# Monitoring Land Cover Change In Kathmandu City Using Spatial Metrics And Remote Sensing Techniques

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***Abstract***

*This paper explores the urban land cover changes in Kathmandu city area in the past one and half decades. Multi-temporal satellite images and spatial metrics were used to quantify the land cover changes. The study area was setup to 10x10 km covering the Kathmandu metropolitan area. After pre-processing the satellite images, supervised classification with maximum likelihood classifier was applied to create thematic urban land cover maps. Random sampling method was used to create geographic points for each thematic map to assess the accuracy of the maps. Five land use classes: urban builtup area, cultivated land, orchard, water and natural vegetation were identified. For detecting land cover changes quantitatively, a land use land cover conversion matrix was computed between the year 1989-1999 and 1999-2005. Spatial metrics (patch density, largest patch index, edge density, Euclidian nearest neighbor mean, contagion index and area weighted mean patch fractal dimension index) were computed to evaluate landscape structure of the metropolitan area.0The overall result shows rapid expansion of urban built environment and shrinkage of the agriculture land. The agriculture and orchard lands were mostly transformed into urban uses. The existence of water and vegetation were found very low as compared to other land covers. The urban expansion trend was confined in the peri-urban of the urbanized territory. The overall urban landscape seems to be very complex and fragmented in later years.*

## 1. Introduction

Urbanization is regular socioeconomic process that induces a general transformation in the landscape. Rapid urbanization is a global phenomenon, and cities require an increasing amount of land and other resources. Urban environment has emerged as a primary concern for city planners and the urban residents. Understanding the dynamics of complex urban environment and solving the real world problems necessitate robust method and technologies for urban resources managers. Remote sensing technology has great potential for acquisition of detailed and accurate land use/cover information for management and planning of urban regions. The urban environment represents one of the most challenging areas for remote sensing analysis due to high spatial and spectral diversity of surface materials (Herold et al. 2003; Maktav et al. 2005; Torrens 2006). In recent years, series of earth observation satellites are providing abundant data from high resolutions (i.e. QuickBird, IKONOS, OrbitView, SPOT, ALOS) to moderate resolution (i.e. ASTER, IRS, Landsat) for urban area mapping. However, remote sensing data from these systems have a specific potential for detailed and accurate mapping of urban areas.

With the advancement in remote sensing (RS) and geographic information system (GIS) techniques, characterizing a landscape and quantifying its structural change has become possible in recent years (Donnay et al. 2001; Maguire et al. 2005). Remote sensing provides an efficient tool to monitor land use/cover changes in and around urban areas since the past three and half decades. With time series satellite data we can monitor long-term changes (Herold et al. 2003; Thapa et al. 2005) whereas GIS provides a framework for spatial analysis and modeling based on geographic principles and seeks to integrate the analytical capabilities to broaden the understanding of the real world system (Murayama 2001; Maguire et al. 2005).

The populations and socio-economic domain have changed the urban land use pattern in Nepal significantly. The population has significantly increased within the period of 1952 to 2001 with the annual growth rate reaching 6.6% in 2001 (Sharma 2005) (Figure 1). The ever-growing demand for urban services and deteriorating urban environment in the context of limited capacities and resources pose a serious challenge for the country (Pradhan and Perera 2005; Haack and Rafter 2006; ICIMOD 2007). Rapid urban growth in Nepalese cities has prompted concerns over the degradation of environmental and ecological health (National Planning Commission 2003; Dhakal 2003). Many agricultural and forest lands have been converted into urban areas and human settlements. Visual comparison of the images also shows the increase in the number of houses between 1967 and 2001 with almost all the agricultural and vacant spaces occupied with built up areas (Figure 2).

Satellite based Normalized Differential Vegetation Index (NDVI[1]) of past 15-years presents deteriorating agriculture and natural vegetation land covers in Kathmandu metropolitan city (Figure 3). These land covers may be covered by the urban infrastructures, residential and commercial buildings in recent years. Business opportunities, commercial and social interests, and security risk created by political turmoil after restoration of democracy in 1990 have increased the people movement to the valley from other areas in Nepal (Haack and Rafter 2006). The population density of Kathmandu metropolitan city has been boosted from 8,370 persons/$km^2$ in 1990 to 13,235 persons/$km^2$ in 2001 (Figure 4). High population influx and uncontrolled momentum of urban sprawl may cause a serious pressure to the limited resources with adverse impact to the environmental conditions and livelihoods of inhabitants in the Kathmandu valley. The main objective of this paper is to

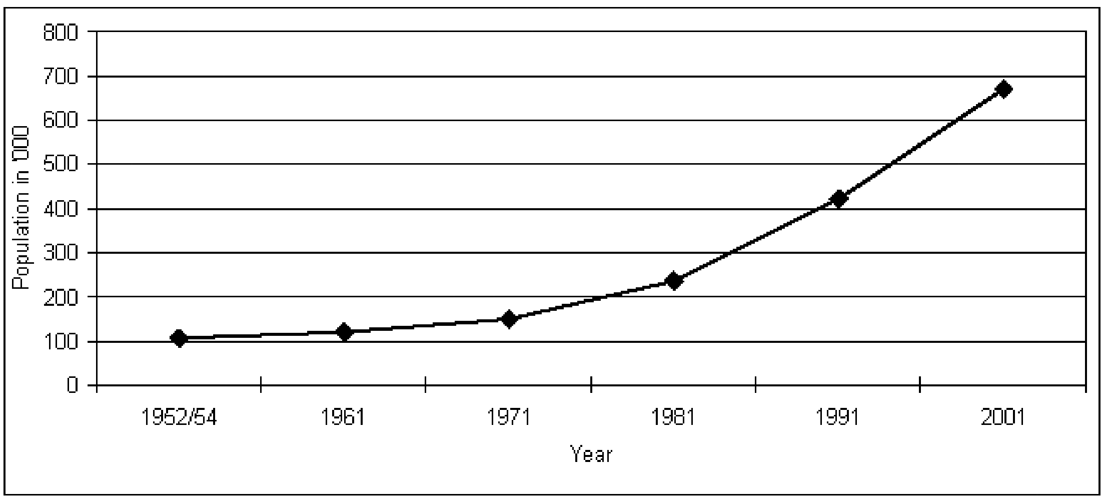


Figure 1: Population change in Kathmandu city (Sharma 2005).

Figure 2: CORONA satellite image acquired in 1967 (left) and IKONOS satellite image acquired in 2001 (right).

1. NDVI is an index that computes a ratio of coefficients based on the spectral responses reflected from land covers in red and near infrared bands of satellite sensors. High coefficients represent existence of healthy vegetation in particular geographic areas.

monitor the land cover change in Kathmandu metropolitan area using time series remote sensing data and spatial metrics.

In this study, we describe a technique to quantify spatial urban patterns from moderate resolution optical remote sensing data to describe structures and changes in urban land use/cover. Multispectral optical remote sensing allows an accurate separation of diverse urban land-cover types (including built-up areas, vegetation, and water) to derive accurate thematic land-cover maps. However, residential and commercial urban land-use categories typically cannot be accurately discriminated by applying per-pixel analysis methods. Spatial and textural context is important information for understanding urban area landscape. Therefore, we utilize spatial metrics as quantitative measures of spatial structures and pattern to describe urban land-use features.

## 2. Method

hree remote sensing images (Table 1), two from Landsat and one from IRS satellites, were processed for identifying the urban land use/cover changes patterns. Multi-sensor and multi-temporal data are useful for assessing change dynamics but seasonal variances could affect the images for quantitative analysis (Thapa *et al* 2005). In order to avoid the influences of cloud cover and seasonal variances, the images are selected from same season (winter). The images were processed using ERDAS Imagine 9.0 software. Remotely sensed data always experience some geometric distortions due to various causes such as earth's rotation, platform's instability, etc. (Richard and Jia 1999). A GIS based road layer was prepared for the Kathmandu valley using 1:25000 scale topographic maps obtained from Survey Department, Nepal. This road map was employed for rectifying the geometric distortions in the images. Sixteen evenly distributed ground control points were used for rectifying the images. A first order polynomial geometrical model with bicubic spline algorithm was applied to correct the geometry of the images. In order to compute the change by pixel, the LISS III image was resampled from 24-meter to 30-meter as same as resolution of Landsat images. The root mean square errors for all three images were maintained less than 0.5 pixels. The UTM, WGS84 North, Zone 45 projection system was used. The images were further resized into 10x10 km of spatial extent covering the whole Kathmandu metropolitan city.

Five land use/cover categories (i.e. urban builtup area, cultivated land, orchard, water and natural vegetation) were schemed based on NDVI index analysis, unsupervised classification (ISODATA algorithm), knowledge-based visual interpretation, and texture and association analysis. The urban builtup area class covers the commercial and residential houses, road and other urban structures. The land covered by the basic agriculture such as paddy, maize, vegetables are categorized into cultivated land. The orchard indicates the gardening near by the urban houses, horticulture, parks and bare land.

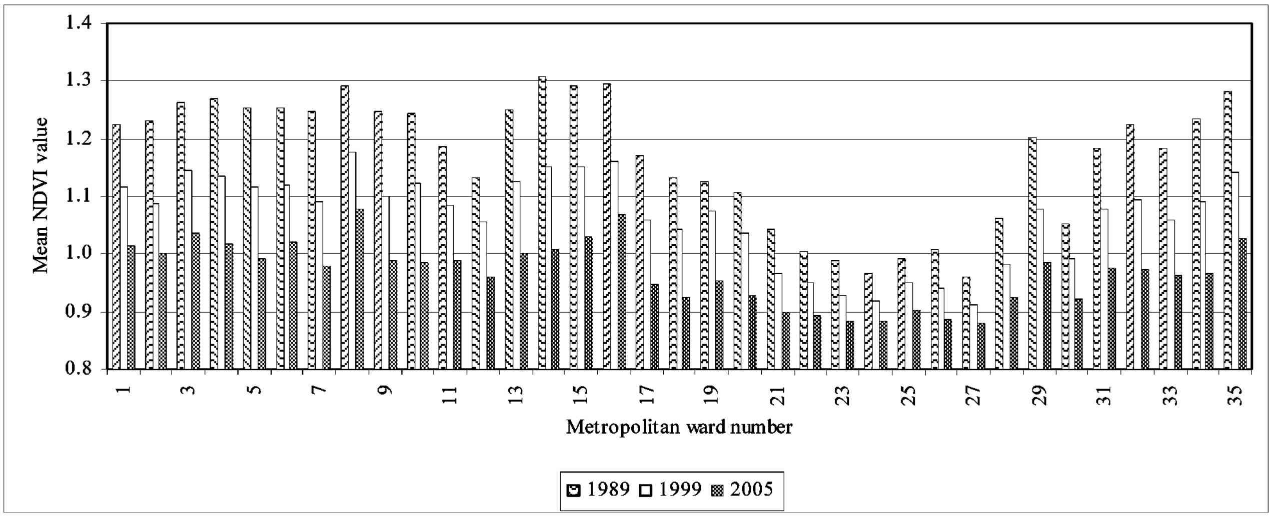


Figure 3: Land cover change in Kathmandu metropolitan area using NDVI of Landsat 1989, 1999 and LISS III 2005 images of winter season.

Table 1: Database description

| Satellites | Date | Resolution |
|---|---|---|
| Landsat TM | 31-10-1989 | 30 meters, 6 channels |
| Landsat ETM | 04-11-1999 | 30 meters, 6 channels |
| IRS LISS III | 18-12-2005 | 24 meters, 4 channels |

Urban areas typically exhibit a spatially heterogeneous land cover and there is probability of similarity in spectral response from the different land cover and land uses in this environment (Johnsson 1994). Supervised classification approach tackles such problems through the statistical classification techniques using a number of well distributed training pixels. These training pixels as representative of land use class are used to calculate descriptive statistics (e.g. mean and variability) for each class (Hubert-Moy *et al*.2001, Racolt *et al*.2005). The basis of the class descriptions derived, each pixel is allocated to the class with which it has the greatest similarity, as assessed relative to the classifier's decision rules. Maximum likelihood classification, for example, labels each pixel as belonging to the class with which it has the highest posterior probability of membership (Lillesand and Kiefer 1994, Jensen 2005). The maximum likelihood classifier, often used in supervised classification which is a parametric decision rule developed from statistical decision theory that has been applied to problem of classifying image data (Richard and Jia 1999). Supervised classification technique with maximum likelihood classifier was implemented while preparing the thematic urban land cover maps for 1989, 1999 and 2005. More than 30 geographic training samples for each image were collected for the classification. After obtaining a suitable indication for satisfactory discrimination between the classes during spectral signature evaluation, the supervised classification process was run. The 3x3 majority kernel filter was used as post classification process in the classified maps in order to remove salt and pepper noises.

The accuracy assessment in remotely sensed image classification is necessary for evaluating the obtained results (Congalton 1991). This will allow a degree of confidence to be attached to those results and will serve to indicate whether the analysis of objectives has been achieved. Randomly selected reference pixels lessen or eliminate the possibility of biasness. Reference pixels represent geographic points on the classified image for which actual data are known. The reference data are often derived from field survey, high resolution satellite imageries or aerial photographs. A set of reference pixels is usually used in accuracy assessment. Hundred geographically allocated random points were created for each thematic map for accuracy assessment. These points were further verified with aerial photos, IKONOS image acquired in 2001 and Google Earth explorer. Kappa index is computed for each classified map to measure the accuracy of the results. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Kappa accounts for all elements of the confusion matrix and excludes the agreement that occurs by chance. Consequently it provides a more rigorous assessment of classification accuracy. The accuracy of classification results achieved were 91% (Kappa=0.87), 92% (Kappa=0.88) and 91% (Kappa= 0.86) for the year 1989, 1999 and 2005, respectively.

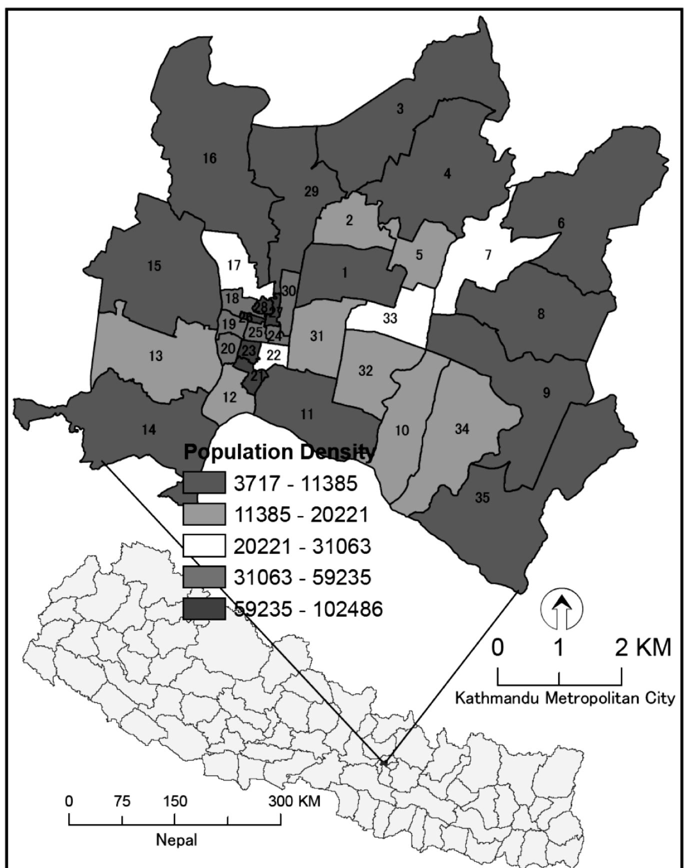


Figure 4: Population density/km$^2$ (2001) by ward number in Kathmandu metropolitan area.

Land use/cover conversion matrix was computed for analyzing detailed land use change patterns in the study area. The matrix is a useful tool which has been widely accepted in land use change analysis (Tang *et al*. 2005; Yu and Ng 2006; Thapa and Murayama 2006). Spatial metrics are developed based on information theory and fractal geometry. The metrics provide a means for quantifying spatial heterogeneity of individual patches, all patches in a class, and over the whole landscape as a collection of patches. Numerous metrics have been developed to quantify landscape structure and spatial heterogeneity based on landscape composition and configuration (McGarigal and Marks 1995; Herold *et al*. 2003, Torrens 2006). Important applications of spatial metrics include the detection of landscape pattern, biodiversity, and habitat fragmentation (Keitt *et al*, 1997), the description of changes in landscapes and the investigation of scale effects in describing landscape structures (O'Neill *et al*, 1996). In this study, we selected patch density (PD), largest patch index (LPI), edge density (ED), Euclidian nearest neighbor mean (ENN_MN), contagion index (CONTAG) and area weighted mean patch fractal dimension index (AWMPFD) to evaluate the configuration of the Kathmandu metropolitan landscape. The selection of the indices was based on their value in representing specific landscape characteristics as already explored in previous research on urban areas.

**3. Results and discussions**

The vegetation index (NDVI) has produced relative results based on electromagnetic spectrum recorded in the images. It enhances the chlorophyll properties of healthy vegetation significantly. The mean score of the index (Figure 3) was computed at ward level for Kathmandu metropolitan city to present the environmental changes in respect to the vegetation, agriculture and urban activities. The high score of the NDVI represents the majority of the vegetation covers. The index shows decreasing trend of vegetation during the last 15-years period which might be replaced by the urban built environment as the urban population density increased significantly. High speed of urbanization is observed after the political change in 1990. Therefore, the multi-spectral images (after 1989) were used to evaluate the land use/cover changes in the city. Figure 5 presents the land use/cover maps (a, b, c) and changing patterns of the land uses at quantitative level (d) for the years 1989, 1999 and 2005. The figures clearly show the small coverage of urban built-up area until 1989. In later years, shopping malls, residential house, road networks are being constructed in the city, which has consequently lead to expansion of urban built-up area over the cultivated and orchard lands which could be a breeder of many environmental consequences currently faced in the city.

Each pixel for the first year was compared to the same pixel location in the second year and similarly second year to the third year (Table 2). The most obvious changes were the conversion of orchard and cultivated land to urban [1675.3 ha, 1284.6 ha land was commissioned during the period of 1989-1999 and 1999-2005, respectively]. It seemed the areas classified as orchard near by the houses were converted to the urban structures. A mutual land conversion is observed between the orchard and cultivated land, for example, 1011 hectare of orchard land was transformed to cultivated land during the period of 1989 to 1999 then in later years, the cultivated land was used for orchard. About 111 hectare of natural vegetation area was also consumed for the urban construction during 1999. The lower rate of the natural vegetation replacement was found in later years. The water bodies also became duly dry which could be due to collapse of many aquatic functions, for instance, fish ponds in Balaju area. Some hectare of urban land was transformed to other land use/cover categories but with a very low proportion of change. However, additional 1629 hectare land has been urbanized during the last 15 years where the cultivated land has been lost by 1374 hectare.

A slight change is observed in PD, CONTAG and ENN_MN indices (Figure 6). It means the trend of land use change has remained somewhat same in the past fifteen years. However a slight change in aggregation of land use in city center may result the improvement in large patch index evidenced by showing increasing pattern of LPI and decreasing trend of mean nearest distance (ENN_MN) in later years. The LPI in 1989 was the lowest as compared to the later years. This may be due to newly developed shopping malls, residential areas, and wider roads in the city. Squatter settlement is being grown in the suburb area of the metropolitan which helps to fragment the large patch

Table 2: Land use conversion matrix of Kathmandu city between 1989 and 2005 (hectare)

| Class | 1989 In Total | 1 | 2 | 3 | 4 | 5 | 1999 In Total | 1 | 2 | 3 | 4 | 5 | 2005 In Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2639.8 | 1999.9 | 354.8 | 238.1 | 31.2 | 15.8 | 3809.7 | 2948.6 | 170.8 | 614.4 | 17.9 | 58.0 | 4268.9 |
| 2 | 3311.2 | 497.4 | 2069.4 | 713.2 | 14.4 | 16.8 | 3523.8 | 885.6 | 1292.1 | 1330.7 | 0.9 | 14.4 | 1933.3 |
| 3 | 3363.5 | 1177.9 | 1010.6 | 1111.7 | 24.8 | 38.4 | 2350.9 | 399.0 | 456.8 | 1364.2 | 2.2 | 128.7 | 3406.3 |
| 4 | 84.7 | 23.6 | 14.7 | 18.0 | 27.2 | 1.3 | 148.0 | 28.9 | 10.7 | 50.9 | 10.8 | 46.6 | 33.4 |
| 5 | 1116.8 | 1110.9 | 74.3 | 270.0 | 50.3 | 611.3 | 683.6 | 6.8 | 2.8 | 46.0 | 1.6 | 626.4 | 871.1 |

Note: 1 = Urban Built-up area, 2 = Cultivated Land, 3 = Orchard, 4 = Water and 5 = Natural Vegetation

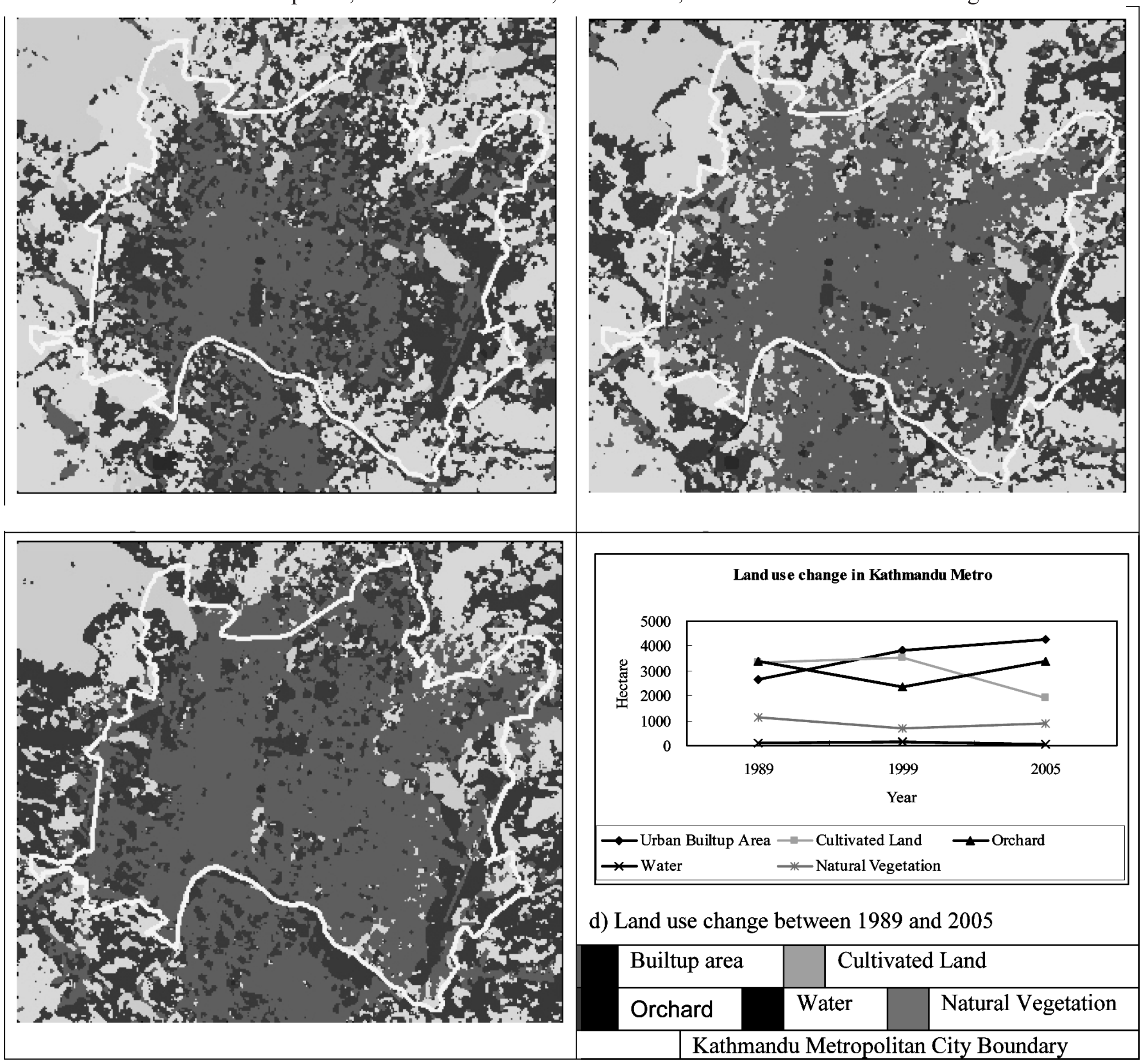


Figure 5: Land use/cover map of Kathmandu Metropolitan City during 1989-2005 (Area: 10Km X 10Km)

of agricultural land. Such activities have been observed more amplified after 1999 which was clearly measured by the AWMPFD index showing an increase in the year 2005. The ED measures the total length of the edge of the land use/cover patches that increases when land use fragmentation is heightened. Constructing more individual houses in agricultural spaces helps to enhance more fragmentation of the lands. The ED has increased in the metropolitan landscape but not as sharply as AWMPFD. The ED and AWMPFD may decline when the spaces between the individual patches are urbanized. In case of Kathmandu metropolitan landscape, still some agricultural lands are left to be urbanized in fringes. Constructing commercial and residential houses in the Kathmandu city are widely observed in the last fifteen years. Land brokers are very active to trade lands of urban fringe to individual land users which makes the large patches of agricultural lands fragmented in later years as evidenced of increasing in fractal dimension index (i.e. AWMPFD) and showing straight line of CONTAG index. However, the rate of urban fringes shaping to urban is escalating faster and faster. The urban expansion and subsequent landscape changes are governed by population growth, geographical and socio-economical factors and government policies. After restoration of democracy in 1990, there have been major changes in government policy, such as direct foreign investments, participation to the global trade, open market, opening of foreign labor market, etc.

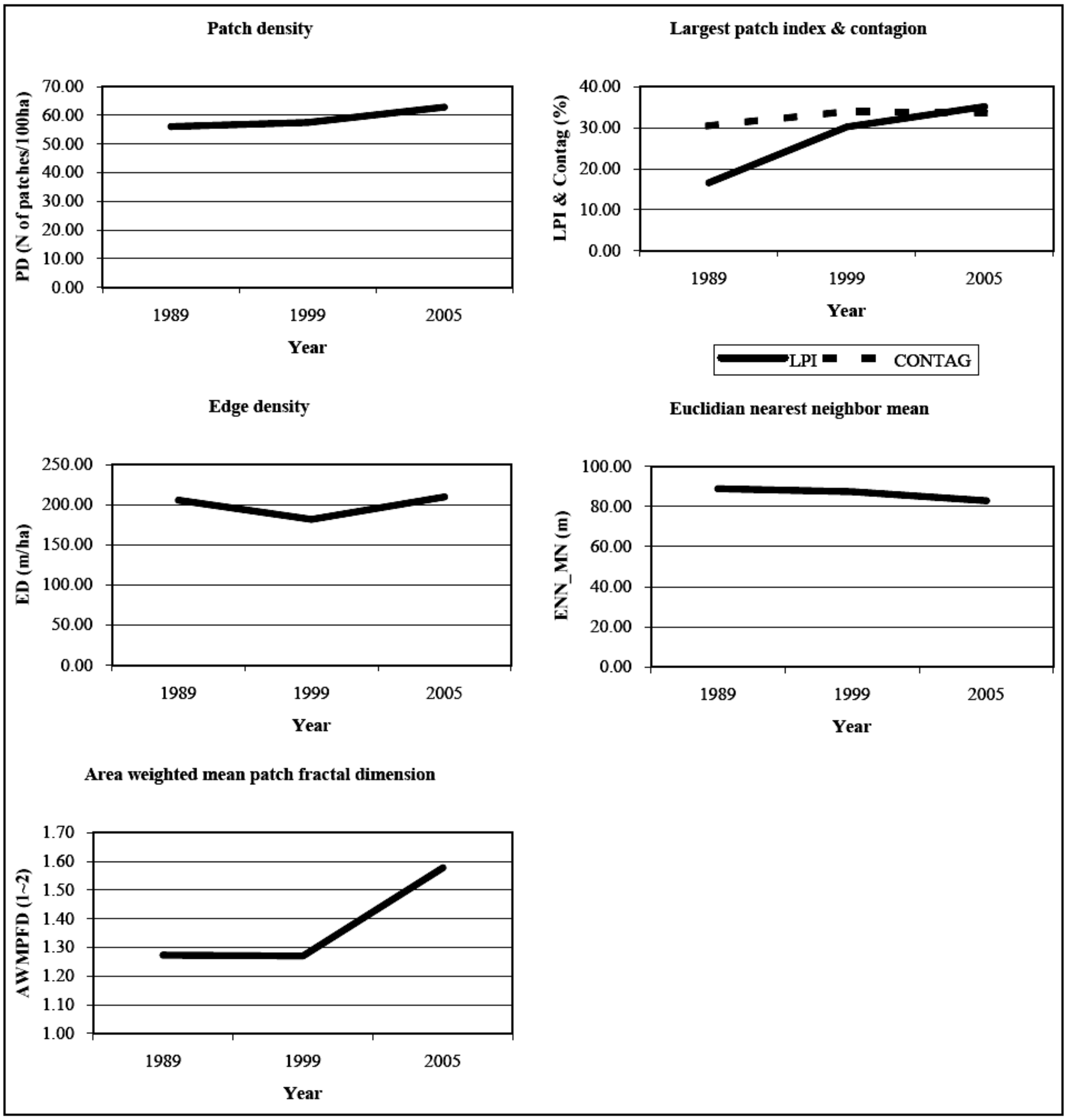


Figure 6: Landscape structure change in Kathamandu Metorpolitian Area ( 1989-2005)

## 4. Conclusions

Due to high spatial and spectral diversity of surface materials in urban area, the complexity of urban environment is one of the most challenging areas for remote sensing analysis. However, multi-temporal Landsat and IRS satellites imageries are found useful to detect the major land use/cover changes in the Nepalese capital city. The approaches allowed a separation of urban land use categories and description of its changes providing a robust quantitative measure of the spatial urban configuration. Rapid land cover change in the metropolitan area was observed in recent years. Agricultural land was significantly transformed to urban uses. The urban built environment was further stretched by additional 1629 hectare whereas 1374 hectare of cultivated land was diminished. The overall result showed rapid expansion of urban built environment and shrinkage of the cultivated land. The urban expansion trend was confined around the fringes of the urbanized periphery during the past fifteen years. Overall configuration of urban landscape seemed to be more complex and fragmented in later years. However, the aggregation of urban structures is being improved as urban builtup area expands but it may help to fragment other land use categories such as agriculture land and forest land. This extensive growth of urban area may create difficulties in the lack of adequate infrastructure and also various negative environmental impacts, for example, the most obvious changes faced in recent years are the loss of valuable agricultural lands and increased air and water pollution. Thus, the combined approach of remote sensing and spatial metrics is useful in improving thematic mapping of complex urban environment.

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