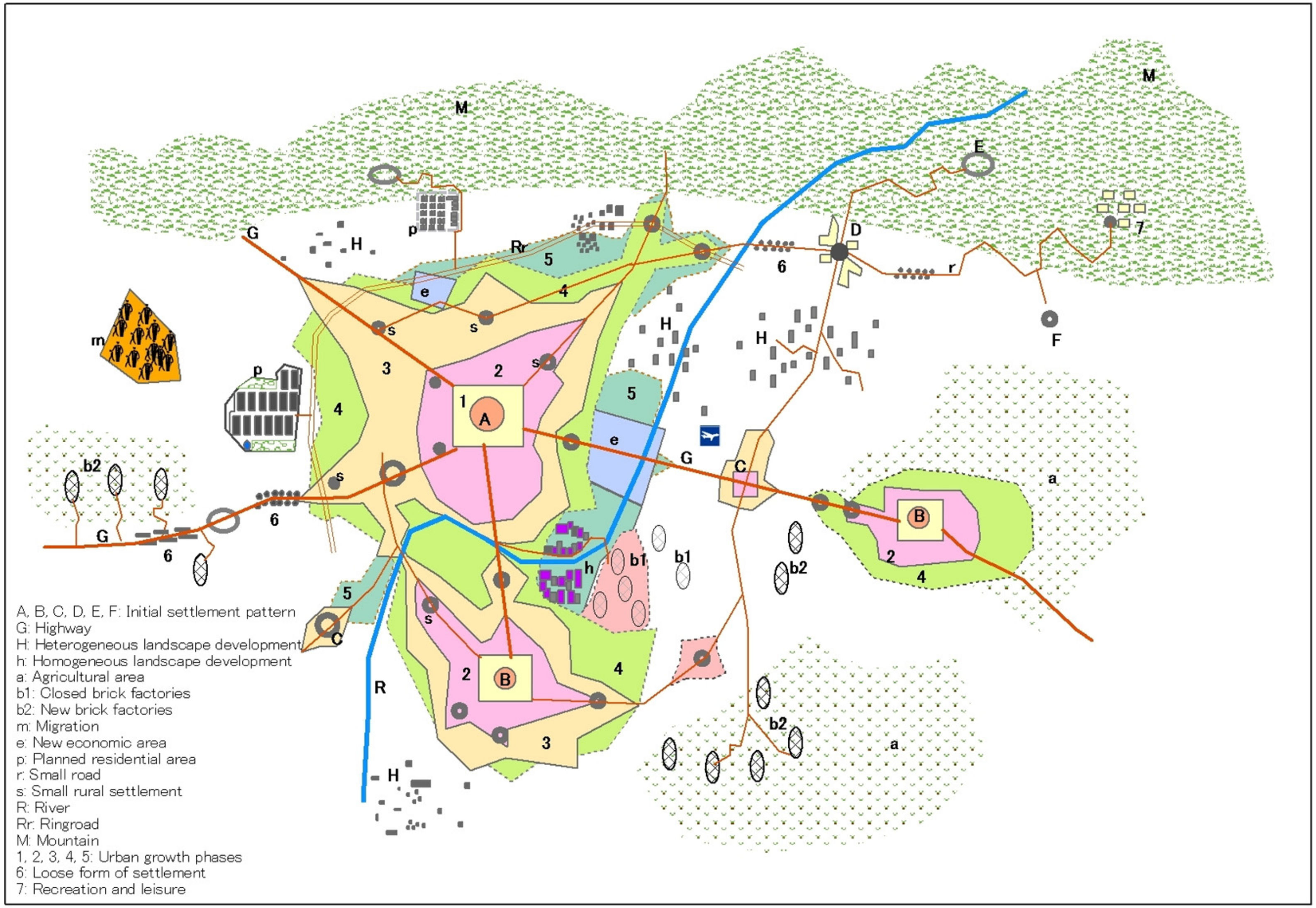

Figure 4-19: Spatial patterns of urbanization in Kathmandu Valley.

Chapter Five

Driving Factors of the Urbanization Process in Kathmandu Valley

5.1 Driving factors of the urbanization process

As discussed in an earlier chapter, the Kathmandu valley has been facing rapid urbanization, causing landscape fragmentation, an increase of land use heterogeneity, and a deteriorating ecosystem. A complex process of converting rural land uses to urban uses usually causes various impacts on the ecosystem structure, function, and dynamics, and the livelihood of human beings. Given these impacts, understanding the mechanisms that drive the changes in the valley is crucial. The following discussion is limited to the last decade, and emphasizes the driving factors that contributed to the urbanization process in the valley.

In general, the land use changes are a result of the complex interaction of behavioral and structural factors associated with the demand, technological capacity, and the social relations affecting demand and capacity that ultimately put strains on the environment. However, these are difficult to understand without reference to relationships between factors that affect land use change. The factors are usually correlated, and it is possible that one variable can affect another directly or indirectly through several variables in the land use change process. Therefore, some researchers (Turner *et al.*, 1990; Verburg *et al.*, 2004) have highlighted the importance of a theory of land use change that conceptualizes the relations among the driving forces of land use change, as well as their mitigating processes, activities, and human behavior and organization.

A range of disciplines focuses on the analysis of the spatial aspects of land use change. Macro-scale processes that drive land use conversion, the proximate causes, and the underlying driving factors of land use change, such as population growth, migration, and economic change, are directly or indirectly related to the processes that determine the spatial pattern of the urbanization. There are no universal driving factors of the change. Although some similar driving factors can be found in several studies so far, their degrees of contribution to landscape change are different. People, government plans and programs, landforms, landscape change processes, and available resources often cause differences in the degrees of the roles among the factors. Kathmandu valley also has similar perspectives about the factors of urbanization process.

People's behaviors and their daily interactions with the environment over time have caused observable changes in the valley landscape. Therefore, it is considered in this research that the local residents, experts, researchers, urban and regional planners, and academicians working in diversified disciplines view the surrounding changing environment and the causes of changes with different perspectives. Group discussions, informal interviews, and reviews of existing studies conducted during the field work provided the key information to identify the driving factors of urbanization for the last decade. Synthesis of these data has contributed to the derivation of seven representative factors, ranging from biophysical to socioeconomic, for further evaluation (Table 5-1). These factors are *physical conditions, public service accessibility, economic opportunities, land market, population growth, political situation,* and *government plans and policies*.

The degree of the relationships and their contributions among the factors can be different. Therefore, a set of questionnaires (Appendix II) within the AHP framework was used, where the respondents could state the relative importance of each factor with respect to the others, for example, the importance of physical conditions of the land with respect to the accessibility of public services, economic opportunities, land market, population growth, the political situation in the country, and plans and policies, and vice versa. An additional option (other) was also provided in the AHP-modeled questionnaires (Appendix II) in case a respondent considered additional factors to be important.

Conceptually, a metropolitan region comprises of three thematic zonal characteristics: core, fringe, and rural areas. These thematic zones were also synthesized for the valley considering that the same driving factors may have different significances according to the zones (Figure 5-1). Three sets of the same questionnaires were prepared for each respondent so as to obtain responses for each thematic zone. The respondents were requested to evaluate the driving factors based on the thematic zones.

Table 5-1: Driving factors of urbanization – representation and synthesis

No.	Synthesis	Representation characteristics
1	Physical conditions	Topography, slopes, soils and rivers in the valley are playing a role to land use changes, for example, soil with lower slope area for brick factories, river dynamic (erosion, deposition, and changing route pattern), and hillocks for attractive residences or resorts and so on.
2	Public service accessibility	Services available in the valley are: transportation, electricity, education, drinking water, health services, commercial services, waste disposal, open spaces, and recreation facilities. The concentration of these services may differ by location.
3	Economic opportunities	Kathmandu, as a major economic hub in the country, provides several well-off jobs and business opportunities in tourism, finance, industry, education, health, wholesale, and retails.
4	Land market	Local people, land broker and real estate developers in Kathmandu are very active in acquiring the undeveloped lands with scattered ownerships, and later develop the land and put on sale.
5	Population growth	High population influx (5.2%/yr) in the valley puts high pressure on limited resources by demanding more urban services ultimately increasing the land use changes.
6	Political situation	Kathmandu, as the capital of the county, is the safest place during the conflict period of time. People having interest or business in politics and seeking safety have migrated in different places that enhanced the demand of services.
7	Plans & policies	The effectiveness of zoning, land reforms, land pooling, guided land development, economic and investment plans of the government were considered.

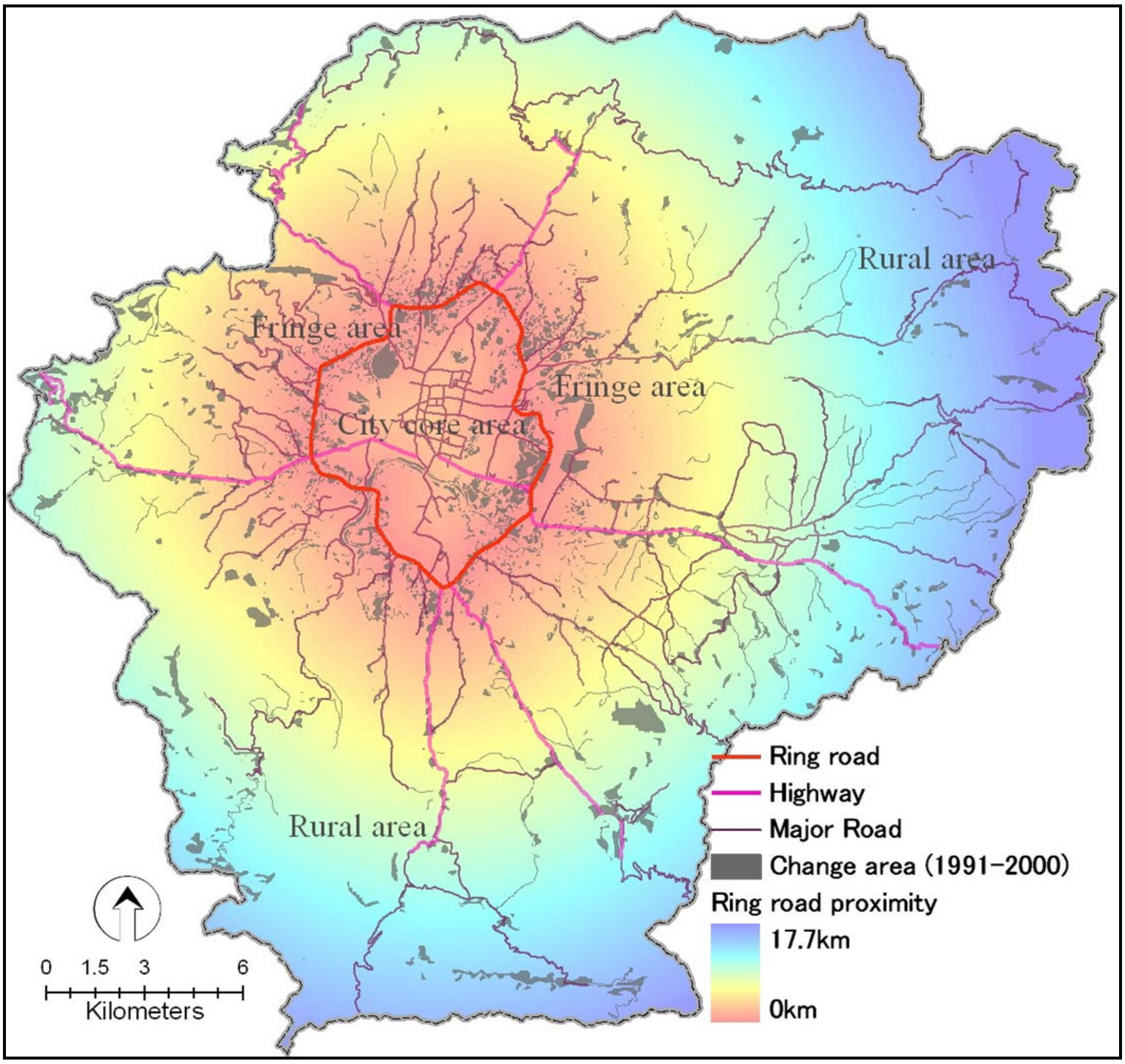

Figure 5-1: Three thematic areas (city core, fringe and rural) in the valley.

Note: These fuzzy zones are synthesized by computing proximity distance to the ring road.

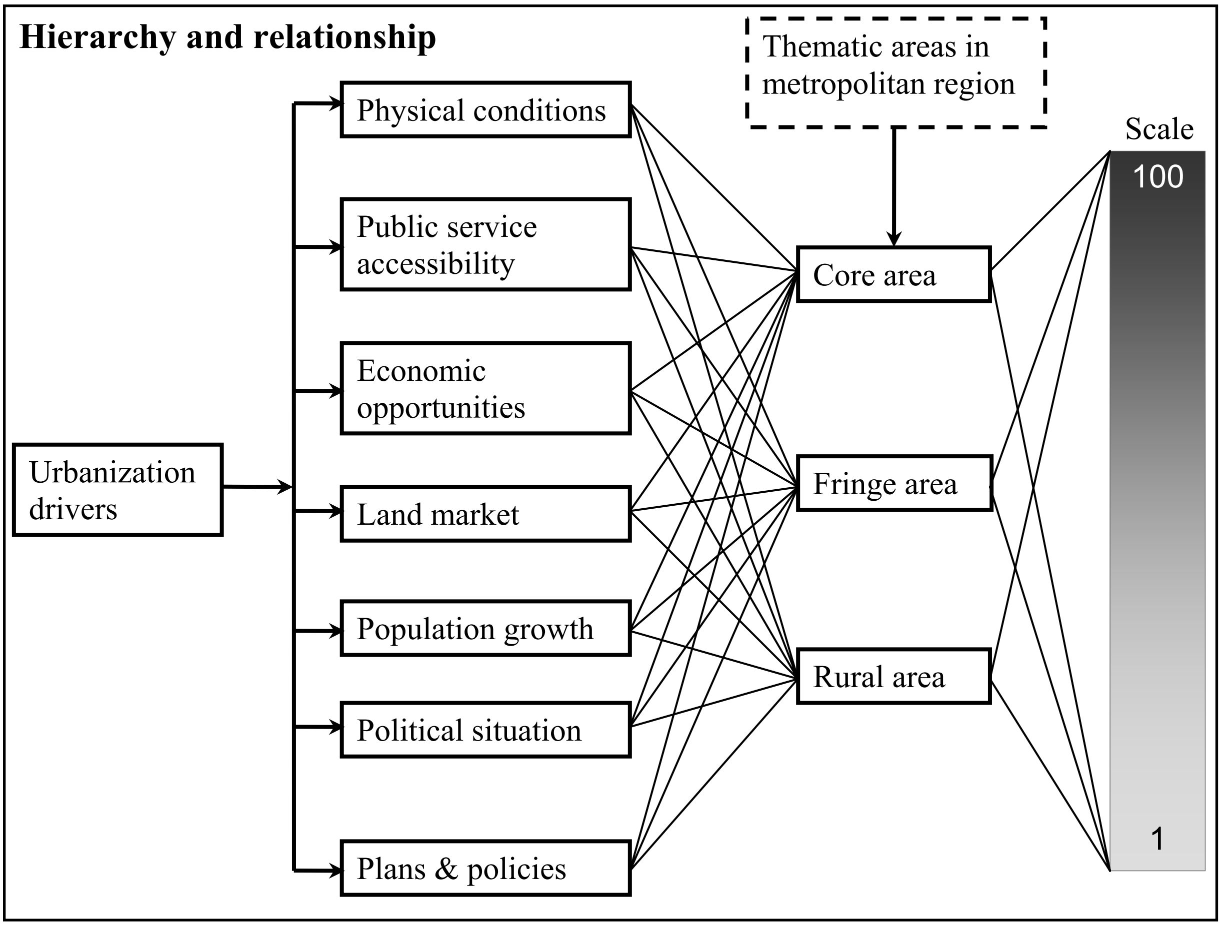

Figure 5-2: Hierarchical relationship between the driving factors and the thematic areas in the valley.

A schematic hierarchical relationship between the seven driving factors and the three thematic zones in the valley is shown in Figure 5-2. The figure presents the relationships among the factors and the locations. At this stage, the degrees of the relationships were unknown, and could be different case by case. Therefore, the degree of relationship among the factors for each zone was evaluated by the key respondents, where the responses were modeled based on the AHP framework (Figure 3-2).

The data collected from the fieldwork was modeled to identify the degrees of the relationships and their contributions among the factors to changing the spatial patterns of urbanization. A wide range of interviewees with various areas of expertise and academic backgrounds responded during the fieldwork (Figure 5-3). A total of 29 responses were received for each thematic zone. As indicated in the figure, 83% of the respondents had a master's degree, while others had a PhD (10%) or a bachelor's (7%) degree.

An interesting pattern of specialization in the respondents can be observed. Altogether, eleven diversified areas of specialization were found among the respondents. The urban and regional planning specialties share the majority (22%) among the categories. Respondents in this group also comprised diverse backgrounds, including geography, urban planning, rural development planning, agriculture planning, and resource planning. Population, migration, and urbanization specialties made up 17% of the total respondents. The RS, GIS, and Information Sciences category is also diversified, as this bridges several academic disciplines. The information collected from all these respondents is a great resource for the analysis of driving factors.

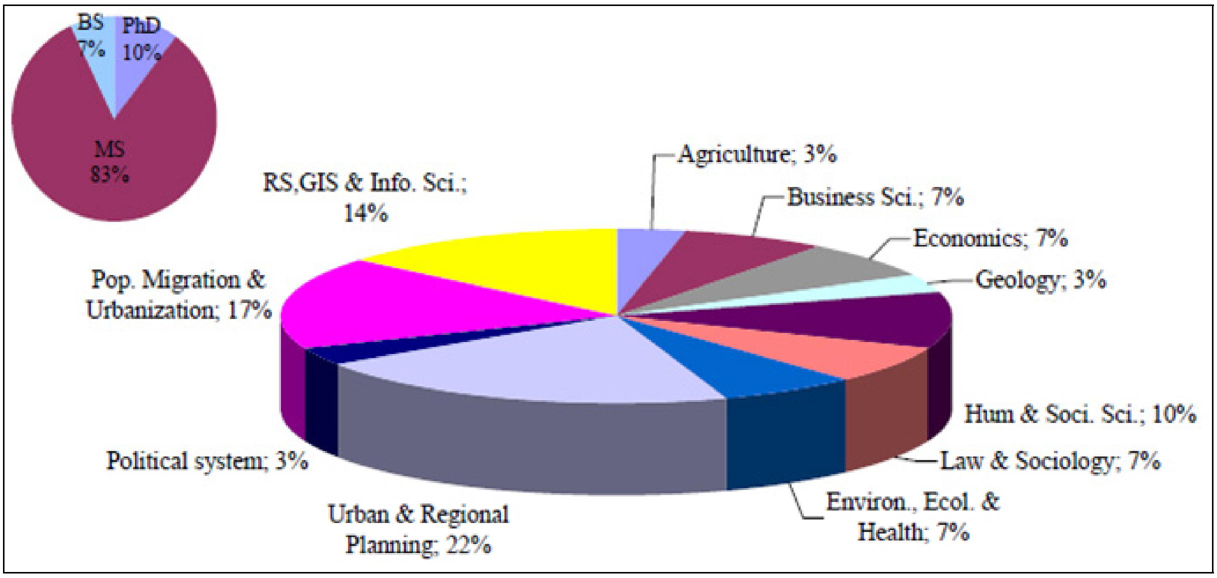

Figure 5-3: Respondents characteristic: Academic degree and specialization.

An automated spreadsheet system was developed using the AHP framework (Figure 3-2). This system provides a rapid assessment tool to predict the contribution level of each factor to changes in the landscape in different zones in the valley. A total of 29 matrices were developed for each study zone. The matrices of each zone were linearly combined using a geometric average function. As per the AHP rule, reciprocal computation, value normalization, principal vector weights computation, and consistency judgments were performed for each study zone (see Figure 3-2 and Appendix V for details). Consistency judgments, referred to as the consistency ratio (CR), indicate the probability that the matrix ratings were randomly generated. The prediction results in all study zones are achieved within a consistency ratio of 0.01, which is far better than the maximum acceptable (<= 0.1) ratio (Saaty, 1980). This means that the prediction result for each factor of each study zone is highly significant. The final scores of the driving factors were scaled to 0-100.

5.2 Driving factors in the city core area

Figure 5-4 shows the weight of each driving factor to changing the landscape in the city core area. The economic opportunities factor, with a weight of 23.2, is found to have a major impact on the urbanization process in the area. Major commercial establishments and government agencies are confined to the city core area. Much of the land in the area can be observed transforming into these types of establishments. These establishments have created various types of jobs that significantly absorb large populations in various capacities, which is indirectly proportional to the population growth factor. Population growth (20.7) is considered to be a second major factor in the area.

Almost equal roles are played by public service accessibility (15.4) and the political situation (15.1). Road, hospitals, parks, and educational institutions are well-established in this zone. Government ministries and headquarters of the major governmental agencies are located in the area. The city core is already crowded and the land is very expensive. The available lands are only affordable to large scale investors or commercial organizations. Therefore, in the core area, the land market factor (12.5) is not as important compared to the previous ones. The plans and policies factor has a weight of 8.7 for the last decade. This may be because the landscape in the core area is already developed or constrained for redevelopment projects. The physical condition of the land played a very weak role compared to all other factors. Most of the land in the city core area is flat and was converted to built-up surface earlier or by other driving factors.

5.3 Driving factors in the fringe area

Figure 5-5 presents the quantified results of the driving factors for changing the landscape in the fringe areas. Interestingly, the population growth factor has a weight of 24.1, which is the highest in the area. The fringe area emerged with both urban and rural lifestyles. Therefore, it might be an interesting place for the people from both categories. On one hand, as confirmed by the micro-scale study, the fringe areas also consist of a majority of people who inherited their land. In the other hand, the land is comparatively cheaper than in the city core. Several businessmen and workers select the fringe area as it is in close proximity to their working places. These processes enhance the population growth significantly by accelerating demand for urban services that ultimately change the landscape.

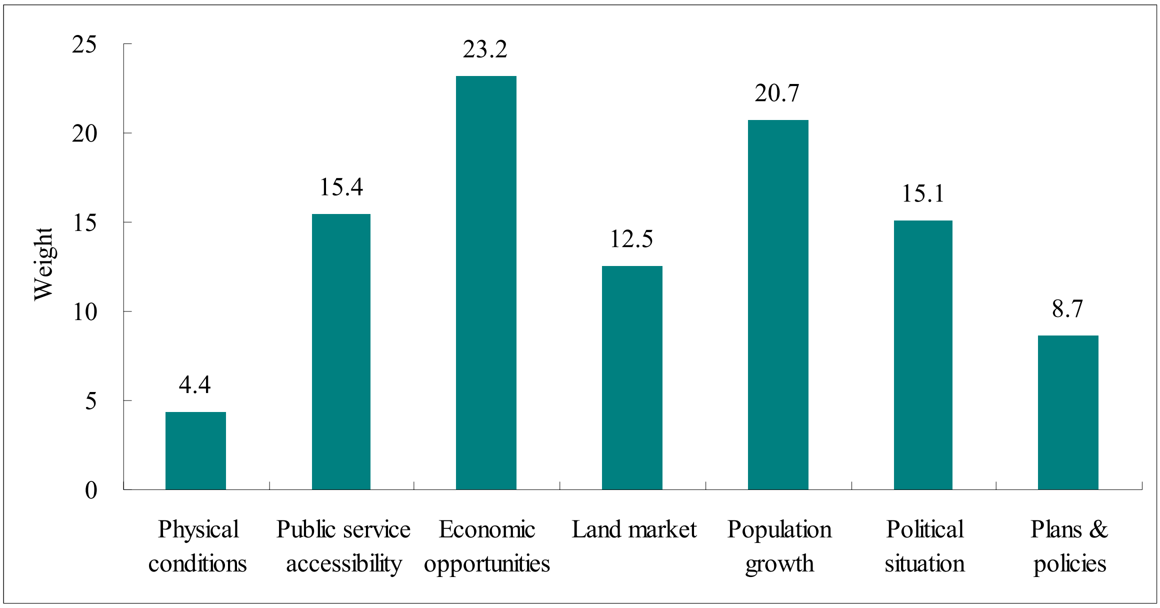

Figure 5-4: Weight of driving factors in city core area.

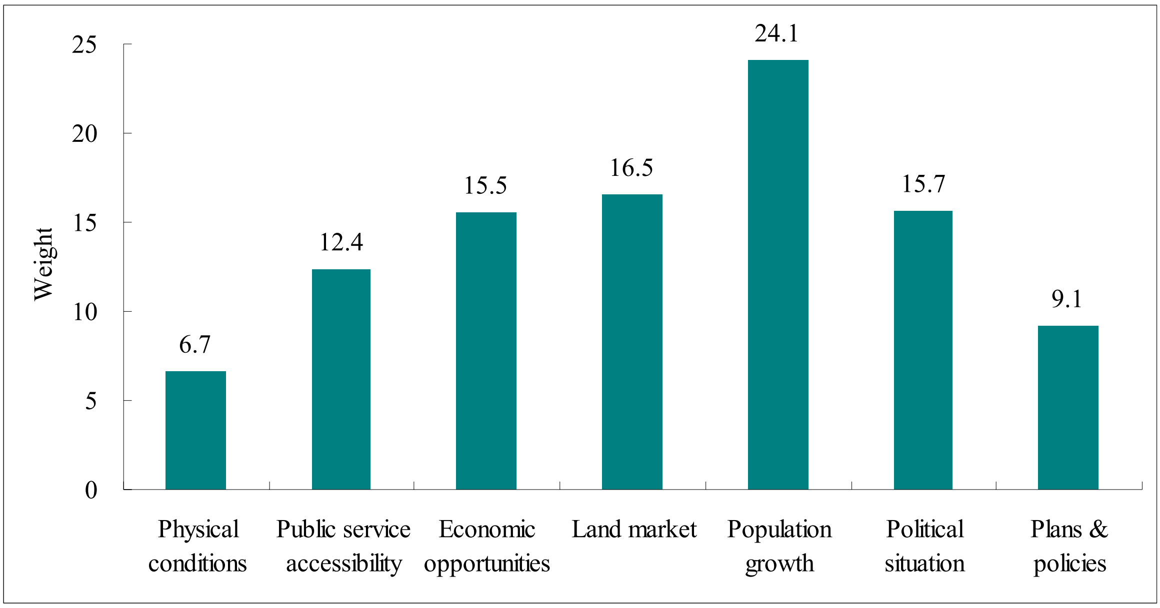

Figure 5-5: Weight of driving factors in fringe area.

The land market factor (16.5) is the second major factor of land use change in this area. The fieldwork revealed that local people, land brokers, and real estate developers are very active in changing the landscape. First, real estate developers acquired the lands from one or more local people depending on the land parcel size and availability for sale, and later either developed housing or sold the land to customers at a relatively higher price. After a customer buys the land in a particular area, the social network becomes active through the buyers. However, the political situation (15.7) and economic opportunities (15.5) were the third and fourth major roles, with only a small difference in their weights, while public service accessibility had only 12.4 points. Relatively few economic activities, schools, small retail shops and restaurants, and small health centers are located in the fringe areas. The plans and policies and physical conditions of the land played smaller roles, less than 10 points each, in the urbanization process of the fringe area.

5.4 Driving factors in the rural area

Figure 5-6 shows the weights of driving factors to changing the rural landscape. The political situation in the country (20.3) put higher pressure on changing the landscape in the area than the other factors. Several displaced people from the countryside were found living in the area. During the decade long political turmoil, the valley was considered to be the safest place in the country. Population growth (18.8) and land market (17.2) are the second and third most influencing factors, respectively. Due to lower land prices as compared to the fringe and city core areas, migrants have found more affordable lands in the area.

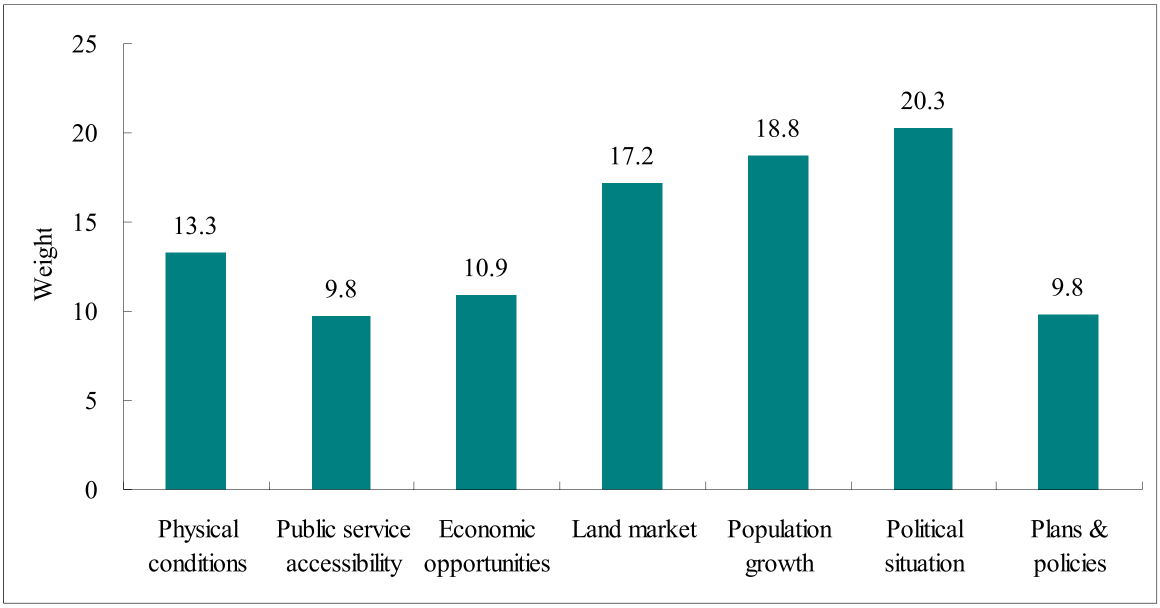

Figure 5-6: Weight of driving factors in rural area.

The physical conditions factor (13.3) is the fourth most important contributor to rural landscape change. The fertile soils and availability of water have attracted many commercial farmers. In addition, the soil in the area is useful for brick production. These might be the causes of the physical conditions factor being higher than the next three factors. The economic opportunities, public service accessibility, and plans and policies factors scored poorly as compared to the others. Other than brick and quarry factories, many fewer economic activities existed. People living in the rural areas have less access to public transportation, education, and other services. When in need of these services, most people have to commute to the fringe or city core areas. The fewer public services have caused less impact in changing the land uses. Some planned residential areas are being developed by private developers, but the effect is very nominal at present. Therefore, the respondents realized that the plans and policies factor has a lower impact in the landscape change.

5.5 Comparison of driving factors by thematic areas

Figure 5-7 shows that the influence of the physical conditions factor is more than 50% higher in the rural areas than in the other areas. Many brick factories and quarries are diffused throughout the area due to the suitable soil conditions and texture. The physical condition factor is not as important in the city core area due to the limited space availability. This factor often remains under shadow if other factors actively influenced. For example, if there is higher public service accessibility, the physiographic complexity is not the main issue in the city core and fringe areas, while the public service accessibility factor was slightly above 40% in the city core area, where most of the services are confined. Furthermore, opening of new commercial activities is observed in close proximity to the public services, which is a recent trend.

The influence of economic opportunities in rural areas is proportionately less than half that in the city core area. The land market factor has a higher influence in rural areas, and is a bit better than in the fringe areas. Lands in rural areas are being acquired at cheaper prices for new developments or land businesses. Land brokers and local residents are very active in land businesses in the rural and fringe areas. These might be the causes of the land market factor being proportionately higher in these areas than in the city core area.

The population growth factor is more likely to change the fringe landscape as compared to the urban core and the rural area. Some of the local people are still active in preserving their inherited land, which was also confirmed by the micro-scale case study. Thus, the natural population growth continues. Fringe areas in the valley are also the main attraction for the business people for residential purposes. Some of the new upper class people in the country are migrating to these areas. As population increased, the demand for housing increased proportionately. However, the population growth factor plays a second prominent role in the city core and rural areas, but it has noticeable variations in quantity as compared to the fringe areas.

The political situation factor played a larger role in changing the rural landscape than in the city core and fringe areas. The plans and policies factor seems to be effective in rural areas, but the difference in weights between the three landscapes is the least. Implementation of government plans and policies in the last few decades remained very weak, as has been claimed by other studies (HMGN/UNCTN, 2005; Thapa *et al.,* 2008).

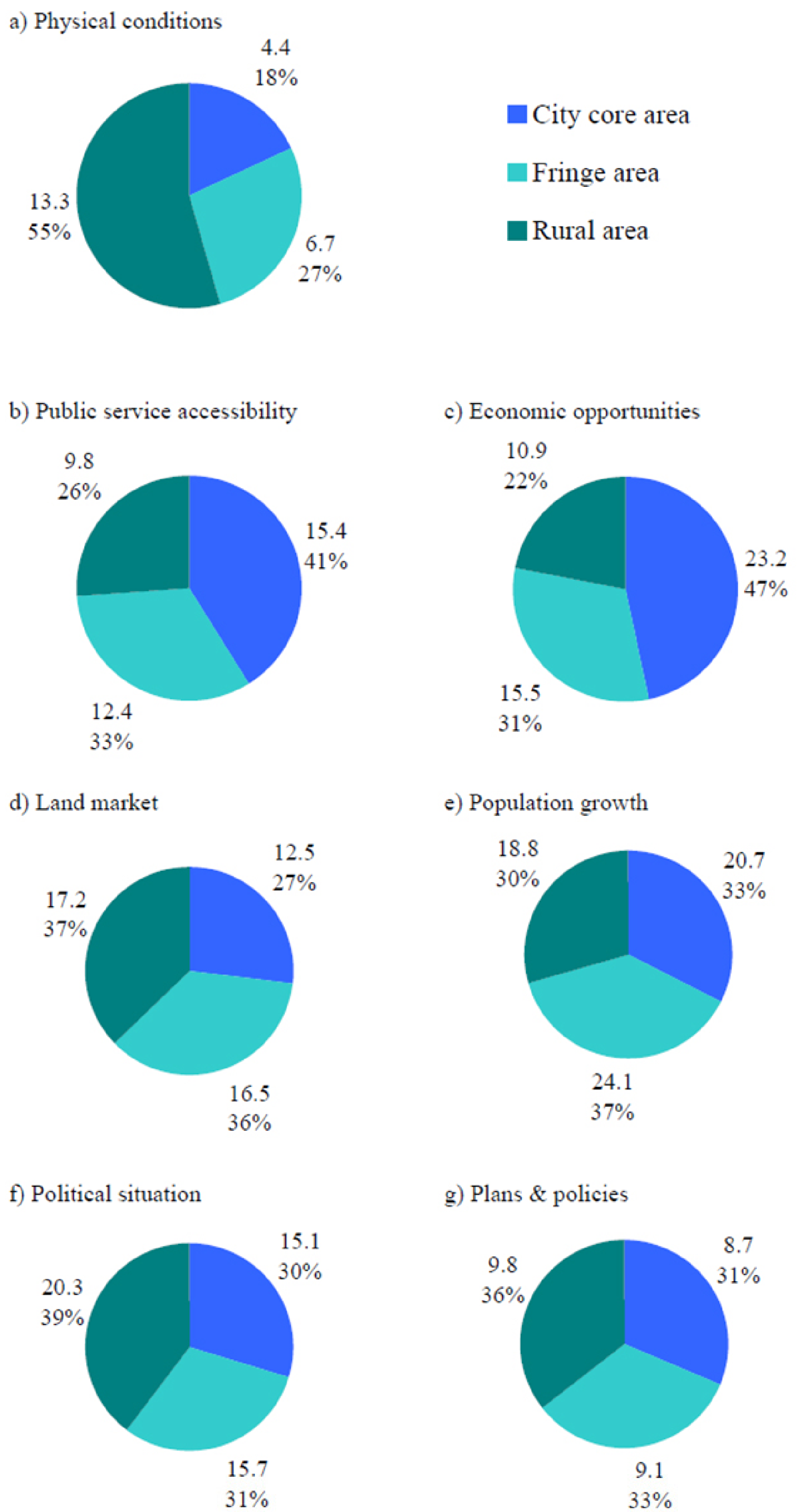

Figure 5-7: Comparison of driving factors' proportion by thematic areas.

5.6 Ranking of driving factors by thematic areas

Figure 5-8 presents the driving factors from 1st order (lowest impact) to 7th order (highest impact). The political situation factor is observed as the highest in rural areas, but was only 5th and 4th in the fringe and core areas, respectively. This has been an important subject in the past decade in Nepal. During the decade-long political turmoil, many people from elsewhere in the country migrated to the rural areas in the valley, as it was considered to be the safest place in the country. Some of the migrants became sources of labor for the brick factories and agriculture. The impact of the population growth factor is recognized as the 2nd highest in both the core and rural areas, ranking in the 6th position, but it ranked 7th in fringe areas, which is the highest impact factor. This shows that population growth has a higher impact on landscape change in the fringe areas in the valley. The land market factor seems to be modest ranking 6th, 5th, and 3rd in the fringe, rural, and core areas, respectively.

The physical conditions factor had the lowest impact in the city core and the fringe areas, but it ranked 4th in the rural areas. Economic opportunities had the highest rank in the city core area, but gradually lowered to 4th and 3rd in the fringe and rural landscapes, respectively. It is true that there are many opportunities, ranging from employment to businesses, in the city core area. Several traditional residential areas in the core are being transformed into business complexes. However, this factor plays a smaller role in the rural landscape due to lack of opportunities for business and employment.

The role of plans and policies is not as great in the valley. It is the 2nd lowest impact factor in all the landscape types in the valley. The residents of Kathmandu think that the government plans and policies performed poorly in changing the landscape. Due to less accessibility to public services in rural areas, it ranked lowest. With increasing proximity to the city core, its impact order gradually improved, from 3rd order in the fringe to 5th in the core areas.

Taken together, the economic opportunities, population growth, and political situation factors are the highest rank factors impacting change in the core, fringe, and rural areas, respectively. In the radar chart, two factors, population growth and land market, touched the sixth ring. The physical conditions factor appeared to be the lowest impact factor in the core and fringe areas, while the public service accessibility factor is the lowest in rural areas.

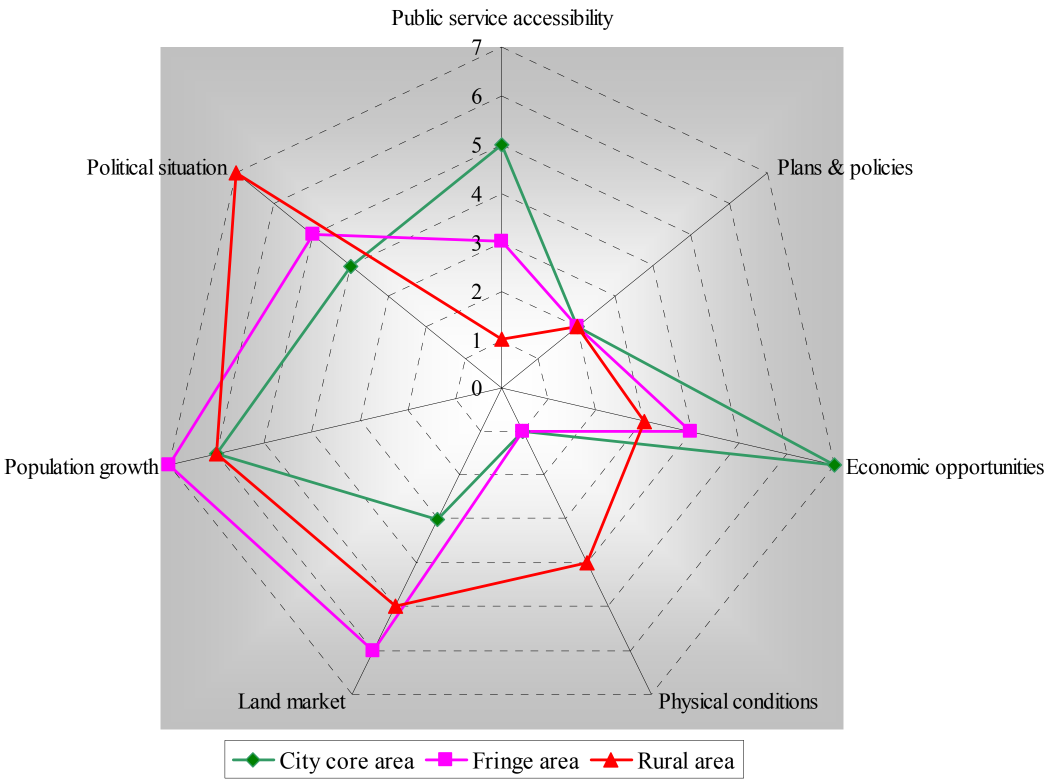

Figure 5-8: Driving factors impact ranking.

Chapter Six

Spatial Mechanism of Urbanization in the Last Decade

6.1 Spatial process of land use changes

Spatiotemporal analyses were employed to assess the changes in land uses and its influence on landscape patterns for four years in the Kathmandu valley. The analyses clearly showed that the intensity of human induced activities affected the landscape pattern of the study area. However, the other important finding was that it also influenced the dynamic changes in the land use types. The rapid urbanization process over productive agricultural lands in close proximity to the road network in the valley is apparent. The built-up area increased by 5% in each decade of the 1980s, and 1990s. This rate of increase is much higher than in the United States, Canada, and New Zealand (Li and Yeh, 2004).

A large share of agricultural space was transformed to urban/built-up areas in different time periods, and mainly occurred in the valley floors and neighboring villages. A proportional transition of other land uses to the urban/built-up areas was also found to be consistently increasing. Interestingly, a significant level of agricultural encroachment over the shrubs and forest lands was found in the 1980s. The urbanization process resulted in the increase of agricultural activities in rural areas in the valley. This is a common phenomenon near metropolitan regions of developing countries (Abdullah and Nakagoshi, 2006).

The urbanization process in the valley has caused fragmentation of the landscape and heterogeneous land use development. Haphazard land development practices and uncontrolled urban growth enhance those processes and generate a range of environmental problems affecting human health and welfare (Lopez *et al.*, 2001). The demand for infrastructure and services has caused the emergence of a number of urban environmental problems in Kathmandu (Thapa *et al.*, 2008). However, the heterogeneous landscape development will continue into the next few decades as the built-up areas in the valley floor have already started to agglomerate. Planned residential developments are emerging recently in the fringe and rural areas. Furthermore, the decreasing trend of nearest neighborhood distance is an indication that homogeneity will improve by refill type development after a certain period of time.

By looking at the planning initiatives in the valley, along with the establishment of infrastructure that provided easy access to the valley, it can be seen that the agglomeration of rural settlements into urban forms started in the early 1960s. Continuation of existing growth trends of the Kathmandu-Lalitpur complex, as well as the bipolar development of Bhaktapur with the reinforcement of transportation linkages and expanding settlements, can be observed in the maps (Figures 4-1 and 4-2). This could be linked with the impact of the first physical development plan for Kathmandu valley (HMGN, 1969). This plan was a foundation of Kathmandu Valley development and brought several changes in the later decades. A significant acceleration of the urbanization process can be observed (Figure 4-3) around the Kathmandu and Lalitpur municipalities in the 1980s, which might have been a result of the Kathmandu Valley Town Development Plan of 1976. This plan led to the development of a ring road around the Kathmandu and Lalitpur municipalities (Figure 4-2).

Government intervention in the urban development process through guided land development strategies, land pooling projects (Karki, 2004; ICIMOD, 2007), and road network expansion to several rural villages (Figures 4-3 and 4-4) also complimented the urbanization process in the 1990s; these were also outcomes of the Kathmandu Valley Urban Development Plans and Programs of 1991.

Industrialization also contributed to the urbanization of the valley, particularly in the 1970s and 1980s (IDM, 2007; Thapa *et al.*, 2008). Three major industrial estates, Balaju, Patan, and Bhaktapur, and several small scale industries scattered around the ring road and along major highways were established in the valley during these decades. The carpet industry was one of the industries that flourished in the valley. High worldwide demand for Nepalese carpet in the 1980s and early 1990s encouraged entrepreneurs to make investments in this sector. By that time, 5000 carpet factories were established in the valley, producing over 300,000 jobs (Eastman *et al.*, 1998), which enhanced the population pressure in the valley during that time. This fact shows that the carpet industry may have been a major driving force of urbanization in the 1980s. At present, however, due to the negative environmental consequences, enforcement of environmental laws and public awareness in the valley (ICIMOD, 2007) have caused the decline of the carpet industry by 50% (Gautam *et al.*, 2008).

A significant extension of the road network is observed during the 1980s and 1990s. The development of road networks to the rural periphery in the valley reduced the travel time for commuters living in the villages. It made it easier for rural farmers, the sole producers of the perishable goods for urban dwellers in the valley, to commute to the city for urban services and markets. This process enhanced rural prosperity and attracted migrants from neighboring districts. The rural villages gradually become urban frontiers. Along with the increased income, the agricultural landscapes in close proximity to the roads were gradually converted to urban/built-up areas (Figures 4-3, 4-4, and 4-10), stretching the urbanization influences to rural areas. Many individual developments occurred nearby in later years, showing that travel time was indicating major driver of change. Usually, the influence of roads is not linear. Bruijn (1994) indicated that the factors influencing land development probabilities often have a strong ‘distance decay function’. For example, the influence of a road or existing built-up areas on land development diminishes quickly with distance.

The land use change maps show that the most productive agricultural lands are now being converted to urban uses, particularly in the valley floor and nearby hills. This pattern is driven, in part, by migration. Migrants tend to move to areas in close proximity to economic opportunities and urban services in the valley, which is usual in most developing countries in Asia (Seto and Kaufmann, 2003). Consequently, urban centers emerge from areas where people first moved to the land with highest productivity. From the field observations, most of the lands in the fringes and nearby villages are growing high value agricultural products (i.e., vegetables, flowers, and fruits), where they used to be rice paddies a few years ago. Some of the paddy terraces in the hills of the city fringes, most with easy access to water and roads, were duly converted to perishable agricultural production land. Many rice paddies were converted to other types of agricultural land use for better revenue under the influences of market mechanisms. Rice paddies having suitable soils for brick production in the fringe and rural areas have also been converted to brick kiln areas in the dry season and back to rice paddies in the rainy season (Photo 2-3).

An interesting perspective of land use change was also revealed from interviews with the local residents. Although there are no official estimates of the privately funded development projects, the field observations and interviews confirm that the numbers are likely to be high. When developers first offered to finance projects, village leaders (largely composed of farmers) were quick to negotiate contracts to lease out their land. These lease agreements usually involved the payment of one lump sum, rather than a steady income stream of rents. Therefore, while farmers were able to compare current agricultural prices to lease rents, they did not consider future revenues from the agricultural income stream.

All these processes changed the spatial structure of the urban form in the valley floor, which is observed as a multiple-nuclei pattern. It has some similarity in structure with the classical model of Harris and Ullman (1945). However, depending on the culture and socioeconomic processes, the tendency of economic activity clusters appears differently in the valley as compared to the Harris and Ullman urban land use model. Furthermore, the spatial process of urbanization enhanced the fragmentation and heterogeneous landscape development in the valley. The trend of landscape structure and configuration change investigated in this study does not fully comply with the plans, although the urban and regional development plans have now been practiced for many years; however, as we have seen, they have had very limited impact in reality. The plans were reluctant to address other long term problems in the valley, the impact of which can still be observed today. The valley experienced high population influx and a heterogeneous land use environment caused by unrestrained urban development, which posed serious threats to the inhabitants (Karki, 2004; Dhakal, 2006; Haack and Rafter, 2006; Thapa *et al.*, 2008).

6.2 Factors affecting the spatial process in the last decade

In a broad sense, the changes in landscape patterns in the valley in the 1970s and 1980s were driven by transportation accessibility and the implementation of government plans and policies. However, land use change is driven by the interaction in space and time between the biophysical and human dimensions. The potential impact of land use and land cover change on the physical and social environment has stimulated research into the understanding of land use change and its main causes and effects. Several factors have emerged to cause changes to the landscape in the last decade with the increasing environmental and socioeconomic awareness of the people residing in the valley. Therefore, more specific studies with specific terms are necessary to understand the spatial process of rapid urbanization in the recent decade.

Various driving factors of land use changes in the valley have been important in the last decade. Many of these factors, sometimes in variations, have been found to be important in other studies. For example, Antrop (2005) highlighted accessibility, urbanization, calamities, and global economic opportunities as important factors. Verburg *et al.* (2004) identified biophysical characteristics, socioeconomic conditions, accessibility, neighborhood interaction, and spatial policies as major driving forces of land use change. Political, economic, cultural, technological, natural/structural, and policies factors are found to be major land use change drivers in studies by Schneeberger *et al.* (2007) and Hersperger and Burgi (2007).

In this empirical study, biophysical, socioeconomic and plan and policy factors were synthesized into seven specific factors for the Kathmandu valley. The field observations, group discussions, and interviews, including the micro-scale case study, helped to synthesize the factors. These factors were empirically evaluated creating three thematic regions: city core, fringe, and rural areas of the metropolitan landscape. The territorial landscape of the thematic regions can be dynamic characters over time. The rapid spatial diffusion process occurring in metropolitan areas often makes it dynamic at different time periods, which can be observed in Figures 4-5, 4-6, and 4-7. These figures represent the same location at the same scale, but the landscape at time 1 is rural, completely agricultural land, and where its transformation can be seen to fringe at time 2, and it is entirely agglomerated to urban core at time 3. Urbanization can be seen as sprawling over time. Although the location properties changed at each time, the thematic regional character (core, fringe, and rural) in the metropolitan region appears in different places in different forms; they are never eliminated. Thus, the activities of the driving factors also synchronize with these thematic regions in the metropolitan landscape. The role of different driving factors could be dynamic for a particular location because of the spatial diffusion of urbanization.

Significant variations between these thematic boundaries and between the factors are observed. For example, economic opportunities in the city core area, population growth in the fringe area, and the political situation in the rural area are the highest impact factors that played significant roles in changing the corresponding landscapes in the valley. Although these factors competed with other factors in the corresponding regions, a difference in the weights of these highest factors was also noticed (Figure 6-1). The decade-long political turmoil in the country had different causes and effects at different level in the valley urbanization process. Recent political developments, if they continue, may nullify this factor in the next decade. The dimension of other factors may also change in the future. If the implementation of urban development plans and policies can overcome the current delusions created by the political crisis, the plans and policies factor may become more effective than it has been over the last decade.

Figure 6-1 further clarifies the roles of the driving factors and how each factor competes with the others in the different landscapes. The population growth factor in the fringe area is six time stronger than the physical condition factor's strength in the core area. However, the physical conditions strength in the rural area is similar to the land market factor's role in the core area. Similar factor strengths can also be found in the same thematic region; for example, between the public service accessibility and plans and policies factors in the rural area. However, it is shown that the similar driving factors played different roles in the different landscapes of the valley, as they carried different human-nature interaction properties for different periods of time.

The AHP framework developed during the course of this study effectively models the driving factors problem to understand the competition between the factors in changing the metropolitan landscape. The inclusion of experts' decisions through the participation of local people in the process of evaluating the driving factors minimized the probability errors significantly and made the research more original. The quantification of the driving factors' contributions/roles in changing the land use patterns is an important piece of information that will be an input to modeling urban growth to understand future processes.

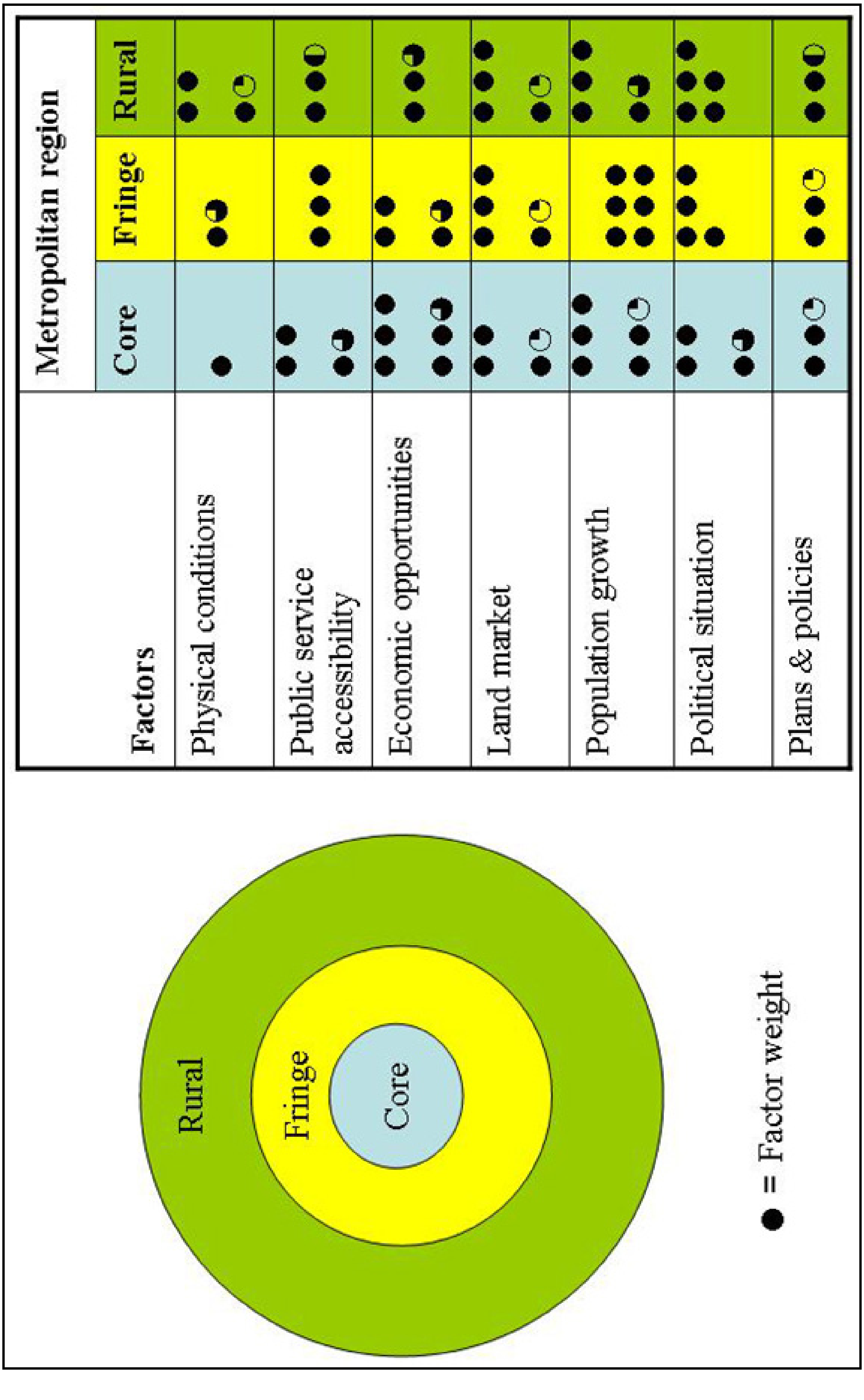

Figure 6-1: Driving factors of urbanization process in the last decade.

Chapter Seven

Conclusions

Kathmandu Valley exhibits the attributes of a typical metropolitan region in the Himalayan region. With its beautiful mountain landscape, the valley accommodates more than 1.5 million people within a very limited space. The increasing population pressure caused the spatial pattern of urbanization to be highly dynamic. The predominantly agricultural landscape gradually changed to an urban landscape with increasing human settlement in the 1960s and 1970s. The changing process has escalated since the 1980s. It has proved to be very high in the urban fringe area. Spatial diffusion of urban/built-up areas has spread outward from the city core and along the major roadways.

The urban built-up area has increased by four times in the last four decades. Almost half of the shrubs land in the valley has disappeared during this period. Similarly, forest land decreased dramatically in the 1980s. Shrubs and forest landscape in rural areas of the valley mostly changed to agricultural areas. Half of the land in the valley is still agricultural area, but it has faced changing circumstances in different time period. Agricultural encroachment in rural hills and mountain peripheries and urbanization in the valley floor area are identified as the most common phenomenon in the study period. The micro-scale study revealed that the spatial pattern of urbanization in the fringes doubled since 1991. A nominal land use transition between the other land uses was also noticed.

The sparsely developed built-up area with individual unordered housing practices in the fringe areas indicated a complex urbanization process in the valley. An increasing trend of land use diversity is explored using the spatial metrics analysis. The land use patch density significantly increased during the period. Such urbanization process and scattered individual developments created fragmentation and a heterogeneous landscape that gradually increased in the 1980s and 1990s. These processes are mostly observed in the city fringes and adjacent villages in the valley. However, the overall nearest neighbor distance between the similar land use patches in the valley has decreased over the last two decades. The city core area seems to be agglomerated, which eventually creates homogeneity by the refilling type of development.

Seven key driving factors, physical conditions, public service accessibility, economic opportunities, land market, population growth, political situation, and plans and policies, are identified as indicators of the urbanization process over the last decade. Among these factors, the economic opportunities factor is found to be a major influence in changing the city core area, whereas the population growth factor has played a greater role in changing the fringe areas. The political situation factor is identified as a prominent factor in rural areas in the valley. The plans and policies factor seems to be very weak in changing the landscape; however it plays a consistent role regardless of thematic areas.

The physical condition factor has very low impact in the city core and fringe areas, but played a larger role than the economic opportunities, public service accessibility, and plans and policies in the rural areas. The land market factor played a second major role in the fringe areas and the third most important role in the rural area, while it is less important in the city core area. Due to spatial disparities in the public service establishments in the valley, the public services accessibility factor has a very low impact in rural land use changes. The physical condition factor for the city core area and the fringe area, and public service accessibility factor for rural areas, are considered to be extremely low impact factors in the overall urbanization process of the metropolitan region. The land market is found to be a modest factor in all thematic areas.

The empirical observations and the integrated framework outlined in this dissertation represent a different approach to investigating urbanization dynamics and their driving factors. It has provided a robust quantitative measure of land use dynamics and the driving factors, which conveys an important message to urban planners and researchers working in the valley and beyond. The entire framework applied in this research, from mapping to fieldwork, can be useful to modelers in developing policies and scenarios for sustainable land use planning and steer the urbanization in an environmentally friendly direction. However, more detailed scientific surveys in the fringe and rural areas, and frequent monitoring of the urbanization, are needed in order to understand the dynamic spatial process of urbanization at finer scales and make decisions at the local level.

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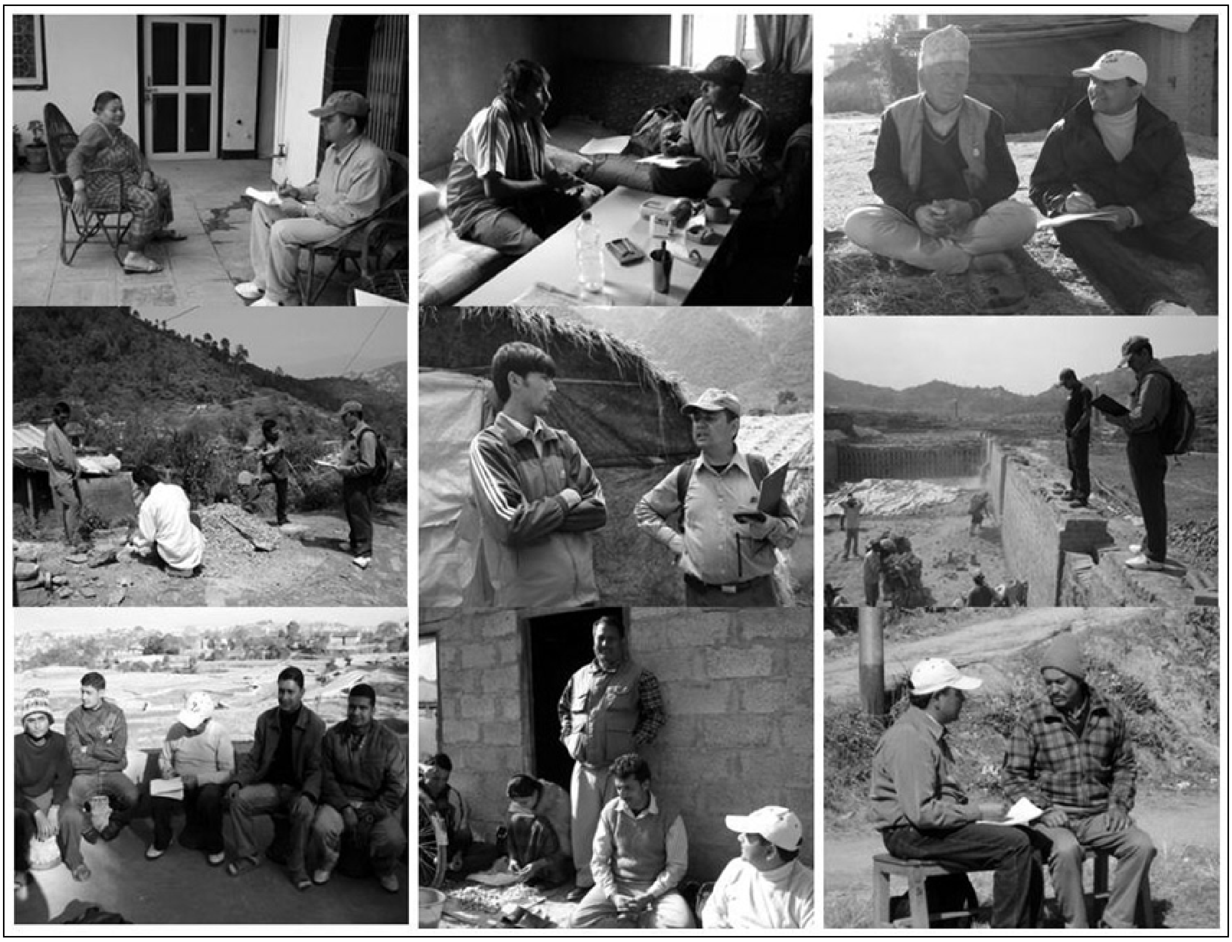
Appendix I: Fieldwork - interviews and discussions

Some of the photographs from interview and group discussion with local people.



Appendix II: AHP Questionnaire module

Field survey for PhD thesis research,
Rajesh Bahadur Thapa,
Graduate Student, University of Tsukuba

Please input your personal details as following.

Respondent's name:

Highest academic degree: Bachelors/Masters/PhD

Academic background: Specialization:

Designation: Office/Department:

Please have a look in the following indicators as land use change drivers in Kathmandu valley and provide your judgment in the next page.

Land use change drivers in Kathmandu valley

1. Physical condition (topography, slopes, soils, rivers, climate, etc.)
2. Access to public services (transportation, electricity, communication, water, health, waste disposal, open spaces and recreation facilities)
3. Economic opportunities (employment, business, industries, market)
4. Land market (land price, local people, land broker, real estate)
5. Population growth (increase in population by natural and by migration)
6. Political situation (political opportunity, conflict in the country, displaced people, public security in the valley)
7. Govt. plan & policies (zoning, land reforms, economic and investment plans)
8. Others (if you wanted to add one more variable)

Please, compare the strength of the drivers and circle the value based on their roles to change the land use.

1. Equal 3. Moderate 5. Strong 7. Very strong 9. Extreme

You may circle 2,4,6,8 as intermediate value when you feel compromise.

Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Public services access
Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic opportunities
Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Land market
Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Population growth
Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political situation
Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Plan & policies
Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)
Public services access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic opportunities
Public services access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Land market
Public services access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Population growth
Public services access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political situation
Public services access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Plan & policies
Public services access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)
Economic opportunities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Land market
Economic opportunities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Population growth
Economic opportunities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political situation
Economic opportunities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Plan & policies
Economic opportunities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)
Land market	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Population growth
Land market	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political situation
Land market	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Plan & policies
Land market	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)
Population growth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political situation
Population growth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Plan & policies
Population growth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)
Political situation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Plan & policies
Political situation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)
Plan & policies	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Other (your opinion)

For example: physiographic condition plays **strong** role than the urban facilities for changing the land use in the valley.

Physical condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Public services access

Appendix III: Accuracy assessment of the land use classification

The accuracy of thematic maps derived by image classification analyses is often compared in remote sensing studies. Accuracy assessment is a general term for comparing predicted (i.e., classification) results to geographical reference data that are assumed to be true. This comparison is typically achieved by a basic subjective assessment of the observed difference in accuracy but should be undertaken in a statistically rigorous fashion. A set of reference pixels representing geographic points on the classified image is required for the accuracy assessment. Randomly selected reference pixels lessen or eliminate the possibility of bias. In this study, random sampling method was used to prepare the ground reference data. A total of 180 reference pixels, 30 for each land use type, were prepared for each map as ground truth, using the source data as discussed earlier in the ground reference data section.

An error matrix was prepared for each resulting thematic map. The matrix provided the correspondence between the predicted and the actual classes of membership for an independent testing dataset. It made it possible to derive a range of quantitative measures of classification accuracy. Four measures (*producer's, user's* and *overall accuracy,* and K_{hat} *statistic*) of accuracy assessment were computed to evaluate the accuracy of the thematic maps. The producer's accuracy represents the measure of omission errors that corresponds to those pixels belonging to the class of interest that the classifier has failed to recognize. The user's accuracy, on the other hand, refers to the measure of commission errors that correspond to those pixels from other classes that the classifier has labeled as belonging to the class of interest. The overall accuracy is the percentage of correctly classified samples. The K_{hat} measure of agreement or accuracy based on Kappa analysis that expresses the proportionate reduction in error generated by a classification process. Kappa accounts for all elements of the confusion matrix and excludes agreement that occurs by chance. Consequently, it provides a more rigorous assessment of classification accuracy. More references about the accuracy assessment can be found in Thapa and Murayama (*in press*).

The following equations were used while assessing the accuracies.

Producer's accuracy

$X_{ii} / X_{+i} \, x \, 100\%$

Where,

X_{ii} = total number correct cells in a class, and

X_{+i} = sum of cell values in the column.

User's accuracy

$X_{ii} / X_{i+} \, x \, 100\%$

Where,

X_{ii} = total number correct cells in a class, and

X_{i+} = sum of cell values in the row.

Overall accuracy

D / N *x* 100%

Where,

D = total number correct cells as summed along the major diagonal, and

N = total number of cells in the error matrix.

K_{hat}

$$N\sum_{i=1}^{r} xii - \sum_{i=1}^{r}(x_i + X_{x+i}) / N^2 - \sum_{i=1}^{r}(x_i + X_{x+i})$$

Where,

r = number of rows in the matrix,

X_{ii} = total number correct cells in a class (i.e., value in row *i* and column *i*),

X_{i+} = total for row *i*,

X_{+i} = total for column *i*, and

N = total number of cells in the error matrix.

Table III-1: Error matrix for land use classification (1999)

Classified data	Reference data							
	SA	FA	WA	BA	OS	AA	Total	UA %
SA	25	4	0	0	0	1	30	83
FA	3	27	0	0	0	0	30	90
WA	2	3	22	0	0	3	30	73
BA	0	1	1	24	1	3	30	80
OS	0	0	0	3	27	0	30	90
AA	4	0	0	1	0	25	30	83
Total	34	35	23	28	28	32	180	
PA %	74	77	96	86	96	78		

Overall accuracy = 83.33%.

Overall K_{hat} statistics = 0.80.

SA = Shrubs area; FA = Forest area; WA= Water area; BA= Builtup area; OS = Open space; AA = Agriculture area; PA= Producer's accuracy; and UA = User's accuracy (number unit in pixel).

Table III-2: Error matrix for land use classification (1989)

Classified data	Reference data							
	SA	FA	WA	BA	OS	AA	Total	UA %
SA	24	2	2	1	0	1	30	80
FA	3	26	0	0	0	1	30	87
WA	0	3	25	0	0	2	30	83
BA	0	1	1	25	1	2	30	83
OS	0	1	0	2	27	0	30	90
AA	3	0	0	1	1	25	30	83
Total	30	33	28	29	29	31	180	
PA %	80	79	89	86	93	81		

Overall accuracy = 84.44%

Overall K_{hat} statistics = 0.81

Table III-3: Error matrix for land use classification (1976)

Classified data	Reference data							
	SA	FA	WA	BA	OS	AA	Total	UA %
SA	20	7	1	0	0	2	30	67
FA	3	24	1	0	0	2	30	80
WA	1	2	25	1	0	1	30	83
BA	0	0	1	27	2	1	31	87
OS	0	0	0	2	26	2	30	87
AA	1	0	3	2	0	24	30	80
Total	25	33	31	32	28	32	181	
PA %	80	73	81	84	93	75		

Overall accuracy = 80.66 %

Overall K_{hat} statistics = 0.76

SN:…………

Appendix IV: Interview questionnaire for micro study purpose

Determinants of urbanization
Field survey interview for PhD thesis
Rajesh Bahadur Thapa, Graduate Student, University of Tsukuba

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1. Location/Personal

1.1 District: Kathmandu
V.D.C./Municipality: Kathmandu Metropolitan Ward:
Tole : ………………………………………House No.:

1.2 Respondent's age: Gender: Male/Female Ethnicity:

2. Migration

2.1 Where did you come from?
- ☐ District Name
  - o VDC/Municipality Name :…………………………………Ward No:
  - o Tole: …………………………………

2.1 When did you come? Year: AD/BS
2.2 When did you build the house? …………AD/BS
2.3 Current land use:
2.4 State of the land before the present house was built?
- ☐ Old house ☐ Ag. Land ☐ Other……….

3. Process/Reasons

3.1 Why did you choose this place (as much as details)?

Local
- ☐ Inherited land
- ☐ Urban facilities
- ☐ Business
- ☐ Employment
- ☐ Land value
- ☐ Public safety
- ☐ Other

Migrant
- ☐ Urban facilities
- ☐ Business
- ☐ Employment
- ☐ Land value (reasonable price)
- ☐ Public safety
- ☐ Social network
- ☐ Other

3.2 How did you know about this place?
- ☐ Relatives
- ☐ Friends
- ☐ Land broker
- ☐ Media
- ☐ Others (specify……………..)

3.3 How did you buy?
- ☐ Local people ☐ Local agent ☐ Real estate (name:

4. How do you perceive current urbanization?

Appendix V: Driving factors evaluation and consistency judgment

V-I. For city core area

Table I-A: Geometric mean from 29 matrices

		j						
	Factors	F1	F2	F3	F4	F5	F6	F7
	F1	1.00	0.34	0.22	0.30	0.21	0.26	0.49
	F2	x	1.00	0.83	1.59	0.62	0.81	1.85
	F3	x	x	1.00	2.01	1.28	1.80	2.60
i	F4	x	x	x	1.00	0.58	0.90	1.65
	F5	x	x	x	x	1.00	1.35	2.29
	F6	x	x	x	x	x	1.00	1.56
	F7	x	x	x	x	x	x	1.00

Note: F1: Physical condition; F2: Public service accessibility;
F3: Economic opportunities; F4: Land market; F5: Population growth;
F6: Political situation; F7: Plan & policies.

Table I-B: Reciprocal calculation of Table I-A

Factors	F1	F2	F3	F4	F5	F6	F7
F1	1.00	0.34	0.22	0.30	0.21	0.26	0.49
F2	2.98	1.00	0.83	1.59	0.62	0.81	1.85
F3	4.64	1.20	1.00	2.01	1.28	1.80	2.60
F4	3.31	0.63	0.50	1.00	0.58	0.90	1.65
F5	4.75	1.62	0.78	1.71	1.00	1.35	2.29
F6	3.86	1.24	0.56	1.11	0.74	1.00	1.56
F7	2.04	0.54	0.38	0.61	0.44	0.64	1.00
Total	22.58	6.56	4.26	8.33	4.87	6.76	11.45

Table I-C: Normalized matrix of paired comparison and calculation of factor weights

Factors	F1	F2	F3	F4	F5	F6	F7	∑	∑/N	Wt.
F1	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.31	0.04	4.38
F2	0.13	0.15	0.19	0.19	0.13	0.12	0.16	1.08	0.15	15.42
F3	0.21	0.18	0.23	0.24	0.26	0.27	0.23	1.62	0.23	23.16
F4	0.15	0.10	0.12	0.12	0.12	0.13	0.14	0.88	0.13	12.52
F5	0.21	0.25	0.18	0.21	0.21	0.20	0.20	1.45	0.21	20.72
F6	0.17	0.19	0.13	0.13	0.15	0.15	0.14	1.06	0.15	15.13
F7	0.09	0.08	0.09	0.07	0.09	0.09	0.09	0.61	0.09	8.67
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	100.00

Note: N = Number of factors

Table I-D: Consistency calculation for Wt.

Factors	A							B	C	D
	F1	F2	F3	F4	F5	F6	F7			
F1	1.00	0.34	0.22	0.30	0.21	0.26	0.49	0.04	0.31	7.046
F2	2.98	1.00	0.83	1.59	0.62	0.81	1.85	0.15	1.09	7.057
F3	4.64	1.20	1.00	2.01	1.28	1.80	2.60	0.23	1.64	7.061
F4	3.31	0.63	0.50	1.00	0.58	0.90	1.65	0.13	0.88	7.051
F5	4.75	1.62	0.78	1.71	1.00	1.35	2.29	0.21	1.46	7.058
F6	3.86	1.24	0.56	1.11	0.74	1.00	1.56	0.15	1.07	7.054
F7	2.04	0.54	0.38	0.61	0.44	0.64	1.00	0.09	0.61	7.050
									∑D	49.377

Note: [C] = [A] x [B]; [D] = [C] / [B]

$\lambda_{\mathbf{max}}$ (∑D / N) = 7.054; **CI** {(λ_{max} - N) / N - 1} = 0.009; **RI** (Table at N^{th})= 1.32;

Consistency Ratio (CI / RI) = 0.0068

V-II. For fringe area

Table II-A: Geometric mean from 29 matrices

		j						
	Factors	F1	F2	F3	F4	F5	F6	F7
	F1	1.00	0.57	0.32	0.40	0.29	0.47	0.81
	F2	x	1.00	0.96	0.61	0.42	0.79	1.73
	F3	x	x	1.00	0.86	0.73	1.00	1.40
i	F4	x	x	x	1.00	0.60	1.10	1.50
	F5	x	x	x	x	1.00	1.36	2.58
	F6	x	x	x	x	x	1.00	1.83
	F7	x	x	x	x	x	x	1.00

Note: F1: Physical condition; F2: Public service accessibility;
F3: Economic opportunities; F4: Land market; F5: Population growth;
F6: Political situation; F7: Plan & policies.

Table II-B: Reciprocal calculation of Table II-A

Factors	F1	F2	F3	F4	F5	F6	F7
F1	1.00	0.57	0.32	0.40	0.29	0.47	0.81
F2	1.76	1.00	0.96	0.61	0.42	0.79	1.73
F3	3.11	1.05	1.00	0.86	0.73	1.00	1.40
F4	2.50	1.63	1.17	1.00	0.60	1.10	1.50
F5	3.44	2.40	1.37	1.67	1.00	1.36	2.58
F6	2.11	1.26	1.00	0.91	0.74	1.00	1.83
F7	1.23	0.58	0.71	0.67	0.39	0.55	1.00
Total	15.17	8.48	6.53	6.11	4.16	6.27	10.85

Table II-C: Normalized matrix of paired comparison and calculation of factor weights

Factors	F1	F2	F3	F4	F5	F6	F7	∑	∑/N	Wt.
F1	0.07	0.07	0.05	0.07	0.07	0.08	0.07	0.47	0.07	6.68
F2	0.12	0.12	0.15	0.10	0.10	0.13	0.16	0.87	0.12	12.38
F3	0.21	0.12	0.15	0.14	0.18	0.16	0.13	1.09	0.16	15.51
F4	0.17	0.19	0.18	0.16	0.14	0.18	0.14	1.16	0.17	16.54
F5	0.23	0.28	0.21	0.27	0.24	0.22	0.24	1.69	0.24	24.10
F6	0.14	0.15	0.15	0.15	0.18	0.16	0.17	1.10	0.16	15.65
F7	0.08	0.07	0.11	0.11	0.09	0.09	0.09	0.64	0.09	9.15
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	100.00

Note: N = Number of factors

Table II-D: Consistency calculation for Wt.

Factors	A							B	C	D
	F1	F2	F3	F4	F5	F6	F7			
F1	1.00	0.57	0.32	0.40	0.29	0.47	0.81	0.07	0.47	7.056
F2	1.76	1.00	0.96	0.61	0.42	0.79	1.73	0.12	0.87	7.057
F3	3.11	1.05	1.00	0.86	0.73	1.00	1.40	0.16	1.09	7.057
F4	2.50	1.63	1.17	1.00	0.60	1.10	1.50	0.17	1.17	7.071
F5	3.44	2.40	1.37	1.67	1.00	1.36	2.58	0.24	1.70	7.073
F6	2.11	1.26	1.00	0.91	0.74	1.00	1.83	0.16	1.10	7.058
F7	1.23	0.58	0.71	0.67	0.39	0.55	1.00	0.09	0.65	7.054
									∑D	49.425

Note: [C] = [A] x [B]; [D] = [C] / [B]

$\lambda_{\mathbf{max}}$ (∑D / N) = 7.061; **CI** {(λ_{max} - N) / N - 1} = 0.010; **RI** (Table at N^{th})= 1.32;

Consistency Ratio (CI / RI) = 0.0077

V-III. For rural area

Table III-A: Geometric mean from 29 matrices

		j						
	Factors	F1	F2	F3	F4	F5	F6	F7
	F1	1.00	1.66	1.27	0.84	0.71	0.52	1.23
	F2	x	1.00	0.98	0.65	0.46	0.54	0.97
	F3	x	x	1.00	0.67	0.51	0.62	1.22
i	F4	x	x	x	1.00	1.38	0.85	1.50
	F5	x	x	x	x	1.00	1.08	1.85
	F6	x	x	x	x	x	1.00	2.51
	F7	x	x	x	x	x	x	1.00

Note: F1: Physical condition; F2: Public service accessibility;
F3: Economic opportunities; F4: Land market; F5: Population growth;
F6: Political situation; F7: Plan & policies.

Table III-B: Reciprocal calculation of Table III-A

Factors	F1	F2	F3	F4	F5	F6	F7
F1	1.00	1.66	1.27	0.84	0.71	0.52	1.23
F2	0.60	1.00	0.98	0.65	0.46	0.54	0.97
F3	0.79	1.02	1.00	0.67	0.51	0.62	1.22
F4	1.18	1.53	1.49	1.00	1.38	0.85	1.50
F5	1.42	2.15	1.98	0.73	1.00	1.08	1.85
F6	1.92	1.86	1.61	1.17	0.92	1.00	2.51
F7	0.81	1.03	0.82	0.67	0.54	0.40	1.00
Total	7.73	10.24	9.15	5.74	5.51	5.02	10.27

Table III-C: Normalized matrix of paired comparison and calculation of factor weights

Factors	F1	F2	F3	F4	F5	F6	F7	∑	∑/N	Wt.
F1	0.13	0.16	0.14	0.15	0.13	0.10	0.12	0.93	0.13	13.26
F2	0.08	0.10	0.11	0.11	0.08	0.11	0.09	0.68	0.10	9.76
F3	0.10	0.10	0.11	0.12	0.09	0.12	0.12	0.76	0.11	10.88
F4	0.15	0.15	0.16	0.17	0.25	0.17	0.15	1.21	0.17	17.22
F5	0.18	0.21	0.22	0.13	0.18	0.22	0.18	1.31	0.19	18.77
F6	0.25	0.18	0.18	0.20	0.17	0.20	0.24	1.42	0.20	20.30
F7	0.11	0.10	0.09	0.12	0.10	0.08	0.10	0.69	0.10	9.81
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	100.00

Note: N = Number of factors

Table III-D: Consistency calculation for Wt.

Factors	A							B	C	D
	F1	F2	F3	F4	F5	F6	F7			
F1	1.00	1.66	1.27	0.84	0.71	0.52	1.23	0.13	0.94	7.061
F2	0.60	1.00	0.98	0.65	0.46	0.54	0.97	0.10	0.69	7.058
F3	0.79	1.02	1.00	0.67	0.51	0.62	1.22	0.11	0.77	7.064
F4	1.18	1.53	1.49	1.00	1.38	0.85	1.50	0.17	1.22	7.081
F5	1.42	2.15	1.98	0.73	1.00	1.08	1.85	0.19	1.33	7.073
F6	1.92	1.86	1.61	1.17	0.92	1.00	2.51	0.20	1.44	7.070
F7	0.81	1.03	0.82	0.67	0.54	0.40	1.00	0.10	0.69	7.065
									∑D	49.473

Note: [C] = [A] x [B]; [D] = [C] / [B]

$\lambda_{\mathbf{max}}$ (∑D / N) = 7.068; **CI** {(λ_{max} - N) / N - 1} = 0.011; **RI** (Table at N^{th})= 1.32;

Consistency Ratio (CI / RI) = 0.0085