SHRINKING FOREST AND CONTESTED FRONTIERS: A CASE OF CHANGING HUMAN-FOREST INTERFACE ALONG THE PROTECTED AREAS OF NAGAON DISTRICT, ASSAM, INDIA

Kuleswar SINGHA
Government of Assam, Forest Department
hoff-assam@gov.in

Dhrubajyoti SAHARIAH
Gauhati University , Department of Geography
dhrubajyoti@gauhati.ac.in

Anup SAIKIA
Gauhati University, Department of Geography
asaikia@gauhati.ac.in

Abstract

Anthropogenic activities have resulted in manifold land use/land cover (LULC) changes across the globe particularly since the 1980s. In this study, LULC changes of Nagaon district, India were assessed from 1987 to 2013 by using Landsat TM, Landsat ETM+ and Landsat 8 OLI/TIRS images. The study demonstrates the consistent increase of non-forest areas within and outside reserved forests (RF) and in mining areas. Dense, open / degraded forest and trees outside RFs consistently declined during the entire period. Dense forest decreased by 8173.1 ha (13.5%) during 1987-2001, and 4340.5 ha (10.2 %) during 2001-13. Similarly, open /degraded forest registered losses of 1449.5 ha (2.4%) during 1987-2001 and 429.7 ha (1%) during 2001-13. Trees outside forest areas also experienced losses of 16897.7 ha (27.9%) and 12803.1 ha (30%) during 1987-2001 to and 2001-13 respectively. The overall supervised classification accuracies were 91.1%, 89.1% and 90 % and Kappa values were 0.89, 0.87, and 0.88 during1987, 2001, and 2013, respectively.

Keywords: *land use change, human-forest interface, protected forest, supervised classification,*

1. INTRODUCTION

Land use/land cover (LULC) change has become an important issue at global, regional and local level, as a consequence of anthropogenic activities causing significant in ecosystem modifications (La Mela Veca, Cullotta, Sferlazza, and Maetzke, 2016). The nature of spatial arrangement of ecosystems across landscapes is well explained by its composition and configuration which characterizes the landscape as heterogeneous in nature (Tolessa, Senbeta, & Kidane, 2016). Human activities have altered the natural environment to such an extent that most common landscape patterns portray a mosaic of human settlements, agricultural land, and scattered fragments of natural ecosystems (Sundaresan et al. 1995;Midha & Mathur, 2010;See et al., 2016;Tang, Sun, Zhang, He, & Wu, 2018;Suter, 2012). Most conservation reserves, including larger reserves, are becoming increasingly surrounded by intensively modified environments (Wilson, Sleeter, B. M., Sleeter, & Soulard, 2014;Hansen & DeFries, 2007;DeFries, Hansen, Turner, Reid, & Liu, ;2007;Saikia, Hazarika & Sahariah, 2013;Sarma

& Saikia, 2018), and in the long term appear destined to function as isolated natural ecosystems (Bennett, 1999). As with other ecosystems, the dynamic nature of forest LULC change has a great impact on forest ecosystems and forest composition (Polasky, Nelson, Pennington, & Johnson, 2011; Mokarram, Boloorani, and Hojati, 2016) and resulted in massive destruction of wildlife habitats (Hazarika, 2011). North east India, a global biodiversity hotspot has experienced widespread ecological destruction, much of which is human induced. When the world is gearing up for the conservation measures it is imperative to understand the linkages between deforestation, habitat fragmentation and the survival of species. The districts of Nagaon and Karbi Anglong in Assam, India possess rich and continuous natural forests that have, unfortunately been rapidly depleted of late. This study aims to analyze the LULC changes within the protected areas of Nagaon district. As per records of the State Forest Department (2017), 495.8 hectares of forest land have been converted to non-forest area in Nagaon. Of this, 6.2 hectares, were converted for stone quarrying activities, 292.86 hectares to roads, 1.4 hectares for transmission lines and 195.3 hectares for defence purposes. With 78% of the population being directly or indirectly, engaged in the agriculture sector, the strain on exploitation of forest resources has been intense.

2. THE STUDY AREA

The Nagaon district located on the left bank of the river Brahmaputra, (Figure1) covers an area of 399701.3 hectares in the state of Assam, India.

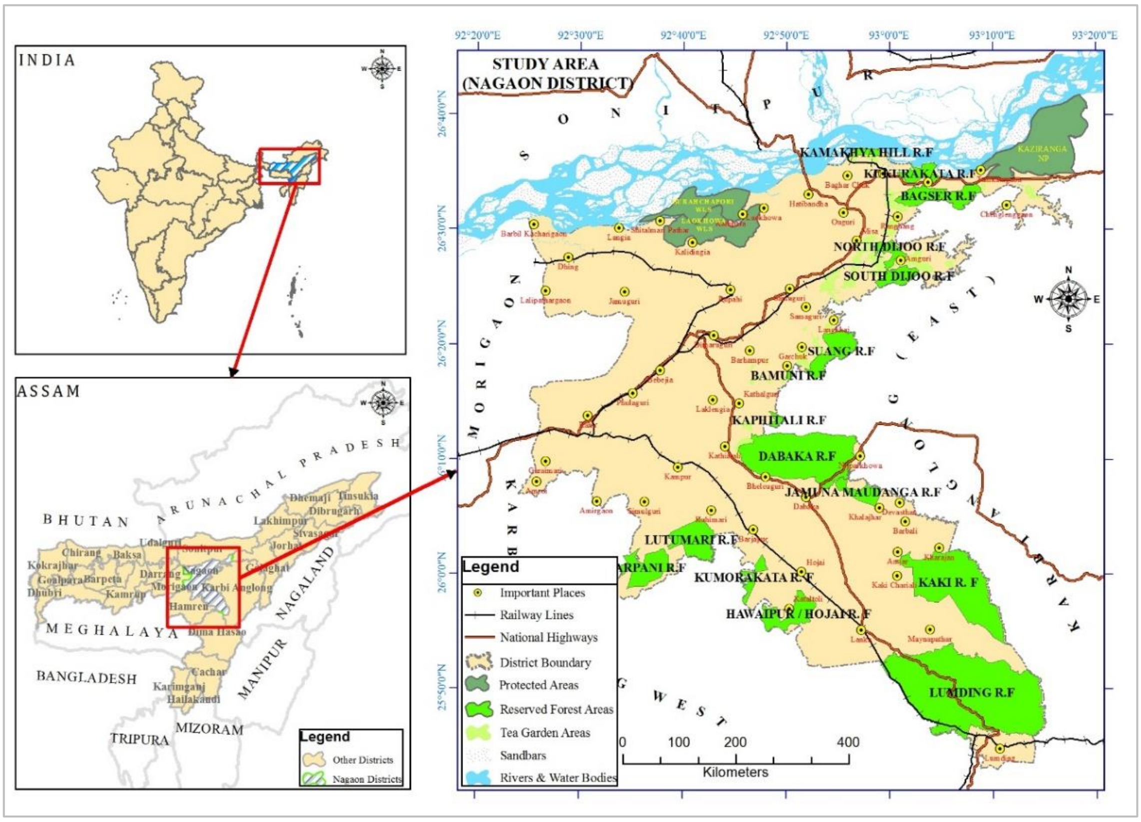

Figure 1: Location of the Nagaon district in Assam, India

Reserved forests (RF) cover an area of 70687 hectares or 17.7% of the total geographical area of the district. There are 17 RFs in Nagaon district of which 7are located in hilly areas. Five different types of forest have been found in the district such as 2B/C2 Cachar Tropical Semi-Evergreen Forest, 2B/ C1a Assam Alluvial plains Semi-Evergreen Forest, 2/2S1

Secondary Moist Bamboo Brakes, 3C/C2d iv App. Kamrup Sal and 3C/C3 b East Himalayan Moist Mixed Deciduous Forest (Champion & Seth, 1968). Like other districts of Assam, due to unabated and growing anthropogenic activities, illegal felling of trees and deforestation have rapidly changed the LULC of the Nagaon district. Segments of intact forest cover are increasingly being converted to small fragmented areas thereby disturbing the natural forest landscape to considerable extent causing severe threats to flora and fauna even within the notified RF areas.

3. DATA AND METHODS

3.1 Land use classification

Supervised classification has been used in this study to classify the different land use/land cover following the work of (Anderson, 1976, Chen & Stow, 2002, Saha, Arora, Csaplovics, & Gupta, 2005, Gupta, & Roy, 2012, Hazarika, & Saikia, 2013, Patil, Desai, & Umrikar, 2012. Sahebjalal & Dashtekian, 2013). Landsat 5 TM (Thematic Mapper), Landsat 7 ETM^{+} (Enhance Thematic Mapper) and Landsat 8 OLI-TIRS (Operational Land Imager/Thermal Infrared Sensor) multispectral satellite imageries pertaining to three epochs i.e. 1987, 2001 and 2013 were obtained (Table 1) from the USGS (United States Geological Survey) Earth Explorer with minimal percent cloud cover to enable the analysis.All the scenes are radiometrically corrected using dark pixel subtraction method. Spectral enhancement techniques such as band ratio were applied to enhance the image quality and to improve the quality of the interpretation.

Table 1. Detailed information about the satellite datasets used in this study.

Satellite	Sensor	Path/ Row	Acquisition Date	Spatial Resolution (m)	Spectral Band (s) (µm)	Data Source
Landsat- 8	OLI/TIR S	136/42	19/03/2013	30	Band2(Blue):0.452 - 0.512 Band3(Green):0.533-0.590 Band4(Red):0.636- .673 Band5(NIR):0.851 - 0.879	USGS Earth Explorer
Landsat- 7	ETM+	136/42	07/02/2001	30	Band1(Blue):0.45-0.52 Band2(Green):0.52-.60 Band3(Red):0.63-0.69 Band4(NIR):0.76-0.90	
Landsat -5	TM	136/42	26/12/1987	30	Band1(Blue):0.45-0.52 Band2(Green):0.52-.60 Band3(Red):0.63-0.69 Band4(NIR):0.76-0.90	

Supervised classification techniques was used for all three years with sub-setted satellite imageries using both parametric (Maximum likelihood) and non-parametric (Feature space) decision rules in Erdas Imagine (v 2013). During the signature collection process, information from Google Earth, Survey of India topographical maps (1:50,000), ASTER DEM data and a handheld Global Positioning System (GPS) device were used to identify the LULC training sets. In addition, Normalized Differential Vegetation Index (NDVI) and unsupervised image classification techniques are also applied before the supervised classification of the study area as an aid to the identification of LULC types so as to achieve an improved classification accuracy. The classification scheme has been developed based on ancillary information (Forest

Survey of India Report, 2017); field work, local knowledge and visual interpretation of each class of land cover over satellite imagery and Google Earth. The district has been classified into nine broad classes namely dense forest, open /degraded forest, non-forest area (inside RFs) (as per FSI report 1987), non-forest area (outside RFs), grassland (riverine grassland), tree outside forest area, mining area (stone quarrying), rivers & water bodies and sand & dry river beds (Table 2).

Table 2. Description of LULC categories

LULC Categories	Description of LULC categories
Dense forest	Areas with more than 40 % tree cover
Open forest / Degraded forest	Areas with 10 - 40 % tree cover
Non-forest area (Inside R.F)	Agricultural croplands, fallow land, build up areas & scrub forest
Non-forest area (Outside R.F)	Agricultural croplands, fallow land& built up areas)
Grassland	Riverine grasslands
The tree outside forest area	Homestead gardens, agriculture plantations and greenwash areas)
Mining area	Stone quarries
Rivers & water bodies	All perennial and non-perennial streams or water bodies
Sand & dry river beds	All old and new sandbars

As the focus of the study is on the forest cover changes in the RF areas, the forest cover inside the latter and the protected forest area has been classified into dense forest and open / degraded forest area. The trees outside forest area (includes mainly homestead gardens, agriculture plantations and greenwash areas) were not classified as dense forest and open /degraded forest area. Due to the low resolution (30 meter) of satellite imageries, it was difficult to differentiate the agriculture croplands, grasslands, fallow lands, built-up areas and scrub forests area inside the RF area and as well as agricultural croplands, fallow lands &built-up areas outside the RF area. Therefore, only two types of non-forest area categories were delineated as non-forest area (inside RFs) and non-forest area (outside RFs). The resulting LULC maps were analysed and their attribute values were compared to detect the changes during 1987-2013.The accuracy of each classification was expressed in the form of an error matrix (Congalton, 1991, Congalton & Green, 1998).

The process of LULC analysis (Figure2) in Erdas Imagine (v2014) using supervised classification techniques, creating signatures that were evaluated for separability and contingency and an accuracy assessment were performed for each classified image using 350 randomly generated points. It was ensured that these points were distributed throughout the classified image using ‘stratified random’ (the number of points is stratified to the distribution of thematic layer classes) distribution parameters. Generally, more than 250 reference pixels are needed to estimate the mean accuracy of a class within plus or minus five percent (Congalton, 1991). Finally, the classified land use/land cover maps were analysed and compared and areas were calculated and their attribute values were compared. Thereafter for each year the changes were detected and mapped accordingly.

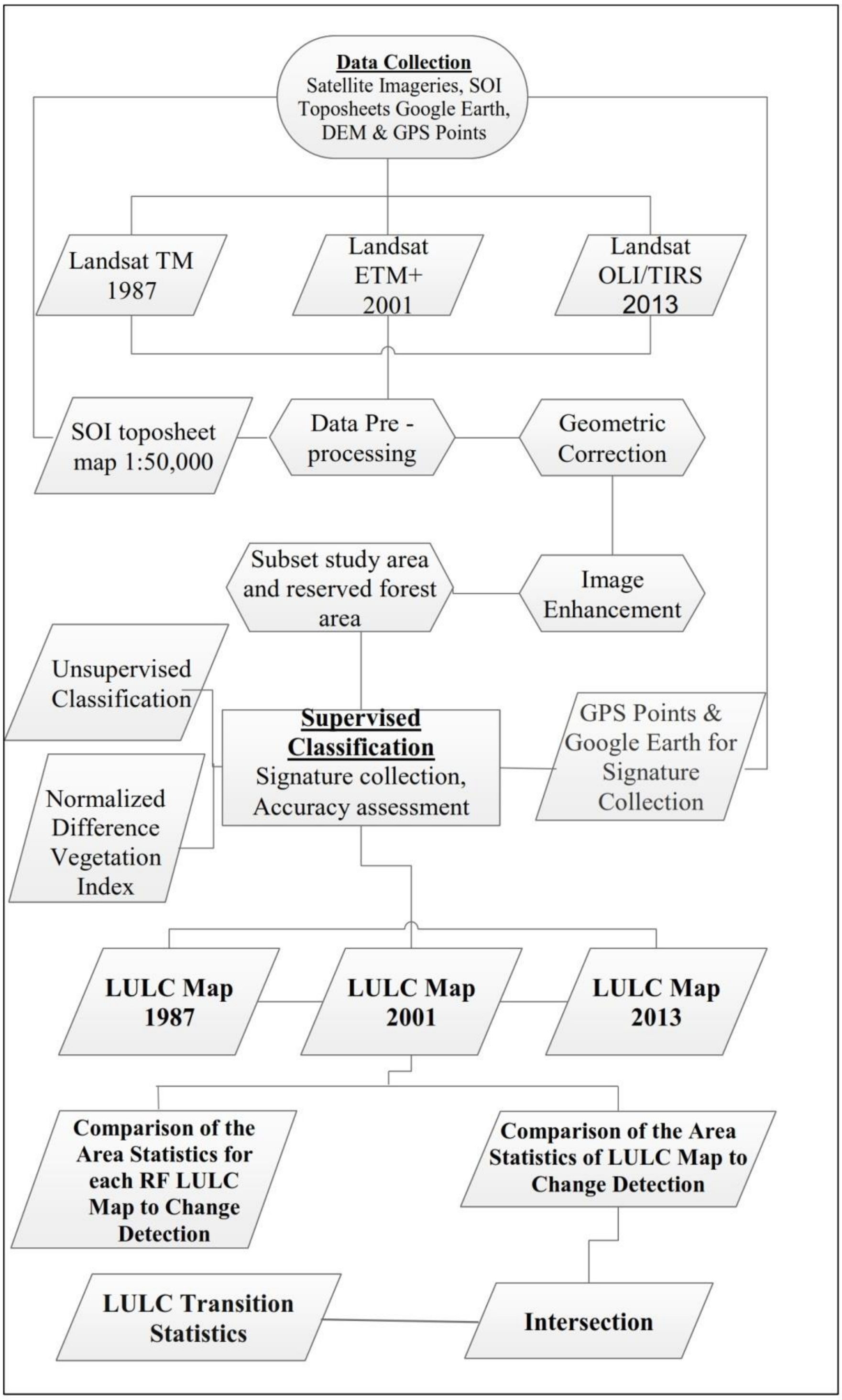

Figure 2: Flowchart of the methodology used for LULC change mapping

The study used supervised classification techniques for image classification to analyze the spatiotemporal trends in LULC changes during 1987, 2001 and 2013.This assessment also examined the role of elevation in impacting LULC changes. Finally the spatial metrics program Fragstats was used to assess forest fragmentation.

4. RESULTS AND DISCUSSION

4.1 Landscape level land-cover change

A spatio-temporal quantification of changes in the LULC pattern of Nagaon district during 1987-2013 was performed and the areal changes therein were determined (Table 3).The results indicate that in 1987, the dense forest category occupied the maximum area followed by open /degraded forest which comprised mainly moist mixed deciduous forests (MMD).

Table 3: LULC changes in Nagaon district

Landuse/ Landcover	YEAR 1987		YEAR 2001		YEAR 2013	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)	Area (Ha)	Area (%)
Dense forest	36310.5	9.1	28137.4	7.0	23796.9	6.0
Open forest / Degraded forest	29030.6	7.3	27581.1	6.9	27151.4	6.8
Non forest area (inside R.F)	11923.3	3.0	20491.7	5.1	27546.5	6.9
Non forest area (outside R.F)	235183.8	58.8	255943.0	64.0	269218.7	67.4
Tree outside forest area	65631.9	16.4	48734.2	12.2	35931.1	9.0
Mining area (stone quarries)	0.0	0.0	37.1	0.0	66.8	0.0
Grassland (riverine vegetation)	10239.1	2.6	11146.4	2.8	7597.1	1.9
Rivers & water bodies	7548.2	1.9	5212.8	1.3	6151.4	1.5
Sands & dry river beds	3833.9	1.0	2417.7	0.6	2241.4	6.0
Total	399701.4	100	399701.4	100	399701.4	100

Rapid population growth (Table 4) and growing anthropogenic requirements trees outside forest area (namely homestead gardens, agriculture plantations and greenwash areas) decreased rapidly.

Table 4. Decadal percentage variation in the population of Nagaon district

Year	Percentage of population
1901-11	15.84
1941-51	36.65
1951-61	35.91
1961-71	38.99
1971-91	51.26
1991-01	22.26
2001-11	22.00

Source: Economic Survey, Assam-2011-12

The analysis of gains and losses of the various LULC categories indicated that except non-forest area categories, all of them had decreased (Table 5). In 2001 and 2013 gains were observed in the non-forest area (within RFs), non-forest area (outside RFs) and mining area (stone quarries) categories. An area of 8,568.4 hectares was converted to the non-forest area (within RFs) during 1987-2001 and 7,054.8 ha during 2001-2013. Further, 20,759.2 and 13,275.7 ha were converted to non-forest area (outside RFs) during 1987- 2001 and 2001-13 respectively. The mining area (stone quarries) category likewise converted 37.1 and 29.7 ha during 1987-2001 and 2001-13 respectively.

The increases of such non-forest categories resulted in a corresponding decrease in the other LULC categories. Disconcertingly, all the forest cover categories decreased in 2013 with the maximum decrease in the dense forest category, followed by open/degraded forest and trees outside RFs. An increase of 907.2 ha of grassland (riverine vegetation) accrued during 1987-2001. However, due to seasonal variation of river courses and conversion of grasslands to agricultural area (occupied by the illegal settlers in riverine sandbar areas, locally known as '*char'* areas), grassland decreased by 3,549.3 ha during 2001-13. However, through 1987-2013 as a whole, rivers and water bodies showed a decreasing trend of 2,335.4 ha (1987-2001), but increased 938.7 ha over 2001-13. These fluctuations were on account of seasonal changes and corresponding variation in the extent of sand in the dry river beds.

Table 5. Gain and loss of LULC categories in Nagaon District

Landuse/ landcover	Changes during 1987 - 2001	Changes during 1987 - 2001	Changes during 2001-2013	Changes during 2001-2013	Changes during 1987-2013	Changes during 1987-2013
	Area (Ha)	Area (%)	Area (Ha)	Area (%)	Area (Ha)	Area (%)
Dense forest	-8173.1	13.5	-4340.4	10.2	-12513.6	12.6
Open forest / Degraded forest	-1449.5	2.3	-429.7	1.0	-1879.2	1.9
Non forest area (in side R.F)	8568.4	14.2	7054.8	16.6	15623.2	15.7
Non forest area (outside R.F)	20759.1	34.3	13275.7	31.2	34034.9	34.2
Tree outside forest area	-16897.7	27.9	-12803.1	30.1	-29700.8	29.9
Mining area (stone quarries)	37.1	0.1	29.7	0.1	66.8	0.1
Grassland (riverine vegetation)	907.2	1.5	-3549.3	8.3	-2642.0	2.7
Rivers & water bodies	-2335.4	3.9	938.7	2.2	-1396.7	1.4
Sands & dry river beds	-1416.2	2.3	-176.3	0.4	-1592.5	1.6
Total	60543.8	100	42597.7	100	99449.7	100

Substantial LULC changes occurred in the different categories over the period 1987 to 2013 (Table 5). The extents of non-forest area (inside RFs), non-forest area (outside RFs) and mining area (stone quarrying) category consistently increased, while those of dense forest, open/ degraded forest and trees outside RFs consistently decreased. Grassland (riverine vegetation), rivers and water bodies and sands & dry river beds experienced both gains as well as losses during 1987-2013. The maximum changes occurred during 1987- 2001 and reduced in intensity during 2001-13 across 60543.8 and 42597.7 ha respectively.

Considering the category wise LULC changes, gains were made in the non-forest area (inside RFs) over 8568.4 ha (14.2 %) and 7054.8 ha (16.6 %) during 1987-2001 and 2001-13 respectively. Thus a total increase of 15623.2 ha accrued during 1987-2013 in non-forest area within the loosely protected limits of RFs. The non-forest area (outside RFs) did not fare too well either, increasing 20759.1 (34.3 %) and 13275. 7 ha (31.2 %) during 1987-2001 and 2001-

13 respectively. The mining area (stone quarrying) category increases were far less substantial and extensive amounting to merely 37.1 ha (1987-2001) and 29.7 ha (2001-13).

In Nagaon, the loss of forest areas is particularly important since the former are categorised as RFs. Losses in forests within RFs reflect poor levels of protection afforded to them or the inadequacy thereof. Unfortunately, however, such scenarios persist in several protected areas in other parts of north east India (Hazarika and Saikia, 2013; Saikia, 2009) wherein rising anthropogenic pressures (Saikia, 1998) have not helped.

In Nagaon's RFs forest degradation and deforestation occurred progressively in the peripheral and low lying areas. Illegal felling of trees, illegal extraction of forest products and conversion of RF area to homesteads and paddy fields cumulatively contributed to these losses. The dense forest area decreased 8173.1 ha (13.5 %) from 1987 to 2001, and 4340.5 ha (10.2%) during 2001-13. During 1987-2013 the category lost an area of 12513.6 ha (12.6 %). Similarly, the open /degraded forest lost 1449.5 ha (2.4%) during 1987 -2001 and 429.7 ha (1.0%) area from 2001-13 and amounting to 1879.2 ha during 1987-2013. Trees outside forests likewise lost a substantial acreage of 29700.8 hectares (29.9 %) during 1987-2013 (Table 5).

LULC changes were more susceptible in low and medium elevation areas compared to those at relatively higher elevation areas. Thus, the losses in dense and open /degraded forests occurred mostly in the low and medium elevation stretches. The lower altitude zones are more amenable to anthropogenic activities, hence these areas were experienced greater forest losses. A similar situation accrued for trees outside RFs which tended to decline very markedly in low elevation stretches of Nagaon. On the other hand, extraction of forest resources was slightly more difficult in hill areas, a situation not unlike that prevailing in the neighbouring province of Manipur (Sharma and Saikia, 2018)

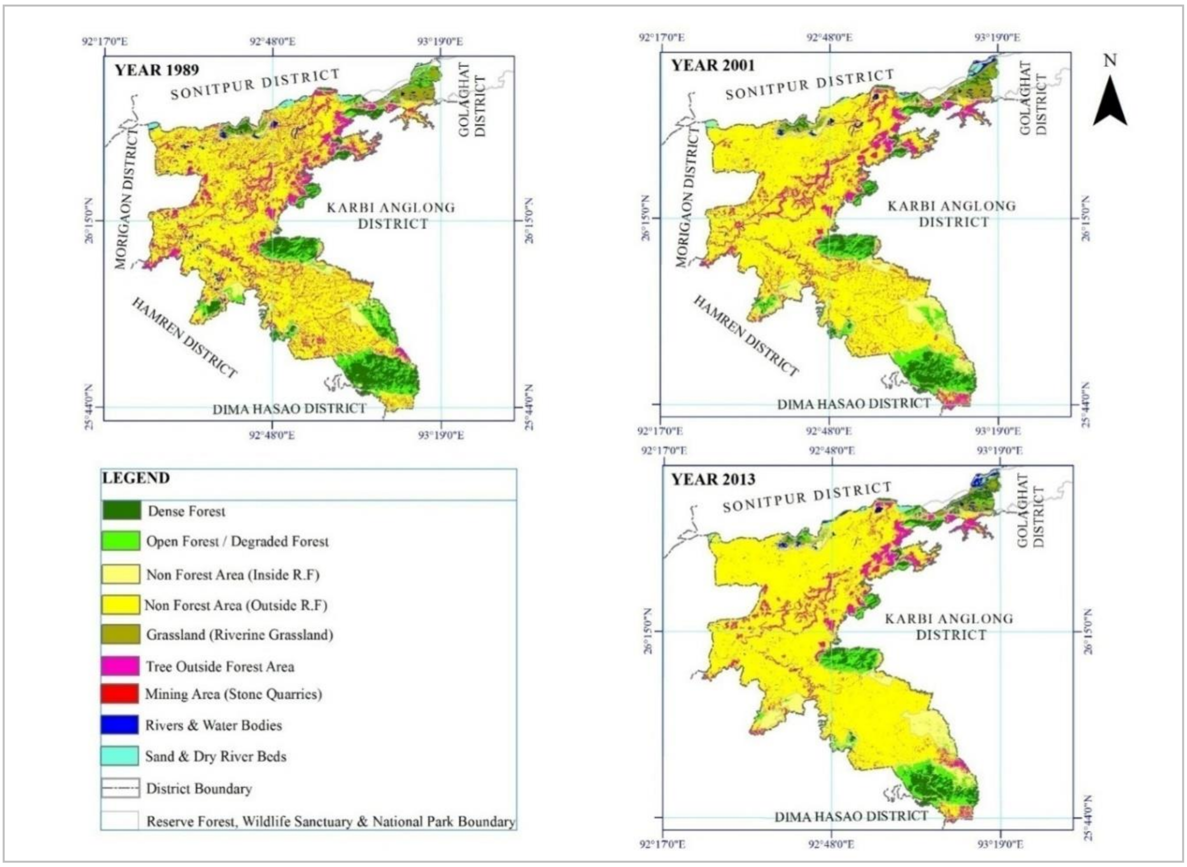

Figure 3: LULC map of Nagaon district

4.2 LULC classification accuracy assessment

LULC maps derived from remote sensing data frequently present various errors as result of various factors, classification techniques or the method of satellite data capture. The quantification of LULC changes thus requires an accuracy assessment. The accuracy assessment process entails the quantitative assessment of how effectively the pixels are sampled into the correct LULC categories. Therefore, classification accuracy assessment is an important step in LULC mapping and to assess map quality and reliability. Ultimately there is no satisfactory accuracy assessment method to assess the absolute accuracy of image classification for remote sensing earth observation applications (Erasu, 2017, Alqurashi, & Kumar, 2013).

Before the accuracy assessment, the created signatures were evaluated for separability and contingency and then accuracy assessment was done for each classified image with the randomly generated sample points throughout the classified image using 'equalized random' distribution parameters. A total of 360 sample points were created for the eight LULC categories in Nagaon district. For each class a total of 45 random points were collected as reference points from the Landsat TM & ETM satellite imageries as well as from ground-based data, particularly for the year 2013. During the accuracy assessment process, the mining area (stone quarrying) category was excluded from the process due to their absence in 1987. Thus, the mining was assessed on the basis of official government records and verified on the basis of field surveys.

An error matrix is similar to a contingency matrix described in evaluation of training sites and it is the most common method used to assess the accuracy of classified remotely sensed data (Congalton, 1991; Congalton & Green, 1999; Ismail & Jusoff, 2008). The matrix provides a cross-comparison of pixels taken from the classified image with corresponding ground reference data. One dimension of the matrix is the ground reference data while the other dimension are of the corresponding classified pixels. The elements in major diagonal of matrix error are pixels that are correctly classified for each category. In this study, standard criteria of accuracy assessment of the classification such as producer's accuracy, user accuracy, over all accuracy and kappa coefficient were computed from the error matrix (Congalton & Green, 1999; Ismail & Jusoff, 2008). Kappa coefficient, also known as Kappa hat or K-hat ($\hat{K}$) values indicate how closely the remotely sensed classification agrees with or approximates the reference data (Lubis & Nakagoshi, 2011). The Kappa coefficient value represent three groups of acceptance: a value greater than 0.80 represents strong agreement or a good classification performance; values between 0.40-0.80 and those less than 0.40 indicate moderate or poor classification performances respectively (Im & Jensen, 2005).

Result of the LULC accuracy assessments for 1987 (Table 6), 2001 (Table 7) and 2013 (Table 8) indicate that they meet an acceptable level of 85% overall classification accuracy. The overall classification accuracy for the year 1987 was 91.1%. Non-forest area (within RFs), non-forest area (outside RFs), rivers and water bodies and sands and dry river beds were classified with above 90% accuracy while dense forest, open /degraded forest, grassland (riverine vegetation), trees outside RFs and mining areas, had the least correctly classified total of below 90%. Overall Kappa statistics for the classification of 1987 was 0.89.

The overall accuracy of the classification for the year 2001 was 89.1% while the overall Kappa statistics were 0.8. Out of 360 reference points, 321 were classified correctly. Dense forest, open /degraded forest, non-forest area (inside RFs), non-forest area (outside RFs), trees outside RFs and grassland (riverine vegetation) areas had a user's accuracy of 88.9% and 86.6 % respectively, while rivers & water bodies and sands & dry river beds had accuracy levels of 93.3% and 91.1% respectively.

Table 6. Error matrices showing Producer's and User's Accuracy for the classified map of 1987

Classified Data	Reference Data									
	Dense forest	Open forest / Degraded forest	Non forest area (inside R.F)	Non forest area (outside R.F)	Tree outside R.F Area	Grassland (riverine vegetation)	Rivers & water bodies	Sands & dry river beds	Row Total	User's Accuracy
Dense forest	40	4	0	0	0	1	0	0	45	88.9%
Open forest / Degraded forest	3	40	1	0	0	1	0	1	46	88.9%
Non forest area (inside R.F)	1	2	42	0	0	0	0	0	45	93.3%
Non forest area (outside R.F)	0	0	0	42	2	0	0	0	44	93.3%
Tree outside R.F Area	0	0	0	5	39	0	0	0	44	86.6%
Grassland (riverine vegetation)	1	3	0	0	0	40	0	1	45	88.9%
Rivers & water bodies	1	0	0	0	0	1	43	0	45	95.5%
Sands & dry river beds	0	0	0	2	0	0	0	42	44	93.3%
Column Total	46	49	43	49	41	43	43	44	360	-
Producer's Accuracy	86.9%	83.3%	97.6%	85.7%	95.1%	93%	95.5%	95.4%	-	-

Table 7. Error matrices showing Producer's and User's Accuracy for the classified map of 2001

Classified Data	Reference Data									
	Dense forest	Open forest / Degraded forest	Non forest area (in side R.F)	Non forest area (outside R.F)	Tree outside R.F Area	Grassland (riverine vegetation)	Rivers & water bodies	Sands & dry river beds	Row Total	User's Accuracy
Dense forest	40	3	0	0	0	2	0	0	45	88.9%

Open forest / Degraded forest	3	39	3	0	0	0	0	0	45	86.7%
Non forest area (inside R.F)	0	3	40	0	0	0	0	2	45	88.9%
Non forest area (outside R.F)	0	0	0	40	5	0	0	0	45	88.9%
Tree outside R.F Area	0	0	0	5	40	0	0	0	45	8
Grassland (riverine vegetation)	1	2	0	0	0	39	1	2	45	86.6%
Rivers & water bodies	0	0	0	1	1	0	42	1	45	93.3%
Sands & dry river beds	0	0	0	2	0	1	1	41	45	91.1%
Column Total	44	47	43	48	46	42	44	46	360	-
Producer's Accuracy	90.9%	82.9%	93%	83.3%	86.9%	92.8%	95.4%	93.6%	-	-

Table 8. Error matrices showing Producer's and User's Accuracy for the classified map of 2013

Classified Data	Reference Data									
	Dense forest	Open forest / Degraded forest	Non forest area (in side R.F)	Non forest area (outside R.F)	Tree outside R.F Area	Grassland (riverine vegetation)	Rivers & water bodies	Sands & dry river beds	Row Total	**User's Accuracy**
Dense forest	40	2	0	0	0	3	0	0	45	88.8%
Open forest / Degraded forest	0	39	1	0	0	5	0	0	45	86.6%
Non forest area (inside R.F)	0	4	41	0	0	0	0	0	45	91.1%
Non forest area (outside R.F)	0	0	0	44	1	0	0	0	45	97.7%
Tree outside R.F Area	0	0	0	7	38	0	0	0	45	84.4%
Grassland (riverine vegetation)	0	0	1	1	0	38	2	3	45	84.4%
Rivers & water bodies	0	0	3	1	0	1	40	0	45	88.9%
Sands & dry river beds	1	0	0	0	0	0	0	44	45	97.8%
Column Total	41	45	46	53	39	47	42	47	360	-
Producer's Accuracy	97.5%	86.6%	89.1%	83%	97.4%	80.8	95.2%	93.6%	-	-

For the year 2013, the overall accuracy for the classification was 90% and the Kappa coefficient was 0.8. During the classification process for 2013, the signature and reference point collection were performed on the basis of field survey and high resolution Google earth imagery. Thus, the resultant accuracy assessments were higher those in 2001. 324 of the 360 reference points were classified correctly.

4.3 Landscape metrics

Landscape metrics have gained importance in land use studies (Sharma, Robeson, Thapa, & Saikia, 2017, Yuan et al. 2015, Tomaselli, Tenerelli, & Sciandrello, 2012). The percentage of landscape (PLAND) quantifies the proportional abundance of each patch type in the landscape. Like total class area, it is a measure of landscape composition and is important in many ecological applications. PLAND equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100 (to convert to percentage). It has been observed that there has been considerable decrease of percentage of patch type in each category except non-forest area inside and outside RFs (Table 9). While dense forest area registered a decrease of 3.6 % in 1987 to 2.4% in 2013, open forest 2.9% in 1987 to 2.7% in 2013, there was considerable increase of non-forest area within as well as outside the RFs (Table 9).Further the mining area registered a slight increase from 0% to 0.01% in 2013. Similarly the number of patches (NP) of all categories except non forest areas decreased considerably.

Table 9. Landscape metrics of the Nagaon district of Assam, India

Landuse / land cover categories	PLAND (%)			NP (number of patches)			LPI (%)			MPS (mean patch size) ha			ED (edge density) (m ha)		
	1987	**2001**	**2013**	**1987**	**2001**	**2013**	**1987**	**2001**	**2013**	**1987**	**2001**	**2013**	**1987**	**2001**	**2013**
Dense forest	3.6	2.8	2.4	1930	4203	1105	1.3	0.8	0.4	18.8	6.7	21.6	3.5	4	2.3
Open forest	2.9	2.7	2.7	3107	3846	2524	0.3	0.5	0.4	9.3	7.1	10.7	4.6	5.1	3.4
Tree outside forest area	6.5	4.8	3.6	12776	12552	6714	0.3	0.6	0.2	5.1	3.8	5.3	13.4	10.5	6.4
Non-forest area (inside RF)	1.2	2.1	2.7	697	1624	917	0.3	0.8	1.1	17.1	12.6	30.1	1.2	2	1.9
Non-forest area (outside RF)	23.5	25.6	26.9	2006	2956	2122	21.9	22	25.6	117	86.5	126.7	14.1	11.2	7.37
Grassland	1	1.1	0.7	465	766	491	0.5	0.5	0.2	21.9	14.5	15.6	1.1	1.2	1.1
Mining area (Stone quarries)	0	0	0.01	0	14	16	0	0	0	0	2.6	4.1	0	0	0
River & water bodies	0.7	0.5	0.6	2568	997	1333	0.03	0.1	0.1	2.9	5.2	4.6	2	1.1	1.3
Dry river bed	0.3	0.2	0.2	371	130	178	0.1	0.1	0.1	10.2	18.6	12.9	0.4	0.2	0.2

Edge density (ED) is another parameter used in many studies related to fragmentation of habitats. Increases in edge density are a primary outcome of habitat fragmentation (Sharma et al., 2017) which are related to reducing ecosystem functionality and habitat quality (Taubert et al. 2018; Hansen et al., 2013, Haddad et al., 2015). Studies assert that edge effects have a distinct impact on species richness, biomass dynamics, increasing tree mortality and recruitment, and alter forest structure and composition (Nascimento & Laurance, 2004; Harper et al. 2005; Wade, Ritters, Wickham & Jones, 2003; Laurance et al., 2002). Changes in PLAND, NP, mean patch size (MPS), and ED statistics clearly show an increasing fragmentation in the study area. The LPI shows that dense forest had the largest LPI among the forest classes i.e. 1.35 in 1987; however, this reduced significantly to 0.4 in 2013. Notably, though the MPS of dense forest registered a downward slide from 20.6 in 1987 to 8.8 in 2001, but recovered to 21.5 ha in 2013 (Table 10). This was most likely the outcome of a successful replantation programme by the state Forest Department. The MPS of open forest category (Table 11) shows a similar trend.

Table 10. Patch metrics of the dense forest land-use category

Patch Size	1987			2001			2013		
	NP	Area (ha)	MPS (ha)	NP	Area (ha)	MPS (ha)	NP	Area (ha)	MPS (ha)
<1	1212	406.8	0.3	2578	507.5	0.2	816	264.2	0.3
1 to 4.9	361	813.4	2.2	430	713.1	1.6	206	436.2	2.1
5 to 39.9	152	1947.4	12.8	122	1349.2	11	50	624.3	12.4
40 to 99.9	15	991.8	66.1	13	746.0	57.3	9	636.3	70.7
100 to 999.9	15	4669.2	311.2	20	7201.5	360.1	18	7137.5	396.5
1000 to 1999.9	5	7098.7	1419.7	4	6501.1	1625.3	3	4140.9	1380.3
2000 to 5999.9	0	0	0	1	2539.4	2539.4	3	10557.2	3519.1
above 6000	2.00	20383.02	10191.51	1	8579.29	8579.29	0.00	0.00	0.00
Total	1762	36310.5	20.6	316	28137.4	8.8	1105	23796.9	21.5

Table 11. Patch metrics of the open forest land-use category

Patch Size	1987			2001			2013		
	NP	Area (ha)	MPS (ha)	NP	Area (ha)	MPS (ha)	NP	Area (ha)	MPS (ha)
<1	2016	671.5	0.3	2083	622.3	0.3	1744	605.9	0.3
1 to 4.9	521	1111.6	2.1	455	972.3	2.1	538	1153.7	2.1
5 to 39.9	215	3041.2	14.1	171	1707.8	9.9	177	2165.8	12.2
40 to 99.9	34	2283.6	67.1	28	1416.7	50.6	33	2264.9	68.6
100 to 999.9	34	10557.7	310.5	28	6274.7	224.1	27	7818.1	289.5
1000 to 2999.9	2	4768.7	2384.4	3	6112.0	2037.3	4	8577.6	2144.4
above 3000	2	6596	3298	2	10474.9	5237.4	1	4565.1	4565.1
Total	2824	29030.6	10.2	2770	27581.1	9.9	2524	27151.4	10.7

5. CONCLUSION

Nagaon is emblematic of the losing battle faced by tropical forests in the face of agriculture and allied anthropogenic pressures. Tropical forests are variously converted either by large scale land operations or by smallholders. Tropical forest areas are often susceptible to land cover changes arising from smallholders, or colonist farmers steadily converting forest tracts into homesteads and agricultural plots (Caldas et al., 2007; Hazarika & Saikia, 2013; Tritsch & Le Tourneau, 2016) and Nagaon is no exception to this. Small farmers impact tropical forests when their numbers are substantial (Caldas et al., 2007) and rising population densities in Nagaon add to the pressure these forests are experiencing. There has been growing recognition of anthropogenic pressure on protected areas as well and the tussle between conservation and anthropogenic pressures are problematic around the globe. Identifying issues related to deforestation and related livelihoods is therefore critical to managing resources as well as conserving them for sustainable use.

Indeed, the real challenge is achieve a compromise between conservation and preservation of forests and the poverty alleviating requirements of smallholders (Cabral, Saito, Pereira & Laques, 2018). This study is an attempt to provide information on the status and trajectory of LULC and fragmentation in Nagaon, India upon which attempts to plan conservation strategies can be built.

REFERENCES

Alqurashi, A. F., & Kumar, L. (2013). Investigating the use of remote sensing and GIS techniques to detect land use and land cover change: A review. *Advances in Remote Sensing*, *2*(02), 193.

Anderson, J. R. (1976). *A land use and land cover classification system for use with remote sensor data* (Vol. 964). US Government Printing Office.

Bennett, A. F. (1999). *Linkages in the landscape: the role of corridors and connectivity in wildlife conservation* (No. 1). IUCN.

Cabral, A. I. R., Saito, C., Pereira, H., & Laques, A. E. (2018). Deforestation pattern dynamics in protected areas of the Brazilian Legal Amazon using remote sensing data. *Applied Geography*, 100, 101–115.

Caldas, M., Walker, R., Arima, E., Perz, S., Aldrich, S., & Simmons, C. (2007). Theorizing Land Cover and Land Use Change: The Peasant Economy of Amazonian Deforestation. *Annals of the Association of American Geographers*, 97(1), 86–110.

Champion, S. H., & Seth, S. K. (1968). A revised survey of the forest types of India. *A revised survey of the forest types of India*.

Chen, D., & Stow, D. (2002). The effect of training strategies on supervised classification at different spatial resolutions. *Photogrammetric Engineering and Remote Sensing*, *68*(11), 1155-1162.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote sensing of environment*, *37*(1), 35-46.

Congalton, R. G., & Green, K. (2008). *Assessing the accuracy of remotely sensed data: principles and practices*. CRC press.

DeFries, R., Hansen, A., Turner, B. L., Reid, R., & Liu, J. (2007). Land use change around protected areas: management to balance human needs and ecological function. *Ecological Applications*, *17*(4), 1031-1038.

Erasu D (2017) Remote Sensing-Based Urban Land Use/Land Cover Change Detection and Monitoring. J *Remote Sensing & GIS* 6, 196

Forest Survey of India. (1987). *India State of Forest Report* 1987. Forest Survey of India.

Forest Survey of India. (2017). *India State of Forest Report 2017*. Forest Survey of India.

Guide, E. F. (2010). Technical documentation. *ERDAS Inc*.

Gupta, S., & Roy, M. (2012). Land Use/Land Cover classification of an urban area-A case study of Burdwan Municipality, India. *Int. J. Geomat. Geosci*, *2*(4), 1014-1026.

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D. & Cook, W. M. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, *1*(2), e1500052.

Hansen, A. J., & DeFries, R. (2007). Ecological mechanisms linking protected areas to surrounding lands. *Ecological Applications*, *17*(4), 974-988.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A. A., Tyukavina, A. & Kommareddy, A. (2013). High-resolution global maps of 21st-century forest cover change. *science*, *342*(6160), 850-853.

Harper, K. A., Macdonald, S. E., Burton, P. J., Chen, J., Brosofske, K. D., Saunders, S. C. & Esseen, P. A. (2005). Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology*, *19*(3), 768-782.

Hazarika, R. (2011). People, Pachyderms and Pixels: The Impact of Forest Cover Changes in Sonitpur District, Assam(. PhD Thesis (Unpubl.) Gauhati University, India.

Hazarika, R., & Saikia, A. (2013). The pachyderm and the pixel: an assessment of elephant habitat suitability in Sonitpur, India. *International Journal of Remote Sensing*, 34(15), 5317-5330.

Im, J., & Jensen, J. R. (2005). A change detection model based on neighborhood correlation image analysis and decision tree classification. *Remote Sensing of Environment*, *99*(3), 326-340.

Ismail, M. H., & Jusoff, K. (2008). Satellite data classification accuracy assessment based from reference dataset. *International Journal of Computer and Information Science and Engineering*, *2*(2), 96-102.

La Mela Veca, D. S., Cullotta, S., Sferlazza, S., & Maetzke, F. G. (2016). Anthropogenic influences in land use/land cover changes in Mediterranean forest landscapes in Sicily. *Land*, *5*(1), 3.

Laurance, W. F., Lovejoy, T. E., Vasconcelos, H. L., Bruna, E. M., Didham, R. K., Stouffer, P. C., & Sampaio, E. (2002). Ecosystem decay of Amazonian forest fragments: a 22-year investigation. *Conservation Biology*, *16*(3), 605-618.

Lubis, J.P.G &Nakagoshi, N. (2001). Land use and land cover change detecting using remote sensing and geographic information system in Badri Watershed, central Java, Indonesia. *Journal of International Development Cooperation*, 18 (1), 139-151

Midha, N., & Mathur, P. K. (2010). Assessment of forest fragmentation in the conservation priority Dudhwa landscape, India using FRAGSTATS computed class level metrics. *Journal of the Indian society of Remote Sensing*, *38*(3), 487-500.

Mokarram, M., Boloorani, A.D. and Hojati, M., (2016). Relationship between Land Cover and Vegetation Indices. Case Study: Eghlid Plain, Fars Province, Iran. *European Journal of Geography*, 7(2), pp.48-60.

Nascimento, H. E., & Laurance, W. F. (2004). Biomass dynamics in Amazonian forest fragments. *Ecological Applications*, *14*(sp4), 127-138.

Patil, M. B., Desai, C. G., & Umrikar, B. N. (2012). Image classification tool for land use/land cover analysis: A comparative study of maximum likelihood and minimum distance method. *Int J Geol Earth Environ Sci*, *2*, 189-196.

Polasky, S., Nelson, E., Pennington, D., & Johnson, K. A. (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. *Environmental and Resource Economics*, *48*(2), 219-242.

Saha, A. K., Arora, M. K., Csaplovics, E., & Gupta, R. P. (2005). Land cover classification using IRS LISS III image and DEM in a rugged terrain: a case study in Himalayas. *Geocarto International*, *20*(2), 33-40.

Sahebjalal, E., & Dashtekian, K. (2013). Analysis of land use-land covers changes using normalized difference vegetation index (NDVI) differencing and classification methods. *African Journal of Agricultural Research*, *8*(37), 4614-4622.

Saikia, A. (2009) NDVI variability in North East India. *Scottish Geographical Journal*, 125 (2), 195-213.

Saikia, A., Hazarika, R., & Sahariah, D. (2013). Land-use/land-cover change and fragmentation in the Nameri Tiger Reserve, India. *Geografisk Tidsskrift-Danish Journal of Geography*, *113*(1), 1-10.

Sanderson, E. W., Jaiteh, M., Levy, M. A., Redford, K. H., Wannebo, A. V., & Woolmer, G. (2002). The human footprint and the last of the wild: the human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not. *AIBS Bulletin*, *52*(10), 891-904.

See, L., Fritz, S., Perger, C., Schill, C., Albrecht, F., McCallum, I.,& Saikia, A. (2016). Mapping human impact using crowd sourcing. In *Mapping Wilderness* (pp. 89-101). Springer, Dordrecht.

Sharma, K., & Saikia, A. (2018). How green was my valley: forest canopy density in relation to topography and anthropogenic effects in Manipur valley, India. *Geografisk Tidsskrift-Danish Journal of Geography*, 1-14.

Sharma, K., Robeson, S. M., Thapa, P., & Saikia, A. (2017). Land-use/land-cover change and forest fragmentation in the Jigme Dorji National Park, Bhutan. *Physical Geography*, *38*(1), 18-35.

Suter, L.K., (2012). Land succession and intensification in the agricultural frontier: Sierra del Lacandón National Park, Guatemala. *European Journal of Geography*, 7(2), pp.116-138

Tang, Z., Sun, G., Zhang, N., He, J., & Wu, N.(2018). Impacts of Land-Use and Climate Change on Ecosystem Service in Eastern Tibetan Plateau, China. *Sustainability*, *10*(2), 467.

Taubert, F., Fischer, R., Groeneveld, J., Lehmann, S., Müller, M. S., Rödig, E., & Huth, A. (2018). Global patterns of tropical forest fragmentation. *Nature*, *554*(7693), 519.

Tolessa, T., Senbeta, F., & Kidane, M. (2016). Landscape composition and configuration in the central highlands of Ethiopia. *Ecology and evolution*, *6*(20), 7409-7421.

Tomaselli, V., Tenerelli, P., & Sciandrello, S. (2012). Mapping and quantifying habitat fragmentation in small coastal areas: a case study of three protected wetlands in Apulia (Italy). *Environmental monitoring and assessment*, *184*(2), 693-713.

Tritsch, I., & Le Tourneau, F.-M. (2016). Population densities and deforestation in the Brazilian Amazon: New insights on the current human settlement patterns. *Applied Geography*, 76, 163–172.

Vishwakarma, C.A., Thakur, S., Rai, P.K., KAMAL, V. and MUKHERJEE, S., (2016). Changing Land Trajectories: A Case Study From India Using A Remote Sensing Based Approach. *European Journal of Geography*, 7(2), pp.61-71.

Wade, T. G., Riitters, K. H., Wickham, J. D., & Jones, K. B. (2003). Distribution and causes of global forest fragmentation. *Conservation Ecology*, *7*(2).

Wilson, T. S., Sleeter, B. M., Sleeter, R. R., & Soulard, C. E. (2014). Land-use threats and protected areas: a scenario-based, landscape level approach. *Land*, *3*(2), 362-389.

Yuan, J., Cohen, M. J., Kaplan, D. A., Acharya, S., Larsen, L. G., & Nungesser, M. K. (2015). Linking metrics of landscape pattern to hydrological process in a lotic wetland. *Landscape ecology*, *30*(10), 1893-1912.