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Dynamics of Asian Elephant Habitat in Shivalik Landscape and Environs of Kalesar-Rajaji–Corbett Protected Area Network

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ABSTRACT

Kalesar-Rajaji–Corbett National Parks and Sonanadi Wildlife Sanctuary are part of protected area network in Shivalik landscape, and western most distribution limit for Asian elephant. During the past four decades the forest-agricultural-urban landscape and environs have undergone changes due to migration of humans, urban sprawl, infrastructure and industrial development within and very close proximity to protected areas. These changes could be linked to increased levels of human-animal conflicts. The present study analyses the forest cover and land use/land cover dynamics in the last 36 years using Landsat multispectral satellite images of year 1979, 1991, 2003 and 2015. The overall classification accuracy is 84.01% for 1979, 86.53% for 1991, 87.24% for 2003 and 89.12% for 2015. The study indicates that forest cover is nearly stable but environs of landscape have undergone changes with the highest during 2003-2015, soon after the formation of Uttarakhand state. The built-up and orchards have increased by about 185.23 km^2 and 117.93 km^2 for the period 1979-2015 in close proximity of protected areas around cities like Hardwar, Rishikesh, Kotdwar, Dehradun, etc., juxtaposed to the habitats of elephant, tiger, leopard, spotted deer, hog deer and affecting the Motichur-Chilla corridor. In the forest area, the highest changes are observed in ravine forest with 20.19 km^2 increase.

Key Words: Shivalik Landscape; Time-series Satellite Data; Forest Cover; Land Cover /Land Use Dynamics.

INTRODUCTION

Human activities have brought changes in physical characteristics of earth surface at various levels in the last century other than natural forces and calamities such as earthquakes, flash floods, volcanos, Tsunami, etc. (Turner and Ruscher 1988, Deka et al. 2014). These can be either negative or positive (Brown and Garver 2009).

Shivalik ranges form a narrow strip between the Himalaya to its north and Indo-Gangetic plains in the south. The valleys and lower hills between Shivalik and Himalaya, and Indo-Gangetic plains are highly fertile regions of Ganga river basin. These areas are also one of the most densely populated areas in India. The protected area network of Kalesar-Rajaji–Corbett National Parks and Sonanadi Wildlife Sanctuary in Shivalik landscape (KRCSL) may not be considered sufficiently a large landscape for long-range migratory species like elephants to survive, evolve and adapt to the changing environmental set up. And recent reports and our observations on the occurrence of elephants and tigers in Kalesar landscape in Haryana and Himachal indicate that both species could be migrating further westward from Rajaji National Park to find new home ranges due to increased population, setting Kalesar landscape as the western most limit of elephant distribution. However, changing environs in and around KRCSL due to developmental activities related to road, rail, urbanization, hotels, resorts, industrialization, particularly religious tourism ('Kavandias', 'Melas', 'Char Dham Yatras'); and urban sprawl due to migration of population from interior of Himalaya to cities such as Dehradun, Haridwar, Rishikesh, Ramnagar, Kotdwar and their outskirts in search of better life and employment opportunities, may undermine the conservation efforts in long-run. The vehicular traffic has increased many times; and disturbance due to infrastructure development, encroachment, habitat degradation, etc. have caused discontinuities in already narrow wildlife corridors in forested landscape. The half-finished, long delays and abandonment of Hardwar-Motichur-Raipur-Doiwala elevated road project is a challenge to our seriousness and socio-political system to biodiversity conservation. It is also forcing wild animals to find new migratory routes passing through agricultural landscape and causing more conflict.

Since KRCSL is the home of two most charismatic species such as Asian elephant and tiger with large home-ranges, which require the large and contiguous area to survive (Rodgers and Panwar 1988, Choudhury et al. 2008). The alterations in land use/land cover (LULC) have led to the increasing human-animal conflict incidences particularly human-elephant conflict (HEC) and leopard in and around the existing protected areas (PAs) network of KRCSL. Therefore, to conserve the biodiversity and maintain the connectivity among PA network the entire landscape was declared as the Shivalik Elephant Tiger Reserve in 2002. Apart from that, the landscape is also part of major conservation unit called Terai Arc Landscape Conservation Unit (TALCU), encompassing 14 PAs of India and Nepal with the areal extent of 49000 km^2 which also helps in preserving its biodiversity, ethical and cultural integrity. Despite the forest landscape discontinuities, habitat degradation and fragmentation, several important wildlife corridors of different length and width still exist throughout the landscape which not only provides contiguous landscape but also facilitates the movement and dispersal of wildlife (Menon et al. 2005, Nandy et al. 2007). Therefore, it is essential to map the status of habitats and corridors intermittently to understand time-domain spatial characteristics and changes to possibly regulate various management planning activities such as utilization of natural resources, various socio-economic activities involving different land use practices and biodiversity conservation.

Mapping of the natural resources is an important activity worldwide. Time-series multispectral Earth observation (EO) satellite data have been widely used to assess area and monitor the natural resources particularly forests- the home to biodiversity from local to global levels (Sivakumar et al. 2010, Joshi 2016). Several classification and change detection techniques have been developed considering specific requirements such as based on training sample (supervised and unsupervised classification), parameters assumption (parametric and non-parametric classifiers), pixel information (per-pixel classifier, sub pixel classifier, pre-field classifier and object-oriented classifiers), spatial element based (hard and soft classifier) and spatial information based (spectral classifier, contextual classifier and spectral-contextual classifier) (Kamavisdar et al. 2013, Pareta and Pareta 2015). The additional approaches include various classification methods i.e., fuzzy logic (Burrough et al. 2001, Tapia et al. 2005), artificial neural network (ANN) (Skldmore et al. 1997, Ingram et al. 2005), decision tree/ knowledge-based (Singh et al. 2003; Davranche et al. 2010), object-based image segmentation (Hay et al. 2005, Blaschke 2010, Singha et al. 2016), supervised (Roy et al.1991, Joshi et al. 2011), unsupervised (Townshend and Justice 1980, Singh et al. 2005, Areendran et al. 2013), hybrid (supervised-unsupervised) (Singh et al. 2002, Singh et al. 2003, Joshi et al. 2006) and on-screen visual interpretation techniques (Hanna et al. 2001, Joshi et al. 2001, Gupta et al. 2006, Nandy et al. 2007, Panigrahy et al. 2010).

The change detection methods using EO data have been reviewed from time-to-time and new approaches

have been suggested or offered (Singh 1989, Yuan et al. 1998). The choice and selection of change detection methods is always based on the objectives, however, several studies and experience suggest that post classification image comparison approach is capable to provide information about the transitional changes (from–to) which otherwise are not possible using pre-classification comparison (Ridd and Liu 1998). At global level, pre-classification methods have used monitoring of LULC (Michalek et al. 1993, Li and Yeh 1998, Lyon et al. 1998, Prakash and Gupta 1998), and at regional and local levels post classification change detection methods (Srivastava et al. 2002, Kushwaha and Hazarika 2004, Gupta et al. 2006, Panigrahy et al. 2010, Krishna et al. 2014, Onojeghuo and Onojeghuo 2015, Dutta et al. 2016). In Shivalik landscape post-classification comparison techniques were applied for change detection analysis (Hanna et al. 2001, Nandy et al. 2007, Areendran et al. 2017). Therefore, present study attempts to use time-series satellite images of the year 1979, 1991, 2003 and 2015 to map entire landscape and its immediate environs to analyse forest cover and land use/land cover dynamics. It is hoped that these maps will be useful to PA network management as well as planning for new infrastructure requirement considering biodiversity conservation in KRCSL and offer insights in mitigating the human-animal conflict hot spots.

STUDY AREA

The study area covers about 10,000 km^2, extending from 29° 05' to 30° 43' N latitude and elongated from 77° 19'to 79° 25' E longitude. It is bounded by Kalesar national park (Haryana) in the west and Kosi river (Uttarakhand) in the east covering about 250 km in length (Figure 1). The area spans across the four states *i.e.,* Haryana, Himachal Pradesh, Uttar Pradesh and Uttarakhand (major area). From forest department (FD) management perspective Shivalik hills are divided into 9 major units i.e., Kalesar FD, Shivalik FD, Dehradun FD, Hardwar FD, Rajaji FD, Lansdowne FD, Corbett FD, Ramnagar FD and Terai West FD (Menon et al. 2010). The Shivalik ranges, often called Sub-Himalaya tract run almost parallel to the lesser Himalaya. Geologically, this landscape is part of outer and lesser Himalaya, and was formed due to the displacement between Tethys in north and Indian lithosphere. Because of its unique geographic location (transition zone), the area has the great ecological and economic significance. It is ecologically fragile and seismologically active with main boundary thrust passing through.

Geomorphologically, typical Shivalik, northern aspect has gentle slope and southern slopes are highly rugged with vertically cut southern and sloping northern aspects. Relatively moist and shadowed northern aspect supports moist Sal forest, whereas southern aspect is highly dissected with numerous steep ridges and narrow valleys form the habitat of mixed vegetation of moist and dry deciduous forests and grasses on nearly barren slopes. *Euloliopsis duthei* Sur is endemic and endangered grass occurs in this area. The altitude varies between 160 and 2230 m above msl, due to which the area experiences a great variation in its temperature range i.e., 23-46°C in summer and 20-22°C in winter. The mean annual precipitation is 1800 mm with maximum rainfall from July to August (Rathore et al. 2013). The dominant forest types are tropical moist deciduous forest, tropical dry deciduous forest, subtropical Pine forest and Riverine dry deciduous forest (Champion and Seth, 1968). The area is well known for elephant, tiger, leopards, sloth bear, jackal, wild boar, monkey, barking deer, sambar, mountain goat goral, several species of birds, etc. (Roy et al. 1995, Menon 2014, Grimmett and Inskipp 2018). Elephants are distributed throughout except in highly dissected terrain and high-altitudes.

DATA AND METHODOLOGY

A total of 16 multispectral temporal satellite images of Landsat sensors (MSS, TM, ETM+, OLI and TIRS) of two seasons (summer and winter) to capture phenological variability for discriminating features for periods 1979-80, 1991-93, 2002-2003 and 2015-2016 were downloaded from earth explorer site (https://earthexplorer.usgs.gov/) (Table 1). The outline of the methodology is presented in Figure 2. The images were radiometrically corrected (DN to radiance using gain and bias value; and then radiance to reflectance using solar zenith angle, solar exoatmospheric irradiance, etc. parameters given in metadata file) to improve the quality of images and to make images spectrally compatible to each other (Davranche et al. 2010, Singh et al. 2013). These images were mosaicked and then stacked season-wise as shown in Figures 3 (a,c,e,g).

Level I and II classification schemes were adopted and applied uniformly for classification of forest cover

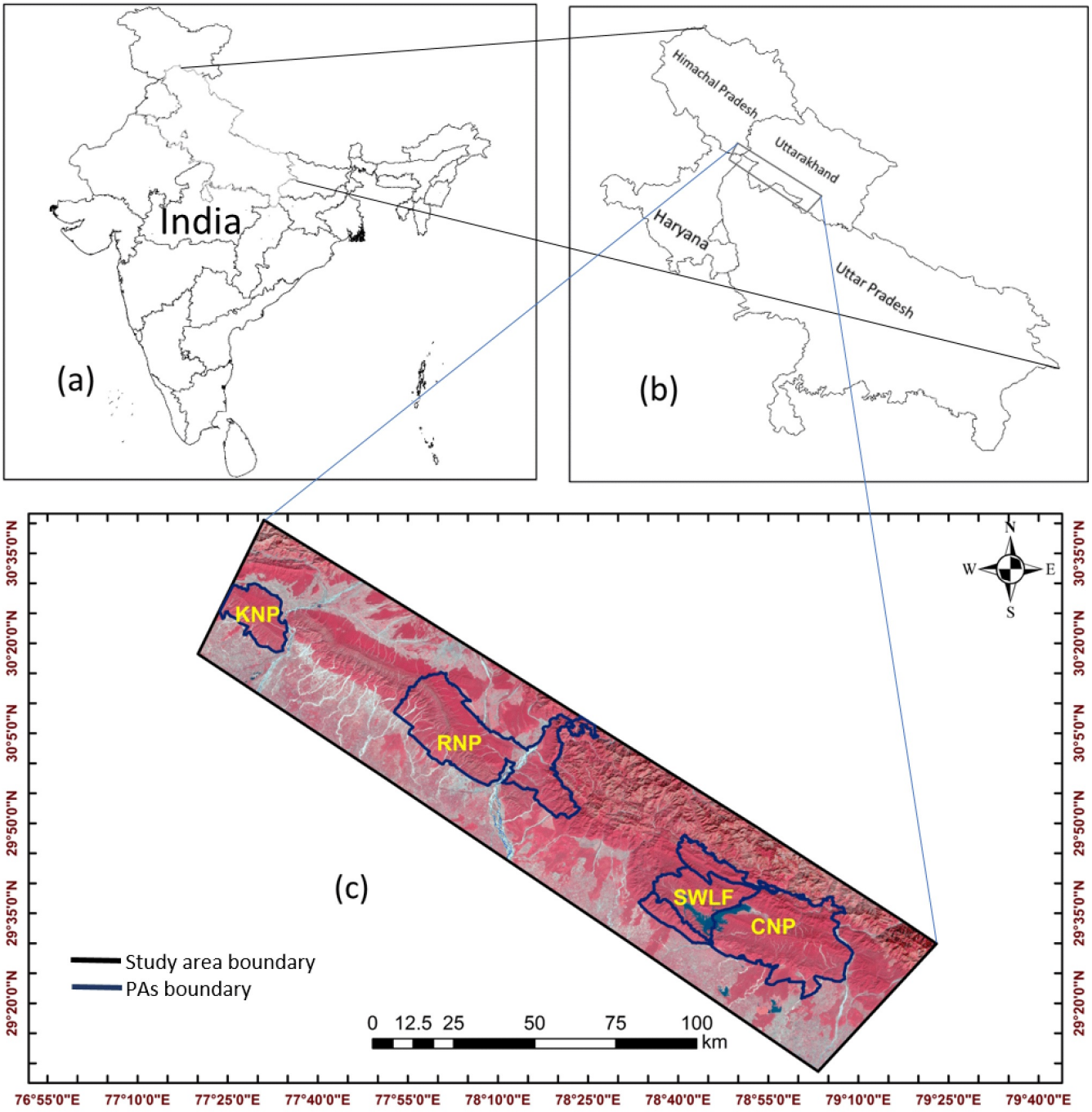

Figure 1. (a) Map of India, (b) Administrative states boundaries covering the study area and (c) False Colour Composite Landsat 8 OLI satellite data (RGB 5,4,3)of Shiwalik landscape of Kalesar (KNP)-Rajaji (RNP)- Sonanadi (SWLS)-Corbett (CNP) Protected Areas (NP=National Park, WLS=Wildlife Sanctuary).

and land use / land cover (FCLULC) (Anderson 1976) (Table 2). The classification schemes were adopted considering mapping of the vegetation types/habitat and environs. It was assumed that natural forested landscape is reasonably well managed and nature/type of forest is not likely to change in such a short span of time, therefore, physiognomy and phenological variability will remain uniform across the landscape because of similar terrain and climatic conditions. Latest dataset (2015) was considered for classification first to facilitate reconnaissance survey and ground truth collection, comparison, validation and accuracy assessment of the features and

ground conditions and then applied on past datasets. The unsupervised approach using ISODATA clustering algorithm of classification was adopted and applied uniformly. This enabled us to fully explore the spectral variability. After several iterations, from 50 to 500 clusters, finally 230 clusters were generated for all the datasets. The sufficient sample locations representing different areas were identified based on image characteristics in the entire landscape assuming that forest types are not likely to change because of protection and remoteness. These were treated as benchmarks, and were kept constant for checking and cross verification while assigning attributes.

Accuracy assessment of each of the classified map was done using 2015 dataset. A total of 3235 ground points belonging to different FCLULC collected during field surveys conducted in different seasons and time periods between 2015 to 2017 were imported and overlaid on the maps. The illustration of agreement and disagreement of each FCLULC was done by comparing observed ground truth with extracted corresponding pixels in the form of error matrix and then used for evaluation in assessments of overall accuracy, user's accuracy, producer's accuracy and kappa statistic. FCLULC dynamics analyses was done in Idrisi Taiga software using change detection analysis using each possible combination of datasets i.e., 1979 & 1991; 1979 & 2003; 1979 & 2015; 1991 & 2003; 1991 & 2015 and 2003 & 2015, are given in Figure 2.

Table 1. Details of the satellite data used in study (Source: http://earth explorer.usgs.gov)

Satellite	Sensor	Path & Row	Acquired Date	Spatial Resolution (m)	Spectral Bands
Landsat 08	OLI & TIRS	146039 & 145040	12/02/2015 11/11/2015 & 21/02/2015 13/11/2015	30	Band 1 (Ultra Blue): 0.435-0.45 µm Band 2 (Blue): 0.452-0.512 µm Band 3 (Green): 0.533-0.590 µm Band 4 (Red): 0.636-0.673 µm Band 5 (NIR): 0.851-0.879 µm Band 6 (SWIR) 1: 1.566-1.651 µm
				15	Band 7 (SWIR) 2: 2.08-2.35 µm Band 9 (Cirrus): 1.363-1.384 µm Band 10 (Thermal): 10.40-11.19 µm Band 11 (Thermal): 11.50 -12.51 µm Band 8 (Panchromatic): 0.503-0.676 µm
Landsat 07	Enhanced Thematic Mapper Plus (ETM)	146039 & 145040	07/03/2003 14/10/2002 &01/04/2003 23/10/2002	30	Band 1 (Blue): 0.45-0.52 µm Band 2 (Green): 0.52-0.60 µm Band 3 (Red): 0.63-0.69 µm Band 4 (NIR): 0.76-0.90 µm Band 5 (SWIR) 1: 1.55-1.75 µm
				(60*)30	Band 6 (Thermal): 10.40-12.50 µm
				30	Band 7 (SWIR) 2: 2.08-2.35 µm
				15	Band 8 (Panchromatic): 0.52-0.90 µm
Landsat 4-5	Thematic Mapper	146039 & 145040	04/04/1993 & 07/03/1991	30	Band 1 (Blue): 0.45-0.52 µm Band 2 (Green): 0.52-0.60 µm Band 3 (Red): 0.63-0.69 µm Band 4 (NIR): 0.76-0.90 µm Band 5 (SWIR) 1: 1.55-1.75 µm
				(120*) 30	Band 6 (Thermal): 10.40-12.50 µm
				30	Band 7 (SWIR) 2: 2.08-2.35 µm
Landsat 1-5	Multi–Spectral Scanner (MSS)	146039 & 145040	20/04/1979 & 26/10/1979	60	Band 2 (Green): 0.5-0.6 µm Band 3 (Red): 0.6-0.7 µm Band 4 (NIR): 0.7-0.8 µm Band 5 (NIR): 0.8-1.1 µm

Table 2. Classification scheme used in classification modified after (Anderson 1976)

Classification Scheme	Level I	Level II	Abbreviation
FCLULC	Forest	Sal Forest	SF
		Hill Sal Forest	Hill Sal
		Sal Mixed Forest	SM
		Mixed Moist Deciduous Forest	MMF
		Dry Deciduous Forest	DDF
		Pine Forest	Pine
		Oak Forest	Oak
		Tropical Hill Valley Swamp Forest	THVSF
		Ravine Grasslands	RG
		Ravine Forest	RF
		Miscellaneous Forest	Misc. F
		Swampy Grasslands	SG
		Scrubland	SL
	Plantation	Taungya Plantation	TP
		Holoptelea Plantation	HP
		Teak Plantation	TP
		Eucalyptus Plantation	Euc.
		Tea Plantation	Tea
	Non-Forest	Orchards	Orchard
		Built up	Built up
		Open Degraded Land	ODL
		Agriculture	Agri
		Dry River Beds	DRB
		Water Body	WB

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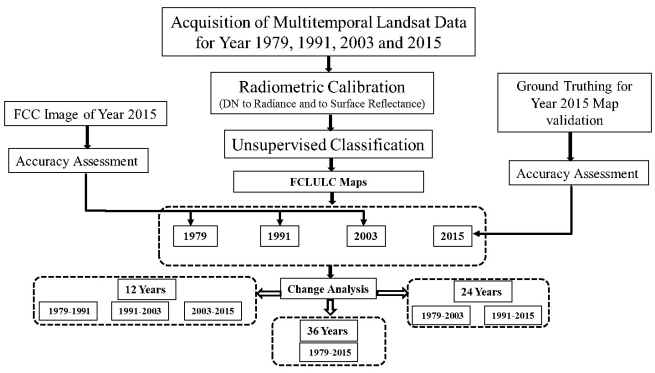

Figure 2. Outline of methodology for mapping, time-series analysis and change dynamics.

RESULTS

FCLULC Classification and Accuracy Assessment

The overall accuracy and kappa co-efficient of respective datasets are 84.01% & 0.72 for 1979, 86.53% & 0.84 for 1991, 87.24% & 0.85 for 2003 and 89.12% & 0.88 for 2015 (Table 3). An improvement in classification accuracy with recent dataset may be attributed to better sensor characteristics. The producer's accuracy was noticed highest 89.5% for 2003 and lowest 86.2% for 2015 datasets whereas user's accuracy was observed highest 86.7% for 2003 and lowest 85.3% for 1979 and 2015 datasets, respectively. The user's accuracy for ravine grasslands, dry deciduous forest and scrub land were below 80.0% possibly due to mixing of spectral signature from soil/boulders, while for hill Sal, swampy grasslands, *Holoptelea* plantation and open degraded land was 100%. However, pure Sal was found above 85% accurate.

The time-series classified FCLULC maps for the years 1979, 1991, 2003 and 2015 are presented in Figures 3 b,d,f,h and the area analyses is summarised in Tables 4 a & 4b. The area analyses at Level-1 mapping is given in Table 4a. It showed the highest area was covered by forest, followed by non-forest and plantation. The area covered under forest ranged between 53.68% (1979) to 53.7% (2015) whereas for plantation between 3.79% (1979) to 3.60% (2015) and non-forest between 42.54% (1979) to 42.7% (2015). The area analysis at Level-II categories is given in Table 4b. Among forest cover types Sal forest (12.1%) contributed the most, followed by Sal mixed forest (11.1 %) and mixed moist deciduous forest (10.67%) in all the years. Tropical hill valley swamp forest (0.11%) and swampy grasslands (0.11 to 0.19%) were the least. Under production forestry areas, Teak plantation covered 0.06% for the years 1979 to 2015. The agriculture land decreased from 34.97% in 1979 to 33.06% in 2015, while orchards cover increased from 0.25% in 1979 to 1.40% in 2015. Open degraded land cover fluctuated from 0.33% in 1979, 0.38% in 1991, 0.40% in 2003 and 0.32% in 2015.

FCLULC Dynamics

The FCLULC dynamics during 1979-1991, 1979-2003, 1979-2015, 1991-2003, 1991-2015 and 2003-2015 indicates various patterns of changes. The area changes between 1979-1991 (12 years), 1979-2003 (24 years), 1979-2015 (36 years), 1991-2003 (12 years), 1991-2015

(24 years) and 2003-2015 (12 years) have been summarised at level I in Table 5a and level II in Table 5b.

FCLULC Level-I Dynamics

At level-I from 1979 to 2015, non-forest category indicated positive growth (0.16%) whereas plantation area has deceased marginally (0.19%; Table 5a). The results also indicate that changes were highest in non-forest (mostly agriculture), which are adjacent to protected areas, followed by forest and plantation. For 12 years-period analysis indicates that non-forest area has increased by 5.88 km^2 between 1979-1991, 4.67 km^2 during 1991 to 2003 and 5.96 km^2 during 2003 to 2015 whereas for 24 years time-span increase in area under non-forest was accounted for 10.55 km^2 for each 1979-2003 and 10.64 km^2 during 1991-2015, thus net gain in non-forest in 36 years is 16.50 km^2, which is mostly juxtaposed to PAs.

The forest cover dynamics for 12 years from 1979-1991 indicates increase by 3.13km^2 whereas it decreased by 1.04 km^2 during 1991-2003 and increased again by 0.92 km^2 in 2003-2015, probably indicates impact of management practices. However, for 24 years time-interval, 2.09 km^2 forest area had increased between 1979-2003 but decreased by 0.12 km^2 during 1991-2015. Time–series change analysis for 36 years indicates that forest area has net gained by 3.01 km^2, mostly in riverine systems, regrowth due to diverted water channels.

Table 3. Year-wise accuracy assessment

FCLULC	Year - 1979		Year - 1991		Year - 2003		Year - 2015	
	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's
Sal	82.5	92.6	83.0	88.5	83.1	88.4	83.8	96.0
Hill Sal	82.5	100.0	84.0	100.0	84.2	100.0	85.2	100.0
Sal Mixed	81.9	80.8	81.4	76.7	82.0	77.5	82.1	78.6
MMF	82.8	79.9	83.2	81.9	83.9	83.0	84.7	77.5
DDF	83.6	70.9	84.1	76.8	84.4	78.6	85.4	72.9
Pine	82.4	86.4	84.7	85.6	85.4	89.1	85.9	84.6
Oak	86.0	86.0	90.7	90.7	87.5	90.3	88.2	93.8
THVSF	90.0	81.8	90.9	90.9	90.0	90.0	88.9	88.9
RG	85.0	73.9	91.7	78.6	86.7	72.2	83.3	55.6
RF	86.1	84.9	81.4	83.8	82.9	84.1	83.7	85.7
SG	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SL	80.4	59.2	82.3	66.0	83.5	60.0	84.9	63.3
TP	80.0	100.0	85.7	92.3	86.7	92.9	87.5	100.0
HP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Teak	85.5	74.7	88.4	79.2	86.8	84.6	88.6	81.3
Euc.	89.4	97.7	89.4	91.3	86.0	86.0	87.5	100.0
Tea	91.7	100.0	100.0	93.3	100.0	92.3	100.0	100.0
Misc F	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Orchard	92.9	43.3	91.7	47.8	92.0	65.7	93.4	87.7
Built up	94.4	65.4	90.0	67.5	93.6	75.9	94.9	92.5
ODL	91.7	100.0	83.3	100.0	90.9	100.0	100.0	100.0
Agri	93.0	96.9	93.9	97.3	92.8	97.5	93.9	96.5
DRB	90.3	89.3	92.6	92.1	91.9	91.0	92.9	96.3
WB	91.7	83.3	91.2	83.9	93.5	81.1	94.9	96.1
Total	88.5	85.3	89.3	86.0	89.5	86.7	86.2	85.3
Overall accuracy	84.01%		86.53%		87.24%		89.12%	
Kappa statistic	0.72		0.84		0.85		0.88	

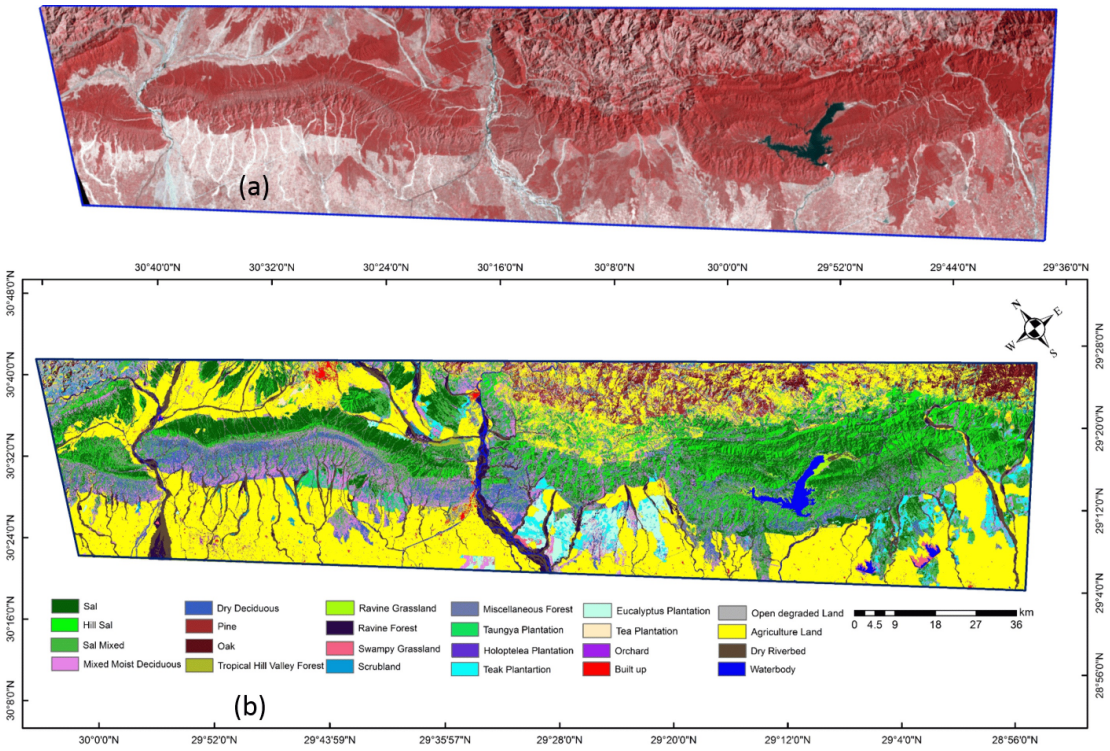

Figure 3. (a) False Colour Composite (RGB 4,3,2) of Landsat 1-5 Multispectral Scanner (MSS) sensor's satellite data, (b) Forest Cover Land Use Land Cover map of 1979.

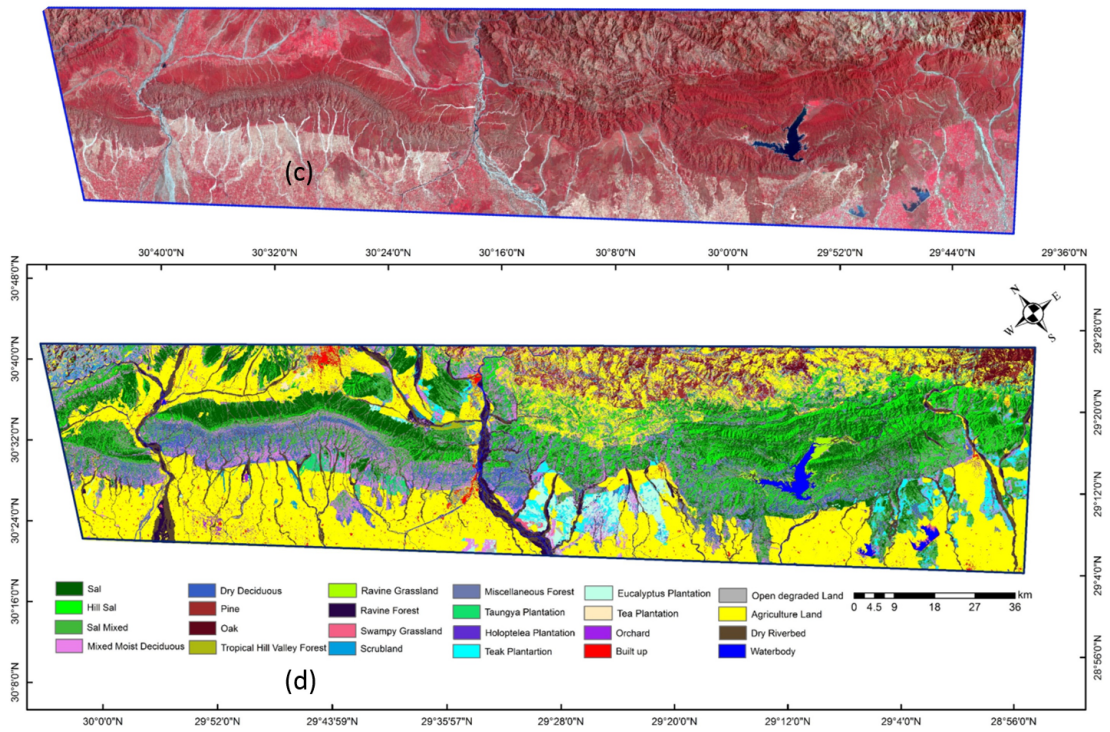

Figure 3. (c) False Colour Composite (RGB 4,3,2) of Landsat 4-5 Thematic Mapper (TM)sensor's satellite data, (d) Forest Cover Land Use Land Cover map of 1991.

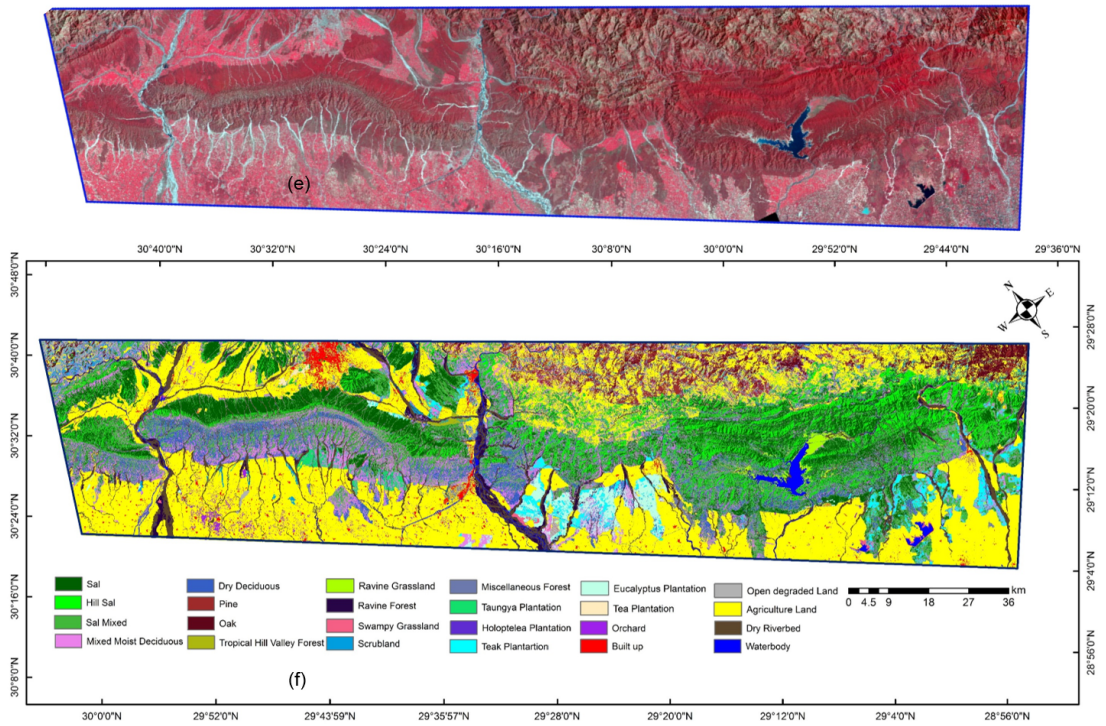

Figure 3. (e) False Colour Composite (RGB 4,3,2) of Landsat 7 Enhanced Thematic Mapper Plus (ETM$^+$) sensor's satellite data, (f) Forest Cover Land Use Land Cover map of 2003.

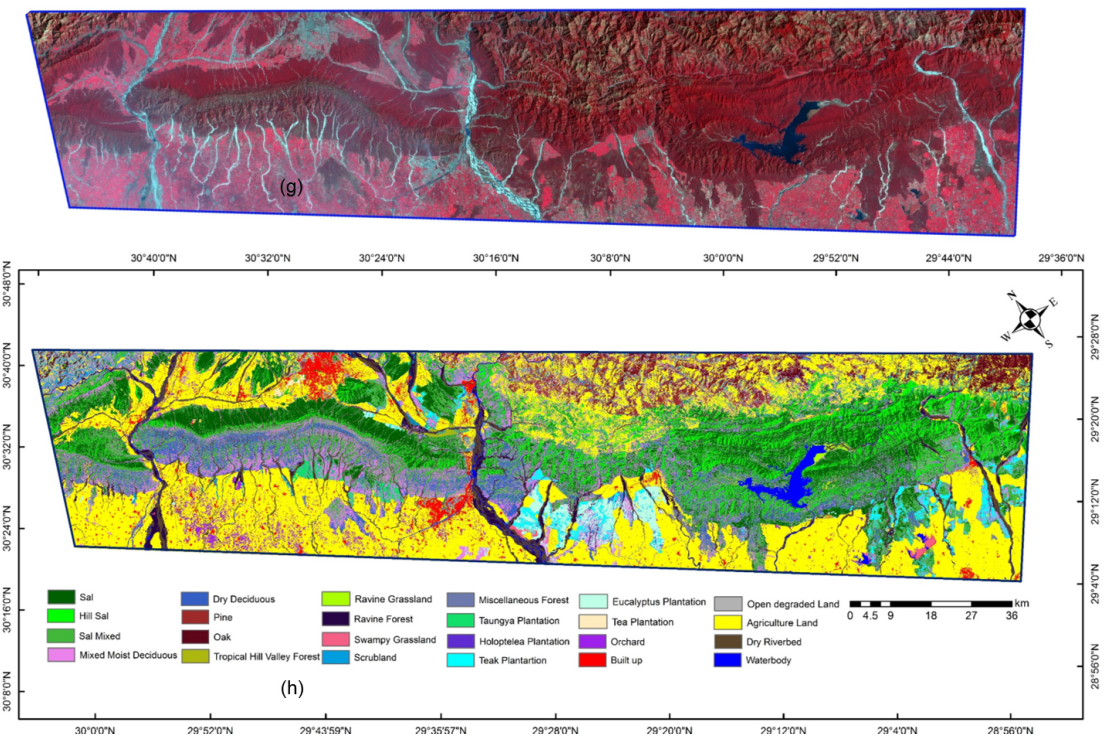

Figure 3. (g) False Colour Composite (RGB 5,4,3) of Landsat 8 Operational Land Imager (OLI) sensor'ssatellite data, (h) Forest Cover Land Use Land Cover map of 2015.

Table 4a. Level-I FCLULC time-series area statistics

FCLULC	1979		1991		2003		2015	
	km²	%	km²	%	km²	%	km²	%
Forest	5487.71	53.68	5490.84	53.71	5489.79	53.70	5490.71	53.70
Plantation	387.42	3.79	378.41	3.70	374.78	3.67	367.91	3.60
Non-Forest	4348.80	42.54	4354.68	42.59	4359.34	42.64	4365.30	42.70

Table 4b. Level-II FCLULC time-series area statistics

FCLULC	1979		1991		2003		2015	
	km²	%	km²	%	km²	%	km²	%
Sal	1236.86	12.10	1236.86	12.10	1236.86	12.10	1236.86	12.10
Hill Sal	624.36	6.11	624.36	6.11	624.36	6.11	624.36	6.11
Sal Mixed	1134.95	11.10	1134.95	11.10	1134.95	11.10	1134.88	11.10
MMF	1090.82	10.67	1090.82	10.67	1090.82	10.67	1090.53	10.67
DDF	414.04	4.05	414.04	4.05	414.04	4.05	414.04	4.05
Pine	277.16	2.71	277.16	2.71	277.16	2.71	277.16	2.71
Oak	143.54	1.40	143.54	1.40	143.54	1.40	143.54	1.40
THVSF	11.41	0.11	11.41	0.11	11.41	0.11	11.41	0.11
RG	38.42	0.38	42.94	0.42	49.06	0.48	24.77	0.24
RF	165.32	1.62	171.32	1.68	164.46	1.61	185.50	1.81
Misc. F	31.38	0.31	31.38	0.31	31.38	0.31	31.38	0.31
SG	18.38	0.18	11.42	0.11	12.26	0.12	19.55	0.19
SL	301.06	2.94	300.63	2.94	299.49	2.93	296.72	2.90
TP	34.82	0.34	34.82	0.34	34.82	0.34	34.82	0.34
HP	0.68	0.01	0.68	0.01	0.68	0.01	0.68	0.01
Teak	177.65	1.74	177.16	1.73	176.85	1.73	176.24	1.72
Euc.	168.03	1.64	159.52	1.56	156.20	1.53	149.93	1.47
Tea	6.24	0.06	6.24	0.06	6.24	0.06	6.24	0.06
Orchard	25.06	0.25	33.25	0.33	65.09	0.64	142.98	1.40
Built up	53.86	0.53	82.75	0.81	127.15	1.24	239.09	2.34
ODL	33.89	0.33	38.93	0.38	41.15	0.40	32.98	0.32
Agri	3574.85	34.97	3565.67	34.88	3520.61	34.44	3380.05	33.06
DRB	520.00	5.09	503.03	4.92	485.52	4.75	419.36	4.10
WB	141.15	1.38	131.05	1.28	119.83	1.17	150.83	1.48
Total	10223.92	100.00	10223.92	100.00	10223.92	100.00	10223.92	100.00

Table 5a. FCLULC dynamics at Level-I

FCLULC	12 Years Gap						24 Years Gap				36 years Gap	
	1979-1991		1991-2003		2003-2015		1979-2003		1991-2015		1979-2015	
	%	km²	%	km²	%	km²	%	km²	%	km²	%	km²
Forest	0.03	3.13	-0.01	-1.04	0.01	0.92	0.02	2.09	0.00	-0.12	0.03	3.01
Plantation	-0.09	-9.01	-0.04	-3.62	-0.07	-6.87	-0.12	-12.63	-0.10	-10.50	-0.19	-19.51
Non-Forest	0.06	5.88	0.05	4.67	0.06	5.96	0.10	10.55	0.10	10.62	0.16	16.50

Table 5b. FCLULC dynamics at level-II

FCLULC	12 Years Gap						24 Years Gap				36 years Gap	
	1979-1991		1991-2003		2003-2015		1979-2003		1991-2015		1979-2015	
	%	km²	%	km²	%	km²	%	km²	%	km²	%	km²
Sal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hill Sal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sal Mixed	0.00	0.00	0.00	0.00	0.00	-0.07	0.00	0.00	0.00	-0.07	0.00	-0.07
MMF	0.00	0.00	0.00	0.00	0.00	-0.29	0.00	0.00	0.00	-0.29	0.00	-0.29
DDF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RG	0.04	4.52	0.06	6.12	-0.24	-24.28	0.10	10.64	-0.18	-18.16	-0.13	-13.65
RF	0.06	6.00	-0.07	-6.86	0.21	21.04	-0.01	-0.86	0.14	14.18	0.20	20.19
Misc. F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SG	-0.07	-6.96	0.01	0.84	0.07	7.29	-0.06	-6.12	0.08	8.13	0.01	1.17
SL	0.00	-0.43	-0.01	-1.14	-0.03	-2.77	-0.02	-1.57	-0.04	-3.91	-0.04	-4.34
TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Teak	0.00	-0.50	0.00	-0.30	-0.01	-0.61	-0.01	-0.80	-0.01	-0.91	-0.01	-1.41
Euc.	-0.08	-8.51	-0.03	-3.32	-0.06	-6.26	-0.12	-11.83	-0.09	-9.58	-0.18	-18.10
Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orchard	0.08	8.20	0.31	31.83	0.76	77.89	0.39	40.03	1.07	109.73	1.15	117.93
Built up	0.28	28.89	0.43	44.40	1.09	111.94	0.72	73.29	1.53	156.34	1.81	185.23
ODL	0.05	5.04	0.02	2.22	-0.08	-8.18	0.07	7.26	-0.06	-5.95	-0.01	-0.91
Agri	-0.09	-9.18	-0.44	-45.06	-1.37	-140.56	-0.53	-54.25	-1.82	-185.62	-1.91	-194.80
DRB	-0.17	-16.97	-0.17	-17.51	-0.65	-66.16	-0.34	-34.47	-0.82	-83.66	-0.98	-100.63
WB	-0.10	-10.10	-0.11	-11.22	0.30	31.01	-0.21	-21.32	0.19	19.79	0.09	9.69

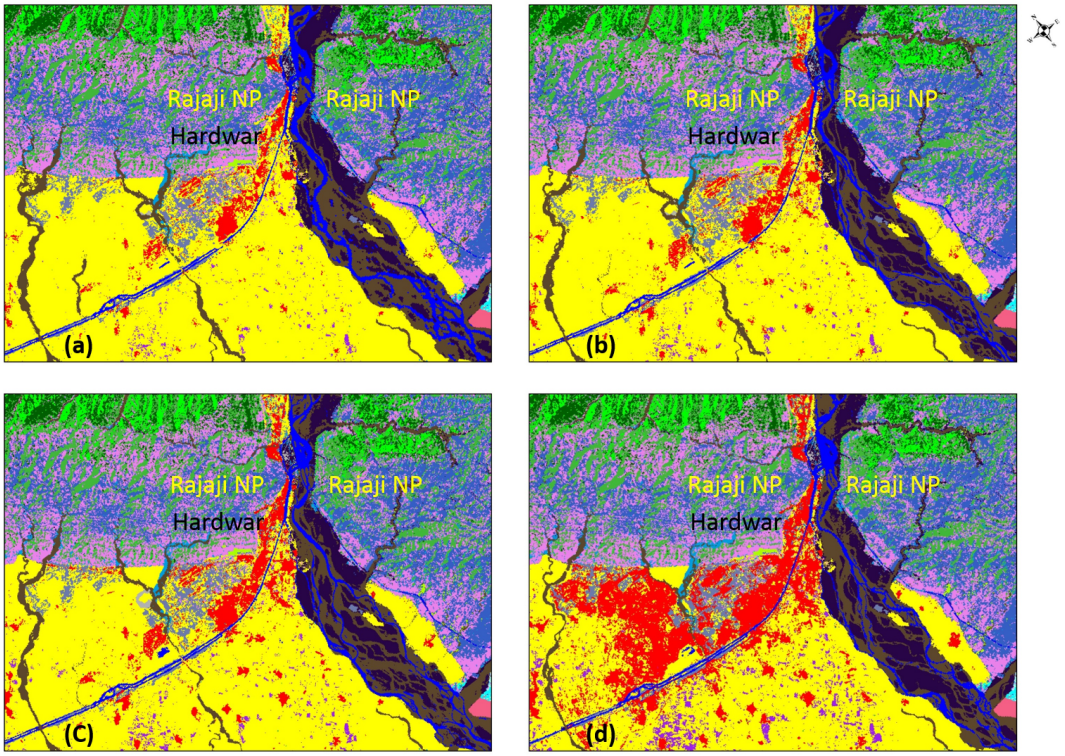

Figure 4. Urban sprawl in Haridwar district for the period: (a)1979, (b) 1991, (c) 2003 and (d) 2015.

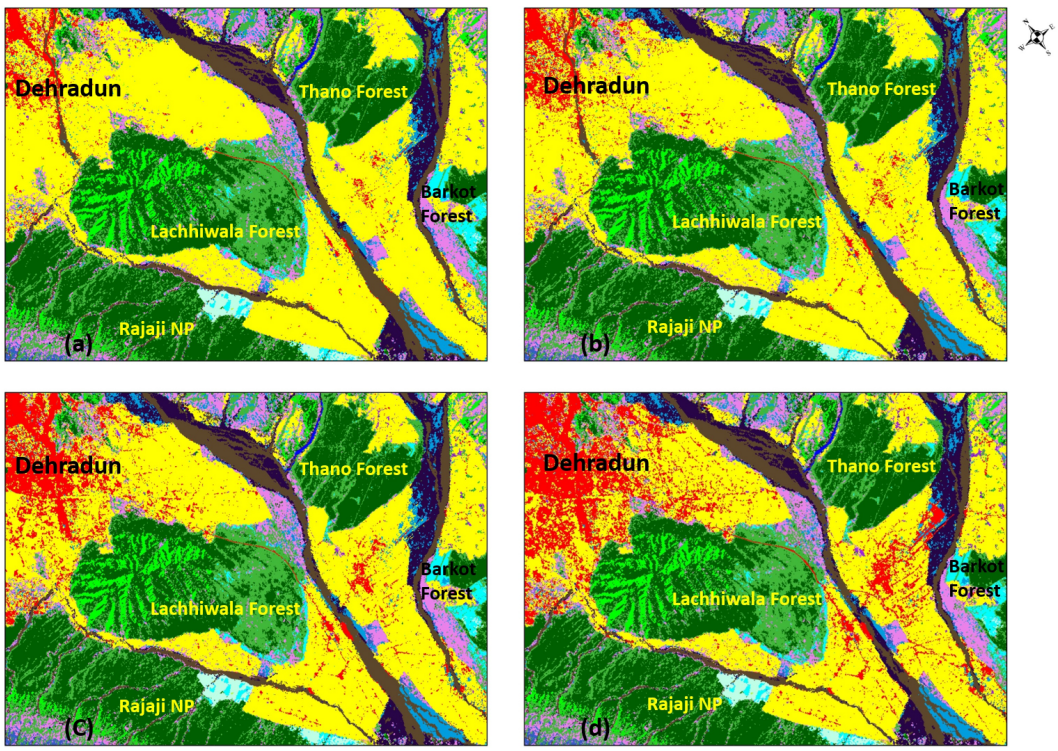

Figure 5. FCLULC dynamics in Dehradun–Doiwala–Barkot area for the period: (a) 1979, (b) 1991, (c) 2003 and (d) 2015.

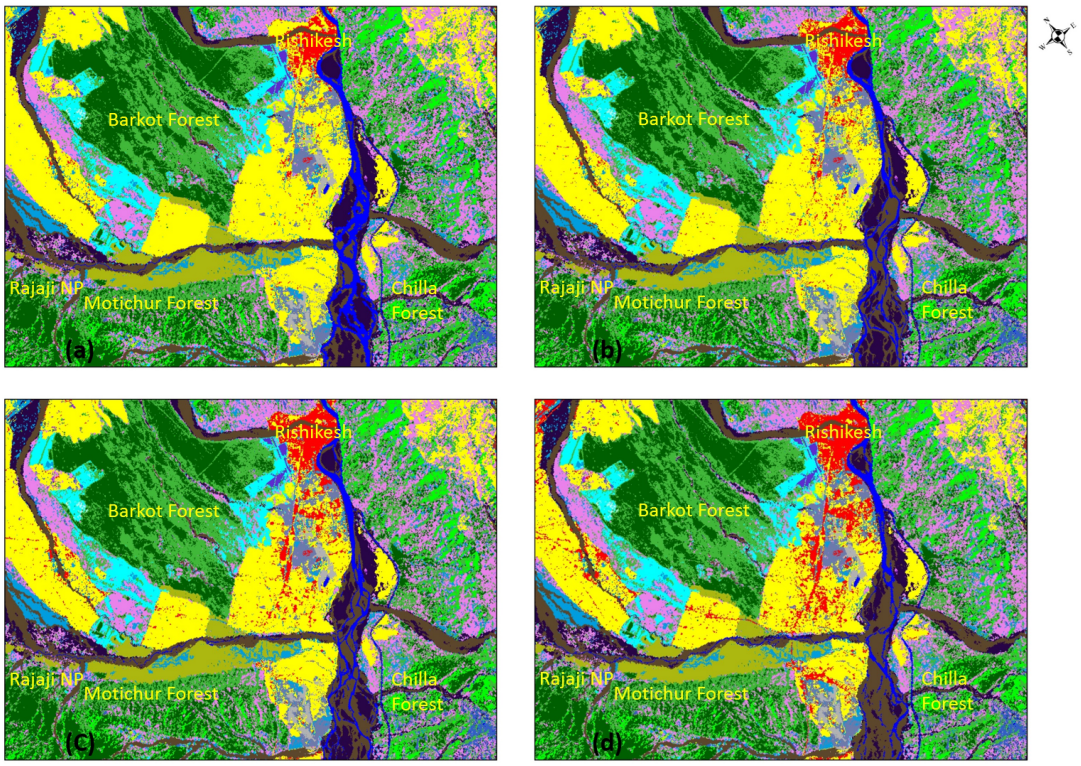

Figure 6. FCLULC dynamics in Motichur-Chilla Wildlife corridor for the period: (a) 1979, (b) 1991, (c) 2003 and (d) 2015.

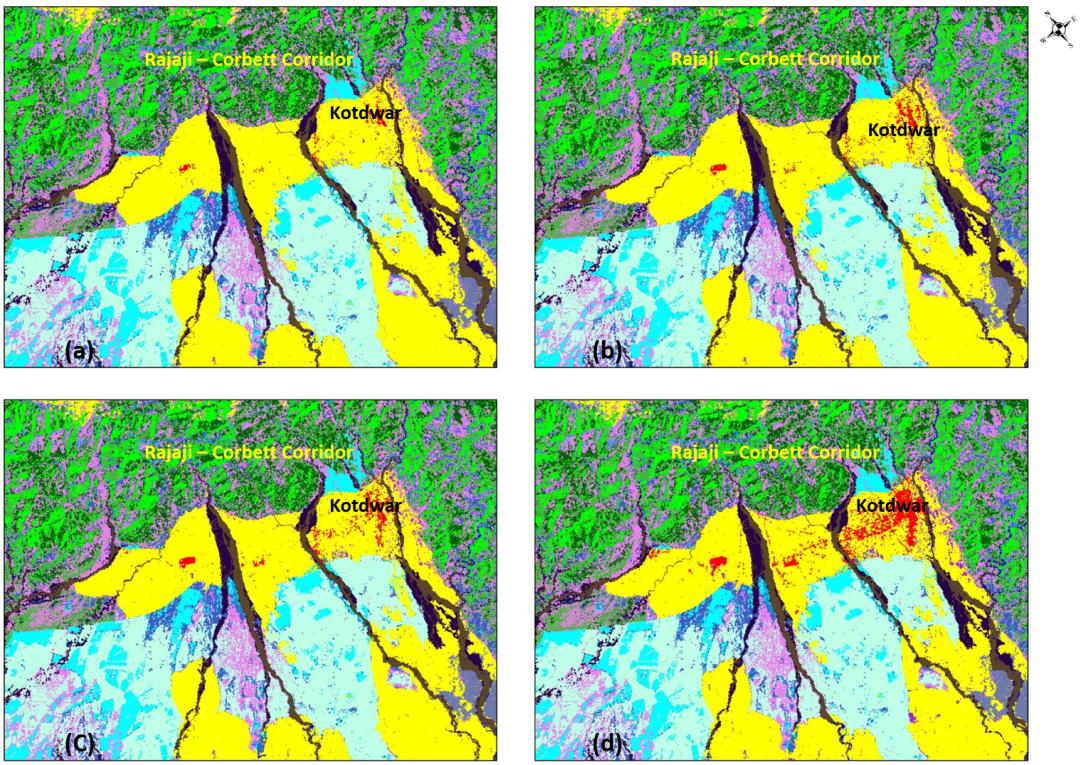

Figure 7. Urban sprawl in Kotdwar town for the period: (a) 1979, (b) 1991, (c) 2003 and (d) 2015.

Unlike forest, plantation area has decreased for different time periods. For 12 years of gap, the plantation area has decreased by 9.01 km^2 from 1979 to 1991, 3.62 km^2 during 1991 to 2003, and 6.87 km^2 during 2003-2015, whereas during 1979 to 2003 decrease is 12.63 km^2 and from 1991 to 2015 the loss 10.50 km^2. So, between 1979 to 2015, plantation area showed net loss of 19.51 km^2 due to agriculture expansion in Pathari and Sambhalgarh forest block of Haridwar forest division.

FCLULC Level-II Dynamics At 12 Years Intervals

Though the landscape is well protected, diversion of forest area for road widening has resulted in loss of 0.07 km^2 of Sal mixed and 0.29 km^2 of mixed moist deciduous forest between 2003 to 2015 and 1979 to 2015. The highest gain was noticed in built up amounting 28.89 km^2 during 1979 to 1991, 44.40 km^2 during 1991 to 2003, 111.94 km^2 during 1991 to 2003. Orchard area increased by 8.20 km^2 during 1979 to 1991, 31.83 km^2 during 1991 to 2003, and 77.89 km^2 during 2003-2015. Loss in area was noticed highest by riverbed and agriculture. The riverbed area decreased by 16.97 km^2 during 1979-1991, 17.51 km^2 during 1991 to 2003 and 66.16 km^2 during 2003 to 2015. Agriculture land has been lost by 9.18 km^2 during 1979 to 1991, 45.06 km^2 during 1991 to 2003 and 140.56 km^2 during 2003-2015 (Table 5b).

FCLULC Level-II Dynamics At 24 Years Intervals

FCLULC dynamics indicates the highest gain in built up area (73.29 km^2) followed by Orchards (40.03 km^2) and ravenous vegetation (10.64 km^2) during 1979 to 2003 (Table 5b). This trend continued during 1991 to 2015 and built-up area increased to 156.34 km^2 followed by Orchards (109.73 km^2) but ravenous vegetation decreased by 18.16 km^2. However, agriculture land decreased by 54.25 km^2 followed by river bed (34.47 km^2) during 1979 to 1991. The trend of loss continued and agriculture land decreased to 185.62 km^2 followed by river bed (83.66 km^2) during 1991 to 2015.

FCLULC Level-II Dynamics in 36 Years: 1979-2015

During 1979 to 2015, the highest area gain was in built up area (185.23 km^2), followed by Orchards (117.93 km^2) and ravenous vegetation (20.19 km^2). The highest loss in area was in agriculture land (194.80 km^2) followed by river bed (100.63 km^2). This loss in agriculture area is mostly to built up area near Hardwar (Figure 4), Rajaji NP and forests of Lachhiwala-Thano-Barkot (Figure 5), Barkot Forest-Motichur-Chilla forest corridor of Rajaji NP between Rishikesh and Hardwar (Figure 6) and Rajaji-Corbet NP corridor around Kotdwar (Figure 7 and Table 5b).

FCLULC Transition Analysis

A detailed matrix representing direction of the change and the class into which it has been transformed to along with its changed values are tabulated for the years 1979-1991, 1991-2003, 2003-2015, 1979-2003, 1991-2015 and 1979-2015, respectively (Annexures 1-6). Rows and columns indicate percent of the stock information of all 24 classes for the subsequent year.

Percent Transition (From–to) Analysis of FCLULC

During 1979-1991, about 163.52km^2 (1.60%) area has undergone transitional changes. The highest transition was observed in swampy grassland (45.9%), of which 27.75% has converted to waterbody and 18.14% to agriculture whereas the second highest transition change (20.48%) was registered for waterbody with 12.31% of its area has converted into riverbed and 5.44% into ravine grassland (Annexure 1).

Similarly, about 190.71 km^2 (1.87%) of the area has undergone transition during 1991-2003. The classes which showed highest transition changes are: waterbody (20.77%) and swampy grassland (16.32%). It is observed that 9.63% of waterbody has converted into riverbed (possibly due to diversion of river channel), 5.04% into agriculture land, probably reclaimed or encroachment and 3.69% into ravine grassland whereas 15.53% of swampy grassland has undergone to agriculture, mostly around the wetland situated in Jaspur forest range (Annexure 2).

Likewise, it can be inferred that during 2003-2015 period, a total of 358 km^2 (3.51%) underwent changes. Of this, ravine grassland changed to waterbody (50.58%) and open degraded land (20.13%) have undergone the highest change. It was found that open degraded land has undergone to agriculture (17.46%), to riverbed (1.96%) and (0.71%) to built-up (Annexure 3).

Percent Transition (From–to) Analysis of FCLULC

Annexures 4 and 5 show percent transition of categories for the period 1979 to 2003 and 1991 to 2015, respectively. An area of 282.63 km^2 (2.76%) changed during

1979 to 2003. Major transitional areas were in swampy grassland (46.23%) of which 23.85% diverted to agriculture and 22.37% to water body. Riverine forest changed to agriculture (3.5%), river bed (4.99%) and water body (1.25%). Water body (river channels) changed to river bed (13.46%), riverine grassland (8.94%) and swampy grassland (1.44%). About 1.12% of agriculture area was converted to Orchards and 2.01% to built-up area (Annexure 4).

During 1991 to 2015 about 457.55 km^2 (4.57%) went under different transition classes. The rivers are highly dynamic and keep changing the course, so are the associated ecosystems like riverine forest, riverine grassland, swamps and agriculture nearby. An area of about 45.59% of the riverine grassland changed to water bodies. Riverine forest was lost to river bed (5.60%), waterbody (2.90%) and agriculture (2.84%). About 23.65% for water bodies changed to river bed (8.33%), Agriculture (7.02%), swampy grassland (7.11%), etc. (Annexure 5).

Percent Transition Analysis of FCLULC: 1979-2015

During 36 year-time span a total of 534.98 km^2 (5.23%) area has undergone change, of the categories ravenous ecosystem has been found the most dynamic. The highest transitions are noticed for ravine grassland (40.51%) to waterbody, followed by swampy grassland (32.11%), riverbed (24.66%) and waterbody (23.27%). Swampy grassland was converted to agriculture (20.06%) and to water body (10.76%) whereas riverbed was converted to agriculture (12.63%), to swampy grassland (7.42%). Water body was converted to river bed (10.7%), agriculture (6.59%) and swamp grassland (4.3%) (Annexure 6).

DISCUSSION

In unsupervised classification approach optimum number of clusters is important and high number of clusters have been found useful to separate spectral class and then to information class. Even though it is time taking activity but it is observed that there is an improvement in accuracy assessment of the classification from 84.01% in 1979 to 89.12% in 2015. It may also be attributed to improved spectral resolution in Landsat 8. Factors such as mixed pixel spectral response also contributed in misrepresentation and misinterpretation of classes such as dry riverbeds, built up, mixed moist deciduous forest, dry deciduous forest and scrub forest, hence produced lower accuracy. The agriculture land is most dominant, occupied around 34.97%, 34.88%, 34.44% and 33.06% in year 1979, 1991, 2003 and 2015, respectively. There is no significant change in area of the forest cover in last 36 years in the landscape barring riverine ecosystem, which are very dynamic. The pattern of the FCLULC indicates physiography and moisture conditions have profound impact on the occurrence.

The entire landscape is part of the either PA network or under some category of conservation such as national park, tiger reserve or elephant reserve. Even though the developmental activities have hastened during 2003 to 2015 period after formation of Uttarakhand, and relatively forest area is less affected due to good management despite under four states administration and area being diverted to road widening. On the contrary, the area under non-forest is most dynamic.

The area under built-up and orchard has increased manifold at the expanse of agriculture land in Dehradun and Hardwar. Comparative analysis of the rate of increase in built up and orchard for periods (1979-1991, 1991-2003 and 2003-2015) indicates that it was found highest between 2003 and 2015. It may clearly attributed to enhanced developmental activities after formation of separate Uttarakhand state in year 2000. There is change in demography because of population migration, setting up of several new education institutions, industrial and natural and religious tourism in and around Dehradun, Haridwar, Rishikesh and Ramnagar. The changes in crop grown (agriculture to orchards) are also observed in Saharanpur, Roorkee and Hardwar regions and however, it needs further investigation. It is observed that river systems are very dynamic, and courses keep on changing leading to accretion and erosion. The loss of riverbeds into agriculture land and built up is more obvious (Mahmood et al. 2017). Accretion motivates farmers to go for agriculture in small and seasonal tributaries and streams and low reservoir levels. Among natural forest ecosystems Sal, Sal mixed and mixed moist deciduous forests have shown the highest per cent of persistence, in spite of showing marginal decrease in area during subsequent periods as against the 1979-1991 due to broadening of Dehradun-Haridwar-Rishikesh highway. A noticeable loss was seen after the year 1990 in Pathari forest block, where the land was diverted for settlement by government to Gujjar families moved out of Rajaji National Park during early 1992. Loss in plantation is also observed in Sambhalgarh forest block of Haridwar district, where the newly identified Gujjar families of Rajaji National park were relocated in late 1990s.

The river-related ecosystems such as ravine grassland, swampy grassland, ravine forest and riverbed which together with waterbody comprise ravinous ecosystem, showed highest transition change in all time periods due to fluctuation in water level. The ravine grasslands predominately occur inside the protected area and particularly in the core zone of Corbett National Park (Dhikala range). Swampy grasslands were found both inside (Jhilmil wetland) and outside protected areas. For different time periods, transition between swampy grasslands and agriculture land is predominately observed in two of the wetlands situated in Jaspur range, 10 kilometres down the Corbett National Park where nearby villagers occasionally are found to cultivate some of the area of swampy grasslands (not permanent in nature) when it dries up or it remains swampy land otherwise. In the process, people without being noticed, have gradually encroached the wetland. As consequences of this, the wetlands are shrinking.

CONCLUSION

Despite lot of anthropogenic pressures and developmental activities KRCSL PA network is dominated by good forest cover and its environs by intensive agriculture. There is manifold increase area in orchards (5.7 times) and built up (4.3 times) during past 36 years. Among the 12 years gap periods *i.e.,* 1979-1991, 1991-2003 and 2003-2015, the highest increase of 2.2 times for orchards and 1.89 times for built up was observed during 2003-2015. Built-up adjacent to Rajaji national park near south-west of Hardwar, between Kansrao-Lachhiwala forest ranges and Balawala, Kansrao-Barkot and Motichur and Chilla ranges will exert pressure in times to come and increase man-animal conflict because of enhanced suburban-rural sprawl. The agricultural land has been diverted for orchard and built up purposes. Transition matrices analysis indicates that a total of 13 classes exhibited transitional changes and the rest remained unchanged, particularly Sal and Sal dominated forests. The analysis of transition potential of different classes among 12 years of gap periods has indicated highest for period 2003-2015, during which a total of 3.51% area of Shivalik landscape has undergone conversion. Within 36 years of span from 1979 to 2015, 5.23% of the total area has experienced transitional changes. LULC close to river system are highly dynamic. Our findings suggest that there has been marginal decrease in forest cover in Chilla-Motichur wildlife corridor due to flyover under construction. The rapid conversion of agriculture land to built up in vicinity of forest and inside the wildlife corridors in particular, is a matter of serious concern because it has not only disrupted the movement of free ranging wildlife but also has enhanced the human wildlife conflict incidences. Hence, there is need for government to take key initiatives to safeguard connectivity and to maintain the genetic flow between forests in not-so fragmented landscape before it is too late.

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Annexure 1. FCLULC transition matrices for years 1979-1991 (Area in percent)

	1991	Sal	Hill Sal	Sal M	MMF	DDF	Pine	Oak	THVSF	RG	RF	SG	SL	TP	HP	Teak	Euc.	Tea	Misc F	Orchard	Built up	ODL	Agri	DRB	WB	Total
1979	Sal	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.10
	Hill Sal	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11
	Sal M	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.10
	MMF	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.67
	DDF	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05
	Pine	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
	Oak	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
	THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
	RG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	87.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.60	7.95	0.38
	RF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	2.69	0.78	1.62
	SG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.14	0.00	27.75	0.18
	SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.31	0.08	0.00	2.94
	TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Teak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.72	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	1.74
	Euc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94.93	0.00	0.00	0.00	0.00	1.98	3.08	0.00	0.00	1.64
	Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
	Misc F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
	Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.25
	Built up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.53
	ODL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.18	0.36	0.46	0.00	0.33
	Agri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.81	0.00	98.56	0.31	0.06	34.97
	DRB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	2.09	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.29	5.66	89.98	1.41	5.09
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.44	1.30	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.39	12.31	79.52	1.38
	Total	12.10	6.11	11.10	10.67	4.05	2.71	1.40	0.11	0.42	1.68	0.11	2.94	0.34	0.01	1.73	1.56	0.31	0.06	0.33	0.81	0.38	34.88	4.92	1.28	100.00

Annexure 2. FCLULC transition matrices for year 1991-2003 (Area in percent)

	2003	Sal	Hill Sal	Sal M	MMF	DDF	Pine	Oak	THVSF	RG	RF	SG	SL	TP	HP	Teak	Euc.	Tea	Misc F	Orchard	Built up	ODL	Agri	DRB	WB	Total
1991	Sal	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.10
	Hill Sal	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11
	Sal M	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.10
	MMF	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.67
	DDF	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05
	Pine	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
	Oak	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
	THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
	RG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.13	4.00	0.42
	RF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	91.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.60	5.14	1.24	1.68
	SG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	83.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.53	0.00	0.80	0.11
	SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.51	0.05	0.00	2.94
	TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Teak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.83	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	1.73
	Euc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.39	0.00	0.00	0.00	0.12	1.83	0.67	0.00	0.00	1.56
	Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
	Misc F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.00	0.06
	Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.33
	Built up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.81
	ODL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.18	0.00	0.00	0.00	0.13	90.55	6.56	0.59	0.00	0.38
	Agri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	1.21	0.04	97.57	0.22	0.07	34.88
	DRB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	1.60	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.33	4.60	90.53	1.94	4.92
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.69	0.38	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.04	9.63	79.23	1.28
	Total	12.10	6.11	11.10	10.67	4.05	2.71	1.40	0.11	0.48	1.61	0.12	2.93	0.34	0.01	1.73	1.53	0.31	0.06	0.64	1.24	0.40	34.44	4.75	1.17	100

Annexure 3. FCLULC transition matrices for year 2003-2015 (in percent)

	2015	Sal	Hill Sal	Sal M	MMF	DDF	Pine	Oak	THVSF	RG	RF	SG	SL	TP	HP	Teak	Euc.	Tea	Misc F	Orchard	Built up	ODL	Agri	DRB	WB	Total
2003	Sal	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.10
	Hill Sal	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11
	Sal M	0.00	0.00	99.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	11.10
	MMF	0.00	0.00	0.00	99.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	10.67
	DDF	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05
	Pine	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
	Oak	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
	THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.11
	RG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.58	0.48
	RF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.15	3.48	2.40	1.61
	SG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	83.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.53	0.00	11.41	0.12
	SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.71	0.13	0.00	2.93
	TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Teak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.65	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	1.73
	Euc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	95.99	0.00	0.00	0.00	0.05	0.00	3.75	0.00	0.00	1.53
	Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
	Misc F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
	Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.72	0.07	0.00	0.21	0.00	0.00	0.64
	Built up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	1.24
	ODL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	79.87	17.46	1.96	0.00	0.40
	Agri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	3.11	0.00	94.48	0.07	0.09	34.44
	DRB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	6.38	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.02	6.65	82.41	4.27	4.75
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.07	6.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.07	8.30	80.88	1.17
	Total	12.10	6.11	11.10	10.67	4.05	2.71	1.40	0.11	0.24	1.81	0.19	2.90	0.34	0.01	1.72	1.47	0.31	0.06	1.40	2.34	0.32	33.06	4.10	1.48	100.00

Annexure 4. FCLULC transition matrices for year 1979-2003 (in percent)

	2003	Sal	Hill Sal	Sal M	MMF	DDF	Pine	Oak	THVSF	RG	RF	SG	SL	TP	HP	Teak	Euc.	Tea	Misc F	Orchard	Built up	ODL	Agri	DRB	WB	Total
1979	Sal	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.10
	Hill Sal	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11
	Sal M	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.10
	MMF	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.67
	DDF	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05
	Pine	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
	Oak	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
	THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
	RG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	89.98	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	7.59	0.38
	RF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50	4.99	1.25	1.62
	SG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.85	0.00	22.37	0.18
	SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.16	0.87	0.06	0.00	2.94
	TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Teak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.55	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	1.74
	Euc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92.96	0.00	0.00	0.00	0.19	3.08	3.77	0.00	0.00	1.64
	Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
	Misc F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
	Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.25
	Built up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.53
	ODL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.79	2.21	0.00	0.00	0.33
	Agri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	2.01	0.00	96.54	0.24	0.08	34.97
	DRB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	2.60	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.45	8.05	86.26	1.74	5.09
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.94	1.19	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.93	13.46	70.04	1.38
	Total	12.10	6.11	11.10	10.67	4.05	2.71	1.40	0.11	0.48	1.61	0.12	2.93	0.34	0.01	1.73	1.53	0.31	0.06	0.64	1.24	0.40	34.44	4.75	1.17	100.00

Annexure 5. FCLULC Transition matrices for year 1991-2015 (in percent)

	2015	Sal	Hill Sal	Sal M	MMF	DDF	Pine	Oak	THVSF	RG	RF	SG	SL	TP	HP	Teak	Euc.	Built-up	Misc F	Orchard	Built up	ODL	Agri	DRB	WB	Total
1991	Sal	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.10
	Hill Sal	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11
	Sal M	0.00	0.00	99.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	11.10
	MMF	0.00	0.00	0.00	99.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	10.67
	DDF	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05
	Pine	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
	Oak	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
	THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.11
	RG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.59	0.42
	RF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	2.84	5.60	2.90	1.68
	SG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.07	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.81	0.00	2.11	0.11
	SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	1.16	0.00	0.00	2.94
	TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Teak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.48	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	1.73
	Euc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	93.99	0.00	0.00	0.00	0.16	0.00	5.64	0.00	0.00	1.56
	Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
	Misc F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
	Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.45	0.14	0.00	0.41	0.00	0.00	0.33
	Built up	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.81
	ODL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	83.96	14.35	1.11	0.00	0.38
	Agri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.08	4.27	0.00	92.52	0.04	0.07	34.88
	DRB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	6.69	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.06	9.16	78.81	4.70	4.92
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.08	7.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.02	8.83	76.35	1.28
	Total	12.10	6.11	11.10	10.67	4.05	2.71	1.40	0.11	0.24	1.81	0.19	2.90	0.34	0.01	1.72	1.47	0.31	0.06	1.40	2.34	0.32	33.06	4.10	1.48	100.00

Annexure 6. FCLULC transition matrices for year 1979-2015 (in percent)

	2015	Sal	Hill Sal	Sal M	MMF	DDF	Pine	Oak	THVSF	RG	RF	SG	SL	TP	HP	Teak	Euc.	Tea	Misc F	Orchard	Settle	ODL	Agri	DRB	WB	Total
1979	Sal	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.10
	Hill Sal	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11
	Sal M	0.00	0.00	99.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	11.10
	MMF	0.00	0.00	0.00	99.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	10.67
	DDF	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.05
	Pine	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
	Oak	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40
	THVSF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.11
	RG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.51	0.38
	RF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	87.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	3.80	5.66	2.69	1.62
	SG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.29	67.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.06	0.00	10.76	0.18
	SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.04	1.62	0.00	0.00	2.94
	TP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Teak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.21	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	1.74
	Euc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	89.23	0.00	0.00	0.00	0.28	0.00	10.29	0.00	0.00	1.64
	Tea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
	Misc F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
	Orchard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.25
	Settle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.53
	ODL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	95.48	4.06	0.00	0.00	0.33
	Agri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.30	5.05	0.00	91.48	0.09	0.07	34.97
	DRB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	7.42	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.10	12.63	75.34	3.48	5.09
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	1.32	4.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	6.59	10.70	76.73	1.38
	Total	12.10	6.11	11.10	10.67	4.05	2.71	1.40	0.11	0.24	1.81	0.19	2.90	0.34	0.01	1.72	1.47	0.31	0.06	1.40	2.34	0.32	33.06	4.10	1.48	100.00