

Forest Canopy Density Monitoring by using Geospatial Techniques: A Study of Gadchiroli District, Maharashtra, India

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Abstract

Forest cover is a crucial part of the environment. It makes an essential contribution to the socio-economic and environmental welfare of the Nation. However, these forests are seriously threatened by deforestation, increased mining activity, population growth, uncontrolled urbanisation, a developing tendency of industrialisation, agricultural land purpose, shifting cultivation, effects on soil, water, and biodiversity, unsustainable forms of human activities and others. As a result, developing strategies to promote sustainable forest management, prevent desertification, prevent soil erosion, and halt environmental degradation is essential. Remote Sensing has enabled humans to observe and obtain information about the earth's surface with spatiotemporal changes. The Indian state of Maharashtra's Gadchiroli district is used as a study region. This study investigates forest canopy density and the spatiotemporal changes in forests. The geographical pattern of forest canopy density is displayed by several indices using data from Landsat 5 and Landsat 8 at 30 m spatial resolution. Try to make the study more relevant in the contemporary world. The research area's forest cover has changed through time, as shown by several multi-temporal data sets (1989 and 2019). The results revealed that between 1989 and 2019, forest canopy cover and forest density decreased. It indicated that over 30 years, 1045.51 sq. km of land had degraded. The amount of highly dense forest has decreased significantly over the research period, whereas the non-forest area has been gradually growing for the past 30 years.



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Introduction


Forests in India and globally are under constant threat due to deforestation, urbanisation, and climate change. Monitoring forest canopy density offers critical information for managing, conserving, and

comprehending how these threats affect forests. Gadchiroli District in Maharashtra, India, is renowned for its dense forest cover and diverse wildlife. But over time, there have been experienced significant land-use land-cover changes over the years.

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Forests are crucial for the environment and economic growth. Roughly one-third of the world's population uses forest resources directly or indirectly for residential, industrial, recreational, and medicinal purposes. In nature, the primitive humans lived in harmony. Nonetheless, the deterioration began with the development of contemporary industrial civilisation. Forest cover also shows a location's viability and reveals the natural health requirements of a site. Researchers must understand how human action affects the Spatio-temporal changes in forest cover area. Although vegetation density and forest canopy cover may establish a balanced situation in an ecosystem or the ecosphere, forests are being harmed on a large scale daily as a result of some illegal anthropogenic activities.¹

The preservation of biodiversity and the management of tropical forests have gained importance in developing nations in recent years. The Earth's Forest cover has been consistently impacted over the past three decades by several climatological and anthropogenic factors, including tropical deforestation, rangeland transformation, improved productivity in farming, high-growing urbanisation, and population expansion.² Although the destruction of tropical forests was considerably less in the first decade of this century, there were still 13 million hectares lost yearly on average. For studying the configuration of the landscape and how it changes over time, geospatial techniques provide a well-established, affordable, and accurate option. Due to its extensive geographical and temporal coverage at frequent intervals, satellite data is instrumental in identifying forest changes. Image interpretation and analysis are now possible on an even greater scale than in earlier times because of recent improvements in the quality and accessibility of satellite imagery.³

Changes in forest cover have an impact on the catchment processes by affecting a variety of hydrological variables, including streamflow, sediment yield, runoff coefficient, and evapotranspiration, as well as biochemical cycles, biodiversity at a global, regional, and local scale; and increasing the likelihood that floods and other catastrophic events will occur. Consequently, inventorying and monitoring the forest cover are essential challenges to managing natural resources within the current environmental change research. Forest canopy changes can occur

randomly or according to established patterns. Although these are essentially natural processes, the possibility of human intervention cannot be excluded. Humans are mainly interested in forest resources for social values, economic security, and cultural and social identity.⁴ To effectively manage forest resources, changes that have taken place have to be carefully studied, from which probable future changes can be deduced. Detecting changes in the environment, in general, is a challenging task since the changes take place at varying temporal and spatial scales, with the two exhibiting interrelationships and interdependence.

In the 1970s, several satellites were commissioned to capture Earth's surface data from space. These vary in resolutions (temporal, spatial, radiometric and geometric) and applications. Newer satellites have always been more advanced than their predecessors, particularly in geometric resolution. RS GIS has been used to store, process and disseminate remotely sensed data for some applications. GIS also integrates statistical and mathematical packages to simulate, interpolate, extrapolate and predict scenarios and is extensively used in vegetation studies, including forest management. Forest management studies can be done from different perspectives, such as change analysis, yield analysis and ecosystem service value, five mapping forest types, forest succession, assessment of stand structure, evaluation of forest damage, estimate of physiological parameters and forest productivity.⁵

The spatial forest health of any region may be determined due to advanced techniques in science and technology, as well as RS and GIS approaches. The 1986 forest policy stipulates that each Indian state shall build an RS-GIS techniques chamber in order to monitor the extent of land degradation.⁶ The vegetative property and phenology are identified Using multitemporal, multispectral, and hyperspectral imagery.⁷ Using information from wide-field sensors, the Normalised Difference Vegetation Index (NDVI) distinguishes between different types of vegetation and measures the quantity and vigour of vegetation.⁸ Several sensors, including TM, ETM, and LISS, have been employed in the global Forest Canopy Density (FCD) investigation as well as in the case of multiple NDVI.⁹ In the recent decade, it has been possible to limit the forest depletion rate through forestland and

scientific management approaches.¹⁰ Anthropogenic factors including habitat loss, human encroachment for buildings and industry, and expansion of agricultural land cause a thick forest to become isolated. These vulnerable forest hotspots can be identified using high-resolution satellite images.¹¹

The forests have been degraded in recent years due to the industrial and agricultural revolutions. Correct experimental land cover development is critical for forest resource conservation. Changes in density should be considered for improved reforestation. Forest canopy density is most significant considerations when designing and implementing restoration programs. The forest's density and canopy may change, but the area remains.¹² The spatiotemporal shifting prototype FCD model has been observed in various developing nations today.¹³ Rikimaru was initially used to study forest health and deforestation

using TM data; however, it is now widely utilised. It is also commonly used in tropical forest regions to detect forestland depletion and reforestation amounts within the core forest and buffer areas.¹³

In 2002, the CLEAR created a GIS-based forest fragmentation analysis technique and updated in 2009 and it has the potential to play a significant role in forest resources management and the long-term maintenance of forest ecosystems.^{14,15,16} Researchers are attempting to measure the forest cover condition and forest canopy in the study region, as well as develop a relationship between topographic characteristics and forest cover status.¹⁷ This study aims to examine the changes in forest canopy density over 30 years, specifically from 1989 to 2019, in the Gadchiroli District of Maharashtra. The research work utilized the use of both remote sensing indices and geospatial approaches.

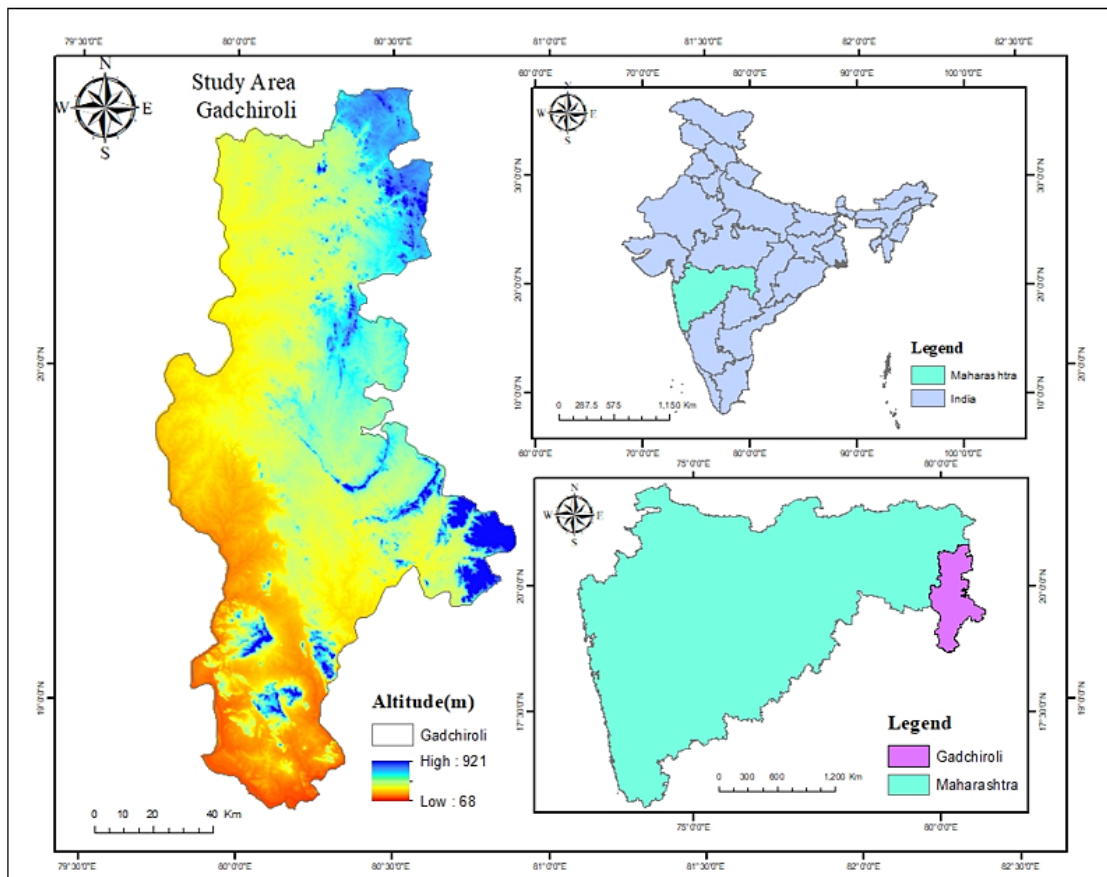


Fig. 1: Location of Study Area: Gadchiroli District

Study Area

The Gadchiroli district is between latitudes 18.44 and 21.51 North and 79.46 and 80.53 East longitude. It is located on Maharashtra's northeastern border, and shares state boundaries with Telangana and Chhattisgarh. It has a boundary with the districts of Bhandara and Gondia in the north, Chandrapur in the west, Rajnandgaon and Bastar in Chhattisgarh to the east and Karimnagar, Bhopalpalli, and Adilabad in Telangana to the south. Gadchiroli is situated at around 667 meters AMSL. The rivers in the Gadchiroli district are Godavari, Pranhita, Wainganga, Gadhavi, Khobragadhi, Sati, Kathani, and Pohar, supplies a sufficient quantity of river sand and water. The district's total area is 14,412 sq. km. covering 4.68% of Maharashtra State's total area, as given in Figure 1.

Materials and Method

The Gadchiroli district of Maharashtra is selected for the forest canopy density monitoring. The satellite imagery is obtained from Landsat 5 imagery of January 1989 and Landsat 8 Operational Land Imager (OLI) scenes in February 2019 from USGS Earth Explorer with 30-meter spatial resolution of satellite images. These were regarded as the best times because the scenes were cloud-free. The ERDAS IMAGINE 2014 has been used for Image analysis and recording, and for creating the maps of indices, Arc GIS 10.3 has been used. The flowchart in Figure 2 illustrates how the equations were used to calculate the NDVI, AVI, BSI, SI, TI, and FCD indices.

Normalised Differential Vegetation Index

The NDVI is prominent and frequently used vegetation indexes for measuring global and regional vegetation cover changes.¹⁸ According to Richardson and Everitt (1992),¹⁹ By dividing the variance between the red and near-infrared by the sum of the two bands, the NDVI is calculated (Equation 1). The classification of high and low vegetation areas is frequently done using NDVI. It is not appropriate to draw attention to minute variations in canopy density.

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \quad \dots(1)$$

Advanced vegetation index (AVI)

on the Basis of red and NIR spectral band, one of the key factors to identify healthy vegetation is AVI

and it is similar to NDVI. This investigation selected AVI using the infrared response's power intensity. Equation (2) is used to calculate this index.

$$\text{AVI} = [(\text{NIR}) * (1 - \text{Red}) * (\text{NIR} - \text{Red})]^{1/3} \quad \dots(2)$$

Bare Soil Index (BI)

BI is used to classify agricultural and non-agricultural vegetation for a specific area. It is computed using the shortwave infrared band, which increases the land's bare soil property, and the red and NIR bands, which add the vegetation property to the index.²⁰ According to BI, vegetation and forest cover are valued less highly than bare land. We can evaluate the exposed soil conditions by integrating the bare soil state and vegetation properties. Equation 3 is used to calculate it mathematically.

$$\text{SI} = (\text{SWIR2} + \text{R}) - (\text{NIR} + \text{B}) / (\text{SWIR2} + \text{R}) + (\text{NIR} + \text{B}) \quad \dots(3)$$

Shadow Index (SI)

To determine the three-dimensional structures of the forest, Using the low radiance of visible bands, SI is calculated. Depending on how the forest's trees are arranged, younger plants emit less light than adult trees.²¹ Because it is dependent on the arrangement of trees and canopy cover, SI gives the forest canopy a higher value and areas of bare soil and grasslands a lower value. Equation 4 is used to define the shadow index using the visible bands.

$$\text{SI} = ((256 - \text{Blue Band}) \times (256 - \text{Green Band}) \times (256 - \text{Red Band}))^{1/3} \quad \dots(4)$$

The Thermal Index

Landsat 8 OLI images were used to generate the thermal index using the spectral radiance technique.

Forest Canopy Density

By allocating weights to the calculated biophysical factors—AVI, BI, and SI for the FCD calculation examined the conditions of the forest cover and track changes that occur in the forest during forestry activities, which may involve degradation or rehabilitation. FCD is one of the key parameters for these analyses. Equation 5 is used to compute FCD for the study region.

$$\text{FCD} = (\text{VD} * \text{SSI} + 1)^{1/2} - 1 \quad \dots(5)$$

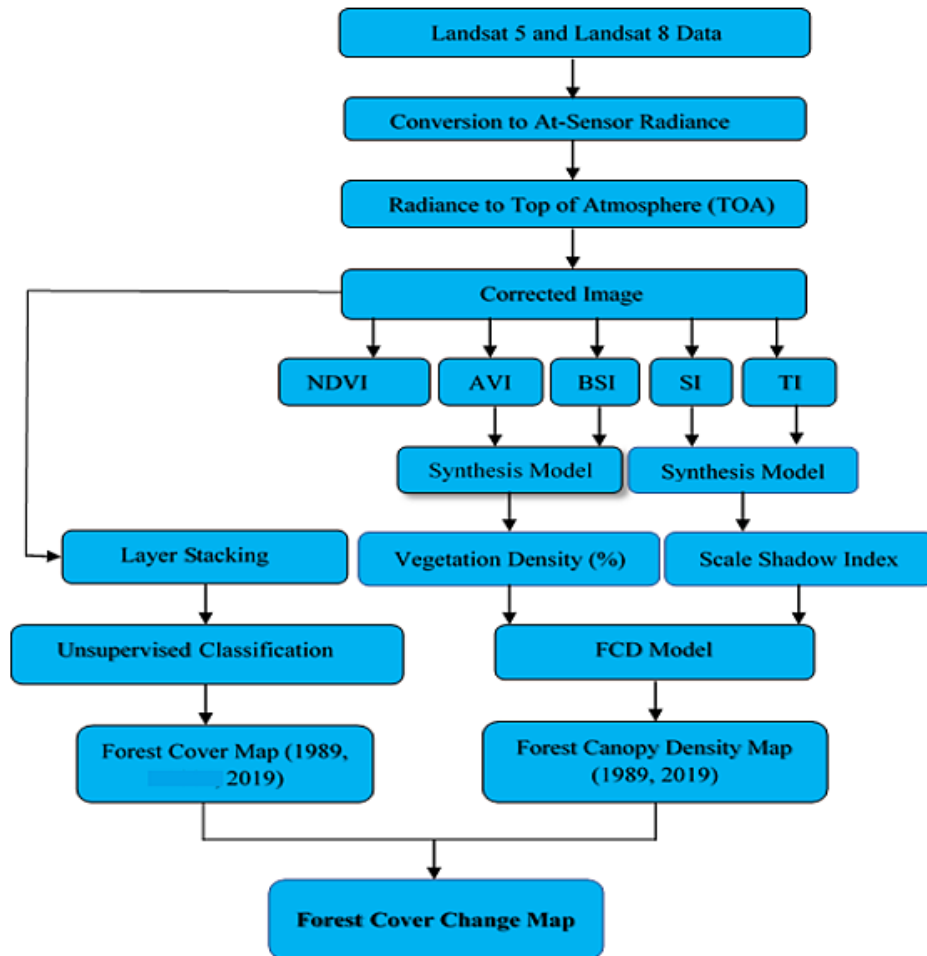


Fig. 2: Methodology

Results and Discussion

Normalized Difference Vegetation Index

The NDVI indicates health of the vegetation. It has been shown that the NDVI value in Maharashtra's Gadchiroli district ranges from -0.9 to 0.8. The NDVI range has been further divided into five categories. There is a threshold value for each class. The NDVI value for the highly dense forest class is between 0.413 and higher. Inside the dense forest, high-NDVI values were observed and dominated, as shown in Figure 3. These dense forest enclaves have been discovered in the hilly regions of Gadchiroli District's Bhamragad, Etapalli, Dhanora, and Korchi tehsils (the eastern border of Maharashtra). The study area's moderate NDVI value is concentrated in the upper and middle sections. Values below 0.165 NDVI are mostly confined to Gadchiroli's less vegetated parts while dominating areas exhibit barren land and

water bodies. According to Google Earth, scrubs and agricultural land are typically found in the medium and low NDVI values.

Advanced Vegetation Index (AVI)

Green vegetation (healthy vegetation) is characterised by absorption and wavelength reflection in the RS spectral response. Due to pigment absorption, the visible portions have low reflectance, whereas the IR zone has high reflectance governed by the leaf's cell structure. Healthy vegetation absorbs the red band of wavelength and reflects it more in the infrared band. We investigate healthy vegetation using this advantage and the scientific ratio index (NDVI) technique. The enhanced Vegetation Index is another prominent vegetation index (AVI shown in Figure 4.

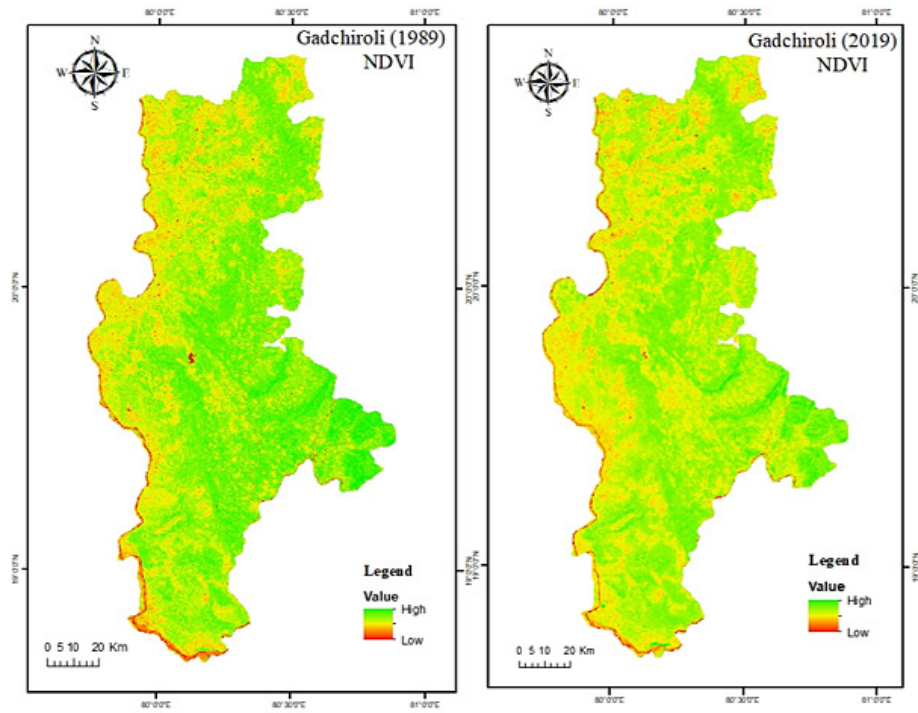


Fig. 3: NDVI Map (1989 and 2019)

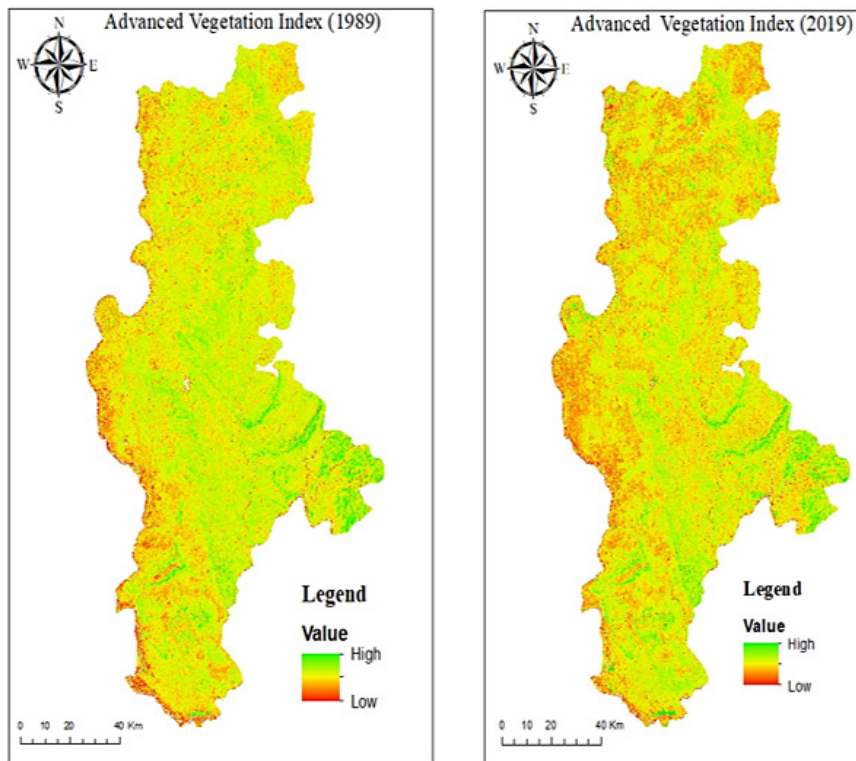


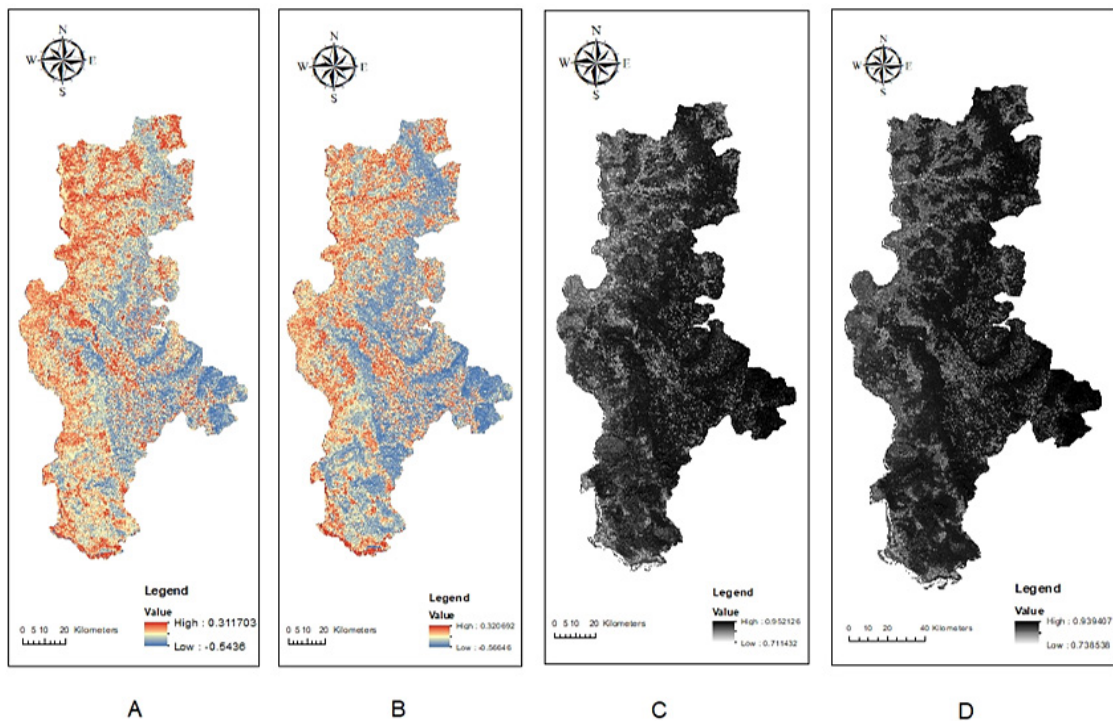
Fig. 4: Advanced Vegetation Index (AVI) Map (1989 and 2019)

The AVI value for a specific pixel span from -1 to +1; nevertheless, no green leaves have a value close to zero. Negative values primarily represent water and other non-vegetated surfaces, while zero signifies no vegetation. Values close to plus 1 (0.8 to 0.9) show the highest potential density of green leaves, whereas negative values primarily represent water and other non-vegetated surfaces.

Bareness Index (BSI)

A spectral reflectance index is abbreviated as BI. Soil bareness ratings range from -0.54 to 0.31. Each

of the five classes in the district has a unique threshold value that separates it from the others. The river channel and exposed land in Maharashtra's Gadchiroli District show a high bareness value (-0.13 to +0.31) in the district's centre and western areas. Low to shallow BI values (0.54 to 0.19) are found in agricultural land and forest regions, concentrated on the district's eastern side and covered by tropical deciduous forests. The remaining areas are classified as middle BI value groups, as shown in Figure 5.



**Fig. 5: A. Bareness Index of Gadchiroli 1989; B. Bareness Index of Gadchiroli 2019
 C. Shadow Index of Gadchiroli 1989; D. Shadow Index of Gadchiroli 2019**

Shadow Index (SI)

Compared to young forest regions, mature forests have a greater SI value. There is a threshold value for each class. Due to the dominance of tropical deciduous forests, high and extremely high SI values are confined to the eastern half of the district (Maharashtra – Chhattisgarh border region hills). Due to their low and meagre SI values, river networks, aquatic bodies, and exposed land areas have all been prohibited. The remainder falls into the medium SI value category shown in Figure 5.

Thermal Index (TI)

The Thermal Index (TI) is calculated using two variables influencing the forest's chilly relative condition. The forest canopy's initial shielding impact is its absorption and block of solar radiation and the leaf's surface area, which minimises heating.¹⁶ Data on temperature was then utilised to distinguish between soil and a non-tree shadow, as shown in Figure 6.

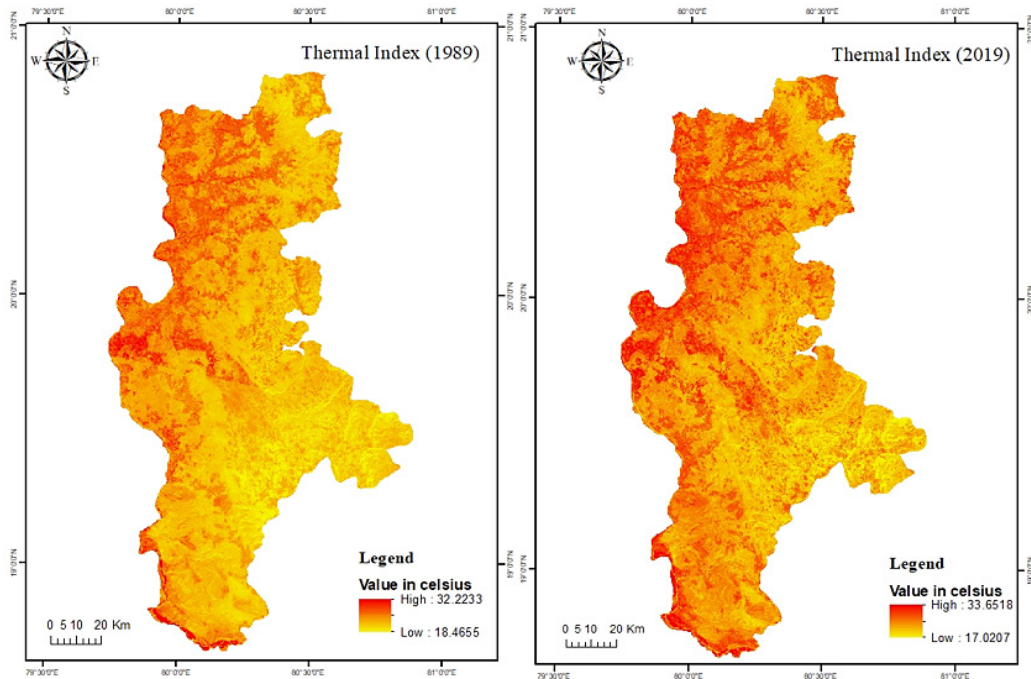


Fig. 6: Thermal Index of Study Area

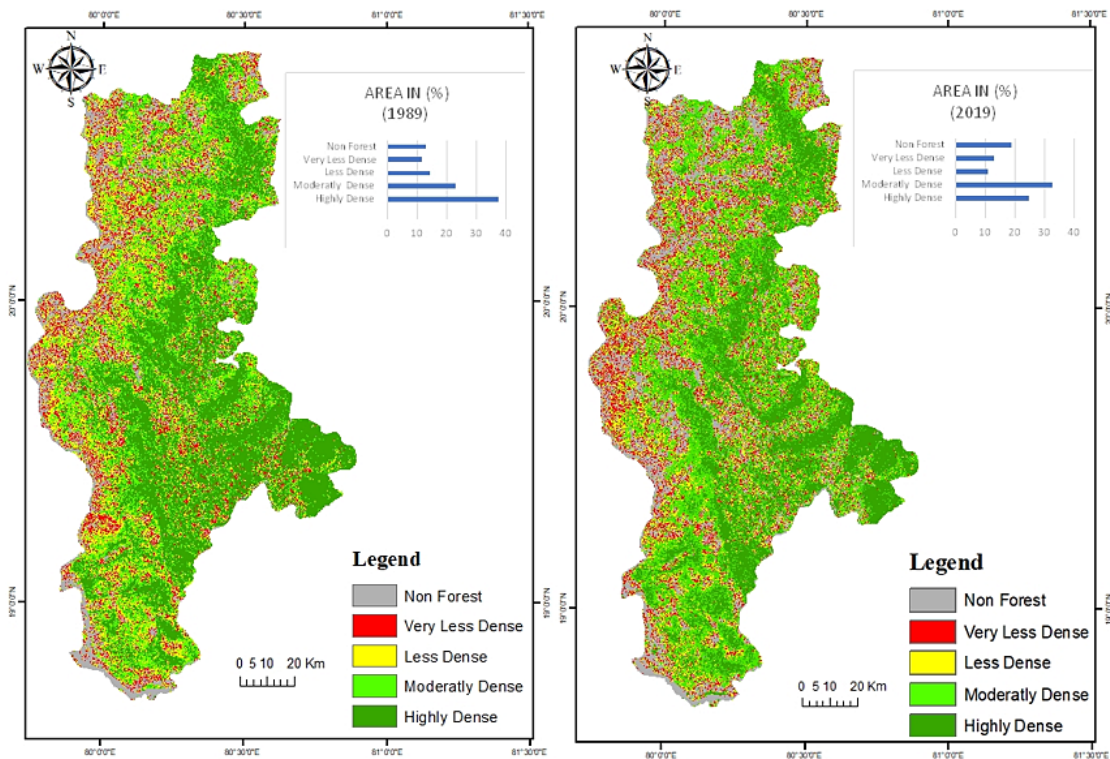


Fig. 7: Forest cover density map of Gadchiroli district of Maharashtra using FCD model

Forest Canopy Density Model

The FCD Model of Maharashtra's Gadchiroli District was created by combining five indicators, including the NDVI, AVI, BI, and SI and the Thermal Index. FCD is one of the metrics used to assess the quality of the forest. They are combining VD and SSI results in a change in the value of the forest canopy density. VD and SSI determine FCD on a scale from '0' to 100, as shown in Figure 7.

The five classes were evaluated using FCD values ranging from zero to one hundred percent. Due to optimum climatic in the study area, the district's eastern hilly ranges and lower eastern main side have considerable forest cover. The western half of the Gadchiroli District comprises an undulating plateau with a dispersed open forest and a medium to low canopy density. The Gadchiroli District's regions are non-forest scrub, open forest, medium canopy density, and high canopy density forests, with respective percentages of 19.7%, 12.9%, 10.8%, 32.6%, and 24.57%. Tropical deciduous forest, which includes Sal, Palash, bamboo, and teak trees, usually surrounds high canopy density places. Agricultural fields and bare landscapes have moderate to low FCD values. The FCD approach for assessing the amount of forest canopy and the health of the forest is very appropriate and scientific.

Kappa Coefficient = 0.80, Overall Accuracy = 89.3 %

Most of the forest in the research region had a canopy closure of 100% > 70%. The 100 % > 70 % density class, during both the study period and the comprehensive evaluation of forest canopy density, has decreased noticeable changes in forest canopy density A, which fell from 37 percent in 1989 to 26.50 percent in 2019.

The study further indicates that the 40 % to 70% density area has increased from 23.2% in 1989 to 30.6 % in 2019, registering 7.04 %. However, the forest canopy density in the 40% to 10% density class decreased from 14.23% in 1989 to 10.8% in 2019.

Classification

The unsupervised classification results show that the classification was accurate. The Overall type for all the images was above the minimum acceptable threshold of 85 % and 93.00 % for 1989 and 2019. For 1989 and 2019, the Kappa coefficients were

0.80 and 0.90, respectively. These show a good agreement between original imagery and classified images. Although these are acceptable values, they could have been improved by collecting field reference data.

Evaluation of Forest Cover Change from 1989 to 2019

From the worldwide perspective, societal advancement affects the environment, and forest regions and forests are collapsing because of the implementation of some infrastructural developmental as building and complex construction, railway construction, highway construction, and cropland increase.^{17,18} Rapid population expansion and rising anthropogenic activities, particularly in tropical and developing nations, are posing a threat to a forest region by significantly altering land use.¹⁹ Gadchiroli district had roughly 10,887.66 sq. km of forest cover in 1989, accounting for 74 percent of the total area. In 2019, the forest-covered size was estimated to be around 9847.15 sq. km or 68 percent of the entire district area. During the 30 years (1989–2019), the 1040.51 sq. km (7.1%) has been degraded. There was a negative trend and an unfavourable signal for the physical environment, particularly biodiversity. During the study years of 1989 and 2019, the forest was divided into four categories: highly dense, moderately dense, less dense and very less dense.

In 1989, it was discovered that highly dense, moderately dense forests, and open forests covered 5462.90 sq km, 3368.12 sq km, and 2056.22 sq km of area, respectively. The high percentages of core forest areas suggest that natural resources are not under anthropogenic stress. It was revealed that in 2019, there were regions of highly dense, moderately dense and open forest covering 3846.63 sq. km, 4432.21 sq. km, and 1568.31 sq. km, respectively forest (refer table: 1). It has been noticed that the highly dense forest area has reduced over time due to continual human encroachment on the forest of time during the study period (1989–2019). The area of reasonably dense woodland has grown by 1063.86 sq. km. The non-forest area has steadily increased by 876.29 sq km due to severe anthropogenic interference with the forest; the forest has been cleared for agriculture, which has grown the settlement area shown in Figure 8.

Table 1: Forest cover density for the years 1989 and 2019

No.	Forest Cover Type	1989 (Area in %)	2019 (Area in %)	Change in %
1	Highly dense forest	37.7	26.5	-11.2
2	Moderately dense forest	23.2	30.6	+7.4
3	Open forest	14.23	10.8	-3.43
4	Scrub	11.77	12.9	-1.13
5	Non - Vegetation	13	19	+6

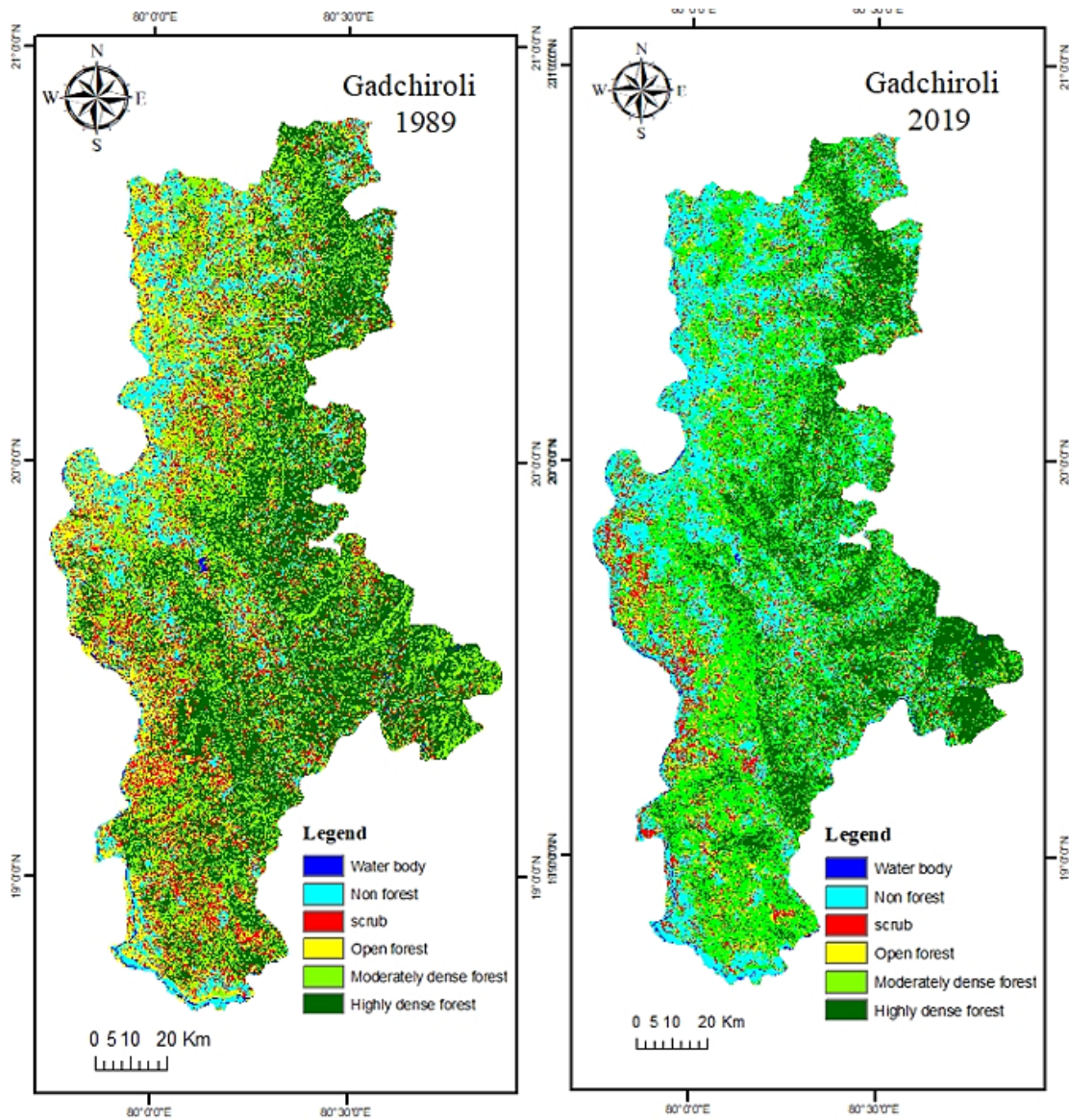


Fig. 8: Forest Cover Change Map for The Years 1989 and 2019

The decline in canopy density indicates the necessity for increased conservation measures to protect the region's remaining forests. Local authorities and policymakers should consider these findings when deciding whether to use land, especially in areas where the canopy density has changed significantly. For climate change mitigation methods to be effective, it is essential to comprehend how variations in canopy density affect carbon sequestration. The study's identification of regions with lower canopy densities, which would need particular conservation measures, can assist direct efforts to protect biodiversity.

Conclusion

Understanding changes in forest ecosystems over time requires continuous monitoring of forest canopy density using a combination of geospatial methods and vegetation indicators. Using the NDVI, AVI, BSI, SI, TI, and FCD indices, a study was carried out in the Gadchiroli District of Maharashtra, India, and offers insightful information on the condition of the area's forests between 1989 and 2019. In response to changing canopy density, the findings illustrate the significance of conservation, land-use planning, climate action, and biodiversity preservation. More investigation and continuous monitoring are required to ensure these essential ecosystems' long-term survival and health.

FCD showed that healthy forests have suffered significant degradation, with a higher class of forest canopy density losing more than 70% between 1989 and 2019. A few centres and a few pockets in the Gadchiroli district's northwestern portion reveal largely non-forest areas with low FCD values. The eastern part of the district, which encompasses the entire Forest region, has exceptionally high FCD values. The forest covers the district's eastern portion, including the talukas of Sironcha, Etappali, Aheri, and Dhanora. In the eastern part of the district, hills may be found in Bhamaragad, Tipagad, Palasgad, and Surjagad. Similarly, somewhat dense forest

rangers can be found in the district's upper reaches, such as the Armori, Wadasa, Kurkheda, and Korchi forest ranges. In the research period (1989–2019), it was found that the area of highly dense forest decreased; nevertheless, the moderately dense forest area expanded by 1063.86 sq. km, while the non-forest area increased by 876.29 sq. km.

The total forest cover area was 74 percent in 1989 but only 6 percent in 2009 and 2019 compared to 1989. Forest fires, increased mining activities, agricultural land use, and urban growth may contribute to deforestation and forest fragmentation in the district's centre and northern pockets. People's predisposition towards growing various crops has increased in recent years, as farming, along with animal husbandry, has become the main employment of the people in the Gadchiroli area, resulting in a significant rate of deforestation. Over time, the situation of intact forest cover might change in tropical and subtropical forest zones due to significant anthropogenic stress. As previously said, further research and development is needed to improve the accuracy of these models. When making decisions about balanced regional growth, sustainable development and forest ecological sustainability, policymakers and administrators should take these research findings into account.

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Conflict of interest

The authors declare that there is no conflict of interest.

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