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DYNAMICS OF FOREST LOSS IN NAGALAND, INDIA, 2000 - 2024: A GOOGLE EARTH ENGINE-BASED ANALYSIS

Moirangthem Sukanta Singh[1*], Mayengbam Binata Devi[2], Renubala Rajkumari[3]

[123]Research Scholar, Department of Geography, Manipur University, Manipur, India

Corresponding Author:
Email:moirangthemsukanta11@gmail.com

Abstract

Forest Cover loss is a crucial driver of environmental degradation. Forest loss has a significant impact on biodiversity and ecosystem services. Despite being the most forested and biologically diverse regions in India, the forests of Northeast India have experienced significant alteration due to growing human pressures. This study evaluates the spatio-temporal patterns of forest cover loss in Nagaland from 2000 to 2024 using the Google Earth Engine (GEE) platform. Annual forest cover loss was assessed using the Hansen Global Forest Change (GFC) v1.12. Proximate drivers of forest loss were examined using the WRI/Google DeepMind Global Drivers of Forest Loss v1.2 dataset, and results were validated against biennial state-level forest cover estimates from the Indian State of Forest Report. The results reveal a cumulative forest loss of approximately 3,646.97 sq. km over the study period. A distinct shift was observed from relatively steady forest loss during 2001-2010 to accelerated deforestation after 2011. The highest forest loss occurred in 2017 and remained consistently high through 2024. Spatial analysis shows that forest loss is unevenly distributed within the eastern and southeastern Nagaland, experiencing the most extensive and concentrated loss. Driver analysis indicates that shifting cultivation is the dominant driver, which accounts for nearly 77% of driver-attributed forest loss, followed by logging. Strong agreement between Hansen-derived forest loss estimates and Forest cover trends from the India State of Forest Report confirms that the observed decline reflects a persistent transformation in Nagaland's Forest cover. The findings highlight the need for targeted land-use interventions and sustainable forest management strategies to address anthropogenic forest loss in the region.

Keywords: *Forest Cover Loss, Hansen Global Forest Change, Drivers of forest loss, GEE*

INTRODUCTION

Forests are critical to global ecological stability, supporting over half of the world's terrestrial biodiversity and sustaining livelihoods for 1.6 billion people (United Nations Environment Programme, 2025). In addition to biodiversity conservation, forests provide essential ecosystem services such as watershed regulation (Mello et al.,2018), carbon sequestration and storage (Lewis et al., 2009; Nunes et al., 2020), maintenance of traditional forest-based practices (Garnett et al.,2018), and regulation of local and regional climate systems (Bonan,2008; Samarasinghe et al., 2022), thereby playing a pivotal role in maintaining ecological stability. (Betts et al.,2017; Marco et al., 2019).

Forest cover loss remains one of the most prominent drivers of global ecosystem degradation (Balthazar et al., 2015). Key drivers of deforestation include shifting cultivation, agricultural expansion, fuelwood extraction, logging, and plantation development (Houghton, 2012; Hosonuma et al., 2012). Effective assessment of these dynamics increasingly relies on cloud-based geospatial platforms such as Google Earth Engine, which enable large-scale, efficient monitoring of forest cover change using freely available satellite data (Huang et al., 2017; Kumar & Mutanga, 2018).

Across various geographical contexts, numerous studies have documented profound forest transformations driven by land-use changes. For instance, forest degradation and fragmentation have been linked to mechanized agriculture, logging, grazing, and infrastructure development in Sudan (Sulieman, 2018), while large-scale conversion of native vegetation to monoculture agriculture and pasture has been reported in Brazil;s Cerrado Biome (da Cunha et al., 2020). Similar trends of deforestation have also been observed in the mountainous regions of Europe, where forest loss has disrupted traditional livelihoods and increased economic vulnerability (Andronache et al., 2019).

In India, forest cover changes are particularly pronounced in the Northeastern region, characterized by complex terrain, high biodiversity, and forest-dependent indigenous communities (Devi & Shimrah, 2022). Although the region accounts for nearly 66.81% forest cover (Forest Survey of India, 2009), it remains highly vulnerable to deforestation driven by agricultural intensification, shifting cultivation, infrastructure development, and increasing biotic pressure (Nandy et al., 2011; Batar et al., 2017). The reduction in fallow periods under traditional shifting cultivation systems has further reduced forest regeneration capacity, thereby accelerating degradation and fragmentation.

Nagaland represents one of the most critical cases of forest cover loss in Northeast India. While forests occupy over 81% of the state's geographical area, nearly 88.3% are privately or community owned, which poses significant government challenges (Rawat et al., 2018). The state forest report 2003 estimates that approximately 5,476 sq. km of forest area in the region has been degraded due to jhum practices, with Nagaland alone accounting for 1,332 sq. km (24.3%) ,making it the most severely affected state. Rapid population growth, urbanization, jhum cultivation, agricultural expansion, fuelwood dependence, and logging have led to extensive forest degradation (Rawat et al., 2018). The continued decline of forest cover in Nagaland, despite its ecological value, highlights the necessity for a detailed assessment of forest cover dynamics and their driving forces is essential to support sustainable land use planning and effective forest conservation strategies in the state. Accordingly, this study assesses spatio-temporal forest cover changes and examines the key drivers of forest loss in Nagaland using the Google Earth Engine (GEE) platform.

Study Area

Nagaland is situated in Northeast India between 25°6' N to 27°4'N latitudes and 93°20'E to 95° 15'E longitudes (Figure 1). The state shares its boundaries with Assam to the west, Myanmar to the east, Arunachal Pradesh and part of Assam to the north, and Manipur to the South (State Profile, Government of Nagaland). Covering a total geographical area of 16,579 sq. km, Nagaland is administratively divided into 17 districts and is home to 17 major tribes along with several sub tribes. According to the 2011 Census, the state has a population of 19,78,502. The terrain is highly varied, with elevation ranging from 190m to 3,048m above mean sea level, and climatic conditions vary from sub-temperate to sub-tropical. This unique combination of topography, climate, and ecological conditions supports a rich diversity of flora and fauna, making Nagaland a critical region for biodiversity and forest ecosystems. Therefore, forest cover change analysis was conducted in the state of Nagaland, India which is located in the eastern Himalayan region of North East India. The region is characterized by complex topography, high biodiversity, and forest landscapes. Forests in Nagaland are subject to both anthropogenic and natural disturbances, making it an important region for long term forest change assessment.

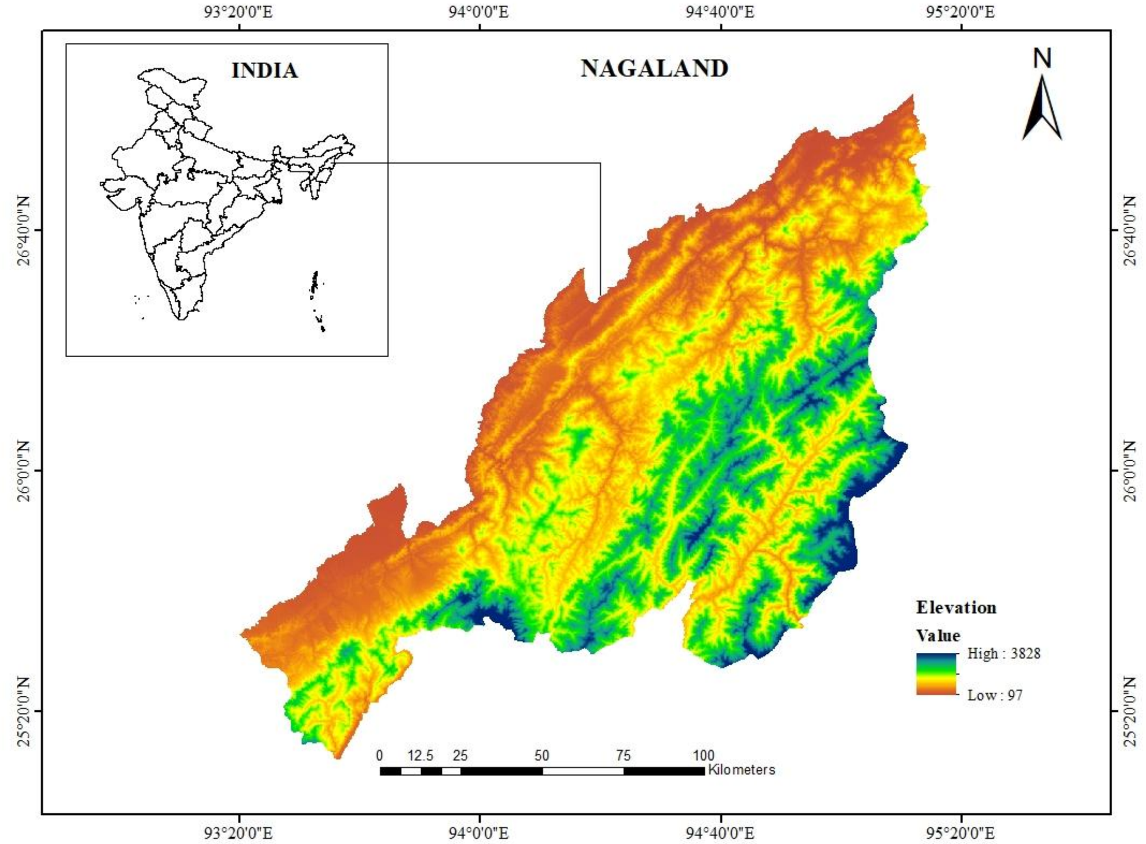

Figure 1 Study Area

Data and Methods

Forest cover loss for the period of 2000-2024 was analyzed using the Google Earth Engine (GEE), a cloud-computing platform (Figure 2). Annual forest loss data were derived from the Hansen Global Forest Change (GFC) version 1.12 dataset, accessed via the GEE Data Catalog (ee. Image("UMD/Hansen/global_forest_change_2024_v1_12")) (Hansen et al., 2013).

The baseline forest extent was defined using the treecover2000 band, which represents percent tree canopy cover for the year 2000 at a 30m spatial resolution. Areas with canopy cover of threshold ≥30% canopy cover were applied to delineate forested areas, consistent with commonly used definitions of forest cover in regional-scale studies.

Forest loss was identified using the loss year band, where non-zero pixel values represent stand-replacement canopy disturbance occurring between 2001 and 2024. Each pixel value corresponds to the year of forest loss, allowing for the derivation of annual forest loss layers.

The annual forest loss area was calculated by summing the area of pixel-level (30m×30m) which are classified as forest loss pixels within the baseline forest mask for each year from 2001 to 2024. Pixel areas were derived using the pixelArea() function in GEE and spatially aggregated within the administrative boundary of Nagaland.

Cumulative forest loss for the study period was obtained by aggregating annual forest loss values across all years. All area estimates were expressed in square kilometers (sq. km).

The proximate drivers of forest loss were analyzed using the WRI/Google DeepMind Global Drivers of Forest Loss version 1.2 dataset (ee. Image("projects/landandcarbon/assests/wri_gdm_drivers_forest_loss_1km/v1_2_2001_2024")) (Sims et al., 2025). This dataset provides a 1 km spatial resolution global classification of the dominant drivers responsible for forest loss, including categories such as shifting cultivation, permanent agriculture, forestry, wildfire, urbanization, and other disturbances.

To ensure spatial compatibility with the spatial resolution of Hansen Forest loss data, the driver dataset was resampled to 30m resolution using nearest-neighbor interpolation. The resampled driver layer was subsequently masked by using Hansen forest loss pixels, so that driver attribution was restricted exclusively to areas experiencing observed canopy loss.

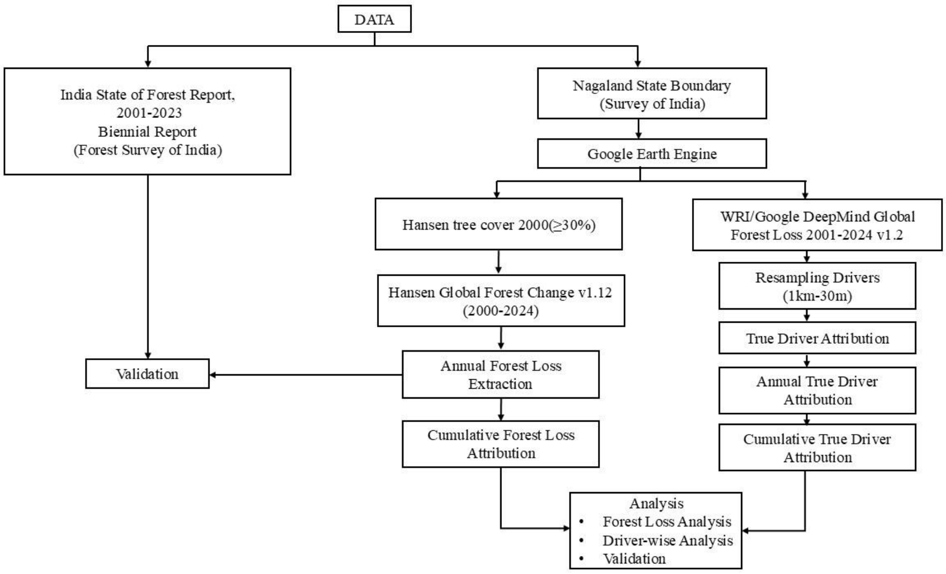

Figure 2 Methodological Flowchart

Results and Discussion

Trends of Forest Cover Loss in Nagaland (2000 – 2024)

The analysis of forest cover loss in Nagaland between 2001 and 2024 shows a steadily increasing loss of forest cover throughout the study period (Table 1, Figure 3).

Cumulatively, the state loses approximately 3,646.97 sq. km of forest cover, which indicates a persistent long-term pressure on forest ecosystems and limited recovery over time. Annual forest cover loss exhibits considerable interannual variability (Figure 3), which ranges from 49.97 sq. km (1.37%) in 2010 to a maximum of 333.68 sq. km in 2017. Despite these fluctuations, the cumulative loss curve shows a consistent upward trajectory with a marked acceleration after 2011, indicating a fundamental shift in the intensity of forest disturbance.

During the initial decade (2001-2010), annual forest loss remained relatively low and stable. Annual loss during this period varied between 51.01 sq. km in 2007 and 126.87 sq. km in 2001. However, cumulative forest loss during this period reached 792.39 sq. km, accounting for approximately 21.7% of the total loss recorded over the entire study period.

Table 1 Forest loss derived from Hansen Global Change (2000-2024)

Year	Forest Loss (km^2)	Cumulative Loss (km^2)	Annual Loss (%)
2001	126.87	126.97	3.48
2002	80.74	207.62	2.21
2003	74.49	282.11	2.04
2004	102.64	384.75	2.81
2005	92.19	476.94	2.53
2006	71.84	548.78	1.97
2007	51.01	599.80	1.40
2008	67.36	667.15	1.85
2009	75.27	742.42	2.06
2010	49.97	792.39	1.37
2011	75.24	867.63	2.06
2012	145.37	1013.00	3.99
2013	171.55	1184.55	4.70
2014	283.89	1468.44	7.78
2015	260.83	1729.27	7.15
2016	309.13	2038.40	8.48
2017	333.68	2372.08	9.15
2018	249.09	2621.17	6.83
2019	177.99	2799.16	4.88
2020	242.77	3041.93	6.66
2021	191.96	3233.89	5.26
2022	145.13	3379.02	3.98
2023	153.67	3532.68	4.21
2024	114.28	3646.97	3.13
Total	3646.97		100.00

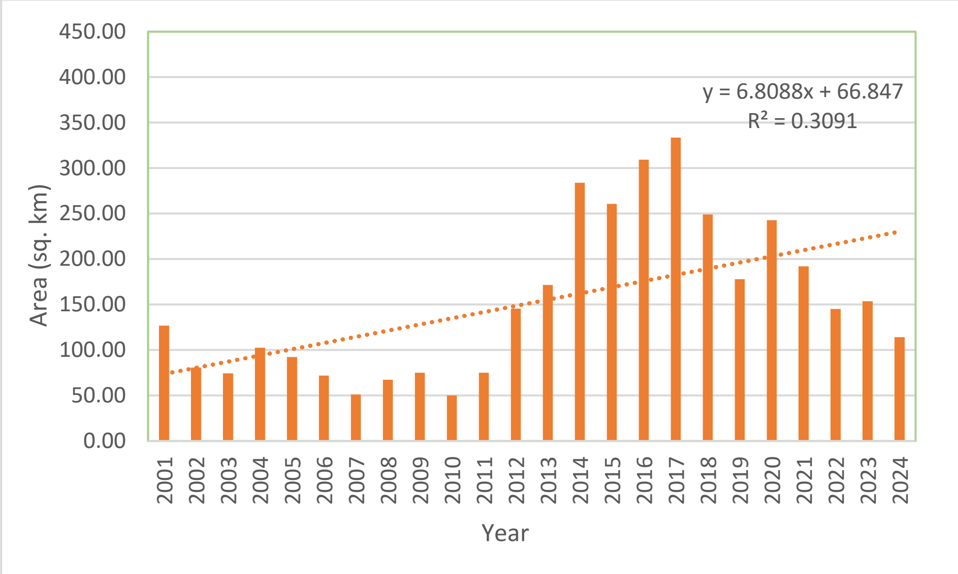

Figure 3 Hansen Global Forest Loss Trend (2000-2024)

A clear transition is observed in the 2011 to 2013 period when annual forest loss increased from 75.24 sq. km (2011) to 145.37 sq. km (2012) and 171.55 sq. km (2013). This increase marks the onset of accelerated forest cover loss, with cumulative loss exceeding 1,184.55 sq. km by 2013.

The most severe forest cover loss occurred from 2014 to 2017, representing a phase of intensified deforestation. Annual forest loss rose sharply to 283.89 sq. km (7.78%) in 2014, remained high in 2015, which is 260.83 sq. km (7.15%), and further increased in 2016 to 309.13 sq. km (8.48%). The peak was recorded in 2017, when forest loss reached 333.68 sq. km, the highest annual value in the dataset. By the end of 2017, cumulative forest loss expanded to 2,372.08 sq. km, representing nearly 65% of the total forest loss observed during the study period.

In the recent period (2018-2024), annual forest loss declined slightly relative to the 2017 peak but stayed at a generally high level. Losses frequently exceeded 200 sq. km per year, particularly in 2018 (249.09 sq. km) and 2020 (242.77 sq. km). Even in comparatively lower losses such as 2022 (145.13 sq. km) and 2024 (114.28 sq. km), annual forest loss remained substantially higher than levels observed during the early 2000s. By 2024, cumulative forest loss reached 3,646.97 sq. km, showing that forest decline in Nagaland has been steady and ongoing.

Overall, the results demonstrate a transition from moderate and relatively stable forest loss in the early 2000s to accelerated and persistent deforestation after 2011. The significant increase in forest loss observed in the mid-2010s, along with high magnitude in recent years, indicates sustained landscape-scale disturbance with limited opportunity for forest recovery.

Figure 4 illustrates the spatial distribution of forest loss across Nagaland, with red areas representing regions where forest cover has been lost. Forest loss is widespread but exhibits clear spatial variability, with distinct patterns emerging.

The high density of forest loss is observed in the eastern and southeastern regions of Nagaland. These regions exhibit widespread forest loss, indicating intense pressure on land use.

In comparison, the western and central regions exhibit a more dispersed and fragmented pattern of forest loss. The northern and northwestern regions of Nagaland show relatively less forest loss, marked by fewer and smaller patches of deforestation. Thus, the spatial distribution of forest loss in Nagaland is uneven, with the eastern and southeastern regions experiencing the most extensive and concentrated reduction in forest cover.

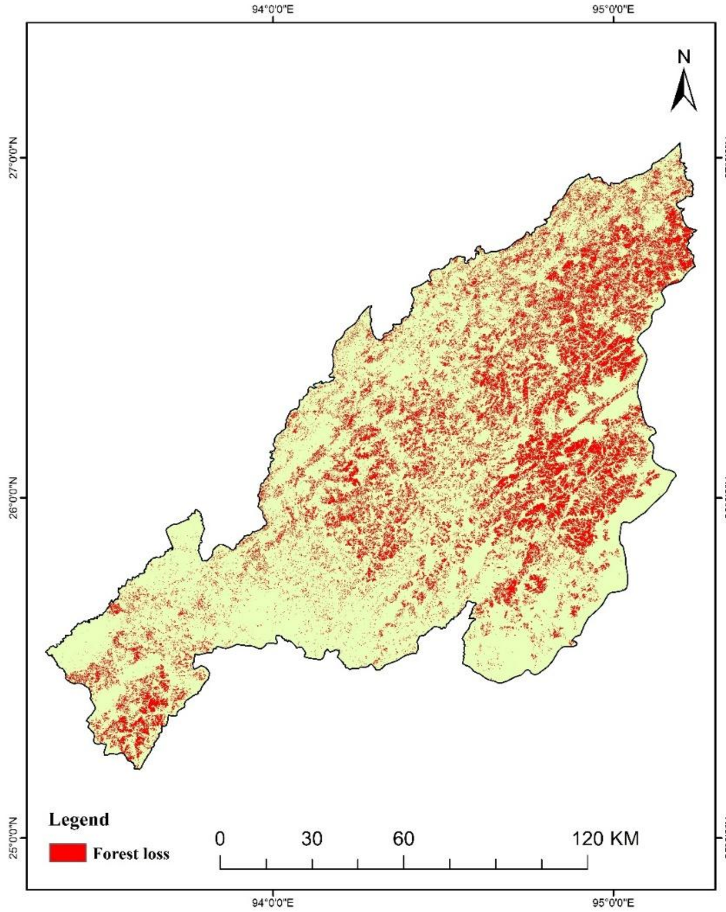

Figure 4 Spatial Distribution of Forest Loss

Validation of Hansen-Derived Forest Loss based on State Forest Cover Statistics

To validate the satellite-based forest loss estimates, state-level forest cover statistics from the India State of Forest Report were compared with the Hansen Global Forest Change dataset. The India State of Forest Report is a biennial assessment published by the Forest Survey of India (FSI). Forest cover data, as per the India State of Forest Report, in Nagaland has declined between 2001 and 2024, indicating a net reduction in forest extent over the past 24 years (Table 2).

Table 2 Forest Cover Statistics (2001-2023)

Year	Forest cover (Km2)
2001	13,345
2003	13,609
2005	13,665
2007	13,464
2009	13,464
2011	13,318
2013	13,017
2015	12,939
2017	12,489
2019	12,486
2021	12,274
2023	12,222

Source: India State of Forest Report, 2023

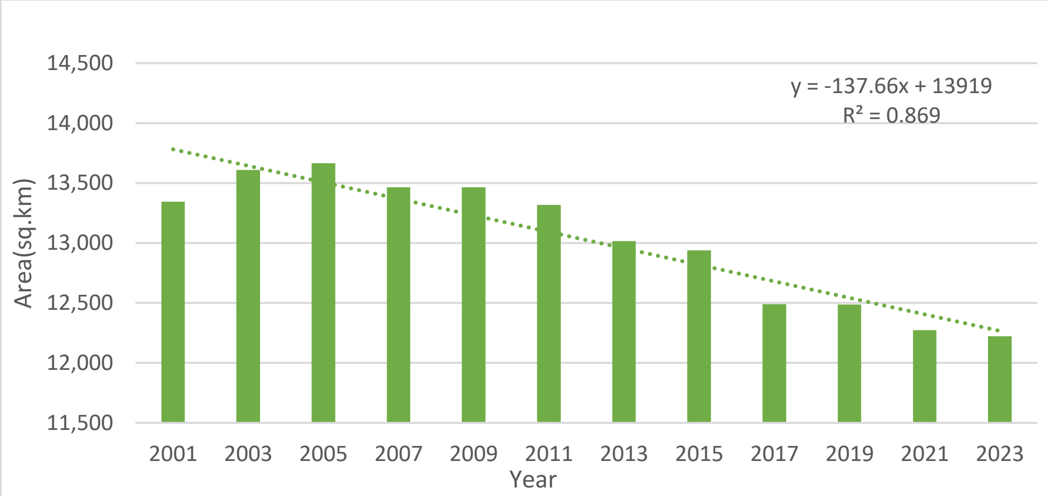

Figure 5 Forest Cover Trend (India State of Forest Report, 2023)

Although short-term fluctuations are observed, the overall trend shows a clear downward trajectory (Figure 5). This pattern is consistent with the increasing forest loss, with cumulative forest loss of approximately 3,646.97 sq. km identified using the Hansen dataset over the study period. Thus, there is a strong agreement in both direction and magnitude, which provides robust cross-validation. The convergence of these independent datasets confirms that the observed forest decline reflects a persistent and large-scale transformation of Nagaland's Forest landscape.

Drivers attributed to observed Forest Loss

The analysis of the proximate drivers of forest loss in Nagaland over the 24-year period (Table 3) reveals a highly uneven contribution among different factors, with anthropogenic activities overwhelmingly responsible for the majority of forest decline.

Shifting cultivation emerges as the principal driver of forest loss, accounting for approximately 2,807.64 sq. km (76.9%) of the total forest loss attributed to identifiable causes. This large-scale impact indicates that repeated clearing cycles within forest landscapes are likely due to short fallow periods and intensified agricultural practices. The results indicate that shifting cultivation is a significant contributor to long-term forest degradation, particularly in the context of a growing population and increasing socio-economic pressures.

Logging and forest management activities represent the second-largest driver contributing roughly 587.78 sq. km (16%) of the forest loss. Although smaller than shifting cultivation in scale, logging plays a critical role in fragmenting forest loss and weakening ecosystem integrity which may facilitate further land conversion and degradation.

Permanent agriculture accounts for 200.96 sq. km (5.5%) of the cumulative forest loss. Unlike shifting cultivation, this driver involves irreversible conversion of forest to long-term agricultural use, directly reducing forest cover. Losses related to settlements and infrastructure amount to 29.64 sq. km, representing less than 1% of total loss. Hard commodities (mining/energy) contribute 5.46 sq. km, wildfires are responsible for 0.87 sq. km, and other natural disturbances account for 14.24 sq. km. These findings clearly show that natural processes have had minimal impact on forest loss in Nagaland compared to human-driven land-use changes.

Table 3 Forest loss attributed to different drivers derived from WRI

Year	Permanent agriculture	Hard commodities (mining/energy)	Shifting cultivation	Logging / forest management	Wildfire	Settlements & infrastructure	Other natural disturbance	Total
2001	6.81	0.03	91.17	28.28	0.00	0.46	0.12	126.87
2002	5.41	0.03	61.54	13.22	0.00	0.33	0.23	80.75
2003	3.09	0.03	57.31	13.51	0.00	0.44	0.10	74.48
2004	8.28	0.08	73.05	19.93	0.00	0.80	0.50	102.63
2005	6.64	0.07	66.70	17.37	0.00	0.99	0.40	92.18
2006	8.49	0.08	48.52	13.20	0.01	0.80	0.70	71.81
2007	4.00	0.09	36.60	8.94	0.00	1.12	0.28	51.03
2008	8.20	0.05	43.29	13.92	0.01	0.86	1.00	67.33
2009	7.57	0.24	51.55	13.98	0.29	1.12	0.50	75.25
2010	5.37	0.04	33.26	9.58	0.10	1.03	0.55	49.94
2011	9.85	0.12	45.80	17.13	0.01	1.62	0.69	75.22
2012	9.76	0.20	102.87	29.18	0.02	2.41	0.90	145.35
2013	5.69	0.04	132.58	32.34	0.01	0.56	0.28	171.51
2014	13.71	0.34	219.13	48.13	0.14	1.63	0.77	283.86
2015	10.11	0.11	208.65	40.07	0.07	1.31	0.54	260.85

2016	12.04	0.28	240.02	54.52	0.01	1.53	0.72	309.11
2017	11.14	0.36	284.32	34.75	0.03	1.84	1.19	333.63
2018	8.27	0.30	216.35	22.23	0.02	1.28	0.63	249.08
2019	6.76	0.27	149.12	20.58	0.00	0.79	0.46	177.98
2020	9.78	0.37	185.99	44.42	0.01	1.44	0.74	242.75
2021	9.74	0.36	143.79	34.48	0.01	2.81	0.77	191.96
2022	9.33	0.35	109.29	24.00	0.00	1.38	0.75	145.10
2023	10.48	0.60	120.31	19.81	0.06	1.71	0.68	153.65
2024	10.44	1.00	86.42	14.21	0.05	1.36	0.77	114.25
Total	200.96	5.46	2807.64	587.78	0.87	29.64	14.24	3646.58

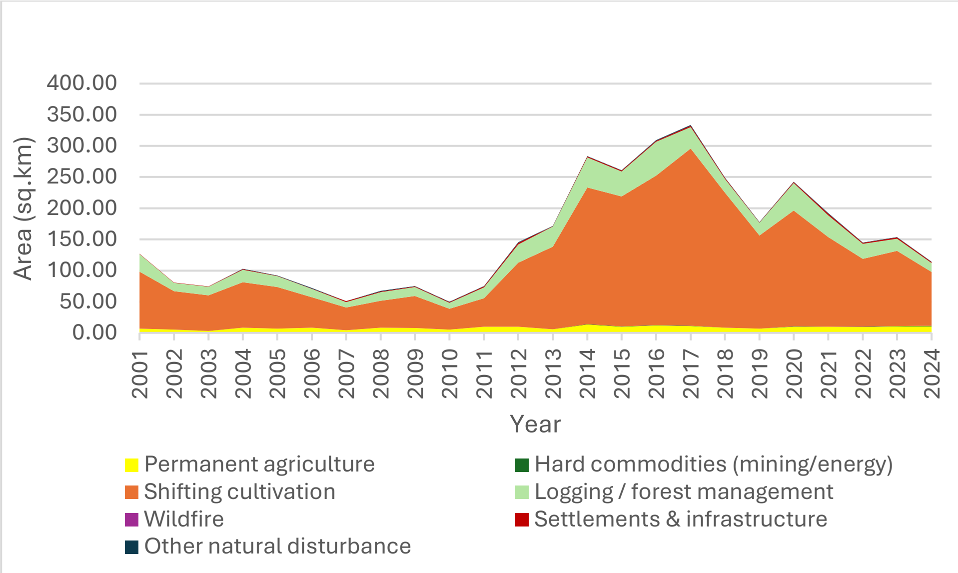

Figure 6 Annual driver-wise forest loss derived from WRI

Temporal Dynamics of Drivers

Yearly data show that shifting cultivation consistently dominated forest loss in the early years (2001-2010) with relatively low contributions from logging, permanent agriculture, settlements, and infrastructure. After 2011, a marked increase in shifting cultivation-related loss coincides with the overall rise in forest loss, peaking in 2017 at 284.32 sq. km. Logging and forest management activities also increased during this period, suggesting a synergistic effect where forest extraction activities intensified forest degradation. Permanent agriculture exhibited a gradual increase over time, which indicates a continued conversion of forest land to permanent cropland.

Following the 2017 peak, shifting cultivation remained the main driver through 2018-2024, while settlements showed moderate increase post 2015 potentially amplifying forest loss. Thus, the results clearly demonstrate that forest loss in Nagaland is primarily driven by anthropogenic land use practices, especially shifting cultivation and logging.

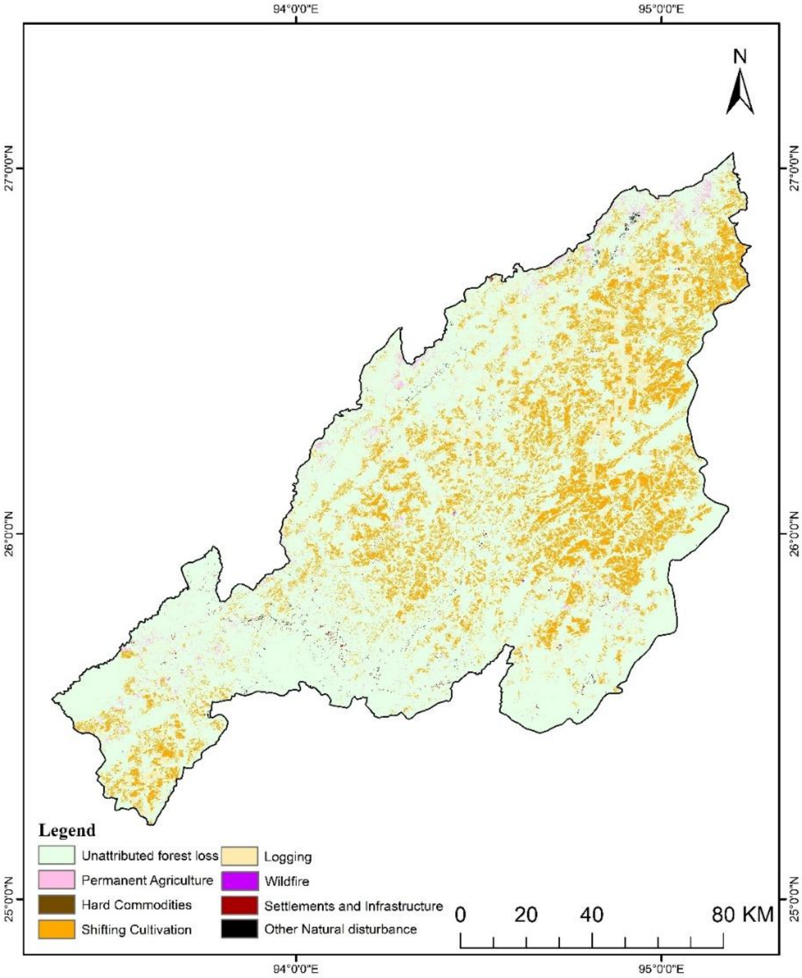

Figure 7 Spatial Distribution of forest loss derived from WRI

Conclusion

This study presents a comprehensive assessment of forest cover loss in Nagaland from 2000 to 2024 using the Hansen Global Forest Change v1.12 dataset with driver-specific attribution from the WRI/Google DeepMind Global Drivers of Forest Loss v1.2 dataset on the Google Earth Engine platform. The results reveal an accelerated forest loss with a cumulative loss of approximately 3,646.97 sq. km. Forest decline transitioned from moderate and stable rates in the early 2000s to sharply accelerated deforestation after 2011, reaching a peak in 2017. Spatially, the eastern and southeastern regions experienced the most significant reduction in forest cover. Anthropogenic activities, particularly shifting cultivation, logging, and permanent agriculture, emerged as the dominant drivers accounting for approximately 98% of identified forest loss. Shifting cultivation remains prevalent across Nagaland and much of Northeast India, and its prevalence has intensified due to anthropogenic pressure, resulting in shortened fallow cycles from 10-15 years to 3-5 years, which prevents adequate soil and vegetation recovery (Rawat et al., 2018).

The satellite-based findings are strongly supported by studies and official data. India State of Forest Report data confirm a steady decline in Nagaland's Forest cover over the study period. Regional assessments, including Hazarika and Bhattacharjee (2023) and Guria et al. (2024), report that Nagaland experienced one of the highest levels of forest cover among the Northeastern states, validating both the temporal trends observed in this study.

However, this study has limitations. The reliance on satellite-based datasets may not capture fine-scale forest degradation. Limited field validation and the absence of high-resolution socio-economic or land-use data have restricted the ability to assess localized impacts and indirect drivers. Despite these limitations, the study clearly demonstrates extensive forest loss in Nagaland and highlights the urgent need for targeted forest conservation, sustainable land-use strategies, and community-driven management to address the ongoing forest degradation.

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Authors' contributions Conceptualisation: Methodology: [Moirangthem Sukanta Singh,]; Writing–original draft preparation: [Moirangthem Sukanta Singh, Renubala Rajkumari, Mayengbam Binata Devi]; Review and editing: [Mayengbam Binata Devi].

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Data availability: The authors declare that the data used in this manuscript are obtained from Hansen Global Forest Change v1.12 , WRI/Google DeepMind Global Drivers of Forest Loss v1.2 and Forest Survey of India Report, 2023.

Conflict of interest: The authors declare no competing interests

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