Data-Driven Mapping of Forest Cover Changes in Chhattisgarh, India (2000–2024) Using Google Earth Engine

Abhimanyu Kumar Gond[1*], Aarif Jamal[1], Tarun Verma[1]

[1]*Department of Mining Engineering, IIT (BHU), Varanasi-221005, India*
[*1]*Corresponding Author: abhimanyukrgond.rs.min21@itbhu.ac.in*

Abstract: *Forests are critical for biodiversity, carbon sequestration, and livelihoods, yet deforestation poses a significant threat in biodiverse regions like Chhattisgarh, India, necessitating robust monitoring to inform sustainable management. This study aims to quantify and map forest cover dynamics in Chhattisgarh (135,154.63 km²) from 2000 to 2024 to support data-driven conservation strategies, addressing the need for precise, high-resolution forest change analysis. Using Google Earth Engine (GEE), a cloud-based platform for geospatial analysis, we processed the Hansen Global Forest Change dataset through raster and vector conversions to calculate forest cover in 2000 (tree canopy cover greater than 30 percent), forest cover in 2024, total loss (2000 to 2024), total gain (2000 to 2012), and annual loss trends, visualized via spatiotemporal maps and time-series charts. The forest cover declined from 25,965.28 km² in 2000 to 25,417.67 km² in 2012, reflecting a net loss of 547.61 km². Total forest loss reached 810.47 km² by 2024, with a modest gain of 4.78 km² in the southern region (2000 to 2012). Annual loss peaked at 90 km² in 2011, dipped to 18 km² in 2003 and 2020, and rose to 60 km² by 2023 to 2024. Spatial analysis revealed denser forests in southern and northern regions compared to central areas. These findings highlight significant deforestation pressures, offering insights for targeted conservation policies and afforestation initiatives to identify deforestation hotspots and temporal trends, supporting sustainable forest management, informing regional biodiversity conservation and climate mitigation strategies.*

Keywords: *Forest cover, deforestation, sustainable management, Chhattisgarh, Google Earth Engine,*

1. Introduction

Central India's unique climate, soil, and topography support a rich mosaic of dry deciduous forests, which, while not exceptionally diverse in species or endemics, are vital for sustaining large human populations and diverse wildlife (Myres, 1992). These forests face growing threats from

overexploitation and fragmentation, driven by human activities that disrupt their ecological balance. Chhattisgarh, a forested state in central India, embodies these challenges, with its tribal communities historically reliant on forests for food, medicine, shelter, and grazing (Kala, 2009). However, modern pressures, such as mining, infrastructure expansion, and illegal logging, have intensified forest degradation, compounded by socio-economic shifts and weak conservation enforcement outside protected areas (Majila & Kala, 2010). The creation of protected areas, while aimed at preserving biodiversity, has shifted pressures onto unprotected forests, further strained by ongoing human settlements and civil insurgency (Dwivedi et al., 2009). Prior studies highlight significant forest loss in Chhattisgarh due to mining and development. Yet, research gaps remain in understanding the spatial and temporal dynamics of forest cover changes post-2000, particularly with advanced geospatial tools, and the effectiveness of afforestation initiatives like the National Afforestation Programme in countering these losses.

The research question has forest cover, loss, and gain in Chhattisgarh from 2000 to 2024, and what are the key drivers and spatial patterns of these changes? By leveraging the Hansen Global Forest Change dataset within the Google Earth Engine platform, this research aims to fill the gap in recent, high-resolution analyses of Chhattisgarh's forest dynamics, offering insights into the balance between deforestation pressures and conservation efforts.

This study aims to quantify forest cover, loss, and gain in Chhattisgarh from 2000 to 2024 using the Hansen Global Forest Change dataset, examine temporal trends in annual forest loss to pinpoint critical deforestation periods, analyze the spatial distribution of forest cover across the northern, southern, and central regions of the state, and assess the impact of anthropogenic activities, such as mining and infrastructure development, on forest cover dynamics to propose targeted conservation strategies.

2. Description of Study Area

Chhattisgarh, located in central India, spans 135,197 km², representing 4.1% of India's geographical area, with coordinates ranging from 17°47'N to 24°06'N latitude and 80°15'E to 84°24'E longitude. Carved from Madhya Pradesh in 2000, it comprises 33 administrative districts across three agro-climatic zones: Central Plain (51.0%), Northern Hills (21.0%), and Bastar Plateau (28.0%). Forests cover 59,772 km² (44.21% of the state), including very dense (4,152 km²), moderately dense (34,846 km²), and open forests (16,588 km²), with 117 km² of scrub (Forest Survey of India, 2015). These forests, classified as tropical moist deciduous (44.03%) and tropical dry deciduous (55.56%) per Bahugunaa et al, (2016), support 11,185 forest-fringe villages and are vital for ecological and livelihood functions, including the origin of major central Indian rivers. The region of interest (ROI) was defined using the FAO/GAUL Simplified 500m (2015) dataset, filtered for Chhattisgarh at the first administrative level (ADM1), with its geometry extracted for spatial analysis. Chhattisgarh was chosen due to its significant forest cover, ecological importance, and dependence of rural communities (76.76% of the 25,545,198 population) on forest resources (Census of India, 2011) shown in Figure 1.

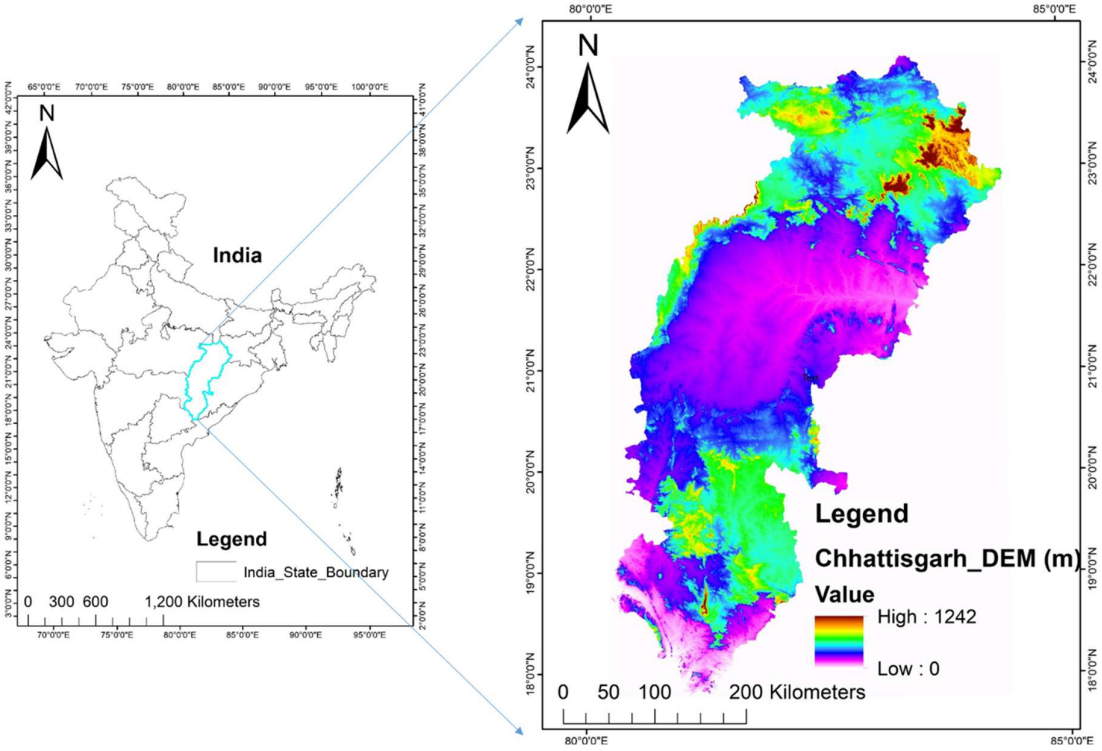


Figure 1: Study area of Digital elevation model (m)

3. Materials and Methodology

This study assesses forest cover dynamics in Chhattisgarh, India, from 2000 to 2024 using geospatial analysis within the Google Earth Engine (GEE) platform. The Hansen Global Forest Change dataset (version 1.12, 2024) serves as the primary data source, enabling the quantification of forest cover, loss, and gain through satellite data processing, spatial analysis, and visualisation (Gorelick et al, 2027). The methodology is outlined below and summarised in a flowchart (Figure 2).

3.1 Data Source

The Hansen Global Forest Change dataset (version 1.12, 2024) serves as the primary data source, offering global tree cover, loss, and gain data at a 30-meter resolution. It includes key bands: treecover2000, which indicates the percentage of tree canopy cover in 2000; loss, a binary mask identifying forest loss from 2000 to 2024; lossyear, specifying the year of forest loss between 2000 and 2024; and gain, a binary mask denoting forest gain from 2000 to 2012.

The analysis involved the following steps.

Data Clipping: The Hansen dataset was clipped to Chhattisgarh's region of interest (ROI) to focus the analysis.

Forest Cover 2000-2024: Forest cover in Chhattisgarh for 2000 was identified as areas with tree canopy cover exceeding 30%, derived from the treecover2000 band of the Hansen Global Forest Change dataset, resulting in a binary mask. For 2024, forest cover was defined as areas meeting either of two conditions: (a) tree cover greater than 30% in 2000 with no recorded loss, or forest gain between 2000 and 2012 with no subsequent loss, determined through logical operations combining the treecover2000, loss, and gain bands.

Forest Loss and Gain: Total forest loss (2000–2024) and gain (2000–2012) areas were calculated by multiplying loss and gain binary masks by pixel areas, aggregating results at a 100-meter scale using a sum reducer.

Annual Forest Loss: Annual loss areas (2000–2024) were computed by filtering the lossyear band, multiplying by pixel areas, and aggregating with a sum reducer, stored as a feature collection for visualisation.

To support further analysis and reproducibility, the following raster layers were exported to Google Drive. A line chart was created to visualise annual forest loss trends (2000–2024), with years on the x-axis and area lost (km^2) on the y-axis. A custom legend and layer toggle panel were integrated into the GEE map interface to enhance interactivity and clarity.

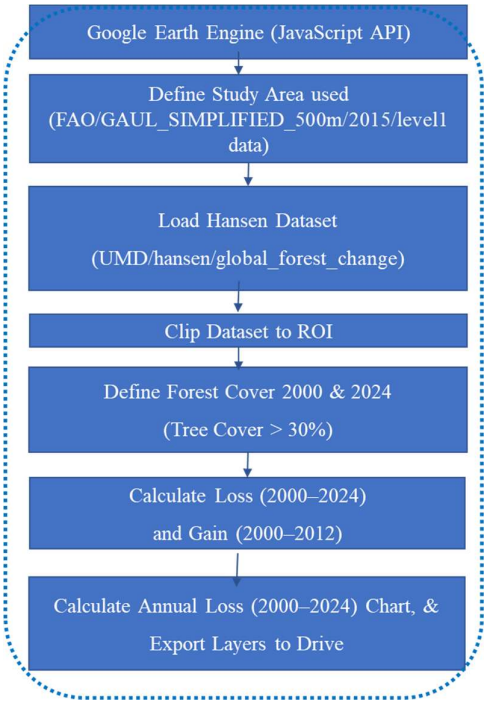


Figure 2 Methodology flowchart for forest cover change analysis

4. Results and Discussion

The analysis of forest cover dynamics in Chhattisgarh, India, spanning 2000 to 2024, utilised the Hansen Global Forest Change dataset within the Google Earth Engine platform. The study area, encompassing approximately 135,154.63 km², revealed significant spatial and temporal variations in forest cover, loss, and gain.

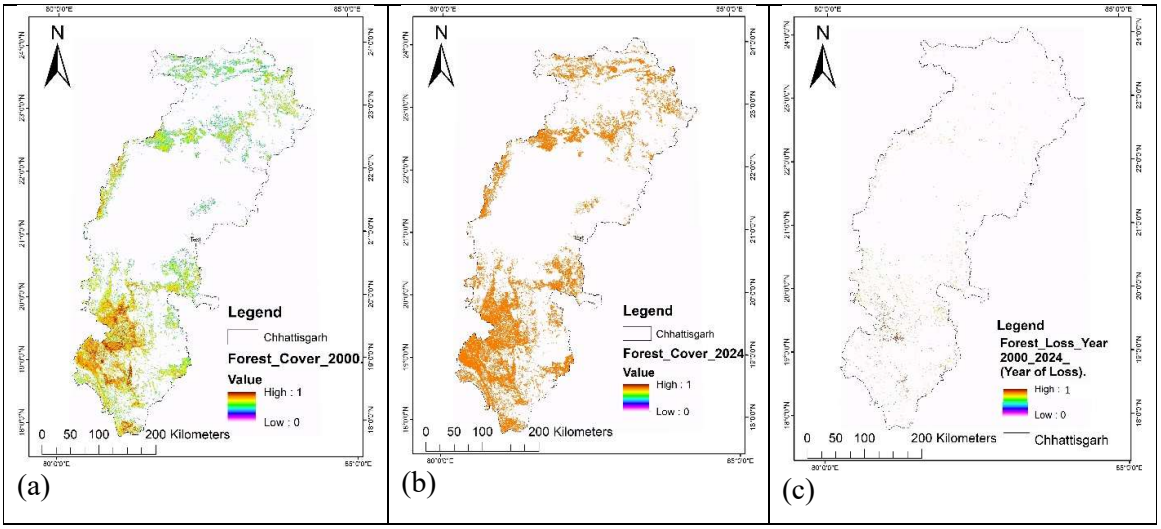
Forest Cover in (2000-2012): In the year 2000, Chhattisgarh's forest cover, defined as areas with tree canopy cover greater than 30%, totalled 25,965.28 km². By 2012, this had decreased to 25,417.67 km², reflecting a net loss of 547.61 km² over the 12-year period. The southern and northern regions of Chhattisgarh exhibited the highest forest cover percentages during this period, while central areas showed relatively lower forest density. Additionally, the southern region experienced a forest gain of 4.78 km² between 2000 and 2012, primarily due to regrowth or afforestation efforts.

Total Forest Loss and Gain (2000–2024): Over the full study period (2000–2024), the total forest loss in Chhattisgarh amounted to 810.47 km². This loss, combined with the limited gain of 4.78 km²

(restricted to 2000–2012 due to dataset limitations), contributed to the observed reduction in forest cover by 2024.

Temporal Trends in Annual Forest Loss (2000–2024): The time-series analysis of annual forest loss from 2000 to 2024 revealed distinct temporal patterns. Forest loss increased gradually from 2000 to 2001, followed by a decline to a minimum of approximately 18 km² in 2003. A similar low loss of 18 km² was observed in 2020. The loss peaked in 2011, reaching 90 km², driven by significant deforestation events. Post-2011, the annual loss declined in 2013 and remained relatively stable, with no drastic changes, through 2020, averaging around 18 km² per year. From 2021, the loss began to rise again, reaching approximately 60 km² in 2023, a level maintained into 2024, indicating a renewed increase in deforestation activity.

Spatio-temporal Distribution: The spatial distribution of forest cover highlighted that the southern and northern parts of Chhattisgarh retained higher forest cover percentages from 2000 to 2012 compared to the central regions, which exhibited lower forest density. This pattern underscores the regional variability in forest conservation and land-use pressures within the state. The dark red colour shows high forest cover density in Figure 3.



(d)

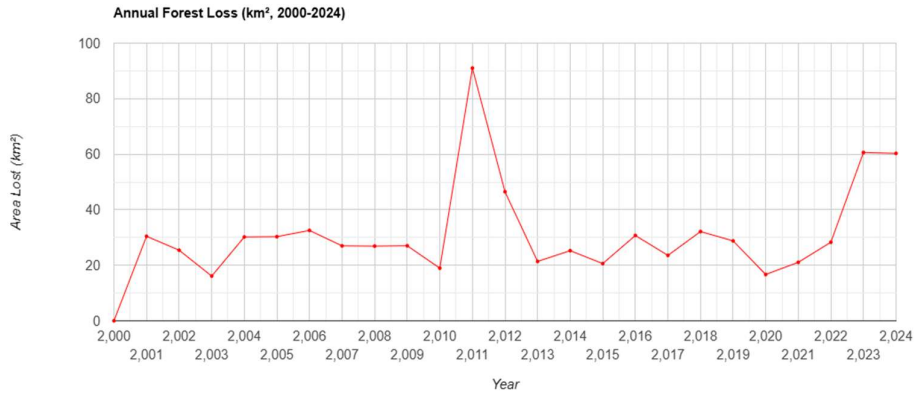


Figure 3 Spatio-temporal Distribution of (a) Forest cover in 2000, (b) Forest cover in 2024, (c) forest loss between 2000-2024, (d) Annual forest loss in 2000-24(km²)

5. Discussion

Our study on Chhattisgarh's forest cover from 2000 to 2024, using the Hansen Global Forest Change dataset, paints a clear picture of the state's deforestation and afforestation trends. We found a net loss of 547.61 km² of forest cover by 2012, growing to 810.47 km² by 2024, with only a small gain of 4.78 km² in the southern region between 2000 and 2012. The northern and southern districts, home to dense Sal and Teak forests, faced the heaviest losses, while the central plain showed some gains, likely thanks to sustainable management and large-scale planting under the National Afforestation Programme, which added about 1,265.47 km² of new forest area by 2016.

Looking at the timeline, deforestation peaked in 2011 with a 90 km² loss, likely tied to mining, infrastructure projects, and timber extraction (Mishra & Reddy, 2009). Things stabilised around 2020, with losses dropping to about 18 km² annually, possibly due to conservation efforts. But by 2023–2024, losses climbed back to 60 km², especially in southern districts where reliance on forest resources and ongoing civil unrest, like Naxalism, complicate conservation (Sinha, 2011). These areas, less developed socio-economically, face added pressure from illegal logging and encroachment.

The higher forest density in the northern and southern regions compared to the central plain highlights how land-use pressures vary across the state. Some inconsistencies in the data might come from improved mapping by the Forest Survey of India or untracked activities like illegal felling and mining, which diverted 214.21 km² of forest land from 1980 to 2008 (Mishra & Reddy, 2009). Cross-checking with state forest department records on planting and land diversion could help clarify these trends. Overall, the slight 0.70% increase in forest cover reflects a tug-of-war between afforestation efforts and persistent deforestation, calling for stronger, region-specific conservation strategies to protect Chhattisgarh's vital forests.

6. Conclusion and Limitations

The analysis of Chhattisgarh's forest cover dynamics from 2000 to 2024, using the Hansen Global Forest Change dataset, reveals a concerning net loss of 810.47 km², with a peak deforestation rate of 90 km² in 2011 and a resurgence to 60 km² annually by 2023–2024, primarily in the northern and southern regions rich in Sal and Teak forests. Despite a modest gain of 4.78 km² in the southern region (2000–2012), the central plain's afforestation efforts highlight successful conservation strategies. These findings underscore the need for targeted policies to address deforestation pressures from mining, infrastructure, and socio-economic dependencies, particularly in insurgency-affected areas. However, limitations include the dataset's restriction of gain data to 2000–2012, potentially underestimating recent afforestation, and possible inaccuracies from mapping improvements or untracked activities like illegal logging, necessitating validation with ground-based data from state forest departments.

Abbreviation:

LULC:	Land use/Land cover
GEE:	Google Earth Engine
NASA:	National Aeronautics and Space Administration
SRTM:	Shuttle Radar Topography Mission

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