International Journal of Ecology and Environmental Sciences 47: 303-324, 2021
ISSN: 2320-5199 (Online)



# Spatio-Temporal Assessment of Forest Cover Types and Land Use/Land Cover with Reference to Galliformes Habitats in the Upper Catchment of Tons Valley Using Earth Observation Data

**SONAL ARORA[1*], SARNAM SINGH[2] AND SAMBANDAM SATHYAKUMAR[3]**

[1]*Forestry & Ecology Department, Indian Institute of Remote Sensing (IIRS), ISRO, Dept. of Space, Govt. of India, 4 Kalidas Road, Dehradun – 248001, Uttarakhand, India.*
[2]*School of Ecology and Environment Studies, Nalanda University, Rajgir, Bihar 803 166, India.*
[3]*Department of Endangered Species Management, Wildlife Institute of India, Chandrabani, Dehradun – 248001, Uttarakhand, India,*
E-mail: sonal.arora73@gmail.com, sarnam.singh@gmail.com, ssk@wii.gov.in
ORCID iD: 0000-0003-1829-7941 (S. Singh) and 0000-0003-2027-4706 (S. Sathyakumar)

**ABSTRACT**

The Himalayan Galliformes inhabit varied habitats in forested landscape of subtropical to alpine vegetation with dense to moderate undergrowth. These beautiful birds are highly secretive and sensitive to human presence. These are poached for feathers and meat, and four of them (inhabiting this area) are listed in WPA Schedule I and two are designated as Vulnerable by IUCN. Therefore, information of the status of their habitats is important for long-term conservation and management planning. The forest vegetation and land use/land cover types were mapped using Landsat series data of 1994, 2002 and 2016 for evaluating dynamics of ecosystems and/or habitats of Galliformes in upper catchment of Tons river covering Govind Pashu Vihar National Park, Biodiversity hotspot region of Western Himalaya. The forest vegetation varied from degraded scrub to dense temperate broadleaf and coniferous forests that provide wide range of habitat to different species of Galliformes. Though the area is not densely populated by humans, but the activities such as fuelwood collection, lopping for fodder, overgrazing by livestock, including migratory nomadic grazers, tourists' camps and other activities occur in the habitats of the sensitive and habitat specialist fauna including Galliformes. We used hybrid classification approach to classify three times data and an overall accuracy of these maps ranged between 81.25 % (1994), 82.85 (2002) and 84.4% (2016). The Forest Cover and LULC area analyses indicated very marginal but significant loss in subtropical scrub (1.34 $km^2$), and subtropical Chir Pine forest (0.53 $km^2$) mainly due to expansion of agriculture land at lower altitude. Also, a decrease in Conifer-wooded forest (1.09 $km^2$) was noticed due to human activities. Thus, it may be concluded that overall tree cover has not undergone drastic changes at ecosystem and landscape level and may be attributed to good forest management practices. We recommend that along with maintenance of tree cover, protection to under-storey vegetation, that is one of the critical requirements for Galliformes, is also provided.

**Keywords**: Satellite data; Forest Cover Type Mapping; Galliformes; Biodiversity Conservation, LULC dynamics, Anthropogenic pressure.

## INTRODUCTION

The Govind Pashu Vihar National Park (GPVNP) is part of biodiversity hotspot, Western Himalaya and is also home to several threatened wildlife species especially high-altitude Galliformes (Sati and Sinha 2004). Some of the Galliformes are listed in Schedule I of the Indian Wildlife (Protection) Act, 1972 and designated vulnerable by IUCN i.e., Western Tragopan and Cheer Pheasant (Table 1) (Garg et al. 2016, Venkataraman and Sivaperuman 2018). They are highly secretive in nature and very sensitive to change in their habitats (Ramesh et al. 1999, Ramesh 2003). The challenging terrain and harsh climatic conditions of these habitats render them ideal for their survival as well as largely inaccessible to field researchers (Miller 2010). Their territorial behavior, high endemism and high habitat specificity which varies from species to species and seasonally make them more vulnerable and justify the low-density presence of some of them in literature (Sathyakumar et al. 2007). Western Tragopan and Cheer Pheasant are subject of conservation breeding programmes; where huge amount of funds, are being invested by the government for their reintroduction in to the wild, in places where they are locally extinct (Garson 1992). Also, they are bioindicator of the health of the ecosystem as well as they form major prey base for variety of predators including mammalian carnivores, raptors, and reptiles. They share their habitat with other ecologically important species such as Snow Leopard, musk deer, Himalayan Tahr, making their conservation more imperative (Ramesh et al. 1999). Many pheasants are likely to become extinct within the next 100 years, if over exploitation and habitat destruction continues (Ramesh 2003). Several researchers have emphasized the importance of their management and conservation in Western Himalaya, due to continuous rise in developmental activities and expansion of agriculture; and also, the need for their population estimation, habitat requirement, distribution and threat assessment (Gaston 1980, McGowan and Garson 1995, Sathyakumar et al. 2007). Habitat loss and degradation being one of the major threats, the analysis of changes in land use land cover becomes an important stepping stone in planning conservation and management strategies (Sathyakumar et al. 2007). The region has witnessed an increase in tourism from 2007-08 (~2051 tourists) to 2017-18 (~11,000), which in addition to creating employment opportunities, might also have brought out some changes in Land Use Land Cover (LULC) (Anonymous 2019). Limited arable land for terrace agriculture is facing degradation due to loss of top fertile soil on high slopes and rainfall.

LULC mapping and monitoring using different remote sensing satellite data started soon after the availability of Earth Resources Technology Satellite (ERTS) data from 1972 onwards. In India, the first nationwide satellite databased LULC mapping for 1972-75 and 1980-82 periods highlighted loss of 91710 $km^2$ (2.79%) forest cover (NRSA, 1985). The latest $16^{th}$ assessment report of 2019 used Resourcesat-2 LISS III satellite datasets for 1:50,000 scale mapping (2019) at pan India scale. A well-known study by Richards and Flint (1994) on South and Southeast Asia reported forest cover loss of 13.5% between 1880 and 1980. Various Earth Observing satellites with variety of sensors have been deployed by US, European Union, India, China, etc. to monitor earth and its environment, regularly (Jensen 2015). Several Studies have been conducted in India for LULC mapping using visual image interpretation (Gautam and Chennaiah 1985, Gupta et al. 2006, Almeida et al. 2008, Panigrahy et al. 2010) and various other classification techniques i.e., supervised classification (Yadav et al. 2012, Akike and Samanta 2016, Islam et al. 2017), unsupervised classification (Areendran et al. 2013, Areendran et al. 2017, Babu et al. 2019), supervised-unsupervised classification (hybrid approach) (Yuan et al. 2005, Abd El-Kawy et al. 2011), fuzzy classifiers using fuzzy classification logic, object oriented classification using high to very high spatial resolution images, geographic object-based image analysis and classification, spectral mixture analysis using hyperspectral data (Song 2005, Jensen 2015). Expert classifiers use artificial intelligence or knowledge-based on hypotheses, rules and conditions (field as well as image characteristics) (Singh et al. 2013, Jensen 2015) and integration of DEM improves the classification accuracy (Singh et al. 2005, Singh et al. 2013). Machine learning decision tree and regression trees with single or multiples trees (Random Forest Classifiers, Bagging, Boosting), Support Vector machines, Artificial Neural Networks based classifiers, etc. are important developments to improve the classification accuracy with introduction of more conditions and decision rules in the decision making process of classifying pixels (Jensen 2015). However, the classification algorithms based on single pixel analysis often are not capable of extracting the information desired from high spatial resolution remote sensor data (Pena-Barragan et al. 2011), basically because of shadowing, phenology and different illumination conditions of same species and tree, importantly in Himalayan forested landscapes. Therefore, moderate resolution satellite images with 20 to 30 m spatial resolution are suited better in terms of efforts, output and acceptable user's accuracy, considering that the average canopy size of the trees and shrubs are large. The recent approaches of Random forest classification, Support Vector Machine (SVM) algorithms, etc. are more data intensive for building hypotheses, rules, etc. at different levels.

The mapping and management for retaining and sustainable use of various biotic and abiotic resources in biodiversity hotspot of Himalayan landscape, has been a challenge because of its fragile nature, high terrain complexity and inaccessibility, seismically and anthropologically active region (Gairola et al. 2013, Lele and Joshi 2008). One of the recent national level studies on forest cover type mapping in India was done under Biodiversity Characterization Project on 1:50,000 scale using IRS P6 LISS-III satellite data (Roy et al. 2002, 2012) in which supervised, unsupervised and hybrid approaches were followed considering the terrain complexity and vegetation composition. Several advanced classification algorithms have been attempted.

The mapping of LULC in Western Himalayan region has drawn interest from watershed to biome levels and other regions of Himalaya, such as Nepal (Garrard et al. 2016, using object based classification), Bhutan (Chamling and Bera 2020, using supervised classification), Sikkim (Sharma et al. 2015, using visual interpretation and supervised classification; Mishra et al. 2019, using supervised classification), Himachal Pradesh (Chandrashekhar et al. 2003, using supervised and unsupervised classification), Kumaon in Uttarakhand (Chakraborty et al. 2016, via Random Forest classification), Rudraprayag district in Uttarakhand (Batar et al. 2017, using supervised classification) and far eastern Himalaya in Arunachal Pradesh (Singh and Singh 2002, using visual interpretation; Singh et al 2002, using hybrid classification). Mathur and Naithani (1999) and Singh (1999) characterized vegetation for generating habitat suitability models for Western Tragopan and Musk Deer in Great Himalayan National Park Conservation Area (GHNPCA), further west to present study area.

The acceptable classification accuracy in mountainous terrain is constrained by topographic shadowing (Millette et al. 1995). The non-discernable spectral or tonal characteristics on satellite data in climax forest ecosystems created due to overlapping and wide ecotonal zones and complex environmental setup due to continuously varying slope, aspect, altitude, soil and drainage systems have been the biggest challenge. Therefore, in order to increase the classification accuracy ancillary data of topographic variables and governing factors such as digital elevation model, slope and aspect have been integrated with satellite data to overcome the limitations (Thomson and Jones 1990, Eiumnoh and Shrestha 1997, Ricchetti 2000, Singh et al. 2005, Lillesand et al. 2014). The importance and drawbacks of using topographic data for classification of satellite data, has been discussed by Hutchinson (1982) and Harris and Ventura (1995) via three different approaches, viz. pre-classification stratification, classifier modification and post-classification sorting. Several studies have demonstrated the utility of this approach with supervised classification (Gerçek 2002); DEM integrated with IRS ICLISS-III data for unsupervised classification technique (Singh et al. 2005); Digital Elevation Model (DEM) and Normalized Difference Vegetation Index (NDVI) data along with IRS LISS III data during supervised classification (Saha et al. 2005) and decision tree model using topographic variables with LISS- III data, for Expert classification method (Singh et al. 2013). All these studies concluded that integration of topographical layers improved the overall accuracy of LULC classification. The significance of Green-Red Vegetation Index (GRVI) also has been analyzed in detecting the phenological changes in vegetation (Motohka et al. 2010).

The GPVNP has data deficiency for its proper management mainly being located in remote Inner and Greater Himalaya region with very challenging terrain and environmental conditions. We came across a few studies such as by Rawat and Chandhok (2009) on phytosociological analysis and distribution patterns of tree species, Krishan et al. (2009) on land degradation mapping using geospatial technology and Nandy et al. (2011) on forest degradation in the upper catchment of the river Tons using remote sensing and GIS. Therefore, the present study is aimed at spatio-temporal assessment of LULC, so that the geospatial information can be used further as improved baseline information in framing conservation and management strategies for range-restricted, WPA Schedule I rare and endangered birds of the order Galliformes. Even though several automated digital change detection methods are available, the vast majority of the studies followed post classification comparison method for change detection to overcome issues of different sensors characteristics, terrain and illumination conditions. The present study mapped and evaluated the forest cover types and land use/land cover (FCTLULC) changes spanning over two decades with a focus on generating baseline data for habitat characterization for Galliformes conservation planning and management. The research questions addressed in this study are: what is the extent of forest cover and land use/land cover change in the area? Are there any trends in changes in land use/land cover along the altitudinal gradient? Is there any pattern of impact due to anthropogenic pressures on Land use/Land cover? Are there any area changes in habitat of different Galliformes? And to study the directionality of changes in forest types in the different time periods?

MATERIAL AND METHODS

**Study area**

The Upper Catchment of Tons River Valley, the global biodiversity hotspot landscape under investigation covers an area of ~2,000 km$^2$ and is within geographical limits of 31.36° - 30.87° N and 77.85° – 77.62° E (Fig. 1). It includes forest protected areas i.e., Govind Pashu Vihar National Park and Wildlife Sanctuary and areas of Supin, Rupin and Sankri forest ranges, located in Purola Block of Uttarkashi district, Uttarakhand and Demarcated

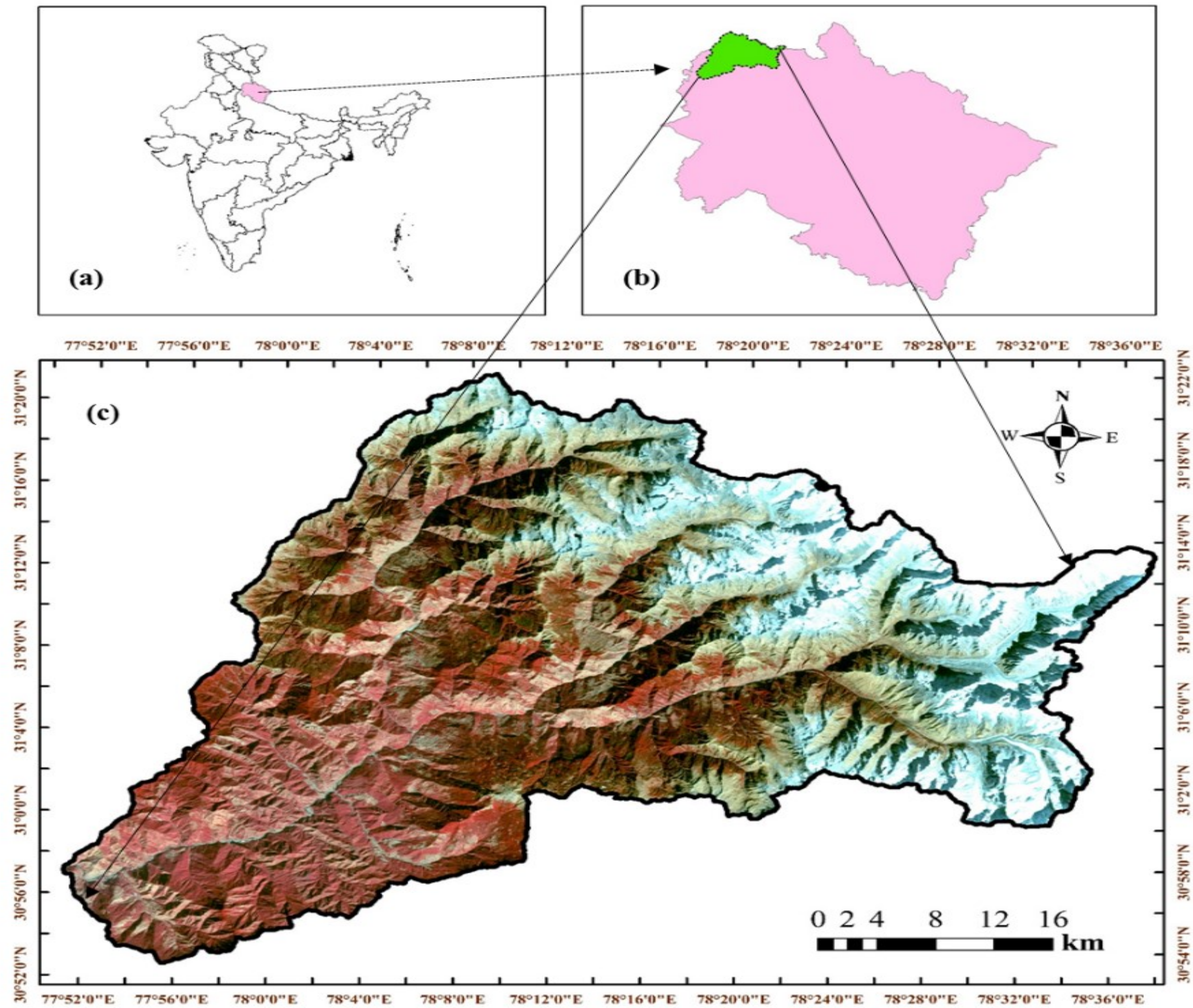


Figure 1. Map of the study area (a) India and Uttarakhand as inset (b) Uttarakhand state and study area inset and (c) False Colour composite of (Landsat 8 OLI, 2016) of Tons river upper catchment

Protected Forests of Himachal Pradesh. The area is comprised of several land cover features like forest, grasslands, snow, glaciers, waterbodies, etc. between the altitudinal range 1200 – 6387 m AMSL. Because of great variation in elevation and aspect making it a highly complex terrain, the variety of vegetation in this area can be categorized into four major vegetation type such as (i) Subtropical Pine, (ii) Himalayan Moist Temperate, (iii) Sub Alpine and (iv) Moist Alpine Scrub forest and may further be subdivided into 29 subgroups (Champion and Seth 1968). The main river Tons and its tributaries of Maninda Gad, Har Ki Doon Gad, Obra Gad, Ruinsara Gad, Istar Gad, Liyari Gad, Supin and Rupin are fed by glaciers such as Bandarpunchh and Jamdar Bamak glaciers. Soil on moderate to steep slopes in narrow valleys are of shallow-moderate depth, containing rich organic content whereas on higher elevation and very steep slopes, due to colluvial movement of soil particles and weathering effects, these are not formed properly. The area has variable climate which is subtropical in lower part of the valley having hot and more or less humid monsoon season from July to September, pleasant autumn and spring and a cold and dry winter season bracing with clear and bright weather alternating with occasional winter rains. The annual rainfall ranges from 300-1,500 mm with ~60% of it received under south-west monsoon (Anonymous 2019). Maximum rainfall is experienced during month of July and August, and minimum rainfall during the months of January-February and October-November. The snowfall occurs more often throughout the winters occasionally in November and March-April. The average annual humidity is observed to be ~60% with maximum i.e., from 55 - 90% during monsoon. Resulting from great variation in forest habitat types, the area is inhabited by variety of threatened mammals such as Snow leopard, Common leopard, Himalayan brown bear, Himalayan musk dear, Asiatic black bear, Himalayan tahr, Bharal, Serow and other species (Anonymous 2019) and, threatened birds, such as Western Tragopan (*Tragopan melanocephalus*), Himalayan Monal Pheasant (*Lophophorus impejanus*), Koklass Pheasant (*Pucrasia macrolopha*), Cheer Pheasant (*Catreus wallichii*), etc. as mentioned in Table 1 (Grimmett and Inskipp 2018). These birds inhabit variety of

Table 1. Galliformes in the study area as per the FCTLULC classes. 1= Subtropical Chir Pine (H”<1800 m), 2= Subtropical Scrub (H”<2300 m), 3= Lower (Ban & Moru) Oak Forest (H”1800-2500 m), 4= Moist Deodar Forest (H”1800-2800 m), 5= Mixed Coniferous Forest (H”1800-2600 m), 6= Moist Temperate Deciduous Forest (<3300 m), 7= Temperate Secondary Scrub (H”2300-4000 m), 8= Temperate Kharsu Oak Forest (H”2500-3300), 9= Temperate Upper Oak/ Fir Forest (H”2600-3400), 10= Parkland, 11= Blue Pine (H”2800-3400 m), 12= Sub-Alpine Fir Forest (H”>3000 m), 13= Rhododendron Scrub (H”>3000 m), 14= Dwarf Juniper Scrub (H”>3000 m), 15= Alpine Pastures (H”>3000 m), 16= Snow, 17= Waterbody, 18= Riverbed, 19= Agriculture (Based on Sathyakumar and Sivakumar 2007)

| Common Name | Scientific Name | Elevation Schedule | WPA | FCTLULC classes | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Kalij Pheasant | *Lophura leucomelanos* | 245-3050 | I | A | P | P | A | P | P | P | A | P | A | A | A | A | A | A | A | A | A | P |
| Chukar | *Alectoris chukar* | 1200- 5000 | IV | A | P | A | A | A | A | P | A | A | P | A | A | A | A | P | A | A | A | P |
| Hill Partridge | *Arborophila torqueola* | 400- 4000 | IV | A | P | P | A | P | P | P | P | P | A | A | A | A | A | A | A | A | A | A |
| Koklass Pheasant | *Pucrasia macrolopha* | 2100- 3300 | IV | A | A | A | P | P | P | A | P | P | A | A | P | A | A | A | A | A | A | A |
| Cheer Pheasant | *Catreus wallichii* | 1500- 3050 | I | A | P | A | A | A | P | P | A | A | P | P | A | A | A | A | A | A | A | P |
| Himalayan Monal | *Lophophorus impejanus* | 2000- 4875 | I | A | A | A | P | P | P | P | P | P | P | P | P | P | P | P | P | A | A | P |
| Western Tragopan | *Tragopan melanocephalus* | 1735- 3600 | I | A | A | A | P | P | P | A | P | P | A | A | P | A | A | A | A | A | A | A |
| Himalayan Snowcock | *Tetragallus himalayensis* | 3000- 5800 | IV | A | A | A | A | A | A | A | A | A | A | A | A | A | A | P | P | A | A | A |
| Snow Partridge | *Lerwa lerwa* | 3000- 5500 | IV | A | A | A | A | A | A | A | A | A | A | A | A | P | P | P | P | A | A | A |

habitats. Western Tragopan is found in temperate and sub-alpine wooded forest with dense undergrowth. Himalayan Monal is widespread in temperate, sub-alpine and alpine region. Koklass Pheasant prefers temperate forests with dense undergrowth and bamboo. Kalij pheasant is found in all types of forests from tropical to sub-alpine region with dense undergrowth. Cheer Pheasant prefers steep rocky cliffs, long grasses and scattered trees in Sub-tropical, temperate forests. Chakur is seen in open rocky, barren hillsides with scattered scrub and grassy slopes of tropical to alpine region. Hill Partridge inhibits slopes of evergreen broadleaf forests with undergrowth from tropical to alpine region. Himalayan Snowcock is seen in steep slopes and stony ridges of Sub-alpine and Alpine region. Snow Partridge inhibits steep rocky and grassy slopes of Sub-alpine and Alpine region (Sathyakumar and Sivakumar 2007).

**Satellite data acquisition and processing**

We used same sensor data, maintained closest possible seasonality and sensor characteristics of 3-time dataset to minimize the issues of radiometry, phenology, shadow and to some extent snow while mapping and spatio-temporal assessment. Landsat satellite data of 30 m spatial resolution (path/row 146/38,39), TM 4,5 of 1994 (November 11, 1994) and 2002 (October 30, 2002) and OLI (October 28, 2016) were downloaded from https://earthexplorer.usgs.gov. The images were geometrically corrected. We chose only common spectral bands across all the dataset for mapping. Prior to image classification, each image was pre-processed for radiometric distortion corrections. To improve the radiometric quality, the images were converted from digital number (DN) to radiance initially, followed by radiance to reflectance (Yarbrough et al. 2005) in ERDAS IMAGINE 2014 software. The data from different orbital paths were mosaicked. The watershed boundary was demarcated on Landsat 2016 data and vector was used for extracting study area. CartoDEM (10 m) was acquired from NRSC (https://www.nrsc.gov.in/) and was used to derive slope and aspect of the region.

METHODOLOGY

**Reconnaissance and field surveys**

The activities of reconnaissance survey, mapping and additional field visits were concurrently performed during 2016-19 to collect ground truth on the forest/vegetation and other land uses/land covers specially in shadowed areas. The greater Himalayan region has very narrow weather-window for visits due to high rainfall both in summer and winter seasons, and snowfall in winter coupled with challenging terrain conditions makes it more inaccessible. Since, the entire area, being highly undulating with rugged terrain and steep mountains, random observations possible along selected tracks/trails (N=28) of different lengths (7 to 14 km), along the altitudinal gradient, slope and aspect were taken up. In view of purposive mapping considering habitat characterization of Galliformes, sample plots of 10 m radius (n= 1544) were also taken to understand the structural composition of the life-forms in different forest vegetation types and plant-forms at 200 m interval along the trail and entering sideways alternatively 20 m into the forest. The 1544 ground truth (GT) points were geotagged. Information available on Survey of India topo maps (1:50,000) was also used appropriately for remote and inaccessible areas.

**Forest cover type and land use/land cover (FCTLULC) classification**

A very comprehensive classification scheme was developed based on field visits and considering the habitat characteristics of the Galliformes and was adopted uniformly across all datasets. An improved objective-based purposive FCTLULC mapping at level II was attempted (Anderson et al. 1976, NRSA 1982) and equivalent to the forest type in classification system of Champion and Seth (1968), as discerned on satellite data. The area is very complex in terms of variability in tree maturity, phenology, climax forests/vegetation, terrain, climatic conditions, altitudinal gradient and human-altered ecosystems, etc. leading to spectral overlapping. Therefore, attempts were made to harness the spectral separability of the image features using unsupervised and supervised approaches to the best possibility and then field-based knowledge was applied to classify unclassified or wrongly classified areas. At first unsupervised classification approach with very high number of clusters (250-500) was attempted to extract the pure formations/patches of FCTLULC. The classified area was masked. Thereafter, supervised classification approach with well distributed and geotagged training sites based on field observations was attempted to classify and extract the feature with desirable accuracy. However, shadow and spectral mixing of mature forest trees with other degraded vegetation were the major factors for unclassified pixels and low classification accuracy. Therefore, at the end knowledge-based classification that integrated digital elevation model (DEM), slope, aspect, Normalized Difference Vegetation Index (NDVI) and Green-Red Vegetation Index (GRVI) was followed. Nineteen FCTLULC classes such as Subtropical Chir Pine Forest, Subtropical Scrub, Lower (Ban & Moru) Oak Forest, Moist Deodar Forest, Mixed Coniferous Forest, Moist Temperate Deciduous Forest, Temperate Kharsu Oak Forest, Temperate Secondary Scrub, Temperate Upper Oak Fir Forest, Parkland, Blue Pine, Sub-Alpine Fir Forest, Rhododendron Scrub, Dwarf Juniper Scrub, Pasture, Snow, Waterbody, Riverbed and Agriculture were mapped. At first step the latest Landsat 8 (OLI) data of 2016 was classified using unsupervised Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering algorithm with 500 clusters but the classification accuracy was about 60% and purely classified areas such as snow, gregarious vegetation formations, sand and waterbodies were masked by generating binary images. The supervised classification was performed by developing training sites data from 1088 ground truth points in the remaining image. The classification accuracy of the product was 64%. Because of spectral overlapping in features such as alpine pastures with temperate grasslands/parklands and agriculture, and alpine scrub of Rhododendrons and Junipers with old orchards/plantations, etc. the classification accuracy was low. Thereafter, ancillary data of DEM, slope, aspect, Normalized Difference Vegetation Index (NDVI) and Green-Red Vegetation Index (GRVI) were integrated with remaining raw image (after unsupervised classification) to perform

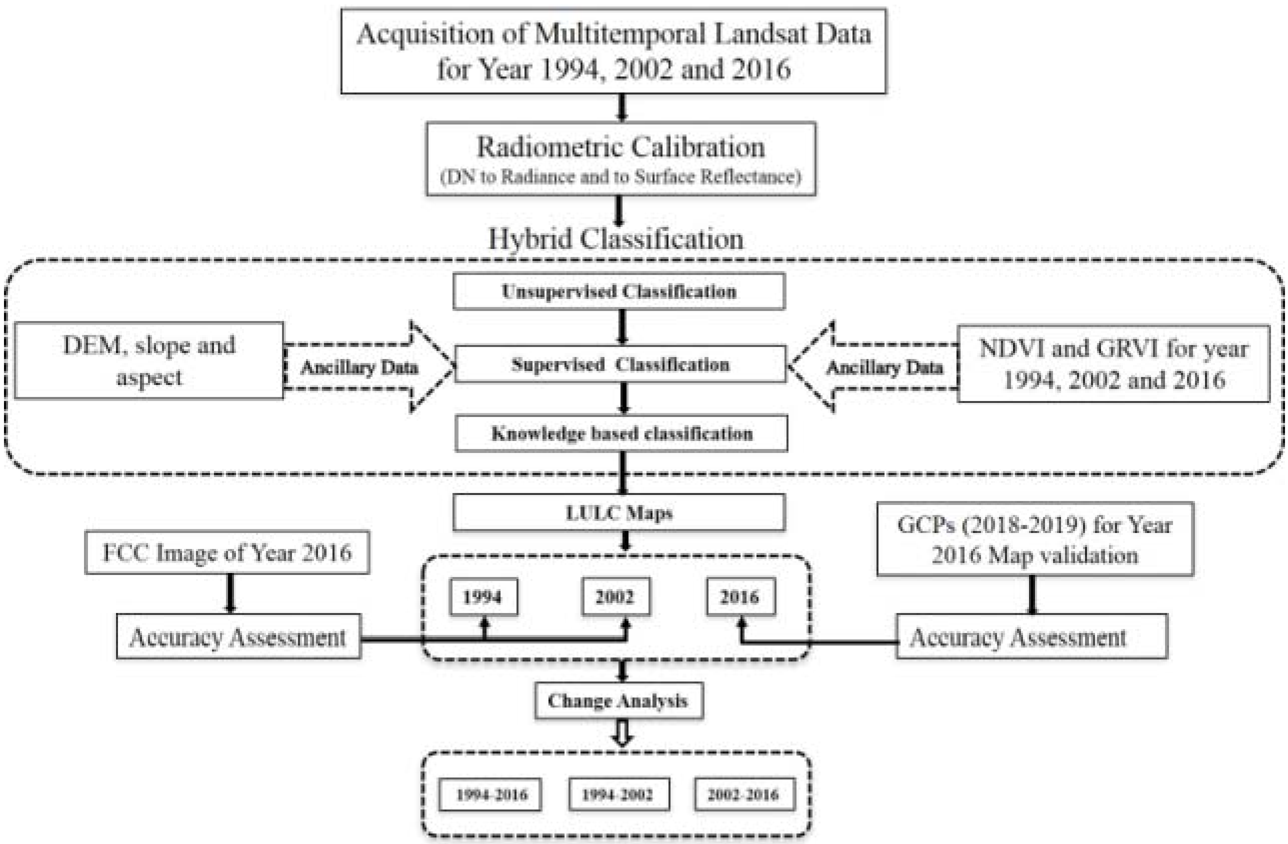


Figure 2. Flowchart of methodology adopted for the multidate FCTLULC mapping

supervised and knowledge-based classification (Fig. 2). Locale-specific knowledge-based classification approach was followed for mapping areas under shadow and intermixing covers such as grasslands, scree and sand, etc. All the individual layers were added in GIS.

**Accuracy assessment and change analysis**

The accuracy assessment of FCTLULC map of 2016 was done using 456 GCPs. The validation of 1994 and 2002 FCTLULC maps was done using the classified image and FCC of Landsat 2016, to check for classification errors. Thereafter, error-matrix for year 2016 was generated by comparing the information of GCPs collected during field work with corresponding pixels of 2016 FCTLULC map whereas for generating error-matrix for years 1994 and 2002, characteristics of features discernable on FCC image (2016) were compared with corresponding pixels of the respective year maps and subsequently the user's accuracy, producer's accuracy and kappa statistics were calculated, and class-wise area was analyzed. The transition (from-to) matrix analyses were performed in GIS domain for different time periods of 1994-2002, 2002-2016 and 1994-2016.

## RESULTS AND DISCUSSION

**Mapping**

The FCTLULC maps of year 1994, 2002 and 2016 are given in Figures 3, 4 and 5. The overall accuracy achieved was 84.40, 82.85 and 81.25% with kappa value of 0.87, 0.85 and 0.84 for FCTLULC maps of 2016, 2002 and 1994, respectively. An improvement in overall accuracy in 2016 FCTLULC map was observed, which may be attributed to the better spectral resolution of Landsat 8, it has more number of bands, with narrower width in the visible and near-infrared region in comparison to that of LANDSAT

Table 2. Classification accuracy (%) of different time-period FCTLULC maps. P's A= Producer's Accuracy and U's A= User's Accuracy

| Sr no. | FCTLULC classes | 1994 | | 2002 | | 2016 | |
|---|---|---|---|---|---|---|---|
| | | P's A | U's A | P's A | U's A | P's A | U's A |
| 1 | Subtropical Chir Pine | 81.40 | 89.74 | 90.36 | 89.87 | 83.72 | 91.14 |
| 2 | Subtropical Scrub | 84.54 | 91.11 | 92.39 | 92.13 | 83.84 | 92.22 |
| 3 | Lower (Ban & Moru) Oak Forest | 88.89 | 66.67 | 84.21 | 66.67 | 88.89 | 76.19 |
| 4 | Moist Deodar Forest | 77.46 | 96.49 | 98.44 | 96.49 | 85.92 | 98.39 |
| 5 | Mixed Coniferous Forest | 83.33 | 46.88 | 62.50 | 46.88 | 83.33 | 51.72 |
| 6 | Moist Temperate Deciduous Forest | 76.67 | 69.70 | 78.79 | 69.70 | 83.33 | 75.76 |
| 7 | Temperate Secondary Scrub | 83.72 | 66.67 | 80.00 | 68.52 | 86.05 | 69.81 |
| 8 | Temperate Kharsu Oak Forest | 85.94 | 73.26 | 94.34 | 75.12 | 82.98 | 78.06 |
| 9 | Temperate Upper Oak/Fir Forest | 76.92 | 87.72 | 91.43 | 87.93 | 83.08 | 88.52 |
| 10 | Parkland | 89.19 | 76.74 | 89.74 | 76.74 | 89.19 | 82.50 |
| 11 | Blue Pine | 71.08 | 57.38 | 84.08 | 61.09 | 76.92 | 71.48 |
| 12 | Sub-Alpine Fir Forest | 83.53 | 94.67 | 97.37 | 94.67 | 84.71 | 96.00 |
| 13 | Rhododendron Scrub | 87.50 | 66.67 | 82.35 | 66.67 | 93.75 | 68.18 |
| 14 | Dwarf Juniper Scrub | 74.00 | 72.55 | 87.76 | 74.51 | 80.00 | 80.00 |
| 15 | Pastures | 89.29 | 94.59 | 97.95 | 94.59 | 92.86 | 96.81 |
| 16 | Snow | 92.04 | 100.00 | 100.00 | 100.00 | 94.25 | 100.00 |
| 17 | Waterbody | 87.50 | 87.50 | 87.50 | 87.50 | 87.50 | 87.50 |
| 18 | Riverbed | 93.33 | 53.85 | 73.68 | 53.85 | 93.33 | 58.33 |
| 19 | Agriculture | 88.37 | 67.86 | 85.42 | 67.86 | 95.35 | 75.93 |
| | Overall accuracy | 81.25 | | 82.85 | | 84.40 | |
| Kappa statistic | | 0.84 | | 0.85 | | 0.87 | |

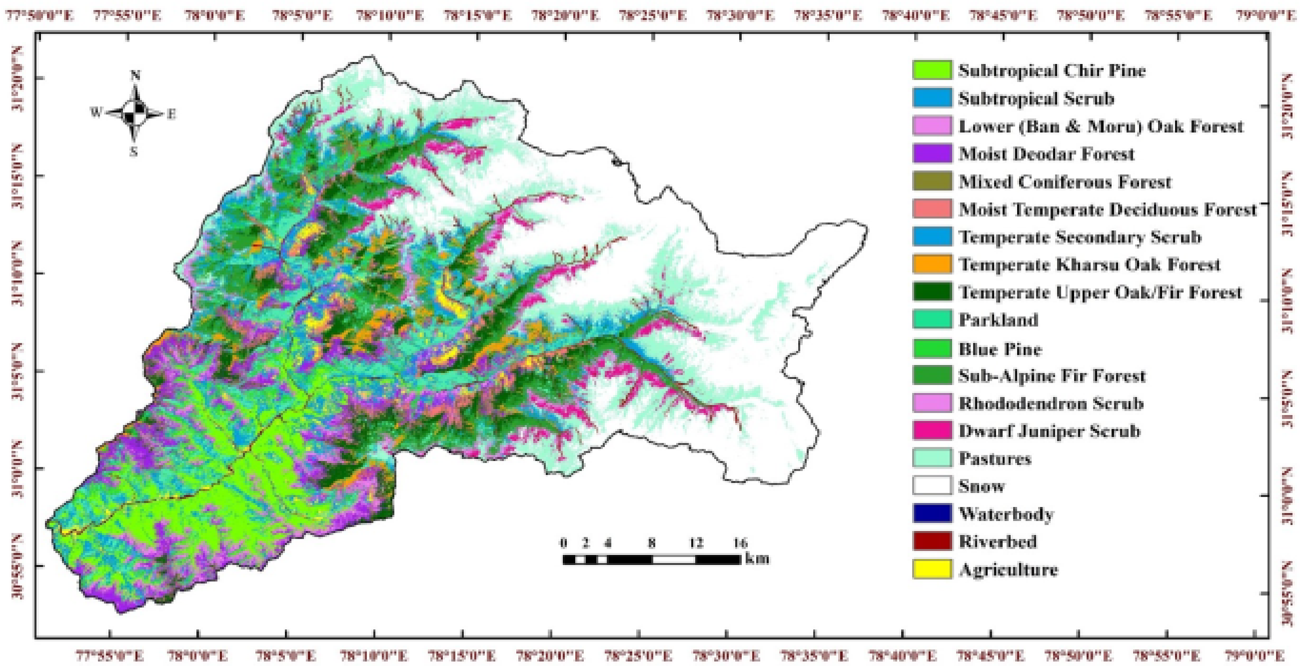


Figure 3. FCTLULC map of year 1994 based Landsat TM 4,5 (November 11, 1994)

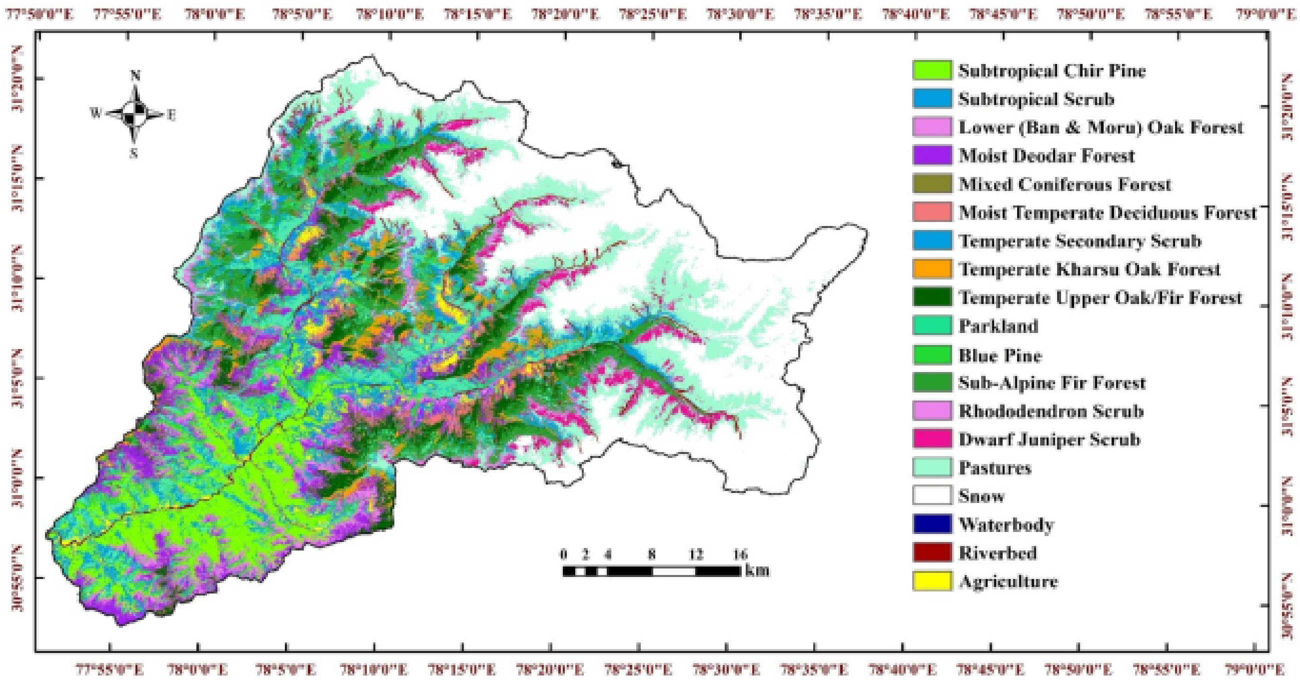


Figure 4. FCTLULC map of year 2002 based Landsat TM 4,5 (October 30, 2002)

TM 4 and 5 data. The user's accuracy was, as expected, highest for Snow, i.e. 100% in all the FCTLULC maps and the producers' accuracy was highest in agriculture (95.35%), snow (100%) and dry riverbed (93.33%) in that of year 2016, 2002 and 1994, respectively (Table 2). The area analyses of forest and non-Forest is summarized in Table 3. The multi-temporal satellite-based study exhibited that the large area primarily consists of ~80.21% of forest while ~19.79% area is only non-forest. The forest and non-forest area changed from the ratio of 73:27 in 1994 to 80:20 in 2016. Though the change is not much evident if the area of forest without pasture i.e. (Wooded forest and Scrub) is analyzed, which is

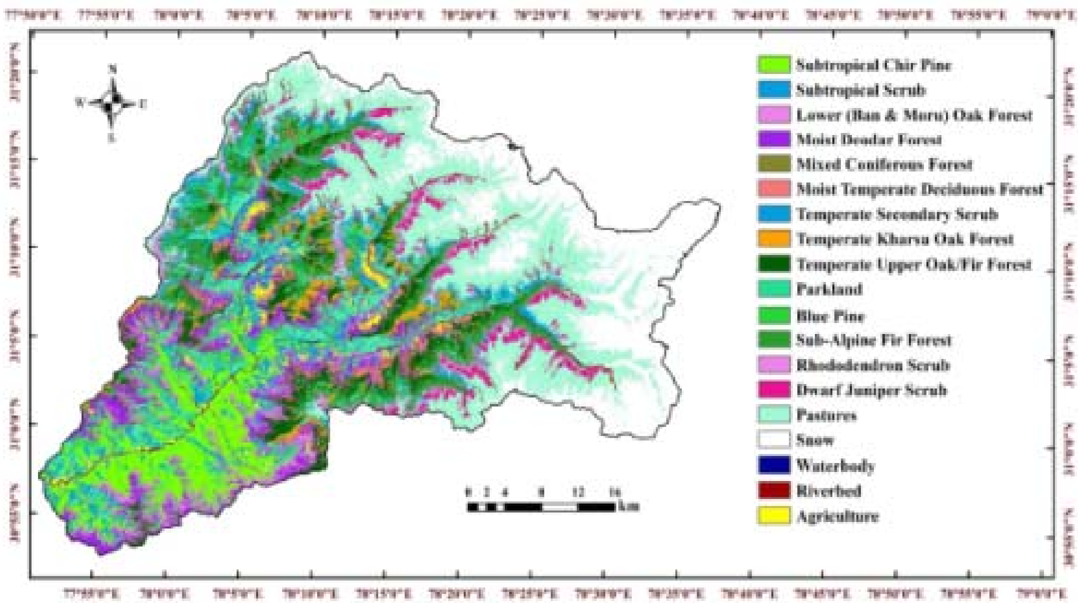


Figure 5. FCTLULC map of year 2016 based Landsat OLI (October 28, 2016)

Table 3. Level I class-wise area statistics for different time-period FCTLULC maps

| Sr no. | FCTLULC classes | 1994 | | 2002 | | 2016 | |
|---|---|---|---|---|---|---|---|
| | | km² | % | km² | % | km² | % |
| 1 | Forest | 1464.92 | 73.31 | 1459.84 | 73.06 | 1602.73 | 80.21 |
| 2 | Non-Forest | 533.24 | 26.69 | 538.35 | 26.94 | 395.45 | 19.79 |
| **Total** | | **1998.16** | **100** | **1998.19** | **100** | **1998.18** | **100** |

2.98 km$^2$ of increase in the span of 22 years (pastures get covered by snow). The area analyses of FCTLULC maps at level II classification is given in Table 4. It is evident that in 2016 the largest area was covered by Pastures (20.27%) and Snow (16.65 %), and the smallest area was under waterbody (0.11%) and riverbed (1.31%). Among various vegetation types the highest area was covered by Pastures (405.01 km$^2$), followed by Subtropical Chir Pine Forest (155.68 km$^2$), Sub-Alpine Fir Forest (128.75 km$^2$) and Moist Deodar Forest (119.06 km$^2$) and lowest area was covered by Mixed Coniferous Forest (35.99 km$^2$) and Rhododendron Scrub (38.33 km$^2$). However, among the Land-use classes area under agriculture was observed 34.51 km$^2$, 33.93 km$^2$ and 32.97 km$^2$ in the year 2016, 2002 and 1994, respectively. Because of varying snow-cover there are variations in area analyses of alpine pastures and snow cover in each year.

**FCTLULC dynamics for the period between 1994 and 2016**

The FCTLULC-wise area analyses among three time-periods FCTLULC is given in Table 5. Between 1994 and 2016, i.e. in an interval of 22 years, other than the changes due to varying snow cover, the highest change was observed in Temperate Secondary Scrub (-1.85 km$^2$); and Agriculture (1.54 km$^2$), which may be attributed to anthropogenic activities (Fig. 6). The expansion of the agriculture land was 1.54 km$^2$ due to diversion from 2.20, 0.50 and 0.07 km$^2$ of land from subtropical, temperate and Sub-Alpine Forest areas. The largest land was diverted to agriculture is from Subtropical Scrub (1.34 km$^2$), followed by Subtropical Chir Pine Forest (0.53 km$^2$) and Temperate Secondary Scrub (0.37 km$^2$). This reflects the preference of low and middle altitude areas for farming. There has been a significant increase in Subtropical Scrub and

Table 4. Level II class-wise area statistics for different time-period FCTLULC maps

| Sr no. | FCTLULC classes | Year-wise area statistics | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1994 | | 2002 | | 2016 | |
| | | km² | % | km² | % | km² | % |
| 1 | SCP | 156.61 | 7.84 | 156.13 | 7.81 | 155.68 | 7.79 |
| 2 | SSc | 101.88 | 5.10 | 102.01 | 5.11 | 102.24 | 5.12 |
| 3 | LOF | 78.46 | 3.93 | 78.50 | 3.93 | 78.39 | 3.92 |
| 4 | MDF | 119.22 | 5.97 | 119.22 | 5.97 | 119.06 | 5.96 |
| 5 | MCF | 35.99 | 1.80 | 36.02 | 1.80 | 35.99 | 1.80 |
| 6 | MTD | 39.12 | 1.96 | 39.28 | 1.97 | 39.66 | 1.98 |
| 7 | TSS | 97.13 | 4.86 | 96.19 | 4.81 | 95.28 | 4.77 |
| 8 | TKOF | 46.57 | 2.33 | 46.56 | 2.33 | 46.52 | 2.33 |
| 9 | TUO/FF | 102.05 | 5.11 | 102.08 | 5.11 | 102.05 | 5.11 |
| 10 | Pl | 115.13 | 5.76 | 115.50 | 5.78 | 115.45 | 5.78 |
| 11 | BP | 80.83 | 4.05 | 80.83 | 4.05 | 80.83 | 4.05 |
| 12 | SAFF | 128.78 | 6.44 | 128.67 | 6.44 | 128.75 | 6.44 |
| 13 | RSc | 38.23 | 1.91 | 38.13 | 1.91 | 38.33 | 1.92 |
| 14 | DJSc | 54.74 | 2.74 | 54.31 | 2.72 | 59.49 | 2.98 |
| 15 | Pastures | 270.18 | 13.52 | 266.40 | 13.33 | 405.01 | 20.27 |
| 16 | Snow | 472.47 | 23.65 | 476.84 | 23.86 | 332.63 | 16.65 |
| 17 | Wb | 1.64 | 0.08 | 2.33 | 0.12 | 2.10 | 0.11 |
| 18 | Rb | 26.16 | 1.31 | 25.25 | 1.26 | 26.21 | 1.31 |
| 19 | Agri | 32.97 | 1.65 | 33.93 | 1.70 | 34.51 | 1.73 |
| **Grand Total** | | **1998.16** | **100** | **1998.16** | **100** | **1998.16** | **100** |

SCP= Subtropical Chir Pine, SSc= Subtropical Scrub, LOF= Lower (Ban & Moru) Oak Forest, MDF= Moist Deodar Forest, MCF= Mixed Coniferous Forest, MTDF= Moist Temperate Deciduous Forest, Temperate Secondary Scrub= TSc, TKOF= Temperate Kharsu Oak Forest, TUO/FF= Temperate Upper Oak/Fir Forest, Pl= Parkland, BP= Blue Pine, SAFF= Sub-Alpine Fir Forest, RSc= Rhododendron Scrub, DJSc= Dwarf Juniper Scrub, Pastures= Pastures, Snow= Snow, Agri= Agriculture, Rb= Riverbed, Wb= Waterbody.

Table 5. Class-wise change area statistics between different three time-periods FCTLULC

| Sr no | FCTLULC classes | Change area statistics | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1994-2002 | | 2002-2016 | | 1994-2016 | |
| | | km² | ROC | km² | ROC | km² | ROC |
| 1 | SCP | -0.49 | -0.06 | -0.44 | -0.03 | -0.93 | -0.04 |
| 2 | SSc | 0.13 | 0.02 | 0.23 | 0.02 | 0.36 | 0.02 |
| 3 | LOF | 0.04 | 0.01 | -0.11 | -0.01 | -0.07 | 0.00 |
| 4 | MDF | 0.00 | 0.00 | -0.16 | -0.01 | -0.16 | -0.01 |
| 5 | MCF | 0.03 | 0.00 | -0.03 | 0.00 | 0.00 | 0.00 |
| 6 | MTDF | 0.16 | 0.02 | 0.38 | 0.03 | 0.54 | 0.02 |
| 7 | TSc | -0.94 | -0.12 | -0.91 | -0.07 | -1.85 | -0.08 |
| 8 | TKOF | -0.01 | 0.00 | -0.04 | 0.00 | -0.05 | 0.00 |
| 9 | TUO/FF | 0.03 | 0.00 | -0.03 | 0.00 | 0.00 | 0.00 |
| 10 | Pl | 0.37 | 0.05 | -0.05 | 0.00 | 0.32 | 0.01 |
| 11 | BP | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | SAFF | -0.11 | -0.01 | 0.08 | 0.01 | -0.03 | 0.00 |
| 13 | RSc | -0.10 | -0.01 | 0.20 | 0.01 | 0.10 | 0.00 |
| 14 | DJSc | -0.43 | -0.05 | 5.18 | 0.37 | 4.75 | 0.22 |
| 15 | Pastures | -3.78 | -0.47 | 138.61 | 9.90 | 134.83 | 6.13 |
| 16 | Snow | 4.37 | 0.55 | -144.21 | -10.30 | -139.84 | -6.36 |
| 17 | Wb | 0.69 | 0.09 | -0.23 | -0.02 | 0.46 | 0.02 |
| 18 | Rb | -0.91 | -0.11 | 0.96 | 0.07 | 0.05 | 0.00 |
| 19 | Agri | 0.96 | 0.12 | 0.58 | 0.04 | 1.54 | 0.07 |
| **Grand Total** | | **0.03** | **0.00** | **-0.01** | **0.00** | **0.02** | **0.00** |

SCP= Subtropical Chir Pine, SSc= Subtropical Scrub, LOF= Lower (Ban & Moru) Oak Forest, MDF= Moist Deodar Forest, MCF= Mixed Coniferous Forest, MTDF= Moist Temperate Deciduous Forest, Temperate Secondary Scrub= TSc, TKOF= Temperate Kharsu Oak Forest, TUO/FF= Temperate Upper Oak/Fir Forest, PL= Parkland, BP= Blue Pine, SAFF= Sub-Alpine Fir Forest, RSc= Rhododendron Scrub, DJSc= Dwarf Juniper Scrub, Pastures= Pastures, Agri= Agriculture, Rb= Riverbed, Wb= Waterbody and ROC ($km^2$/yr) = Rate of Change (Change in area per year)

Parkland of 0.36 and 0.32 $km^2$, respectively, due to logging and pastoralism as well as regrowth. The changes in forest area below 2500 m altitude consisting of Chir Pine, Moist Deodar Forest and Lower (Ban and Moru) Oak Forest is 0.93, 0.16 and 0.07 $km^2$, respectively, attributed to collection of fodder and fuelwood as well as expansion of agriculture (Annexure 1).

## FCTLULC dynamics for the period between 1994 and 2002

The expansion of agriculture land was 0.96 $km^2$, again due to diversion from subtropical scrub (0.81 $km^2$), followed by Subtropical Chir Pine Forest (0.31 $km^2$) and Temperate Secondary Scrub (0.27 $km^2$). A significant decrease in Temperate Secondary Scrub (0.94 $km^2$) was observed due to its diversion to river (0.49 $km^2$), agriculture (0.27 $km^2$) and Parkland (0.25 $km^2$). The decrease in Chir Pine Forest (0.49 $km^2$) can be attributed mainly to the expansion in agriculture. Minor change was observed in Sub-Alpine Fir Forest (0.11 $km^2$) and minor increase in Moist Temperate Deciduous Forest (0.16 $km^2$) and subtropical scrub (0.13 $km^2$) (Fig. 7, Annexure 2).

## FCTLULC dynamics for the period between 2002 and 2016

The expansion of agriculture (0.58 $km^2$) showed slow rate of increase (0.04 $km^2$/year) as compared to between 1994 and 2002 (0.12 $km^2$/year) (Table 5.).

Table 6. Broad classes of FCTLULC

| Sr no. | Broad Classes | FCTLULC Classes |
|---|---|---|
| 1 | Conifer-wooded forest (CF) | Subtropical Chir Pine, Moist Deodar Forest, Mixed Coniferous Forest and Blue Pine |
| 2 | Broadleaf-wooded forest (BF) | Lower (Ban & Moru) Oak Forest, Moist Temperate Deciduous Forest and Temperate Kharsu Oak Forest |
| 3 | Mixed forest-wooded forest (MF) | Temperate Upper Oak/Fir Forest and Sub-Alpine Fir Forest |
| 4 | Scrub (SC) | Subtropical Scrub and Temperate Secondary Scrub |
| 5 | Alpine scrub (AS) | Rhododendron Scrub and Dwarf Juniper Scrub |
| 6 | Pasture and parkland (PP) | Pastures and Parkland |
| 7 | Non-forest (man-made) (NF) | Agriculture |
| 8 | Natural non-forest (NNF) | Snow, Waterbody and Riverbed |

Table 7. Broad class-wise area statistics of different time period FCTLULC Maps

| Sr no. | FCTLULC classes | Year-wise area statistics | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1994 | | 2002 | | 2016 | |
| | | km² | % | km² | % | km² | % |
| 1 | CF | 392.65 | 19.65 | 392.20 | 19.63 | 391.56 | 19.60 |
| 2 | BF | 164.15 | 8.22 | 164.34 | 8.22 | 164.57 | 8.24 |
| 3 | MF | 230.83 | 11.55 | 230.75 | 11.55 | 230.80 | 11.55 |
| 4 | SC | 199.01 | 9.96 | 198.20 | 9.92 | 197.52 | 9.88 |
| 5 | AS | 92.97 | 4.65 | 92.45 | 4.63 | 97.82 | 4.90 |
| 6 | PP | 385.31 | 19.28 | 381.90 | 19.11 | 520.46 | 26.05 |
| 7 | NF | 32.97 | 1.65 | 33.93 | 1.70 | 34.51 | 1.73 |
| 8 | NNF | 500.27 | 25.04 | 504.42 | 25.24 | 360.94 | 18.06 |

Table 8. Broad class-wise change area statistics between different time-period FCTLULC maps

| Sr no. | FCTLULC classes | Change area statistics | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1994-2002 | | 2002-2016 | | 1994-2016 | |
| | | km² | ROC | km² | ROC | km² | ROC |
| 1 | CF | -0.45 | -0.06 | -0.64 | -0.05 | -1.09 | -0.05 |
| 2 | BF | 0.19 | 0.02 | 0.23 | 0.02 | 0.42 | 0.02 |
| 3 | MF | -0.08 | -0.01 | 0.05 | 0.00 | -0.03 | 0.00 |
| 4 | SC | -0.81 | -0.10 | -0.68 | -0.05 | -1.49 | -0.07 |
| 5 | AS | -0.52 | -0.07 | 5.37 | 0.38 | 4.85 | 0.22 |
| 6 | PP | -3.41 | -0.43 | 138.56 | 9.90 | 135.15 | 6.14 |
| 7 | NF | 0.96 | 0.12 | 0.58 | 0.04 | 1.54 | 0.07 |
| 8 | NNF | 4.15 | 0.52 | -143.48 | -10.25 | -139.33 | -6.33 |

ROC ($km^2$/yr) = Rate of Change (Change in area per year)

The increase in moist temperate deciduous forest (0.38 $km^2$) and subtropical scrub (0.23 $km^2$) shows higher rate of increase. The decrease in subtropical Chir pine forest (0.44 $km^2$) shows similar direction of transition to subtropical scrub (0.23 $km^2$) and agriculture (0.22 $km^2$) but with almost half rate of change as compared to the previous period. The decrease in area of forest under moist Deodar, Lower (Ban And Moru) Oak, Temperate Kharsu Oak, Mixed Coniferous and Temperate Upper Oak /Fir; (which was less evident in 1994-2002 period) altogether reflect gradual rise in anthropogenic activities such as cutting and lopping for fuelwood and fodder in this time period (Fig. 8, Annexure 3).

**Broad class-wise area analyses of different time period FCTLULC maps (2016, 2002 and 1994)**

The level-II FCTLULC classification scheme discussed earlier was collapsed into broad categories to understand overall impact of the anthropogenic pressures. As for timber wood requirements of local villagers for repairing their houses, logging is mainly done for conifers like Deodar (*Cedrus deodara*), East Himalayan Fir (*Abies spectabilis)*, Kail (*Pinus wallichiana*) and Chir Pine (*Pinus roxburghii*); due to preference for durability of wood. And for fodder broad leaf trees like Moru Oak (*Quercus floribunda*), Banj Oak (*Quercus leucotrichophora*) and Kharsu Oak (*Quercus semicarpifolia)*; are lopped and pressure from pastoral activities is majorly in Pastures followed by Scrub. Thus, analysis of the FCTLULC dynamics in broad classes, viz. Conifer-wooded forest, Broadleaf-wooded forest, Mixed-wooded forest, Scrub, Alpine scrub, Pasture and parkland, Non-forest (man-made) and Non-forest (Natural); was done (Table 6). Table 7 and 8 show the class wise area statistics and change in area in year 1994, 2002 and 2016.

**Broad class-wise FCTLULC transition between 1994 and 2016, 1994-2002 and 2002-2016**

During 1994 to 2016 analysis indicates an increase in area of alpine pastures and parkland due to

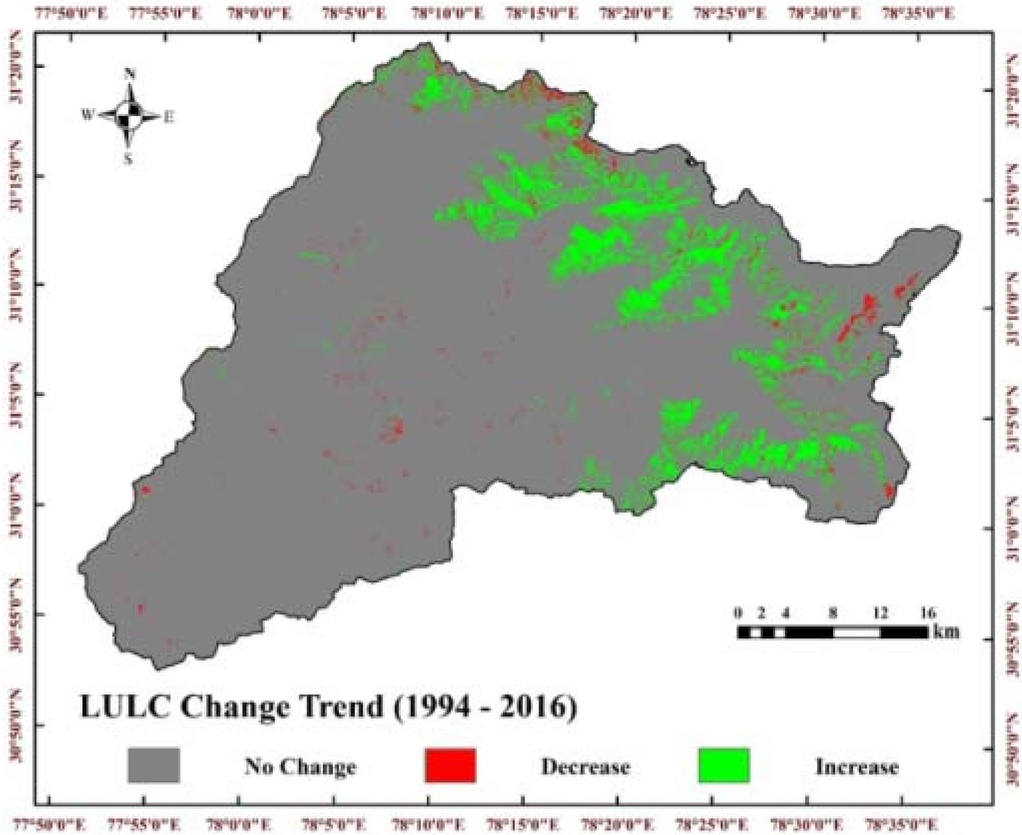


Figure 6. Map showing the spatio-temporal change trend of FCTLULC between period 1994 and 2016

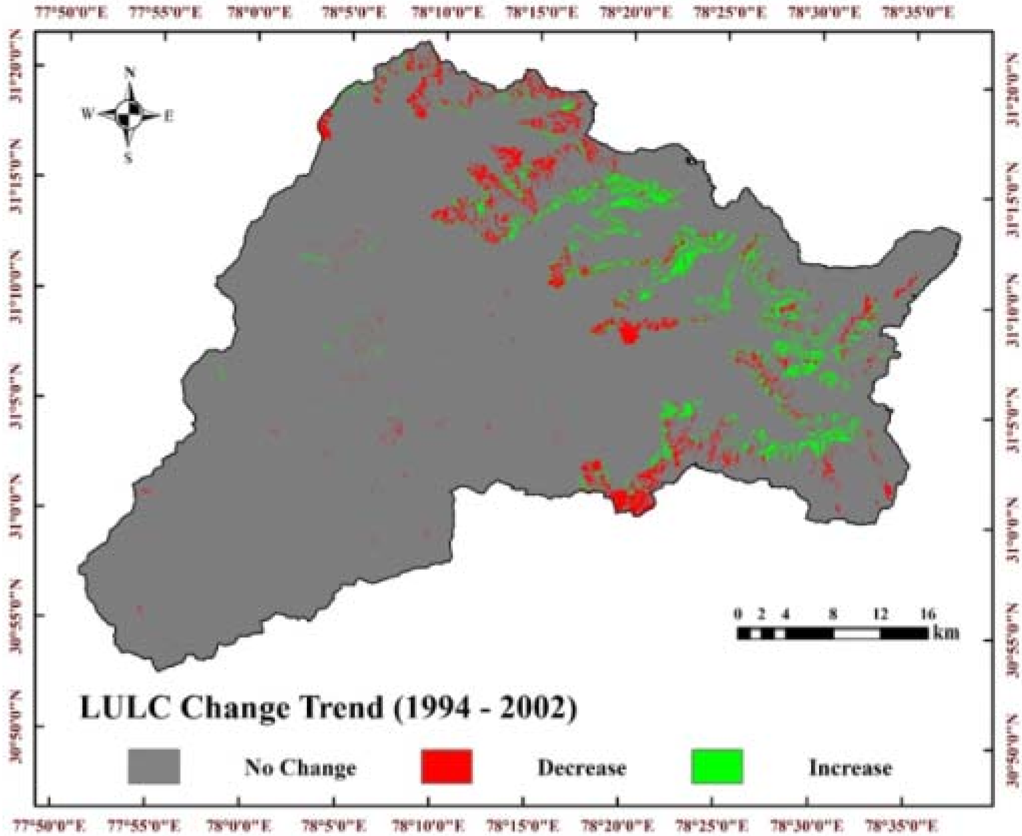


Figure 7. Map showing the spatio-temporal change trend of FCTLULC between period 1994 and 2002

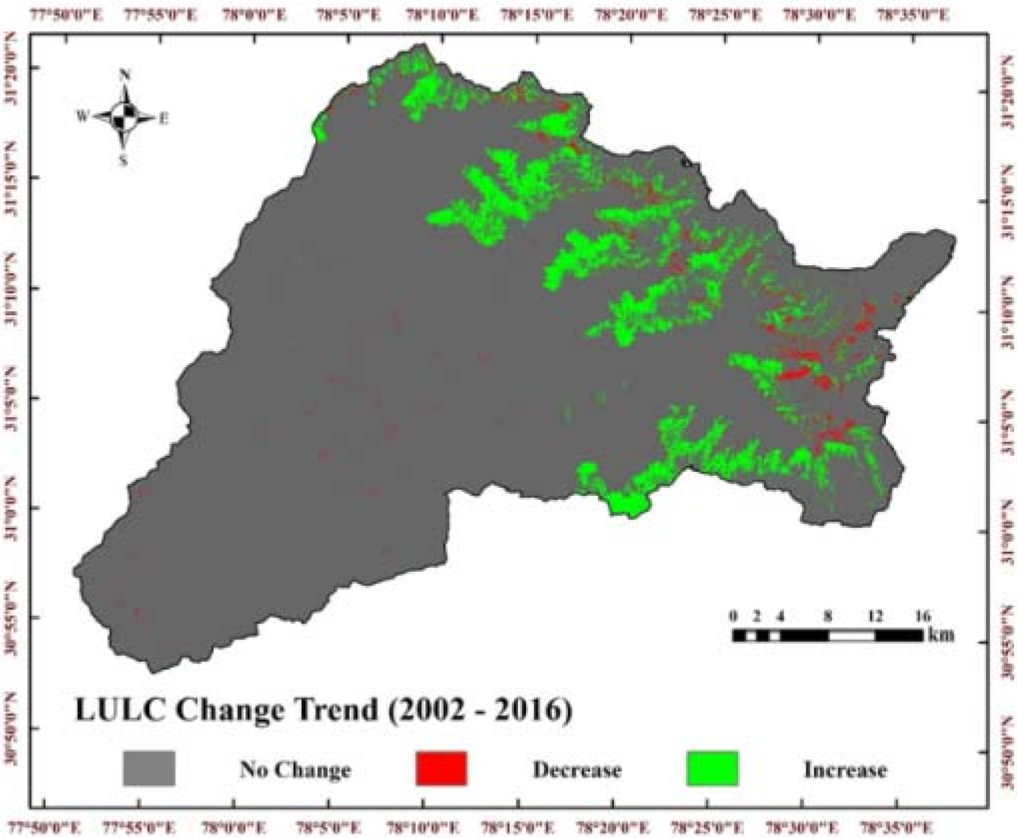


Figure 8. Map showing the spatio-temporal change trend of FCTLULC between period 2002 and 2016

fluctuations decrease in snow cover, and a decrease of 1.49 km$^2$ in scrub 1.71, 1.36 and 0.4 km$^2$ lost to non-forest, natural non-forest, pasture and parkland, respectively (Table 9). A significant decrease in 1.09 km$^2$ area of Conifer-wooded forest was also be seen due to transition of 0.75 and 0.42 km$^2$ of area to non-forest (man-made) and scrub, respectively, which may be attributed to the activities like logging for timber wood. Table 10 and 11 show the broad class-wise FCTLULC dynamics in 8-year time period between 1994 and 2002 and 14-year time period between 2002 and 2016, respectively. A significant decrease in scrub and conifer-wooded forest by 0.81 and 0.45 km$^2$ in 1994-2002 period and 0.68 and 0.64 km$^2$ in 2002-2016 period respectively is evident, which is cause of concern as the scrub, shrub, etc. are the most favored habitats of Galliformes.

## CONCLUSIONS

Presently the FCTLULC changes due to anthropogenic activities are less but evident. This also indicates the good forest protection. The dynamism of agriculture area depends upon people's dependency on agriculture as well as other sources of income in these years. The foot-print of anthropogenic activities can be seen in the form of cleared below canopy vegetation in coniferous forests, preferred by Galliformes. The abandoned agriculture fields mostly lying in higher altitude, i.e. temperate zone, are potential habitat for Galliformes like Cheer Pheasant, Kalij Pheasant, Chukar and Himalayan Monal after successful succession. The expansion of agriculture was more evident in the lower altitudes, due to collection of fuel wood and fodder, and horticulture activities and were prevalent below Taluka village in the Supin Range and below Doni village in the Rupin Range. The decrease in forest area in temperate zone was marginal due to inaccessibility and harsh weather but is evident, which is a cause of concern as it constitutes to highest diversity of Galliformes, in the area; and anthropogenic activities like pastoralism, NTFP collection (medicinal herbs and mushrooms) and tourism are continuously on the rise. The decrease in Conifer-wooded forest and Scrub is more evident

Table 9. Broad class-wise FCTLULC transition between 1994 and 2016 (in km²)

| | 2016 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1994** | **CF** | **BF** | **MF** | **SC** | **AS** | **PP** | **NF** | **NNF** | **Grand Total** |
| **CF** | 391.48 | 0.01 | 0.00 | 0.42 | 0.00 | 0.01 | 0.75 | 0.00 | 392.67 |
| **BF** | 0.00 | 163.95 | 0.00 | 0.01 | 0.00 | 0.02 | 0.17 | 0.00 | 164.15 |
| **MF** | 0.00 | 0.00 | 230.80 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 230.83 |
| **SC** | 0.02 | 0.07 | 0.00 | 195.44 | 0.00 | 0.40 | 1.71 | 1.36 | 199.00 |
| **AS** | 0.00 | 0.00 | 0.00 | 0.00 | 92.97 | 0.00 | 0.00 | 0.00 | 92.97 |
| **PP** | 0.00 | 0.03 | 0.00 | 0.06 | 0.00 | 369.04 | 0.04 | 16.14 | 385.31 |
| **NF** | 0.06 | 0.49 | 0.00 | 0.65 | 0.00 | 0.02 | 31.74 | 0.00 | 32.96 |
| **NNF** | 0.00 | 0.02 | 0.00 | 0.93 | 4.85 | 150.97 | 0.06 | 343.43 | 500.26 |
| **Grand Total** | **391.56** | **164.57** | **230.80** | **197.51** | **97.82** | **520.46** | **34.50** | **360.93** | **1998.15** |

Table 10. Broad class-wise FCTLULC transition between 1994 and 2002 (in km²)

| | 2002 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1994** | **CF** | **BF** | **MF** | **SC** | **AS** | **PP** | **NF** | **NNF** | **Grand Total** |
| **CF** | 392.01 | 0.01 | 0.00 | 0.18 | 0.00 | 0.01 | 0.46 | 0.00 | 392.67 |
| **BF** | 0.00 | 164.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 0.00 | 164.15 |
| **MF** | 0.00 | 0.00 | 230.72 | 0.00 | 0.00 | 0.00 | 0.03 | 0.09 | 230.84 |
| **SC** | 0.09 | 0.05 | 0.00 | 196.86 | 0.00 | 0.31 | 1.08 | 0.61 | 199.00 |
| **AS** | 0.00 | 0.00 | 0.00 | 0.00 | 89.41 | 0.00 | 0.00 | 3.56 | 92.97 |
| **PP** | 0.00 | 0.03 | 0.00 | 0.04 | 0.00 | 329.00 | 0.01 | 56.23 | 385.31 |
| **NF** | 0.09 | 0.23 | 0.03 | 0.30 | 0.00 | 0.13 | 32.18 | 0.01 | 32.97 |
| **NNF** | 0.00 | 0.02 | 0.00 | 0.80 | 3.04 | 52.44 | 0.04 | 443.92 | 500.26 |
| **Grand Total** | 392.19 | 164.35 | 230.75 | 198.18 | 92.45 | 381.89 | 33.94 | 504.42 | 1998.17 |

Table 11. Broad class-wise FCTLULC transition between 2002 and 2016 (in km²)

| | 2016 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **2002** | **CF** | **BF** | **MF** | **SC** | **AS** | **PP** | **NF** | **NNF** | **Grand Total** |
| **CF** | 391.51 | 0.02 | 0.00 | 0.37 | 0.00 | 0.00 | 0.30 | 0.00 | 392.2 |
| **BF** | 0.01 | 164.08 | 0.00 | 0.18 | 0.00 | 0.01 | 0.05 | 0.00 | 164.33 |
| **MF** | 0.00 | 0.00 | 230.72 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 230.75 |
| **SC** | 0.00 | 0.03 | 0.00 | 196.54 | 0.00 | 0.12 | 0.64 | 0.87 | 198.2 |
| **AS** | 0.00 | 0.00 | 0.00 | 0.00 | 92.45 | 0.00 | 0.00 | 0.00 | 92.45 |
| **PP** | 0.01 | 0.09 | 0.00 | 0.08 | 0.00 | 362.98 | 0.04 | 18.7 | 381.9 |
| **NF** | 0.03 | 0.34 | 0.00 | 0.09 | 0.00 | 0.02 | 33.45 | 0.00 | 33.93 |
| **NNF** | 0.00 | 0.01 | 0.09 | 0.24 | 5.37 | 157.33 | 0.02 | 341.36 | 504.42 |
| **Grand Total** | 391.56 | 164.57 | 230.81 | 197.53 | 97.82 | 520.46 | 34.5 | 360.93 | 1998.18 |

in the period 1994-2002 as compared to that in 2002-2016 due to the decrease in the rate of negative change. Though the study area provides habitat to varied species of Galliformes, according to information available in the literature the presence of *Tragopan satyra* (Styr Tragopan, sympatric to Western Tragopan) has been reported in this region in past (Prasad et al. 1993a, b) and has not been reported after that, which indicates the increased disturbance.

Though from satellite view the forest cover may be good, habitats are still not secured of anthropogenic pressures, especially if we would focus on ground layer which is essential in order to control anthropogenic pressure; so that Galliformes can be conserved for the future. There are several threats which require attention of the authorities. Uncontrolled incidents of fire in Subtropical Chir Pine Forest, an important habitat for Cheer Pheasant is a serious threat (Bisht and Dobriyal 2002). Increasing farming activities as well as widespread livestock grazing in scrub and grassy slopes of subtropical and temperate region also affect Cheer Pheasant habitat. Camping and littering by tourists, cause considerable damage in protected areas (Bhattacharya and Sathyakumar 2007). Collection of montane bamboo (ringal) by locals in Temperate Deciduous forest is a source of disturbance for most of the species of Galliformes due to their preference for ground cover as well as its growth along the stream where most of them visit for drinking water. In temperate forests, inhibited by Koklass, Western Tragopan and Himalayan Monal, the collection of 'gucchi' mushroom (*Agaricus* sp.), lichens and medicinal plant from wild, coincides with the breeding season of Galliformes (Gaston et al. 1992). The transhuman migration also coincides with the breeding season of these birds and gives rise to increase in grazing pressure, hunting, nest predation by shepherds, plus the accompanying sheep dogs which increase the nuisance (Virdi 2007). Temperate and alpine forests are flocked by Gujjars in May to October, leading to logging and lopping of Kharsu for forage and fuelwood (Bhattacharya and Sathyakumar 2007). Galliformes species in Western Himalaya have experienced decrease in abundance due to excessive hunting (Bisht and Dobriyal 2002, Ramesh 2003).

## ACKNOWLEDGEMENTS

Authors would like to express their deep sense of gratitude to past and present Director, Indian Institute of Remote Sensing for providing the lab facilities to pursue this work. They also acknowledge the valuable help and support of the Uttarakhand Forest officials and for providing the permission to work in the protected area. The first author is very grateful to the Rufford Foundation, for their support in funding for fieldwork, through Rufford Small Grant. She also would like to thank Head, Forestry & Ecology Department, IIRS for his valued support. She is thankful to Dr. Ishwari Datt Rai for his guidance in identification of plants of the study area. She appreciates the participation of volunteers, who accompanied her during different parts of the fieldwork; Neeru Saini, Nidhi Bisht, Reuben Malekar, Dhiraj Bhaisare, Suhotra Rajput, Kartik Thevar, Ankit Vikrant and Thangsuanlian Naulak.

**Authors Contribution**: Ms. Sonal Arora has done field surveys, analysis and writing. Dr. Sarnam Singh and Dr. S. Sathyakumar have contributed as resource-persons and gave their invaluable guidance and inputs throughout the work.

**Conflict of Interest**: The author(s) declare no competing interests.

## REFERENCES

Abd El-Kawy, O.R., Rød, J.K., Ismail, H.A. and Suliman, A.S. 2011. Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. Applied Geography, 31(2), 483–494.

Akike, S. and Samanta, S. 2016. Land use/land cover and forest canopy density monitoring of Wafi-Golpu project area, Papua New Guinea. Journal of Geoscience and Environment Protection, 4, 1-14.

Almeida, C.A.De., Coutinho, A.C., César, J., Mora, D., Adami, M., Venturieri, A., Diniz, C.G., Dessay, N.. Durieux, L. and Gomes, A.R. 2008. High spatial resolution land use and land cover mapping of the Brazilian legal Amazon in 2008 using Landsat-5 / TM and MODIS data. Acta Amazonica, 46(3), 291–302.

Anderson, J.R., Hardy, E.E., Roach, J.T. and Witmer R.E. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. Geological Survey Professional, U.S. Government Printing Office, Washington DC 964. 28pp.

Anonymous. 2019. Management Plan of Govind National Park. Department of Forests and Wildlife, Government of Uttarakhand, Dehradun.

Areendran, G., Raj, K., Mazumdar, S. and Sharma, A. 2017. Land use and land cover change analysis for Kosi river wildlife corridor in Terai Arc landscape of Northern India: Implications for future management. Tropical Ecology, 58(1), 139–149.

Areendran, G., Rao, P., Raj, K., Mazumdar, S. and Puri, K. 2013. Land use/land cover change dynamics analysis in mining areas of Singrauli district in Madhya Pradesh, India. Tropical Ecology, 54(2), 239–250.

Babu, S., Singh, S., Goyal, S.P. and Shruti, M. 2019. Dynamics of asian elephant habitat in Shivalik landscape and environs of Kalesar-Rajaji–Corbett Protected Area Network. International Journal of Ecology and Environmental

Sciences, 45(2), 205-228.

Batar, A.K., Watanabe, T. and Kumar, A. 2017. Assessment of land-use/land-cover change and forest fragmentation in the Garhwal Himalayan region of India. Environments, 4(2), 34.

Bhattacharya T. and Sathyakumar S. 2007. Impact of anthropogenic pressures on abundance and distribution of Galliformes at Bedini-Ali, Nanda Devi Biosphere Reserve, Uttarakhand. Pp 155-162. In. Sathyakumar S. and Sivakumar K. (Eds). Galliformes of India. ENVIS Bull., Wildlife Protected Areas 10, Dehradun.

Bisht, M. and Dobriyal, A.K. 2002. Status and distribution of Cheer Pheasant *Catreus wallichii* in Garhwal Himalaya, Uttaranchal. Pp.6-10, In: Proceedings of National Symposium on Galliformes, Division of Wildlife Biology, A.V.C. College, Mayiladuthurai, Tamil Nadu.

Chakraborty, A., Sachdeva, K. and Joshi, P.K. 2016. Mapping long-term land use and land cover change in the central Himalayan region using a tree-based ensemble classification approach. Applied Geography, 74, 136-150.

Chamling, M. and Bera, B. 2020. Spatio-temporal patterns of land use/land cover change in the Bhutan–Bengal foothill region between 1987 and 2019: study towards geospatial applications and policy making. Earth Systems and Environment, 4, 117-130.

Champion, H.G. and Seth, S.K. 1968 A Revised Forest Types of India. Manager of Publications, Government of India, New Delhi. 404 pp.

Chandrashekhar, M.B., Singh, S. and Roy, P. 2003. Geospatial modelling techniques for rapid assessment of phytodiversity at landscape level in western Himalayas, Himachal Pradesh. Current Science, 84, 663-670.

Eiumnoh, A. and Shrestha, R.P. 1997. Can DEM enhance the digital image classification? Pages 1-6, In: Proceedings of the 18th Asian Conference on Remote Sensing, Kuala Lumpur, Malaysia.

Gairola, S., Proche, S. and Rocchini, D. 2013. High-resolution satellite remote sensing: A new frontier for biodiversity exploration in Indian Himalayan forests. International Journal of Remote Sensing, 34(6), 2006–2022.

Garg, S., Javed, R., Sood, S. and Singh, H. 2016. Genetic evaluation of ex situ conservation breeding projects of cheer pheasant (*Catreus wallichii*) and western tragopan (*Tragopan melanocephalus*) in India. Zoo biology, 35(3), 269-273.

Garrard, R., Kohler, T., Price, M.F., Byers, A.C., Sherpa, A.R. and Maharjan, G.R. 2016. Land use and land cover change in Sagarmatha National Park, a world heritage site in the Himalayas of Eastern Nepal. Mountain Research and Development, 36(3), 299-310.

Garson, P., Young, I. and Kaul, R. 1992. Ecology and conservation of the Cheer pheasant (*Catreus wallichii*): Studies in the wild and the progress of a reintroduction project. Biological Conservation, 59, 25-35.

Gaston, A. 1980. Census techniques for Himalayan pheasants including notes on individual species. Journal of World Pheasant Association, 5, 40-53.

Gautam, N.C. and Chennaiah, G.C. 1985. Land-use and land-cover mapping and change detection in Tripura using satellite LANDSAT data. International Journal of Remote Sensing, 6(3-4), 517-528.

Gerçek, D. 2004. Improvement of image classification with the integration of topographical data. Pages 1-6, In: Proceedings of the XXth ISPRS Congress, Turkey.

Grimmett, R. and Inskipp, T. 2018. Birds of Northern India. Second Edition. Bloomsbury Publishing, London. 304 pp.

Gupta, S., Singh, S., Agarwal, S. and Roy, P. S. 2006. Degradation of tropical evergreen forests in Mokokchung, Nagaland, India. International Journal of Ecology and Environmental Sciences, 32(4), 345–356.

Harris, P.M. and Ventura, S.J. 1995. The integration of geographic data with remotely sensed imagery to improve classification in an urban area. Photogrammetric Engineering and Remote Sensing, 61, 993–998.

Hutchinson, C.F. 1982. Techniques for combining Landsat and ancillary data for digital classification improvement. Photogrammetric Engineering and Remote Sensing, 48, 123–130.

Islam, K., Jashimuddin, M., Nath, B. and Kumar, T. 2017. Land use classification and change detection by using multi-temporal remotely sensed imagery/ : The case of Chunati wildlife sanctuary. The Egyptian Journal of Remote Sensing and Space Sciences, 21(1), 37–47.

Jensen, J.R. 2015. Introductory Digital Image Processing: A Remote Sensing Perspective (4th ed.). Prentice Hall Press.

Krishan, G., Kushwaha, S.P.S. and Velmurugan, A. 2009. Land degradation mapping in the upper catchment of river Tons. Journal of the Indian Society of Remote Sensing, 37(1), 119-128.

Lele, N. and Joshi, P. K. 2008. Analyzing deforestation rates, spatial forest cover changes and identifying critical areas of forest cover changes in North-East India during 1972–1999. Environmental Monitoring and Assessment, 156(1), 1-159.

Lillesand, T., Kiefer, R.W. and Chipman, J. 2014. Remote sensing and image interpretation. Sixth Edition. John Wiley and Sons, Hoboken, NJ. 756 pp.

Mathur, V.B. and Naithani, S. 1999. Development of a Spatial Database of the Great Himalayan National Park Conservation Area (GHNPCA) in GIS Domain. Wildlife Institute of India, Dehradun, India. 69 pp.

McGowan, P.J. and Garson, P.J. 1995. Status survey and conservation action plan. 1995-1999. Partridges, Quails Francolins, Snowcocks and Guineafowl. WPA/Birdlife/ SSC Partridge, Quail and Francolin Specialist Group, IUCN. Gland, Suiza. 116 pp.

Miller, J.R. 2010. Survey of Western Tragopan, Koklass Pheasant, and Himalayan Monal populations in the Great Himalayan National Park, Himachal Pradesh, India. Indian Birds, 6(3), 60-65.

Millette, T.L., Tuladhar, A.R., Kasperson, R.E. and Turner, B.L. 1995. The use and limits of remote sensing for analysing environmental and social change in the Himalayan Middle Mountains of Nepal. Global Environmental Change, 5(4), 367-380.

Mishra, P.K., Rai, A. and Rai, S.C. 2019. Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India. The Egyptian Journal of Remote Sensing and Space Science, 23(2), 133-143.

Motohka, T., Nasahara, K.N., Oguma, H. and Tsuchida, S. 2010. Applicability of green-red vegetation index for remote sensing of vegetation phenology. Remote Sensing, 2(10), 2369-2387.

Nandy, S., Kushwaha, S.P.S. and Dadhwal, V.K. 2011. Forest degradation assessment in the upper catchment of the river Tons using remote sensing and GIS. Ecological Indicators, 11(2), 509-513.

NRSA. 1982. Satellite Remote Sensing surveys of resources of lower reaches of Arunachal Pradesh. A project report from National Remote Sensing Agency, Hyderabad.

NRSA. 1985. Forest Cover Assessment of India Using Satellite Remote Sensing Data during 1972–1975 and 1980–1982 Periods. National Remote Sensing Agency Tech. Report.

Panigrahy, R., Kale, M., Dutta, U., Mishra, A., Banerjee, B. and Singh, S. 2010. Forest cover change detection of Western Ghats of Maharashtra using satellite remote sensing based visual interpretation technique. Current Science, 98(5), 657-664.

Pena-Barragan, J.M., Ngugi, M.K., Plant, R.E. and Six, J. 2011. Object-based Crop Classification using Multiple Vegetation Indices, Textural features and Crop Phenology. Remote Sensing of Environment, 115, 1301–1316.

Prasad, S.N. 1993b. A survey of the potential Western Tragopan habitat in the Tons Catchment of Uttar Pradesh, from and Aerospace: Remote Sensing Perspective. A report submitted in Salim Ali Centre for Ornithology and Natural History, Coimbatore, India. 11 pp.

Prasad, S.N. 1993a. On the occurrence of Western Tragopan and Satyr Tragopan together in Uttar Pradesh. Newsletter for Birdwatchers, 33 (1), 1-6.

Ramesh, K. 2003. An ecological study on pheasants of The Great Himalayan National Park, Western Himalaya. Ph.D. Thesis, Wildlife Institute of India, Dehradun, Forest Research Institute, Deemed University, Dehradun, Uttarakhand, India. 79 pp.

Ramesh, K., Sathyakumar, S. and Rawat, G.S. 1999. Ecology and conservation status of the pheasants of Great Himalayan National Park, Western Himalaya. Wildlife Institute of India, Dehradun. 69 pp.

Rawat, V.S. and Chandhok, A. 2009. Phytosociological analysis and distribution patterns of tree species: A case study from Govind Pashu Vihar, National Park, Uttarakhand. New York Science Journal, 2(4), 58-63.

Ricchetti, E. 2000. Multispectral satellite image and ancillary data integration for geological classification. Photogrammetric Engineering and Remote Sensing, 66(4), 429-437.

Richards, J.F. and Flint, E.P. 1994. Historic land use and carbon estimates for South and Southeast Asia 1880–1980. Technical Report. In: Daniel, R.C. (Editor). Carbon Dioxide Information Analysis Center [CDIAC], Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A., 326 pp.

Roy, P.S., Kushwaha, S.P.S., Murthy, M.S.R., Roy, A., Kushwaha, D., Reddy, C.S., Behera, M.D., Mathur, V.B., Padalia, H., Saran, S. and Singh, S. 2012. Biodiversity Characterization at Landscape Level: National Assessment, Indian Institute of Remote Sensing, Dehradun, India, 140 pp.

Roy, P.S., Singh, S., Dutt, C.B.S., Tiwari, A.K. et al. 2002. Biodiversity Characterization at landscape level in Western Himalayas using satellite remote sensing and geographic information system: Department of Biotechnology and Department of Space, Indian Institute of Remote Sensing (NRSA), 234 pp.

Saha, A.K., Arora, M.K., Csaplovics, E. and 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.

Sathyakumar, S. and Sivakumar, K. (Eds.). 2007a. Galliformes of India. ENVIS Bulletin: Wildlife and Protected Areas 10, Wildlife Institute of India, Dehradun, India. 252 pp.

Sathyakumar, S., Kalsi, R. and Kaul, R. 2007b. Techniques for Monitoring Galliformes in India. ENVIS Bulletin: Wildlife and Protected Areas 10: 179-171.

Sati, J. and Sinha, N. 2004. Gobind Pashu Vihar, Zoological Survey of India, Northern Regional Station, Dehradun. 95pp.

Sharma, N., Das, A.P. and Shrestha, D.G. 2015. Land use and landcover mapping of East District of Sikkim using IRSP6 Satellite Imagery. Pleione, 9(1), 1-193.

Singh, S. 1999. Assessment of floral and habitat diversity and collection of base line data to monitor vegetation of GHNP conservation area. Indian Institute of Remote Sensing Dehradun, India. 38 pp.

Singh, S. and Singh, T.P. 2002. Arunachal Pradesh (Eastern). Pp. 52-67. In Roy, P.S. (Ed.). Biodiversity Characterization at Landscape Level Using Satellite Remote Sensing and Geographic Information System in North Eastern India, Department of Biotechnology and Department of Space, IIRS, Dehradun.

Singh, S., Singh, T. and Srivastava, G. 2005. Vegetation cover type mapping in mouling national park in Arunachal Pradesh, Eastern Himalayas- an integrated geospatial approach. Journal of the Indian Society of Remote Sensing, 33, 547-563.

Singh, T.P., Singh, S. and Tiwari, S.C. 2013. Assessment of digital image classification algorithms for forest and land-use classification in the eastern Himalayas using the IRS LISS III sensor. International Journal of Remote Sensing, 34(11), 4105-4126.

Singh, T.P., Singh, S., Roy, P.S. and Rao, B.S.P. 2002. Vegetation mapping and characterization in West Siang District of Arunachal Pradesh, India–a satellite remote sensing-based approach. Current Science, 83(10), 1221-1230.

Song, C. 2005. Spectral Mixture Analysis for Subpixel Vegetation Fractions in the Urban Environment: How to Incorporate Endmember Variability? Remote Sensing of Environment, 95, 248–263.

Thomson, A.G. and Jones, C. 1990. Effects of topography on radiance from upland vegetation in North Wales. International Journal of Remote Sensing, 11, 829–840.

Venkataraman, K. and Sivaperuman, C. 2018. Biodiversity hotspots in India. In Indian Hotspots Springer, 1-27.

Virdi, M. 2007. Translating global biodiversity values into local benefits: conservation initiatives of a village forest council in Kumaon Uttarakhand. Pages 171-175, In: Sathyakumar, S. and Sivakumar, K. (Eds.). Galliformes of India. ENVIS Bulletin: Wildlife and Protected Areas, vol. 10. Wildlife Institute of India, Dehradun, India.

Yadav, P.K., Kapoor, M. and Sarma, K. 2012. Land use land cover mapping, change detection and conflict analysis of Nagzira-Navegaon Corridor, Central India using geospatial technology. International Journal of Remote Sensing and GIS, 1(2), 90–98.

Yarbrough, L.D., Easson, G. and Kuszmaul, J.S. 2005. Using at-sensor radiance and reflectance tasseled cap transforms applied to change detection for the ASTER sensor. Aster, 2, 141-145.

Yuan, F., Sawaya, K.E., Loeffelholz, B.C. and Bauer, M.E. 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) metropolitan area by multitemporal Landsat remote sensing. Remote Sensing of Environment, 98(2–3), 317–328.

*Received:11th June 2021*
*Accepted:20th July 2021*

Annexure 1. Class-wise change transition matrix of FCTLULC for the period between 1994 and 2016 (in km$^2$)

| | 2016 | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1994** | **SCP** | **SSc** | **LOF** | **MDF** | **MCF** | **MTDF** | **TSc** | **TKOF** | **TUFF** | **PL** | **BP** | **SAFF** | **RSc** | **DJSc** | **PA** | **Snow** | **Wb** | **Rb** | **Agri** | **Grand Total** |
| **SCP** | 155.67 | 0.39 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.53 | 156.61 |
| **SSc** | 0.00 | 100.38 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.34 | 101.88 |
| **LOF** | 0.00 | 0.01 | 78.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 78.46 |
| **MDF** | 0.00 | 0.00 | 0.00 | 118.98 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.21 | 119.22 |
| **MCF** | 0.00 | 0.00 | 0.00 | 0.00 | 35.99 | 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 | 0.01 | 35.99 |
| **MTDF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 39.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 39.12 |
| **TSc** | 0.00 | 0.01 | 0.00 | 0.02 | 0.00 | 0.00 | 95.06 | 0.00 | 0.00 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.36 | 0.37 | 97.13 |
| **TKOF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 46.52 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 46.57 |
| **TUFF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 102.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 102.05 |
| **PL** | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 114.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 115.13 |
| **BP** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 80.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 80.83 |
| **SAFF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 128.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 128.78 |
| **RSc** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.23 |
| **DJSc** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 54.74 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 54.74 |
| **PA** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 254.05 | 16.13 | 0.00 | 0.00 | 0.00 | 270.18 |
| **Snow** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.11 | 4.74 | 150.93 | 316.50 | 0.00 | 0.00 | 0.00 | 472.47 |
| **Wb** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.55 | 1.08 | 0.00 | 1.64 |
| **Rb** | 0.00 | 0.73 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 1.55 | 23.75 | 0.06 | 26.16 |
| **Agri** | 0.00 | 0.65 | 0.00 | 0.06 | 0.00 | 0.49 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 31.74 | 32.97 |
| **Grand Total** | **155.68** | **102.24** | **78.39** | **119.06** | **35.99** | **39.66** | **95.28** | **46.52** | **102.05** | **115.45** | **80.83** | **128.75** | **38.33** | **59.49** | **405.01** | **332.62** | **2.10** | **26.21** | **34.51** | **1998.19** |

SCP= Subtropical Chir Pine, SSc= Subtropical Scrub, LOF= Lower (Ban & Moru) Oak Forest, MDF= Moist Deodar Forest, MCF= Mixed Coniferous Forest, MTDF= Moist Temperate Deciduous Forest, Temperate Secondary Scrub= TSc, TKOF= Temperate Kharsu Oak Forest, TUFF= Temperate Upper Oak/Fir Forest, PL= Parkland, BP= Blue Pine, SAFF= Sub-Alpine Fir Forest, RSc= Rhododendron Scrub, DJSc= Dwarf Juniper Scrub, PA= Pastures, Agri= Agriculture, Rb= Riverbed, Wb= Waterbody.

Annexure 2. Class-wise change transition matrix of FCTLULC for the period between 1994 and 2002 (in $km^2$)

| | 2002 | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1994** | **SCP** | **SSc** | **LOF** | **MDF** | **MCF** | **MTDF** | **TSc** | **TKOF** | **TUFF** | **PL** | **BP** | **SAFF** | **RSc** | **DJSc** | **PA** | **Snow** | **Wb** | **Rb** | **Agri** | **Grand Total** |
| **SCP** | 156.11 | 0.18 | 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 | 0.00 | 0.31 | 156.61 |
| **SSc** | 0.00 | 100.86 | 0.00 | 0.07 | 0.00 | 0.03 | 0.02 | 0.02 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.81 | 101.88 |
| **LOF** | 0.00 | 0.00 | 78.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 78.46 |
| **MDF** | 0.00 | 0.00 | 0.00 | 119.08 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 119.22 |
| **MCF** | 0.00 | 0.00 | 0.00 | 0.00 | 35.99 | 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 | 35.99 |
| **MTDF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 39.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 39.12 |
| **TSc** | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 95.98 | 0.00 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.00 | 0.49 | 0.27 | 97.13 |
| **TKOF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 46.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 46.57 |
| **TUFF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 102.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 102.05 |
| **PL** | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 115.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.01 | 115.13 |
| **BP** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 80.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 80.83 |
| **SAFF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 128.66 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.03 | 128.78 |
| **RSc** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.09 | 0.00 | 0.00 | 0.14 | 0.00 | 0.00 | 0.00 | 38.23 |
| **DJSc** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.33 | 0.00 | 3.42 | 0.00 | 0.00 | 0.00 | 54.74 |
| **PA** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 213.97 | 56.21 | 0.00 | 0.00 | 0.00 | 270.18 |
| **Snow** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.05 | 2.99 | 52.42 | 416.85 | 0.00 | 0.00 | 0.00 | 472.47 |
| **Wb** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.56 | 1.08 | 0.00 | 1.64 |
| **Rb** | 0.00 | 0.64 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 1.78 | 23.66 | 0.04 | 26.16 |
| **Agri** | 0.01 | 0.28 | 0.07 | 0.05 | 0.03 | 0.16 | 0.02 | 0.00 | 0.03 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 32.18 | 32.97 |
| **Grand Total** | **156.12** | **102.01** | **78.50** | **119.22** | **36.02** | **39.28** | **96.19** | **46.56** | **102.08** | **115.50** | **80.83** | **128.67** | **38.13** | **54.31** | **266.40** | **476.84** | **2.33** | **25.25** | **33.93** | **1998.19** |

SCP= Subtropical Chir Pine, SSc= Subtropical Scrub, LOF= Lower (Ban & Moru) Oak Forest, MDF= Moist Deodar Forest, MCF= Mixed Coniferous Forest, MTDF= Moist Temperate Deciduous Forest, Temperate Secondary Scrub= TSc, TKOF= Temperate Kharsu Oak Forest, TUFF= Temperate Upper Oak/Fir Forest, PL= Parkland, BP= Blue Pine, SAFF= Sub-Alpine Fir Forest, RSc= Rhododendron Scrub, DJSc= Dwarf Juniper Scrub, PA= Pastures, Agri= Agriculture, Rb= Riverbed, Wb= Waterbody.

Annexure 3. Class-wise change transition matrix of FCTLULC for the period between 2002 and 2016 (in km$^2$)

| | 2016 | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2002** | **SCP** | **SSc** | **LOF** | **MDF** | **MCF** | **MTDF** | **TSc** | **TKOF** | **TUFF** | **PL** | **BP** | **SAFF** | **RSc** | **DJSc** | **PA** | **Snow** | **Wb** | **Rb** | **Agri** | **Grand Total** |
| **SCP** | 155.67 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.22 | 156.12 |
| **SSc** | 0.00 | 101.40 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.53 | 102.01 |
| **LOF** | 0.00 | 0.08 | 78.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 78.50 |
| **MDF** | 0.00 | 0.10 | 0.00 | 119.01 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 119.22 |
| **MCF** | 0.00 | 0.03 | 0.00 | 0.00 | 35.99 | 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 | 36.02 |
| **MTDF** | 0.00 | 0.08 | 0.00 | 0.01 | 0.00 | 39.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 39.28 |
| **TSc** | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 95.11 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.87 | 0.11 | 96.19 |
| **TKOF** | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 46.52 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 46.56 |
| **TUFF** | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 102.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 102.08 |
| **PL** | 0.00 | 0.08 | 0.00 | 0.01 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 115.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 115.50 |
| **BP** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 80.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 80.83 |
| **SAFF** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 128.66 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 128.67 |
| **RSc** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 38.13 |
| **DJSc** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 54.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 54.31 |
| **PA** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 247.71 | 18.69 | 0.00 | 0.00 | 0.00 | 266.40 |
| **Snow** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 0.00 | 0.00 | 0.02 | 0.00 | 0.09 | 0.20 | 5.17 | 157.28 | 313.93 | 0.00 | 0.00 | 0.00 | 476.84 |
| **Wb** | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.08 | 1.25 | 0.00 | 2.33 |
| **Rb** | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 1.02 | 24.08 | 0.02 | 25.25 |
| **Agri** | 0.00 | 0.09 | 0.00 | 0.03 | 0.00 | 0.34 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 33.45 | 33.93 |
| **Grand Total** | **155.68** | **102.24** | **78.39** | **119.06** | **35.99** | **39.66** | **95.28** | **46.52** | **102.05** | **115.45** | **80.83** | **128.75** | **38.33** | **59.49** | **405.01** | **332.62** | **2.10** | **26.21** | **34.51** | **1998.11** |

SCP= Subtropical Chir Pine, SSc= Subtropical Scrub, LOF= Lower (Ban & Moru) Oak Forest, MDF= Moist Deodar Forest, MCF= Mixed Coniferous Forest, MTDF= Moist Temperate Deciduous Forest, Temperate Secondary Scrub= TSc, TKOF= Temperate Kharsu Oak Forest, TUFF= Temperate Upper Oak/Fir Forest, PL= Parkland, BP= Blue Pine, SAFF= Sub-Alpine Fir Forest, RSc= Rhododendron Scrub, DJSc= Dwarf Juniper Scrub, PA= Pastures, Agri= Agriculture, Rb= Riverbed, Wb= Waterbody.