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Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India

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A B S T R A C T

Mapping and monitoring of land use land cover (LULC) changes in the Himalayas is vital for sustainable development, planning and management. Based on remote sensing (RS) and geographic information system (GIS) techniques, the study is an attempt to monitor the changes in LULC patterns of Rani Khola watershed of Sikkim Himalaya for the periods 1988–1996, 1996–2008 and 2008–2017. Images from Landsat-5 Thematic Mapper (TM) and Sentinel 2A (Multispectral Instrument) MSI data were used to extract land cover maps. Supervised classification using Maximum Likelihood Classifier (MLC) was applied to prepare LULC maps of the watershed. The accuracy of the classified map was assessed using a High Resolution Planet scope image and ground realities have been verified and ascertained through field observations and site specific interviews. As a result of policy changes and traditional agroforestry systems, LULC in the study watershed has undergone a series of complicated changes over the past three decades. Six major LULC classes viz; agriculture, barren land, built-up area, dense forest, open forests and water bodies have been identified and indicate that major land use in the watershed is forestry. Results shows, dense forest, built-up area and water bodies have increased by 16.40% (41.76 km^2), 2.13% (5.41 km^2) and 0.11% (0.28 km^2) while open forest, agriculture and barren land have decreased by −13.98% (−35.59 km^2), 2.83% (−7.22 km^2) and −1.82% (0.4.64 km^2) respectively. The analysis and findings of the study highlights important policy implications for the sustainable LULC management in the Rani Khola watershed of the Sikkim Himalaya.

1. Introduction

The potential of satellite based data as a basis for generating valuable information for LULC is by now widely recognized (Hathout, 2002; Herold et al., 2003; Lambin et al., 2003; Yuan et al., 2005; Saadat et al., 2011), although initial efforts was made since mid seventies for application of different interpretation techniques in LULC mapping (Anderson, 1976; Colwell 1983). Over the last few decades various techniques of LULC mapping and change detection have been developed and applied all over the globe (Jin et al., 2013; Jia et al., 2014; Zhu and Woodcock, 2014; Zhang et al., 2014; Phiri and Morgenroth, 2017; Jin et al., 2017; Sekertekin et al., 2017; Lv et al., 2018; Wu et al., 2018). Rapid replacements of land cover by various land use categories are observed globally (Geist and Lambin, 2001). LULC changes on the surface of the earth are generally divided into land use and land cover which are two concepts (Barnsley et al., 2001) and are often used interchangeably (Dimyati et al., 1996). The importance of investigating LULC and their impacts as a baseline requirement for planning and sustainable management of natural resources (Verburg et al., 1999; Lambin et al., 2000; Petit et al., 2001; Read and Lam, 2002). These researchers have argued that land use has significant impacts on the functioning of socio-economic and environmental systems with important tradeoffs for sustainability, food security, biodiversity and socio-economic vulnerability of people and ecosystems.

Land-use/cover is largely determined by the ecological conditions, altitudes, geological structure and slope along with technological, socio-economic and institutional set-up, which also influences the land-use pattern (Rai et al., 1994). Population growth, industrialization and urbanization have rapidly changed the LULC (Voogt and Oke, 2003). Though changes in land cover by land use do not necessarily imply degradation of the land however, LULC change is one of the most significant drivers of global

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changes (Lambin, 1999) and this affects many parts of geo-environmental and natural ecosystems such as biodiversity, water, radiation budget (Riebsame et al., 1994; Pauleit et al., 2005; Lambin and Meyfroidt 2011; Kiruki et al., 2017; Yang et al., 2017; Guzha et al., 2018). Changes in the condition and composition of land-cover affects climate, bio-geochemical cycles, energy fluxes and livelihoods of people (Vitousek et al., 1997; Salazar et al., 2015; Duong et al., 2016; Tolessa et al., 2017; Niquisse et al., 2017; Gashaw et al., 2018). With the increase in population and urbanization, large areas of forest covers are being converted into other land use in the Himalayan states of India resulting in severe soil erosion (Sharma et al., 2007) contrary to this recently various studies show increasing trend in forest cover in various region of Himalayas (Sharma et al., 2015; Forest Survey Report, 2017). According to Forest Survey Report, 2017 India is ranked 8th in countries reporting the highest annual forest area gain (2010–2015). Sustainable LULC is crucial not only for the sustainable livelihood of 115 million Himalayan people, but also many more people living in the adjoining Indo-Gangetic plains as accelerated erosion due to inappropriate land-use practices in the Himalaya partly contributes to devastating floods in the plains (Ives and Messerli, 1989; Semwal et al., 2004).

In the present study Multi-temporal satellite images of Landsat-5 Thematic Mapper (TM) and a High resolution (10 m) Sentinel 2A Imagery has been used to map the changing pattern of LULC of Rani Khola watershed from 1988 to 2017. Land-use/cover in the study watershed is largely determined by the ecological conditions, altitudes, geological structure and slope. Apart from the above factors, technological, socio-economic and institutional set-up is also expected to influence the LULC pattern (Rai et al., 1994). With increasing scale of anthropogenic change and impacts on environment, it has become extremely important to have land resources inventory of watershed. In Sikkim nearly two-third of the overall work force depends on agriculture and allied activities, with only 16% of geographical area available for cultivation (Sikkim Government, 2007). The study area is one of the densely populated agrarian watershed of Sikkim Himalaya, having a diverse geo-physical and socio-economic characteristic. Farming in the watershed is characterised by strong traditional agroforestry system, horticulture, animal husbandry and recently introduced floriculture. In Sikkim the area under agroforestry (large cardamom) increased by 135% during 1975 to 1995 (Sharma et al., 2007). Change in cropping systems in the watershed from irrigated (*Khet-paddy fields*) to un-irrigated (*Bari-*) *agroforestry systems* which comprises of mixture of trees, shrubs and herbs is quite common due to its increased crop production and economic gain such as agroforestry cash crops.

There have been some attempts to study the LULC and inventory of resources in Sikkim Himalaya (Sharma et al., 1992; Sharma, 2017) however no attempt has been made to inventories the available land resources in the study watershed; therefore, the paper aims to utilize geospatial techniques to detect the LULC changes in Rani Khola watershed from 1988 to 2017. An overview of the LULC with an analysis regarding the appropriateness of future development within the study watershed is also outlined.

2. Materials and methods

2.1. Study area

The present study was conducted in Rani Khola watershed located in the East District of Sikkim State, India (Fig. 1). The water-

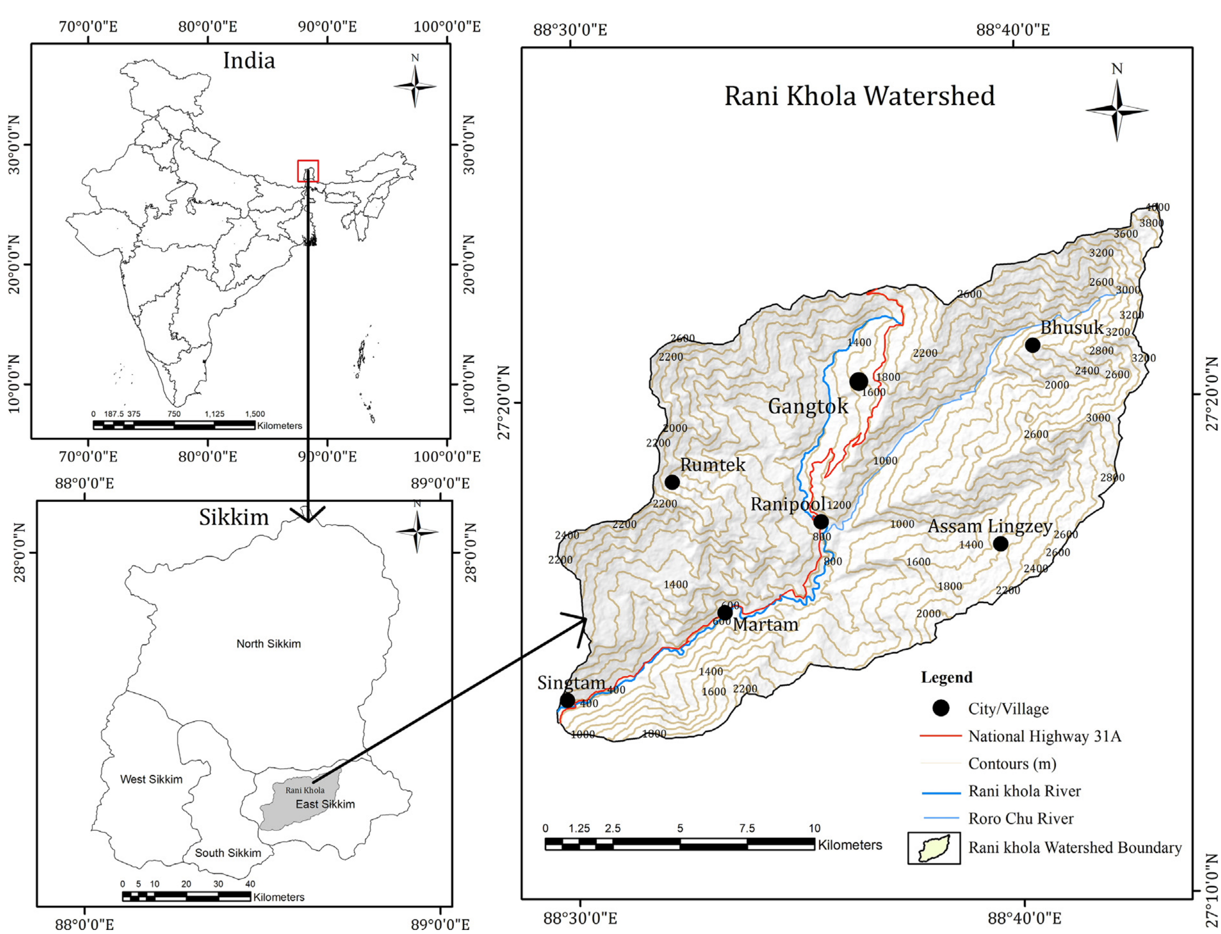

Fig. 1. Location map of Rani Khola watershed of the Sikkim Himalaya.

shed lies between 27°13′9N to 27°23′51 N and 88°29′31E to 88°43′18E with an area approximately 254 km^2. Elevational range of watershed varies from 300 to 4100 m from mean sea level at the extreme north. Geology of the watershed is characterized by Gorubathan Formation, Chungthang Formation (Paro), Lingtse Granite Gneiss rock formations. More than 50% of the area is made up of the rocks belonging to Gorubathan Formation and concentrated in the central and western part of the watershed (GSI, 2006). Rani Khola is one of the major tributaries of Teesta River and is also known as *Rongni Chu* in local dialect. Rani Khola watershed is one of the very prominent watersheds of Teesta basin and it is characterised by variety of landforms. Most of the area in this watershed falls in high mountain region with very steep slopes, the average angle being 30°–40°. North-east region is mainly characterized by moraines and exposed rocks. Vegetation in this area consists of dense forests, open forest and alpine scrubs. Reserved forests namely Martam Reserved Forest, Bhusuk Reserved Forest and Assam Reserved Forest enrich the floral diversity of the study area. Rani Khola watershed is also famous for agroforestry practices. Climatically, the watershed enjoys sub-tropical to alpine climatic conditions. The average annual rainfall is more than 3300 mm, most of the rainfall occurs from July to September. Many areas in the higher reaches of the watershed also receive heavy snowfall during the month of January. The average annual temperature of the watershed ranges from 0° to 26 °C. Agriculture is the main source of livelihood in the rural areas of the watershed and represents most of the human habitation zones that exist in the Sikkim Himalaya. The watershed consists of 44 villages and has a total population of 1,61,394 (COI, 2011). The watershed represents most of the human habitation zones that exist in the Sikkim Himalaya.

2.2. Data source

Multi-temporal Landsat-5 Thematic Mapper (TM) imageries of 1988, 1996, 2008 and a high resolution cloud free Sentinel 2A MSI (Multispectral Imager) Level-1C image of 2017 was used for mapping LULC classes of Rani Khola watershed from 1988 to 2017 (Table 1). The main application of both sensors (TM and MSI) is in the areas of forest, agriculture, coastal, inland water resources and LULC mapping and monitoring. Aster DEM was also used to generate watershed boundary of the watershed. All the images were downloaded from USGS earth explorer website

Table 1
Description of the satellite images used in the study.

Satellite	Sensor	Acquisition Date	Bands used	Spatial Resolution	Processing
Sentinel 2A	Multispectral Imager (MSI)	11/11/2017	Visible (B2, B3, B4) NIR (B8) SWIR (B11)	10 m 10 m 20 m	Level 1c
Landsat 5	Thematic Mapper (TM)	15/11/1988 05/11/1996 22/11/2008	Visible (B1, B2, B3) NIR (B4) SWIR (B5)	30 m	Level 1

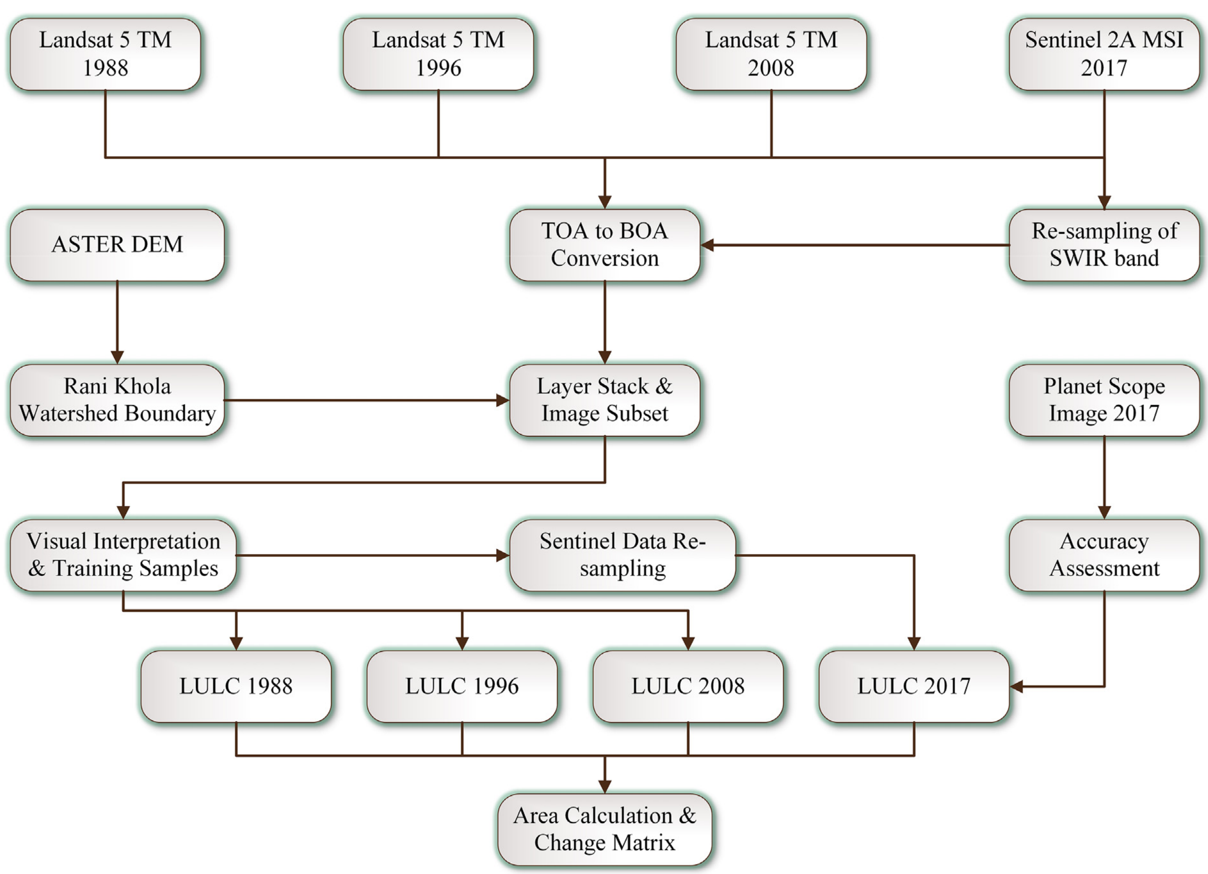

Fig. 2. Methodological workflow and data analysis.

(http://earthexplorer.usgs.gov/). In addition to this Survey of India, topographic map (1:50,000) was also used to obtain additional information about the study watershed.

Sentinel 2A Level 1C data is composed of $100 \times 100\ km^2$ tiles (ortho-images in UTM/WGS84 projection). The Level-1C product results from using a Digital Elevation Model (DEM) to project the image in cartographic geometry. Per-pixel radiometric measurements are provided in Top of Atmosphere (TOA) reflectance along with the parameters to transform them into radiance. Sentinel 2A dataset consists of 13 multispectral bands out of which only five bands have been used in the present study. Landsat 5 TM level 1 datasets were also available in TOA Reflectance and projected in UTM/WGS 84 projected coordinated system.

2.3. Methodology

Overall methodological framework and data analysis is presented in Fig. 2. The detailed methodology for the study is as follows.

2.3.1. Pre-processing

ASTER DEM was used to extract the boundary of the Rani Khola watershed. Satellite imageries were available in TOA and converted in Bottom of Atmospheric Reflectance (BOA) using Semi-Automatic Classification Plug-in of QGIS software. After the conversion of TOA reflectance to BOA reflectance, sentinel SWIR bands were re-sampled from 20 m to 10 m. Thereafter, all five bands of satellite imagery were stacked and watershed boundary generated from ASTER DEM was used for subsetting all the imageries. Standard false colour composite (FCC) of all decades was created for mapping.

2.3.2. Land-cover classification scheme

To prepare the LULC map from satellite imageries, a classification scheme which defines the LULC classes was considered. The numbers of LULC classes are preferred based on the requirement of a specific project for a particular application (Arora and Mathur, 2001; Saha et al., 2005). Six major LULC classes were chosen for mapping the entire watershed area viz; agricultural land; barren land; built-up land; dense forest; open forest and water-bodies (Table 2). Area under irrigated agricultural land was included as agricultural land while area under agroforestry was included under open forest due to the similar spectral response of tree cover in agroforestry systems to open forests.

2.3.3. Post processing

2.3.3.1. Supervised classification. After the preparation of classification scheme one of the most widely used image classification technique, i.e., maximum likelihood classification was adopted for mapping all the land use/cover classes. Before the selection of training samples, empirical analysis of satellite imagery; google earth images and toposheet of the watershed were investigated carefully. For most of the classes, a minimum number of training samples were 100. Selecting training samples for water was tough because of the dense canopy of forests along with the river channel and lack of water in the river channels since the acquisition date of imagery was in mid-November and at that time most of the rivers in the mountains carry less water as compared to the monsoon season.

Table 2
Description of different LULC categories.

LULC category	Classes included-general description
Agricultural land	Irrigated agricultural area and agricultural fallow land,
Barren land	Areas devoid of vegetation; e.g., sediments, exposed rocks, landslide zones, degraded forest area
Built-up	Settlements and roads
Dense forest	Land with tree canopy density more than 40%
Open forest	Shrubs, area under Agroforestry and land with tree canopy density between 10 and 40%
Water-bodies	Areas covered by perennial river

2.3.4. Field survey and accuracy assessment

A field survey was conducted for ground verification of doubtful areas with the help of GPS and local guides in different parts of watershed covering all the LULC classes. Due to mountainous topography, rough terrain and steep slopes, few areas were not accessible. Photographs taken during the field survey are shown in Fig. 4 and location of these photographs is shown on the classified map of 2017 (Fig. 5).

2.3.5. LULC change detection

LULC map of 2017 was re-sampled on 30 m to match the spatial resolution of all the classified maps thereafter; post-classification change detection technique was used for analysing the changes. In the last few decades, many change detection methods have been developed viz; image differencing, post classification change matrix, comparison technique and principal component analysis (Lu et al., 2004). Change matrix presents important information about the spatial distribution of changes in LULC (Shalaby and Tateishi, 2007). Change matrix showing the land cover changes in each decade was generated from classified images of 1988 to 1996, 1996 to 2008, 2008 to 2017 and a change matrix was generated from 1988 to 2017 to assess the overall changes in LULC classes between 1988 and 2017.

3. Results

3.1. LULC status

Multi-temporal LULC covering six major classes: agricultural land, barren land, built-up area, dense forest, open forest and water-bodies of 1988, 1996, 2008 and 2017 are shown in Fig. 3. The spatial distribution pattern of LULC obtained from supervised classification is registered in Table 3.

Results from classified maps indicated that in 1988 area occupied by different classes viz; agricultural land was about 20.46%, barren land was 4.38%, built-up area covered 2.82%, dense and open forest covered most part of the watershed and occupied about 38.26% and 34.07% area respectively. On the other hand, in 1996 about 15.08% of the area was covered by agricultural land against 20.46% area in 1988 showed a decrease in cultivated land. Barren land and built-up area covered 4.25% and 3.51% respectively while, dense forest had largest share of 41.35% followed by open forest 35.81%. The area covered by water bodies was less than 1% ($0.01\ km^2$) of the total geographical area for the year 1988–1996 (Table 3).

Results from the classified image of 2008 illustrate that more than 50% of the area was covered by dense forest, whereas open forest share was 30%. Agricultural land occupied 12.75%; built-up area covered 3.60% while barren land and water bodies collectively covered 2.66% area. In 2017, the area under dense and open forest has fairly grown and covered 74.75% collectively. Agricultural lands and built-up area covered 17.63% and 4.95% area respectively (Table 3).

3.2. Field survey and accuracy assessment

During the field survey and accuracy assessment the notable differences found in classified image and actual ground were the misclassification of unpaved roads as barren lands and dirt roads as agricultural fallow land. In some areas exposed river bedrocks were also misclassified as built-up area.

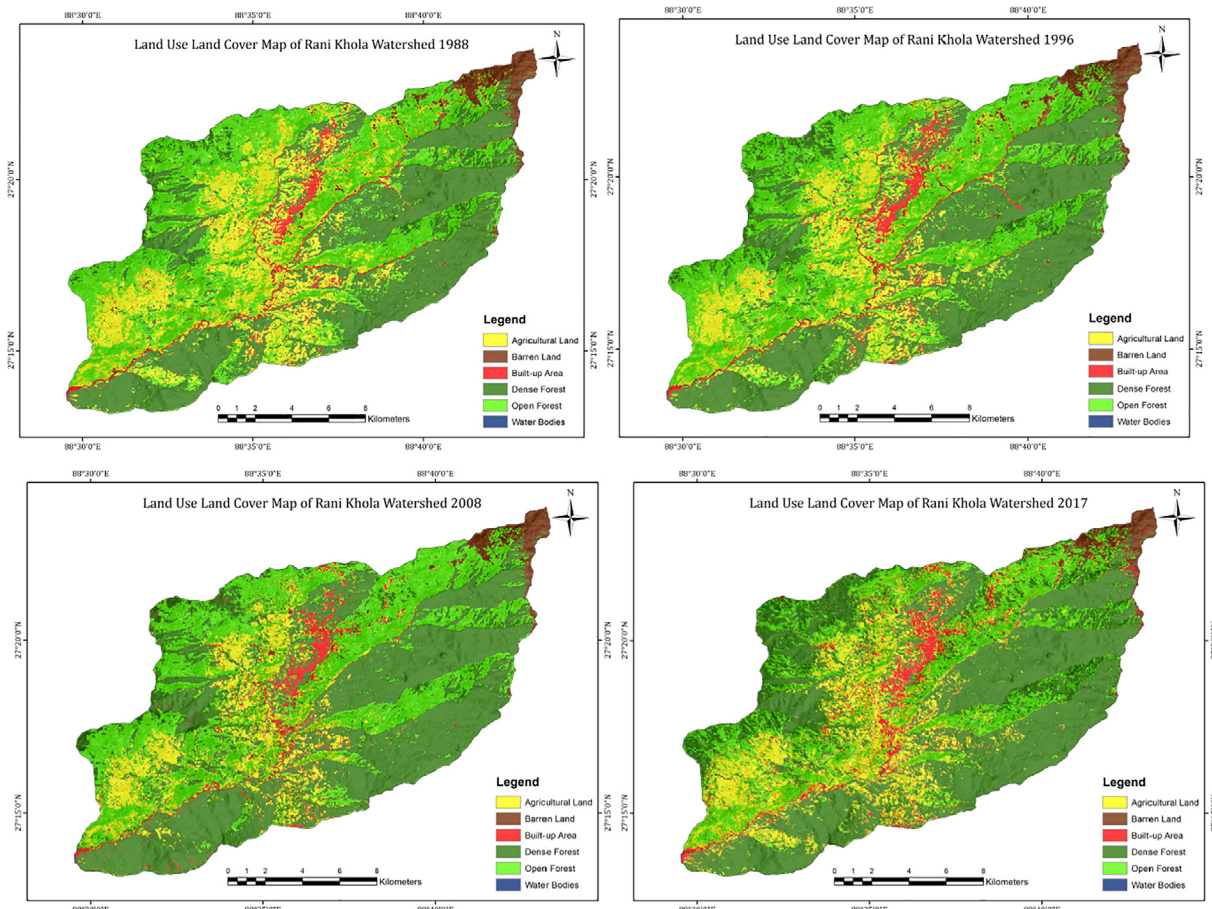

Fig. 3. Land use/cover change in different categories during years 1988, 1996, 2008 and 2017 in Rani Khola watershed.

Table 3
LULC distribution in Rani Khola watershed of Sikkim Himalaya.

LULC Class	1988		1996		2008		2017	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Agricultural Land	52.10	20.46	38.40	15.08	32.46	12.75	44.88	17.63
Barren Land	11.17	4.38	10.82	4.25	6.75	2.65	6.53	2.56
Built-up Area	7.18	2.82	8.94	3.51	9.16	3.60	12.59	4.95
Dense Forest	97.42	38.26	105.28	41.35	130.66	51.31	139.18	54.66
Open Forest	86.74	34.07	91.19	35.81	75.57	29.68	51.15	20.09
Water Bodies	0.03	0.01	0.01	0.00	0.03	0.01	0.31	0.12
Total	254.64	100.00	254.64	100.00	254.64	100.00	254.64	100.00

Photograph A captured the dense forest cover near Bhusuk village as shown in Fig. 4. In photograph B open forests can be seen on the left side while hill on the right is covered with dense forests. Photograph C was taken from Tadong locality; agricultural fields can be observed surrounded by small patches of dense vegetation and settlements. Photograph D and E depicts settlements surrounded by open forest and cultivated lands. Photograph F captured agricultural fields of *Ranka* facing towards Gangtok while photograph G covered the mixed forest of *Luing*. Photograph H was taken near *Singtam*; settlements can be seen in the middle of dense forests.

One of the most frequently used Kappa accuracy assessment technique was selected to assess the accuracy of classified map of 2017. Accuracy assessment was done using a high resolution (3.9 Meters) satellite imagery of Planet scope 300 stratified random points with minimum 20 points in each class were generated (Table 4). Due to the lack of availability and clear google earth images accuracy assessment of 1988, 1996 and 2008 images were not possible. Overall classification accuracy for the classified image of 2017 was found to be 85.67% with overall kappa statistics of 0.8117. Individual producer's and user's accuracy of all the classes are presented in Table 5.

4. Discussion

4.1. LULC changes

Several studies analyses changes in broad LULC in the Himalaya (Rao and Pant 2001; Gautam et al., 2002; Yu et al., 2007) yet information and data on changes in spatio-temporal patterns of LULC, driving factors and their implications within the context of sustainable development is limited (Hurni 2000; Sankhayan et al., 2003).

Fig. 4. Field photographs were taken in different locations of the watershed. A & B; Bhusuk, C; Tadong, D; Namli, E; Rumtek, F; Ranka G; Luing H; Singtam.

The LULC change matrix in the periods 1988–1996, 1996–2008, 2008–2017 and 1988–2017 are shown in Tables 6–9 respectively. The values shown in bold letters indicates no change in LULC categories for the given time period.

Results obtained from LULC change matrix shows major land cover changes in the Rani Khola watershed for the study period.

4.2. LULC patterns over the period of 1988–1996

For the period 1988–1996 major changes were observed from agricultural land to open forest. About 14.23 km^2 of agricultural land got converted to open forest (agroforestry) while 4.26 km^2 areas changed from open forest to agricultural land this was due to conversion of irrigated paddy fields to large cardamom based Agroforestry and vice versa. The area under dense forest have increased about 10.29 km^2 due to conversion of parts of open forests to dense forests by reforestation, establishment of forest reserve and *Fambong Lho Wildlife Sanctuary*. Considering the built-up area about 2.7 km^2 of agricultural land converted to the built-up area around the Gangtok city due to urban sprawl, expansion and developmental activities. About 1.33 km^2 and 1.47 km^2 area from barren land was changed to agriculture and open forest

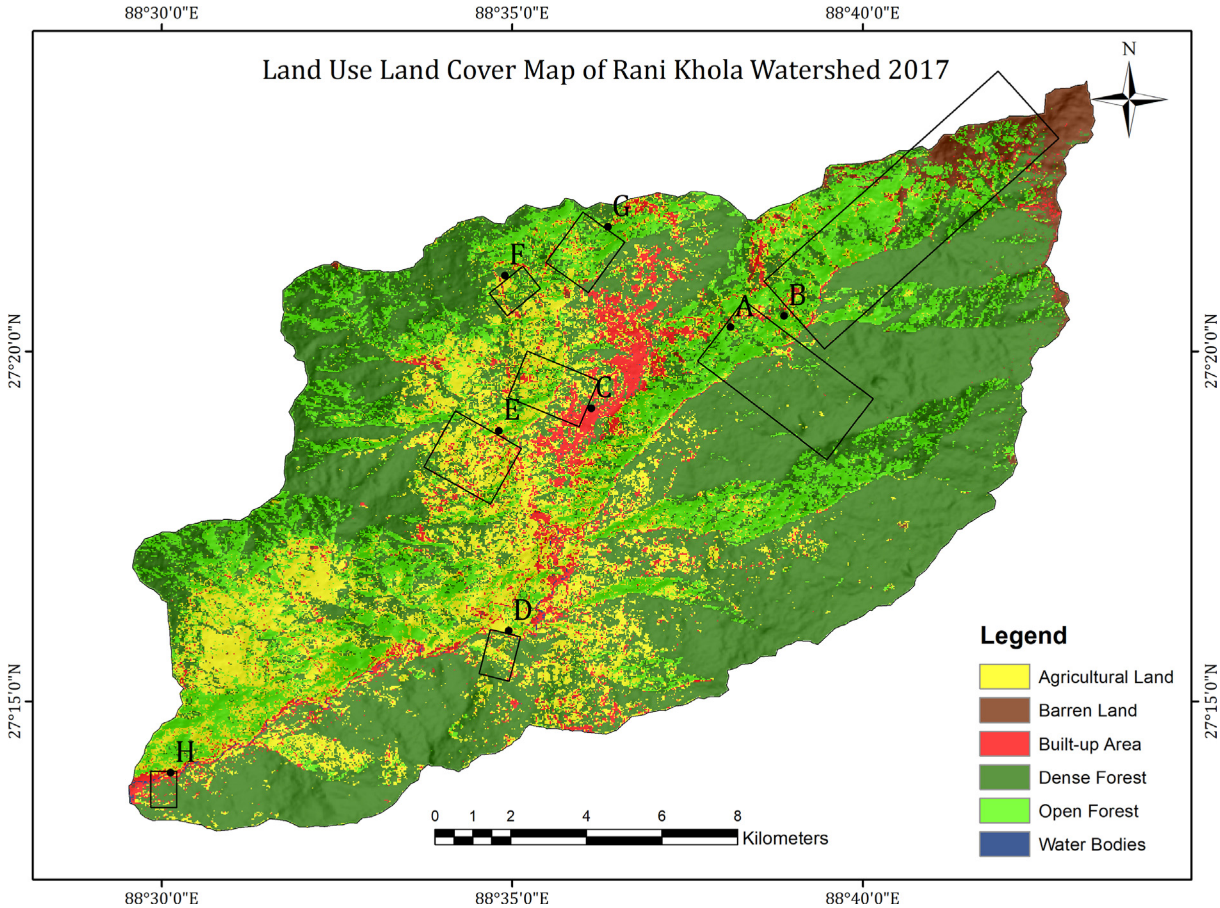

Fig. 5. Location of field photographs presented in Fig. 4 and direction of photos on classified map.

Table 4
Accuracy Assessment Error Matrix of classified image 2017.

Reference Data Classified Data	Agricultural land	Barren land	Built-up Area	Dense Forest	Open Forest	Water bodies	Classified total
Agricultural land	**39**	6	3	0	4	0	**52**
Barren land	0	**19**	4	0	1	0	**24**
Built-up Area	0	5	**22**	1	1	0	**29**
Dense Forest	0	0	1	**116**	2	0	**119**
Open Forest	5	0	2	0	**49**	0	**56**
Water bodies	0	7	1	0	0	**12**	**20**
Reference Total	**44**	**37**	**33**	**117**	**57**	**12**	**300**

Table 5
Producer's and User's Accuracy assessment of 2017 classified map.

LULC Class	Reference total	Classified total	Number correct	Producer accuracy	Users Accuracy
Agricultural land	44	52	39	88.64%	75.00%
Barren land	37	24	19	51.35%	79.17%
Built-up Area	33	29	22	66.67%	75.86%
Dense Forest	117	119	116	99.15%	97.48%
Open Forest	57	56	49	85.96%	87.50%
Water bodies	12	20	12	100.00%	60.00%

respectively. Uppermost areas in the northeastern part of watershed were covered by barren lands and moraine. The area was devoid of vegetation due to high altitude (between 3800 m and 4100 m) and very steep slope. This area receives seasonal snowfall in winters and remains barren rest of the year. Snowfall is decreasing every year due to changing climate resulting expansion of alpine shrubs (included as open forest in map) reaching upper zones were observed in all the study period (Fig. 3). In all, four LULC images, water was only classified near (*Singtam*) southwestern region of the watershed as this area has the lowest elevation and river contains more water.

4.3. LULC patterns over the period of 1996–2008

Dense forests and built up area showed increasing trend during this time period, in contrast to decrease in the change rate of other

Table 6
LULC changes matrix as observed between 1988 and 1996 in Rani Khola watershed.

	LULC Class	1996 (Area in Km^2)						
1988 Area in km^2		Agricultural land	Barren land	Built-up Area	Dense Forest	Open Forest	Water bodies	Grand Total 1988
	Agricultural land	**31.69**	1.95	2.07	2.16	14.23	0.00	52.10
	Barren land	1.33	**7.03**	0.73	0.60	1.47	0.00	11.17
	Built-up Area	0.57	0.82	**4.52**	1.12	0.14	0.00	7.18
	Dense Forest	0.55	0.47	1.46	**91.11**	3.84	0.00	97.42
	Open Forest	4.26	0.54	0.16	10.29	**71.50**	0.00	86.74
	Water bodies	0.00	0.02	0.01	0.00	0.00	**0.00**	0.03
	Grand Total 1996	38.40	10.82	8.94	105.28	91.19	0.01	254.64

Table 7
LULC changes matrix as observed between 1996 and 2008 in Rani Khola watershed.

	LULC Class	2008 Area in Km^2						
1996 Area in km^2		Agricultural land	Barren land	Built-up Area	Dense Forest	Open Forest	Water bodies	Grand Total 1996
	Agricultural land	**22.20**	0.45	2.38	8.25	5.11	0.00	38.40
	Barren land	1.17	**5.29**	1.36	1.48	1.51	0.01	10.82
	Built-up Area	0.67	0.14	**3.88**	4.17	0.07	0.02	8.94
	Dense Forest	0.88	0.39	1.05	**98.32**	4.63	0.00	105.28
	Open Forest	7.54	0.48	0.48	18.43	**64.25**	0.00	91.19
	Water bodies	0.00	0.00	0.00	0.00	0.00	**0.01**	0.01
	Grand Total 2008	32.46	6.75	9.16	130.66	75.57	0.03	254.64

Table 8
LULC changes matrix as observed between 2008 and 2017 in Rani Khola watershed.

	LULC Class	2017 Area in Km^2						
2008 Area in km^2		Agricultural land	Barren land	Built-up Area	Dense Forest	Open Forest	Water bodies	Grand Total 2008
	Agricultural land	**20.30**	0.24	2.55	4.08	5.26	0.03	32.46
	Barren land	0.50	**4.37**	0.51	0.68	0.69	0.00	6.75
	Built-up Area	2.62	0.15	**4.81**	1.21	0.21	0.15	9.16
	Dense Forest	13.15	0.62	3.94	**107.72**	5.13	0.10	130.66
	Open Forest	8.30	1.14	0.77	25.48	**39.87**	0.01	75.57
	Water bodies	0.00	0.00	0.02	0.00	0.00	**0.01**	0.03
	Grand Total 2017	44.88	6.53	12.59	139.18	51.15	0.31	254.64

Table 9
LULC changes matrix as observed between 1988 and 2017 in Rani Khola watershed.

	LULC Class	2017 Area in Km^2						
		Agricultural land	Barren land	Built-up Area	Dense Forest	Open Forest	Water bodies	Grand Total 1988
1988 Area in km^2	Agricultural land	**26.08**	0.58	5.35	9.88	10.16	0.04	52.10
	Barren land	1.69	**4.70**	1.20	1.65	1.85	0.08	11.17
	Built-up Area	1.93	0.07	**2.96**	1.86	0.22	0.14	7.18
	Dense Forest	3.63	0.45	1.70	**89.33**	2.28	0.03	97.42
	Open Forest	11.55	0.71	1.38	36.46	**36.63**	0.01	86.74
	Water bodies	0.00	0.00	0.01	0.00	0.00	**0.01**	0.03
	Grand Total 2017	44.88	6.53	12.59	139.18	51.15	0.31	254.64

land use classes. Similar to the changes observed during 1996–2008, about 18.43 km^2 area converted from open to dense forest, this was due to the reforestation, forest reclamation projects and policy changes implemented in the area. Changes from agriculture land to open forest and vice versa observed commonly and this was due to traditional agroforestry systems practiced widely by the indigenous people of the watershed. About 5.11 km^2 agricultural lands changed to open forest because of traditional *agroforestry systems*. A study on east district of Sikkim (Sharma et al., 2015) shows that the total area under dense forest and agricultural cropland in 2006 was nearly 42% and 18% of the total area and similar results were observed for the watershed where area under dense forest and agricultural land was 51.31% and 12.75% respectively in the year 2008. LULC matrix shown in Table 7 indicate that about 4.17 km^2 of builtup area changed in dense forest, partially this was due to the increase in canopy of dense forest along the course of Rani Khola river, where reflectance of river sediments and exposed rocks were misclassified as built-up area due to the spectral similarity of exposed rocks, sediments and concrete concentration. 1.17 km^2 and 1.36 km^2 area under barren land got converted in agricultural land and built-up area while 1.48 km^2 and 1.51 km^2 area changed in dense and open forest respectively.

4.4. LULC patterns over the period of 2008–2017

About 25.48 km^2 of the area was converted from open to dense forest the reason was same as cited for the other study periods. Contrary to this about 5.13 km^2 dense forest degraded to open forest during 2008–2017 this reason for this is development of agroforestry systems and forest fire. About 5.26 km^2 of agricultural land changed into open forests on the other hand 8.30 km^2 of area converted from open forest to agriculture again mostly due to traditional farming and agroforestry systems. About 4.08 km^2 of agricultural land converted into the dense forest, while 2.55 km^2 of agricultural area transformed into the built-up area due to increasing population. An increasing trend in areas under built-up land was observed in every decade under the pressure of urbanisation and population growth, a major concentration of built-up area near Gangtok city can be seen in the maps from 1988 to 2017 being the capital of Sikkim state. During 2008 to 2017, built-up area increased by 1.35% (3.43 km^2) this is most likely due to the increased expansion rate in residential allotments and industrial areas since 2005.

4.5. Overall gain and loss

Table 10 indicates overall changes from 1988 to 2017. One of the major land cover class of this area is dense forest which shows a significant increase in last three decades. Area covered by dense forest has increased by 41.76 km^2 from1988 to 2017. Similar observation was recorded for Sikkim state (India State Forest Report, 2017). Sikkim covered 3344 km^2 (47.13%) and 2756 km^2 (38.84%) area under forest in 2017 and 1987 respectively, which indicates an increase of 588 km^2 area in last three decades. While in this watershed area under forestry increased from 72.33% in 1988 to 74.75% in 2018. The overall loss of open forest class in last three decades was found to be −35 km^2 (Fig. 6) Major reason for this change was identified as conversion of open forest areas into dense forest and paddy fields.

Agriculture is one of the most important land-use after forestry in the watershed. The agriculture system is characterized by mixed farming viz., agriculture, agroforestry, horticulture, floriculture, livestock and animal husbandry. Major changes from agricultural land to open forest and open forest to agriculture have been observed in all periods due to the conversion of irrigated agricultural lands in widely practiced traditional agroforestry system and vice versa. In this watershed overall change in agricultural area was −7.22 km^2 from 20.46% (1988) to 17.63% (2017).

Table 10
Overview of changes in LULC groups in each period (Km^2).

LULC Class	Net change in 1988–1996	Net change in 1996–2008	Net change in 2008–2017	Overall changes in 1988–2017
Agricultural land	−13.70	−5.94	12.42	−7.22
Barren land	−0.35	−4.07	−0.22	−4.64
Built-up area	1.76	0.22	3.43	5.41
Dense forest	7.86	25.38	8.52	41.76
Open forest	4.45	−15.62	−24.42	−35.59
Water bodies	−0.02	0.02	0.28	0.28

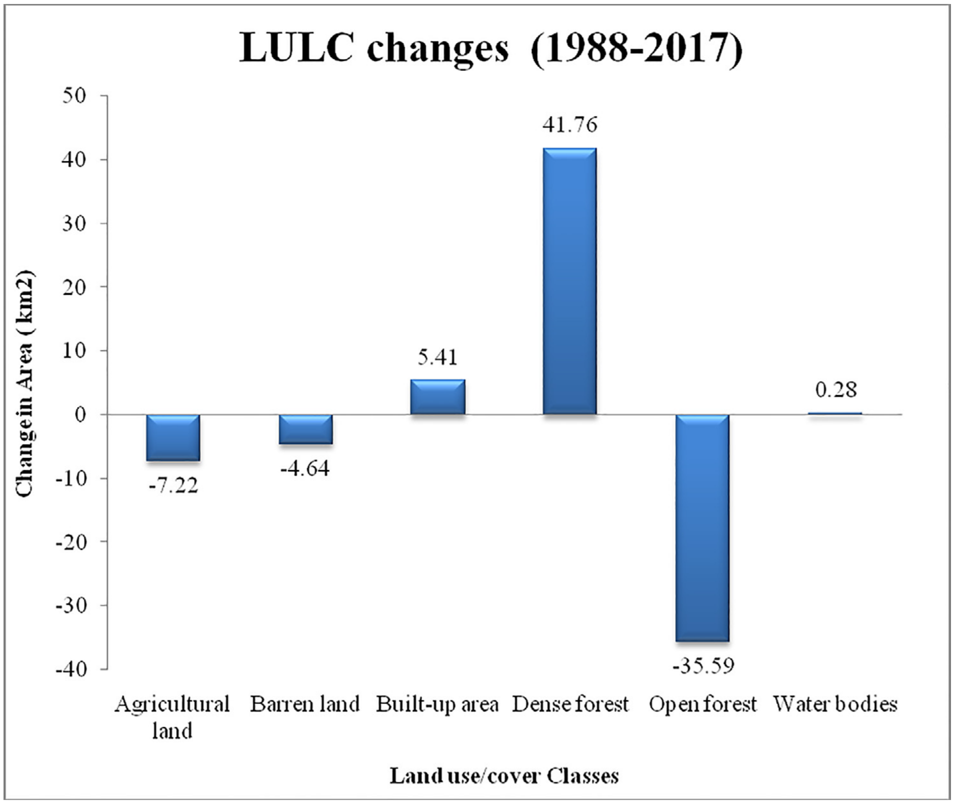

Fig. 6. Diagrammatic illustration of land use/cover change in percent in Rani Khola watershed.

Mapping of water bodies was difficult due to the shallow water and dense canopy along the rivers. Difficulty was further increased with 30 m spatial resolution. Areas covered by water body increased in 2017 as training samples were collected from 10 m resolution data which was later resampled on 30 m at the time of classification.

5. Conclusion

This study assessed and monitored the changes in LULC pattern in the Rani Khola watershed of Sikkim Himalaya using Landsat-5 TM and sentinel-2 data from 1988 to 2017. The result of this study reveals that the major land use in the watershed is forestry. Due to massive afforestation programme, declaration of Sikkim as organic state (2005), stringent law enforcement in forestry sector and sustainable agroforestry systems the area under dense forest has increased by 16.4% (41.76 km^2) between 1988 and 2017. Open forest showed increasing trend during 1988–1996 whereas decreasing trend has been observed during 1996–2017, this may be associated with the conversion of open forest into dense forest area. The second dominant land use is agriculture which was recorded as 17.63% (2017) as against 12.75% in 2008 due to traditional agroforestry practices, horticulture, floriculture and animal husbandry which is widely practiced by the. During the study period (1988–2017), barren land has been decreased significantly due to conversion in agriculture, vegetation and built-up land. The major changes in built up area were noted along the periphery of the Gangtok being the capital city due to urban sprawl and expansion of the town area during the last two decades.

Since forestry and agriculture are the predominant user of land, their quality (soils) and quantity (area) is directly related to the nature of landforms. This data would ultimately help to identify limiting resources as also the environmentally critical areas which can be delimited as hot spots for conservation or remediation. The evaluation of resources would also lead to understand the impacts of various developmental activities on these resources on the one hand and the planning process on the other. Present study utilizes the RS and GIS approach which is one of the most prominent technology at present for spatio-temporal analysis which is not possible through other conventional mapping techniques. The analysis and findings of the study have important policy implications for the sustainable land-use/cover practices in the Sikkim Himalaya.

Conflict of Interests

None.

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