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Forest Canopy Density Monitoring in the Siwaliks of Yamunanagar District, India

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Abstract

This work examine the forest canopy density (FCD) in the Siwalik region of the Yamunanagar district in the northern part of India. The study area includes the lower and upper part of the Siwalik region constituting 6.33% (112.08 sq. Km) of the total geographical area of the district (1768 sq. Km). The Landsat 9 satellite images acquired on 15 December 2022 and Rikimaru's FCD model to estimate the density of forest canopy is used as an input. The result shows that 89.11% (99.88 sq. Km) of the Siwalik forest of the study area is covered with canopy of different density categories. The FCD classification result indicate that: i) 0.35% (0.39 sq. Km) area is moderately dense canopied forest having density 10-40%, ii) 86.22% (96.64 sq. Km) area is dense canopied forest having density 40-70% and iii) 2.55% (2.85 sq. Km) area is very dense canopied forest having density more than 70%. The field visit confirm the study area is rich in Sal, Khair, Papri, Dhak, Shisham and other important tree species of commercial and medicinal importance. The result shows a requirement of forest cover expansion through afforestation and afforestation activities.

1. Introduction

Forests are crucial in providing resources which supports livelihood and also in regulating ecosystem functioning. The anthropogenic activities such as logging, livestock grazing, forest clearing for construction purpose are leading cause of forest degradation and deforestation (Haddad et al., 2015; Grantham et al., 2020). Siwalik region is marked by fragile land formations dissected by networks of innumerable small streams, choes, gullies in varied topography and lying between Himalayan ecosystem and Indo-Gangetic plains in north-western part of India (Rawat and Mukherjee, 2005; Yadav et al., 2015). Weathering and erosion are common and continuous phenomenon in the Siwaliks (Singh, 2001). The Siwalik region is experiencing alteration in the seasonality and intensity of rainfall which is expected to increase the frequency of environmental disturbance (Semwal et al., 2017). In the north-western India, the Siwalik region having the same landscape characteristics extends in the States of Jammu & Kashmir, Punjab, Himachal Pradesh, Uttarakhand and Haryana (Panwar et al., 2012). In Haryana, the Siwalik passes through its Yamunanagar, Ambala and Panchkula districts (Yadav et al., 2015). Siwaliks has a clusters of protected forest areas which are subject to degradation and deforestation causing a decrease in forest canopy cover (Richards et al., 2022).

The density of forest canopy is one of the indicators that reflects the growth of forest (Rikimaru, 1996) which is decreasing due to natural as well as anthropogenic causes (Bandyopadhyay et al., 2017). Therefore, information on the status of forest canopy density (FCD) can be one of the essential tools for forest planners (Biradar et al., 2005). FCD is one of the most useful parameters in the planning and implementation of forest rehabilitation program (Rikimaru et al., 1999; Rikimaru et al., 2002). The use of remote sensing satellite images is considered as the scientifically-proven most competent and cost-effective approach to calculate forest canopy density (Rikimaru, 1996; Falensky et al., 2020). The temporal repeat of remote sensing satellites scanning areas in different spatial and spectral resolution is a cost-effective means of analyzing different environmental components over a geographical area (Vorovencii, 2011). The FCD model calculate the values of different indices using the visible to thermal infra-red spectral bands available in the medium resolution multi-spectral satellite images such as Landsat series and IRS LISS series (Rikimaru et al., l999; Azizi et al., 2008; Falensky et al., 2020). The model is frequently used to analyse and estimating the forest canopy cover, afforestation, deforestation, health of forest etc. (Biradar et al., 2005; Azizi et al., 2008; Mon et al., 2012). After Ladakh, Haryana State of India has a second lowest fraction (3.63%) of recorded forest cover (192.99 sq. Km.) to its total geographical area (1768 sq. Km.) (ISFR, 2021). According to Champion and Seth (1968) classification of India's forests, the forests of Yamunanagar district are occupied mainly with dry Siwalik Sal (deciduous) forest, dry plain Sal forest, mix dry deciduous forest and dry tropical riverine forests. However, ground survey shows that anthropogenic activities such as residential and industrial development is constantly encroaching the outer periphery forest land apart from the illegal logging (Anuradha and Gupta, 2022). In this study, forest canopy density was calculated to assess its present status in the Siwaliks of Yamunanagar district of Haryana State (India) using satellite image and FCD model.

2. Materials and Methods

2.1 Study area: Yamunanagar district is a north-eastern part of Haryana State of India occupying a total population of 1214205 individuals in a geographical area of 1768 sq. Km. (Directorate of Census Operations, Haryana, 2015). The rivers Yamuna, Markanda and their tributaries mainly drained this region. The Siwalik region is on the northern fringe of Yamunanagar district lying from 30^{0}18'40.4454'' to 30^{0}29'07.6158''North latitude and from 77^{0}12'59.4786'' to 76^{0}34'38.2044'' East longitudes covering an area of 112.08 sq. Km. The district is covered by reserved, protected and unclassified forests with a total forest cover of 192.99 sq. Km. (ISFR, 2021). The study area is located in the Siwaliks of Yamunanagar district of Haryana State (Fig 1).

2.2 Input data: The Landsat 9 OLI and TIRS-2 satellite image (path/row 147/39) acquired on 15 December 2022 is downloaded from the online portal of USGS Earth explorer is used in the presented work. Apart from the other bands given in table 1, band 10 (TIRS 1) is used in the estimation of FCD. The boundary of Siwaliks of Yamunanagar district is downloaded from GSI Bhukosh portal and used to subset satellite image of the study area in QGIS environment (QGIS, 2023) and further used for processing.

2.3 The indices and algorithms: The study incorporate the use of FCD mapping model to calculate FCD. The FCD mapping model contains four biophysical indices - Advance Vegetation Index (AVI), Shadow Index (SI), Bare Soil Index (BI) and Thermal Index (TI). The advantage of using these indices is the reduction of the effect of biases such as effect of atmospheric noise on vegetation (Rikimaru et al., 2002).

Table 1 Biophysical Indices used in the estimation of FCD using Landsat 9 satellite image

Indices/FCD	Algorithm
AVI	$(NIR+1)*(65536-R)*(NIR-R)^{1/3}$
BI	(((SWIR1+R)-(NIR+B))/((SWIR1+R)+(NIR+B))*100)+100
SI	$((65536-B)*(65536-G)*(65536-R))^{1/3}$
[1]TI	$K2/(\ln(K1/L_{\lambda}+1))$
FCD	$(SSI*VD+1)^{1/2}$ - 1

The NIR, R, G, B and SWIR1 represents the pixel values (or digital number) in near infra-red, red, green, blue and short-wavelength infra-red1 bands of Landsat 9 image. K1 and K2 are calibration coefficients of band 10 (TIRS 1). L_{λ} is the spectral radiance value (L_{λ}= Bias + (Gain × Band 10). SSI and VD is scaled shadow index and vegetation density, respectively.

[1]Thermal Index (TI) estimate the surface temperature (in degree Kelvin) in two steps: first, changing pixel value of thermal band (band 10) in to spectral radiance and second, calculating the radian temperature of the ground surface in degree Kelvin.

SSI is calculated by integration of SI and TI values through application of Principal Component Analysis (PCA). The first PC image so obtained is then normalized to produce a SSI image. The value of SSI ranges between 0-100% where 0% and 100% correspond to forest areas having lowest and highest possible shadow value, respectively.

VD is derived through integration of AVI and BI values by applying PCA. The first PC image is then normalized to produce a VD image. The value of VD is scaled between 0-100%. Basically, VD is a proportion of soil surface that covered by the projected crown of trees.

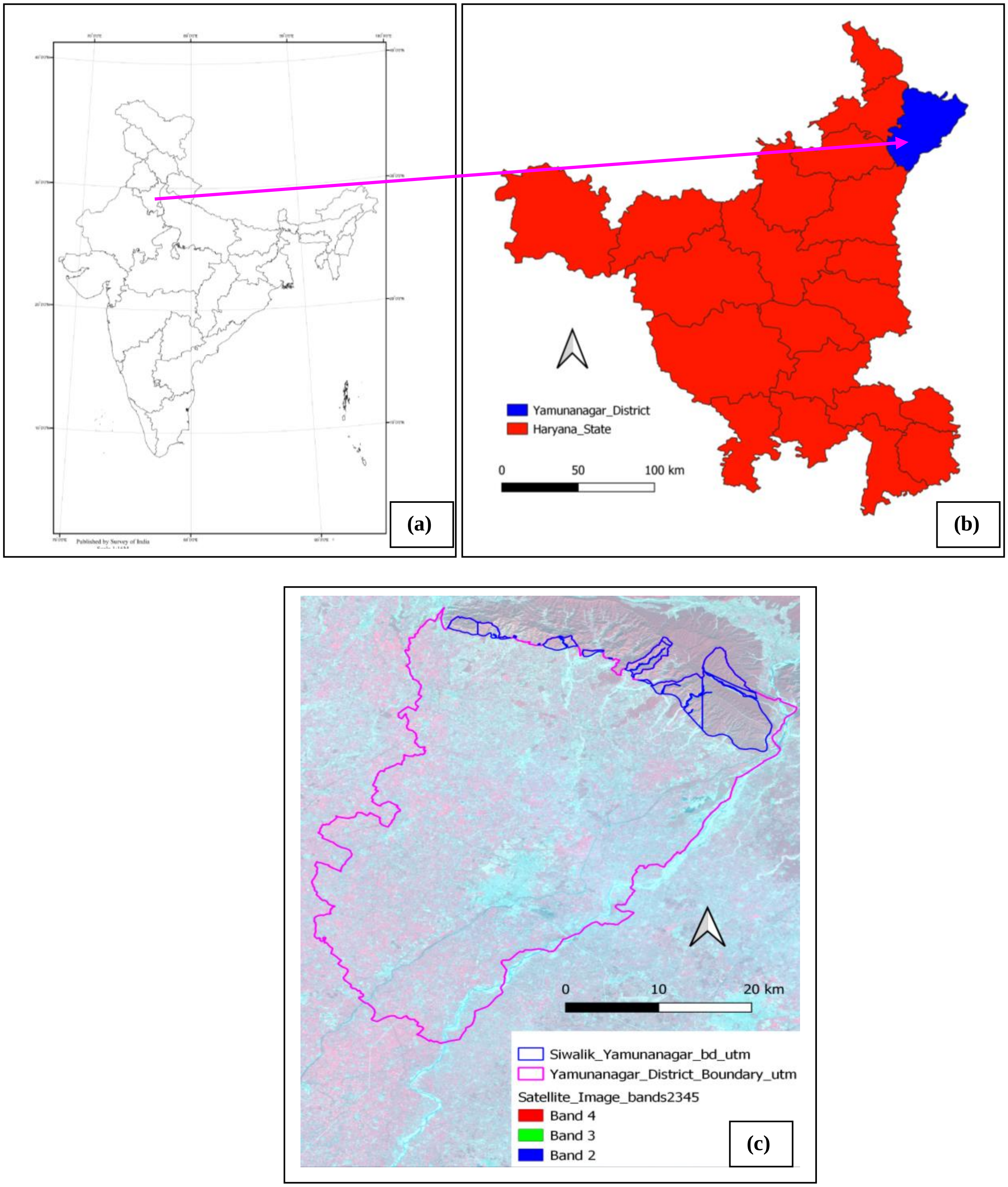

Fig 1: Location map of the study area: (a) †Outline Map of India with State Boundary; (b) Yamunanagar District (in blue color) highlighted on the †Boundary Map Haryana State (in red color); (c) A Satellite View depicting ‡Boundary of Siwaliks (in blue color) of Yamunanagar District (with boundary in magenta color) of northern part of India overlaid on Landsat 9 OLI FCC) satellite image (path/row - 147/39) acquired on 15 December 2022. The band 4 is NIR band, band 3 is red band and band 2 is green band.

†Downloaded and used from Survey of India, Govt. of India (SOI, 2023). ‡Downloaded and used from Geological Survey of India, Govt. of India Bhukosh platform (GSI, 2023).

2.4 Characteristics of FCD indices: The estimation of FCD uses a combination of different indices. The characteristics of the four FCD indices is given in table 2.

Table 2 Combination characteristics between four indices (Rikimaru, 1996)

Indices	Hi-FCD	Low-FCD	Grass Land	Bare Land
AVI	High	Medium	High	Low
BI	Low	Low	Low	High
SI	High	Medium	Low	Low
TI	Low	Medium	Medium	High

TI calculate the temperature variability of spatial objects like for separating a soil and a non-tree shadow. A higher TI leads to higher is ground surface temperature. Similarly, AVI is sensitive to amount of vegetation density in forest (compare to NDVI), therefore lower TI value causes higher AVI. BI is sensitive in separating completely bare soil, sparse canopy and dense canopy, thus higher BI value reveals that the soil is exposed to higher amounts of radiation. In other words, higher is the BI, lower is the AVI which leads to a more dry soil. SI estimate the shadow pattern by crown arrangement in the forest. Thus, a well grown forest distributed at different strata will have a higher SI value compare to the young, even aged forest. In other words, higher AVI is directly proportional to higher SI. We also can conclude that lower value of TI and BI will cause higher value of AVI and SI.

2.5 Methodology to estimate FCD: The flow diagram to calculate FCD is given in figure 2.

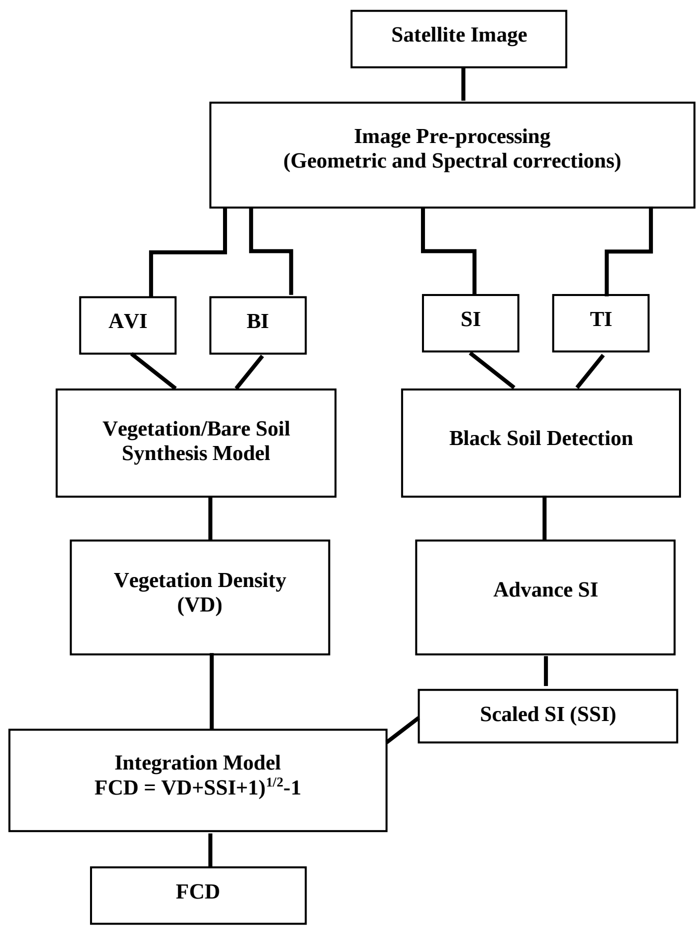

Fig 2: Methodological Framework to estimate FCD.

2.6 FCD classes: The FCD classes used in this study is same as categorised by ISFR (2021).

Table 3 FCD classes

FCD Class	% of Canopy Density
Moderately Dense	10-40%
Dense	40-70%
Very Dense	>70%
*Shrubs	5-10%
*Scrub land	0-5%

*The shrubs and scrub land has not been considered in this study.

3. Results and Discussion

The total geographical area of the Yamunanagar district is 1768 sq. Km and the area under Siwalik region of the district is 112.08 sq. Km which is around 6.33% of the total geographical area. The result from the FDP model under different forest canopy density classes is shown in table 4.

Table 4 FCD area distribution in the Siwaliks of Yamunanagar district, Haryana

FCD Class	% FCD	Area (sq. Km)	% of Total Siwalik Area
Moderately Dense	10-40%	0.39	0.35
Dense	40-70%	96.64	86.22
Very Dense	Above 70%	2.85	2.55
Total		99.88	89.11

FCD model is one of the useful methods for detecting forest canopy density over a large geographical area using remote sensing satellite images (Azizi et al., 2008). The result of FDP mapping reveals the fact that a total of 99.88 sq. Km area in the Siwaliks of Yamunanagar district is covered under forest canopy having different density classes. Thus, the FCD area estimated is around 5.65% of the total geographical area of the district (1768 sq. Km) and is 89.11% of the total Siwalik area of the district (112.08 sq. Km). According to the ISFR (2021) report, the total area covered under different density classes of forests in Yamunanagar district is 192.99 sq. Km. Thus, in reference to ISFR (2021) report, the Siwalik region alone occupies 51.75% canopied forest cover out of the total canopied forest cover present in the Yamunanagar district. The table 4 shows that most of the forest is covered with canopy having 40% to 70% density. This shows that the area has a fair growth of mature tree species.

The field work revealed that the Sal forest is distributed at a higher altitude of the Siwalik region, particularly in the Kalesar forest of the Yamunanagar district. The quantity of vegetation is directly related with the AVI. The study revealed that there are significant variations in SI in the Siwalik area. The patches with mature and/or wide canopied trees such as Sal trees has significantly high AVI and SI values compare to forest patches covered with young and/or short canopied trees. Further, forest areas with high SI values experience a cooling effect which was observed in the Sal forest of Kalesar forest of the study area. On the other hand, open forest areas having a sparse presence of the trees are having high BI and TI values and low AVI and SI values (Rikimaru et al., 1999; Barsi et al., 2014). The ground truthing of the Siwaliks of the study area revealed patches of Papri, Jamun, Jamoya, Kachnaar, Jaal, Kair, Sirus as the dominated evergreen tree species, and Safed Babul, Neem, Dhak, Tendu, Shisham, Khair, Kikar as the major deciduous tree species. Most of the dense forest of Haryana is located on its northern territory in the upper Siwalik range of the Yamunanagar district. The very dense canopied forest is only 2.55% of the total forest cover of the Siwalik region of the district. The field survey reveals that the quantitative decrease in the number of trees, loss of tree species either legally or illegally, replacement of old native tree species, such as Shisham and Khair, with fast growing tree species with short rotational period are some of the valid reasons behind the decrease in the very dense canopied forest cover in the study area. The causes found in the study area is a global issue with its impact on the biodiversity and climate change (Pokhriyal et al., 2020; Hammond et al., 2022). The forest department of Haryana is making a continuing effort towards increasing forest cover in the study area through afforestation and reforestation programs, it was observed in the field that mass wasting in low lying areas of Siwalik and the poor water availability throughout the year, especially in the beginning of the plantation, is a challenge in the fragile region. Further, human encroachment of forest areas for different activities is causing forest fragmentation and degradation (Schmierer et al., 2004). However, a massive plantation drive under Tree outside Forest (ToF) program by the Forest Department and non-governmental organizations (NGOs) can increase tree cover along the edges of the forest boundary.

4. Conclusions

The estimation of FCD is important to monitor the extent and health of forest cover, tracking afforestation and reforestation efforts, identifying and prioritizing critical areas for protection such as biodiversity hotspots. The integrated use of satellite data and semi-expert FCD model has a proven role in forest planning, decision making and sustainable forest management. The work presented is the current status of forest canopy density in the Siwaliks of Yamunanagar district using the FCD model. The quantification of FCD areas in different density classes reveals, both, the status and need of a healthy forest. For example, presence of very dense canopy forest in minor quantity conclude the need of an effective forest management practices such as afforestation and reforestation activities in the study area. This shows the replicability of the model in monitoring and managing other forest ecosystems, especially the vulnerable ones.

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Conflict of interest: The authors declare that they have no conflict of interest.

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