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Research Article
Forest Canopy Density and Fragmentation Analysis for Evaluating Spatio-Temporal Status of Forest in the Hazaribagh Wild Life Sanctuary, Jharkhand (India)

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Abstract

Background and Objective: Forest changes and fragmentation are the major phenomena in the tropical forest. The current study evaluated the status of this phenomenon and their impact in the Hazaribagh Wildlife Sanctuary (HWS), Jharkhand, India from 1992-2017. **Materials and Methods:** Four-time frame data collections, i.e., 1992, 2005,2010 and 2017 were used from the Landsat satellite sensor. Forest cover change and fragmentation measured by Forest Canopy Density (FCD) and Ritter's model. Forest fragmentation contains a proportion of six spatial patterns, i.e., core, transitional, interior perforated, edge and patches. The scatter plot with its regression analysis and chart diagram was the statistical procedure for calculating spectral indices correlation and forest change in the spatiotemporal framework. **Results:** The very dense forest and moderately dense forest declined to 12 and 20 km^2 in 2017 compared to the year 1992. The overall increase in open forest in 2017 was 15 km^2 as equate to the year 1992. The core area in the forest was increased in 2017 due to good management practices inside the forest compared to 1992 but in decreasing trend compared to the year 2005. It puts serious concern that fragmentation continue in the future and affects biodiversity. Forest fragmentation doesn't have much effect in the transitional forest and perforated forest balanced or less shifting of forest to non-forest and vice-versa. The interior forest acts as a protective layer of core forest from the edges. The edge of the forest has decreased, showing good sign due to minimization of the edge effect. **Conclusion:** The FCD and Fragmentation model combines to provides useful insight on understanding forest changing environment and future trend analysis. These types of forest modeling technique aim for effective monitoring of forest to understand the cause of forest disturbance and further help in its mitigation.

Key words: Forest changes, fragmentation, landsat, FCD, ritter's model, core forest

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The forest is one of the major natural resource and magnificent terrestrial ecosystem of the world. The forest in Jharkhand is very important for many indigenous people living in the touch with forestry since ancient times. They worship and protect trees which are revealed by their local festival Sarhul and Karma. The word Jharkhand literary comes from the origin of forest and it means' land area covers with forest. In recent decades, socioeconomic pressures lead to conversions of a vast area of forest cover to other land covers. As a result, the current forest land had come to be a victim of fragmentation[1] and the impairment of forest ecosystem services[2,3]. Expansive regions of tropical forest remain scattered over farming areas, thus understanding the effects of these forest discontinuities is imperative for biodiversity protection[4].

A number of studies on the forest changing dynamics suggested that land acquisition/colonization and land use activities lead to discrete spatial patterns in the forest landscape[5,6] and patch distributions over time[7]. Therefore, forest land use/land cover (LULC) change can lead to forest fragmentation[8]. The combined use of land cover and fragmentation information identifies places and type of change of sort of progress and in addition, the way the forest is changing[9]. The discontinuity has been fundamentally an aftereffect of anthropogenic influences, such as, street building, logging or clearing land for farming exercises and related event of rapidly spreading of wildfires[10-13].

The changes in forest cover caused by different drivers, including natural or/and anthropogenic activities performing at unlike times scales[14]. With the speedy decrease in forest area, implementation of forest management policies, enhanced access to markets and substitution of shifting cultivation with permanent cropping, land use and management in the region are the cause of forest land use alteration[15]. The forest fragmentation is another way of alteration in a forest which creates forest cover into patches. In the tropical country's forest fragmentation is caused by changes in human land use activities is of primary concern for sustainability[16]. The choice of land use where conservation actions, such as revegetation and retention of forest patches, may be prioritized depends on the scale at which we measure fragmentation[17]. If this fragmentation process continues, the ability of the remnant forests to support their original biodiversity and ecological processes will be definitely reduced[18].

The analysis of forest cover is the first step for appraising forest fragmentation, as the forest cover changes the fragmentation pattern will change. There is a linkage between forest fragmentation with forest cover changes. Monitoring of such changes in a forest is significant for coordinated actions at the international and national levels[19]. The mapping of land use and land cover changes is the standard for change detection[20] is performed to know the nature, rate and extent of such change over a period of time[21]. This can be used as contributions to land management and making policy decisions with regard to various themes that link to urbanization, deforestation, water management and land degradation. With image processing techniques used in FCD model[22] quantify the forest cover based on density and post-classification strategy analyses changes in forest cover in the spatiotemporal framework. This application of remotely sensed technologies to see changes in forest cover has reported by many studies[22-26].

The main purposes of this study were to estimate spatial and temporal changes of forest land cover by FCD model and fragmentation by using a fragmentation model[27-29] for understanding the changing environment of forest in the Hazaribagh wildlife sanctuary, Jharkhand, India during the year 1992-2017 using satellite images and GIS.

MATERIALS AND METHODS

Study area: The study area is situated in a low hilly terrain, at an altitude of 615 m in the state of Jharkhand, the Hazaribagh wildlife sanctuary (HWS), Jharkhand, India (Fig. 1) has a habitat of wild animals like the wild boar, Sambar, Nilgai, Chital, Sloth Bear, Tiger and Panther (HWS Working Plan). It lies between 24°45'22" N to 24°08 20"N latitude and 85°30'13" E to 85°21 58" E longitude. The climate in this area is tropical with cold winters and hot summers (HWS Working Plan).

Data and software used: The Landsat Thematic Mapper (Landsat-TM) of the years 1992, 2005 and 2010 and Landsat 8 OLI data of the year 2017 (Table 1) was an input for the Forest Canopy Density (FCD) model. The FCD model comprises modeling of a biophysical phenomenon and result derived from four indices: Advanced Vegetation Index (AVI), Shadow Index or Advance Shadow Index (SI, ASI), Bare Soil Index (BI) and Thermal Index (TI)[21]. It determined canopy density in percentage by integrating the above indices in FCD model. Landsat data acquired on the different year (Table 1) in the month of November were used for spatiotemporal forest canopy density mapping and utilizing it to find forest cover change and further for fragmentation analysis. Vegetation Phenology is one of the critical components to be considered for viable stratification of the forest density. The model processed a shadow, exposed soil and thermal data for the forest canopy cover estimation[30]. The ground truth data

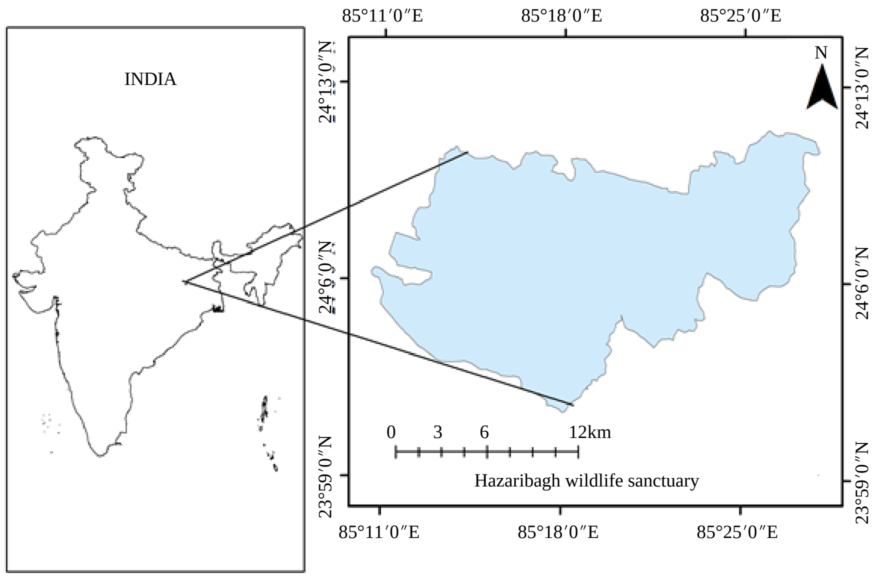

Fig. 1: Study area-Hazaribagh wildlife sanctuary

Table 1: Landsat data acquired on different year

Landsat ID	Date of acquisition	Path/Row	Sun elevation
p140r43_5t19921101	01-11-1992	140/43	43.00
LT51400432005309BKT01	2005-11-05	140/43	44.384
LT51400432010323KHC00	2010-11-19	140/43	41.066
LC81400432017326LGN00	2017-11-05	140/43	47.33

Table 2: Accuracy assessment of the classified forest cover map (Year: 2017)

Object ID	Class value	Non-forest	Open forest	Moderately dense forest	Very dense forest	Total	User accuracy	Kappa
1	Non-forest	143.00	16.00	0.00	1.00	160.00	0.89	0.00
2	Open forest	16.00	119.00	5.00	0.00	140.00	0.85	0.00
3	Moderately dense forest	1.00	13.00	94.00	5.00	113.00	0.83	0.00
4	Very dense forest	0.00	8.00	8.00	70.00	86.00	0.81	0.00
5	Total	161.00	156.00	107.00	76.00	500.00	0.00	0.00
6	Producer accuracy	0.89	0.76	0.88	0.92	0.00	0.85	0.00
7	Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.80

needed for the accuracy assessment of the classified imagery was assessed through field visit taken in the 19, November 2017. Google Earth imagery with the vegetation fraction data[31] was used as accuracy assessment aids. For the accuracy assessments, the classified forest cover of the year 2017 was taken as the base and other year forest cover classified according to it. The kappa coefficient of 0.80 and overall accuracy was 85%, this was acceptable from the reference compared by previous researches (Table 2). The Arc GIS 10.5 used for change detection and mapping layouts of figures. The SAGA GIS used for fragmentation and scatter plot analysis. QGIS software used for atmospheric correction of Landsat imagery, indices calculation and FCD mapping.

Preprocessing of data: Preprocessing entailed Geo-referencing, rectification and sub-setting of data relating to the study area. Georeferencing (study area) was carried out through ground control points collected from geo-referenced topographic maps published by the Survey of India (SOI).The raw satellite images required atmospheric correction for estimating actual reflectance characteristics of objects. The atmospheric correction is very important for intensive or extensive researches. For maintaining high surface reflectance accuracy, three types of models are used for atmospheric correction, calibration and DN conversion which includes 6S, LOWTRAN (DOS) and MODTRAN[32]. The two different groups of a calibration method for atmospheric correction can be identified, that is an absolute radiometric correction and relative calibration methods[33]. These models were used here for the correction of the acquired Landsat Imagery.

For the purpose of the study, the downloaded raw satellite images of Landsat of taken years from USGS Earth Explorer (https://earthexplorer.usgs.gov) were firstly selected for its quality assessment by performing ACCA (Automatic cloud cover assessment) which was proposed by Irish[34]. It needs Landsat band numbers 2, 3, 4, 5 and 6 (thermal band) which was processed from DN to reflectance values and band-6 temperature. The assessment was done for the detection of correct imagery and to predict error in processing. From the study, the cloud cover in the selected or available Landsat data was found to be negligible and in small amount which was not so effective to harm the overall accuracy of processing. Atmospheric correction and Landsat calibration were implemented on these images to abate the influences of errors due to sensor differences, Earth-Sun distance, Sun height and atmospheric condition, which are important in the multi-temporal assay of vegetation indices. The process of implementation is described below.

Firstly, the raw DN to radiance (L_λ) conversion was done through the below-given Eq. 1:

$$L_\lambda = \text{Bias}+(\text{Gain}\times\text{DN}) \tag{1}$$

where, DN is the digital number of each pixel in the image. The reflectance (P_λ) for the band is computed by the following equation (Landsat Science User Data Handbook) (Eq. 2):

$$P_\lambda = \pi\times L_\lambda\times d^2/\text{ESUN}_\lambda\times \text{Cos}\theta \tag{2}$$

where, L and P are at-satellite spectral radiance and reflectance respectively, d is the Earth-Sun distance, ESUN is mean solar exoatmospheric irradiances for the specific band and cos ø is the cosine of the solar incidence angle. The cosine of the solar incidence angle (cos ø) can be calculated from the cos (90-Sun Elevation) supposing the surface is flat. The Landsat calibration was done along with DOS (Dark object subtraction) and then NDVI was calculated. For the At-surface reflectance, the Dark Object Subtraction (DOS) is used for correcting path radiance caused by atmospheric molecules and aerosols[35]. The methodology used in the study is given in Fig. 2.

Calculation of Forest Canopy Density (FCD): The concept of forest canopy density was discussed in the FCD model, which helps in evaluating forest canopy density (1-100%). The FCD model uses indices like Advanced Vegetation Index (AVI) sensitive to the planet's amount and vigor, Bare Soil Index (BSI or BI) which differentiates soil from the forest canopy, Shadow Index (SI) indicates the shadow caused by vegetation and overlay analysis of thermal index with the shadow index for black soil detection[36] (Table 3). The preprocessed images were firstly normalized to value 1 and 0. Then, by the help raster calculator in QGIS, the indices were calculated. The Vegetation Density (VD) in the forest is measured by synthesis of AVI and BI with the help of the principal component analysis, then re-scaled to 1-100%. The advance shadow index was calculated from the overlay analysis of TI and SI and then rescaled to 1-100%. The Forest canopy density was calculated from the formula given[37] in Eq. 3:

$$\text{FCD} = (\text{VD}\times\text{ASI}+1)1/2\text{-}1 \tag{3}$$

Calculation of Forest cover and its changes: The forest classes were classified according to Forest Survey of India (FSI) Dehradun classification scheme of forest based on forest canopy density (Table 4) retrieved from FCD Map (Fig. 5). The classification of forest and its image interpretation key from the false color composite map (Color infrared) (Fig. 3) is given in Table 4.

Table 3: Characteristics and formula of spectral indices used for calculating canopy density from Landsat satellite imagery (based on FCD model

Vegetation indices	Formula	Speciation
AVI	(NIR+)×(256-1)×(NIR-RED) (1/3)	Sensitive to amount of vegetation forest density comparison to NDVI
BSI	{(SWIR+RED)-(NIR+BLUE)/(SWIR+RED)+(NIR+BLUE)}×100+100	Sensitive for separating bare soil, sparse canopy and dense canopy
SI	(256-BLUE)×(256-GREEN)×(256-RED) (1/3)	Calculate shadow pattern by crown arrangement in the forest
TI	1.5+(1.5-0.1238)/255×thermal band	Calculate the temperature variability of spatial objects

Source: Rikimaru[21]

Table 4: Forest cover and with its image interpretation key and classification based on FCD

Forest cover	Tone	Texture	Shape	Pattern	Canopy density
Very dense forest	Dark red	Medium	Varying	Rough	>70%
Moderately dense forest	Medium red	Medium to low	Varying	Rough	40-70%
Open Forest	Light Red	Medium to low	Varying	rough	10-40%
Non-forest with barren land, built-up, roads, rocky land and scrubs	Greyish/whitish and light redmolted	Fine and coarse	Irregular/regular and varying	Smooth	Other than above 5-10% (Scrub) 0-5% (Others)

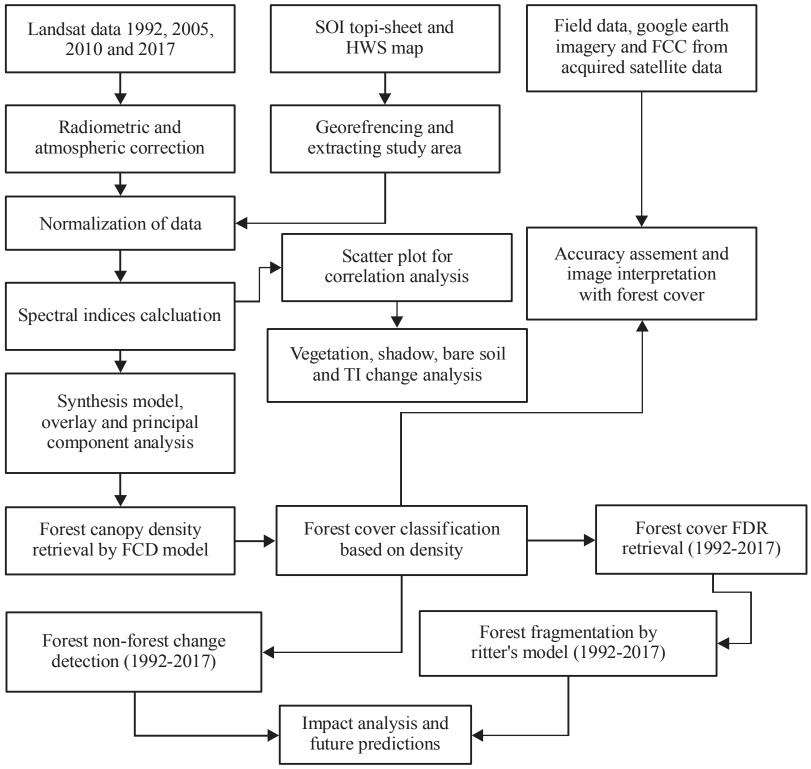

Fig. 2: Flowchart of methodology adopted for the study

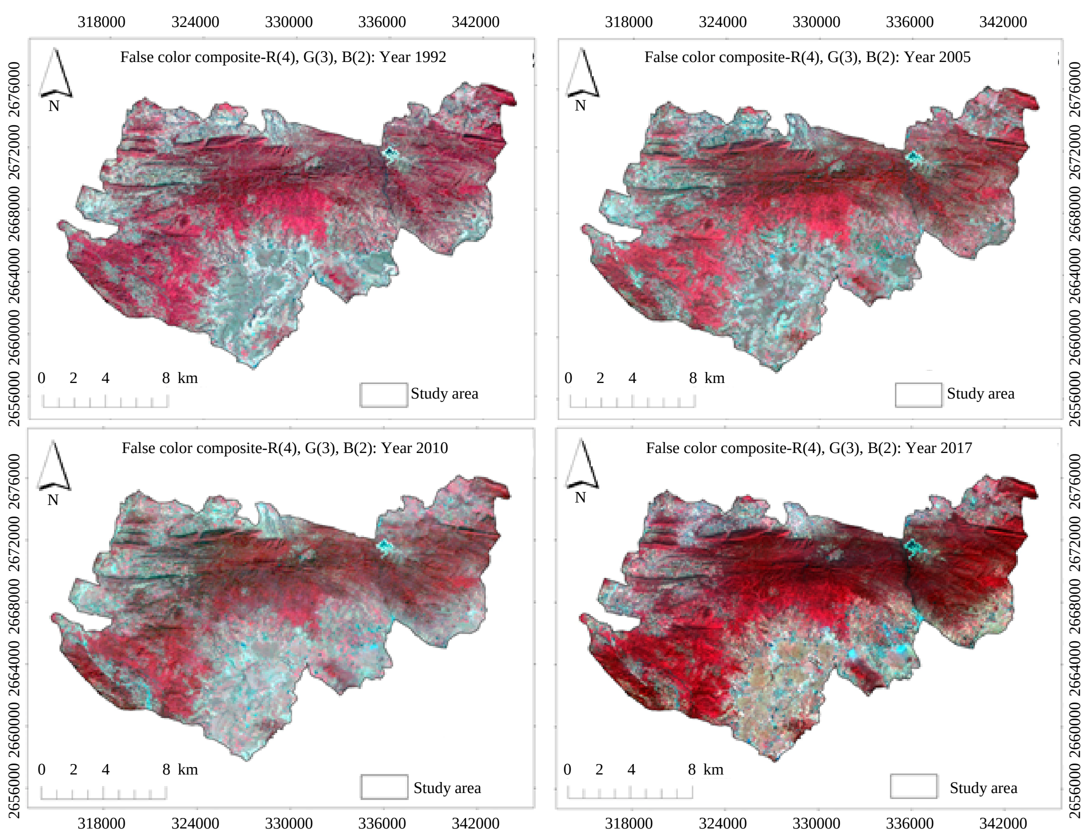

Fig. 3: False color composite (FCC) of the acquired Landsat data from the year 1992-2017

Post-classification comparison strategy was employed to detect the character, the rate of changes, transformation and place of alterations from 1992-2017 in the study field. Raster and vector overlay was applied for analysis of the classification outcome derived from remote sensing information so as to produce change maps and statistical information in regards to the spatial distribution of different forest land cover. The overlay analysis was carried out making use of ArcGIS 10 and QGIS software to receive conversions between the forest land cover. The overlay analysis describes the spatial distribution and attributes of changes in forest land cover during the study periods. The change occurrence map of forest land cover was based on canopy density and the temporal trajectories of land cover changes were also generated based on the four resulting maps in1992, 2005, 2010 and 2017 using GIS.

Forest disturbing region retrieval: In the study area, the non-forest activities such as Grazing, deforestation, illegal acquisition of forest land, forest health deterioration from dust contamination, hunting and gathering, agriculture and other mining activities affects the forest cover and creates a disturbance in the forest ecosystem. These places of non-forest activities are called Forest Disturbing Region (FDR). The forest cover (VDF, MDF, OF) and non-forest were separated out with the help of GIS and FDR were estimated for each year (1992-2017). The FDR was used for forest fragmentation analysis as the literature reviews suggested that the coherence of forest and non-forest activities are responsible for forest fragmentation.

Forest fragmentation: The forest fragmentation was calculated from the forest and non-forest coherence by analyzing forest cover calculated from FCD model. The present study uses the model of fragmentation implemented as SAGA module. The Input of this module involves whether a pixel is forested or not. The study area was re-classified into two classes, one is forest and the other is non-forest and scrub together because they are not included in the forest and forest are affected by these non-forest group. The activity in non-forest part create forest fragmentation, therefore they must be separated to calculate forest fragmentation. The non-forest part taken as first class and non- forest part taken as second class as input in SAGA GIS[38]. From these pixels two parameters are derived, the forest density (forest part) and the forest connectivity (non-forest pixels/FDR). Making use of these processes, six forest fragmented classes were prepared as given below[27]:

- Core, if density = 100%
- Perforated, if density>60% and density is greater than connectivity
- Edge, if density>60% and density is less than connectivity
- Transitional, if density is between 40 and 60%
- Patch, if density is less than 40%

Statistical analysis: The scatter plot was used for the regression analysis of spectral indices used in the FCD analysis in the spatiotemporal framework. For this System of Automatic Geoscientific Analysis software (SAGA GIS) was used for scatter plot mapping of the indices used to get forest changing status based on the indices. The chart diagram from Microsoft Excel was used for the forest cover change detection and fragmentation with their trend analysis.

RESULTS AND DISCUSSION

Characteristic of various vegetation indices used

Advance Vegetation Index (AVI): The AVI has a positive relationship with the quantity of vegetation. Thus, its value is high for high forest density and grassland, low for low forest density and bare land. It has more sensitivity to NDVI for the calculation of forest density due to its more normalization capacity to atmospheric effects. The Fig. 4a showed the scatter plot matrix having relationships of AVI with the consecutive year of changes. This result showed that there were remarkable changes in vegetation phenology over the years.

Bare Soil Index (BSI): The bare soil index increases as the percentage bare soil exposure of ground increases. This index helps in separating the vegetation with a different background. The Fig. 4b show the scatter plot matrix having relationships of BSI with the consecutive year changes. This result showed that there were remarkable changes in soil percentage over the years.

Shadow Index (SI): The SI was utilized for the spectral information on the forest shadow itself and thermal information on the forest influenced by the shadow. The SI takes care of the cooling effect inside the forest and evaporation from the leaf structure. The young tree arrangement has a low shadow casting then matured tree arrangement. The Fig. 4c showed the scatter plot matrix having relationships of SI with the consecutive year changes. This result showed that there were remarkable changes in shadow percentage created by tree canopy over the years.

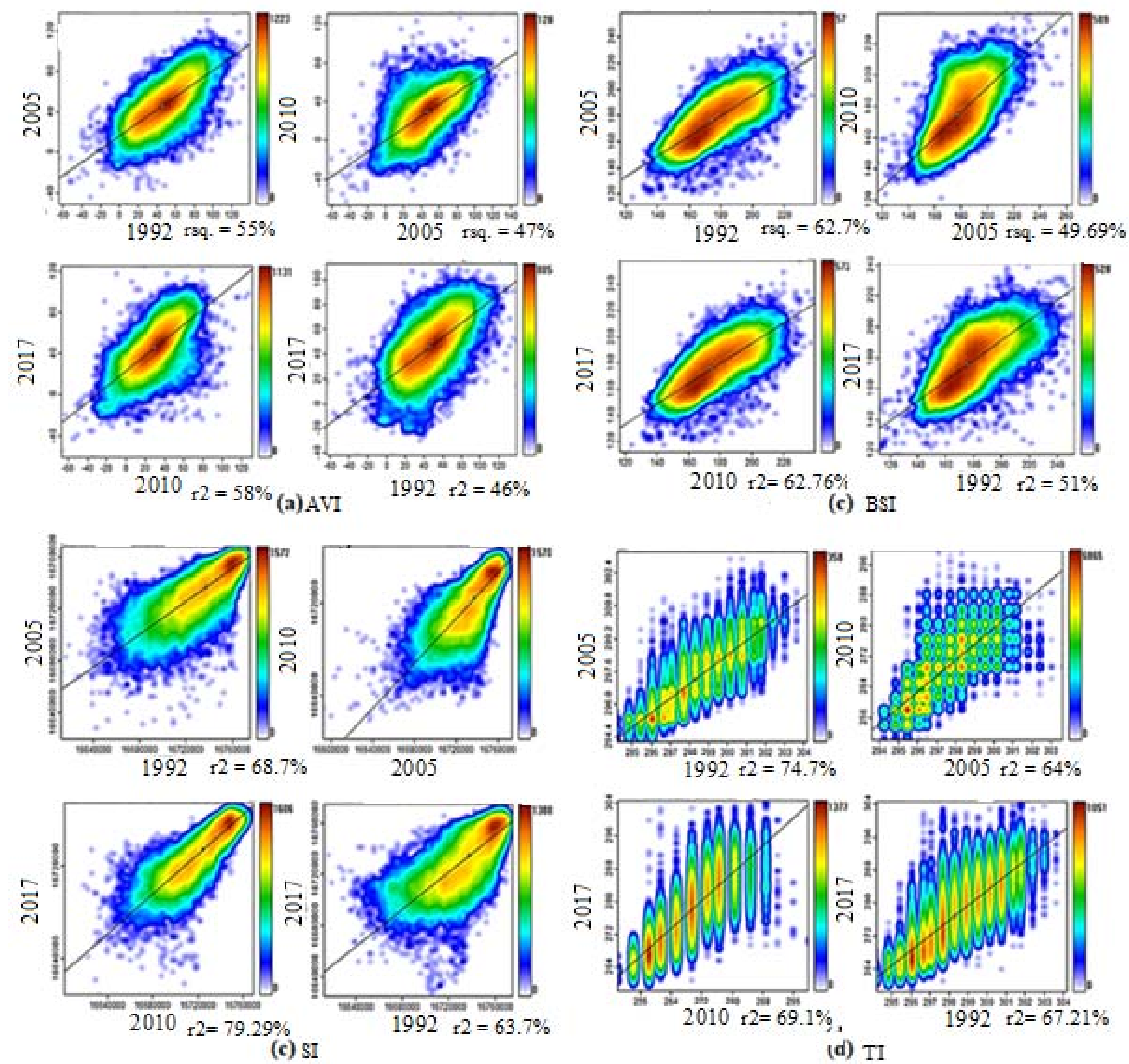

Fig. 4(a-d): Scatter plot matrix of indices used for predicting changes in various forest aspects: (a) Showing change statistics of AVI with the consecutive years, (b) Showing change statistics BSI with the consecutive years, (c) Showing change statistics SI with the consecutive years and (d) Showing change statistics TI with the consecutive years

Thermal Index(TI): Inside the forest stand, the canopy cover blocked the incoming solar radiation and that is the reason for the cool temperature inside the forest. The soil area has characterized by high temperature. The combination of TI with shadow index helpful in the black soil detection. The Fig. 4d shows the scatter plot matrix having relationships of TI with the consecutive year of changes. This result shows that there were remarkable changes in the thermal properties of vegetation and non-vegetation over the years.

Forest canopy density Map of the study area: The synthesis of AVI and BSI gives Vegetation Density (VD) (Fig. 5a). The AVI and BSI both have a negative relationship with each other, the High AVI value shows high vegetation vigor similarly the BSI shows soil exposure. The overlay analysis of SI and TI helpful in black soil detection between the forest canopies. The analysis gives Advance Shadow Index (Fig. 5b) and recalling it to 1-100% gives Scaled Shadow Index(SSI) or Advance Shadow Index (ASI) helpful in forest canopy density mapping. Utilizing

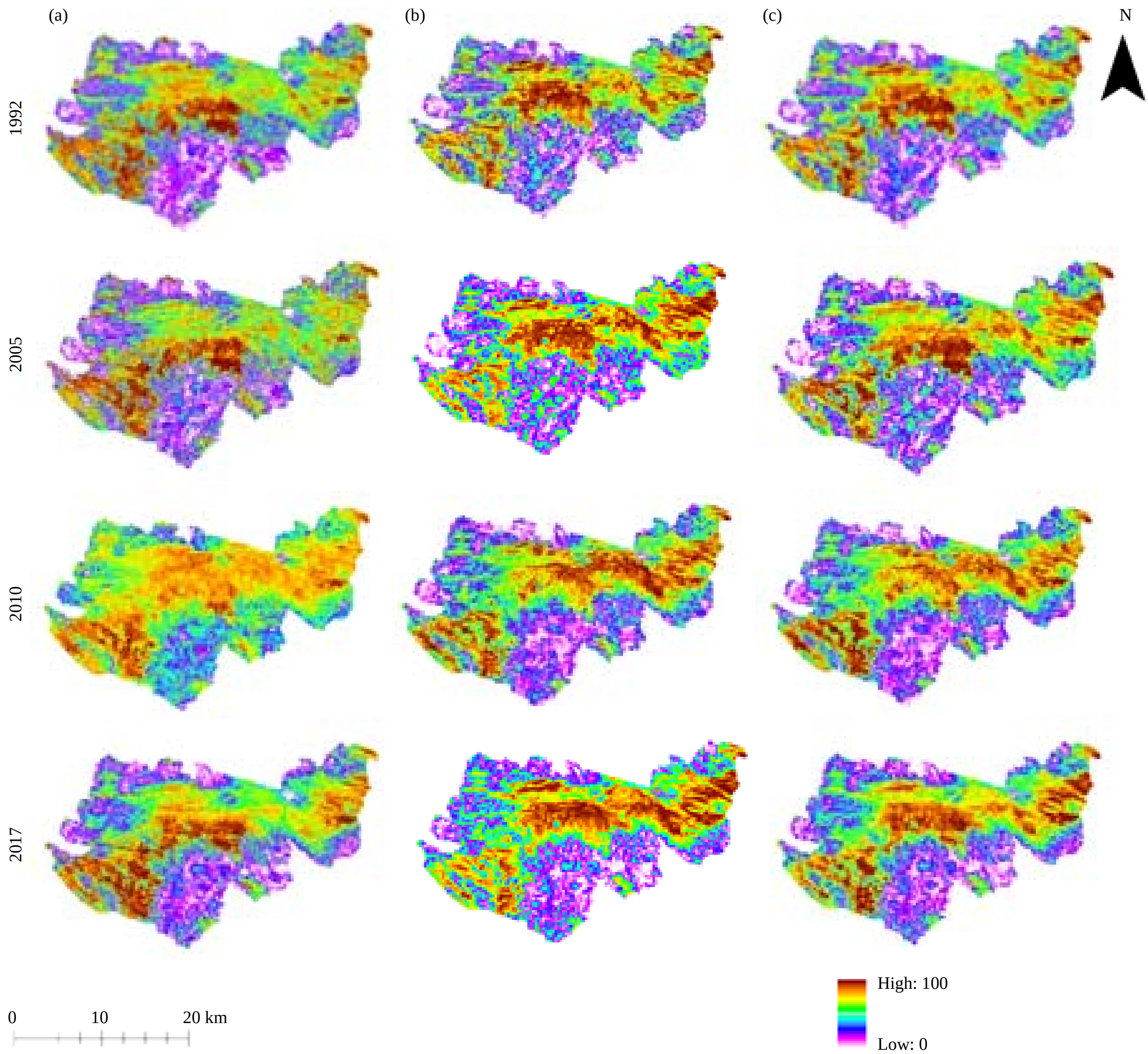

Fig. 5(a-c): Illustrating the process of FCD mapping, (a) Map of vegetation density of the taken year from 1992-2017, (b) Map of advance shadow index of the taken year from 1992-2017 and (c) Map of forest canopy density of the taken year from 1992-2017

the various spectral indices, vegetation density and Scaled Shadow Index (SSI), the forest canopy density map (Fig. 5c) was prepared from the year 1992-2017. Further, it was utilized for the classification of forest cover and its change detection.

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Forest cover pattern in HWS: To know the past forest pattern of the study area, firstly we focus on Landsat TM imagery for the year 1992 and FCD model were used for image analysis, where different forest cover and have been identified and used as past reference with the year 2005, 2010 and 2017. The year 1992 was used as the base year for identification of changes of forest cover from 1992 to present context. The identified forest cover pattern is verified in a cross-examination way at present context, whether the category exists or not or converted into another pattern. As per discussion the Very Dense Forest (VDF), Moderately Dense Forest (MDF). Open Forest (OF), Non- Forest (NF) was obtained from the forest density classification approach.

Spatio-temporal forest cover change detection: From the status of forest cover in each year from1992-2017, the spatiotemporal forest change trajectory was defined, the changing forest cover map is given in Fig. 6. In Fig. 7a, the very dense forest is in a declining state. The maximum coverage was in the year 2005, then in 2010 and its lowest coverage was in 2017. The overall decay of VDF was 12 km^2 in 2017 contrasted with the year 1992. In Fig. 7b, the moderately dense forest is in a declining trend, the maximum coverage of this category of the forest was in the year 2005. It decreases in the year 2010 by 37.21 km^2 contrasted with the year 1992. The moderately dense forest declined to 20 km^2 between 1992-2017. In Fig. 7c, the open forest shows increment between the years 1992-2017 and indicating increasing trend. The maximum coverage of this forest was in 2017 and its lowest coverage is in the year 2005. The overall increase in OF was 15 km^2 in 2017 as distinguished from the year 1992. In Fig. 7d, the non- forest is in increasing trend from the year 1992-2017. The maximum coverage of this forest was in 2017 and the minimum coverage of NF was in 2005. The non- forest having scrub part of the forest area has increasing trend. The maximum coverage was in 2017, it increases in 2010 compare

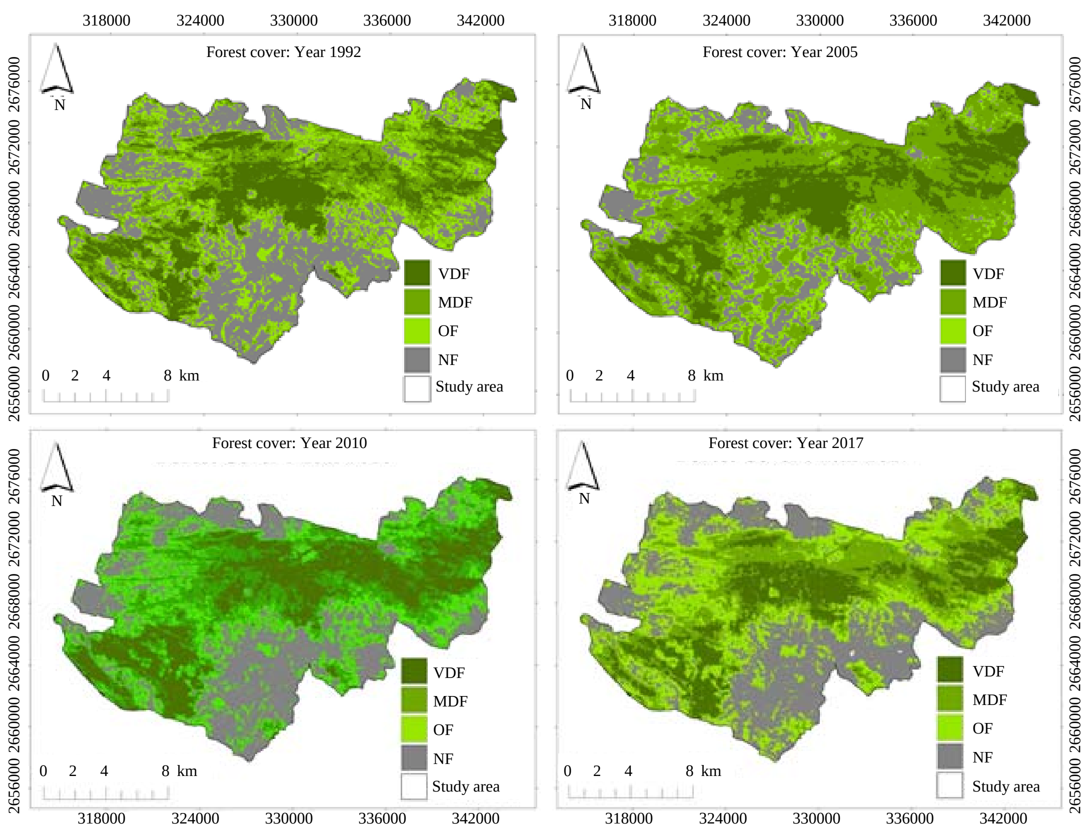

Fig. 6: Map showing the forest cover of the taken year from 1992-2017
VDF: Very dense forest, MDF: Moderately dense forest, OF: Open forest, NF: Non-forest

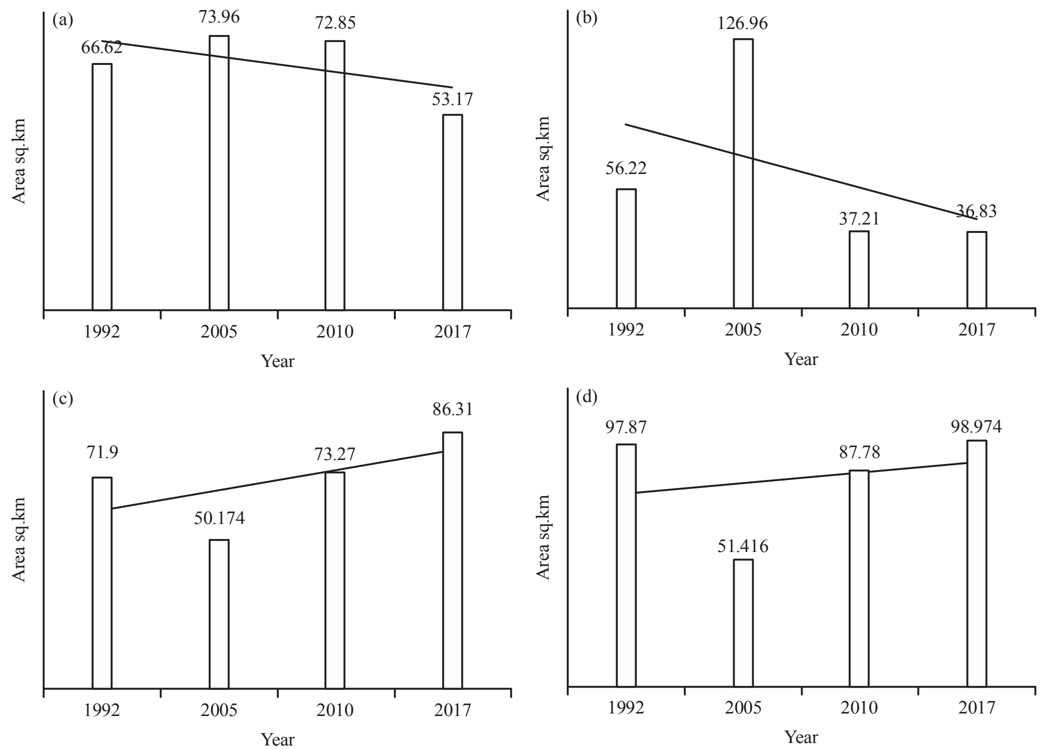

Fig. 7(a-d): Illustration of spatio-temporal change in forest cover: (a) Shows the spatio-temporal status of very dense forest in HWS, (b) Figure shows the spatio- temporal status of moderately dense forest in HWS, (c) Figure shows the spatio-temporal status of open forest in HWS and (d) Figure shows the spatio-temporal status of non-forest in HWS

to 1992 and its lower coverage was in 2005. The non- forest having bare soil, rocks, built-up and roads is in a decreasing trend as eqaute to the year 1992. The maximum coverage of this land was in the year 1992, decreases in 2005 and having lowest coverage, decreases in 2010 and decreases in the year 2017 compared to 1992.

Forest fragmentation: According to the main research objective forest land cover having five forest cover classes as very dense forest, moderately dense forest, open forest and non-forest which was used for understanding the cause of forest fragmentation in the study area. The non-forest (FDR) affect the forest, from which human influences are more considered for the degradation and modification of forest. For understanding and observing the forest fragmentation seven classes of forest fragmentation has been defined as core, interior, perforated, edge, transitional and non. The non-part of the forest is mainly the non-forest region of forest.

Status of forest fragmentation in 1992: In Fig. 8, the forest was found fragmented and classified into seven classes. In Fig. 9, the maximum cover of forest fragmentation was in edge forest. The second most dominant was the core area of the forest. The patches in the forest were well distributed around the edge, perforated, transitional and non-part of fragmented classes. The non-fragmented part of the forest as FDR shared 29.3 km^2 of the forest. The transitional was also the main part of forest fragmentation giving rise to a transitional effect (transformation of land). The forest as interior shared 21.5 km^2 of forest and the other class having a perforated forest shared low cover in the region of forests.

Forest Fragmentation changes of 2005 compared to the year 1992: In Fig. 8, the forest was found fragmented and classified into seven classes. In Fig. 9, the maximum cover of forest fragmentation was in core forest and an increase of 47 km^2 in the area contrasted with the year 1992 showing the improved condition of forest due to an increase of moderately dense and very dense part of the forest cover. The second most dominant was the edge area of forest with an increase of 12 km^2 compared to 1992 and thicker from the year 1992 due to an extension of other fragmented class in the forest. The patches in the forest were well distributed around the edge, transitional and non-part of fragmented classes and

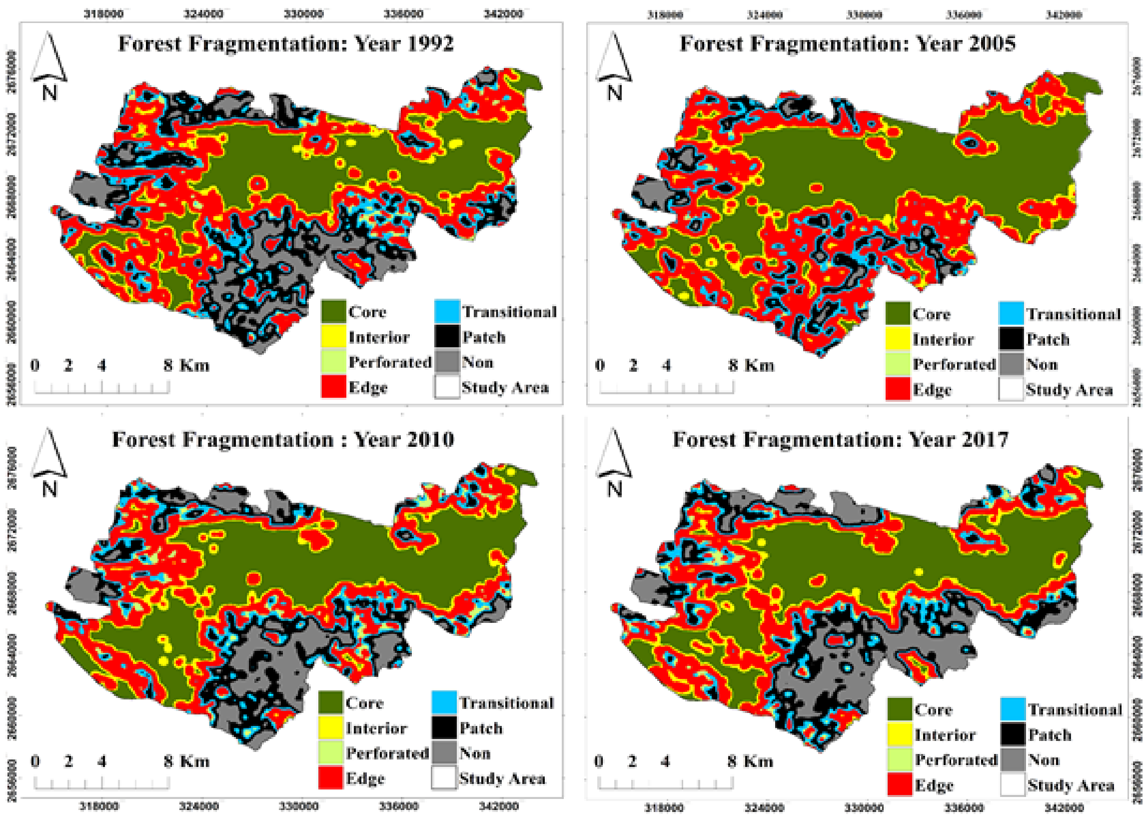

Fig. 8: Figure shows the map of forest fragmentation of the year 1992-2017: The illustration of forest fragmentation by showing core, interior, perforated, transitional, edge and patch area in the forest of HWS

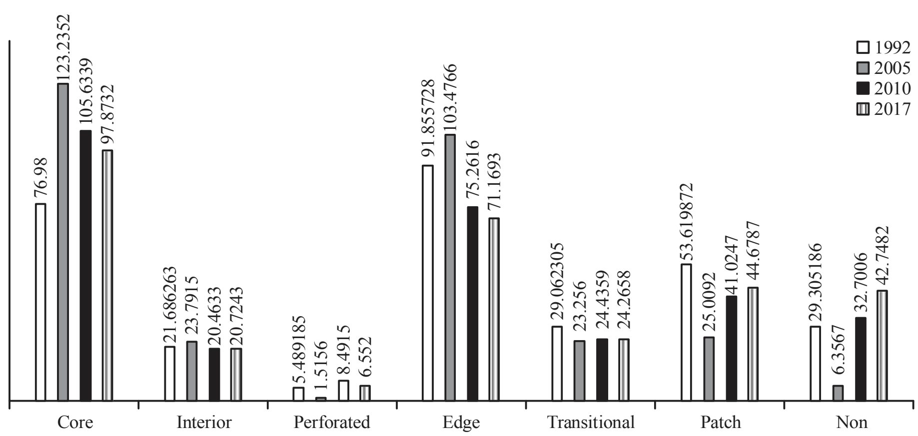

Fig. 9: The area statistics of fragmented classes in the different taken years from 1992- 2017

a decrease of 28 square from the year 1992. The non-fragmented as FDR of the forest shared 6.3 km^2 and decreases of 23 sq.km. The transitional part of forest fragmentation decreases by 3 km^2 as equate to 1992. The forest fragmentation as an interior increase of 2 km^2 from 1992 and the other class having a perforated forest shared low cover I n the region of the forest with a decrease of 3.9 km^2 from 1992.

Forest fragmentation changes of 2010 compared to the year 1992 and 2005: In Fig. 8, the forest was found fragmented and classified into seven classes. In Fig. 9, the maximum cover of forest fragmentation was in the core forest with 16.6 km^2 decreases as equate to the year 2005 and 29.6 km^2 increase from the year 1992. The main reason for the decrease was the decrease in moderately dense forest and compared to 1992 it increases due to an increase of a very dense forest. The second most dominant was the edge area of forest with a decrease of 28.2 km^2 from 2005 and a decrease of 16.54 km^2 from the year 1992. The patches in the forest were well distributed around the edge, transitional and non-part of fragmented classes with the 16 km^2 increase from the year 2005 and decrease of 12.61 square from the year 1992. The non-fragmented class having a Non-Forest Region (FDR) shared 32.7 km^2 of the forest with the increase of 26.34 km^2 from the year 2005 and an increase of 3.394 km^2 from the year 1992. The transitional part of forest fragmentation has evident the increase of 1.174 km^2 from 2005 and a decrease of 4.6 km^2 from the year 1992.The forest as interior shared 20.46 km^2 of the forest with the decrease of 2.33 km^2 from the year 2005 and a decrease of 1.226 km^2 from the year 1992. The other class having a perforated forest shared low cover in the region of the forest with the increase of 6.99 km^2 from the year 2005 and an increase of 3 km^2 from the year 1992.

Forest Fragmentation changes compared to the year 1992, 2005 and 2010: In Fig. 8, the forest was found fragmented and classified into seven classes. In Fig. 9, the maximum cover of forest fragmentation was in the core forest with 8.76 km^2 decreases as equate to the year 2010, 25.365 km^2 decreases from the year 1992 and 20.89 km^2 increase compared to the year 1992. It is showing the improving condition of the forest compared to 1992 but the concern is that its decreasing trend from the year 2005. The second most dominant was the edge area of forest with the decrease of 4.09 km^2 from the year 2010, the decrease of 32.3 km^2 from the year 2005 and the decrease of 20.6864 km^2 from the year 1992. The patches in the forest were well distributed around the edge, transitional and non-part of fragmented classes with the 3.654 km^2 increase from the year 2010, an increase of 19.67 km^2 contrasted to the year 2005 and a decrease of 8.94 km^2 from the year 1992. The non-fragmented class having a non-forest region (FDR) shared 42.748 km^2 of the forest with the increase of 10.0482 km^2 from the year 2010 and an increase of 36.39 km^2 compared to the year 2005 and the increase of 13.44 from the year 1992. The transitional forest decrease by 0.17 km^2 from the year 2010, an increase of 1 km^2 from 2005 and a decrease of 5.33 km^2 as related to the year 1992. The forest as an interior increase to 0.26 km^2 in the year 2010, a decrease of 3 km^2 from the year 2005 and the decrease of 0.96 km^2 in the year 1992. The other class having a perforated forest shared low cover in the region of forest km with a decrease of 1.938 km^2 from 2010, an increase of 5.037 km^2 from the year 2005 and 1.063 km^2 increase as equate to the year 1992.

DISCUSSION

Forest cover change: Spatiotemporal forest cover changes can have a dynamic negative effect on the natural surroundings of species that need forest consistency, i.e., the continuous existence of forest without any disturbance[39]. The declining of very dense forest and moderately dense forest (1992-2017) raises issues about the concern of forest condition. The forest cover loss considered as global concern and effects on climate change and biodiversity[40]. This forest is a very good source of carbon sink from nearby pollution from mines, industry and transportation. It helps in regulating climate, supporting the biogeochemical cycle of the earth and habitat of flora and fauna. The increment of open forest indicates that the forest was more exposed to non- forest activities, grazing, deforestation and other human interferences. Human dependency on forest resources adversely affects the flora and fauna[41]. The overall increase of NF was about 1 km^2, which were in very little amount. These analyses concluded that forest degraded and regenerated with the span of time. Forest degradation and its recovery are the fundamental processes of forest ecosystem development[42]. The increment of non-forest as scrub of 21 km^2 in 2017 compare to 1992 indicates that the grasses, small plants and agriculture have been more prevalent land cover in the forest, the forest area was affected by these land cover mostly by grazing and agriculture activities. It means the forest became more exposed to human interference. The main cause of deforestation in the developing country is the conversion of forest into farmland[43]. These are the bad sign for the future of forest in this region causing degradation and fragmentation of forest. The non-forest other than scrubs decreased to 20 km^2 in 2017 compared to 1992 indicates some good sign in the forest that the built-up lands, roads and bare lands not increased so much and bare lands decreased, occupied by grasses, agriculture and small plants in the region.

Forest fragmentation: The core area in the forest was increased compared to 1992 in 2005 it reached its maximum value and small decrease after this year. The increment in the forest core area compared to 1992 shows the proper management practices inside the forest. But the core area of the forest was in a decreasing trend over the year 2005-2017. This will be a concern for further degradation of the forest in future. The increment in the forest edge in the year 1992 given rise to edge effect, i.e., changing the microclimate[44]. These could be the serious concern for the well being of the wildlife sanctuary. Forest fragmentation doesn't have much effect on the interior of forest and that is the reason of the core area increased compared to 1992. The edge of the forest has been decreased and minimize the forest edge effect that reduces the mortality of trees[45]. The fragmentation in the transitional forest has not much changed but small decrease in the area has been found compared to the year 1992, it reflects less and balance transition of forest to non-forest (mainly scrubs) land use cover and vice-versa between the period of 1992-2017[46]. The good thing in the forest is that patches were in decreasing state shows that the forest is progressing well in management activities result in an increment of forest regeneration rate after its disturbance. The non-fragmentation has increased compared to 1992 due to increase in non-forest area (FDR) will cause more degradation and fragmentation of forest in future.

From the above-given fragmentation fluctuation from 1992-2017 indicates that in the future the core forest will be diminished at a significant rate and increase in the patches of forest. The result suggests that growth in agricultural and built-up zones is the major contributor of forest fragmentation. Therefore, the changes in forest fragmentation have a negative impact on the continuity and extent of the forest area[47]. The trends of forest fragmentation together with the forest cover change have severe impacts on habitat loss, biodiversity and ecosystem amenities in this region. Moreover, the pattern of fragmentation may vary at a different month of the study period and seasonal changes. These could be the future challenge to study the forest cover change and fragmentation according to seasonal or monthly changes. In addition, the core forest is increased in the study area because it is a protected area classified as a wildlife sanctuary.

CONCLUSIONS

This study determined that the forest canopy density and fragmentation model are beneficial for analyzing the spatiotemporal condition of the forest. It contributes to forest managers in decision making, monitoring biodiversity and conservation planning for sustainable forest management. Both fragmentation and forest cover are interlinked with each other. The result suggested the forest changes and fragmentation in the HWS persistent in future likely to be more worsened. The core area disintegrates and patches will increase. The increasing trend of open forest will definitely increases edge effects and the mortality of trees. The transformation of forest to agriculture and built-up giving rise to further degradation and discontinuity in the forest (transitional effect). The analysis suggested that the main focus of forest authority should be at the location of transitional, patch and regular checking of non-forest activities. The forest plantation and removing of native or short lived pioneer from the forest edges will maintain forest continuity and mitigating tree mortality rate. As the study area is under protection mainly in the core area and regular monitoring will help to check further land cover changes and fragmentation in this region from the effect of outside non-forest disturbances.

SIGNIFICANCE STATEMENT

The forest cover and disturbance has been regularly monitored in the study field by Forest Survey of India (FSI, Dehradun). The new things in the article was the method and high-resolution satellite data which provides high accuracy and better result. This approach puts recent advances in the field of forest disturbance analysis and its future predictions.

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