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Land use dynamics and landscape change pattern in a mountain watershed in Nepal

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Abstract

This study analyzed spatial and temporal changes in land use/land cover in a typical mountain watershed covering an area of 153 km^2 in central Nepal by comparing classified satellite images from 1976, 1989 and 2000 coupled by GIS analyses and also investigated changes in the shape of land use patches over the period. The results show an increase in broadleaf forest, conifer forest and winter-cropped lowland agricultural area and decrease in area under shrublands, grasslands and upland agriculture in between 1976 and 2000, although shrublands increased during the second half (1989–2000) of the study period. The number of forest patches decreased substantially in between 1976 and 2000 suggesting merger of patches in the latter periods due to forest regeneration and/or plantation establishment on lands previously separating two or more forest patches. A shape complexity index (SCI) used to study patchiness of land use indicated improved forest habitat in the watershed but increased mean deviation between actual and optimal SCI of forest polygons indicated higher edge effects at the forest patch level during the latter periods. One of the significant changes within non-forestry land use was increased fragmentation of lowland agricultural areas due to expansion of settlements and infrastructural development in the lowlands.

Keywords: Land use change; Forest policy; Landscape pattern; Nepal; Himalaya

1. Introduction

Watershed management has become an increasingly important issue in many countries including Nepal as government agencies and non-governmental groups struggle to find appropriate management approaches for improving productions from natural resource systems. Principles, concepts and approaches related to watershed management have experienced a vast change during the past few years but yet there is no universal methodology for achieving effective watershed management (Naiman et al., 1997; Bhatta et al., 1999). It is generally agreed that sustainable development and management of upland natural resources for the welfare of local populations should be the key objective of watershed management. This objective includes sustainable utilization and conservation of forest resources at community or watershed level as one of its important components (Sharma and Krosschell, 1996). Effective management of forest and other natural resources in turn requires an understanding of the variability in time and space of these resources and the role of human cultures and institutions in bringing those variations (Naiman et al., 1997).

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In addition to area coverage, the shape of land use patches is an important characteristic for evaluating the processes and effects of land use change at landscape and watershed level. The concept is related to edge effects (physical and biotic phenomena) associated with increase in patch complexity due to habitat fragmentation and is emerging as an important field in the management and conservation of fragmented ecosystems at the local as well as regional level (Laurance and Bierregaard, 1997). Patchiness in forested area is of special importance because it serves as an important indicator of natural habitat fragmentation (Kammerbauer and Ardon, 1999). This is particularly important in the hills of Nepal where forest fragmentation has been a common phenomenon in the past few decades and most of the surviving forests consist systems of small patches, which are increasingly coming under community-based forest management in recent years (Gautam and Webb, 2001).

There are various methods that can be used in the collection, analysis and presentation of resource data but the use of remote sensing and geographic information system (RS/GIS) technologies can greatly facilitate the process. Repeated satellite images and/or aerial photographs are useful for both visual assessment of natural resources dynamics occurring at a particular time and space as well as quantitative evaluation of land use/land cover changes over time (Tekle and Hedlund, 2000). Analysis and presentation of such data, on the other hand, can be greatly facilitated through the use of GIS technology (ESCAP, 1997). A combined use of RS/GIS technology, therefore, can be invaluable to address a wide variety of resource management problems including land use and landscape changes.

This study is part of a broader research designed to assess the role of community-based forestry institutions in determining the status of forests in the study area. Within this broad framework, the objectives of this study were: (i) to detect and document changes in major land use in general and forests in particular in a representative mountain watershed in central Nepal in between 1976 and 2000, and (ii) to analyze patterns of changes in the landscape of the study area during the period, with special focus on forest fragmentation. The study used RS/GIS with substantial input from the field to achieve the stated objectives.

2. Study area

The site of this study, Upper Roshi Watershed (85.39–85.57°E, 27.54–27.70°N), is situated in the western part of Kabhrepalanchok district in the Middle Hills of Nepal (Fig. 1). The watershed covers an area of 15,335 ha. The altitude varies between 1420 and 2820 m above sea level. Climate is monsoonal with a dry season normally spanning from November to May and rainy season from June to October. Warm-temperate humid temperature and moisture regime prevails in most part of the watershed except at higher elevation (above 2000 m) where the climate is cool-temperate type. Microclimate varies considerably with elevation and aspect. The south-facing slopes and lower slopes are generally hotter and drier and the north-facing slopes and upper slopes

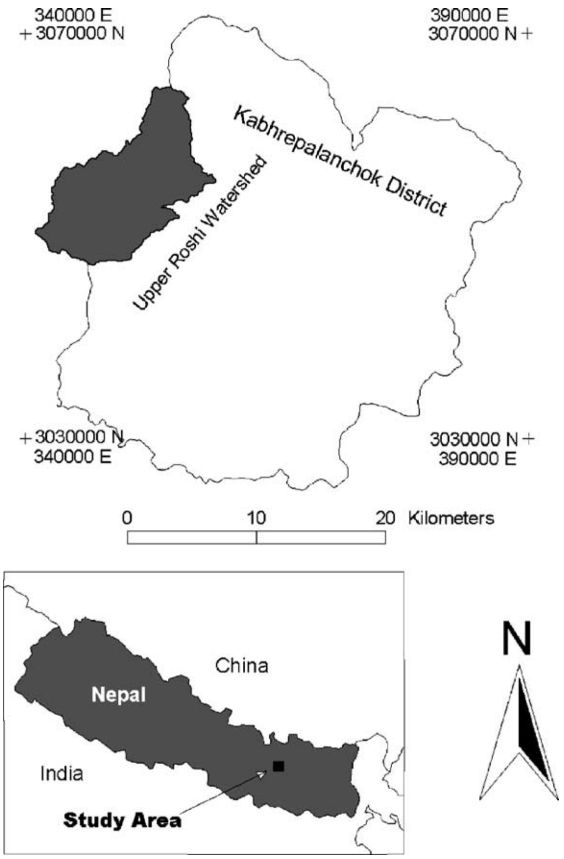

Fig. 1. Location of the Upper Roshi Watershed within Kabhrepalanchok District, Nepal.

are cooler and moister. Three rivers namely Punyamata, Bebar and Roshi along with their numerous tributaries drain the area, which latter converge at the southeastern corner of the watershed into Roshi River.

The watershed can be divided into fertile, relatively flat valleys along the rivers and surrounding uplands with medium to steep slopes. Agricultural lands in the valleys are under intensive management with multiple cropping systems and are mostly irrigated. Paddy, potato, wheat and vegetables are major crops cultivated in the valley. Rain-fed agriculture, with or without outward facing terraces, is practiced on rest of the agricultural lands, many of which are not suitable for crop production without strong soil and water conservation measures because of their high erodability and low productivity (ICIMOD, 1994).

Forests are mostly confined to higher slopes and consist of both natural mixed broadleaf forests as well as pine plantations. A single large block natural forest in the *Mahabharat* Mountains in the southern region represents around 50% of the total forest area of the watershed. The rest of the forests are generally fragmented and scattered over the agricultural landscape. Many of these lower elevation forests have been handed over to the local forest user groups (FUG) under the community forestry program of the government. By the end of 2000, a total of 2135 ha public forestland in the watershed had been handed over to 63 FUGs consisting of 6808 households and many other user groups were awaiting formal registration (DFO, 2001). The Australian Agency for International Development has been supporting the implementation of community forestry program through successive bilateral projects since the inception of the program in 1978. Leasehold forestry is another form of community-based forest management system implemented by the government since 1992 with initial supports from Food and Agriculture Organization of the United Nations and International Fund for Agricultural Development. A total of 128 households living below poverty line were managing 110 ha of degraded forestland in the watershed by the end of 2000 under leasehold forestry program (Singh and Shrestha, 2000).

The development of the watershed is not uniform. The Punyamata River valley stretching from Nala in the north to Panauti in south is one of the most fertile and economically important areas in Kabhrepalanchok district, where most of the commercial activities are concentrated. The local economy and employment opportunities of these semi-urban areas differ from rural areas. Semi-urban centers are connected to Kathmandu valley by all-weather roads, have alternative sources of energy, and most of the households are not dependent on agriculture. Rural people in the surrounding areas are primarily dependent on arable agriculture and livestock raising for their livelihood. This high variability in the ecological and economic conditions makes the watershed an appropriate site to study land use dynamics and factors associated with it.

3. Data sources

The main data used in the research included a Landsat Multi Spectral Scanner satellite image (hereafter MSS image) from 1976, a Landsat Thematic Mapper satellite image from 1989 (hereafter TM image) and an Indian Remote Sensing satellite image from 2000 (IRS-1C, LISS-III; hereafter IRS image). A brief description of the satellite images used is given in Table 1. Eight black-and-white aerial photographs of 1:50,000 scale from 1978 and 1992 each, were used for “ground-truth” information required for classification and accuracy estimation of classified MSS and TM images, respectively. Four photographs from each of the periods were used as training material for land use/land cover (hereafter land use) classification and the rest four were used for testing the accuracy of classification results. Four topographic maps of

Table 1
Satellite images used in land use classification

Satellite type	Sensor	Number of bands	Pixel spacing (m)	Observation date
Landsat 2	MSS	4	57 × 57	20 December 1976
Landsat 4	TM	7	28.5 × 28.5	24 January 1989
IRS-1C	LISS-III	4	23.5 × 23.5	7 March 2000

1:25,000 scales published by the Survey Department, His Majesty's Government of Nepal (HMGN) and digital topographic data with contour interval of 20 m produced by the same agency were also used.

The MSS and TM images were provided by the Center for the Study of Institutions, Population and Environmental Change (CIPEC) at Indiana University, USA. IRS image was acquired directly from Indian Remote Sensing Agency, Hyderabad, India. Aerial photographs and digital topographic data were acquired from the Survey Department, His Majesty's Government of Nepal and the topographic maps were purchased from a bookstore in Kathmandu.

The ground-truth information required for the classification and accuracy assessment of IRS image was collected from the field during January–April, 2001 using a training sample protocol designed by CIPEC (1998) with some modifications. In addition, a self-designed format was used to collect forest level information on forest types, condition and history of land use provided by the local people and direct observation in the field.

4. Methods

4.1. Geometric correction

Subsets of satellite images and aerial photographs were rectified first for their inherent geometric errors using digital topographic maps in Modified Universal Transverse Mercator coordinate system obtained as above as the reference material. IRS image was first registered to the digital topographic maps using distinctive features such as road intersections and stream confluences that are also clearly visible in the image. A first-degree rotation scaling and translation transformation function and the nearest neighbor resampling method were applied. This resampling method uses the nearest pixel without any interpolation to create the warped image (Richards, 1994). A total of 20 points were used for registration of IRS image subset with the rectification error of 0.1083 pixels.

The MSS and TM images were registered to the already registered IRS image through image-to-image registration technique with rectification errors of 0.1612 and 0.0882 pixels, respectively. A very high level of accuracy in georeferencing of the images was possible because of the use of digital source as the reference data that allowed zooming to the nearest possible point location.

The eight aerial photographs used in the research were scanned, saved in tiff format and registered to the digital topographic maps in the same manner as the IRS image. This allowed direct comparison of features between the images and aerial photographs during the selection of sample plots for use in image classification and accuracy assessment of classified images.

4.2. Classification of satellite images

The possibility of discriminating various land features by digital analysis of satellite data depends upon various factors and methods used in classification. We used supervised maximum likelihood classification method for the classification of all the images. Maximum likelihood classifier assigns a pixel to a particular class based upon the covariance information and a substantially superior performance is expected from this method compared to other approaches (Richards, 1994).

Training areas corresponding to each classification item (hereafter, land use class), in case of IRS image, were chosen from among the training samples collected from the field and in case of MSS and TM images they were generated from the interpretation of aerial photographs of the study area from 1978 and 1992, respectively. Although the dates of the aerial photographs used as reference information in classification do not exactly match with the dates of the satellite images, they were used with the assumption that land use in the watershed, particularly forestry land use, was not substantially changed between the time of aerial photography and satellite observation dates. Moreover, this was the best feasible option that could be used in this research.

For producing land use maps for 1976, 1989 and 2000 and to investigate changes that occurred between these periods, the following six land use classes were considered in image classification: broadleaf forest, conifer forest, shrublands, grasslands, lowland agriculture, and upland agriculture and other. Choice of these land use classes was guided by: (i) the objective of the research, (ii) expected certain degree of accuracy in image classification, and (iii) the easiness of identifying classes on the aerial photographs. A brief

Table 2
Land use classes considered in image classification and changes detection

Land use class	General description
Broadleaf forest	Forest areas with estimated 75% or more of the existing crown covered by broadleaf trees. The predominant species are: *Castanopsis* spp. and *Schima wallichii* in most part and *Quercus* spp. in higher elevations.
Conifer forest	Forest areas with estimated 75% or more of the existing crown covered by planted or naturally growing conifer trees. *Pinus roxburghii*, *P. patula* and *P. wallichiana* are common species.
Shrublands	Land covered by shrubs, bushes and young broadleaf regeneration. Degraded forest areas with estimated <10% tree crown cover are also included.
Grasslands	Non-cultivated areas dominated by herbal vegetation.
Lowland agriculture	Irrigated, level-terraced agricultural lands in river valleys, used for multiple cropping including winter crops. Wheat and potato are two major winter crops cultivated in these lands after the harvest of paddy rice in November–December.
Upland agriculture and other	Non-irrigated agricultural lands with or without slopping terraces, barren lands, settlements, roads, construction sites and other built-up areas.

description of each of the land use classes is given in Table 2.

Among all the land use classes, “upland agriculture and other” (hereafter, upland agriculture) is the most complex class. In fact, it includes all other combinations of land uses, which are not included in the rest five classes. During winter, uplands in the study area, like most of the Middle Hills, are mostly barren and have spectral values similar to those of barren lands such as non-vegetative hills and riverbeds (Tokola et al., 2001). Moreover, during the time the satellite imageries were taken (particularly IRS image) many upland terraces had exposed soil due to fresh plowing by farmers as a preparation for the next summer crop. This condition of the cultivated uplands made it impossible to distinguish them from rough roads, new construction sites and other built-up areas. This justifies combining settlements, barren lands and built-up areas (estimated around 7% of this class) with upland agricultural lands in this study, which may not be acceptable at any other time of the year.

Presence of shadow in parts of all the images and cloud in parts of the TM image were other major problems encountered during image classification. Both of these areas were classified as separate classes and latter combined to the respective classes with the help of “ground-truth” information.

4.3. Post classification

After selectively combining classes, classified images were sieved, clumped and filtered before producing final output. Sieving removes isolated classified pixels using blob grouping, while clumping helps maintain spatial coherency by removing unclassified black pixels (speckle or holes) in classified images (Richards, 1994). Finally a 3×3 median filter was applied to smoothen the classified images. All activities related to image processing were performed in Environment for Visualizing Images (ENVI) Version 3.2 (Research Systems Inc., CO, USA).

Classified images were then exported to Arc View GIS Version 3.1 (ESRI, Redlands, USA) from ENVI and rest of the analyses was performed in GIS environments. The images were first converted to grid in Arc View and then to shape format. The polygon themes so generated, were exported to Arc Info GIS Version 3.5.1 (ESRI, Redlands, USA) and polygons of <0.5 ha in size were “eliminated” in Arc Info. This elimination was necessary to minimize the effects of classification errors arising from resolution differences among the three satellite images while at the same time without significantly altering the area under each land use class. The resultant polygon themes were used in further analyses.

4.4. Detection of land use changes

The land use polygon themes for 1976, 1989 and 2000, obtained from the digital classification of satellite data and subsequent GIS analyses using the method described above were overlaid two at a time in Arc View GIS and the area converted from each of the classes to any of the other classes was computed.

4.5. Study of landscape change pattern

The number of land use plots under each land use class, their areas and perimeters in 1976, 1989, and 2000 were determined using information contained in the land use maps developed for respective periods. To study patchiness and degree of irregularity of different land use plots, a shape complexity index (SCI; Kammerbauer and Ardon, 1999) was then calculated by dividing the average perimeter of land use plots by the average area. Higher SCI indicated more irregular patch forms.

Change in the complexity of forest patches was further investigated at polygon level by comparing SCI of existing forest polygons with the SCI of "optimum" polygon shape (i.e. circle) of the same area. The polygon level investigation was necessary to avoid wrong interpretation of patchiness and complexity of forest patches arising from the assumption of normal distribution of polygon sizes across space (e.g. Kammerbauer and Ardon, 1999), which is not always true.

5. Results and discussion

5.1. Changes in land use

The land use maps for 1976, 1989, and 2000 are presented in Fig. 2 and the area under the six land use classes during the three periods is shown in Table 3. Results show that broadleaf forest and conifer forest area increased while upland agriculture and grasslands declined continuously over the study period. Shrublands decreased during the first (1976–1989) period but increased during the second (1989–2000) period, while lowland agricultural area was expanded during the first period but the trend was reversed during the second period. A detail of losses and gains among the six land use classes over the study period is included in Table 4.

Among the major land use groups, around 81% of agriculture and 77% of the forest area in 1976 remained unchanged until 2000. Agricultural lands shrunk by about 3% of 1976 area in between 1976 and 2000. Forest lost 22.5% of its 1976 area to other classes and gained 37.4% from other classes resulting a net 794 ha. increase (5.2% of the total watershed area) in forest area during the study period. The very high losses from shrublands and grasslands were only partially compensated by gains from other classes resulting high net losses to both of these land uses (Table 5).

Although there was a net increase in forest area, a substantial proportion of conifer forests lost to agriculture during both the first and second periods, which might have been resulted due to failure of pine plantations and re-conversion of these lands to barren state. However, it is also possible that some young pine plantation areas were misclassified as upland agriculture in image classification due to exposed soil condition of these lands at the time of satellite observation. Plantations in the Middle Hills of Nepal are generally weeded after the rainy season in October–November with substantial soil works around planted seedlings. The exposed soil after weeding might not have been recovered by vegetation during the time of satellite observation and as a result there is a possibility that some of the plantation areas were misclassified as upland agriculture (which includes exposed soil).

The observed trends of increasing forest and decreasing agricultural areas in the watershed could be

Table 3
Comparison of areas under different land uses during the three periods

Land use class	1976		1989		2000		Percent change in land use		
	Area (ha)	%	Area (ha)	%	Area (ha)	%	1976–1989	1989–2000	1976–2000
Broadleaf forest	4771.4	31.1	4967.1	32.4	5098.4	33.2	+4.1	+2.6	+6.8
Conifer forest	567.9	3.7	819.0	5.3	1034.9	6.7	+44.2	+26.4	+82.2
Shrublands	1318.9	8.6	711.3	4.6	1031.4	6.7	−46.1	+45.0	−21.8
Grasslands	471.6	3.1	236.5	1.5	197.1	1.3	−49.8	−16.7	−58.2
Lowland agriculture	1578.0	10.3	2023.3	13.2	1834.0	11.9	+28.2	−9.4	+16.2
Upland agriculture and other	6627.4	43.2	6578.0	42.9	6139.4	40.0	−0.7	−6.7	−7.4

explained by the following three main reasons. First, a substantial proportion of the agricultural lands in the study area are in inclinations above 13% where slope stability and soil erosion is of critical concern (ICIMOD, 1993). Those steep agricultural fields suffer from rapid soil erosion and nutrient depletion, which forces farmers to abandon their agricultural plots after a few seasons of cultivation. Some earlier studies in

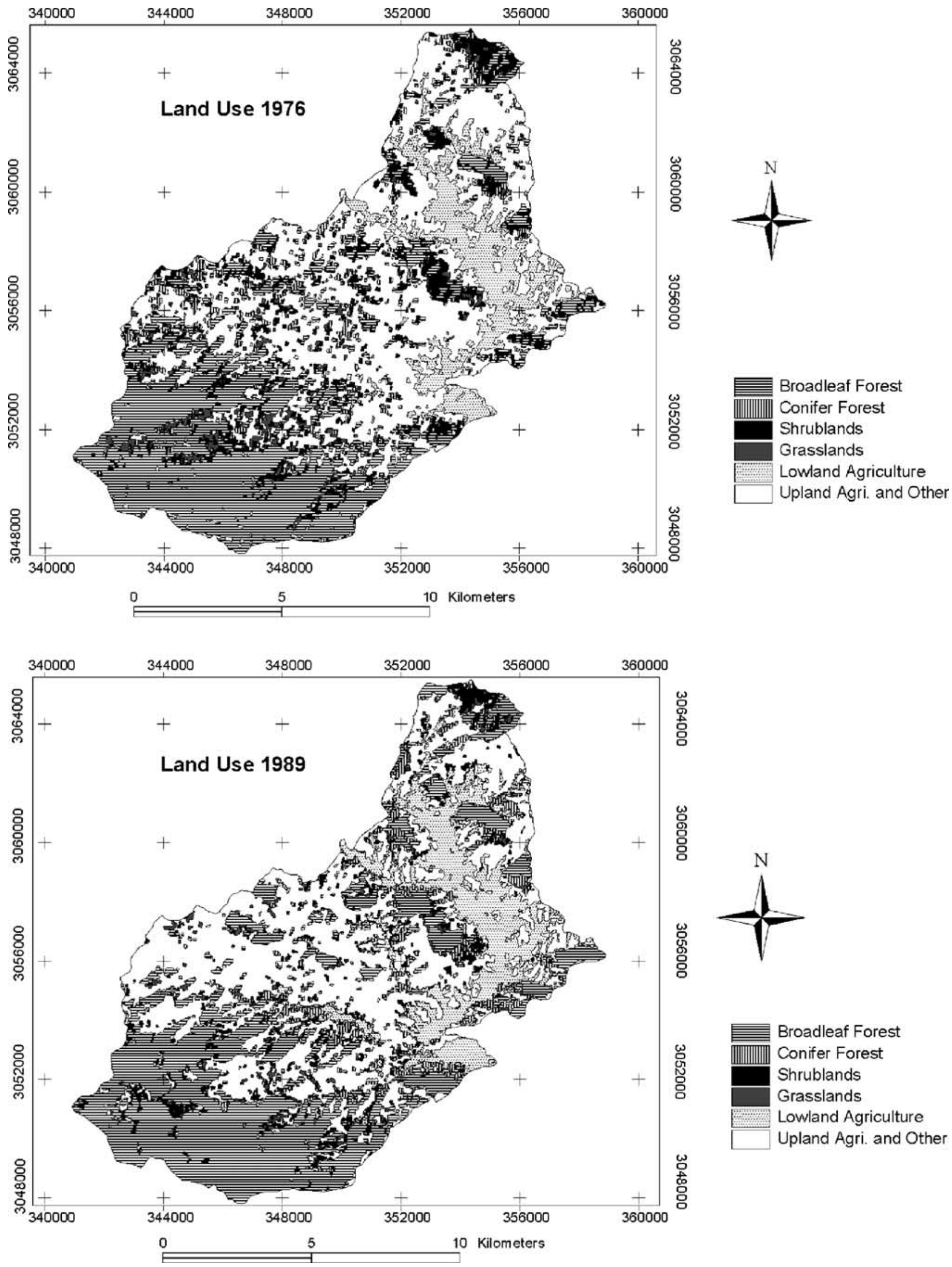

Fig. 2. Land use in Upper Roshi Watershed in 1976 (top), 1989 (middle) and 2000 (bottom).

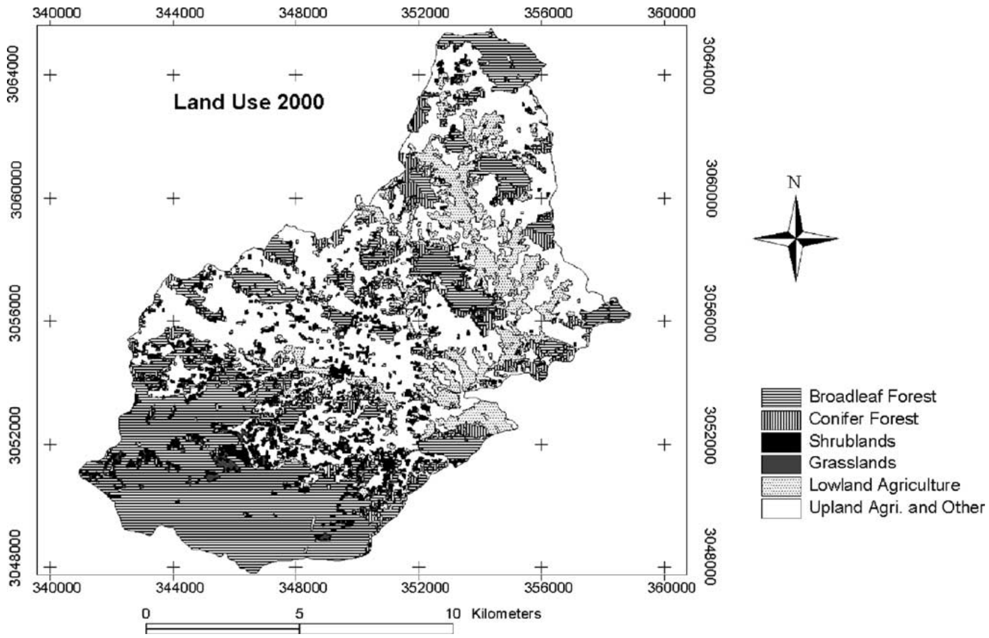

Fig. 2. (*Continued*).

Kabhepalanchok district have found that many households are abandoning unproductive agricultural lands in recent years also due to labor shortage caused by increasing attraction of male members towards wage laboring in Kathmandu and other places (Collett et al., 1996; Jackson et al., 1998). There are evidences also from the hills of Thailand (Fox et al., 1995) and Honduras (Kammerbauer and Ardon, 1999) that declining soil productivity and increased weed competition leads to the eventual abandonment of agricultural plots after few seasons.

Second, plantation establishment by the forest department and FUGs on degraded forestlands, barren lands and grasslands with external assistance has contributed to the increase in forest area. Available records in the District Forest Office, Kabhrepalanchok show that a total of 1564.5 ha plantation, mainly of pines, had been established in the study area during 1972–1999 by forest department and FUGs with supports from the successive bilateral aid projects of the Australian government.

Third, conversion of degraded forest, shrublands, and grasslands into forest after protection by local FUGs organized (both formally and informally) under the community forestry program implemented by the government since the late 1970s contributed to the increase in forest cover. It should be noted that a substantial gain to the broadleaf forest was from the conversion of above 50% of the shrublands (which also includes degraded forests) and 26% of the grasslands in 1976 to forest in 2000 (Table 4), which is an evidence of increased level of forest protection in recent years. In addition to local user groups, the local municipalities have also been involved in forest protection and have been providing financial and moral supports to the local communities for forest protection (Webb and Gautam, 2001).

The improvement in forest cover, however, was not uniform over the whole watershed. The government forests that are located mostly in high elevation areas in the southern region of the watershed are degrading in recent years when many other forests in relatively accessible areas and under community management are improving. For example, forest degradation during 1976–2000 was at least two-times higher compared to improvement in areas above 2300 m, which was one of the reasons for increased shrub cover during the second period (Gautam, 2002).

It is important to note that the base period considered in this study roughly coincides with the inception

Table 4
Percent of land use that was converted from each of the classes into the rest during the study period

Changed from	Changed to	Percent change during		
		1976–1989	1989–2000	1976–2000
Broadleaf forest	Conifer forest	2.2	6.7	5.8
	Shrublands	2.9	3.4	4.1
	Grasslands	0.4	1.0	1.0
	Lowland agriculture	0.2	1.1	0.9
	Upland agriculture and other	12.6	7.4	10.7
Conifer forest	Broadleaf forest	9.8	19.3	16.9
	Shrublands	10.5	10.6	13.7
	Grasslands	5.2	2.1	3.6
	Lowland agriculture	1.3	17.2	4.5
	Upland agriculture and other	67.0	24.0	50.0
Shrublands	Broadleaf forest	37.4	41.1	50.5
	Conifer forest	11.2	8.4	12.9
	Grasslands	4.7	3.5	3.5
	Lowland agriculture	1.2	14.6	4.0
	Upland agriculture and other	32.4	18.4	18.3
Grasslands	Broadleaf forest	14.7	29.6	26.1
	Conifer forest	6.3	9.8	6.5
	Shrublands	16.7	23.1	26.4
	Lowland agriculture	1.0	12.4	8.0
	Upland agriculture and other	52.0	19.5	26.9
Lowland agriculture	Broadleaf forest	1.8	1.6	1.9
	Conifer forest	3.3	3.1	2.4
	Shrublands	0.7	2.1	0.8
	Grasslands	0.0	0.1	0.0
	Upland agriculture and other	14.4	33.4	34.4
Upland agriculture and other	Broadleaf forest	7.0	7.8	7.3
	Conifer forest	6.9	5.1	6.9
	Shrublands	3.9	8.9	7.2
	Grasslands	1.3	1.4	0.9
	Lowland agriculture	11.1	4.4	10.8

Table 5
Overview of changes in major land use groups in between 1976 and 2000

Land use	Percent of land use in 1976			Net gain/loss (%)
	Unchanged in 2000	Lost to other classes in 2000	Gained from other classes in 2000	
Forest	77.5	22.5	37.4	+14.9
Shrublands	10.9	89.1	67.3	−21.8
Grasslands	5.9	94.1	35.9	−58.2
Agriculture and other	81.1	18.9	16.1	−2.8

of the community forestry program in this area (and Nepal). A continuous over time gain in total forest area during the study period despite high loss of conifer forests signifies a positive outcome of combined long-term efforts of forest conservation and development by local communities, the forest department and the donor agency. A combined investment from multiple actors at various levels is indeed one of the important conditions for successful outcomes from collective actions at local level (Ostrom, 1990). The reversal of the trend in shrubs cover change during the second period has, however, raised some concerns regarding the possible continuation of the observed positive trend in future.

The study area is reasonably representative of the Middle Hills in terms of physiographic condition, local livelihood strategies and patterns of forest use. This is also one of the pioneer areas for implementing community forestry program in Nepal. The findings of this study thus can give an indication of possible positive trends in forest cover change occurring in other parts of the Middle Hills during the past few decades as a result of forestation programs and people's involvement in forest management.

The continuous donor support in the implementation of community forestry program in this watershed, however, may be considered as a limiting factor for the widest applicability of these research findings in the region. The argument is that the average financial and technical investments in this watershed might have been higher compared to many other areas where the program has been implemented without or minimal external assistance. But as most of the hill districts in Nepal have some forms of external assistance for community-based forest management and mode of intervention is similar across the region, this factor is expected to have minimum influence on applicability of the research findings in other settings.

The expansion of lowland agricultural area during the first period mostly at the expense of upland agriculture indicated increased agricultural intensification and diversification during the study period. From conversations with local farmers it was reveled that there was indeed a big shift in the use pattern of irrigated lands during this period because of farmers' attractions towards winter cropping of mainly wheat and potato. More recently potato cultivation for commercial purposes has gained momentum on the lowlands due mainly to improved access to local markets and higher profitability compared to wheat and other cereal crops. The gain to lowland agricultural area, however, was not sustained during the second period because of higher loss of this class to other uses particularly to urban expansion and infrastructural development.

Few factors might have caused errors in the classification of land use using satellite images. Relief can lead to image distortions in mountainous regions, while slope and aspect can influence the natural spectral variability (Teillet et al., 1982). In case of MSS and TM images classification, some errors might also have caused by the use of aerial photograph-based training data. Despite these limitations, an overall classification accuracy of 76.6, 80.6 and 76.1% was obtained in the classification of MSS, TM and IRS images, respectively. Moreover, the findings are in tune with some other similar studies conducted in Kabhrepalanchok district (Schreier et al., 1994; Gautam et al., 2002). A comparison of 1989 land use statistics from this research with that from 1992 land use obtained from aerial photo interpretation by Survey Department, HMGN shows about +3% and −4% difference in the area under agriculture and forests, respectively, which is another evidence of reasonable accuracy of classification results in this study.

5.2. Changes in landscape

5.2.1. Patchiness in land use

An analysis of changes in shape of the six land use plots revealed that the number of broadleaf patches declined and average patch area increased continuously over the period. Conifer forest and shrubland patches had different trends of changes during the first and the second period. Grasslands shrunk continuously over the study period in terms of both the number of patches and average patch area. The number of upland agricultural patches too declined continuously but with different rate during the first (8%) and second (35%) periods. There was a substantial and continuous increase in the number of lowland agricultural patches over the years and a substantial decrease in average patch area during the second period (Table 6).

There are two possible reasons for increased fragmentation of lowlands. First, expansion of settlements, other constructions, and infrastructural

Table 6
Patchiness of different land use in 1976, 1989, and 2000

Land use	Number of patches			Average area (ha)			Average perimeter (m)			Shape complexity index (m/ha)		
	1976	1989	2000	1976	1989	2000	1976	1989	2000	1976	1989	2000
Broadleaf forest	292	273	216	16.34	18.20	23.60	1605	1697	2036	98	93	86
Conifer forest	240	363	309	2.37	2.26	3.35	766	800	1031	323	354	308
Shrublands	542	349	490	2.43	2.04	2.11	724	750	758	298	368	359
Grasslands	270	138	124	1.75	1.71	1.59	608	678	663	347	396	417
Lowland agriculture	112	123	216	14.09	16.45	8.49	1791	2278	1622	127	138	191
Upland agriculture and other	208	191	124	31.86	34.44	49.51	3632	3915	5710	114	114	115

development in lowland areas during the last two decades increased patchiness. Second, increased diversification of winter crops in recent years coupled by their different stages of growth created higher variability in reflectance and as a result some of the lowland patches, particularly freshly ploughed fields, might have been wrongly classified as upland agriculture in the classification of IRS image. The speculated error in image classification arising from increased diversification of winter crops in the lowlands could have possibly been reduced by using more than one IRS image. But as the main thrust of the research was to detect changes in forestry land use over the study period, it was not worth putting extra cost and efforts for differentiating between various agricultural crops and lowland/upland agricultural areas.

5.2.2. *Patchiness in forest*

The number of forest patches (broadleaf and conifer combined) decreased continuously from 395 in 1976 to 323 in 1989 and 175 in 2000 while average patch area increased continuously during the same period resulting smaller SCI in the latter period compared to the earlier. Similar trends of changes in SCI over the years were obtained by assuming the forest polygons as circles of the same area (i.e. "optimum" shape with lowest edge effects; Table 7). These results, calculated using the method of Kammerbauer and Ardon (1999), indicated that the complexity of forest patches in the watershed decreased overtime (1976–2000) and forest habitat improved in the latter periods. The significant change in the number of patches and average patch area suggests merging of smaller patches due to forest regeneration and/or plantation establishment on degraded sites previously separating two or more forest patches.

Table 7
Changes in patchiness of forest in between 1976 and 2000

Year	Forest patches	Average area (ha)	Average perimeter (m)	Shape complexity index (m/ha)
(A) Considering actual shape of the forest plots				
1976	395	13.52	1545	114
1989	323	17.91	1795	100
2000	175	35.04	2940	84
(B) Assuming circular shape of the forest plots				
1976	395	13.52	694	51
1989	323	17.91	736	41
2000	175	35.04	989	28

The distribution of SCIs for forest patches across the watershed was normal for 1989 and 2000, while the same for 1976 showed a bimodal tendency in the distribution (Fig. 3). The non-normal distribution of SCI for at least one period indicated that the calculation of SCI based on average value might not be appropriate. To overcome this problem, mean deviation between actual polygon SCI and optimal SCI was computed for all the three periods and compared. Interestingly the results showed a different trend of SCI changes over time—the deviation between actual polygon SCI and optimal SCI was highest (143.2) in 2000 and lowest (95.4) in 1976 (Table 8; Fig. 4). This shows that

Table 8
Comparison of actual and optimal shape complexity index (SCI) averages for forest plots in the three periods

Year	Mean SCI actual	Mean SCI optimal	SCI deviation
1976	363.4 (138.5)	268.0 (127.4)	95.4
1989	396.6 (151.8)	285.8 (124.8)	110.8
2000	395.8 (171.2)	252.6 (129.3)	143.2

Values in parentheses indicate standard deviation.

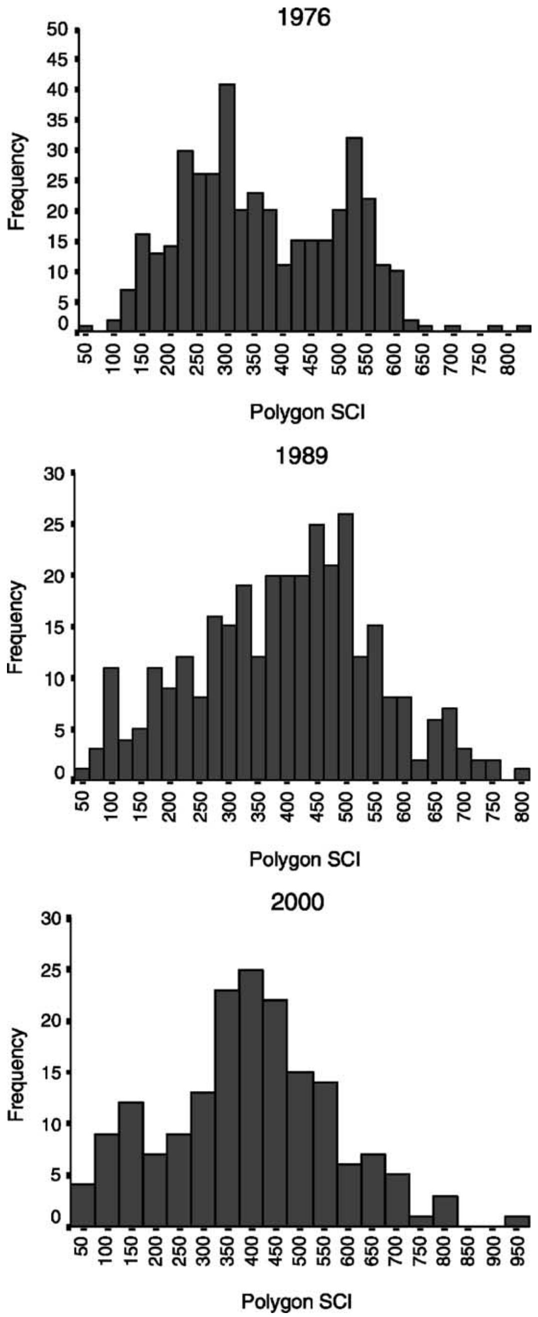

Fig. 3. Frequency distribution of forest patches' shape complexity index (SCI) in Upper Roshi Watershed.

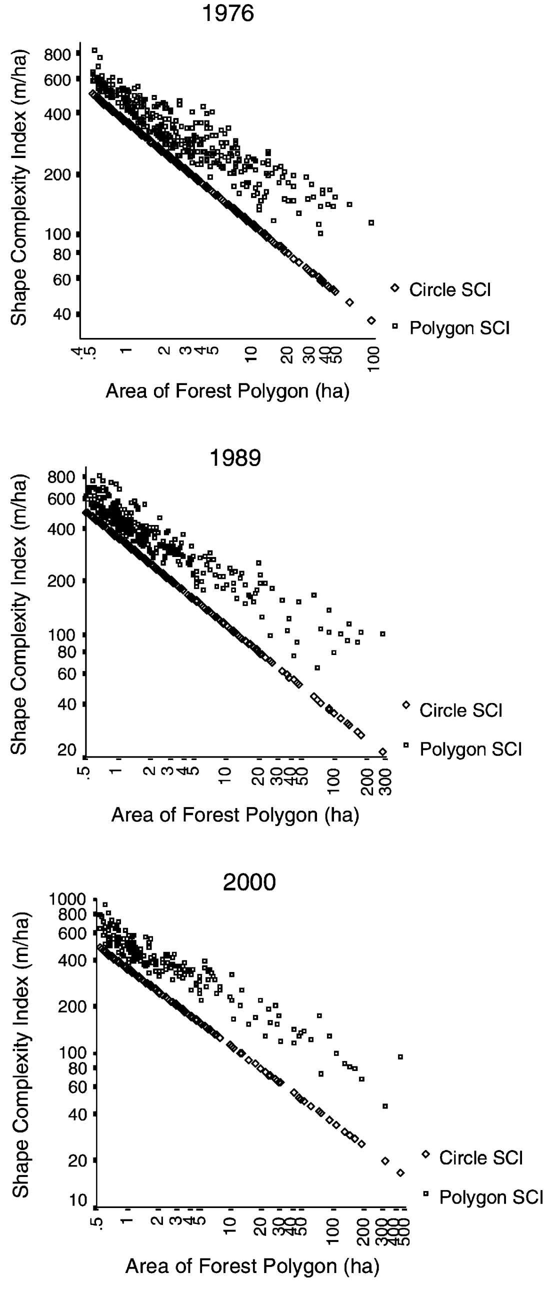

Fig. 4. Relationship between area and shape complexity index (SCI) of forest polygons. One outlier polygon (>3000 ha) in each period has not been included.

along with consolidation, the forest patches became more irregular in shape over the years thus creating higher edge effects at the forest patch level.

The contradictory results on the shape complexity of forest patches obtained from the above two approaches of SCI calculation and interpretation warrants for more discussion on this issue and shows the necessity of refining existing methods of SCI calculation and landscape change interpretation.

6. Conclusions

The quantitative evidences of land use dynamics presented here, which were delivered by repeated satellite images coupled by GIS analyses, corroborate the findings of some earlier studies (Schreier et al., 1994; Jackson et al., 1998; Gautam et al., 2002) that deforestation trend in some areas of the Middle Hills has reversed during the past few decades as a result of forestation programs and people's involvement in forest management. Agrarian changes that took place over the years also contributed to the increase in forest cover.

Decrease in the number of forest patches by above 50% in between 1976 and 2000 and substantial decrease in the watershed level SCI of forest patches indicated improved forest habitat in the watershed, while mean deviation between actual polygon SCI and optimal SCI indicated more irregular shape of forest patches in the latter periods. This difference in results from two approaches warrants more discussion on this issue for refining existing methods of SCI calculation and landscape change interpretation. One of the important changes within non-forestry land use was increased fragmentation of lowland agricultural areas due to urbanization and increased crop diversification in the remaining lowlands.

The positive changes in forest cover provide some evidences of ecological sustainability of the resource. These findings also signify, to some extent, the success of forest conservation efforts by local communities and external agencies involved. The general improvement in forest cover after the implementation of community forestry program indicates the relative superiority of community-based forest governance over government control of the resource. Similar findings have been reported from some other areas in the hills of Nepal (e.g. Schreier et al., 1994; Virgo and Subba, 1994; Schweik et al., 1997) and other parts of the world (e.g. Agrawal and Gibson, 1999; Gibson et al., 2000; Webb and Khurshid, 2000). The reversal of the earlier decreasing trend in shrublands during the second period (1989–2000) has, however, raised some questions regarding the possible continuation of the observed positive trend in future.

This study has provided important insights into the dynamics that occurred in forested area and other major land uses of the study watershed in between 1976 and 2000 and provides a solid quantitative foundation for forest policy and institutional analyses. Building upon this, more location specific in-depth analysis of the relationship between governance arrangement and forest condition may be necessary in order to fully understand the roles played by community-based institutions and other factors in bringing over time changes in forest condition. Some other important concerns that need to be addressed by future researches are whether and how the positive change in forest cover has benefited the local users and how sustainable are the existing community-based forestry institutions in the long run.

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