SAR – OPTICAL REMOTE SENSING BASED FOREST COVER AND GREENNESS ESTIMATION OVER INDIA

P. Lal[1], A. K. Dubey[2], A. Kumar[1, 3], P. Kumar[2,] * C. S. Dwivedi[1]

[1]Department of Geoinformatics, Central University of Jharkhand, Ranchi, India; preet.lal@cuj.ac.in
[2]Department of Earth and Environmental Sciences, Indian Institute of Science Education and Research Bhopal, India; adityadubey@iiserb.ac.in, kumarp@iiserb.ac.in
[3]IUCN Commission of Ecosystem Management; amit.kumar@cuj.ac.in

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ABSTRACT:

Indian natural forest has a high ecological significance as it holds much biodiversity and is primarily affected due to deforestation. The present study exhibits the forest cover change on Global Forest Non-Forest (FNF) data for India and greenness trend using MOD15A2H LAI product, which is the best product available till date. JAXA uses of SAR datasets for forest classification based on FAO definitions. Later, Forest Survey of India (FSI) used different definitions for forest classification from FAO and was to compare with JAXA based forest cover. The global FNF study exhibited that total forest cover was reduced from 568249 Km^2 to 534958 Km^2 during 2007-17 in India. The significant loss of forest cover (33291.59 Km^2; by -5.85% change) was primarily evident in Eastern Himalayas followed by Western Himalayas. Whereas forest cover increase was observed in Eastern and the Western Ghats from 2007 to 2017. The state of forest report by FSI states an increase in the forest cover from 690889 Km^2 to 708273 Km^2 during 2007-17 by 2.51%. The difference in forest cover as estimated by JAXA global FNF datasets and FSI report is attributed to differences in forest cover mapping definitions by both the agencies and use of varied datasets (SAR datasets by JAXA and optical datasets by FSI). It is to note that SAR is highly sensitive to forest cover and vegetation's as compare to optical datasets. Recent satellite-based (2000 – 2018) LAI product reveals the increase in leaf area of vegetation during 2000-18. It may be attributed to proper human land use management and implications of green revolutions in the region. The greening in India is most evident from the croplands with insignificant contribution from forest cover.

1. INTRODUCTION

Forest is the most essential and critical element of earth's surface, and its dynamics on the landscape are driven by both human activities and natural processes (Morales-Díaz et al. 2019; Tucker and Richards 1989). The green leaves of vegetation play a crucial role in maintaining terrestrial carbon balance and also supports climatic systems as it amalgamates sugar from water (H_2O) and CO_2, using the energy that leads to cooling of the surface by transpiring a large amount of water (Chen et al., 2019; Piao et al., 2003). The growth of vegetation in an ecosystem can be strongly influenced by climate change and human activity (Cavicchioli et al., 2019; Chu et al., 2019; Liu et al., 2019). Long-time change in greenness of vegetation are driven by multiple factors such as biogeochemical drivers i.e., fertilization effects of eCO_2, regional change of climatic factors as temperature, precipitation and radiation and varying rate of Nitrogen deposition or cycle change and land-use effects i.e., change in land use/ land cover (LULC) due to land management intensity, including use for fertilizers, irrigation, deforestation and grazing) (Wang et al., 2014). So, it is crucial to monitor vegetation changes because spatiotemporal changes can alter the structure and function of landscapes, subsequently influencing ecology and biodiversity and became an important issue in global biodiversity change (Li et al., 2012; Peng et al., 2012, 2011; Steidinger et al., 2019).

Greenness on earth's surface can be monitored through various developed indices like Normalized Differential Vegetation Index (NDVI), Leaf Area Index (LAI). Enhanced Vegetation Index (EVI) and many more used by several researchers (Chu et al., 2019; Rani et al., 2018). LAI (one half the total green leaf area per unit horizontal ground surface) can be more efficient to monitor the greenness because it is one of the main driving forces of net primary production, water and nutrient use, and carbon balance and important structural property of vegetation (Bréda, 2008; Fang and Liang, 2014).

Remote sensing is a beneficial technique for studying various earth observations on regional to a global scale. Optical remote sensing (ORS) data are widely used for the vegetation mapping by using a near-infrared and red band as it useful for vegetation mapping. As per current research knowledge, very less study has applied microwave remote sensing (MRS) datasets for vegetation mapping due to the requirement of robust hardware for processing. Major advantages of MRS over ORS is that it has day and night capabilities and penetration of cloud cover and can provide an image at any time (Woodhouse, 2005). There are various spectral bands at which SAR data is being captured. X-band is useful for various surface deformation and movement tracking activities (Lal et al., 2018), C-band is used for both ground surface deformation and vegetation studies, L-bands are used for vegetation studies primarily because of its higher penetration depth (Antropov et al., 2017; Kumar et al., 2019; Plank et al., 2017). By increasing the wavelength in SAR datasets, vegetation type classification accuracy will increase because of its penetration depth. Mapping a vast region with optical datasets leads to inaccuracies due to cloud cover data and have to be replaced with another time periods datasets, whereas by SAR datasets researchers can overcome these problems accuracies will be more.

With continuous availability of satellite-based datasets, the efforts to accurately classify forest types have increased over the year to correctly capture the real dynamism of any ecological landforms/landscapes. The ambiguity in management approaches for forest conservation raises the need to develop

* Corresponding author

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newer approaches with higher accuracies in mapping a forest region or types of forest region (Paneque-Gálvez et al., 2013). The trade-off between of spatiotemporal datasets with spectral resolution and availability of cost determines the quality of forest or any land use classifications, unlike different types of spatial and spatial resolution keeps many advantages on species-level distribution mapping in forest region (Eisavi et al., 2015; Pu and Landry, 2012).

India is a country with diverse vegetation types and wildlife. Due to expansion of agricultural land, urban areas and various human-induced changes have caused extensive damage to Indian forests and results in loss of biodiversity hotspot in major regions: The Indo-Burma hotspot, Terai regions of Himalayas and Western Ghats (Datta and Deb, 2012; Deb et al., 2018; Myers et al., 2000; Reddy et al., 2019). To accost this mass and severe deforestation and degradation of ecology, the MoEF, as well as Indian Forestry Department, have declared major regions of forest regions as a biosphere, national parks, sanctuaries or reserve forest and increased the management for conservation in those areas.

Forest cover delineation is well documented in India by Forest Survey of India) in Bi-Yearly report. Also, various researchers have documented for the degradations of forest and restoration of the forest from regional to global scale using remotely sensed data in past two decades and shown vegetation cover change or forest cover change and how ecologically it is transforming. Long term LULC changes has been mapped by Ramachandran et al., (2018) in the Eastern Ghats and identified as timber logging, dam construction, road-rail network and other developmental activities were the major drivers of forest cover change before the 1960s, and after 1960s anthropogenic pressure as increase in demand of land for urban development is a major driver for degradation. The three studies by Chakraborty et al., (2018); Kanade and John, (2018); Ramachandran et al., (2018) establish a relationship very rigorously and unambiguously that there is a significant reduction in green cover in different regions of natural forest and habitat types in India. Forest cover loss in the Western Ghats shows that protected areas (PAs) were able to slow down the rate of deforestation about 32%. However, in areas with high population density, deforestation rates are higher even in the PAs (Krishnadas et al., 2018). As per recent Forest Survey of India report, it claims that Indian forest cover has been increased by 0.94% of total area (FSI, 2017), while some experts point out that government often keeps claiming that the green cover is increasing, but it is usually due to plantations and not due to expansion of forest covers (Padma, 2018). Apart from deforestation in India some studies also suggested that India is greening (Zhang et al., 2017) due to proper land use management as a direct factor whereas climate change and CO_2 fertilization as dominant indirect factors (Chen et al., 2019; Zeng et al., 2014; Zhu et al., 2016) by analysing Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI) from remotely sensed datasets. The objective of the study is to analyse the decadal change in the natural forest of India using PALSAR/PALSAR-2 mosaic and forest/non-forest (FNF) datasets by JAXA, which follows FAO definitions for forest mapping (Shimada et al., 2014) and comparing the results of forest cover with FSI reports. Later, the greening and browning trend from 16 days LAI datasets were also analysed to map the spatiotemporal variability in greenness in the Indian region.

2. STUDY AREA

India, located in South-East Asia, has been considered as a study area for above-said objectives. It is the seventh-largest country in the world can be divided physically into four regions- the Himalayan mountains, the Gangetic river plains, the southern (Deccan) plateau and the islands of Lakshadweep, Andaman and Nicobar. The lofty Himalayan mountain range borders India in the north and contains the nation's highest peak. The Indus, Ganges and Brahmaputra rivers rise in the Himalayas. Southern India consists of a triangular peninsula, and much of this consists of a tableland, the Deccan plateau (Forster and Stallybrass, 1978).

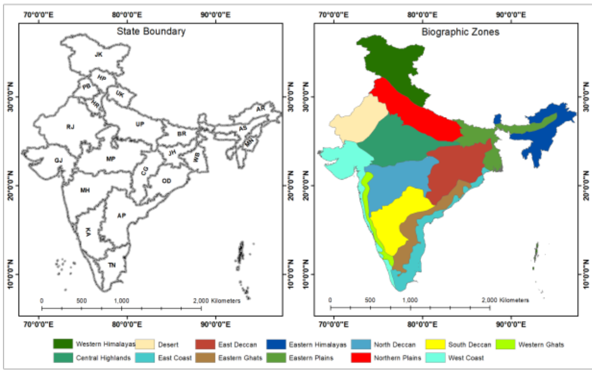

Figure 1. Biogeographic Zones of India

For Forest area change mapping a Biogeography Zones were used and it consists of 13 different zones namely Western Himalayas, Eastern Himalayas, East Deccan, Deserts, North Deccan, South Deccan, Western Ghats, Central Highlands, East Coast, West Coast, Eastern Ghats, Eastern Plains and Northern Plains in India as shown in figure 1.

Biogeographic Zones	**Area in Sq. Km**	**Area Coverage in %**
Eastern Ghats (EG)	190190.61	5.80
Eastern Himalayas (EH)	218325.11	6.66
Desert (D)	217336.97	6.63
Western Himalayas (WH)	323331.91	9.86
Northern Plains (NP)	295662.01	9.01
Eastern Plains (EP)	208608.68	6.36
Central Highlands (CH)	368669.69	11.24
East Deccan (ED)	340963.67	10.39
North Deccan (ND)	330148.69	10.06
South Deccan (SD)	290539.84	8.86
West Coast (WC)	236748.98	7.22
Western Ghats (WG)	70702.95	2.16
East Coast (EC)	189307.70	5.77

Table 1. Area of different Biogeographic Zones considered in these study

3. DATA USED AND METHODOLOGY

Forest Survey of India forest cover datasets which are Bi-yearly released was used to analyse forest cover change with another dataset by JAXA, i.e., is Global forest and non-forest data. JAXA (Japan Aerospace Exploration Agency) used FAO definitions for forest mapping, which is purely different from FSI forest mapping definitions. Forest cover as reported in the SFR includes all the lands having trees with canopy density 10% and above and with the area having one hectare of the forest cover, which corresponds to the cartographic limit on a map at 1:

50,000 scale. It is taken in account based on the availability of cloud-free optical datasets, primarily it uses RESOURCESAT-1 datasets, but due to some limitations, another dataset like Landsat satellite or ESA based Sentinel 2A/2B data were also used (FSI, 2007). As per FAO, the forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or tree able to reach these thresholds in situ. It does not include land that is predominantly under agriculture or urban land use. JAXA based global forest data used FAO definitions and used Synthetic Aperture Radar (SAR) datasets which can capture datasets at cloudy weather (JAXA, 2010; Shimada et al., 2014). Since, SAR signal has the problem in mountainous area and to overcome these issue all the raw scenes were calibrated using a published coefficient (Shimada & Otaki, 2010). "All scenes were ortho-rectified using the 90 m SRTM Digital Elevation Model (Shimada, 2010a, 2010b) and slope-corrected using these same data to account for the variation in the backscattering coefficient with topography" (Shimada et al., 2014). Global FNF data are available in Binary format as data and hdr extension with 0.1°X0.1° area coverage at 25m of spatial resolutions. For each year total, 1625 binary datasets covering over India were merged and converted into tif format. Biogeography Zones were rasterized with a 25 m spatial resolution using ArcGIS 10.6 to match spatially with JAXA FNF data. Zonal summary used in Erdas Imagine for calculating the area of forest in different biogeographic zones, for comparison of forest area in different zones and analysing changes in the different time period. Later Overall forest area of India from FSI and JAXA were compared.

The MOD15A2H Version 6 Moderate Resolution Imaging Spectroradiometer (MODIS) Leaf Area Index (LAI) product is an 8-day composite dataset with 500 meter (m) pixel size were used for analysing the trend and long term of LAI in different seasons of India. Yan et al., (2016a), (2016b) comprehensively evaluated the quality of C6 MODIS LAI datasets against the ground measurement of LAI and also inter-comparison with other satellite LAI product and found that it is the highest quality LAI product available till date. Linear trend analysis of CDO (Climate Data Operator) was used for analysing greenness trend.

4. RESULT AND DISCUSSION

4.1 Analysing Forest Cover Change

JAXA global FNF data were used to analyse forest cover change in different biogeographic zones during the year 2007 and 2017. The study showed that the highest forest cover was present in Eastern Himalayas (24.07 %) followed by East Deccan (16.31 %) and Western Himalayas (11.50 %). These Statistics are with respect to the year 2017. But, when the area is analysed according to forest coverage in zonal wise as Eastern Himalayas have the highest coverage followed by the Western Ghats and East Deccan. These three zones have acted as a biodiversity hotspot, which has high ecological significance in natural forest. The JAXA Global FNF (2007, 2017) based decadal assessment of the forest cover reported a considerable reduction of 33291.59 Km^2 (1.02% area of India) forest cover (from 568249.47 Km^2 to 534957.88 Km^2) during 2007-17. The significant loss in forest cover was observed in Eastern Himalayas (EH, 9.3%) followed by Western Himalayas (WH, 4.62%), East Deccan (2.29%), North Deccan (0.38%) and Central Highlands (0.31%). The decrease of forest in EH was also reported by FSI and attributed to shifting cultivation, rotational tree felling, diversion of forest land for developmental activities, submergence of forest cover, agriculture expansion, natural disasters (viz., flooding, earthquakes) and other pressures. North-East India also has a rich diversity in tree population, but many of the tree species are under threat. Since Western Himalayan region is the best-studied ecoregion in India, yet the region observed a significant (14946.71 Km^2) decrease in forest cover during the last ten years (2007-17), primarily due to higher dependency of local populace on forest resources. In recent years, the stress on forests of the WH has become more intense due to unsustainable developmental activities as well as an increased frequency of natural disasters in changing climatic conditions (Tewari et al., 2017).

Biogeographic Zones	2007	2017
Eastern Ghats (EG)	1.29	1.45
Eastern Himalayas (EH)	4.53	3.93
Desert (D)	0.01	0.01
Western Himalayas (WH)	2.33	1.87
Northern Plains (NP)	0.21	0.26
Eastern Plains (EP)	0.63	0.63
Central Highlands (CH)	0.53	0.50
East Deccan (ED)	2.90	2.66
North Deccan (ND)	1.49	1.45
South Deccan (SD)	0.67	0.73
West Coast (WC)	0.87	0.87
Western Ghats (WG)	1.12	1.16
East Coast (EC)	0.75	0.79

Table 2. Overall forest cover distribution based on JAXA global FNF datasets

North Deccan, South Deccan and Central Highland have observed a minimal loss of forest in the last ten years due to conservation practices in the forest of above-said region unlike reason might be for deforestation due to population pressure and demand for timber etc. There is a high possibility to increase or consistent reliability in forest coverage in these zones of central India in case of successful implementation of effective conservation practices in the unprotected forests and protected forest (Krishnadas et al., 2018).

Although there are regions, where forest cover has been increased due to adoption of afforestation measures and implementation of proper land use management, which is primarily evident in Eastern Ghats (5004.64 Km^2; 2.63%) increase in forest area) followed by Western Ghats (1.92%, 1392.54 Km^2), East Coast (0.74%), South Deccan (0.67%), Northern Plains (0.63%), Eastern Plains (0.10%) and Deserts (0.03%). These increase of forest may be attributed to plantation and conservation practices both within and outside the Recorded Forest areas.

The results of JAXA Global Forest-Non-Forest was compared with the (FSI) State of Forest Reports. The comparative reported an increase of ~17384 Km^2 of forest cover during 2007-17 (FSI, 2007;2017, Figure 4). On the contrary, JAXA Global FNF exhibited a decrease in forest area ~33291.6 Km^2 during the said period. The variation in the records/ observation in forest cover may be attributed to differences in forest classification techniques, survey methods, minimum mappable unit and use of different satellite datasets as adopted by JAXA and FSI.

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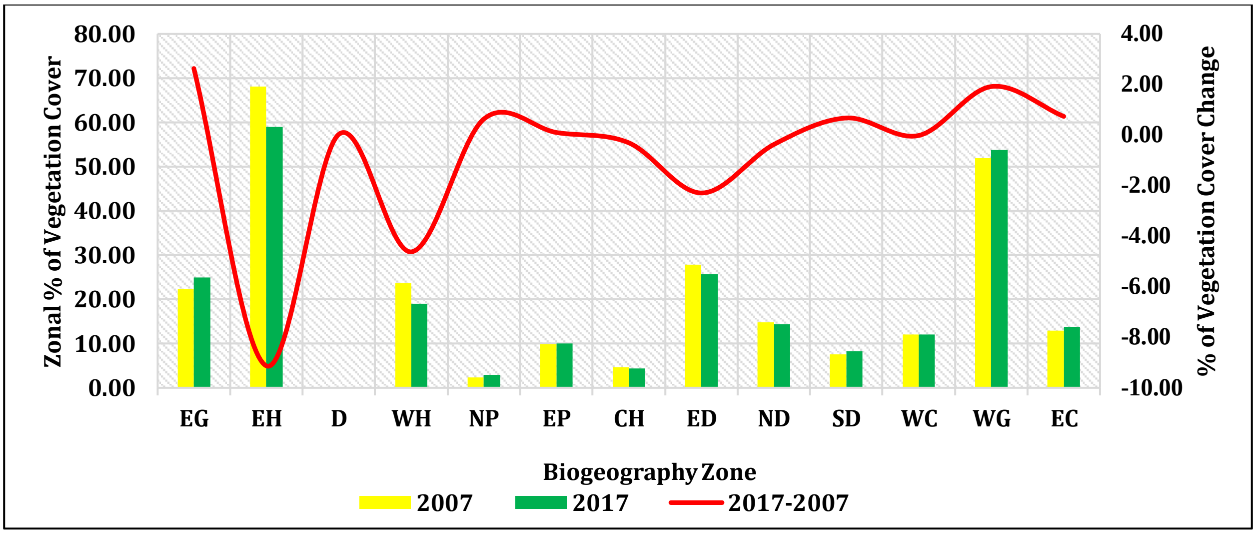

Figure 2. Graph showing changes in forest cover in different biogeographic zones in India

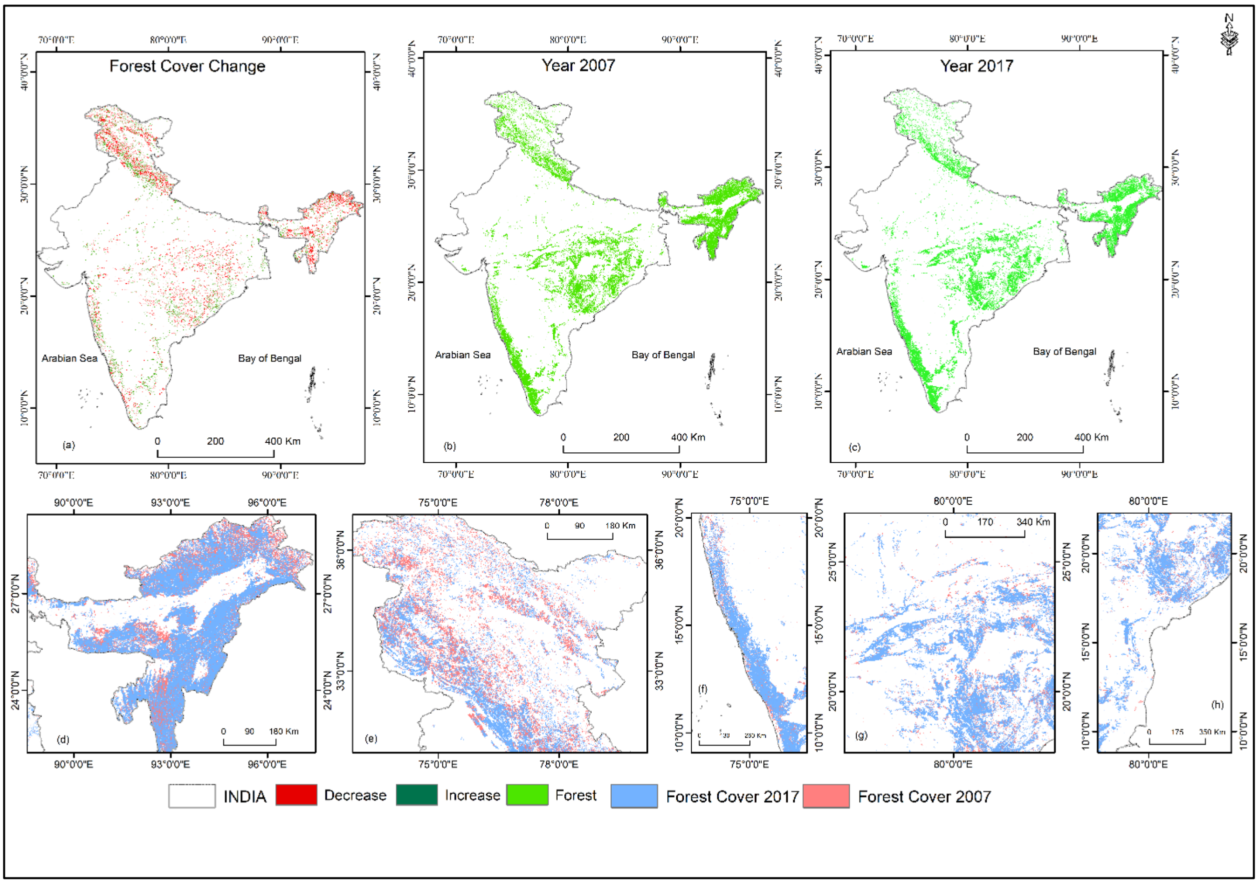

Figure 3. (a) Forest cover change map (b) Forest cover map of year 2007 (c) Forest cover map of year 2017. Comparison of forest cover between year 2007 and 2017 in (d) North-East India (e) North India (f) West Coast (g) Central India (h) East India and East coast.

Due to the limitations in scale, satellite resolution and mapping unit, it is not possible to discriminate natural forests by FSI as stated in SFR 2007. Also, it does not recognize the type of land ownership or land use and legal status of the land. Thus, all species of trees (including bamboo, fruits, coconut, etc.) and all types of land (forest, private, or community) are wrongly included in the forest. On the contrary, JAXA global FNF accounts mainly for the natural forest as it considered area of forest (as some part it also includes the land area behind natural forest) without agricultural, urban or land. One of the major advantages of JAXA global FNF is that it based on microwave SAR images, which are independent to seasonal and day-night limitations, which is classified based on backscatter threshold for forests of different climatic zones, with limited overestimate or underestimate. JAXA claims for 84% accuracy of global FNF datasets. As per FSI, it uses one-time optical datasets for entire India, which may have some limitations in terms of radiometric and atmospheric attenuation (viz., cloud cover, variation in scene contrasts, coarser grids size of temperature and rainfall)

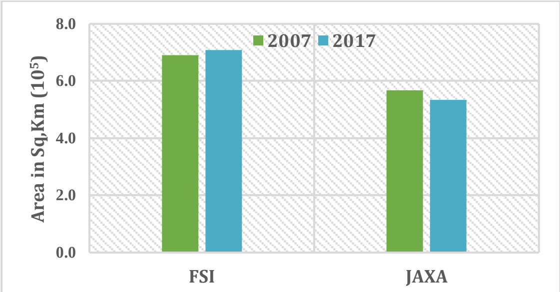

Figure 4. FSI and JAXA satellite-based comparative assessment of changes in forest coverage area during 2007-17 (FSI, 2007;2017)

4.2 Leaf Area Index Seasonal Variations and Trend

Leaf Area Index (LAI) is an important parameter in plant ecology. Because it tells how much foliage there is, it is a measure of the active photosynthetic area, and at the same time of the area subjected to transpiration. Natural vegetation growth in India broadly depends on the monsoon rain (Dash et al., 2010; Elliott et al., 2006) and pattern described by the 8-day MOD15A2H LAI broadly coincide with the arrival and withdrawal of the south-west monsoon. These variations in LAI result may be attributed to the interaction of electromagnetic radiation with vegetation canopies, complex structure and amount of light availability of sparse vegetation (Goel and Strebel, 1983), but other factors also influence the LAI variations such as nutrients and water availability.

The long term seasonal mean and seasonal trend of LAI was estimated in CDO (Climate Data Operator) using MODIS MOD15A2H during the various seasons viz., DJF (December, January and February), MAM (March, April and May), JJA (June, July and August) and SON (September, October and November). Long term seasonal mean LAI exhibit that the value of LAI varies from 0.1 to 7. The forest of Eastern Ghats, Western Ghats, Eastern Himalayas and Western Himalayas observed higher LAI (>5).

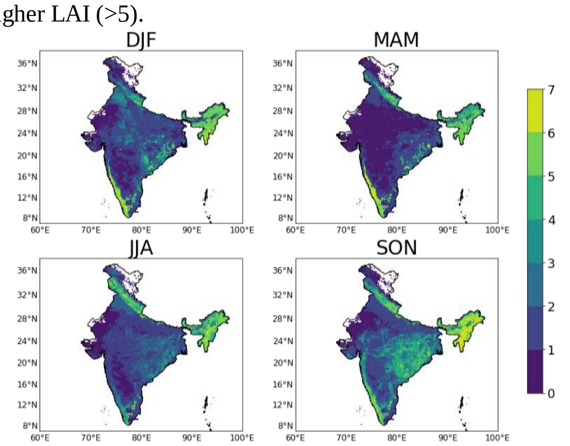

Figure 5. Long term seasonal mean variability of LAI

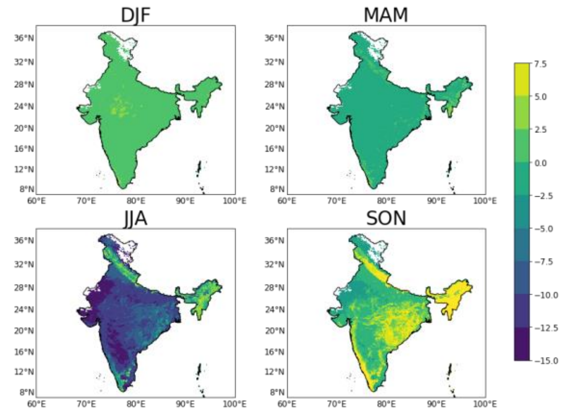

Figure 6. Long term Seasonal trend of LAI

The seasonal patterns of mean LAI indicated the maximum greenness pertaining to high LAI (5-7) was observed in autumn (September and October) and spring (March, April) due to rich vegetation growth after the monsoon. Evergreen forests of Western Ghats are multi-layered and complex in their architectural characteristics. These trees shed their leaves at a slow and steady rate throughout the year, which results in continuous decay and decomposition on the forest floor. The Eastern Ghats of India is a broken chain of hills that extends from Orissa to Tamil Nadu and dominated by deciduous forest (Reddy et al. 2014), and a similar pattern of mean is observed as SON have higher LAI values. Forest shed their leaves due to water availability in the dry season, i.e., during pre-monsoon season and result in a decline of LAI. Besides Ghats and Himalayan region mainly in agricultural dominated areas value of LAI changes with season to season due to change in agricultural patterns. The DJF and MAM season is a cropping season as seed sowing happens starts in December and harvesting starts between the last week of March to April. So, overall LAI value is higher in DJF as compared to the MAM due to growth of Rabi crop in DJF months and its whereas harvesting initiation during from mid-march harvesting starts that leadings to decrease of mean LAI value. Due to tropical hot and humid climate, entire Andaman & Nicobar Islands support very luxuriant and rich vegetation with unique tropical rain/evergreen forest canopy. The climate of Andaman and Nicobar Islands is highly favourable for the evergreen forest and mean LAI above two throughout the year. The trend of Agricultural dominated area was observed higher in DJF than that of MAM and it also coincides with LAI mean value. The overall decreasing trend and mean LAI value in JJA seasons is related with the sowing of Kharif crop in the last week of July, and its maturity in September. In Ghats and Himalayan range of India all four seasons exhibited positive trend and highest trend value observed in SON season followed by DJF and JJA. Least value of LAI trend was observed in the MAM season, and this may be attributed to the summer season. The minor contribution of lower trend of LAI may be attributed to cloudy pixel during monsoon season (JJA). Therefore, the overall trend of LAI exhibit that greenness is increasing due to mainly in agriculture dominated season and natural vegetation are also contributing to LAI increasing trend except for JJA seasonality, and other studies by Chen et al., (2019) also suggested that in India cropland alone contribute 82% of increase in leaf area and 4% of growth in forest which shows that there is little contribution of greenness. Thus, the above result shows that human land use is a dominant driver of greenness in India (Chen et al., 2019; Zhu et al., 2016), as cropland greening contributes the highest greening trend in 3 seasons with a minor contribution of forest in the Himalayas and Ghats area. The green revolution like hybrid mechanisation, crop insurance programme, multiple cropping irrigation, fertilization, hybrid seeds etc. have a significant role in the contribution of the increasing trend of greenness.

Indian satellite which is carrying optical sensors are capable for monitoring the forest cover in India, but it is restricted for the data having a cloud cover and can leads to misclassifications. Whereas, Indian satellite having SAR sensors (RISAT -1) are also capable for monitoring forest cover, but it does not cover whole India, and some of scenes are missing which cannot a real-time quality mapping of Indian forest. Indian upcoming satellite like NASA-ISRO Synthetic Aperture Radar (SAR) or NISAR having L (Foliage penetration) and S (Sensitivity to light vegetation) band which is primarily suitable for vegetation studies and can give a revolution in more accurate forest cover mapping and near real time forest watch as it has twelve days repeat pass with 3 – 10 meters' mode-dependent SAR resolution which is primarily higher resolution then present Indian RISAT (C-Band) satellite.

5. CONCLUSION

India has an immense variety of forests ranging from tropical evergreen to dry deciduous forest and dominantly agriculture land. Forest Cover change has been analysed using JAXA global FNF datasets with 25 m spatial resolution between 2007 and 2017 and found that there is a huge decrease in a forest cover in India which is around 33291.59 Km^2. The major contribution is from the Eastern Himalayan zone (North-East part of India), and it is always a great issue for the continuous increase of Forest in EH. There is also a major contribution of Increase in forests of the Eastern Ghats and the Western Ghats to the nation and may be attributed to conservation practices. When overall forest cover area changes calculated form FSI report of 2007 and 2017, it shows that in India whole forest cover have increased, which is contradictory to global FNF datasets. Since both have different techniques to classify forest that leads to conflicting results. JAXA based global FNF data majorly accounts for natural vegetation. Thus, based on FNF data it can be concluded that Natural forest is decreasing. LAI, being a measure of canopy foliage content is key vegetation characteristic among the different forest types. The study investigated the spatiotemporal and inter-seasonal variations in LAI. Seasonal mean and trend analysis of LAI exhibited that trend of greenness is increasing as a major contribution of greenness from agriculture land and little contribution from the forest. Based on Seasonal trend, JJA has only negative/decreasing trends and rest all the season have positive/increasing trends. This study can tell us that Natural forest is decreasing and it has a significant loss of ecological significance, but greenness is increasing in India due to human use of lands for agriculture and attributes to human land use management in the greening of India. Primary importance towards forest conservation practices should be implemented strictly in the Eastern Himalayas region as it shows colossal loss of forests.

Limitations towards global FNF studies is that it assumes a constant backscatter value (-15 dB) to classify forest and non-forest in Indian regions (Shimada et al., 2014), but taking a constant backscatter value for monitoring diverse forest (covering tropical deciduous forest to tropical evergreen forest) of India which primarily forest type changes with change in latitude and climatic parameters. For different regions different backscatter value should be considered for FNF classification. Another limitation is that it classifies as per FAO parameterization which does not include a forest in TOF (Tree Outside Forest) which is good to map a natural forest and can employ for mapping an ecological significance any way's in today's generations forest regeneration or afforestation is primarily aimed for carbon sequestration (either in TOF or forest area) and mapping those forest is also required to have a regional watch for forest cover and their proper planning for future forest regenerations.

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