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Monitoring Tropical Forest Dynamics in Northeastern Himalayas and Its Health Using Multi-Temporal Satellite Data †

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Abstract: Tropical protected and reserved forests are the most active and diversified ecosystem that plays a significant role in maintaining the ecological balance. These forests are experiencing the problem of extensive forest deforestation due to illegal encroachment by the surrounding communities. Assessing forest cover dynamics and its health assessment plays a significant contribution to the management of the forest biodiversity and ecosystem. The present study aims to assess the forest dynamics using satellite data of 1990 (Landsat-5) and 2022 (Landsat-8). The study has been conducted in Behali Reserve Forest (BRF) located in the northeastern Himalayas. Furthermore, we assessed its health conditions based on biochemical parameters derived from the Sentinel-2A satellite. The key findings indicate that between 1990 and 2022, there were considerable forest cover losses of about 23% (i.e., from 93.2 km^2 to 71.9 km^2). In the last three decades, forest dynamics showed that about 25.2 km^2 (17.3%) of forest areas have undergone deforestation while only 3.7 km^2 (2.5%) areas are considered under afforestation. Furthermore, forest health assessment was performed using leaf chlorophyll which serves as a key indicator of photosynthetic pigment. The Normalized Area Over Reflectance Curve (NAOC)-based method was applied to estimate leaf chlorophyll content of dense forests. The key findings indicate that leaf chlorophyll ranged between 30 and 45 μg/cm^2 and the healthy dense forests showed chlorophyll > 30 μg/cm^2. We can conclude that this study helps to exemplify the potential of remote sensing techniques to evaluate the dynamics of tropical forests and their biochemical properties. It provides critical information about forest dynamics and its health conditions, which are useful for forest conservation and management.

Keywords: Land cover; leaf chlorophyll; Sentinel-2A; NAOC; forest conservation

1. Introduction

The implication of changes in land use and land cover (LULC) are linked to forest fragmentation and degradation processes, which lead to biodiversity loss in natural ecosystems. These changes are frequently induced by activities such as land conversion to agriculture, overgrazing, urbanisation, and forest fires, among others, with major consequences for global environmental change and biogeochemical processes. Between 1951 and 1980, more than 26,200 km^2 of forest lands were converted to agriculture, primarily in India (Forest Survey of India). According to Carmona and Nahuelhual (2012), forest degradation is indicated by a shift in the forest cover to non-forest regions, namely built-up, agriculture, and wasteland. Consequently, the gradual loss of forest productivity and habitats led to forest degradation which causes ecosystem, biodiversity, and soil degradation, all of which are linked to the high rate of population increase, industrialization, and infrastructural development (Shah et al. 2015). Due to population increase and land conversion, the average rate of forest loss between 1990 and 2000 was 380.89 km^2 per year. Several studies used remote sensing satellite data to better understand the consequences of LULC changes on forest ecosystems, biodiversity, and habitats over the long term (Olorunfemi et al. 2020). As a result, remote sensing plays an important role in mapping, monitoring, and assessing forest cover patterns across the world (Kaliraj et al. 2012). Numerous approaches are used to monitor forest dynamics. Forest change detection approaches such as image ratio, image regression, and indices-based change detection, image classification, among others, are commonly employed (Mishra et al. 2020). Therefore, remote sensing-based long-term satellite data was used to investigate patterns of forest change that have been altered by anthropogenic or natural processes.

Earth observation satellite remote sensing data substantially aided in the retrieval of biochemical characteristics such as leaf chlorophyll content and leaf nitrogen. These indicators are essential for determining forest health and forest growth in forest ecosystems. Especially, MERIS Terrestrial Chlorophyll Index (MTCI) and NAOC-based estimates of leaf chlorophyll content were widely used for forest health assessment (Ranjan and Parida 2020; Ogutu and Dash 2013). Plant production, stress, and nutrient availability were mostly analysed using visible red-edge spectral bands (Delegido et al. 2011). Thus, biochemical features from satellite data may be incorporated into terrestrial ecosystem models to monitor forest health, biomass production efficiency, and ecosystem interactions. The forest dynamics of Behali Reserve Forest (BRF) located in the northeastern Himalayas are understudied where anthropogenic interference is still a dominant factor. Therefore, assessment of anthropogenic impacts on forest health is essential in this reserve forest. This study aims to (i) assess the forest dynamics in BRF using multi-temporal satellite data between 1990 (Landsat-5) and 2022 (Landsat-8) and (ii) analyse forest health conditions using NAOC-based chlorophyll estimates which are determined from red-edge spectral bands from Sentinel-2A.

2. Study Area

The study area is the Behali Reserve Forest which is situated between 26º 52' and 26º 57' N and 93º 15' and 93º 53' E. The total geographical area of BRF is 145.61 km^2. BRF is largely covered with tropical wet evergreen and semi-evergreen forest and is located in the Assam district of Biswanath. BRF has a typical tropical monsoon rainforest environment with abundant rainfall and high humidity, as well as warm summers and moderate winters. The average annual temperature in BRF is 23.4 ºC, while the average annual precipitation is around 2544 mm.

3. Material and Methods

Landsat-5 TM and Landsat-8 surface reflectance images were obtained from the USGS Earth Explorer (https://earthexplorer.usgs.gov/) for the years 1990 and 2022 and have been utilised in forest cover change mapping. The spectral bands employed for this forest cover change mapping were blue, green, red, and NIR of Landsat-5 TM and Landsat-8 which has a spatial resolution of 30 m. The supervised classification (maximum likelihood algorithm) was applied to derive forest maps of 1990 and 2022. Accuracy was assessed by utilizing 100 random points on a forest cover map of Google Earth Pro for the years 1990 and 2022. The randomly generated points served as ground validations, which were then compared to the classified map. The overall accuracy and kappa coefficient were used to check the accuracy of the classified maps.

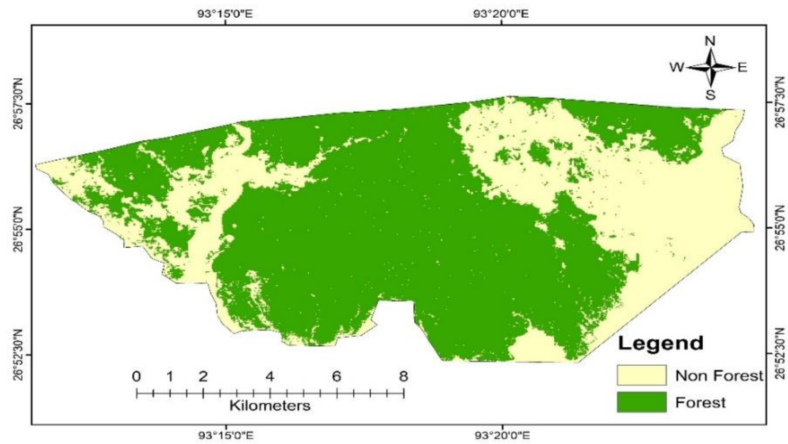
For the assessment of forest health, Sentinel-2A satellite data is utilised to estimate leaf chlorophyll content with spatial resolutions ranging from 10 m. The red-edge bands were used to retrieve leaf chlorophyll content. Delegido et al. (2010) established the NAOC indicator, which has been utilized for monitoring forest health (Parida and Kumari 2021). The NAOC is calculated using red-edge bands from Sentinel-2A, such as 664.5 nm ($\rho_{664.5}$) and 782.5 nm ($\rho_{782.5}$). The NAOC is further applied to estimate the chlorophyll content of the leaves. Using equation 1 (Carmona et al. 2015) and equation 2 (Delegido et al. 2010), we derived NAOC and chlorophyll for the year 2022 over the forests in BRF.

$$NAOC = \frac{1}{2}\left(1 - \frac{\rho_{664.5}}{\rho_{782.5}}\right) \quad (1)$$

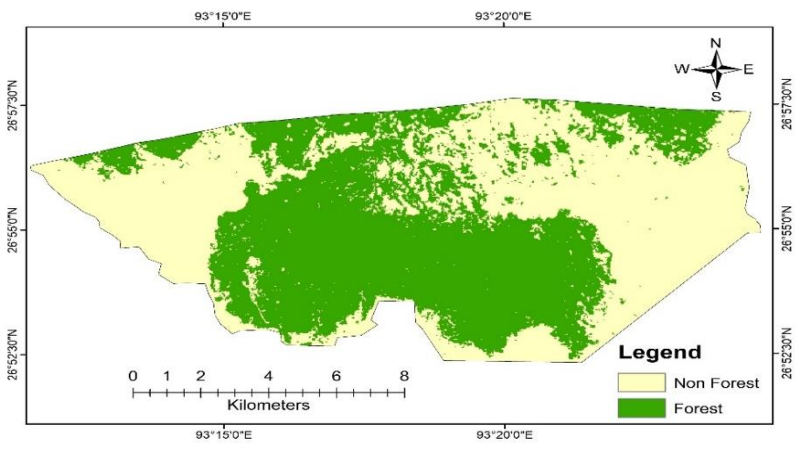
$$\text{Chlorophyll} = -3.8868 + 101.94 \times NAOC \quad (2)$$

3. Results and Discussion

Based on the supervised classification of satellite images, forest maps are shown in Figure 1. In 1990, the forest and non-forest areas accounted for 93.24 km^2 (64%) and 52.37 km^2 (36%), respectively. In 2022, their area changes to 71.9 km^2 (forest) and 73.71 km^2 (non-forest) due to land conversion. Over the span of three decades, about 21.34 km^2 of forest area was converted to non-forest which accounted for the net forest cover loss of 23%. This percent of loss indicates significant changes that can be attributed to anthropogenic impacts and population growth in the surroundings of BRF in Assam. According to Singh et al. (2017), Assam state has lost approximately 2930 km^2 of its total forest area between 1975 and 2015 owing to widespread deforestation and unlawful encroachment. In the context of classified map accuracy, we found that the overall accuracy and kappa coefficient were 96% and 0.93, respectively. In the year 2022, accuracies were 95% and 0.92, respectively.



(a) 1990



(b) 2022

Figure 1. Forest cover maps of BRF in (**a**) 1990 and (**b**) 2022 as derived from supervised classification using Landsat-5 and Landsat-8 satellite data, respectively.

Based on NAOC, the leaf chlorophyll ranged from 25 to 45 μg/cm^2 (Figure 2). The chlorophyll concentration exceeds 30 μg/cm^2 when the forest canopy is dense. Whereas in the spare forests regions, the chlorophyll concentration ranged from 22.5 to 30 μg/cm². The chlorophyll map showed that satellite data played a key role in determining the spatial pattern of chemical properties of vegetation. The decline in forest health is attributed to land use conversion and human encroachment in BRF which causes losses of forest cover. The range of estimates found over the BRF is comparable to other studies which demonstrated a range between 15 to 70 μg/cm² in the Sholayar forest in Kerela located in India (Ahmad et al. 2020).

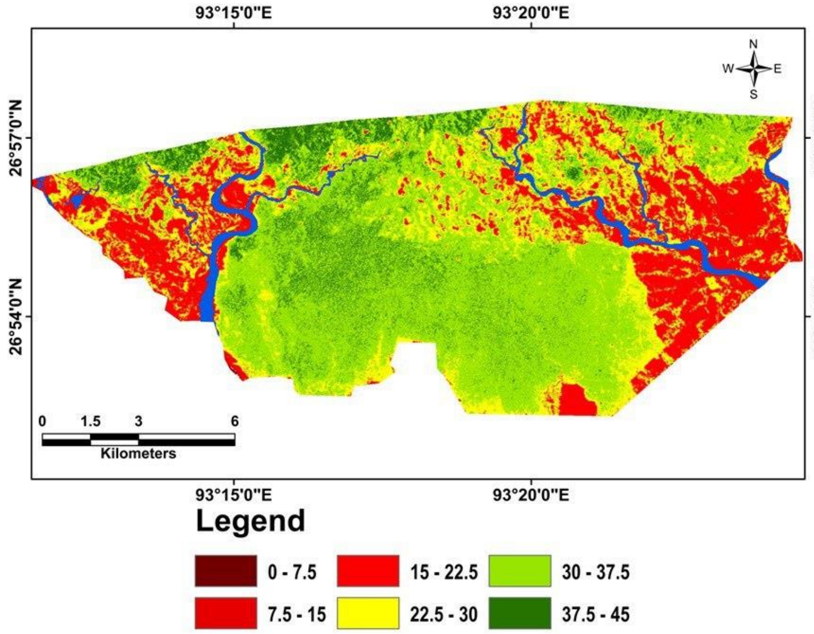


Figure 2. Chlorophyll map of BRF as derived from NAOC using Sentinel-2A.

4. Conclusions

Remote sensing techniques are extensively used for the assessment and monitoring of forest dynamics using various satellite sensors. The present study has provided a framework for mapping and monitoring forest cover change in BRF using satellite data. In this study, efforts were contrived to assess forest cover changes of BRF. The key findings showed that there is a massive decrease in forest areas in the BRF along with the decline in forest health associated with land use conversion and use of forest services. Overall, 21.34 km² (23%) of forest area shifted to non-forest areas over the three decades due to deforestation, illegal encroachment, and various plantation and agricultural activities. As a result, the District Forest Department and the State Forest Department must control and oversee the activities surrounding the BRF. The future scope of this work is to utilize time-series analysis at five-year intervals to improve the effectiveness of detecting changes in the forest. The current research created a model framework for mapping and monitoring forest biochemical characteristics. According to the findings of this study, the NAOC is a trustworthy approach for assessing leaf chlorophyll concentration. The findings of this study are essential for forest health assessment, conservation, planning, and management.

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