SPATIAL STRUCTURE OF LAND USE DYNAMICS IN KATHMANDU VALLEY

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ABSTRACT:

Quantifying landscape pattern and its change are essential for the monitoring and assessment of environmental consequences of urban area. This paper aims to analyze spatiotemporal patterns of urban landscape changes in Kathmandu Valley, Nepal by combining remote sensing, GIS and landscape metrics. Multi-temporal satellite images from high resolution (CORONA, SPIN and IKONOS) to moderate resolution (LANDSAT: MSS, TM) were processed to identify the temporal changes in landscape patterns. A hybrid approach with a series of steps was developed for mapping the land uses in the valley. Four land use maps were prepared from the images for the year 1967, 1978, 1991 and 2000. A set of landscape metrics was used to evaluate temporal dynamics of land uses from the maps at class and landscape levels. The results suggested that the urban/builtup area in the valley increased from 3% in 1967 to 13% in 2000 where the shrubs lands decreased from 20% to 9% and forest lands from 23% to 17%. This trend was more escalated in the 1980s. In the valley floor, the agricultural land was changed to urban lands whereas in rural areas much of the shrubs and forest lands were transformed into agricultural land. The number of patches in the study area was increased from 595 in 1967 to 776 in 1991 toping to 1090 in 2000. Although the landscape in urban rural fringe areas seems to be fragmented, except a slight increase in AWMPFD, decreasing trend of the ENNMN, CONTAG and SHDI shows the improving homogeneity in overall landscape.

1. INTRODUCTION

Investigating spatial structure of land use dynamics is a prerequisite to design sustainable resource management and effective land use planning. Such investigation has been traditionally limited due to labour intensive fieldwork that often lack to reveal spatial pattern of the landscape changes and environmental consequences occurred in a time frame. Significant technological advancement in data acquisition and data analysis techniques in recent years made easy to analyse spatiotemporal dynamics of landscape. Remote sensing data coupled with fieldwork information and geographic information systems (GIS) have been recognized as an effective tool in quantitatively measuring spatial pattern and its change at a relatively large geographic scale. Generally, two types (raster and vector) of method are observed so far for detecting the dynamics of spatial pattern. Pixel by pixel change can be detected in raster based method which is often performed after or before the classification of remotely sensed image. Alternatively, in vector based method, classified results are first converted to several vectors then derive various spatial indices to summarize the spatial patterns which can be compared to identify the dynamics of spatial pattern over different time periods.

The vector based change detection methods are more useful to capture inherent spatial structure of landscape pattern as compared to raster-based change detection methods (McGarigal et al., 2002; Tang et al., 2005). Different representations of space have led to a variety of landscape metrics to measure the dynamics of spatial structure and pattern. These metrics explain spatial relationship among the distribution of human induced land uses, resources, materials and species in relation to the sizes, shapes, numbers, kinds, and their configuration (Turner and Gardner, 1990). Indices of patch size and shape have been widely used to convey meaningful information on biophysically changed phenomena associated with patch fragmentation at a large scale. These configuration indices vary as a function of the shape of patches and usually correlate with the basic parameter of individual patch, such as the area, perimeter, or perimeter–area ratio. Some indices reflect spatial heterogeneity by quantifying the spatial structures and organization within the landscape. The dominance and contagion indices capture major features of spatial patterns whereas the proximity index quantifies the spatial context of patches in relation to their neighbours (Turner, 1989; Herold et al., 2003; Dietzel et al., 2005; Torrens, 2006; Yu and Ng, 2006). The patch-based and heterogeneity-based indices reflect two aspects of the same spatial pattern, and complement each other. However, the selection of either group of indices heavily relies on the emphasis in a specific research; often preferred to adopt both groups of indices when speculating on a spatial pattern because the patterns in a landscape possesses both homogeneous and heterogeneous attributes. This paper aims to analyze spatial structure of land use dynamics in Kathmandu Valley using remote sensing data and GIS techniques coupled with landscape metrics.

2. STUDY AREA

Kathmandu, a bowl shape valley ranks premier among the oldest human settlements in central Himalaya. The agriculture landscape transformed dramatically, since the 1960s, into an urban form stretching across the valley, driven by the transportation and migration. Kathmandu is the capital of

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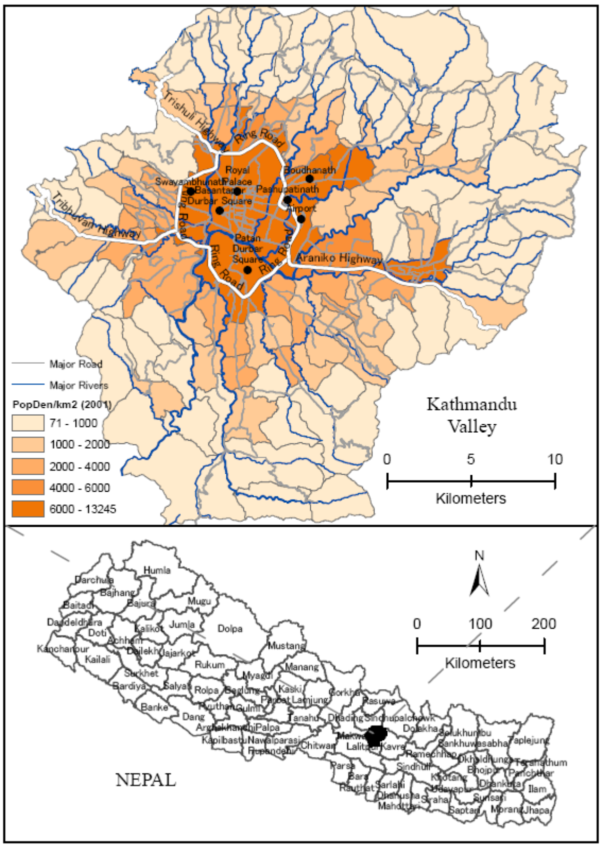

Figure 1. Study area – Kathmandu Valley, Nepal.
Data sources: ICIMOD/UNEP (2001)

Nepal and most populous metropolitan region in the country. The study area (Kathmandu valley) is defined based on watershed boundary delineated from 20-meter Digital Elevation Model (DEM) (Figure 1). The altitude in the study area ranges from 1100-2700 meters. Bagmati river system of which eight major tributaries drains the valley from north to south. The valley extends over 68,500 hectare of area and had a total population of 1.5 million in 2001 where 63% lived in urban area (Sharma, 2003).

Rapid urbanization is a dominant phenomenon in developing countries around the world which has been observed in Nepal from 1970s onward (Thapa et al., 2008). The urbanization rate in the valley (47%, 54% and 60% in the years 1981, 1991 and 2001, respectively) is very high as compared to the national rate (Sharma, 2003). Populations and socio-economic domain have changed the land use pattern in Kathmandu valley significantly. Business opportunities, commercial and social interests have increased the people movement to Kathmandu from other areas in Nepal. Urban development planning practices and interventions in the valley experienced more than five decades but high population influx, untraced urban development and daunting urban environment posed serious threat to the inhabitants (Karki, 2004; Pradhan and Perera, 2005; Haack and Rafter, 2006). Squatters, inadequate housing, poor urban services, heavy traffics, air and water pollutions are most visible problems in urban areas in the valley (IUCN, 1999; ICIMOD, 2007). At this particular juncture, quantifying landscape pattern and its changes are essential for the monitoring and assessment of environmental consequences of Kathmandu Valley.

3. METHODOLOGY

Urban land uses represent one of the most challenging areas for remote sensing analysis due to high spatial and spectral diversity of surface materials. In recent years, series of earth observation satellites are providing enormous data from high (0.6 m) to moderate (30 m) resolution for urban area mapping. Remote sensing data from these diverse resolutions have a specific potential for mapping the urban landscape (Jensen, 2005; Thapa and Murayama, 2007). Multi-temporal satellite images from high resolution (CORONA, SPIN and IKONOS) to moderate (LANDSAT: MSS, TM) were processed to identify the temporal changes in landscape patterns since the 1960s.

A hybrid scenario with series of steps for preparing land use maps was developed (Figure 2). All the images were geometrically corrected using vector layer of road data and radiometrically enhanced for the interpretation at first step. Vegetation, water and bare soils indices, and principal component analysis

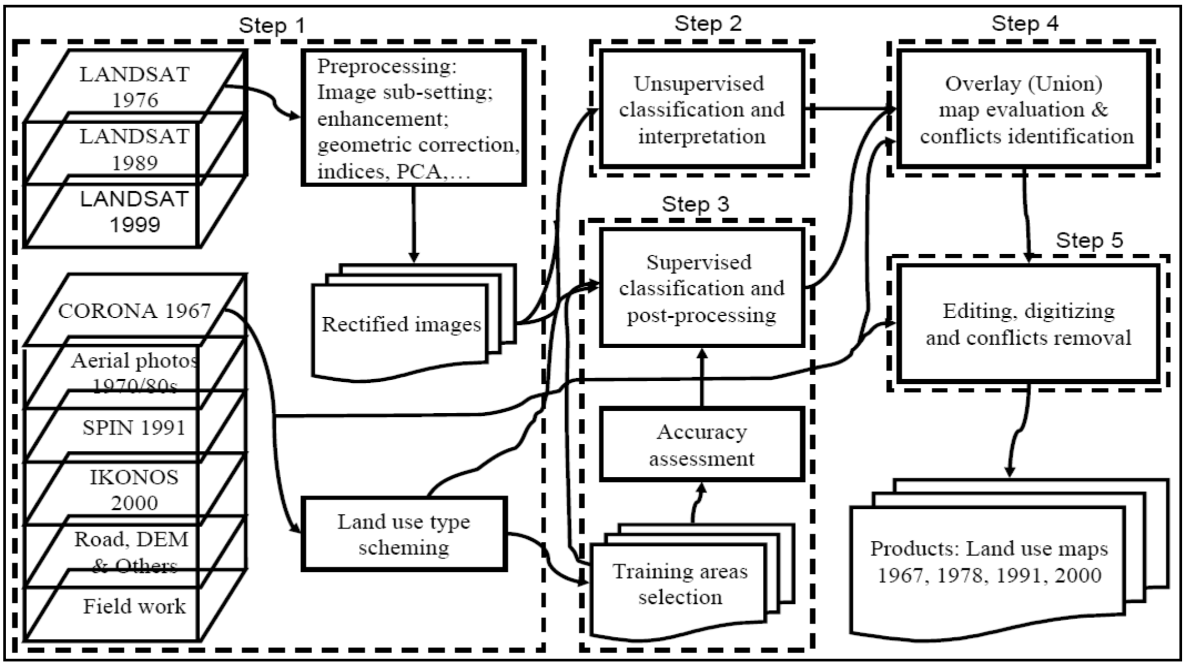

Figure 2. Hybrid scenario for land use map preparation from multi-temporal imageries.

were also conducted in this step. The high resolution images are only available to limited areas in the valley; therefore, most care was given to the MSS and TM images. Detail ground reference data in support of the classification and subsequent accuracy assessment were obtained from aerial photographs acquired in different time periods, high resolution satellite images, Google Earth, and a field work in 2007. These ground references were used in preparing signatures of classification training samples as well as evaluating the accuracy of the classified maps. Because of the mountain terrain in the study area, the topographical data was equally considered as an important source of information while preparing the land use maps. Visual interpretation of the images and field work information were integrated together while determining the land use types to be extracted. Six types of land uses: Urban/Builtup, Open space, Water, Agriculture, Shrubs and Forest were selected for the study (Table 1).

Land use type	Descriptions
Urban/Builtup	Road, industrial area, airport, administrative and institutional area, palaces, and compact settlements.
Open space	Park, playground and golf course
Water	River system, lakes and ponds
Agriculture	Paddy field, dry farmlands
Shrubs	Shrubs, grass and pastures
Forest	Forest

Table 1. Land use type and corresponding descriptions.

Unsupervised classification with ISODATA clustering technique was applied as second step to identify the groups of similar spectral pixels in the MSS and TM images. Clusters in each image were evaluated and labeled to the corresponding land use types. This method helped us to develop sufficient training samples for further classification of the images. Supervised classification method with maximum likelihood parameter was run for each image as the third step. Post-classification and accuracy assessment were also performed in this stage.

The land use maps generated from the second and third steps were overlaid and evaluated to identify the conflict areas between the land use categories in the fourth step. Confusion areas were detected mostly between the water area and shadows of mountain areas; bare lands, brick factories and construction sites; and golf course and shrubs lands. The confusion areas were further verified with DEM, slope and road data to determine appropriate land use type. Editing and digitizing as the fifth step was carried out to resolve all confusions and conflicts occurred in each maps. The maps derived from the fifth step considered as a final product to quantify and interpret the landscape changes for different time periods. The spatial resolution of the resultant maps was fixed to 30m although the data sources vary the resolution from 1m to 57m. Wickham et al. (1997) claimed that the landscape metrics does not alter the results dramatically by the change in pixel size up to 80 meters and existence of some misclassified pixels.

Landscape metrics provide a means of quantifying the spatial heterogeneity of patches, land use classes and whole landscape. More than hundreds metrics are available to interpret the landscape. However, many of them are highly correlated (McGarigal et al., 2002). In this study, we selected a set of landscape metrics: number of patch (NP), largest patch index (LPI), landscape shape index (LSI), Euclidian nearest neighbor distance mean (ENNMN), area weighted mean patch fractal dimension index (AWMPFD), contagion index (CONTAG) and Shannon's diversity index (SHDI) to evaluate spatiotemporal dynamics of landscape structure from the four maps at class and landscape levels (Table 2). All seven metrics were interpreted at landscape level analysis while first five metrics were analyzed at class level. These metrics can reflect their conceptual basis and describe the composition and configuration of landscape pattern changes in Kathmandu Valley. Metrics at the class level are helpful for the understanding of landscape development and while at landscape level metrics provide relatively general information on the assessment in the valley. The selection of the metrics was based on their value in representing specific landscape characteristics as already explored in previous researches (Herold et al., 2003; Dietzel et al., 2005; Torrens, 2006). Detail descriptions of the selected metrics and their measurement units can be found in McGarigal et al. (2002). Erdas Imagine 9.1, ArcGIS 9.2 and Fragstats 3.3 software were used for processing, and analyzing the data.

Metrics	Description
NP	Number of patches in the land uses type or landscape in the study area.
LPI	Largest patch index represents the percentage of the study area comprised by the largest patch.
LSI	Landscape shape index provides a simple measure of class aggregation or disaggregation. It also provides a standardized measure of total edge or edge density that adjusts for the size of the landscape.
ENNMN	Euclidian mean nearest neighbour distance measure the distance mean value of all patches of a land use to the nearest neighbour patch of the land use based on shortest edge-to-edge distance from cell centre to cell centre.
AWMPFD	It describes the complexity and fragmentation of a patch by a perimeter-area ratio. Lower values indicate compact form of a patch. If the patches are more complex and fragmented, the perimeter increases representing higher values.
CONTAG	Contagion index describes the fragmentation of a landscape by the random and conditional probabilities that a pixel of patch class is adjacent to another patch class. It measures to what extent landscapes are aggregated or clumped.
SHDI	Shannon's diversity index quantifies the diversity of the landscape based on two components: the number of different patch types and the proportional area distribution among patch types.

Table 2. Descriptions of landscape metrics used in this study.

4. RESULTS AND DISCUSSION

As a result of hybrid scenario (Figure 2), total four maps were derived for the year 1967, 1978, 1991 and 2000 (Figure 3). The urban/builtup area in the valley increased from 3% in 1967 to 13% in 2000 where the shrubs lands decreased from 20% to

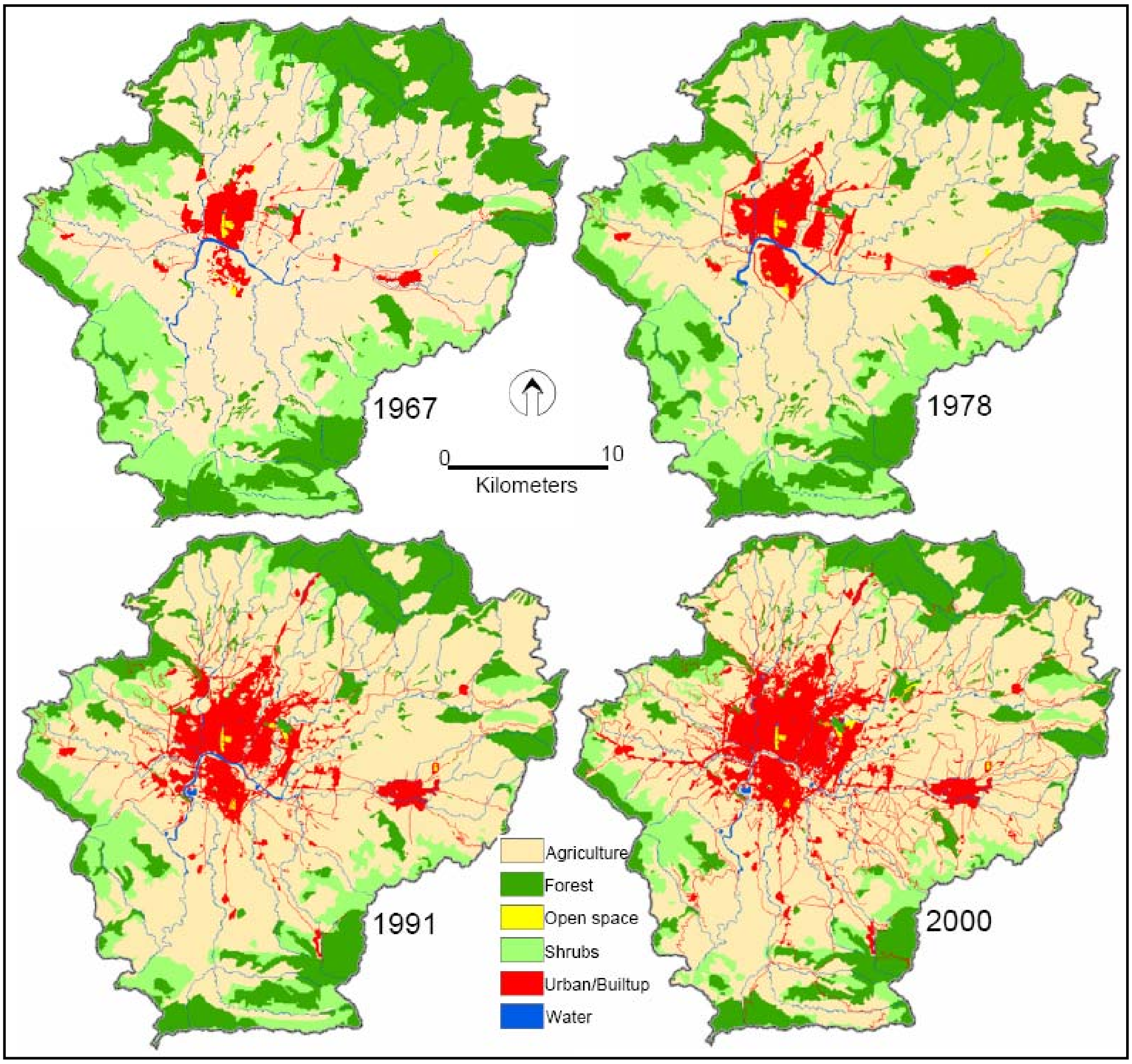

Figure 3. Land use maps of Kathmandu Valley, 1967-2000.

9% and forest lands from 23% to 17% in the same periods (Table 3). Urban/builtup area expansion over agriculture, shrubs and forest lands were more escalated in the 1970s. Construction of the Tribhuvan Highway in the 1950s, linking to India and the Araniko Highway to China, in the 1960s widened commercialization and external influences in Kathmandu. These roads also enabled people from outer regions to migrate into the valley. The development of a ring road around Kathmandu and Lalitpur municipalities in the mid-1970s significantly accelerated the urbanization process in the valley floor and rural periphery (Thapa et al., 2008).

Land use type	1967	1978	1991	2000
Urban/Builtup	2.79	4.76	8.66	12.60
Open space	0.15	0.14	0.14	0.22
Water	1.95	2.02	1.96	1.85
Agriculture	52.73	51.56	59.13	60.16
Shrubs	19.10	17.71	11.66	8.59
Forest	23.29	23.81	18.44	16.57

Table 3. Land use statistics in percentage, 1967-2000.

Agriculture land always occupied more than half of the spaces in the valley remained still dominant. The statistics of agricultural lands seems somewhat stable during 1967-1978 which was escalated in 1991. The locations of agriculture lands have changed significantly in urban rural fringe areas because of urbanization process. After 1978, much of the shrubs and forest lands in rural areas have been used for agriculture purposes. Sprawling trend has been found mostly in the urban/builtup and agricultural land uses. In the valley floor, the agricultural land was changed to urban/builtup lands whereas in rural areas much of the shrubs and forest lands were transformed to agricultural uses. The water area increased a bit in 1978 but decreasing trend observed afterward. Interestingly, the open space was slightly increased in 2000 it may be due to adding of new gulf courses, expansion of Gokarna Gulf Course at Rajnikunja and construction of Army Gulf Courses at Tribhuvan International Airport for example.

From the maps, we could observe multiple-nuclei pattern of urban development in Kathmandu Valley. The urban expansion trend is mostly confined in the existing built-up periphery. Table 4 shows a comparison of metrics at landscape level for the year 1967, 1978, 1991 and 2000. The numbers of patch in the study area were increased from 595 in 1967 to 776 in 1991 showing further rapid increase in 2000. However, aggregation of land use patches and becoming bigger patches also were in progress in later years as evident by the increasing trend of dominance index (LPI) and patch aggregation index (LSI) except a decrease of LPI in 1978. It may be due to compactness of urban/builtup in the valley floor and agriculture sprawl into shrubs and forest lands forming bigger patches in the landscape in the 1980s and 1990s. This is further justified by the ENNMN where the distance to the nearest neighbouring patches of the same land use type had decreasing trend.

The AWMPFD increased slightly reporting the shape of the patches is becoming a bit complex in later years. It may be due to road network expansion towards the rural neighbourhood in the 1980s and 1990s. A slight decrease in CONTAG is observed in 2000 as compared to the year 1967. The contagion metric is a general measure of landscape heterogeneity often getting lower when the urban/rural configuration is more dispersed and fragmented. It does not necessary mean high fragmentation trend existed in the study area because the ratio of the contagion change is smaller than the change of LPI, LSI and ENNMN. A slight decreasing trend in SHDI shows the improving homogeneity by clumping trend of patches for each class in the landscape. Constructing commercial complexes, planned residential housings and roads in the city and beyond, and agriculture expansion over the shrubs and forest lands in the rural areas might reduce landscape heterogeneity in some extent in the recent decade.

Metrics	1967	1978	1991	2000
NP	595.00	607.00	776.00	1090.00
LPI	51.99	48.23	56.17	57.60
LSI	21.64	22.64	29.10	37.93
ENNMN	247.61	246.47	191.62	157.57
AWMPFD	1.26	1.25	1.28	1.32
CONTAG	61.02	59.63	59.65	58.06
SHDI	1.18	1.22	1.17	1.16

Table 4. Metrics at landscape level, 1967-2000.

The Figure 4 shows the comparison of metrics for the year 1967, 1978, 1991 and 2000 in the study area at class level. The most significant change is observed in NP of all land use classes, except fairly stable in open space. The increase of NP is also a result of urbanization process in the valley. Population influxes in the valley floor raised new housing demands subsequently creating new builtup area in the city fringes that segmented the existing agriculture lands in later years. Interestingly, the NP of water also achieved continuous growth. It may be due to growing human encroachment in river banks and developmental activities such as bridges or roads.

Agriculture always has higher LPI score as compared to other land uses. However, a gradual improvement in LPI has been observed in urban/builtup land use type. It is mainly due to road expansion and refilling of the housing in city core and beyond in the following years. Decreasing trend of LPI is observed in both forest and shrubs land uses, an effect of urbanization and agriculture process. LSI of water remained consistently all time high in whole study period which indicated constant desegregation process in water. LSI is increased sharply since 1978 in urban/builtup land use type that also helped to increase the LSI of agriculture land use. The construction of ring road in 1970s enhanced the urban growth eventually adding new houses and complexes in its closer proximities. This process significantly helped to segment existing agriculture land use causing an increase of the LSI. However, the forest, shrubs and open space showed slower change of LSI remaining lower in the whole study period. The ENNMN is decreased rapidly in open space with steady decline in 1991 whereas a bit slow but gradual decreasing trend is observed at urban/builtup, agriculture and shrubs lands. This shows that the distance between the patches of each land use type getting closer. The AWMPFD always remained higher in water area as compared to other land use type indicating constant complexity of rivers shape. It is somewhat natural. The agriculture land still has simple shape as compared to other land uses although the trend of shape complexity is a bit increasing. However the urban/builtup area reported nominal decreasing trend shaping the urban form into more normal and regular as before.

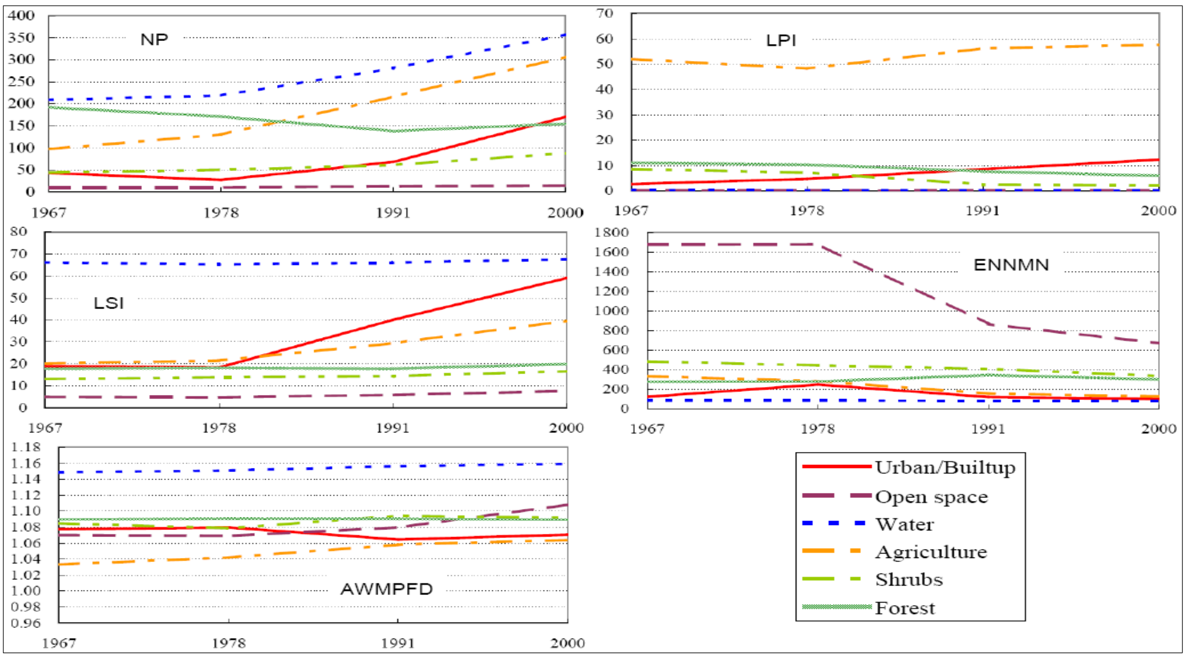

Figure 4. Metrics at class level, 1967-2000.

5. CONCLUSIONS

In this study, we investigated the spatial structure of land use dynamics quantitatively in Kathmandu Valley. We found that the landscapes in Kathmandu valley experienced rapid changes since the 1970s due to urbanization process. This predominantly rural agriculture landscape gradually changed to urban landscape with increasing human settlement in the 1970s and 1980s. Urban/built-up space can be seen to have spread outward from city core and the main road. Lands abutting on the ring road were by 2000 almost all occupied by housing units. The valley with its complex mountainous terrain accommodated one and half million people with 5.22% annual growth of urban population. Due to population pressure, most of the agriculture lands in the valley floor transformed into urban/builtup surface whereas shrubs and forest landscape in rural areas mostly changed into agricultural uses. Such urbanization process and new individual development created new patches in the landscapes that eventually helped to fragment and create more heterogeneity in the landscape. It is mostly observed in city fringes and near by villages in the valley. However, the Shannon's diversity index reveals that the patch diversity is in decreasing order. It may be due to land compactness by clumping similar land uses in city core area. The city core area seems to be in progress towards homogeneity with the new developments of builtup surface.

Long term monitoring with high resolution historical archives of CORONA satellite provided a deep insight to oversee the urban development process in Kathmandu Valley. Although the hybrid method we applied to prepare the land use maps is time consuming and requires dedicated hands for amendments, the results are prominent and able to deliver very good spatial information that could be used for many aspects of spatiotemporal analysis and environmental assessment. The study presented a consolidated approach of remote sensing, GIS and landscape metrics that allows a separation of urban land use categories and descriptions of its temporal changes. It provided robust quantitative measures of land use dynamics using abandoned sources of remotely sensed data for three and half decades which will convey an important message to the urban planners and researchers working in Nepal and beyond.

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