Masters Program in Geospatial Technologies

URBAN CHANGE MONITORING USING GIS AND REMOTE SENSING TOOLS IN KATHMANDU VALLEY (NEPAL)

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URBAN CHANGE MONITORING USING GIS AND REMOTE SENSING TOOLS IN KATHMANDU VALLEY (NEPAL)

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URBAN CHANGE MONITORING USING GIS AND REMOTE SENSING TOOLS IN KATHMANDU VALLEY (NEPAL)

ABSTRACT

The urbanization pattern during the period of 1989 to 2006 of Kathmandu valley was studied using Landsat data. The main aims of the study were to apply Geographic Information Systems (GIS) and Remote Sensing tools for the study of land use and land cover classification, change analysis and urban growth model for 2019 of the Kathmandu valley. The study also reviewed population growth and urbanization trends in connection with increasing built up areas leading to the environmental degradation. The population growth and urbanization trend of Kathmandu valley was the highest among other cities in Nepal. Principal component analysis was applied to spectrally enhance images to get the better image classification results. Images were classified in six land use and land cover classes using supervised classification and maximum likelihood algorithm which were then re-classed into built up and non-built up to focus on urbanization. The analysis showed that the built up area had grown up to 134% in 2006 since 1989. The assessed overall accuracies for the classification of three images were between 86 to 89 percentages. Cellular Automata Markov (CA_MARKOV) and GEOMOD modeling programs were used to project the 2006 and then 2019 land use and land cover classes. The 2019 land use and land covers was projected after satisfactory validation of projected 2006 land classes resulting with Kappa more than 0.55 up to 0.75. The future projection of land classes did not show that the urban growth will have significant effects to the designated areas. However, there will be some effects in water bodies. The Landsat images along with other ancillary data proved to be useful for the overall study.

KEYWORDS

Geographic Information System

Kathmandu valley

Land use & cover change model

Remote Sensing

Urbanization

ACRONYMS

AHP – Analytical Hierarchy Process

CA – Cellular Automata

CBS – Central Bureau of Statistics

CR – Consistency ratio

DoS – Depart of Survey

ESRI – Environmental Systems Research Institute

ETM$^+$ – Enhanced Thematic Mapper Plus

GCPs – Ground Control Points

GIS – Geographic Information System(s)

GoN – Government of Nepal

ICIMOD – International Centre for Integrated Mountain Development

LUCC – Land Use Cover Change

MCE – Multi-Criteria-Evaluation

MoEST – Ministry of Environment, Science, and Technology

SLC – Scan-line corrector

SRTM –Shuttle Radar Topographic Mission

UNEP – United Nations Environment Programme

VDC – Village Development Committee

WLC – Weighted Linear Combination

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Background

Urban change is the result of urbanization process. Urbanization, in general, is known as the process of growth in the proportion of population residing in urban places (CBS[1], 2003a). This is characterized by higher population growth within the city as well as migration of people from outside areas mainly rural to urban. The urbanization process also involves the increase in number of urban fringes. Agricultural land is continuously being converted to urban uses in the process of urbanization all over the world (Pradhan, Perera, 2005). Therefore, rural areas get urbanized as their economy become less and less dependent upon agriculture. In summary, we can say that demography and land use pattern change, industrialization and social transformation occur during the urbanization processes.

In recent decades, a diversified and growing economy has continuously attracted new residents and stimulated significant urban growth (Yuan, Bauer, 2007). About half of the world's current population is urban and total urban population also increased threefold between 1950 and 1990 (Thouret, 1999). According to Pradhan, Perera (2005), 2 billion new residents being added to the cities of the developing world in the next 25 years and industrial development will continue putting pressure on land use and environment in the major city areas. In the developing countries, large cities are growing at a higher rate than those in the rest of the world (Thouret, 1999). This means that 21st century will be the century of rapid urbanization (Pradhan, Perera, 2005).

The environmental condition of Kathmandu valley was very healthy endowed with rich forests and scenic beauty, improved river basin, and lower pollution with clean air. The soil is still very fertile as the valley is considered the site of an ancient huge

[1] CBS (Central Bureau of Statistics) is the central agency in Nepal for the collection, consolidation, processing, analysis, publication and dissemination of statistics in the country.

lake. In the previous decades, the farmers knowingly or unknowingly practiced the organic farming with the adoption of agro-ecosystem (Baniya, 2008). However nowadays, the scenario has been completely reversed as the resources and environmental condition degraded badly due to rapid population growth. Therefore, there is immediate need for proper planning of the Kathmandu valley valuing the land resources for economic and environmental sustainability of the city

This may require more advanced spatial techniques supported by the policy makers involving shifting of emphasis from basic geographic data handling into manipulation, analysis and modeling in order to solve the real problem (Ramachandran, 2010). In recent decades, remotely sensed data have been widely used to provide the land use/cover information such as degradation level of forests and wetlands, rate of urbanization and other human-induced changes (Alrababah, Alhamad, 2006). Moreover, the advent of widely available and less expensive Landsat imagery has permitted the development of highly accurate land cover map products (Goetz, et. al., 2009).

The urban dynamics model driven by Geographic Information Systems (GIS) as well as remote sensing data proved to be useful for identifying urban growth and land use/cover tendencies that enable local planning authorities to recognize and manage city growth according to the environmental carrying capacity, present and envisaged infrastructure availability (Alameida et. al. 2005) as well as socioeconomic considerations.

1.2. Problem statement

The cities in Kathmandu valley are expanding improper way because of rapid population growth. As a consequence, there is a rising demand of land for residential use. Between 1984 and 1998, large numbers of hectares of fertile and productive agricultural land area were lost to urbanization, industrialization, and quarrying of sand, soil, and stone (ICIMOD[2], MoEST/GoN[3], UNEP[4], 2007). There has been a dramatic change in its land use composition during the periods 1984-1994 and 1994-2000 (Pradhan, Perera, 2005). Improper urban development caused an adverse impact not only on agriculture and other land but also on the environmental condition and the livelihoods of the area in the long run.

Due to its geography land is a scarce resource in Kathmandu valley and therefore has to be used cautiously for its optimization and environmental sustainability (Pant, Dongol, 2009). Moreover it is highly desirable to realize and access the real uncontrolled urban situation and its impacts on different important land use/cover to initiate the measures as early as possible to improve the environmental condition of Kathmandu valley. However, the extensive expansion of urban centers over agricultural land is being poorly monitored due to the ill-equipped land monitoring system (Setiawan, Mathieu, Thompson-Fawcett, 2006).

This calls for planned development for the urban area and vicinities to minimize these problems and needs up-to-date information on the land use/cover and population of the Kathmandu valley. Therefore the study is intended to use GIS and Remote Sensing tools to acquire the information from Landsat images for providing knowledge on the trend of land utilization and urban growth that can be useful for assessing the effects on sensitive areas and planning unmanaged urban growth in the Kathmandu valley.

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[2] ICIMOD (International Center for Integrated Mountain Development) is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan
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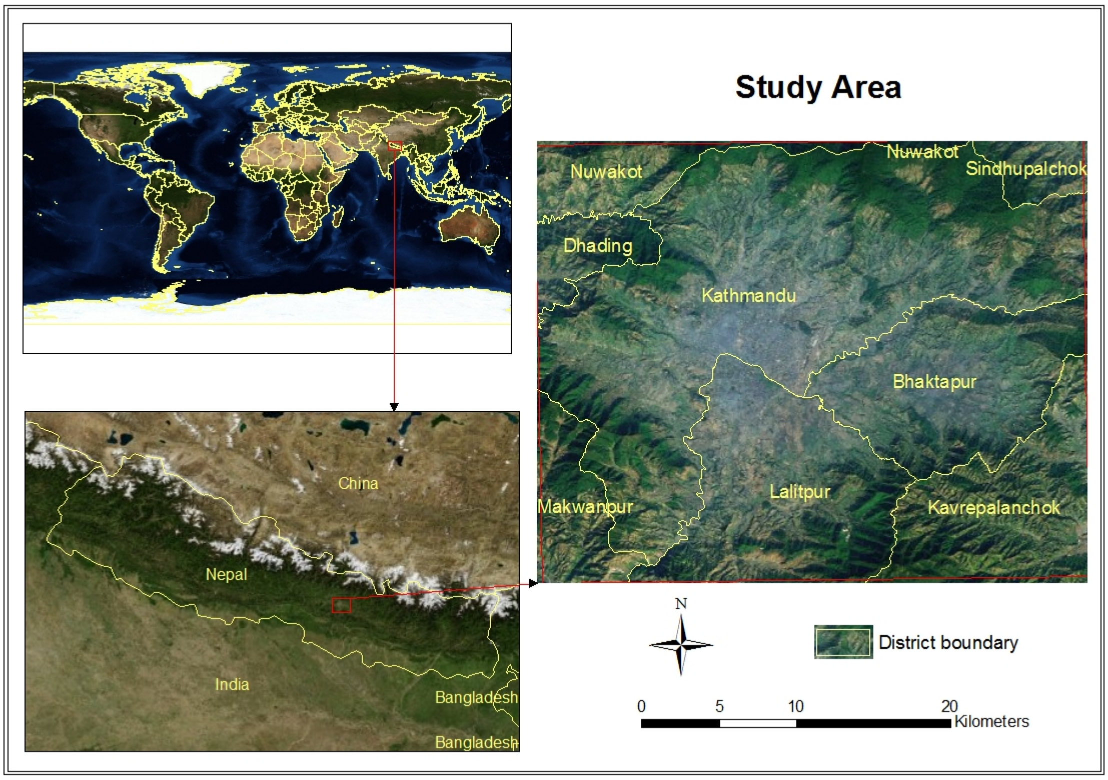
[3] MoEST/GoN (Ministry of Environment, Science and Technology, Government of Nepal) is the government agency in Nepal to promote research and development of science and technology and environmental sustainability in the country.

[4] UNEP (United Nations Environment Programme) is the voice for the environment within the United Nations System.

1.3. Study area

Recently Nepal is in the process of formulating new constitution. In anticipation of the finalization and promulgation of the new constitution, Nepal has been politically divided into 5 development regions, 14 zones and 75 administrative districts. Each of these divisions has headquarters. Kathmandu valley is overall headquarters of the country. Districts are further sub-divided into village development committees (VDC) and municipalities. Currently, there are 3,914 VDCs and 58 municipalities. Nepal is also divided into Plains, Hills, and Mountains respectively from South to North as broad ecological zones.

Kathmandu Valley is the capital of Nepal, a country of highest peak known as the Mount Everest in the world. The valley is bowl shaped and positioned between 27^0 32' 13" to 27^0 49' 10" N latitude and 85^0 11' 31" to 85^0 31' 38" E longitude. It is at a mean elevation of about 1300 meters (4265 feet) above sea level (Pant, Dongol, 2009). It comprises three districts namely Kathmandu, Lalitpur and Bhaktapur. Dhading, Kavrepalanchok, Nuwakot, Makawanpur and Sindhupalchok are the surrounding districts of Kathmandu valley (Figure 1).



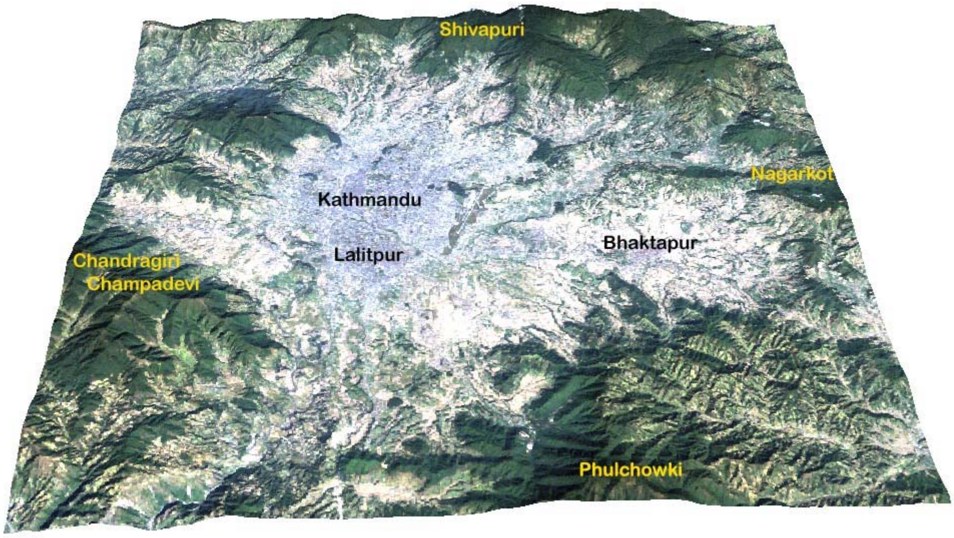
(DoS,[5] 1999; ESRI online,[6] 2009)

Figure 1: Study area

High sandstone mountain ranges stand all around these districts such as Phulchowki in the South East, Chandragiri/Champa Devi in the South West, Shivapuri in the North West, and Nagarkot in the North East (Figure 2). The altitude of these mountains varies around 1500 meters to 2800 meters (Baniya, 2008). The three major river systems in the valley are the Bagmati, Bishnumati, and Manohara. There are lakes and ponds also in all three districts.

[5] DoS (Department of Survey) is the major responsible government agency in Nepal to undertake national surveying and mapping activities in the country.

[6] ESRI online can be accessed through the ArcGIS 9.3.1



(Landsat, 2006)

Figure 2: Kathmandu valley in 3D perspective [Band: 3, 2, 1]

Ancient history of the Kathmandu valley says that it was a huge lake which was settled after draining away all the water through Chobhar gorge by a Chinese Saint. Early settlements were around very few places. Townships developed and flourished through Indo-Nepal-Tibet trade. Though many small towns were established by the second century A.D. and urban centers by the 11th century, according to the records, urbanization of the valley commenced in the late 1950s, accelerating during the 1970s. According to the population census of 2001, Kathmandu district had the biggest urban population and the highest number of households in Nepal (Zurick, Pacheco, Shrestha, Bajracharya 2005; ICIMOD, MoEST/GoN, UNEP, 2007).

1.4. Objectives

The main aim of this research was to apply GIS and Remote Sensing tools for the attainment of the following objectives:

- To use Landsat images for the study of land use classification and analyze land use change of Kathmandu valley
- To know the amount of conversion of other land into urban land in different dates and model urban change pattern of Kathmandu valley

1.5. Research questions

The study was focused to answer the following research questions:

- What was the trend of population growth and its distribution?
- What were the land use classes/practices in the city?
- Which land use classes were mostly used for urban growth?
- What are the future trends of urban growth and which areas are most suitable for urban expansion?
- Are GIS, Remote Sensing tools by means of Landsat images and other data adequate and useful for this kind of study?

1.6. Structure of the thesis

The following chart is the brief structure of the thesis that shows flow of interconnection with different chapters (Figure 3).

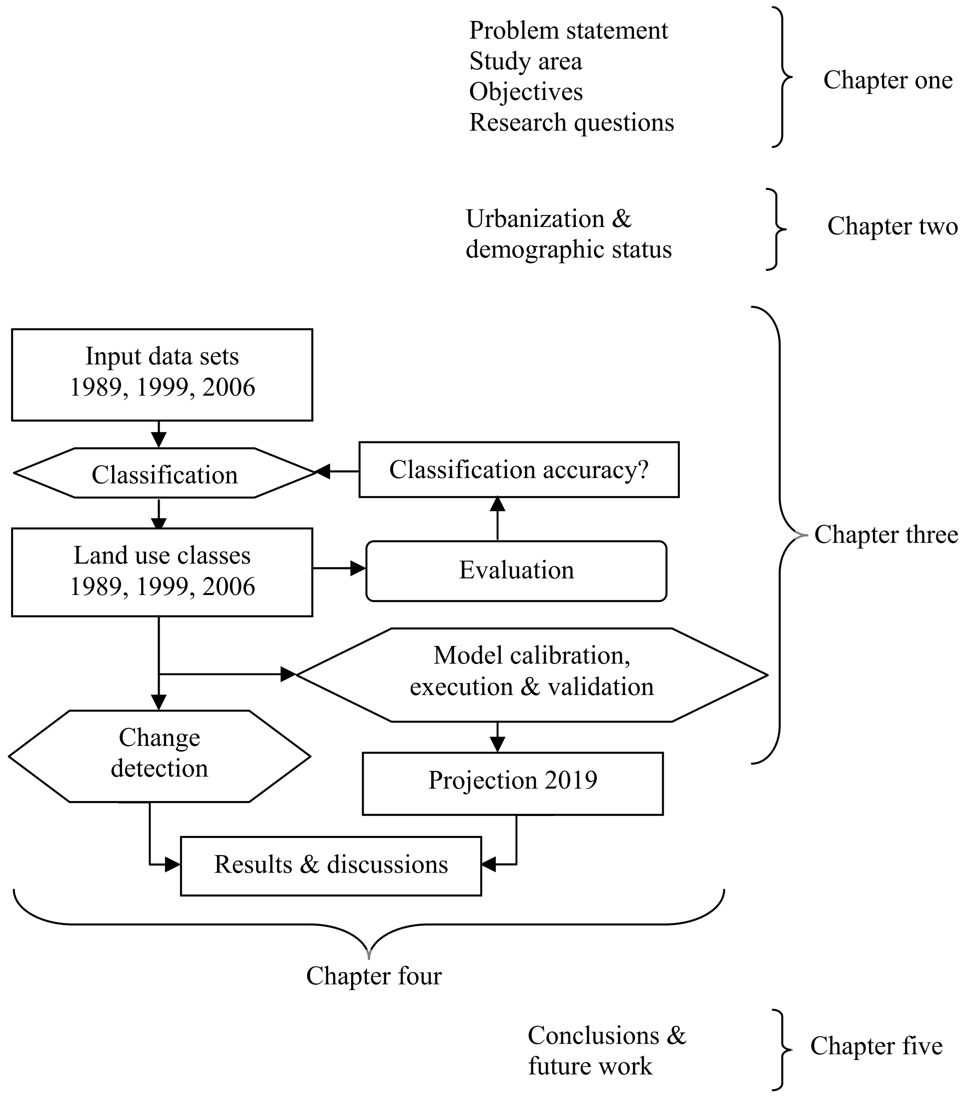


Figure 3: Structure of thesis

2. URBANIZATION OF NEPAL AND KATHMANDU VALLEY

2.1. Introduction

The trend of demographic situation and urbanization process in Nepal particularly in Kathmandu valley has been discussed in this chapter. The evolution of urban areas and its trends in the major cities in different geographic location of Nepal in compare to Kathmandu valley were the major concerns of the chapter. Since the thesis was focused to study urbanization, it became important to study the causes of population growth and urbanization trends in the Kathmandu valley. To solve the problems of causes and effects of urbanization, GIS and remote sensing techniques have been the suitable tools to perform the study.

2.2. Evolution of urban areas

Urban expansion has been occurring outside the Kathmandu valley only after eradication of malaria in 1960s (Pant in Akhtar et. al, 2009) and construction of highways along the country. Nepal had only 10 urban centers, five in the Kathmandu valley and five in the Terai with a population of about more than 5,500 during the 1952-54 censuses (CBS, 2003a). Urban areas had a slow trend of growth in the 1960s and 1970s but have grown rapidly since the 1989s (Thapa, Murayama 2009). The detail of percent distribution of urban population and places by geographical region during 1951/54 to 2001 is given below (Table 1). Figures in parenthesis are the number of cities. It is obvious from the table that the Kathmandu had highest percent of urban population in 1951/54 but it started decreasing as other parts of the country had started increasing the number of cities and the urban population up to 2001.

Regions	1951/54	1961	1971	1981	1991	2001
Mountain	-	4.8 (3)	7.4 (3)	8.7 (4)	11.4 (8)	17.8 (20)
Kathmandu valley	82.6 (5)	64.9(5)	54.0 (3)	38.0 (3)	35.3 (3)	30.9 (5)
Bhitri Madhesh	-	-	3.5 (1)	10.1 (4)	9.5 (4)	12.1 (8)
Terai	17.4 (5)	30.3 (8)	35.0 (9)	43.2 (12)	43.9 (18)	39.2 (25)
Total	100 (10)	100 (16)	100 (16)	100 (23)	100 (33)	100 (58)

(CBS, 2003a)

Table 1: Percent distribution of urban population and places by geographical region

Among geographical regions Kathmandu valley had witnessed a relentless growth in the level of urbanization and remains the most urbanized region in Nepal. Kathmandu-centric development has resulted in rapid urbanization in the valley. In 1952/54 only 47.4 percent of the valley's population was urban. This had risen to 60.5 percent in 2001 (CBS, 2003a). The level of urbanization by geographical region during 1981-2001 was as follows (Table 2).

Region	1981	1981	2001
Hill/Mountains	1.2	2.5	6.4
Kathmandu valley	47.4	54.1	60.5
Inner Tarai	7.6	9.5	18.0
Tarai	6.8	9.4	12.3
Nepal	**6.4**	**9.2**	**13.9**

(CBS, 2003a)

Table 2: Level of urbanization by geographical region

A highly dynamic spatial pattern of urbanization can be observed in the Kathmandu valley which had developed fragmented and heterogeneous land use combinations in the valley (Thapa, Murayama 2009). If the trend of urbanization continues, the total urban area will reach 34.3 per cent of the valley by the end of 2020 and the total population of the five municipalities, which constituted about 61 per cent of the total valley population in 1991, is expected to reach 71 per cent in 2011 (Pradhan, Perera, 2005).

2.3. Demographic situation of Kathmandu valley

According to CBS, (2003a) the population of the three districts of Kathmandu valley increased from 1,107,370 in 1991 to 1,647,092 in 2001. The annual population growth rate in Kathmandu district was 4.71%, increasing at twice the national rate of 2.2%. The population of Kathmandu district was 675,341 in 1991 (3.6% of Nepal's population) and 1,081,845 in 2001 (4.6% of Nepal's population). The population density (Number of persons per square kilometer) of Kathmandu district was 1,069 in 1981; 1,710 in 1991, and 2,739 in 2001. The details (Tables 3, 4) of district wise population distribution and density are presented below respectively.

District	1991	% of total population	2001	% of total population	Annual growth
Lalitpur	257,086	1.39	337,785	1.46	2.73
Bhaktapur	172,95	0.94	225,461	0.97	2.65
Kathmandu	675,341	3.65	1,081,845	4.67	4.71
Total	1,105,379	5.98	1,645,091	7.10	4.06

(CBS, 2003a)

Table 3: Distribution of population by district

District	Area in sq. km	1981	1991	2001
Lalitpur	385	479	670	877
Bhaktapur	119	1,343	1,453	1,895
Kathmandu	395	1,069	1,710	2,739
Total	899	852	1,230	1,830

(CBS 2003a)

Table 4: Population density by district

According to CBS (2003a) the three districts of Kathmandu valley consist of 5 of the 58 municipalities in the country and 114 VDCs. Urban areas are classified into Metropolitan Cities, Sub-Metropolitan Cities, and Municipalities as per the Local Self Governance Act, 1999. As per this Act, there are three municipalities (Bhaktapur, Madhyapur, and Kirtipur), one sub-metropolitan city (Lalitpur), and one metropolitan city (Kathmandu). The population in designated urban areas of Kathmandu valley had increased considerably about 5 times in 2001 than 1952/54. The details (Table 5) of urban population growth trend are shown below.

Region	**1952/54**	**1961**	**1971**	**1981**	**1991**	**2001**
Kathmandu valley	196,777	218,092	249,563	363,507	598,528	995,966
Nepal	238,275	336,222	461,938	956,721	1,695,719	3,227,879

(CBS 2003a)

Table 5: Urban population growth trend

Urbanization had not been uniform throughout the country. Most urbanized areas were in Kathmandu valley, which contributes significantly to the overall urbanization status of the country. The urban population density of Kathmandu valley was 10,265 (the population is 995,966 and the area 97 sq. km) (CBS, 2003a). On the other hand, the rural population is also increasing slowly in the valley. The average annual growth of the rural population was comparatively higher than for Nepal as a whole. The rest of the average annual growth rates are given below (Table 6).

Region	**1952/54**		**1961-71**		**1981**		**1991**		**2001**	
	U	**R**	**U**	**R**	**U**	**R**	**U**	**R**	**U**	**R**
Kathmandu valley	1.29	1.53	1.36	4.32	3.83	0.87	5.11	2.32	5.22	2.50
Nepal	4.40	1.56	3.23	2.03	7.55	2.40	5.89	1.79	6.65	1.72

Key: U=urban; R=rural
(CBS 2003a)

Table 6: Average annual growth rates of urban and rural population

According to ICIMOD, MoEST/GoN, UNEP, (2007), the total population of the Kathmandu valley was the sum of local inhabitants, migrant population (refers to internal and external migrants), and transient population. Uneven allocation of resources for development and institutionalization in the valley had given rise to the transient movement of population for different purposes, mainly seeking services and institutional activities. The rapid urbanization in Kathmandu is stretching municipal boundaries and converting open spaces and agricultural fields into concrete jungles.

According to CBS (2003b), the migrant population accounted for 11.1% of the total urban population in 1981. This proportion had increased in the past decade because of the conflict. A study on migration revealed that it contributed to less than 10% of the urban population of Kathmandu between 1952 and 1961, about 16% between 1961 and 1971, about 42% between 1971 and 1981, and over 64% between 1981 and 1991. The percentage of migrant population was comparatively less in Lalitpur (47% between 1981 and 1991) and Bhaktapur districts (12% between 1981 and 1991). Internal migrants comprised of 10.2% of the population, while foreign-born external migrants comprised of 0.9% in 1981, increasing in 1991 to 19.4 and 2.7% respectively. The large proportion of migrants which constitute 30 to 35% of the valley's estimated total urban population were workers in manufacturing and textile industries such as brick industries, garment industries, carpet weaving, and dyeing industries (Shrestha, Pradhan 2000).

2.4. Causes of population growth in Kathmandu valley

The urban development limited only in the Kathmandu valley and its peripheral areas was due to rugged topography, inaccessibility, poor resource base and a low level of economic development in the other parts of the country. Because of the Kathmandu valley's strategic importance as centrally located between Tibet and India, its urban settlements in the Kathmandu, Lalitpur and Bhaktapur districts became early trade centers. These settlements continued as important towns, economically and politically, for hundreds of years (Pradhan, Perera, 2005).

According to ICIMOD, MoEST/GoN, UNEP, (2007), Kathmandu valley has exceptional scenic beauty. The fertile valley with terraced fields is surrounded by green hills. Snow-capped mountains can be seen behind the hills to the north. Phulchowki hill at 2765 meters is the highest point in the valley; and this hill provides a spectacular view of the Himalayas as well as a part of the Terai plains. Similarly, Nagarkot, at an altitude of 2195 meters, provides a magnificent view of the sun rising over the Himalayas.

The unique combination of monuments, art, and architecture together with mountains and lakes or ponds are attractive to tourists. Ironically, it seems to be so even today from the point of view of physical infrastructure and institutional centralization. There are all kinds of institutions – services and financial institutions, good academic institutions, renowned health care units, research centers, and the entertainment industry all clustered in the valley of Kathmandu. This means there are better job opportunities in Kathmandu than elsewhere in Nepal, resulting in excessive migration and inflow of people from other parts of the country.

The valley houses all the major amenities and institutions, both governmental and non-governmental. Basic amenities like water supplies, electricity, gas, telecommunications, roads, sanitation, education, security, and transportation are well developed in the valley in comparison to the rest of Nepal. New products and services are first launched in the valley; and its inhabitants have access to modern equipment and technology. New technologies and interventions come to the valley first, and this technological sophistication is an important pull factor.

The rate of urbanization had increased due to the migration of people to urban areas and the Kathmandu valley displaced by the insurgency, as they are considered to be safer. The displaced population migrated to the district headquarters and ultimately to the valley in search of employment, government aid, security, and shelter. This has already had an adverse impact on the urban environment.

2.5. Impact of tourism

According to ICIMOD, MoEST/GoN, UNEP (2007), Kathmandu valley is the gateway to Nepal for tourists and their main destination. Ninety percent of tourists enter through Kathmandu. The valley's rich cultural heritage and it's the seven designated world heritage sites have contributed to tourism promotion.

Tourists began visiting Nepal only after the late 1950s. In 1960, the total number of tourists, excluding Indians, was only 4,017. In 1970, this figure had reached 45,970 and in 1992 it increased to 334,353. The figures for 2004 and 2005 are 385,297 and 375,398 according to the Ministry of Culture, Tourism and Civil Aviation[7]. The decrease in tourist flow in 2005 was due to the political situation that led to lack of security in the country. The flow can be expected to increase once peace is re-established

2.6. Discussion

Driven by a constantly accelerating increase of urban population in recent decades urbanization has become one of the most dynamic processes in the context of global land use transformations (Esch et. al. 2009). The role of studying an account of demography and urbanization was very imperative for monitoring urbanization in the Kathmandu valley. Due to good climatic condition, centralization of public services and insecurity concern of a decade long insurgency around the country were the major causes of population growth and urbanization in the cities of Kathmandu valley. Among the urban areas in the whole country Kathmandu valley toped the trend of population and urban growth. Owing to its highest urbanization and population increase rate Kathmandu valley would be suitable area for the urban growth studies that could help the urban planning authorities. The future projection output of urban growth would certainly give the trend and direction of growth which

[7] www.tourism.gov.np

can be key input for the formulation of new urban plans. Therefore it was important to develop a model for studying urban growth, which has been described in the following chapters.

3. DATA AND METHODS

3.1. Introduction

Different approaches underlying the land use change analysis and modeling process have been applied in the study. These entail mostly the theoretical and practical implication of GIS and Remote Sensing knowledge to make use of spatial and temporal data sets for acquiring feature information, analyzing the dynamics on land surfaces to use for the future prediction of land use and land covers. The major landmark processes of the study can be summarized by the flow chart presented as under (Figure 4). The flow chart of modeling for future land use prediction is placed in Figure 5 separately.

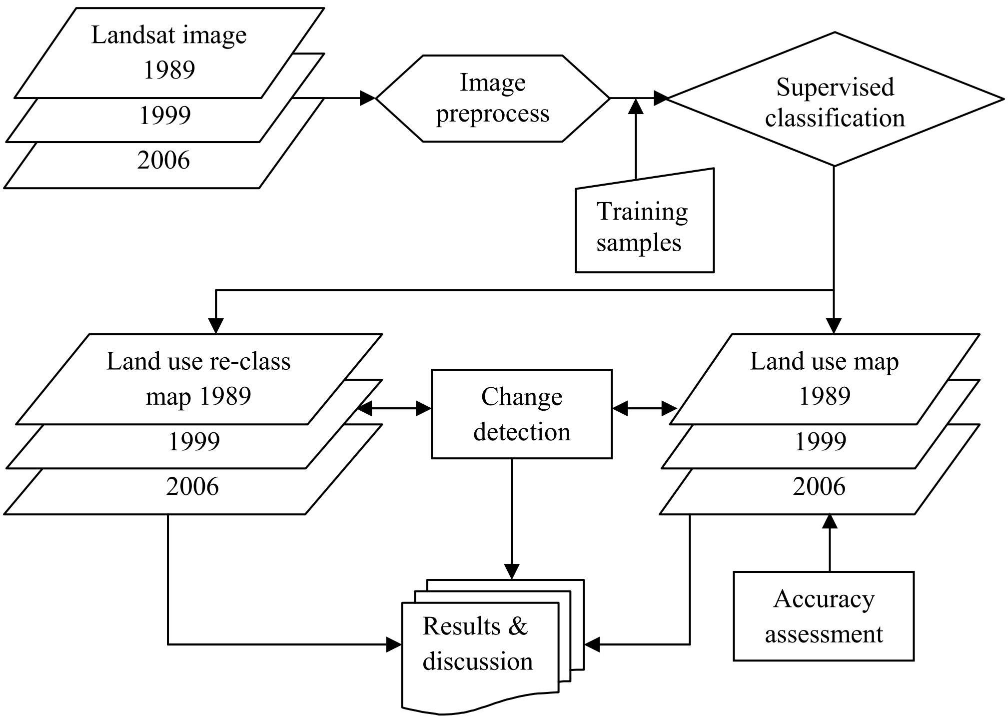


Figure 4: Flow chart of image classification process

The methodology employed to predict land uses in the study can be described by the flow chart given below (Figure 5).

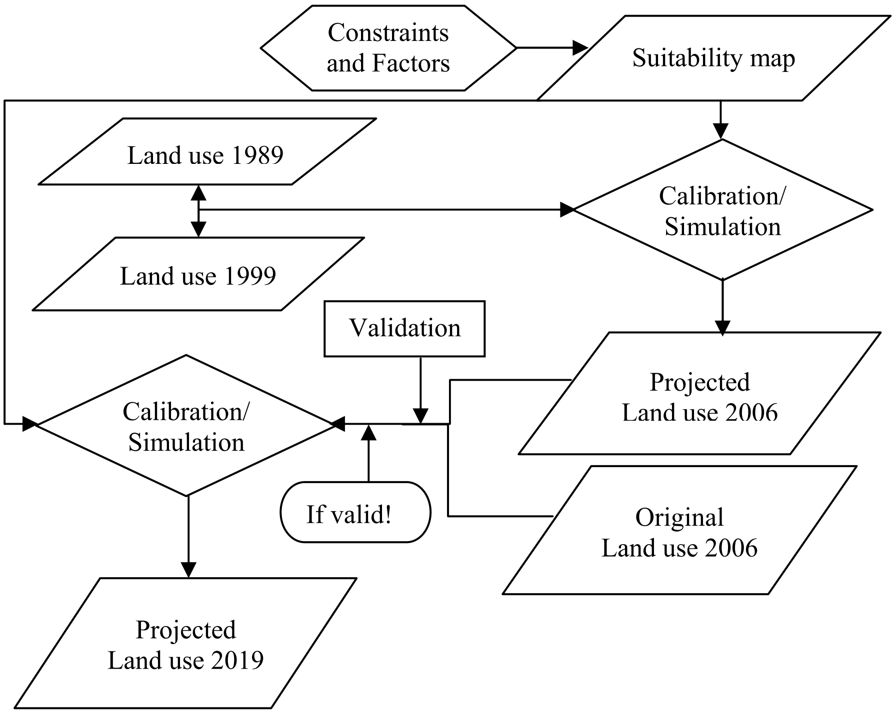


Figure 5: Flow chart showing land use projection calibration method

3.2. Data

Three Landsat satellite imageries during a period of 17 years were used for the study. The dates were 1989, 1999 and 2006 and accessed freely from different agencies' websites[8]. The date gap of all three acquired imageries was about a week of October and November. Details of Landsat imageries and characters are given below (Table 7).

[8] www.landsat.org, http://glovis.usgs.gov

S. N.	Satellite	Sensor	Band	Imagery date	Spatial Resolution (meter)	Path/Row	Source
1	Landsat 5	TM	7	1989-10-31	28.5	141/41	Landsat.org
2	Landsat 7	ETM+	8	1999-11-04	30.0	141/41	USGS
3	Landsat 5	TM	7	2006-10-30	30.0	141/41	USGS

Table 7: Detail characteristics of the Landsat imageries

Landsat images are among the widely used satellite remote sensing data and their spectral, spatial and temporal resolution made them useful input for mapping and planning projects (Sadidy, Firouzabadi, Entezari 2009). The other data sets used in the study were Shuttle Radar Topographic Mission (SRTM) elevation data, digital topographic map and other layers of Kathmandu valley such as road network, rivers and water body and designated areas prepared by the Department of Survey, Nepal.

Raw digital images usually contain distortions due to variations in altitude, attitude, earth curvature and atmospheric refraction, which are corrected by analyzing well-distributed ground control points (GCPs) present within an image and for which accurate ground coordinates are available (Kaiser et. al 2008). However, the Landsat images used in the study were acquired free of distortions from the sources mentioned above. The spatial references of all processed data sets in the study were WGS 1984, UTM zone 45 N and Datum D_WGS_1984. The data sets not in WGS 1984 were converted into WGS 1984 mainly digital topographic map and its layers of Kathmandu valley.

3.3. Software used

The images were processed with various software programs to get required analysis results. Mentioned below were the software programs used for the study.

- ArcGIS 9.3.1
- Erdas Imagine 9.1
- Idrisi 15.0, The Andes Edition

ArcGIS 9.3.1 was used to resample 28.5 meters resolution of image 1989 and 90 meters resolution of SRTM elevation data into 30 meters grid cells and to compose map of the study area. Nearest neighbor assignment method was used to resample 28.5 meters 1989 image into 30 meters. However to resample 90 meters SRTM elevation data into 30 meters, bilinear interpolation and cubic convolution were used since the results were good with these methods. Erdas Imagine 9.1 was used for the image classifications. Idrisi 15.0 was used for the image differencing, cross-tabulation and modeling the urban and other land classes change for the current and future years.

The three classified 1989, 1999 and 2006 maps were exported to ArcGIS 9.3.1 for map composition and to Idrisi 15 (The Andes Edition) for cross-classification tabulation and land use and cover change modeling. The cross-classification was done with re-classified maps i.e. Built up and Non-built up land uses and the resultant map was obtained for changed and unchanged area of 1989, 1999 and 2006 maps.

3.4. Image classification and accuracy assessment process

Digital image classification is the popular and challenging approach of remotely sensed image analysis process. In the process pixels in the image are sorted to obtain meaningful information of the real world as derived in the thematic maps bearing the information such as land cover type; vegetation type, etc. (Matinfar, 2007).

Although there are different classification systems in existence throughout the world, they are generally not comparable one to another and also there is no single internationally accepted land cover classification system (Latham, 2001). Therefore, determination of land cover classification system is decided considering the purpose of the study and usually it varies according to different research projects (Tateishi, 2002).

The basic principle of multi-spectral classification is that the objects in the earth surfaces possess different reflectance characteristic in different parts of the electromagnetic spectrum as digital numbers. Based on this reflectance, the surface features can be categorized into specified number of classes known as land cover classes through classification software in terms of new thematic output image. There are two general classification approaches: supervised and unsupervised. In the supervised approach the useful information categories are defined and examined for their spectral separability where in the unsupervised approach, spectrally separable classes are determined and defined relative to their informational utility to form a supervised classification scheme (Kaiser et. al. 2008). Supervised classification uses the independent information from spectral reflectance to define training data for determining classification categories (Ratanopad and Kainz, 2006). In classification process, supervised classification has been widely used in remote sensing applications (Yüksel, Akay, Gundogan, 2008).

The challenges of urban mapping using Landsat imagery include spectral mixing of diverse land cover components within pixels, spectral confusion with other land cover features (Guindon, Zhang, Dillabaugh, 2004; Lu, Weng 2006). Therefore, it is most desirable to set the remote sensing images to obtain good results prior to classification. For this purpose different image enhancement techniques provided by the software can be employed. One of spectral enhancement techniques is principal component analysis. It enhances the spectral discrimination among reflectance of different features (Kaiser et. al. 2008). Modification of the original bands in digital image classification has also shown to improve land use land cover classification accuracy (KC, 2009).

Six land use and cover classes were determined for supervised classification in the study. The land classes were determined according to the existing practices in the Kathmandu valley combining with the system adopted by the Department of Survey. The land classes were: 1) Agriculture, 2) Bare soil, 3) Built up, 4) Forest, 5) Open area, and 6) Water. All land areas with agricultural crops were included in Agricultural land class whereas agricultural lands without crops and exposed areas were included in Bare soil category. Individual and clusters of building, road networks, airport, etc were included in Built up. The areas covered with trees were incorporated in Forest land cover class. Open area was classified for the land areas with small vegetative ground covers. All kinds of rivers, ponds and lakes were included in Water land class.

In supervised classification, spectral signatures are collected from specified locations (training sites) in the image to classify all pixels in the scene by digitizing various polygons overlaying different land use types (Yüksel, Akay, Gundogan, 2008). For the classification, training sample should be taken for each of reflection property and its number varies as per the requirements. Hence, the training samples were collected accordingly in the spectrally enhanced images for six different land classes as mentioned above to use in the parametric supervised classification approach. At least 50 samples in an average were taken for each of the land classes to be classified. Region growing tool was employed for each of training taken to cover maximum area and the number of pixels per sample. Google Earth, ArcGIS online and digital topographic maps were used as high resolution references to recognize the pattern of land use types in the images. A very insignificant amount of areas beneath clouds were masked stacking in the classification images with the layers of different original land classes extracted with the help of high resolution references to classify original land classes.

All three parametric decision rules Maximum likelihood, Mahalanobis distance and Minimum distance available in the Erdas Imagine 9.1 were employed to classify and compared the image classification results to choose the best one. Maximum likelihood algorithm provided good classification results as compared to Mahalanobis distance and Minimum distance algorithms hence used for further processing. The same algorithm was used for re-classification of the images. Some results of Mahalanobis and Minimum distance classifications are given in the appendices 1 and 2 respectively.

The accuracy of the result is strongly dependent on the processing procedure, consisting mainly of geometric correction, image classification and spectral enhancement (Kaiser et. al. 2008). A common method for accuracy assessment for a classification image is through the use of an error or confusion matrix and some important measures, such as overall accuracy, producer's accuracy, and user's accuracy can be calculated from the error matrix in the classification software. Ground truth data can be used as training sample data in classification processing or as correct data in validation step. The information sources of ground truth are field survey, existing maps, satellite images with better resolution, or any pre-determined classification system. Since field survey is time consuming and needs much budget, the latter three sources are usually used (Tateishi, 2002). The testing samples are used for the establishment of the confusion matrix to assess the classification accuracy (Long-qian, Li, Lin-shan, 2009). In the study accuracy assessments for all three classified maps were done with the test samples generated in the software against high resolution references. The overall test samples generated were 120 for each of the 1989, 1999 and 2006 classified maps. Google Earth, ESRI online, digital topographic map and other layers were used as reference due to lack of high resolution satellite data.

3.5. Land use and cover change modeling and validation

Land-Use & Cover Change (LUCC) modeling is growing rapidly in scientific field. There are many modeling tools in use but the performance of different modeling tools is difficult to compare because LUCC models can be fundamentally different in a variety of ways (Pontius, Chen, 2006). Among the numbers of land use modeling tools and techniques, the commonly used models are the Cellular Automata Markov (CA_MARKOV) and GEOMOD. For the purpose of the study the CA_MARKOV and GEOMOD both available in Idrisi were implemented to predict and compare the land uses for some further period.

Eastman (2006) defined the terms mostly used in the land use and cover change modeling, which are MARKOV, STCHOICE, CA_MARKOV, GEOMOD and VALIDATE. MARKOV analyzes two qualitative land cover images from different dates and produces a transition matrix, a transition areas matrix, and a set of conditional probability images. STCHOICE (Stochastic Choice) creates a stochastic land cover map by evaluating the conditional probabilities that each land cover can exist at each pixel location against a rectilinear random distribution of probabilities. CA_MARKOV is a combined cellular automata/Markov change land cover prediction procedure that adds an element of spatial continuity as well as knowledge of the likely spatial distribution of transitions to Markov change analysis. GEOMOD is a land use change simulation model that predicts, forward or backward, the locations of grid cells that change over time. VALIDATE calculates specialized Kappa measures that discriminate between errors of quantity and errors of location between two qualitative maps.

CA_MARKOV can be used to project with any number of land use classes whereas GEOMOD runs only with two numbers of classes e.g. Built up and Non-built up. A collection of suitability maps needs to be created as decision rules for simulation process which can be prepared using Multi-Criteria-Evaluation (MCE). In the process of creating suitability maps numbers of constraints and factors such as designated areas, distance from existing urban area, distance from road, distance from water body, slope, etc must be used that have direct effect in the change of land uses. The CA_MARKOV uses these suitability maps along with a couple of previous year's classification maps and Markov transition areas file created using MARKOV module in the Idrisi. However, GEOMOD uses suitability maps along with beginning land use map, ending time as well as ending time land classes pixel quantities. The resulting projected output map should be validated against the same year's original land use classification map for its reliability to make use of the model predicting further year's land use and land cover.

According to Pontius, Chen (2006), it is desirable to validate the accuracy of the prediction after the creation of simulated map of the ending time. Although there are different ways of validating the simulated map output, the most used one is VALIDATE module technique in Idrisi. The VALIDATE module examines the agreement between two maps that show the same categorical variable i.e. comparing a pair of true ending time map versus simulated ending time map. In the comparison, the true ending time map is referred as "reference map" and the simulated map as "comparison map". The validation results offer a comprehensive statistical analysis that answers simultaneously the two important questions: 1) "How well do a pair of maps agree in terms of the quantity of cells in each category? and 2) "How well do a pair of maps agree in terms of the location of cells in each category?"

3.6. Discussion

This chapter describes different data sets acquisition procedure used in the study and review of different approaches of image classification and land cover change modeling as the basis for selection of the preferred techniques. Three Landsat images during 1989 to 2006 were undergone with preprocessing from resample of 1989 image to final selection of best resulted image enhancement technique and classification algorithm available in the software for image classification. Principle component analysis spectral image enhancement technique and maximum likelihood algorithm were used for the classification. Maximum likelihood algorithm provided good classification results as compared to Mahalanobis distance and Minimum distance algorithms and used for further processing. CA_MARKOV and GEOMOD were among the chosen urban modeling tools to project the future land classes.

4. RESULTS

4.1. Introduction

The main aims of the study were to focus on the urban change analysis during the 1989 to 2006 period and to know the trend of urban growth in the further years by projecting urban land class using CA_MARKOV and GEOMOD available in Idrisi. All the results derived from image classification, change analysis, land use and cover change model calibration, implementation and validation are presented and discussed in this chapter.

4.2. Image classification

4.2.1. Preprocessing

The information for each specific wavelength range stored as a separate image is called a band which is similar to a black and white digital photograph. It is up to the analyst to combine the images from the different wavelengths to create a color image (Horning, 2009). So, after the entry of the images into the software program, composite layers were made by stacking all band layers of each three year's images (Figure 6). Composite layer of all three images were again subset into the study area. The resolution of 1989 image was 28.5 meters (seems smaller than other images in figure 6) which was made 30 meters by resample technique after subset of study area.

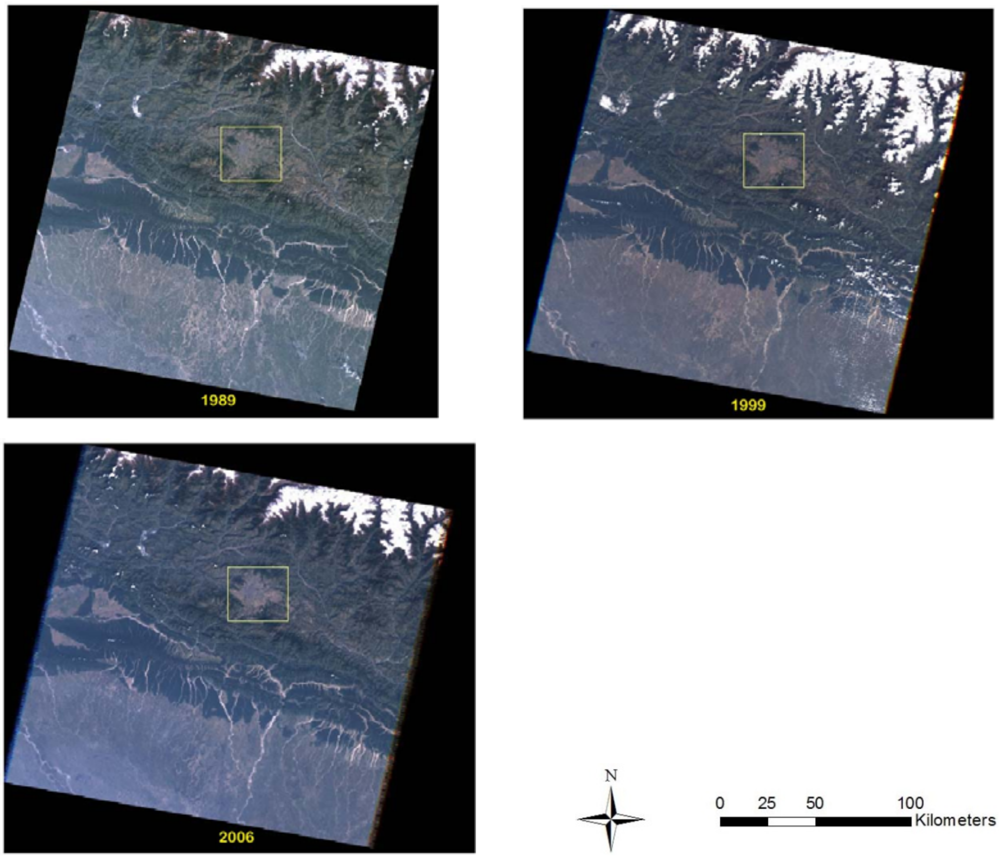


Figure 6: Composite bands of 1989, 1999 and 2006 images showing study area in yellow square [True color]

Principal component analysis was implemented for all three images (Figure 7). It enabled the spectral enhancement, especially for built up and water which had similar reflectance, of the images to easily distinguish for extracting the land classes of the study area. The three spectrally enhanced images were used for the classification and re-classification of the land use and land cover. The training samples were then taken for each of the 1989, 1999 and 2006 enhanced images. An example to show training samples taken in the images is presented in the following figure.

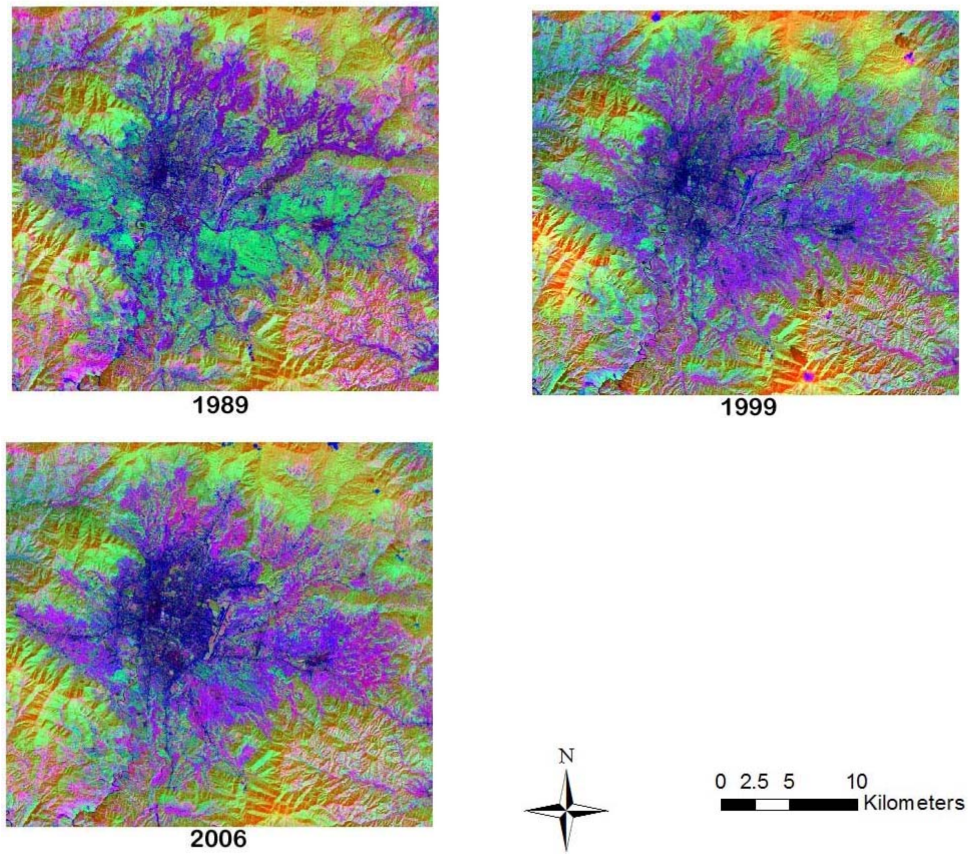


Figure 7: Spectrally enhanced 1989, 1999 and 2006 images of the study area [Band: 3, 2, 1]

Presented below is an illustrative example for showing training samples taken for the classification of 1989, 1999 and 2006 images (Figure 8).

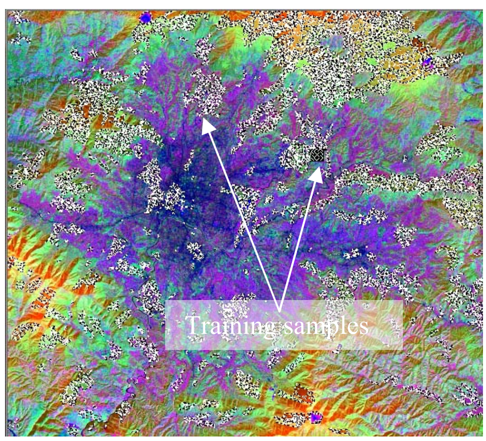


Figure 8: An example of training samples taken in an image

4.2.2. Image classification

The 1989, 1999, and 2006 images were classified into six classes (Figure 9). The overall total area of the land use classes of the study area was 88491 hectare. The maps and the detail statistics of the classification results are given below (Table 9).

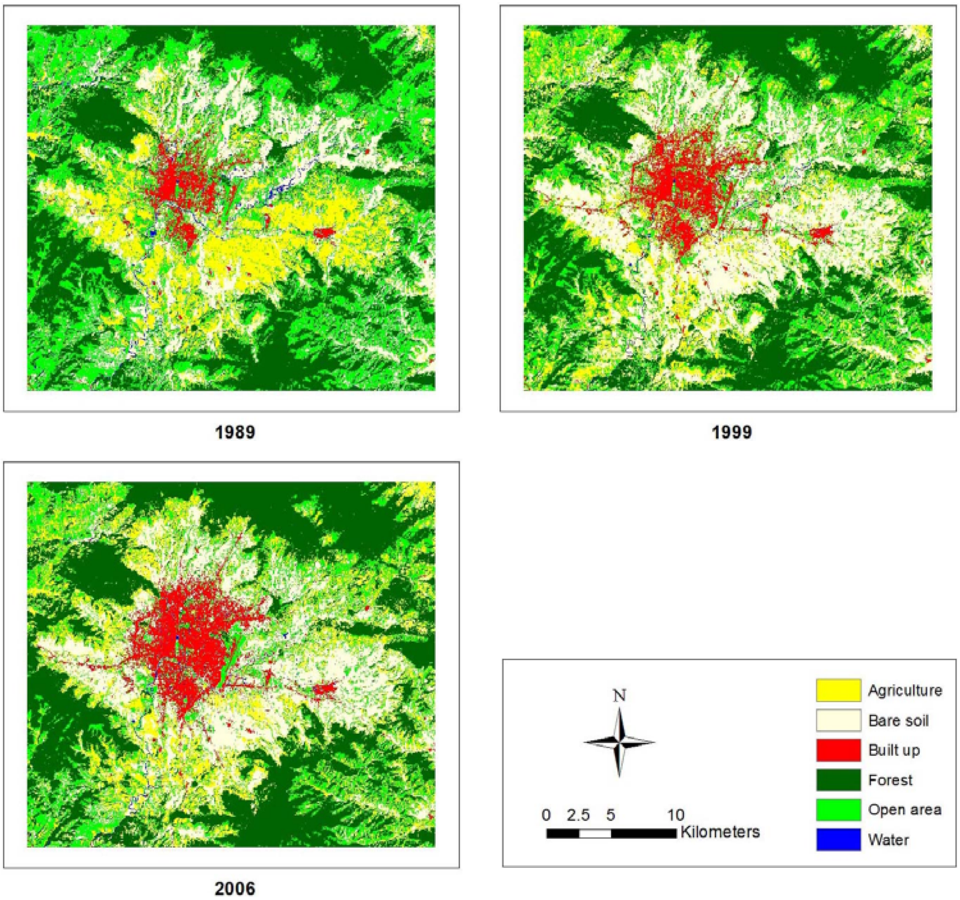


Figure 9: Land use land cover classification maps of Kathmandu valley

The land use classes and the areas derived from the classification of 1989, 1999 and 2006 images are given in the following table 8. The area statistics of the land uses and land covers could better be quantified if interpreted with visual support than numerical.

ID	Land use class	Area in hectare		
		1989	1999	2006
1	Agriculture	13350	12944	14420
2	Bare soil	17434	23742	21140
3	Built up	2454	4366	5732
4	Forest	28044	28366	31509
5	Open area	26266	18680	15267
6	Water	943	393	423
	Total	88491	88491	88491

Table 8: Land use class types of class areas

The bar chart below visually quantifies the six land uses in each date and can be interpreted transitions between different land use classes (Figure 10). The Built up area had increased and water class decreased by more than two folds during the study period. The chart shows that the Open area land class was also the most decreased class followed by Bare soil land class. The rest of the land uses had not changed significantly.

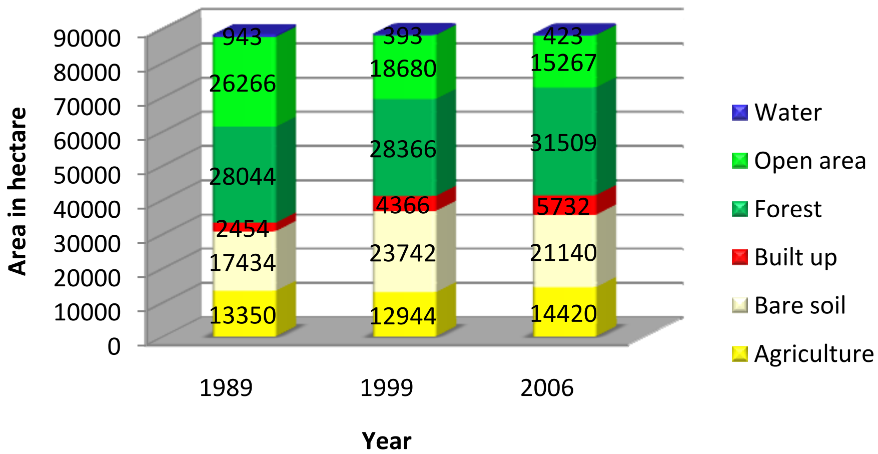


Figure 10: Bar chart land use quantization in 1989, 1999 and 2006

4.2.3. Accuracy assessment

The result of classifications of 1989, 1999 and 2006 images were evaluated through the accuracy assessment process. Accuracy assessment process started with taking number of test samples in an image used for the classification and verifying the samples with high resolution image as a reference. Figure 11 below shows an illustrative example of test samples taken in an image for accuracy assessment. The yellow colored samples were converted into white color after the verification of land classes with the help of reference image (Figure 11).

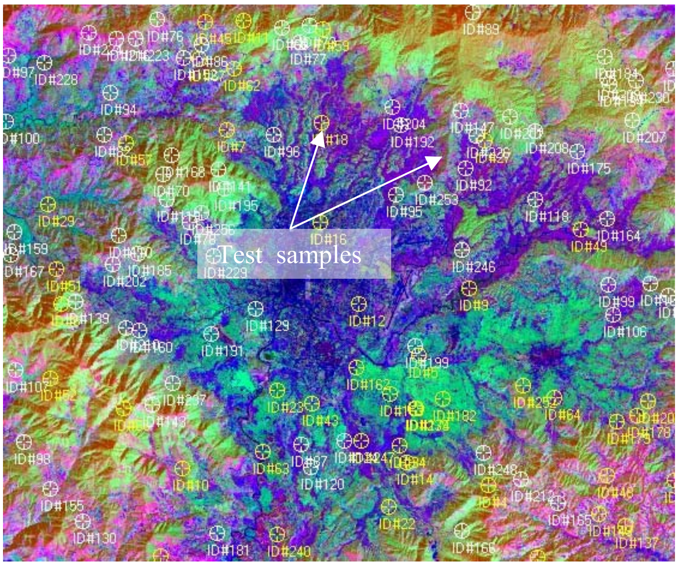


Figure 11: An example for test samples taken in an image

The indices used for the evaluation were overall accuracy, overall Kappa (κ) as well as producer's and user's accuracy for individual land classes. The results are presented below (Table 9).

	1989	**1999**	**2006**
Overall classification accuracy (%)	86.67	88.33	89.17
Overall Kappa (κ) statistics	0.8196	0.8351	0.8576

Table 9: Overall accuracy and Kappa (κ) statistics for the classifications

The results show that the achieved overall classification accuracies were 86.67%, 88.33% and 89.17% and overall Kappa (κ) statistics were 0.8196, 0.8351 and 0.8576 respectively for the classification of 1989, 1999 and 2006 images. The producer's and User's accuracy for individual land classes were as follows (Table 10).

Class name	**1989 (%)**		**1999 (%)**		**2006 (%)**	
	Producer's	**User's**	**Producer's**	**User's**	**Producer's**	**User's**
Agriculture	85.00	80.95	100.00	53. 33	81.25	68.42
Bare soil	75.00	94.74	92.31	100.00	93.55	100.00
Built up	83.33	100.00	100.00	100.00	100.00	100.00
Forest	93.75	95. 74	84.00	95.45	90.70	95.12
Open area	86.36	70.37	85.71	78.26	84.21	76.19
Water	---	---	---	---	100.00	100.00

Table 10: Producer's and User's accuracy for individual land classes

The ranges attained for producer's accuracy were 75% - 93.75%, 84% - 100% and 81.25% - 100% whereas user's accuracy were 70.37% - 100%, 53.33% -100% and 68.42% -100% respectively for the classification of 1989, 1999 and 2006 images. It was apparent from the results that the lowest producer's and user's accuracies could not be attained for the same land classes during the classification years. However, higher producer's and user's accuracies could mostly for Built up land class. This might be because of the focus of the study more to the urban change analysis.

Land use and land cover reclassification

Since the study is focused mainly on urban land class change, the land use and land cover maps were re-classified into Built up and Non-built up land classes (Figure 12) and mentioned below were the results and statistics of the image re-classification (Table 11).

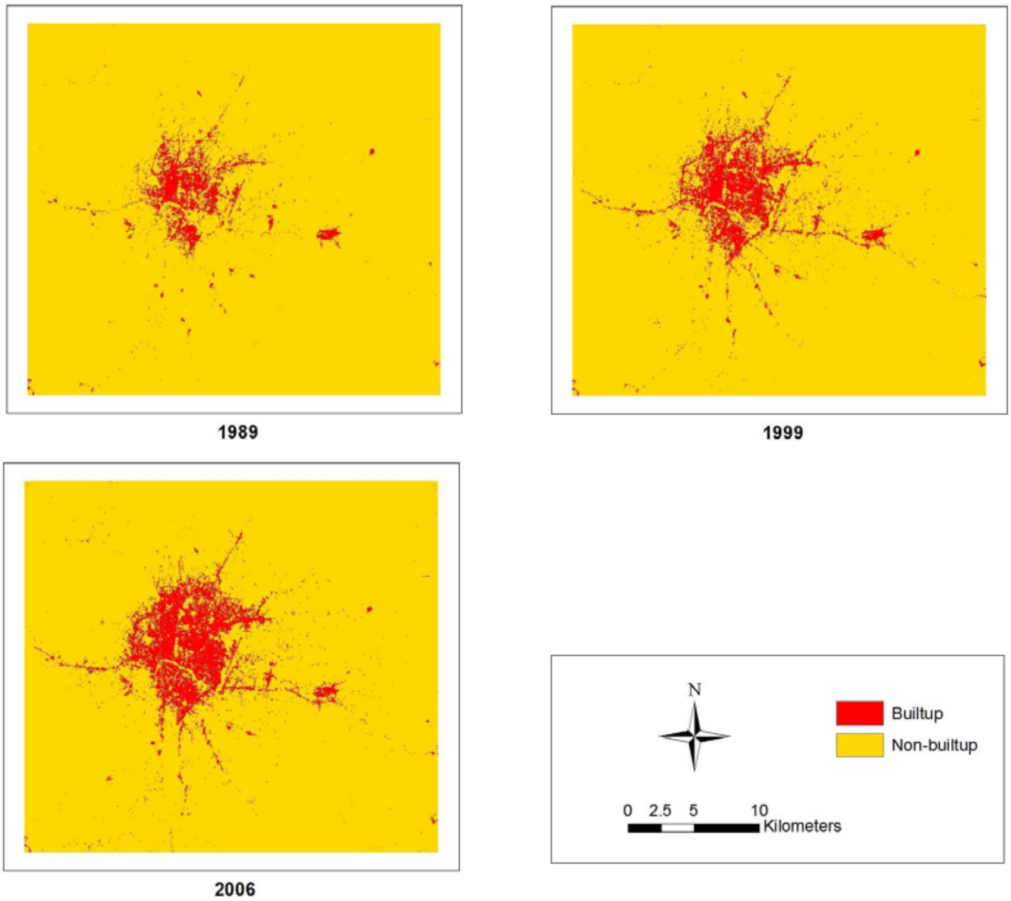


Figure 12: Land use re-classification maps of Kathmandu valley

The land classes and the areas derived from the re-classification of 1989, 1999 and 2006 images are given in the following table 11. The result statistics in table below have been explained with the following bar chart.

ID	Land use class	Area in hectare		
		1989	1999	2006
1	Built up	2454	4366	5732
2	Non-built up	86037	84125	82759
	Total	88491	88491	88491

Table 11: Land use re-class and areas

The bar chart below (Figure 13) shows visually the quantities of Built up and Non-built up land class changes. The statistics on chart explain that Built up areas was increased more than 2 times during the study period.

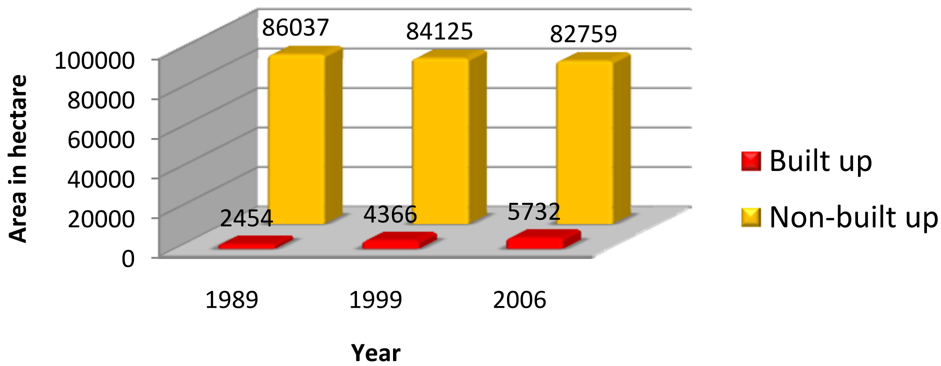


Figure 13: Bar chart land use quantization in 1989, 1999 and 2006

4.2.4. Change analysis

The changes in area in hectare and percentage of all the land use classes and land use re-classes are presented below (Table 12, 13).

ID	Land use	Area change in hectare			Area change in %		
		1989-1999	1999-2006	1989-2006	1989-1999	1999-2006	1989-2006
1	Agriculture	-406	+1476	+1070	-3.0	+11.0	+8.0
2	Bare soil	+6308	-2602	+3706	+36.0	-11.0	+21.0
3	Built up	+1912	+1366	+3278	+78.0	+31.0	+134.0
4	Forest	+322	+3143	+3465	+1.0	+11.0	+12.0
5	Open area	-7586	-3413	-10999	-29.0	-18.0	-42.0
6	Water	-550	+30	-520	-58.0	+8.0	-55.0

Table 12: Area change in hectare and percentage of land classes

The table 13 shows that the areas of Open area and Water land classes decreased significantly. The Built up area has been increased by 134% during the study period.

ID	Land use	Area change in hectare			Area change in %		
		1989-1999	1999-2006	1989-2006	1989-1999	1999-2006	1989-2006
1	Built up	+1912	+1366	+1366	+78.0	+31.0	+134.0
2	Non-built up	-1912	-1366	-1366	-2.0	-2.0	-4.0

Table 13: Area change in hectare and percentage of land re-classes

The table 13 shows that a significant amount of the Built up area has been increased during the study period.

The cross classification map below (Figure 14) shows the quantity of area change between the Built up and Non-built up land use classes. The map shows that during the 1989 to 2006 period 2454 hectare of Built up and 82759 hectare of Non-built up areas remained unchanged. 1912 and 3278 hectares of Non-built up area had been changed into Built up area in 1999 and in 2006 from 1989 respectively.

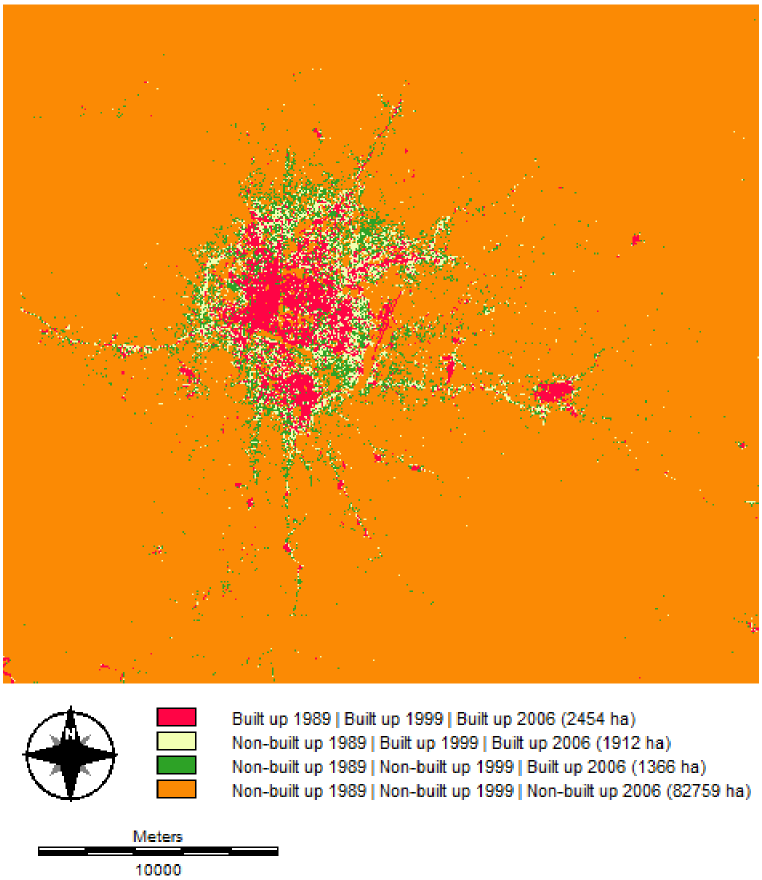


Figure 14: Cross classification of Built up and Non-built up land classes

4.3. Land use and cover change modeling

4.3.1. Model calibration

The modeling process involved number of complex steps. One of these was to create suitability map that could be used as decision rules to predict future land uses and land covers. The low to high suitability range (0 to 255 or 0 to 100) is the decision rule that restricts or allows particular land uses to grow up and/or transform into each other. Two methodologies were employed for creating the suitability maps and their collection. They were explained as "First Methodology" and "Second Methodology" in the following sections.

A. First Methodology

In the first method of creating suitability map, numbers of factors and constraints have been combined. The factors and constraints are the criteria for urban to grow and developed from the Boolean (logical) images which have values 0 = unsuitable, and 1 = suitable.

- **Constraints:**

Constraints are the Boolean conditions which limit the alternatives under consideration (Eastman, 2006). The examples of constraint are the existing built up area, protected areas like forest and wildlife reserve and water bodies, etc. where expansion of urban is restricted. In this case, Forest and Open areas were set as constraints because they have been considered as public properties. The designated areas in the Kathmandu valley i.e. Shivapuri Watershed and Wildlife Reserve and Gokarna and Nagarjun Reserve Forests were also included inside the Forest and Open areas. The Built up and Forest and Open areas constraints were derived from the land use classification map of 1999 and the Water constraint is derived from the digital layers of rivers and water bodies from Department of Survey. The following constraints images were derived from the processes as mentioned above (Figure 15). The black area (value 0) of the maps constrains other land uses to grow to that area.

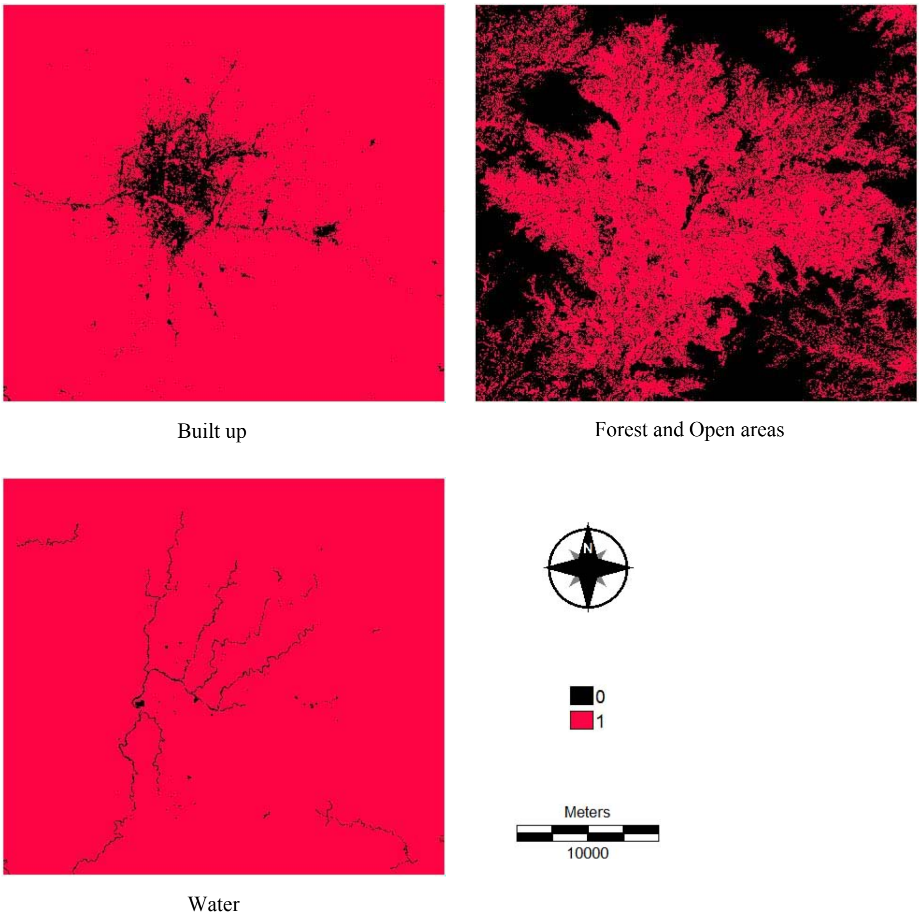


Figure 15: Constraints used to create suitability maps for urban growth

(0-unsuitable; 1-suitable)

The Boolean condition is only possible when all the criteria of interest have only 0 = unsuitable, and 1 = suitable values. However, there are some criteria which have low to highest preference on suitability rather than 0 = unsuitable, and 1 = suitable. So every image with Boolean condition for factors was standardized into probability range of suitability between 0 and 255 for urban growth.

- **Factors:**

Factor is continuous gauge of suitability measured in 0-255 scale. It enhances or detracts from the suitability of a specific alternative for the activity under consideration (Eastman, 2006). For example, nearness to existing built up, roads, certain land uses and relatively flat areas etc. have high level of suitability to develop urban areas and suitability decreases as the distance decreases and slope increases. However the degree of suitability decreases as the nearness to water body increases.

These principles generally should be based on the government policy formulated according to environmental and socio-economic consideration. The development of urban areas should mostly be preferable to underutilized places but these kinds of areas are rarely available in the cities. So, agricultural areas having relatively flat slopes are being extensively utilized nowadays for the urban development. It is also supposed that the urban development takes place closest to existing road networks and developed unoccupied areas. Preference level lowered down as their distances increase due to cost effectiveness. Nearness to water body should also be avoided for the urban development. Considering these general principles the factors with Boolean condition were standardized into "fuzzy" rule, i.e. suitability of contiguous range of 0 = least suitable to 255 = most suitable using Multi Criteria Evaluation (MCE) in Idrisi.

The fuzzy module available in Idrisi is characterized to standardization of Boolean factors into entire range of criteria of "none" to "full" possibilities to transform into either a binary (0 and 1) or a byte (0 to 255) output data format without sharp boundaries as 0 = lowest to 255 = highest suitability for growth where the latter output data format option is recommended because the MCE module has been optimized for using a 0-255 level of standardization (Eastman, 2006). The Idrisi supported monotonically increasing, monotonically decreasing, symmetric, and asymmetric variants and the fuzzy set membership functions: sigmoid, j-shaped, and linear (Eastman, 2006), are available to utilize as control points for the set membership function. The selection of these variants and range of control points fully depends on the analyst familiarity to the study area. The perfectness of selection can be measured in the model validation stage. These criteria were set according to the table 14 follows (Table 14).

Factor	Membership function/variant	Control point	Explanation
Distance from built up	Linear/decreasing	0 - 6508	0-6508 is the minimum and maximum distance values of the built up area in 1999, linear decreasing criteria was set since suitability decreases as distance to built up increases
Distance from the roads	Linear/decreasing	0-7946	Linear decreasing criteria was set since suitability decreases as distance to from roads increases
Slopes	Sigmoid/decreasing	0-25 degree	Slopes between 0 to 25 degree are considered most suitable
Distance from water bodies	Linear/increasing	30-10061	It was assumed that the areas within 30 meter from the water bodies should have low suitability and above this distance suitability increases

Table 14: Criteria to standardize fuzzy module

The land use factor was not considered in the table because it was created by assigning the value for Agriculture and Bare soil land classes as highest suitability and existing built up as the lowest suitability with Edit/ASSAIGN module in Idrisi.

The following factor images were derived from the processes as described above in a continuous scale (Figure 16).

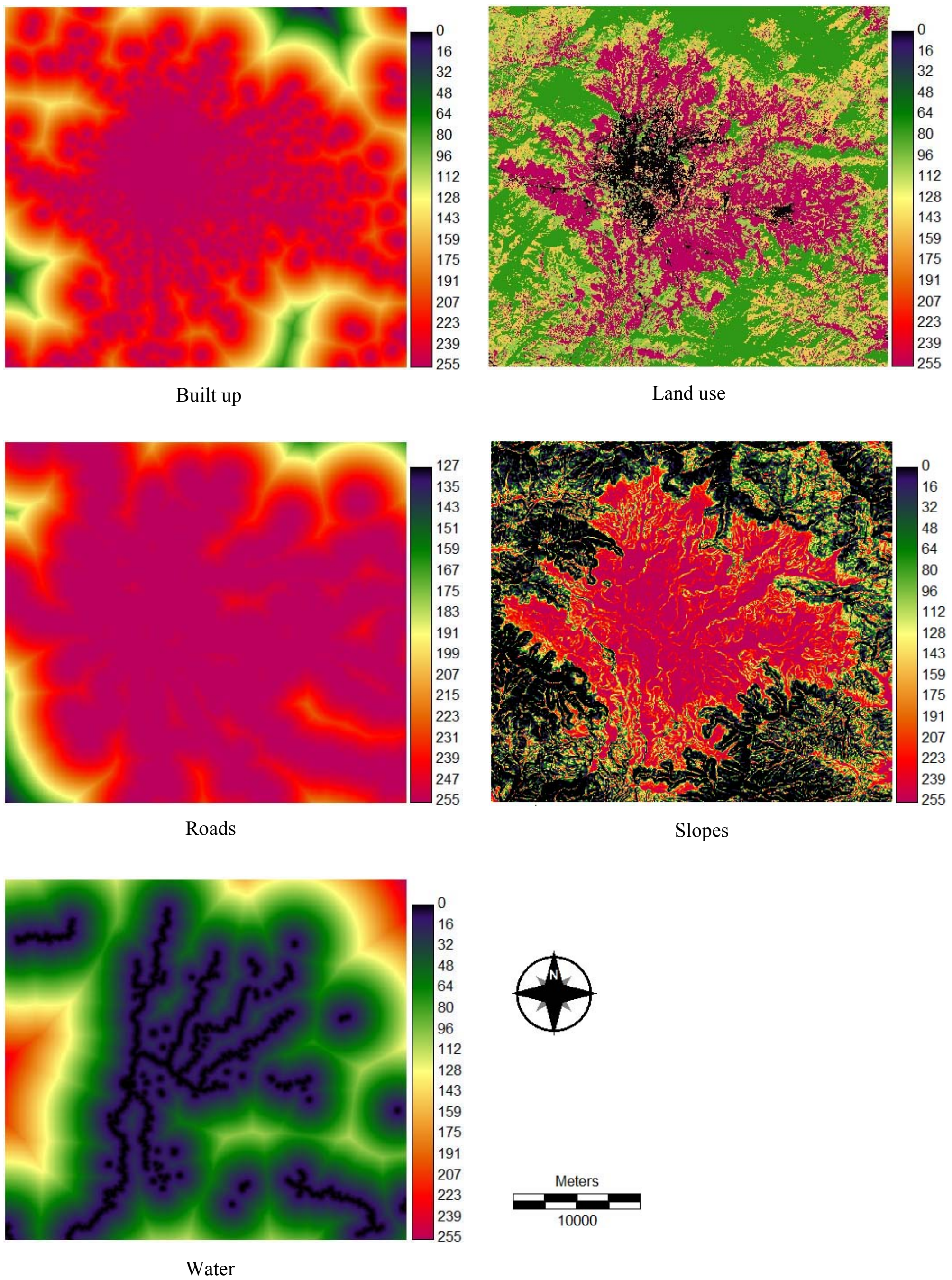


Figure 16: Factor maps showing range of suitability to urban growth

Different factors have different importance affecting the urban growth while creating the overall suitability. Therefore, the weight to each of the factor image was assigned according its importance. Although, variety of techniques exist for the development of weights from very simple to complex as to make many considerations, breaking the information down into simple pair wise comparisons into two criteria considered at a time can produce a more robust set of criteria weights which can be available as Analytical Hierarchy Process (AHP) by Saaty (1977) in Idrisi (Eastman, 2006). The process requires weighting factors rate from extremely "less important" (1/9) to "more important" (9). Consistency ratio (CR) is calculated as the AHP ratings are filled out to identify the inconsistencies in the pair wise comparison ratings. According to Eastman (2006), Saaty indicates that CR greater than 0.1 should be re-evaluated. The assignment of rating needs analyst intuition and repetition unless the consistency is acceptable as shown below (Figure 17).

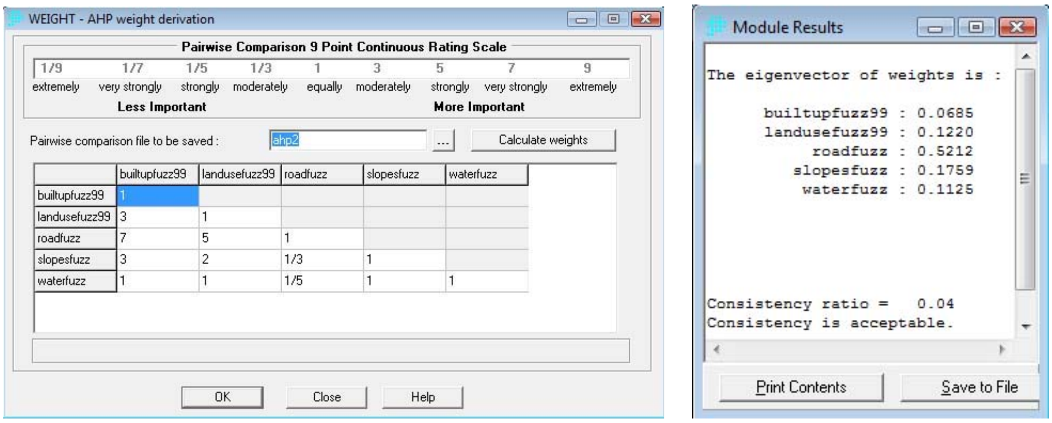


Figure 17: Analytical Hierarchy Process (AHP) ratings and Consistency ratio

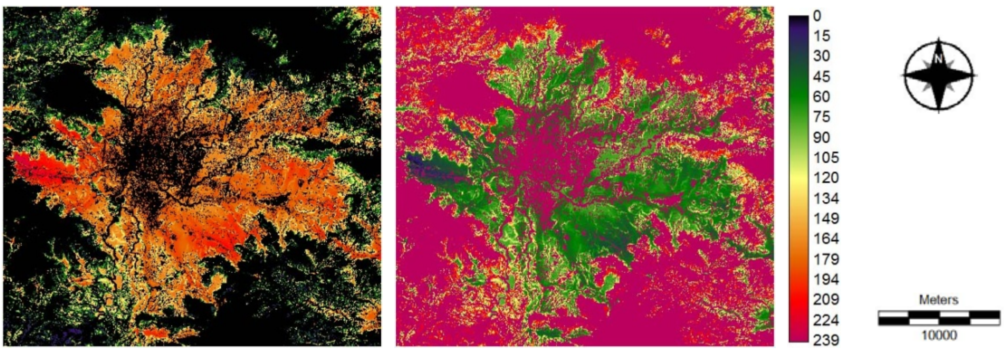
The AHP weights derived from the pair wise comparison matrix to be assigned each of the factors are discussed in the table 15 below (Table 15).

S. N.	Factors	Weight
1	Built up	0.0685
2	Land use	0.1220
3	Road	0.5212
4	Slope	0.1759
5	Water	0.1125

Table 15: Factor weights derived from AHP

Once the constraints and factors were developed and factors weights were derived, all the information was aggregated using Weighted Linear Combination (WLC) available in MCE module in Idrisi. The WLC multiplies each factor images by its weights and sums the results which will have the same range of values as standardized factor images used. The result is then multiplied by each of the constraints to mask out unsuitable areas as the resultant suitability map.

The resultant suitability map used for projecting the urban growth was as under denoted as "Highly suitable" (Figure 18). The suitability map was prepared using numbers of constraints and factors as mentioned above. The next map denoted as "Highly unsuitable" was the inverse of resultant suitability map to be used together in a group created by Collection Editor menu in Idrisi.



Highly suitable Highly unsuitable

Figure 18: Suitability maps showing high to low range of suitability to urban growth

The next step was to use MARKOV module to create a transition probability matrix, a transition areas matrix and a set of conditional probability images. These were created using 1989 and 1999 land use maps. The conditional probability images was the input in STCHOICE as a group file where the transition area matrix was one of inputs necessary to run the CA_MARKOV module along with basis land cover image and transition suitability image collection created above. CA_MARKOV uses cellular automata contiguity filter types 3 x 3 or more.

B. Second methodology

The land use projection processes were also tested with a second methodology without using constraints and factors. Therefore the methodology without employing any constraints and factors may be make use for predicting urban growth where the area has haphazard urban growth or no land use policy. The quantities of each 2006 land use transformed from each of 1999 land uses (see table 16 for cross-tabulation of Kathmandu valley land use 1999 against 2006) were converted into ratio of total transfer for that land use. Likewise, continuous maps for each land use were prepared with the help of Edit/ASSIGN module in Idrisi by assigning 0 to 100 marks to 1999 land use classification map according to the lowest to highest ratio obtained as explained above.

For example, according to the table given below (Table 16), the ratio of the built up areas in 2006 converted from the built up areas of 1999 could be 0.76 and the ratio for non-built up areas could be 0.24. So, if the 100 value was to assign to the highest ratio (0.76) then 32 would be for the lowest value (0.24). These values were used to create suitability map for built up areas using Edit/ASSIGN module. With the same method suitability map was created for non-built up areas also. This would give suitability maps that have ranges 0 to 100. The 100 shows full suitability for 1999 land uses to change into 2006 and 0 unsuitable to change into the same. The suitability maps were then grouped using Collection Editor and applied for projection processes (Figure 19).

		Land use 1999 (Area in hectare)		**Total**
	Land use	Built up	Non-built up	
Land use 2006 (Area in hectare)	Built up	4366	1366	5732
	Non-Built up	0	82759	82759
	Total	4366	84125	88491

Table 16: Cross-tabulation of land use 1999 (columns) against land use 2006 (rows)

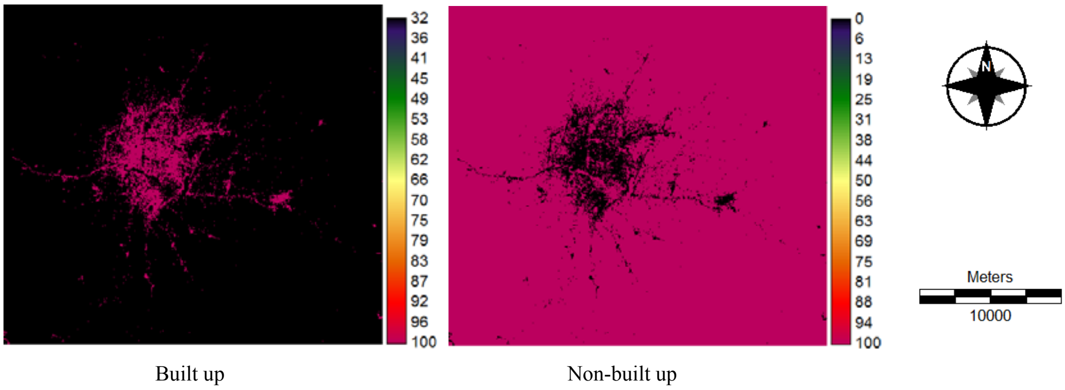


Figure 19: Suitability maps showing range of land use change suitability from 1999 into 2006

4.3.2. Model execution

Cellular Automata Markov (CA_MARKOV) as well as GEOMOD modeler in Idrisi Andes was executed to generate the prediction maps of 2006 and 2019 land use and land cover. The CA_MARKOV uses inputs as the base land cover map which was 1999 from which land use changes were projected, the transition areas file produced by MARKOV from 1999 and 1989 maps, and collection of suitability images produced as described above. During the iteration process every land use class lose and/or gains some of its land to one or more other classes. The default cellular automata contiguity filter type is 5 x 5. Based on these inputs land use changes develop as a growth process in areas of higher suitability adjacent to existing areas.

The GEOMOD, however is a grid-based (Pontius, Chen, 2006) land use change modeler and simulates the change between two land uses category only. Therefore, it was best suited to simulate the built up and non-built up land classes. As already specified in the previous sections, the GEOMOD was supplied with the beginning time map i.e. 1999, beginning (1999) and ending (2006) time, suitability maps prepared as before and the information on the number of grid cells of the built up areas for the ending time i.e. 2006 and 2019. The GEOMOD worked as the simulation process started by searching from non-built up grid cells that were likely to be converted into built up since beginning to the ending time and model predicted the expansion of new built up areas.

Modeling for the future urban land use the previously re-classified (i.e. Built up and Non-built up) maps were used along with the suitability maps derived as above. Both the CA_MARKOV and GEOMOD modeler were employed and the maps below were the projection results of the two land classes for the year of 2006 (Figure 20).

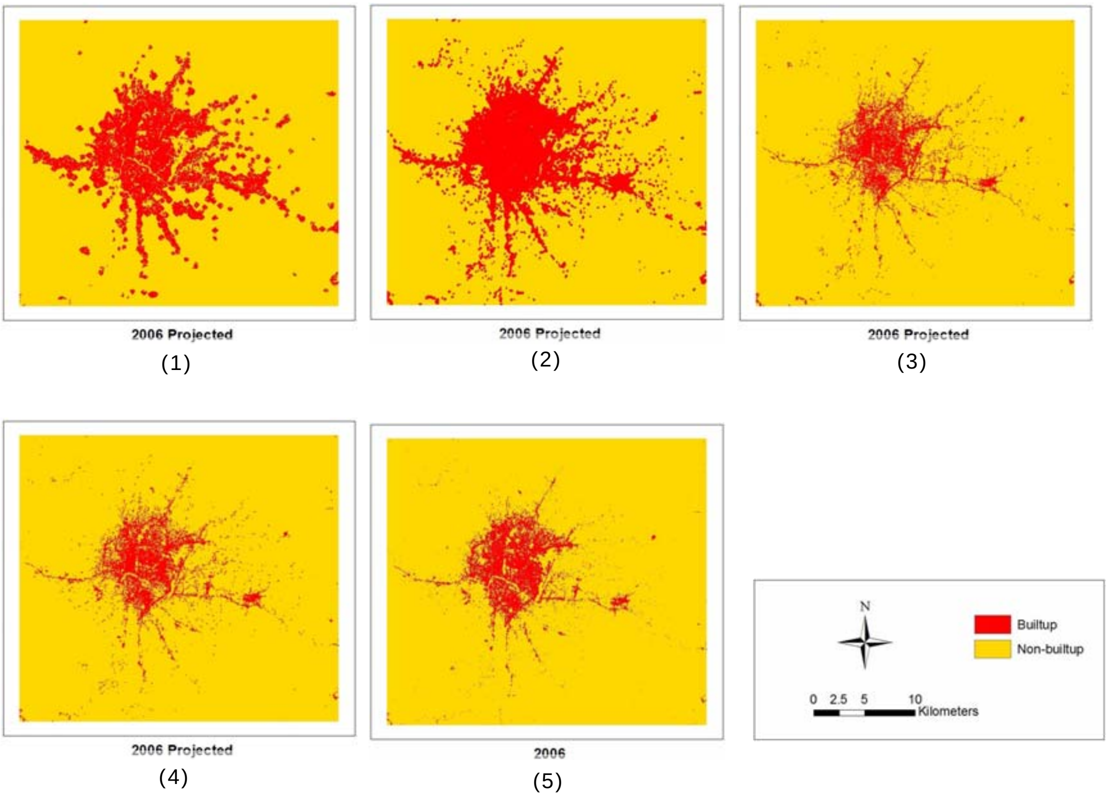


Figure 20: Built up and Non-built up land class projection for 2006

The maps (1) & (2) were the results of CA_MARKOV and (3) & (4) were the results of GEOMOD modeler that used suitability maps derived through both first (maps 1 & 3) and second (maps 2 & 4) methodologies. The (5)th was the real re-classified map of 2006. Before further projecting the land uses, the resulting projected maps of 2006 were compared with real classification land use and land class maps.

The table 17 shows the result of areas in hectare obtained by the projection processes and compares with the result of real land use re-classes of 2006. The prediction statistics show that the areas of true re-classfication were the same as the projected land classes using GEOMOD because it used the same number of grid cells as real land classes during the simulation process. The CA_MARKOV predicted 2 to 3 times more area of land classes than real 2006 re-classification map. The rest of the statistics are presented as given below (Table 17).

ID	Land use 2006	Area in hectare				
		CA_MARKOV		GEOMOD		TRUE RE-CLASSIFICATION (5)
		(1)	(2)	(3)	(4)	
1	Built up	13523	15667	5732	5732	5732
2	Bare soil	74968	72824	82759	82759	82759
	Total	88491	88491	88491	88491	88491

Table 17: Area of predicted land classes for 2006

4.3.3. Model validation

After any model generates a simulated map, it is desirable to validate the accuracy of the prediction because it might have doubtful result. Therefore, model validation is one of the important stages in the prediction regime of land uses. Idrisi provides VALIDATE module in the validation process. The VALIDATE module involves a comparative analysis of the simulated and real maps based on the Kappa Index. However, it is different with traditional Kappa statistic in that it breaks the validation into several components, each with special form of Kappa such as Kno, Klocation, Kstandard, etc and the associated statistics (Pontius, 2000 in Eastman, 2006).

Kno = Kappa for no information

Klocation = Kappa for location

Kquantity = Kappa for quantity

Kstandard = Kappa standard

The validation result of the projected 2006 map against real 2006 map is given below as Kappa measures (Table 18). According to the validation result, the projection of 2006 land classes using GEOMOD and the suitability maps created with second methodology had highest Kappa (maps 3 and 4) whereas the projection for the same year using CA_MARKOV and second methodology had the lowest kappa (map 2).

Kappa	**Value**			
	(1)	**(2)**	**(3)**	**(4)**
Kno	0.8152	0.7963	0.9211	0.9303
Klocation	0.8688	0.9807	0.6744	0.7126
KlocationStrata	0.8688	0.9807	0.6744	0.7126
Kstandard	0.5531	0.5518	0.6744	0.7126

Table 18: Kappa statistics for validation results

Pontius, Chen, (2006) says that comparison among model performances would be difficult even for the same model. It is difficult to separate the quality of the model from the complexity of the landscape and of the data. For example, if a model performs poorly, it is difficult to know whether the conceptual foundation of the model is weak, or the phenomenon of land change at the study site is particularly complex or the data is particularly detailed. Alternatively, if a model performs well, it is difficult to know whether the conceptual foundation of the model is strong, or the phenomenon of land change at the study site is particularly simple, or the data is very simplified. Therefore it is very hard to say something about the results obtained from the projection of land classes for 2006.

4.3.4. Urban land use prediction for 2019

After simulating the model for 2006 land use and validation, the further simulation of land use was performed. The simulation was for the year 2019, in the same way as for 2006 using the real land use re-classification maps of 1989 and 1999, transition areas matrix, group file of suitability maps and the default cellular automata contiguity filter. As presented in the figure 21 below were the simulated maps for 2019 (Figure 21).

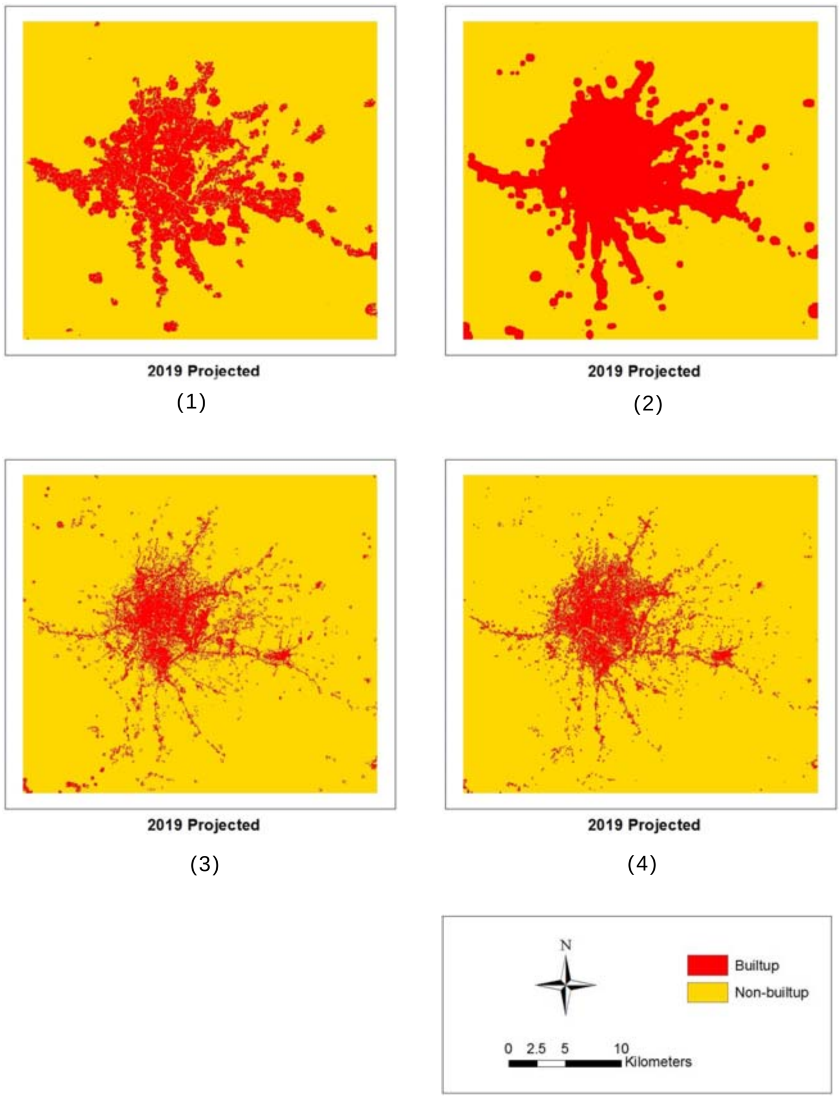


Figure 21: Simulated Built up and Non-built up land class maps for 2019

It was apparent from the visual interpretation that the built up (urban) areas will increase significantly in the simulation year 2019 from 2006. It was especially true for the simulation maps of 2019 derived from CA_MARKOV, which have more than two folds increase in the built up areas. The table 19 below provides all the area statistics of the simulated 2019 maps derived from the CA_MARKOV and GEOMOD and the 2006 map.

ID	Land use 2019	Area in hectare				
		CA_MARKOV		GEOMOD		TRUE RE-CLASSIFICATION 2006
		(1)	(2)	(3)	(4)	
1	Built up	15666	19470	7884	7884	5732
2	Non-built up	72825	69021	80607	80607	82759
	Total	88491	88491	88491	88491	88491

Table 19: Area of simulated maps of 2019 and true 2006 land re-classes

Further testing of second methodology

Further the suitability maps created with second methodology were tested for all six land classes of Kathmandu valley with CA_MARKOV. The table below was the change matrix of conversion into each of 2006 land classes from each of 1999 land classes (Table 20).

		Land use 1999 (Area in hectare)						Total
	Land use	Agriculture	Bare soil	Built up	Forest	Open area	Water	
Land use 2006 (Area in hectare)	Agriculture	5476	2940	0	1287	4684	33	14420
	Bare soil	1708	16828	352	109	2064	79	21140
	Built up	399	916	3900	26	468	23	5732
	Forest	1938	215	0	26263	3031	62	31509
	Open area	3342	2786	30	640	8403	66	15267
	Water	81	57	84	41	31	129	423
	Total	12944	23742	4366	28366	18681	392	88491

Table 20: Cross-tabulation of land use 1999 (columns) against land use 2006 (rows)

The maps (Figure 22) presented below were the collection of suitability maps that were prepared with the second methodology of creating suitability maps from the land use classification maps of 1999 used for the projection of urban growth of 2006 and 2019. The symbols show range of low to high suitability of converting to each of land uses in 2006 and 2019 from each of 1999 land uses.

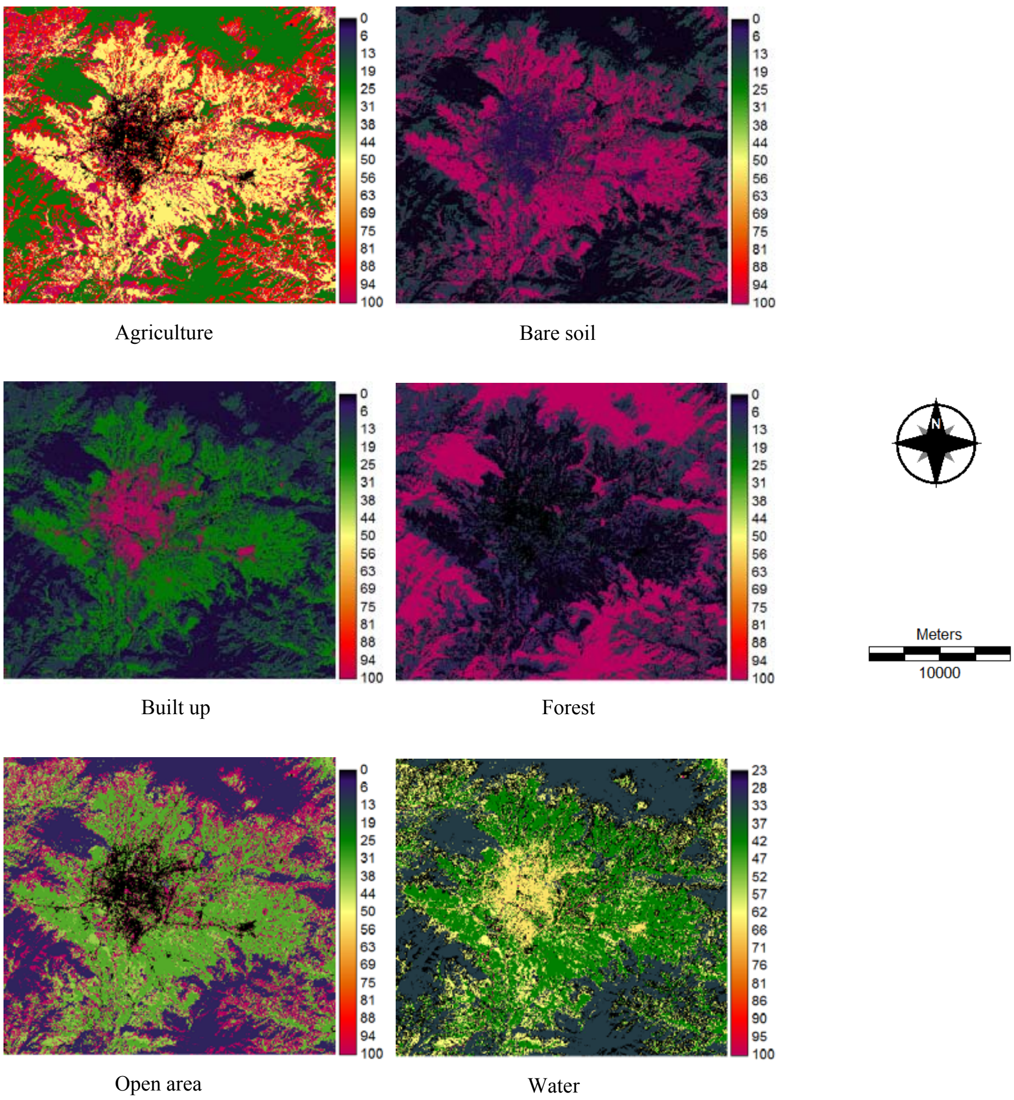


Figure 22: Suitability maps showing range of land change suitability from 1999 into 2006

The suitability maps above created by using second methodology were then applied for projecting combined six land use classes of 2006 and 2019 (Figure 23). The comparison of simulated maps, statistics and validation results are presented below.

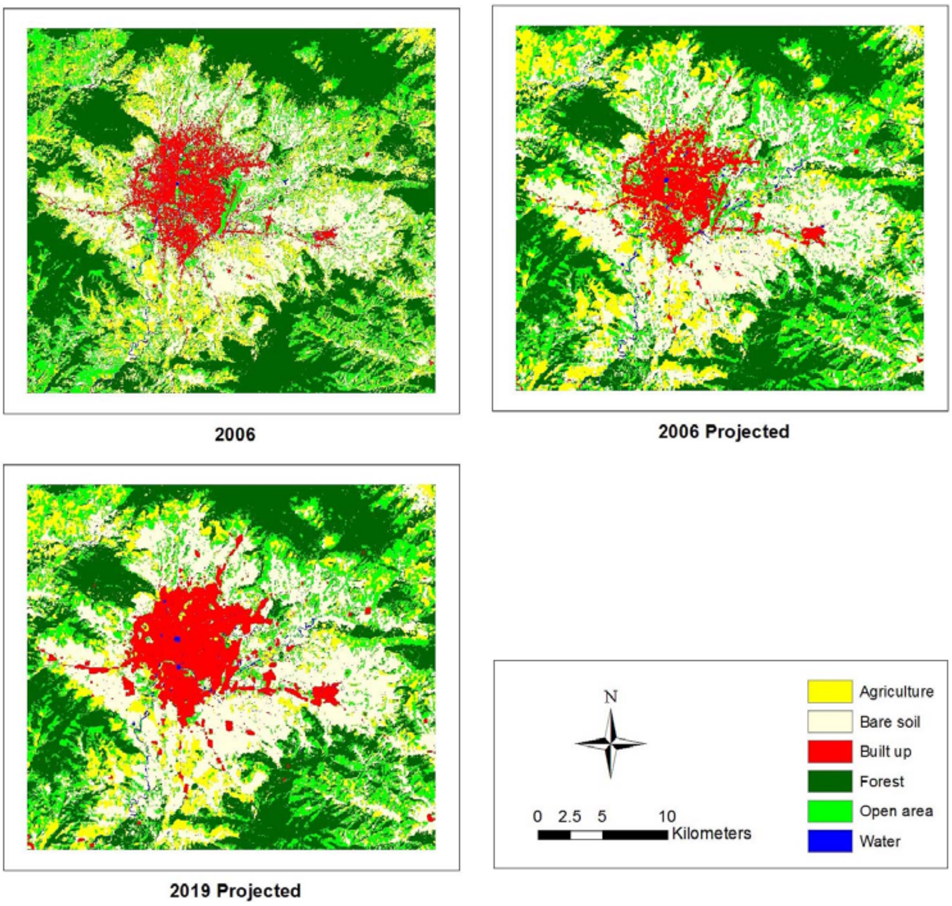


Figure 23: Comparison of true 2006 land class map with projection 2006 and 2019 maps of Kathmandu valley

The comparison matrix of the area statistics of true 2006 land use classification map and projection 2006 and 2019 maps is presented below (Table 21). The statistics show that the differences in areas were not very huge between projected 2006 land classes and real 2006 land classes. The areas in hector for the six land classes of real 2006 and projected 2006 and 2019 were as presented in the table below.

ID	Land use	Area in hectare		
		2006	**2006 Projected**	**2019 Projected**
1	Agriculture	14420	13901	12156
2	Bare soil	21140	24825	26301
3	Built up	5732	5478	7884
4	Forest	31509	25952	25498
5	Open area	15267	17795	16164
6	Water	423	540	488
	Total	88491	88491	88491

Table 21: Comparison area statistics of classified and projected maps

The validation results of the projected 2006 map against classified 2006 land use map is given below as Kappa measures (Table 22). The validation result had been improved than the validation results of only two land classes tested with CA_MARKOV mentioned above.

Kappa	Value
Kno	0.6019
Klocation	0.6243
KlocationStrata	0.6243
Kstandard	0.5659

Table 22: Kappa statistics for validation results

The simulated maps of 2006 and 2019 were reclassified again into Built up and Non-built up. The Kappa increased for re-classed 2006 simulation map than that of combined six land classes mentioned in figure 23 and table 22 above. The resulting map, its statistics and validation result are given below in figure 24 and table 23 and 24 respectively. So, it can be inferred that the validation result may become higher for less number of land use classes than more number of land use classes (Figure 24).

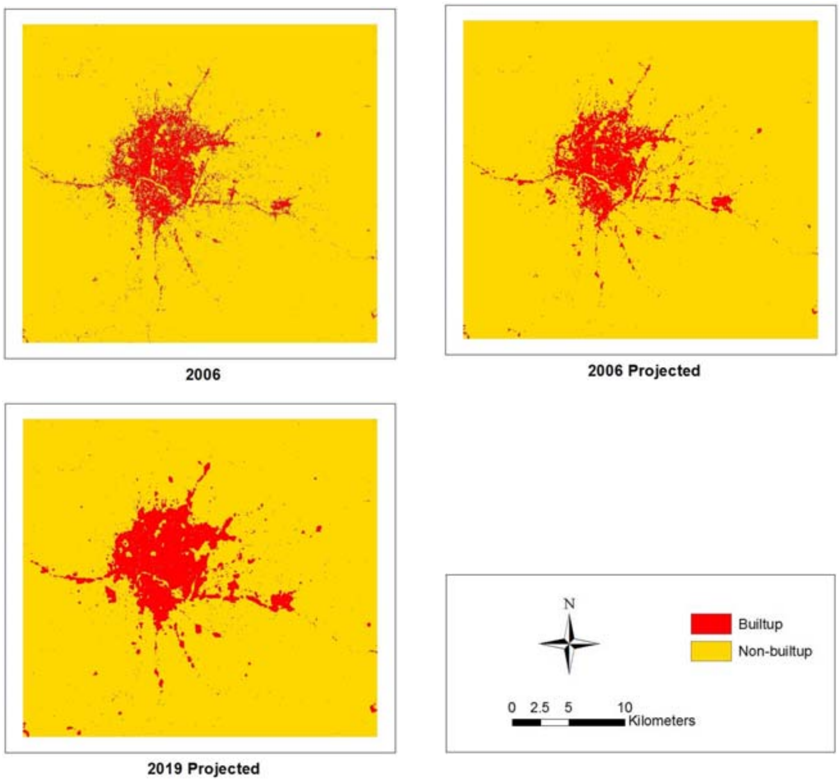


Figure 24: comparison of true 2006 land re-class map with projection 2006 and 2019 land re-class maps

The comparison matrix for area of real 2006 land use re-classed map and projected 2006 and 2019 re-classed maps is presented below (Table 23).

ID	Land use	Area in hectare		
		2006	2006 Projected	2019 Projected
1	Built up	5732	5477	7884
2	Non-built up	82759	83014	80607
	Total	88491	88491	88491

Table 23: Comparison statistics of true and projection maps

The validation result of the re-classed projection 2006 map against real re-classed 2006 land use map is given below as Kappa measures (Table 25). The Kappa was 0.7758 for the simulation of 2006 land classes which was highest yet in the simulations for this study.

Kappa	Value
Kno	0.9468
Klocation	0.7951
KlocationStrata	0.7951
Kstandard	0.7758

Table 24: Validation Kappa statistics

4.3.5. Implication of the urban growth

Though the urban areas will certainly increase significantly in the future, it should not increase in the areas that are environmentally sensitive. Some of the environmentally sensitive areas are the forest and protected areas, water bodies, etc. which were considered during the production of suitability maps assuming that they would not have severe effect by the urbanization process. However, this may not happen exactly in real nature because one can model the physical settings but cannot be easy to model human's behavior. That is why people in the world nowadays truly started worrying for the environmental issues. Human in the world have the most vicious power to degrade the environment.

The interpretation of the simulated maps above suggests that normally the GEOMOD predicted better than CA_MARKOV. Even though the predicted maps of both models did not have higher validation result (i.e. more than 0.8), it could also be learnt that the predicted urban growth would have very little effect in the designated areas of the Kathmandu valley in 2019. However, the water bodies would be affected someway more by the urban growth in the future. The effects of urbanization to the surrounding environment due to the extension of urban areas beyond 2019 could be assessed by further modeling. The figure 25 presented below show the effects of urban growth in the general environment until 2019. Layers of designated areas and water bodies were overlaid in the 2019 prediction maps (Figure 25).

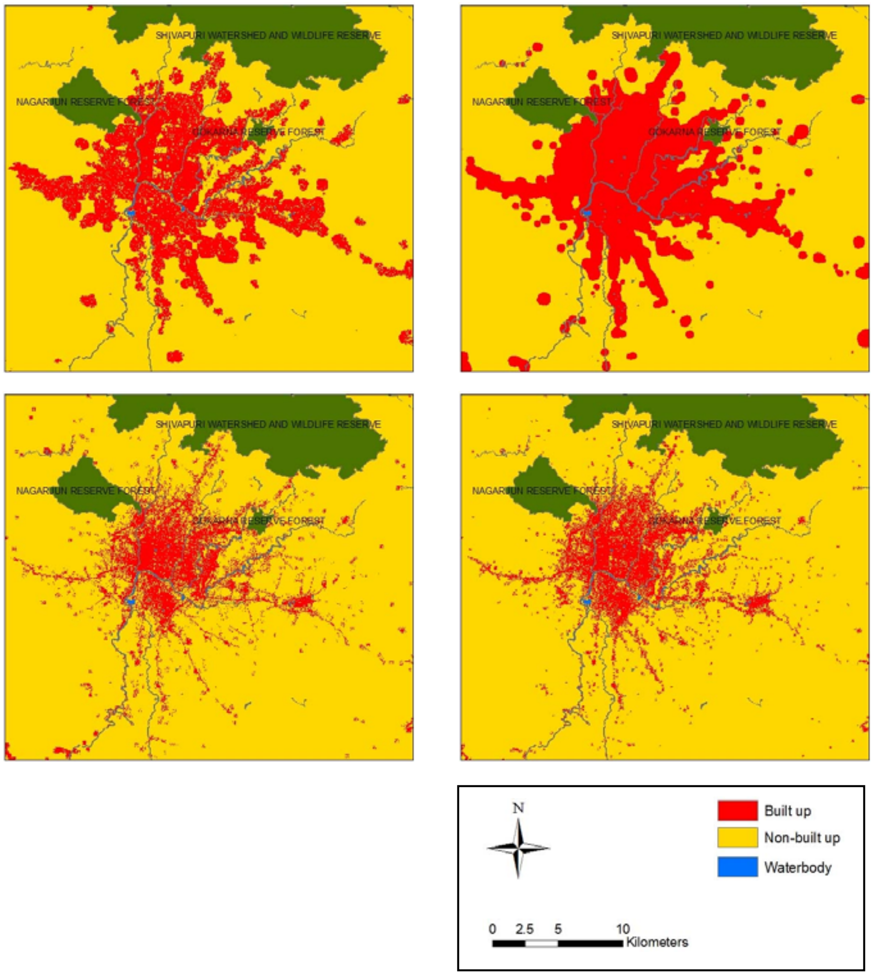


Figure 25: Prediction maps of 2019 showing urban impacts on surrounding environment

5. CONCLUSIONS

5.1. Discussion

Like other areas, urban monitoring and management is also one of application areas of the information sciences and technologies, i.e. GIS and Remote Sensing. These technologies can be used from acquiring information of extensive areas with Remote Sensing data to analyzing spatially as per the requirement with GIS. These technologies can provide computer aided tools for mapping, monitoring, and analyzing urban dynamics to incorporate the acquired information for management purposes.

It was concluded from the study that the centralized public services in the capital cities were the main reasons for the population flood and rapid urbanization in the Kathmandu valley. Another cause of migration flow in the Kathmandu valley was insecurity in the rural and remote places because of a decade long insurgency in Nepal. A review on demographic situation of Kathmandu valley showed that the population had increased about 48% during 1991 to 2001. The annual population growth rate was 4.71%. Due to the population influx and without proper land use plan the urban areas are being increased haphazardly in Kathmandu valley. An analysis in this study showed that the built up areas had increased by 134% since 1989 until 2006. The most fertile lands are being converted into concrete lands. Six percent of agricultural lands including bare soil were converted into built up during the study period. Because of the precious land value of the capital cities people have also started encroaching the open areas which are public lands. About 11985 hectares of open areas have already been encroached of which about 11% was converted into built up. These trends have not been stopped yet and could be expected to grow continuously in the future unless the proper land use plan is formulated. The proper land uses for urban growth should be defined with intensive analysis of different concerns in the formulation of new land use plan.

To overcome such situations, GIS and Remote Sensing technologies could also be one of the important solutions to be realized the true phenomena in the Kathmandu valley and take properly immediate necessary actions. After the advent of the GIS tool in the world it has been possible to simulate the land classes for years to come in the future which could be good news for urban management in Kathmandu valley.

However, to simulate any land use properly one needs to have the knowledge on the place in question and specialized in the simulation. Otherwise the simulation can give false information and may lead to take wrong decision. The right simulation process depends on numbers of factors. In this case, the numbers of pixels for urban land class grew towards unwanted directions with CA_MARKOV but gave satisfactory result with GEOMOD provided the same rule in the modeling process. In the study, even CA_MARKOV was run number of times with various first methods' suitability maps, the pixels did not grow in the constrained region mainly designated areas but the pixels grew more than the expected numbers to unconstrained regions. It might mean that CA_MARKOV does not have limitation on growing number of pixels in the modeling process unlike GEOMOD. It could also be that the suitability map was not created properly. Due to time limitation more suitability maps could not be created and tested. This may pose the situation for further test with CA_MARKOV and also with lower numbers of contiguity filter matrix.

5.2. Limitations

The Landsat images are extensively used data for the urban monitoring and analysis nowadays because of free access. There is a massive 35-year archive of moderate resolution Landsat imageries (Olmanson, Bauer, Brezonik, 2008; IWMI, 2009) which can be suitable for classification, quantification of land use and land cover and spatio-temporal change analysis of any place. Although these are made free to everybody, not all the Landsat images can be of requisite dates and clouds free. Use of Landsat images could also be expensive if combined with other higher resolution images.

The Landsat images on scan-line corrector (SLC) off mode are noisy that may cause unusable some of the available images. The SLC for Enhanced Thematic Mapper Plus (ETM+) sensor, on board the Landsat 7 satellite failed permanently in 2003 consequently resulting about 20% of the pixels not scanned but distributed most part of the ETM+ image. Therefore it has not been possible to get required good condition 2009 image to make 10 years gap of each of the study period duration because the previous images used were 1989 and 1999 before 2006. These are the limitations for using Landsat images. However, some authors have attempted geostatistical interpolation of SLC off ETM+ images (Pringle, Schmidt, and Muir, 2009).

5.3. Future work

The GIS and Remote Sensing technologies are very important in the countries like Nepal because of its complex geographic nature. Most of the places are inaccessible and cannot be reached easily for the measurements of land features at field level. Every spatial analysis in Nepal had been done manually or through limited use of information technology few decades ago. In this context, the GIS and Remote Sensing technologies were introduced only around 90s and have a scope yet to develop a lot in Nepal.

The second methodology should be further tested with more and different kinds of data sets. Further study should also be done with this methodology combining with constraints and factors. The results of GEOMOD simulation with second methodology were satisfactory. The results have been presented with the related maps and tables. Up to this point of the study all available datasets, tools and methodology have been useful and adequate.

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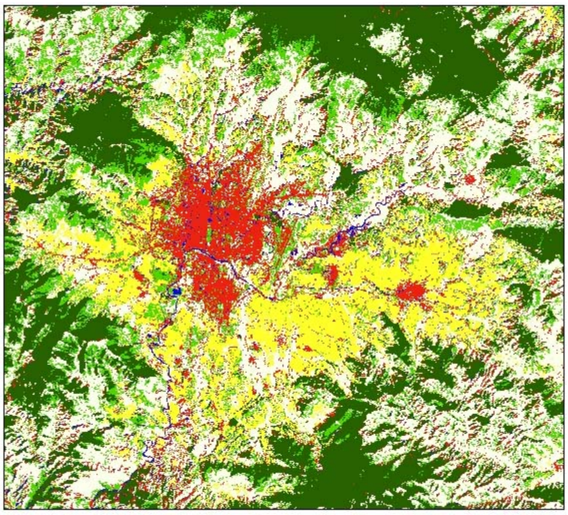
APPENDICES

1. Classification result of Mahalanobis distance



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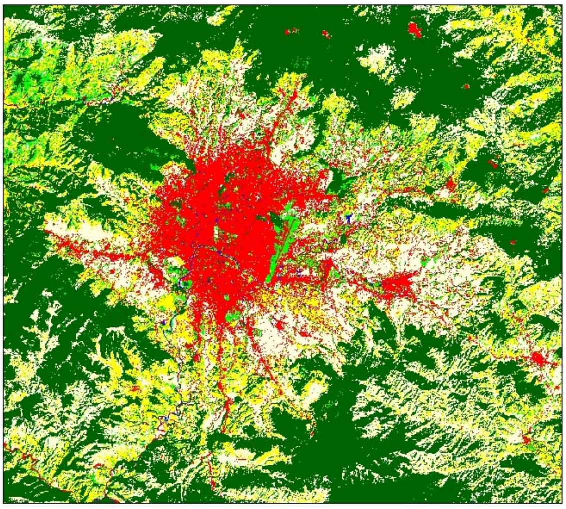
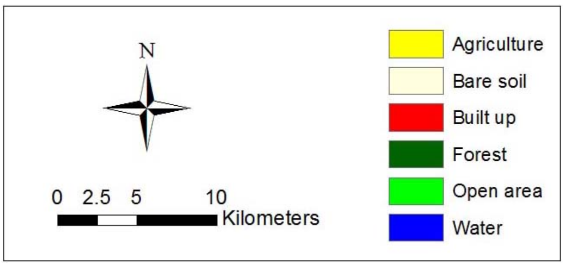
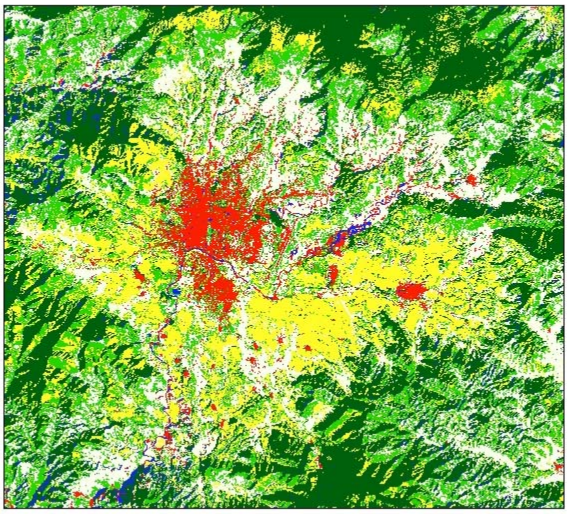


2006



2. Classification result of Minimum distance



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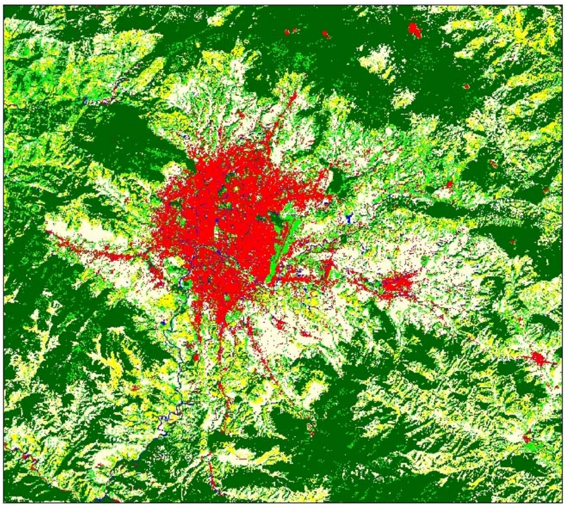

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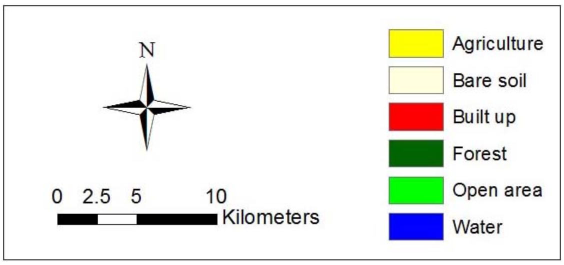

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